

APPLICATION OF REMOTE SENSING AND GIS IN THE ANALYSIS OF ENVIRONMENT OF BAY OF BENGAL

A DISSERTATION

Submitted for the partial fulfillment of the degree

MASTER OF SCIENCE

In
GEOINFORMATICS


By

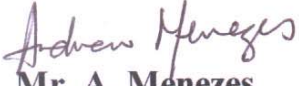
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CADIDATE'S DECLARATION

I hereby declare that, the work which is being presented in the dissertation work entitled "APPLICATION OF REMOTE AND GIS IN THE ANALYSIS OF ENVIRONMENT OF BAY OF BENGAL" in partial fulfillment of requirement for the award of the degree of MASTER OF SCIENCE in "GEOINFORMATICS" and submitted in the Department of Applied Geology, Barkatullah University, Bhopal (M.P.), is an authentic record of my own work, conducted under the supervision of **Dr. D.C. Gupta**, Department of Applied Geology, Barkatullah University, Bhopal (M.P.), and co-supervision of **Dr. S. Prasanna Kumar**, Scientist, POD, NIO and **Mr. A. Menezes**, Scientist, MID, NIO at National Institute of Oceanography, Goa.

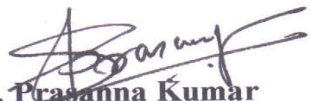
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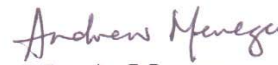
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Chapter 1

General Introduction

CHAPTER 1

General Introduction

1.1 Introduction to Bay of Bengal

The Bay of Bengal is a northern extended arm of the Indian Ocean, which occupies almost 2.2 million sq km area between equator and 22°N latitude and 80°E and 100°E longitudes. It is bounded in the west by the east coasts of Sri Lanka and India, on the north by the deltaic region of the Ganges-Brahmaputra-Meghna river system, and on the east by the Myanmar peninsula. The southern boundary of the Bay is approximately along the line drawn from Dondra Head in the south of Sri Lanka to the north tip of Sumatra. A broad U-shaped basin characterizes the bottom topography of the Bay of Bengal with its south opening to the Indian Ocean. A thick uniform abyssal plain occupies almost the entire Bay of Bengal gently sloping southward at an angle of 8°-10°. In many places underwater valleys dissect this plain mass. The Bay of Bengal plays an important role in the climatic conditions of the adjacent land regions such as India, Bangladesh, Myanmar, Indonesia and Sri Lanka. The information about the seawater of the Bay of Bengal and its characteristics and circulation along the coast has paramount importance in understanding the numerous ocean processes. In the Bay of Bengal, the physical, chemical and biological processes are linked in an intimate manner. Oceanic environmental features such as Sea surface temperature, Sea surface wind and Chlorophyll concentration are important in assessing productivity of Bay of Bengal. The chlorophyll concentration is found to be dependent on the sea surface temperature, wind and monsoon activities.

1.2 Hydrography and circulation in Bay of Bengal

Hydrography and circulation of the Bay of Bengal is basically determined by the monsoon wind, which reverses semi-annually. The Bay of Bengal is forced locally by seasonally reversing monsoon winds and remotely by the winds in the equatorial Indian Ocean (McCreary et al., 1993). During the summer monsoon (June to September) the southwesterly winds of oceanic origin blows over the Bay of Bengal with very high speed (10-15m/s). During winter monsoon (November to February) the northeasterly winds of dry continental origin blows over

the Bay with speed of about 5 m/s. In spring (March-May) and fall (October), the winds are generally weak and variable. In response to these reversing winds the circulation of the Bay of Bengal also changes its direction. Surface circulation is found to be generally clockwise from January to July and counter-clockwise from August to December, in accordance with the reversible monsoon wind systems. The circulation in the Bay of Bengal is characterized by anticyclonic flow during most months and strong cyclonic flow during November. The flow is not constant and depends on the strength and duration of the winds. During the Southwest monsoon season, currents in the entire bay are weak and consists of several circulation features like eddies, meanders etc.

The Bay of Bengal receives a large quantity of fresh water from both rainfall and river runoff from the bordering countries. Annually, the major rivers Irrawaddy, Brahmaputra, Ganga and Godavari discharge about $1.5 \times 10^{12} \text{ m}^3$ of fresh water into the Bay of Bengal and rainfall ranges between 1m and 3m (Shetye et al., 1996). Fresh water from the rivers largely influences the coastal northern part of the Bay. The rivers of Bangladesh discharge the vast amount of 1,222 million cubic meters of fresh water (excluding evaporation, deep percolation losses and evapotranspiration) into the Bay. The temperature, salinity and density of the water of the southern part of the Bay of Bengal is, almost the same as in the open part of the ocean. In the coastal region of the Bay and in the northeastern part of the Andaman Sea where a significant influence of river water is present, the temperature and salinity are seen to be different from the open part of the Bay. Thus, the circulation and hydrography of the Bay of the Bengal is complex due to the interplay of the semi-annually reversing monsoon winds and the associated heat and large amount of freshwater fluxes from rivers. A unique feature of the Bay is occurrence of cyclones during October-November and April-May.

1.3 Oceanic environmental parameters

1.3.1 Sea Surface Temperature (SST)

Sea surface temperature (SST) is the water temperature at 1 meter below the sea surface. The physical property that can be measured with relative ease is the sea surface temperature. It is the most important oceanic parameter for both meteorologists and oceanographers because of its significant role in the exchange of heat, moisture and gases across the air-sea interface.

SST is indicative of ocean surface process - features like upwelling, fronts, eddies and current boundaries, etc. SST is primarily affected by the energy transfer process at the air-sea boundary and advection in the oceanic surface layer. The distribution of temperature in any region of sea or ocean is determined by the fluxes of heat through the sea surface and exchanges of heat, by advection or eddy diffusion, with the water of adjacent regions.

1.3.2 Chlorophyll Concentration

Chlorophyll-*a* concentration is an indicator of the phytoplankton biomass in the sea and is responsible for the photosynthesis. Chlorophyll-*a* concentration in the ocean can be estimated from the radiance detected in a set of suitably selected wavelengths through a retrieval procedure.

1.3.3 Sea Surface Wind

Sea surface wind determines the sea surface roughness and wave climate and thereby play significant role in the energy exchange at the air-sea interface. Sea surface winds drive the circulation of the upper ocean. The wind driven circulation is principally in the upper few hundreds meters and therefore is primarily a horizontal circulation in contrast to the thermohaline one.

1.3.4 Sea Surface Height

Sea surface height is defined as the distance of the sea surface above the referenced ellipsoid. The SSH computed from altimeter range and satellite altitude above the referenced ellipsoid. Sea surface height often shown as a sea surface anomaly or sea surface deviation, this is difference between the SSH at the time of measurement and the average SSH for that region and time of year. The variable height of the sea surface above or below the geoid.

1.4 Statement of problem and motivation

The Bay of Bengal is traditionally considered to be low productive region. Since the fisheries of a region is closely related to the chlorophyll and biological productivity, it is important to understand the distribution of chlorophyll and what controls it. The Bay of Bengal is the least explored region in the Indian Ocean and very few studies have attempted to analyze the satellite derived chlorophyll pigment concentrations. This is the motivation for this dissertation work, which aims at understanding the distribution and variability of the chlorophyll concentrations along with other environmental parameters.

1.5 Objectives

The main objective of this study is to use the GIS and remote sensing tools for analysis of the oceanic parameters in the Bay of Bengal.

The specific objectives of this study are:

- 1) To analyze the seasonal and inter-annual distribution and variability of chlorophyll pigment concentration of Bay of Bengal using GIS and remote sensing.
- 2) To analyze the seasonal and inter-annual distribution and variability of SST, SSH and SSW.
- 3) To analyze the correlation between chlorophyll concentration and others parameters such as SST, SSH and Wind, where these are related.



Chapter 2

GIS

And

Remote Sensing

CHAPTER 2

INTRODUCTION TO GIS AND REMOTE SENSING

2.1 Introduction to GIS

2.1.1 Definitions

A **Geographic Information Systems (GIS)** is a computer system for managing spatial data. The word **geographic** implies that location of the data items are known in terms of geographic coordinates (latitude, longitude). The word **information** implies that the data in a GIS are organized to yield useful knowledge, often as colored maps and images, but also as statistical graphics, tables, and various on-screen responses to interactive queries. The word **system** implies that a GIS is made up from several interrelated and linked components with different functions. Thus, GIS have functional capabilities for data capture, input, manipulation, transformation, visualization, combination, query, analysis, modeling and output. A GIS consists of a package of computer programs with a user interface that provides access to particular functions.

We can define the GIS in following words:

“GIS is a collection of computer hardware, software, and geographic data for capturing, managing, analyzing, and displaying all forms of geographically referenced information.”

In other words GIS as, "a computer based system that provides four sets of capabilities to handle geo-referenced data:

1. Data input
2. Data management (data storage and retrieval)
3. Manipulation and analysis
4. Data output.

2.1.2 Components of GIS

GIS constitutes of five key components:

Hardware, Software, Data, People and Procedure.

Figure1 showing the block diagram of component of the GIS.

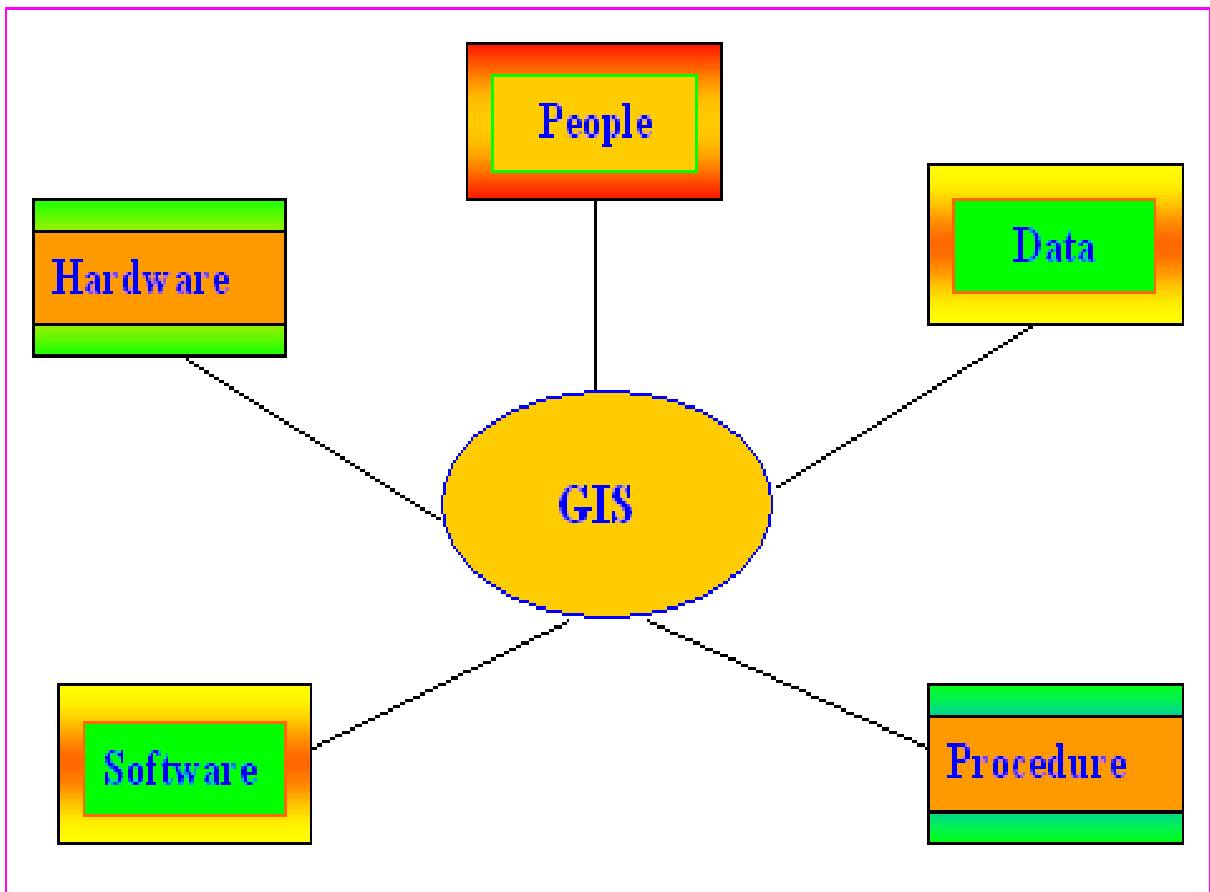


Figure1 Block diagram showing the component of the GIS

Hardware

GIS requires specialized hardware devices. Hardware capabilities affect processing speed, ease of use and the type of output available.

Software

GIS software provides the functions and tools needed to store, analyze, and display geographic information. GIS softwares in use are ARC/GIS, ARC/View, MapInfo, ARC/Info, AutoCAD Map, etc. software includes not just the GIS software, but also the various database, drawing, statistical, imaging, or other specific application software.

Data

The availability and accuracy of data can affect the results of any query or analysis.

People

People are the most important component of GIS. People are required to develop procedures and define the tasks of GIS. People can often overcome shortfalls in other components of the GIS, but the opposite is not true.

Procedure

Analysis requires well-defined, consistent, methods to produce correct and reproducible results.

2.1.3 Applications of GIS

Computerized mapping and spatial analysis have been developed simultaneously in several related fields. The present status would not have been achieved without close interaction between various fields such as utility networks, cadastral mapping, topographic mapping, thematic cartography, surveying and photogrammetry remote sensing, image processing, computer science, rural and urban planning, earth science, and geography and Oceanography.

We can use GIS technology in many fields such as:

- Forestry
- Natural Hazards
- Disaster Management
- Oceanography
- Environmental Study
- Geology
- Land use/ Land Cover Analysis
- Urbanization
- Rural Development
- Infrastructure and Utilities
- Health and Healthcare
- Business Marketing and Sales etc

2.2 GIS for the Oceanic Studies

Applications of GIS technology in the various oceanographic disciplines are multifaceted. They deal with data acquired with a variety of different methods and integration principles from different technological disciplines in an attempt to facilitate the resolution of the dynamics of the marine environment. Oceanographic GIS purpose solution to an ever-increasing number of marine problems and at the same time provide new insights to the unknown abyssal depths of our oceans. Ocean dynamics (oceanographic processes) as well as marine problems have inherent spatiotemporal characteristics. Oceanographic data have two essential parts (location and attributes) that makes them highly suitable for input to geospatial databases, which in turn open new ways for data storage, analysis and visualization. The majority of oceanographic data often have a geographic location, are digital. The spatial attribute of oceanographic data makes them highly suitable for GIS analysis as GIS provides a natural framework for the acquisition, storage, and analysis of georeferenced data. GIS database can store and manipulate oceanic datasets of several environmental parameters about physical, chemical, biological ocean process and present their effects on the marine environment in graphical format. Scientists, academics, and professionals studying the world's oceans and seas use Geographic Information Systems (GIS) to investigate their areas of interest. In recent years, the applications of GIS increased in the studies of oceanic process. Applications of GIS technology are used in a variety of ways, such as distribution tools, mapping tools and monitoring analysis tools and in a variety of disciplines, such as ocean surface processes, environmental and bioeconomic characterisation of coastal and marine system, fisheries, sea level rise and climate change, marine geology and geomorphology, coastal zone assessment and management, deep ocean mapping etc.

Compared to land-based sciences, regarding terms of mapping, managing and modeling, based on spatial data, Geographic Information systems (GIS) are not widely used in marine sciences of the pelagic and deep ocean. The volume of data collected from oceans through remote sensing and acoustic as well as traditional field observation techniques has become tremendously large and complex.

The interdisciplinary nature of studying marine processes requires data integration of multiple types and formats. Despite large variations, all the data share the common characteristic of physical location. This georeferencing feature allows the integration of data from all sources and types under a single platform, a geographic information system. See Figure 2.

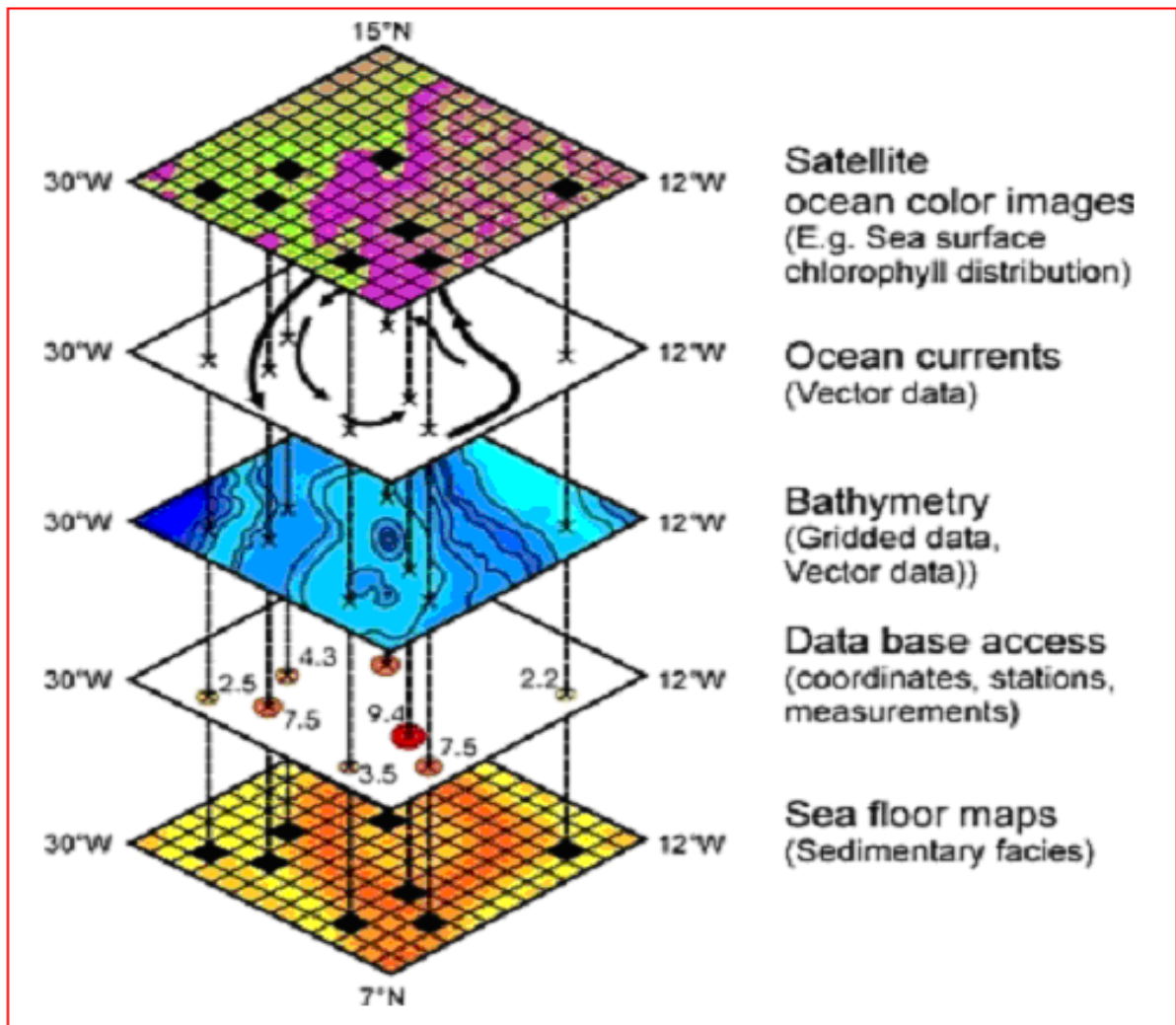


Figure 2 Picture showing capability of GIS, which can generate different layers of information about Ocean.

2.3 Introduction to Remote Sensing

2.3.1 Definitions

We can define the remote sensing in following words:

"Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information."

Electro-magnetic radiation, which is reflected or emitted from an object, is the usual source of remote sensing data. However any media such as gravity or magnetic fields can be utilized in remote sensing. The characteristics of an object such as temperature, height, and chlorophyll concentration etc. of ocean can be determined, using reflected or emitted electro-magnetic radiation, from the object. That is, "each object has a unique and different characteristics of reflection or emission if the type of object or the environmental condition is different." Remote sensing is a technology to use for identifies and understands the characteristics or the environmental condition of the ocean through the uniqueness of the reflection or emission. See Figure 3.

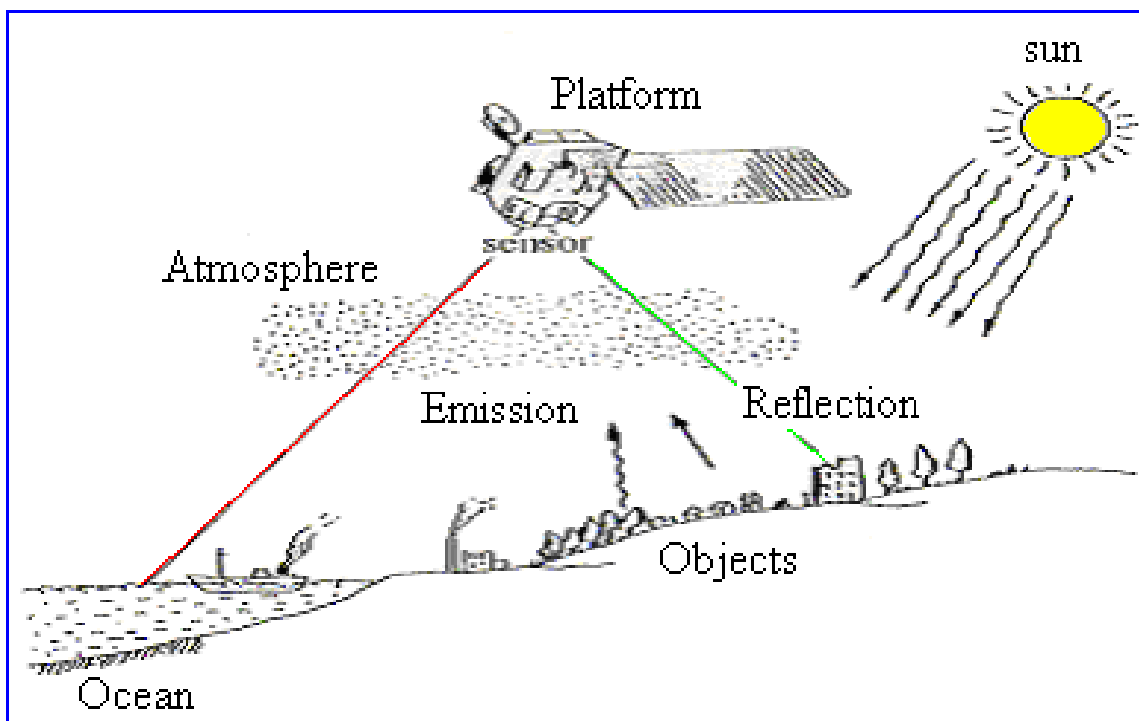


Figure 3 Schematic showing the Data Collection by Remote Sensing

Remote sensing is classified into three types with respect to the wavelength regions:

- (1) **Visible and Reflective Infrared Remote Sensing,**
- (2) **Thermal Infrared Remote Sensing** and
- (3) **Microwave Remote Sensing**

The **energy source** used in the visible and reflective infrared remote sensing is the sun. Remote sensing data obtained in the visible and reflective infrared regions mainly depends on the **reflectance** of objects on the ground surface. Therefore, information about objects can be obtained from the spectral reflectance.

The source of radiant energy used in **thermal infrared remote sensing** is the object itself, because any object with a normal temperature will emit electro-magnetic radiation with a peak.

In the **microwave region**, there are two types of microwave remote sensing, passive microwave remote sensing and active remote sensing. In passive microwave remote sensing, the microwave radiation emitted from an object is detected, while the back scattering coefficient is detected in active microwave remote sensing.

2.3.2 Sensor

A device to detect the electro-magnetic radiation reflected or emitted from an object is called a "remote sensor" or "**sensor**". Cameras or scanners are examples of remote sensors. A vehicle to carry the sensor is called a "**platform**". Aircraft or satellites are used as platforms.

We can divide the sensor in two types - Passive Sensor and Active Sensor.

Passive sensors detect the reflected or emitted electro-magnetic radiation from natural sources, while **active sensors** detect reflected responses from objects, which are irradiated from artificially, generated energy sources, such as radar.

Each is further divided in to non-scanning and scanning systems.

A sensor classified as a combination of passive, non-scanning and **non-imaging method** is a type of profile recorder, for example a microwave radiometer. A sensor classified as passive, non-scanning and **imaging method**, is a camera, such as an aerial survey camera or a space camera, for example on board the Russian COSMOS satellite.

Sensors classified as a combination of passive, scanning and imaging are classified further into **image plane scanning sensors**, such as TV cameras and solid state scanners, and **object plane scanning sensors**, such as multispectral scanners (optical-mechanical scanner) and scanning microwave radiometers. An example of an active, non-scanning and non-imaging sensor is a profile recorder such as a laser spectrometer and laser altimeter. An active, scanning and imaging sensor is radar, for example synthetic aperture radar (SAR), which can produce high resolution, imagery, day or night, even under cloud cover.

2.4 Remote sensing for Oceans

Remote Sensing is a technique based on measuring the electromagnetic energy reflected or emitted by the surface of geographic space (Caloz and Collet, 2003). Satellites are able to sense an array of parameters including ocean color, Sea Surface Temperature, Sea Surface Height Anomalies and Sea Surface winds (Simpson, J.J. 1992). Remote Sensing data provides Sea surface temperature information along with data on sea surface height and also provides information on the oceanic and atmospheric phenomena, chlorophyll concentration, sea surface wind etc. Remote sensing of the ocean environment comprises the greatest source of information about several oceanic environmental parameters of the ocean surface. Remote sensing monitoring provides important tools for better understanding of the marine processes, ecology and the ocean environmental changes. The most widely used remote sensing techniques today are based on the detection/sensing of electromagnetic radiations. Remote sensing of oceanic parameter from space provide advantage point from which maps of oceanic properties on a very large scale can be prepared. Remote sensing techniques is a very useful tool for synoptic and continuous study of oceanic parameters over Bay of Bengal.

2.4.1 Remote Sensing for Chlorophyll Concentration

Satellite ocean color remote sensing is based on sensing the radiance exiting the ocean surface that contains a wealth of spectral information regarding the absorption and scattering processes of the constituents within the water column that include water itself, phytoplankton, colored dissolved organic matter, and suspended sediments (Kirk, 1994). The goal of remote sensing of ocean color is to derive quantitative information on the types and concentrations of these

substances present in the water from variations in spectral form and magnitude of the emergent flux from the ocean. Ocean color is determined by remote sensing reflectance (R_{rs}); the ratio of water leaving radiance (L_u) to down welling irradiance (Kirk, 1994). It is a measure of how much of the down welling light that is incident onto the water surface is eventually returned through the surface and is a product of the specific absorption spectra of the water column constituents. Most commonly, ocean color information is used to determine chlorophyll concentration that is used as a proxy for phytoplankton biomass. This information is then used to quantitatively determine the ocean's role in biogeochemical cycles, determine the magnitude and variability of primary production, and timing of phytoplankton blooms. However, current progressive research is also trying to discern many other parameters from ocean color revealing information about suspended sediments, organic matter concentrations, coccolith concentration, various pigment concentrations, attenuation of light, total absorption, and chlorophyll fluorescence which is used as a proxy for phytoplankton physiological stress.

SeaWiFS for Chlorophyll Concentration

The purpose of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project is to provide quantitative data on global ocean bio-optical properties to the Earth science community. Subtle changes in ocean color signify various types and quantities of marine phytoplankton (microscopic marine plants), the knowledge of which has both scientific and practical applications.

SENSOR DESCRIPTION : The SeaWiFS instrument consists of an optical scanner and an electronics module. Table 1 below provides characteristics of SeaWiFS.

Table 1 Characteristic of SeaWiFS

AGENCY	NASA (USA)
SATELLITE	OrbView-2 (USA)
LAUNCH DATE	01/08/97
SWATH (km)	2806
RESOLUTION (m)	1100
NUMBER OF BANDS	8
SPECTRAL COVERAGE (nm)	402-885

2.4.2 Remote Sensing for Sea Surface Temperature

Satellite remote sensing can provide thermal information in a short time over a wide area. Temperature measurement by remote sensing is based on the principle that any object emits electro-magnetic energy corresponding to the temperature, wavelength and emissivity.

MODIS for Sea Surface Temperature

MODIS (Moderate Resolution Imaging Spectroradiometer) is key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. See Table 2 for the characteristics of MODIS. These data will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. MODIS is playing a vital role in the development of validated, global, interactive Earth system models able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment. This Level 2 and 3 products provide sea surface temperature at 1-km (Level 2) and 4.6 km, 36 km, and 11 (Level 3) resolutions over the global oceans. Table 2 gives showing the characteristics of MODIS.

Table 2 Characteristics of MODIS

Orbit	705 km, sun-synchronous, near-polar, circular
Swath dimensions	2300 km at 110° ($\pm 55^\circ$) from 705 km altitude
Spatial resolution	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)

2.4.3 Remote sensing for Sea Surface Height

One of the ways remote sensing can be used in studying the ocean is by depicting sea surface height anomalies. Sea surface height anomalies are the difference between the observed and the average sea surface height as observed by the TOPEX satellite.

Principles of altimeter

The radar altimeter sends short pulses of microwave energy toward the ocean below; the round-trip travel time of the reflected pulse yields the distance between the spacecraft and the sea surface. In addition, the shape of the reflected pulse is used to determine wave height and sea-surface wind speed. See Figure 4.

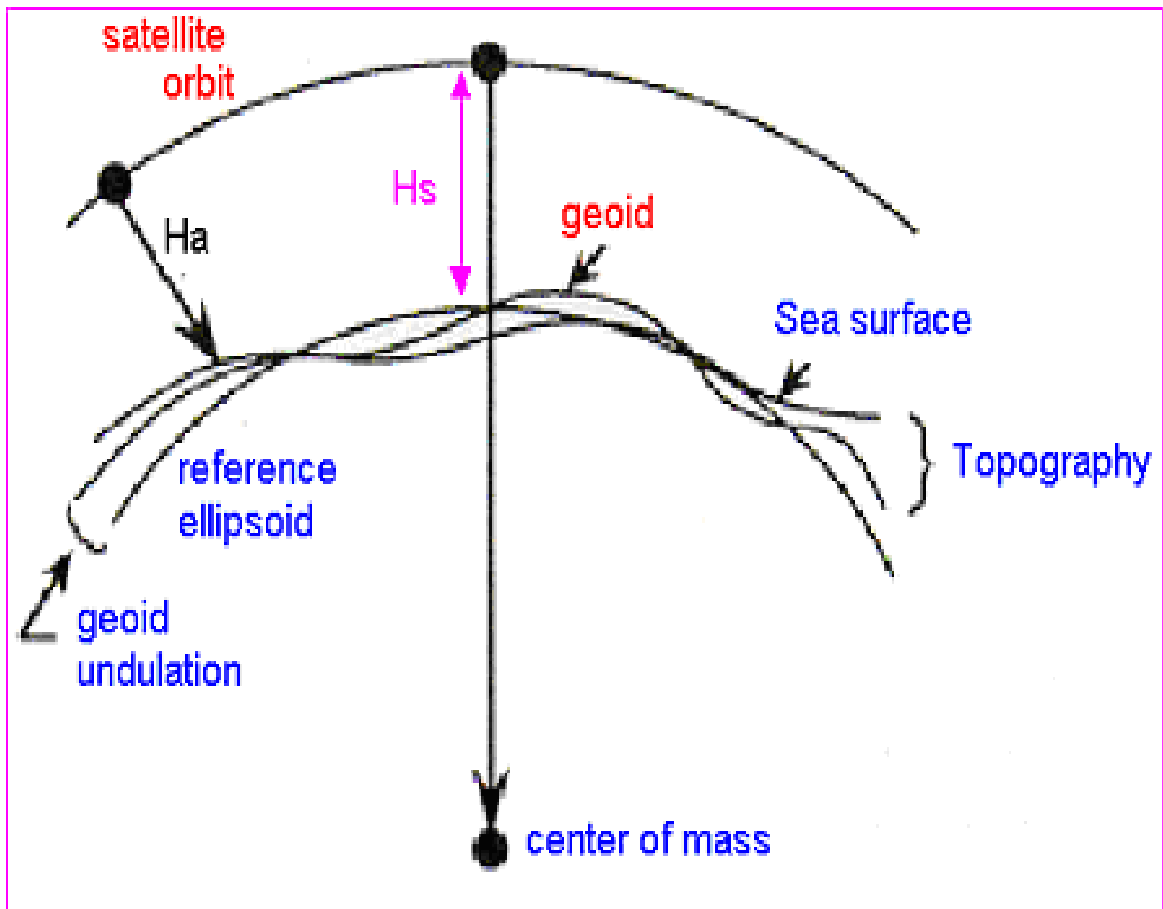


Figure 4 Schematic showing the principle of Radar altimetry

The sea surface height is computed from altimeter range and satellite altitude above the reference ellipsoid. Sea surface height is often shown as a sea-surface anomaly or sea-surface deviation, this is the difference between the sea surface height at the time of measurement and the average sea surface height for that region and time of year. The higher the sea surface height anomaly, the warmer the layer of water. The ground height or the sea surface height is measured from the **reference ellipsoid**. If the altitude of the satellite H_s is given as the height from the reference ellipsoid, the **sea surface height** HSSH is calculated as follows.

$HSSH = H_s - H_a$ where, H_a - measured distance between satellite and the sea surface.

The sea surface height is also represented by the geoid height H_g that is measured between the geoid surface and the reference ellipsoid and the **sea surface topography** DH.

TOPEX/POSEIDON Altimeter Sensor/Instrument and ERS-1

TOPEX/POSEIDON is a satellite mission that uses radar altimetry to make precise measurements of sea level with the primary goal of studying the global ocean circulation. ERS-1 is not as accurate an altimetric satellite as TOPEX, but it has been used for important studies nevertheless. ERS-1 has a much finer spatial resolution ($3/4$ by $3/4$ degree) than TOPEX/POSEIDON (3 by 3) and a much greater spatial coverage than its more modern counterpart. This has led ERS-1 to be used to determine tidal components that has been used to compute the SSH using TOPEX/POSEIDON. The greater spatial coverage with lesser SSH resolution has led to a technique that calibrates the ERS-1 data with TOPEX. These results are then meshed and used to obtain a final merged SSH product. The primary science goal of the TOPEX/POSEIDON mission is to substantially increase our understanding of global ocean dynamics by making precise and accurate observations of sea level for several years. TOPEX/POSEIDON will obtain measurements of global ocean surface topography with a precision of two centimeters and a single-pass accuracy of 13 centimeters along a fixed grid every ten days for a period of three years.

2.4.4 Remote Sensing for Sea Surface Wind

Winds are measured with a microwave radar scatterometer where a radar signal is transmitted to the surface of the ocean and then is backscattered to the sensor. The roughness of the sea surface influences the strength of the signal and is used to determine the relative direction and speed of wind acting on the surface of the ocean. This information is used in air-sea interaction research, climate research, hurricane forecasting, and ocean circulation. Sea surface irradiance is determined from atmospheric parameters that determine the amount of sunlight that reaches the surface of the ocean and is an important factor in climate and also primary production studies.

QuikSCAT/SeaWinds

SeaWinds is a rotating scatterometer (measurement of the surface wind speed and direction over the ocean) onboard **QuikSCAT**, launched by **NASA** on June 19, 1999. The SeaWinds instrument on the QuikSCAT satellite is specialized microwave radar that measures near-surface wind speed and direction under all weather and cloud conditions over Earth's oceans.

Description

Launch Vehicle: Titan II

Orbit: Sun-synchronous, The satellite altitude is about **800 km**, 98.6° inclination orbit.

Swath is **1800 km** large for the outer beam and **1414 km** for the inner beam.

Measurements

1,800-kilometer swath during each orbit provides approximately 90-percent coverage of Earth's oceans every day.

Wind-speed measurements of **3 to 20 meters/second**, with an accuracy of **2 meters/second**; direction, with an accuracy of 20 degrees.

Wind vector resolution - **25 kilometers**.

2.5 Integrating Remotely Sensed Data through GIS

Remotely sensed data, especially satellite data, is in a ready made spatial data format for GIS. Thus, it plays a very important role in the optimum utilization of GIS technology. Merging these two technologies i.e. Remote Sensing and GIS, can results in a tremendous increase in information for many kinds of users. Remote sensing data, thus, bears a synergistic relationship to GIS technology and undoubtedly will be a major source of both original and monitoring information on the earth and ocean's environment. GIS is the most appropriate framework for the merging of these data sets on chlorophyll concentration, SST, SSH and SSW. GIS offers a perfect platform to integrate remotely sensed point data sets. It is a computerized tools and fully integrated environment designed to acquire, manage, process and analyze spatial information (Caloz and Collet, 1997). This allows easy investigations of co-relations of variables and historical and current data can be merged to create a multi-dimensional data set of location, value and time which leads to inquires based upon location, condition, trends, patterns and modeling (Lehmann and Lachavanne, 1997). GIS contributes a new dimension to the modeling of geographic space from a connection to relational or object oriented databases (Caloz and Collet, 1997). GIS is a rich and powerful means of data management, archiving, distribution and analysis.

Chapter 3

Materials And Methodology

CHAPTER 3

Materials and Methodology

The main objectives of this study to evaluate the environmental conditions of Bay of Bengal and analyze the seasonal and inter-annual distribution and variability of oceanic environmental parameters such as sea surface temperature (SST), chlorophyll concentration, sea surface height (SSH) anomalies and sea surface wind (SSW) using GIS technology. For the present study remotely sensed data from different satellites were used to study the environmental characteristics of the Bay of Bengal. These Remote sensing data were further used for the analysis in GIS environment.

Data Used

The study domain is from equator to 22°N latitude and 78°E to 100°E longitude. For present study we used satellite remote sensing monthly mean data on SST, chlorophyll pigment concentration, sea surface winds and sea surface height anomaly from January 2002 to December 2005. These datasets we obtained from different sensors. Table 3 gives the details pertaining to each of the data used in this study.

Data sets:

- ▶ **Sea Surface Temperature (SST)**
- ▶ **Chlorophyll Concentration**
- ▶ **Sea Surface Height (SSH) Anomaly**
- ▶ **Sea Surface Wind (SSW)**

Table 3 Details pertaining to the remote sensing data used for the study including sensor, resolution and data source.

Serial no.	Parameter	Sensor	Resolution	Web site
1	Sea surface temperature (SST)	Modis Aqua	Monthly data at 0.33 degree resolution	http://oceancolor.gsfc.nasa.gov/ , http://poet.jpl.nasa.gov/
2	Chlorophyll pigment concentration	SeaWifs (Sea Viewing wide field of view sensor)	Monthly data at 0.33 degree resolution	http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.seawifs.shtml
3	Sea surface wind	Quikscat (Quick Scatterometer)	Daily wind data at 0.25 degree spatial resolution	http://www.ssmi.com/qscat/qscat_browse.html , http://poet.jpl.nasa.gov/
4	Sea surface height (SSH) anomalies	Topex/Posidon and ERS-1/2 satellites	7-day snap-shots of the merged sea-level anomalies at 0.33 degree resolution	http://las.aviso.oceanobs.com

Methodology

Once the monthly mean data were extracted, further processing was carried out using GIS environment. The present work has been carried out in GIS environment using **Arc GIS 9.0 and Arc View 3.2** are the GIS software. In general, the processing using GIS can be divided into three parts - data conversion, contour map generation and analysis.

1. **Data conversion** - In this step, Remotely sensed ASCII data is first converted in the dbf format for the GIS environment analysis using MS Access and MS Excel.
2. **Contour Map Generation** – Subsequently, point map (shape files) of each of the 4 parameters such as sea surface temperature, chlorophyll concentration, sea surface height and sea surface wind, were prepared in Arc/View 3.2 from the tabular point data. Then these point maps were called in Arc/GIS for creating contour maps for further analysis. Then an inverse distance weighting interpolation methods was used for the creation of filled contour maps of all the parameters.

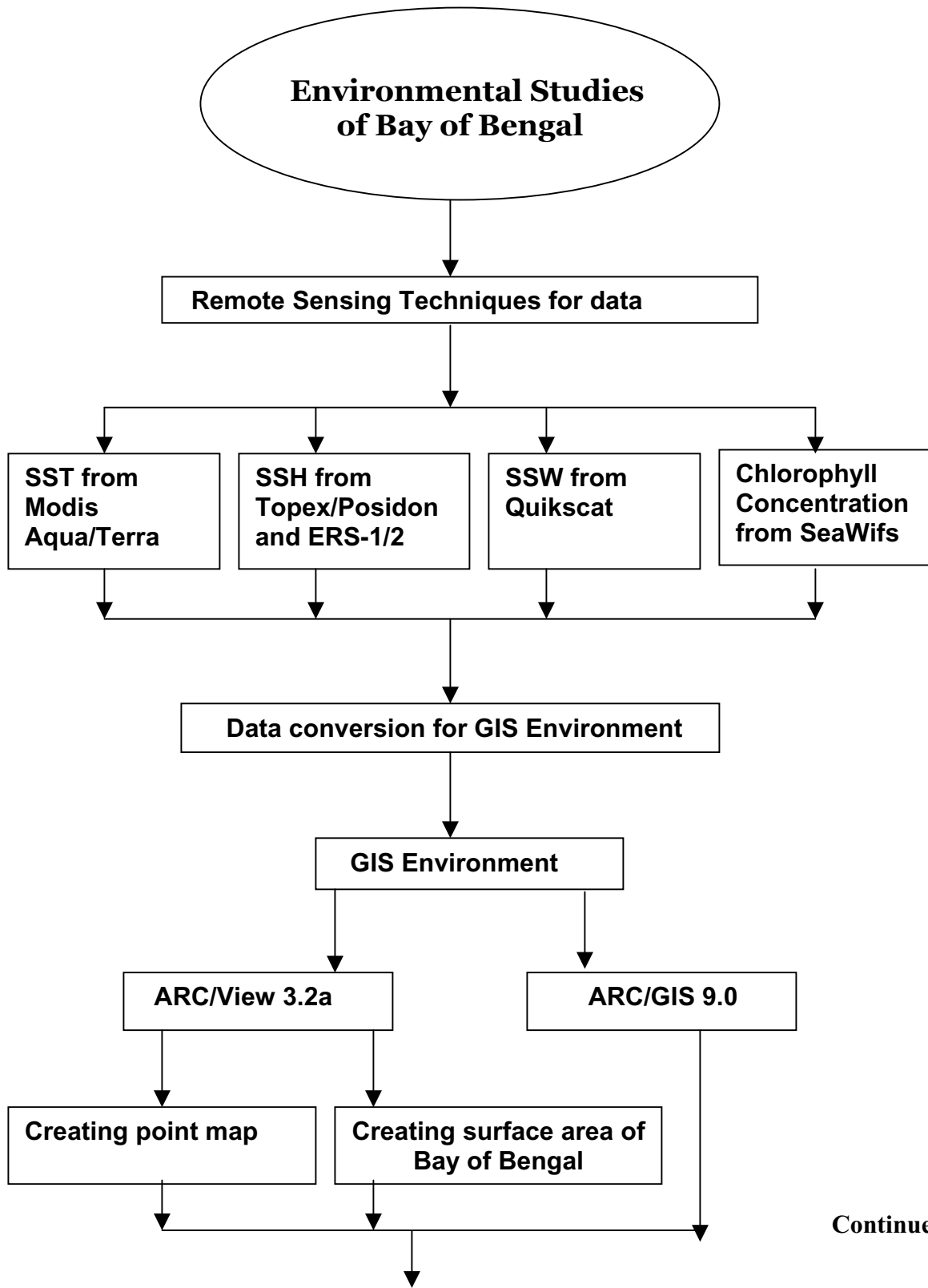
Inverse Distance Weighted

IDW is an exact interpolator, where the maximum and minimum values in the interpolated surface can only occur at sample points. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. It weights the points closer to the prediction location greater than those farther away, hence the name inverse distance weighted. IDW is very suitable for creating filled contour maps that shows the polygon shape of the datasets.

Filled Contour Map

Filled contour is the polygon representation of the geostatistical layer. It is assumed for the graphical display that the values between each contour line are the same for all locations within the polygon. In filled contour every polygon has the minimum and maximum values of the generated maps.

3. **Analysis** - In this part, we analyzed the inter-annual and seasonal distribution and variability of oceanic parameters of Bay of Bengal using filled contour maps of these parameters and discussed the correlation between these parameters.



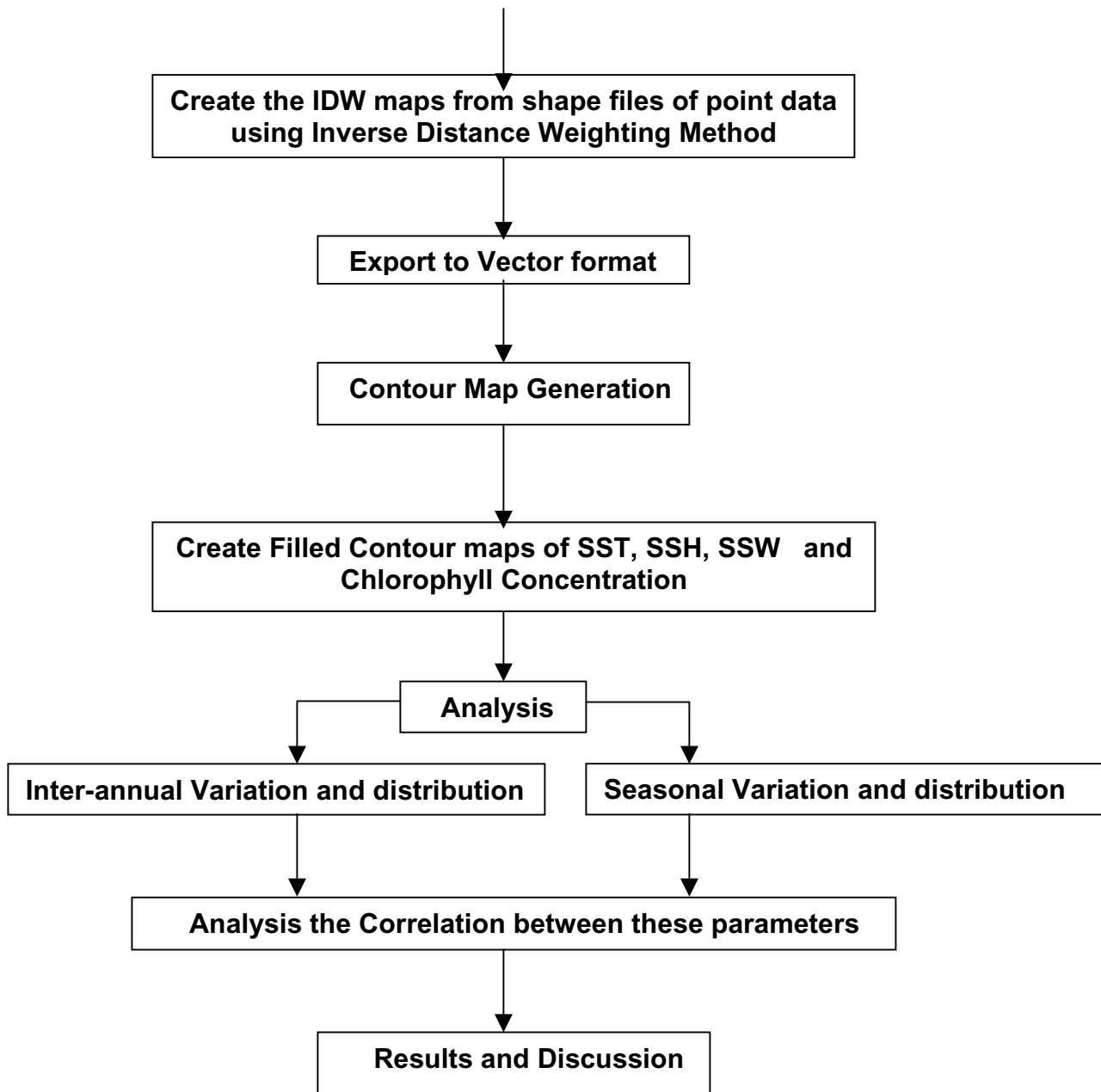


Figure 5 Flow chart showing various steps followed while processing the Remote Sensing data using GIS Techniques.

chapter 4

Results And Discussion

CHAPTER 4

Results and discussion

Seasonal Cycle

To understand the seasonal cycle, we choose the monthly mean data for the months January, April, July, August, and October for the year 2003.

Seasonal cycle of sea surface temperature

Sea surface temperature distribution in January showed a pattern, which was uniform in the zonal direction, but varied meridionally (Fig.6) SST was coldest in the north with the minimum of 22°C and increased steadily towards south where the maximum was 31°C. In western bay average SST was seen about 26°C, while in the eastern Bay, it was about 28°C. In April, the SST showed a rapid heating of 3 to 6°C in the northern Bay compared to winter (Fig.7). Spatially it varied only marginally from 29°C to 31°C in the entire Bay, except in small pockets along the eastern boundary where it was 32°C and in the northern most coastal region where it was 28°C. By July, as the summer monsoon sets in the Bay, the SST was more or less uniform in the entire Bay with a value of 29°C (Fig.8). However, SST of 30°C was noticed in the southwestern and southern region, while 31°C was seen in the southeastern region. Pockets of colder waters with SST 28°C were seen in the central and eastern Bay. In August, the SST pattern remains more or less similar to July, except the occurrence of colder waters around Sri Lanka and northeastern Bay intruding into the central Bay (Fig.9). In October, in the northern Bay SST was warmest of all the months with a value of 31°C. Entire Bay was very warm with SST of 30°C, except in a zonal patch in the south and a small pocket near the western boundary, which was 1°C colder (Fig.10). The distribution pattern of SST during October was just reverse of that during January. See Table 4 for the basin-averaged SST for each of the above-discussed month along with the minimum and maximum values.

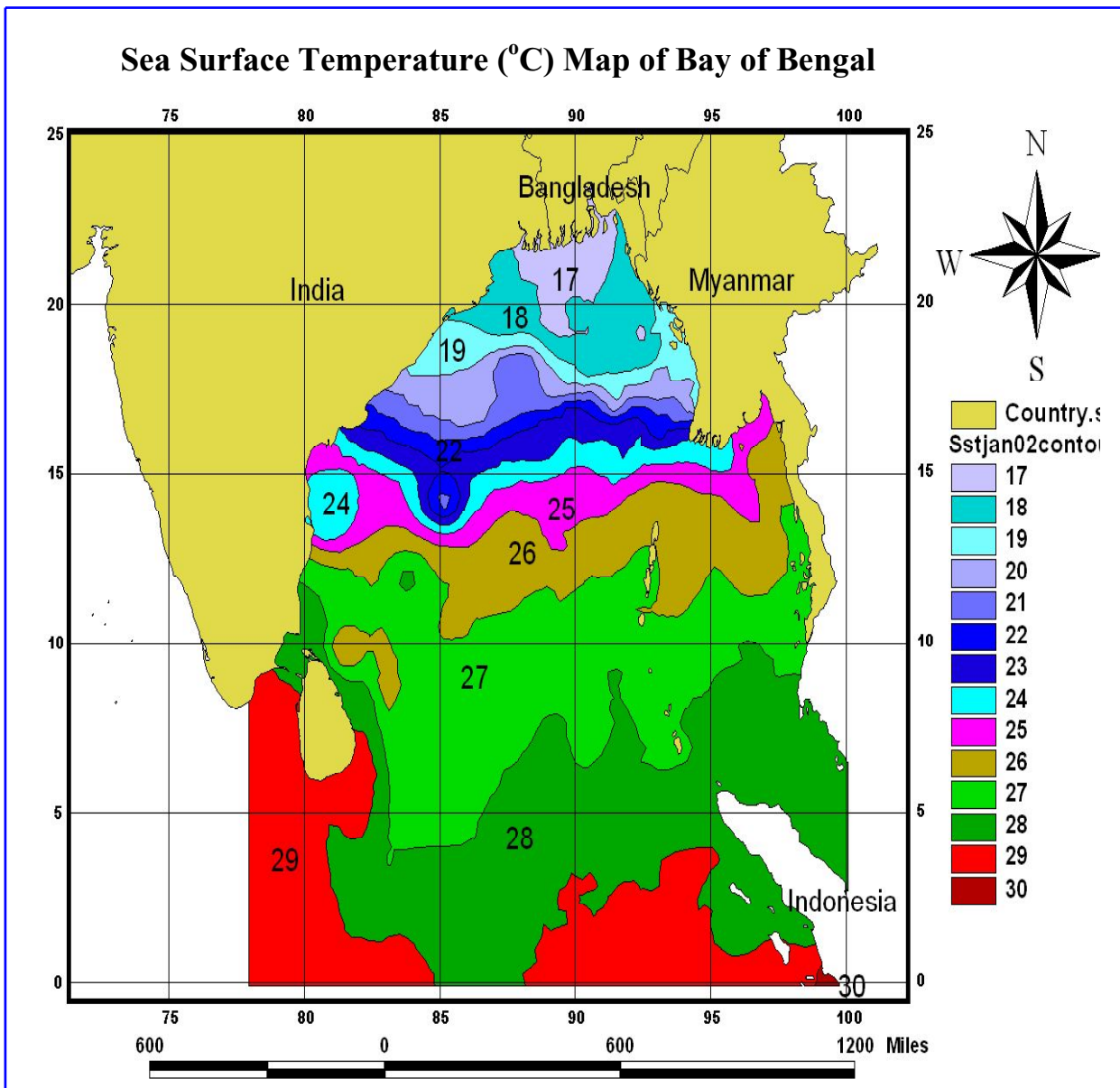


Fig.6 Monthly mean SST ($^{\circ}\text{C}$) distribution in Bay of Bengal in January 2003

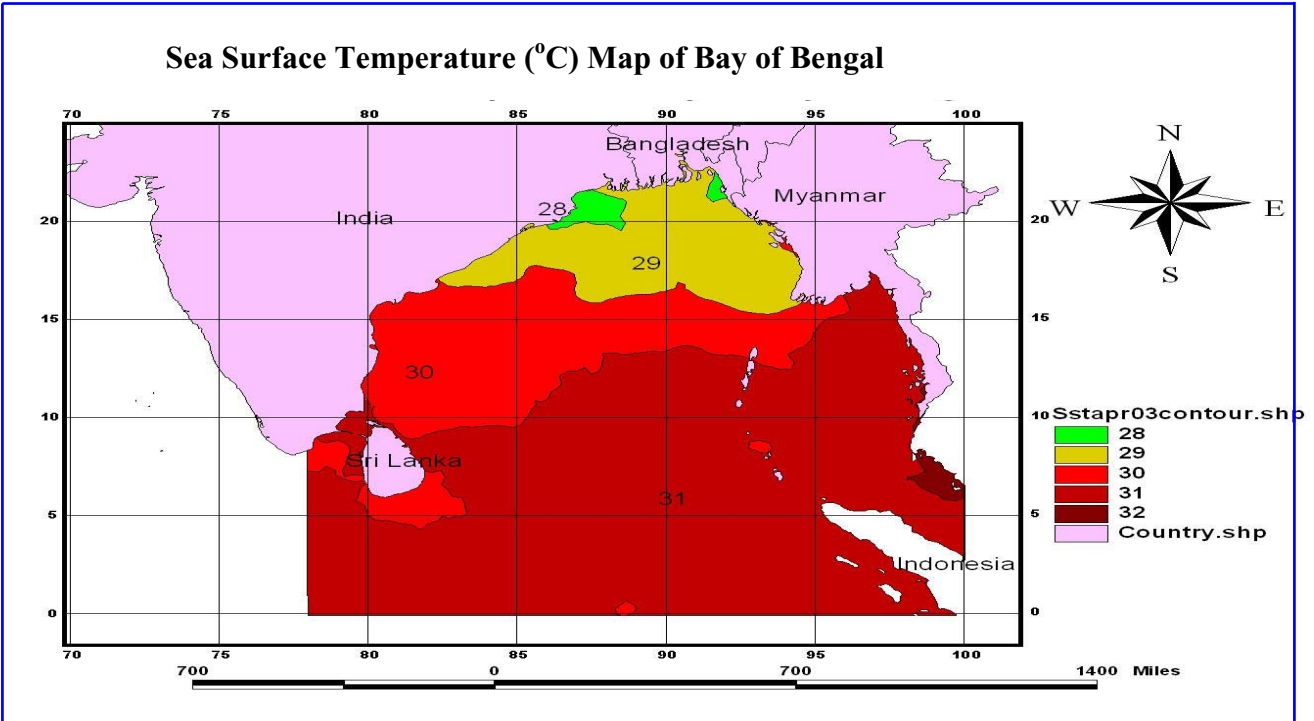


Fig.7 Monthly mean SST (°C) distribution in Bay of Bengal in April 2003

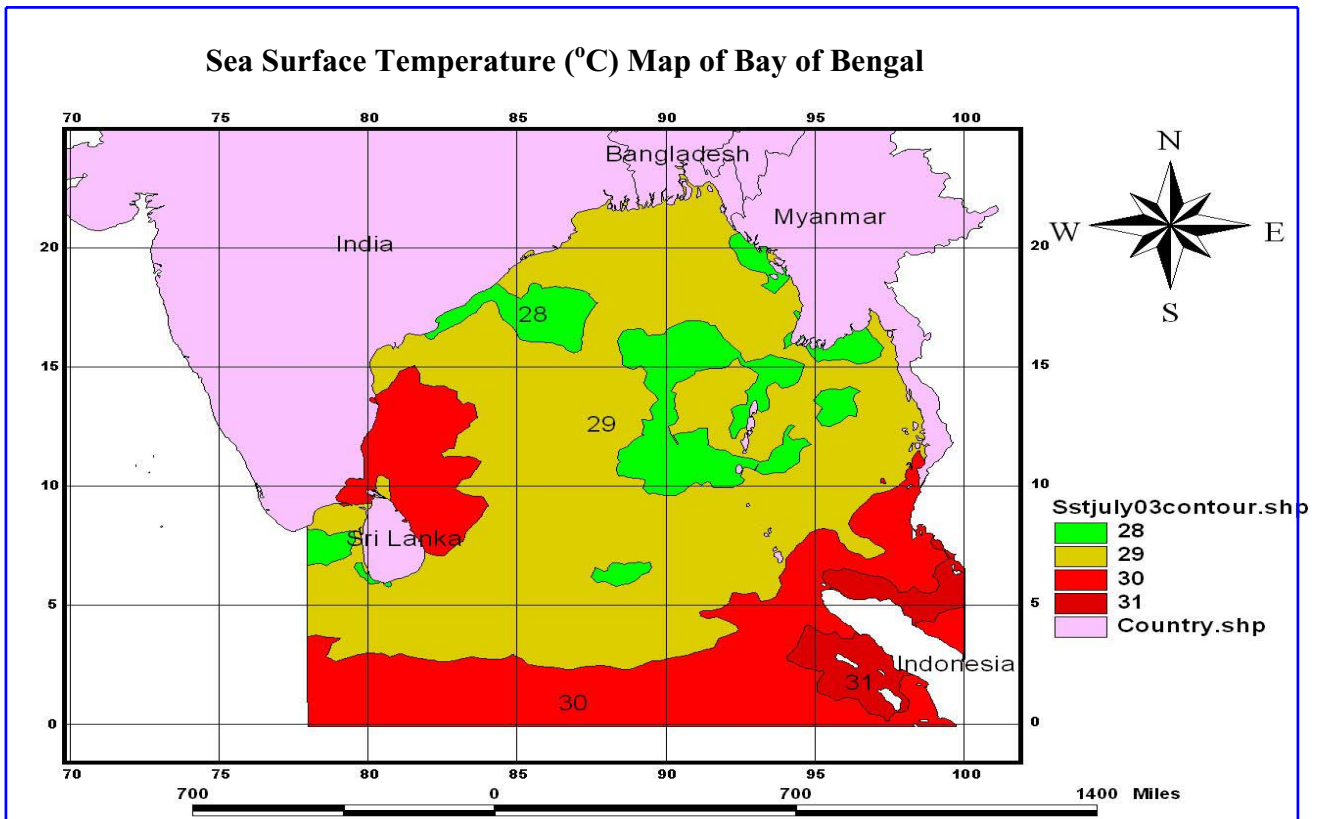


Fig.8 Monthly mean SST (°C) distribution in Bay of Bengal in July 2003

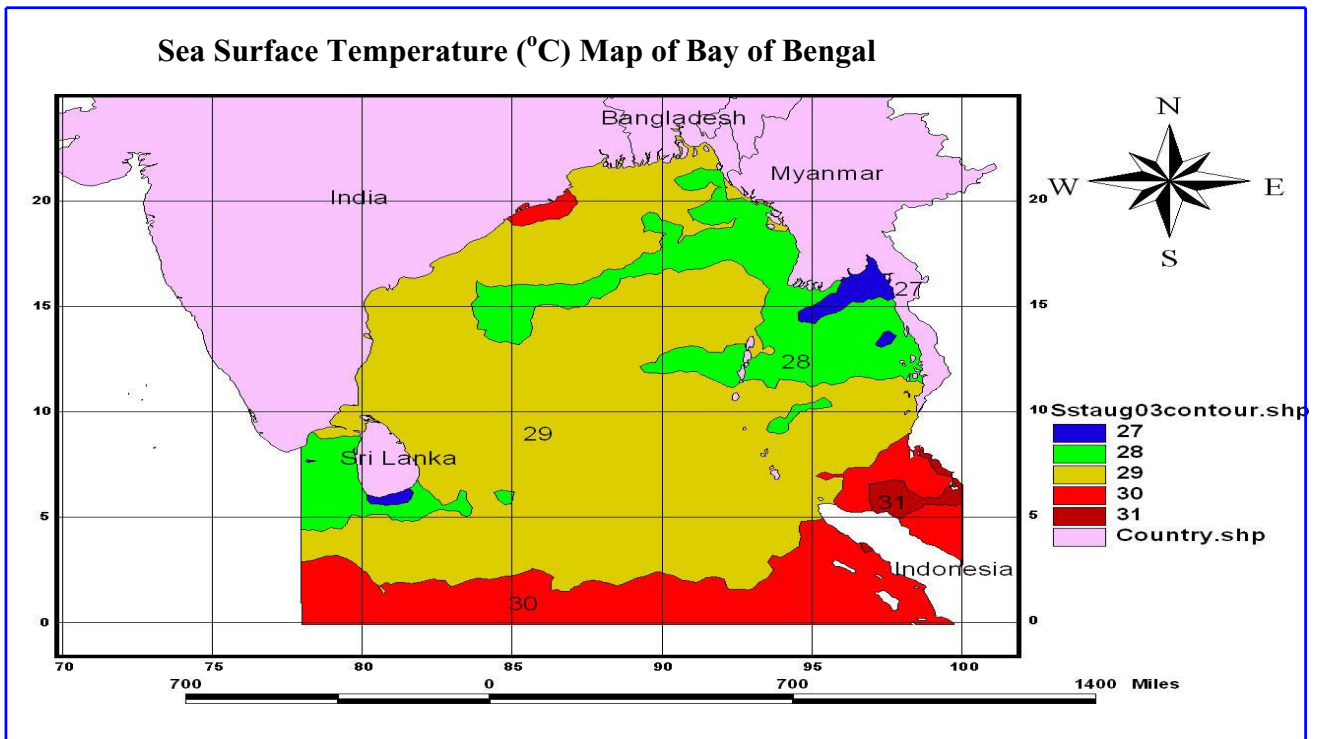


Fig.9 Monthly mean SST (°C) distribution in Bay of Bengal in August 2003

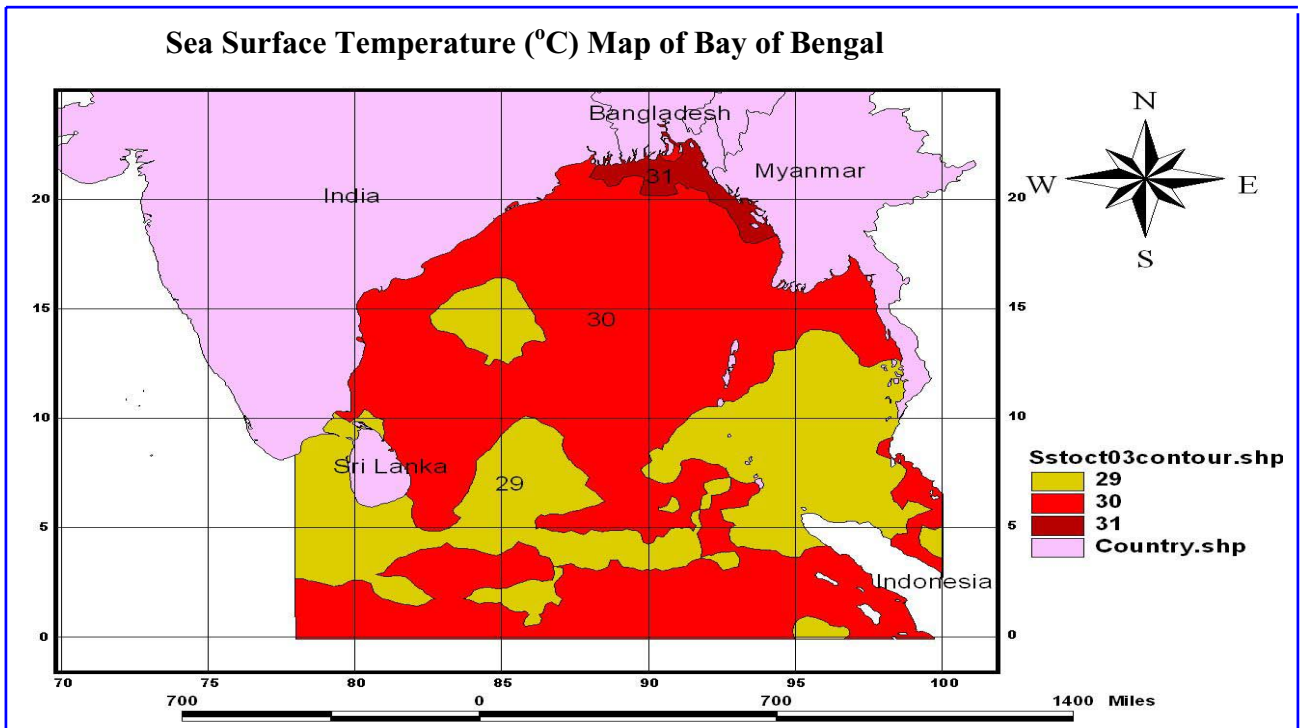


Fig.10 Monthly mean SST (°C) distribution in Bay of Bengal in October 2003

Table 4 Basin averaged SST ($^{\circ}\text{C}$) with its maximum and minimum value during different months in the year 2003

Month of 2003	Sea Surface Temperature ($^{\circ}\text{C}$) in 2003		
	Minimum	Maximum	Average
January	21	31	28
April	27	32	30
July	27	31	29
August	26	31	28
October	28	31	29

Seasonal cycle of chlorophyll pigment concentration

The distribution of chlorophyll pigment concentration in January varied marginally from 0.1 to 0.3 mg/m³ in the Bay except very close to the coast (Fig.11). Near the coastal areas chlorophyll pigment concentrations showed large variations from 0.4 to 10 mg/m³. Higher values of chlorophyll concentration of about 5 to 10mg/m³ were seen near the Ganges-Brahmaputra-Meghna rivers deltaic region in the north and Irrawady river basin in the eastern coastal region. One needs to be cautious in interpreting the values very near the coast due to the possible contamination of signal by sediment load. In April, chlorophyll concentration was the least in the open Bay with values between 0.1 and 0.2 mg/m³ (Fig.12). As in the case of January, the concentrations increased rapidly towards the coastal region with a maximum value of 5 mg/m³, except in 3 small patches near the river mouths of Irrawady, Ganges and Godavari where the values were as high as 10 mg/m³. In July we see an increase in pigment concentrations all along the coastal and near shore regions, especially in the Indo-Sri Lanka region and off Godavari and Krishna rivers where concentrations varied between 2 to 5 mg/m³ (Fig.13). In fact an overall increase in pigment concentrations compared to April was noticed towards the western and southern Bay of Bengal. In August chlorophyll concentrations were the highest in the Bay with open sea values between 0.2 to 0.3 mg/m³, while along the western and northern boundary extending up to the central Bay, the concentrations ranged from 0.4 to 10 mg/m³ (Fig.14). Interesting observation is the extending patch of high chlorophyll concentrations from Indo-Sri Lanka region towards east into the central Bay. Similarly patch of high concentration extends from Godavari and Ganges mouth into offshore region. In October, though the chlorophyll concentrations were high, they were in general less compared to August (Fig.15). Chlorophyll concentrations in the Indo-Sri Lanka region still remain one of the highest. Table 5 shows the basin-averaged chlorophyll pigment concentrations for each of the above-discussed month along with the minimum and maximum values.

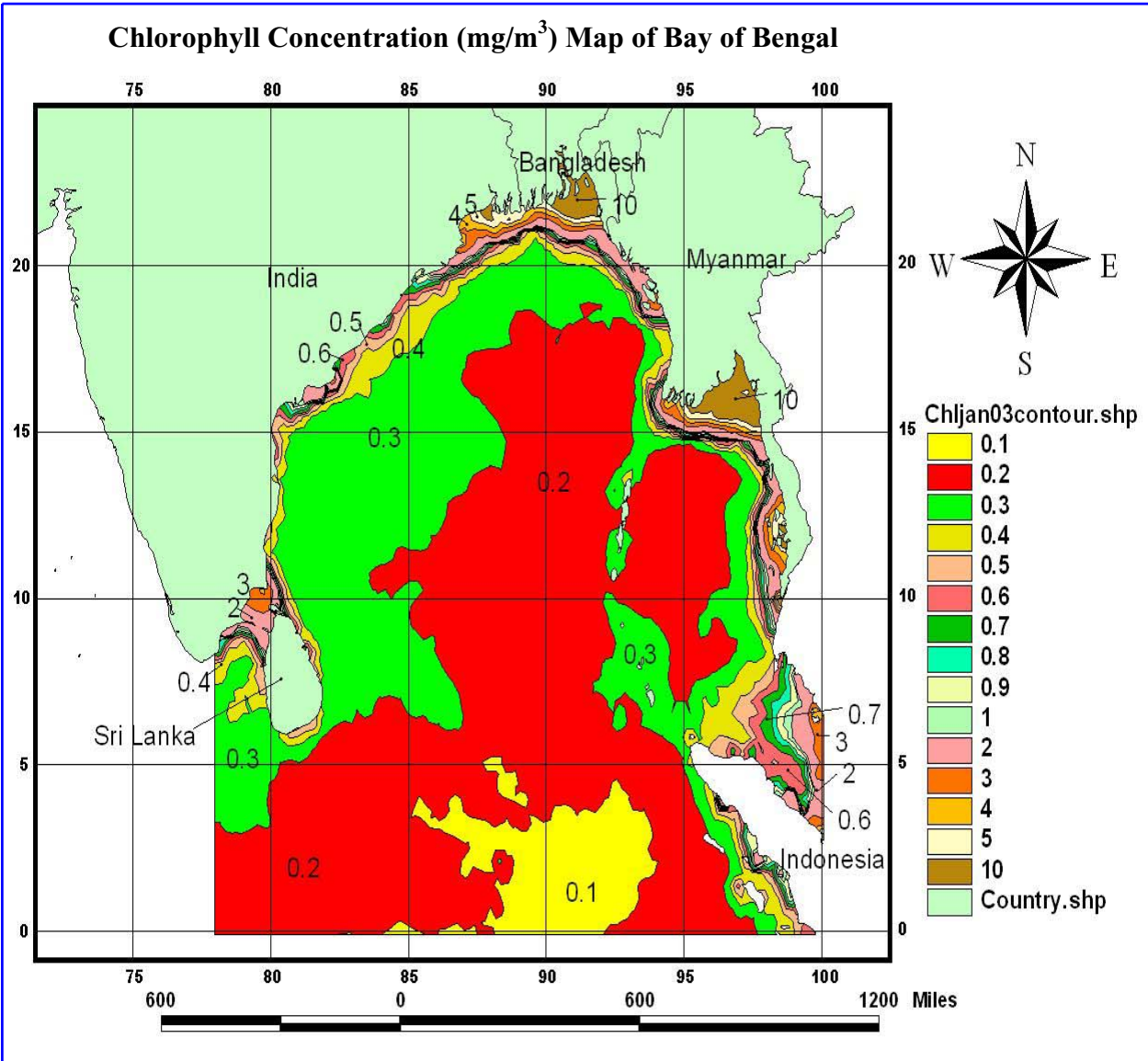


Fig.11 Monthly mean chlorophyll concentration (mg/m^3) distribution in January 2003 in Bay of Bengal

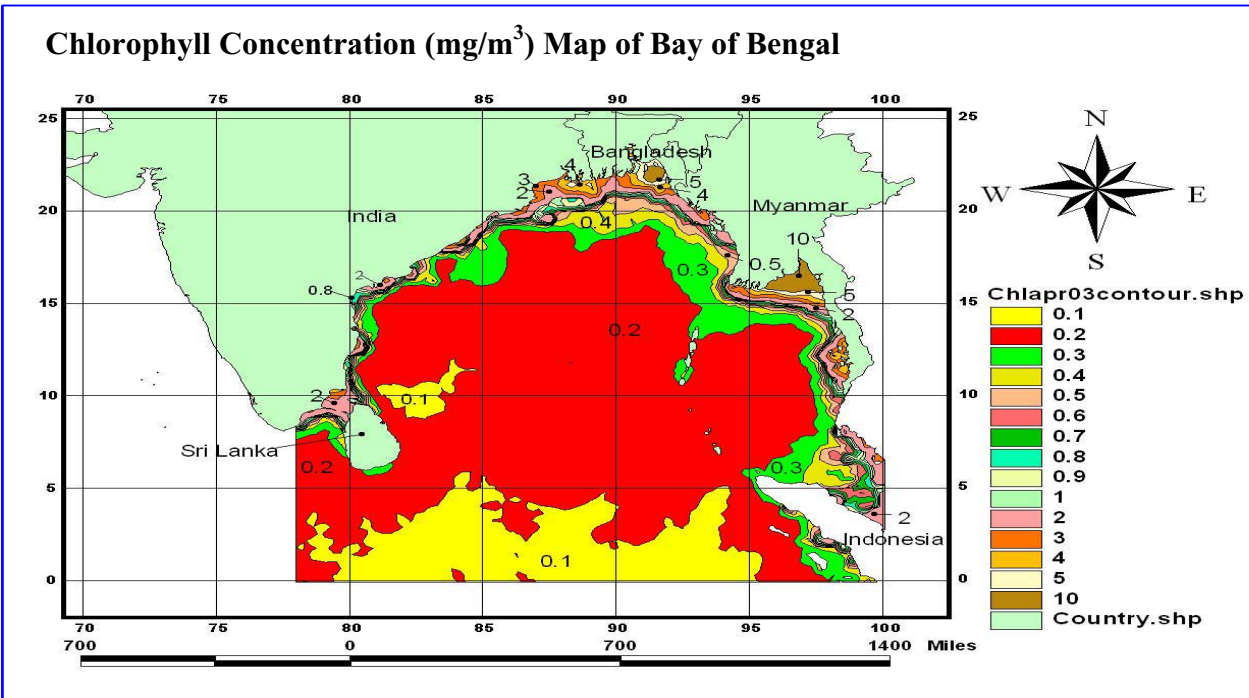


Fig. 12 Monthly mean chlorophyll pigment concentration (mg/m^3) distribution in April 2003 in Bay of Bengal

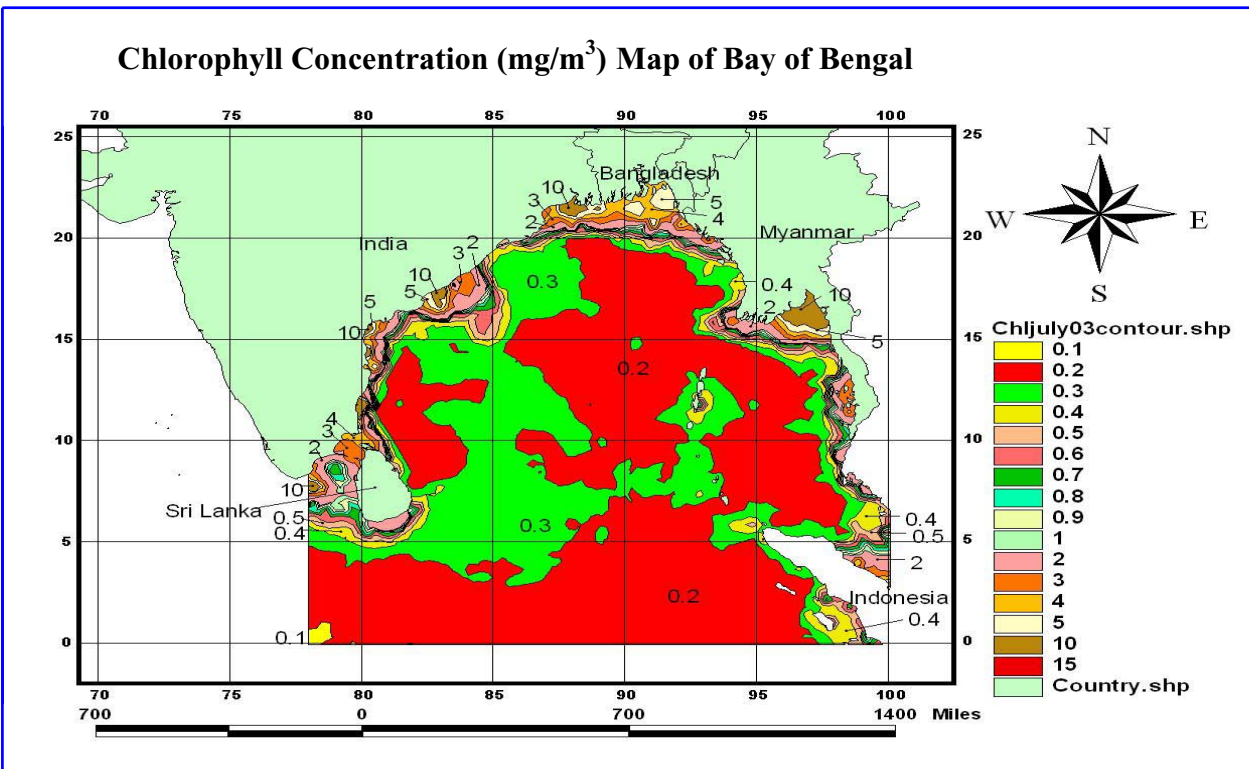


Fig. 13 Monthly mean chlorophyll pigment concentration (mg/m^3) distribution In July 2003 in Bay of Bengal

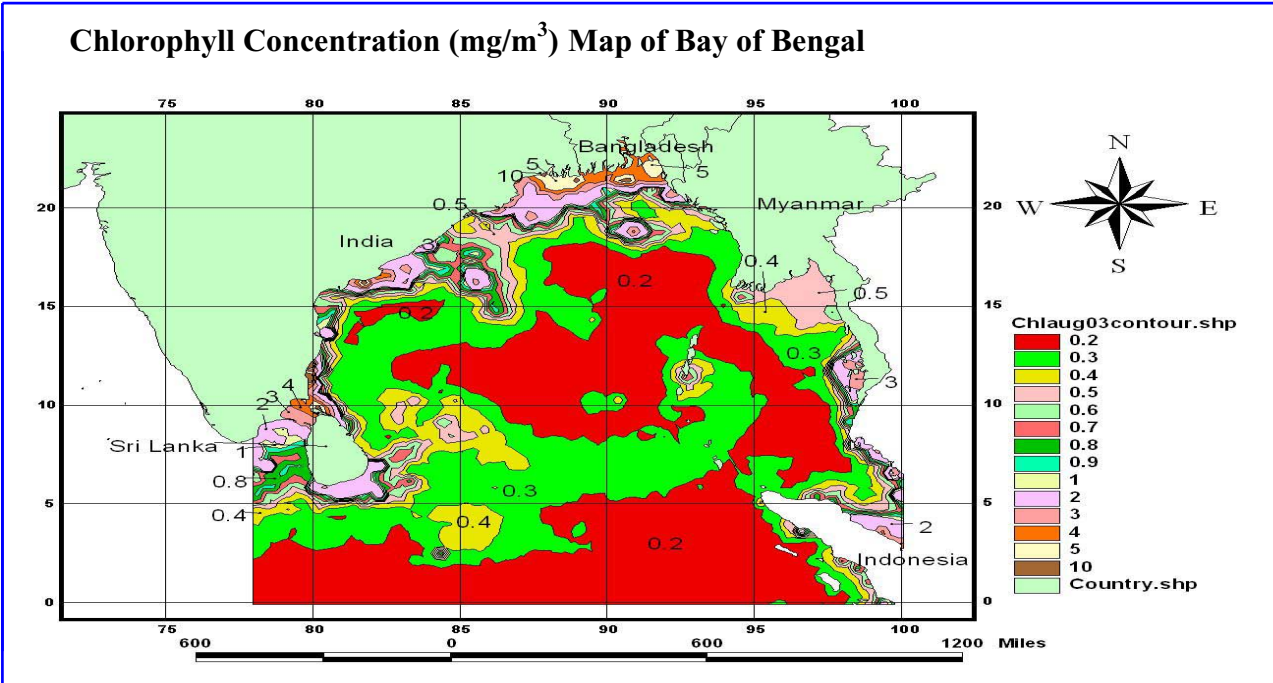


Fig. 14 Monthly mean chlorophyll pigment concentration (mg/m^3) distribution in August 2003 in Bay of Bengal

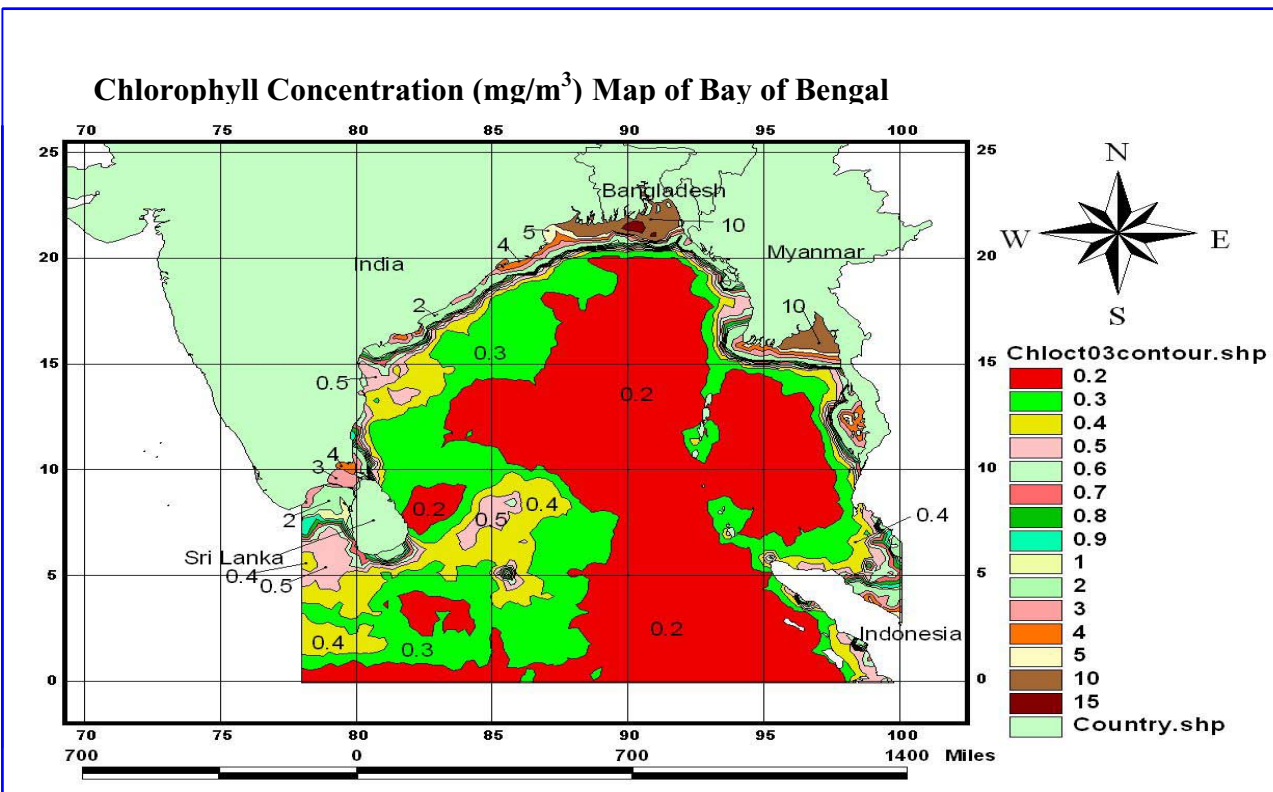


Fig. 15 Monthly mean chlorophyll pigment concentration (mg/m^3) distribution in October 2003 in Bay of Bengal

Table 5 Basin averaged chlorophyll pigment concentrations (mg/m^3) with its maximum and Minimum value during different months in the year 2003

Month of 2003	Chlorophyll Concentration (mg/m^3)		
	Minimum	Maximum	Average
January	0.06	10	0.3
April	0.025	10	0.28
July	0.05	10	0.4
August	0.03	10	0.4
October	0.04	10	0.44

Seasonal cycle of sea surface height anomalies

The sea surface height (SSH) anomaly distribution in January showed alternate band of negative and positive anomaly along the eastern boundary from south to north (Fig.16). In the rest of the region the SSH anomaly is positive except near the eastern equatorial region and a few isolated pockets. In April, along the western boundary we notice series of positive and negative SSH anomalies embedded in a region of positive anomaly (Fig.17). These could be the regions of warm (positive SSH) and cold (negative SSH) core eddies. In July alternative bands of positive and negative SSH anomalies were noticed all along the eastern and western boundary (Fig.18). Open Bay of Bengal, in general, had positive SSH anomaly. The negative SSH anomaly seen off Godavari river in April becomes much more negative by July. In August, high SSH anomaly is seen along the eastern boundary right from equator extending up to the northern part of the western boundary (Fig.19). In fact, positive SSH anomaly occupies the entire bay, except a few regions including Indo-Sri Lanka. The negative SSH anomaly seen off the Godavari river now gets detached and appeared to have move further offshore. In October pattern of SSH anomaly was similar to that of August, but magnitude of the anomaly was smaller in the open Bay (Fig.20). All along the coastal boundary SSH anomaly remained positive. Off Irrawady and Ganges the positive SSH anomaly, 50-60 cm, was the highest.

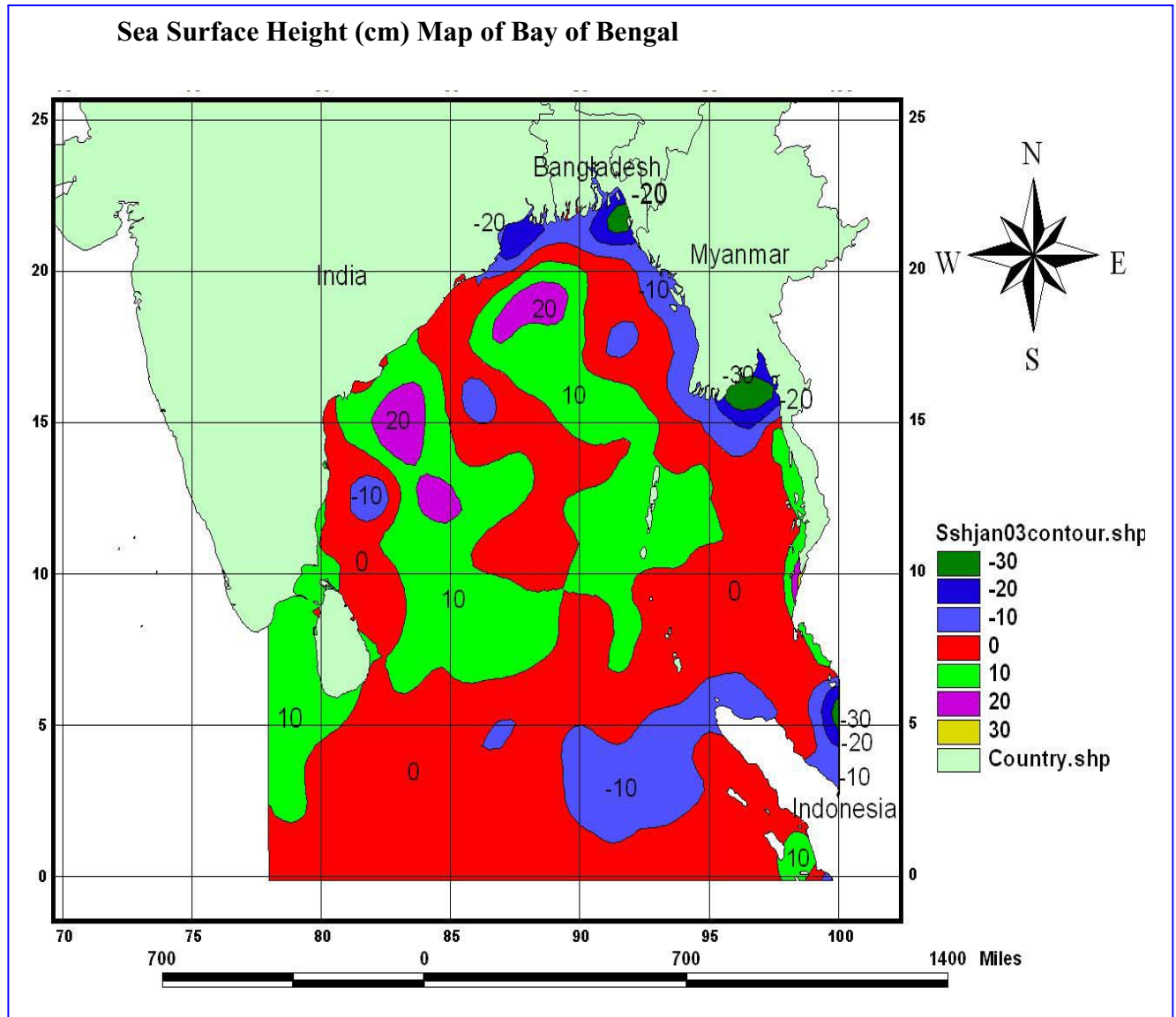


Fig. 16 Monthly mean SSH (cm) distribution in January 2003 in Bay of Bengal

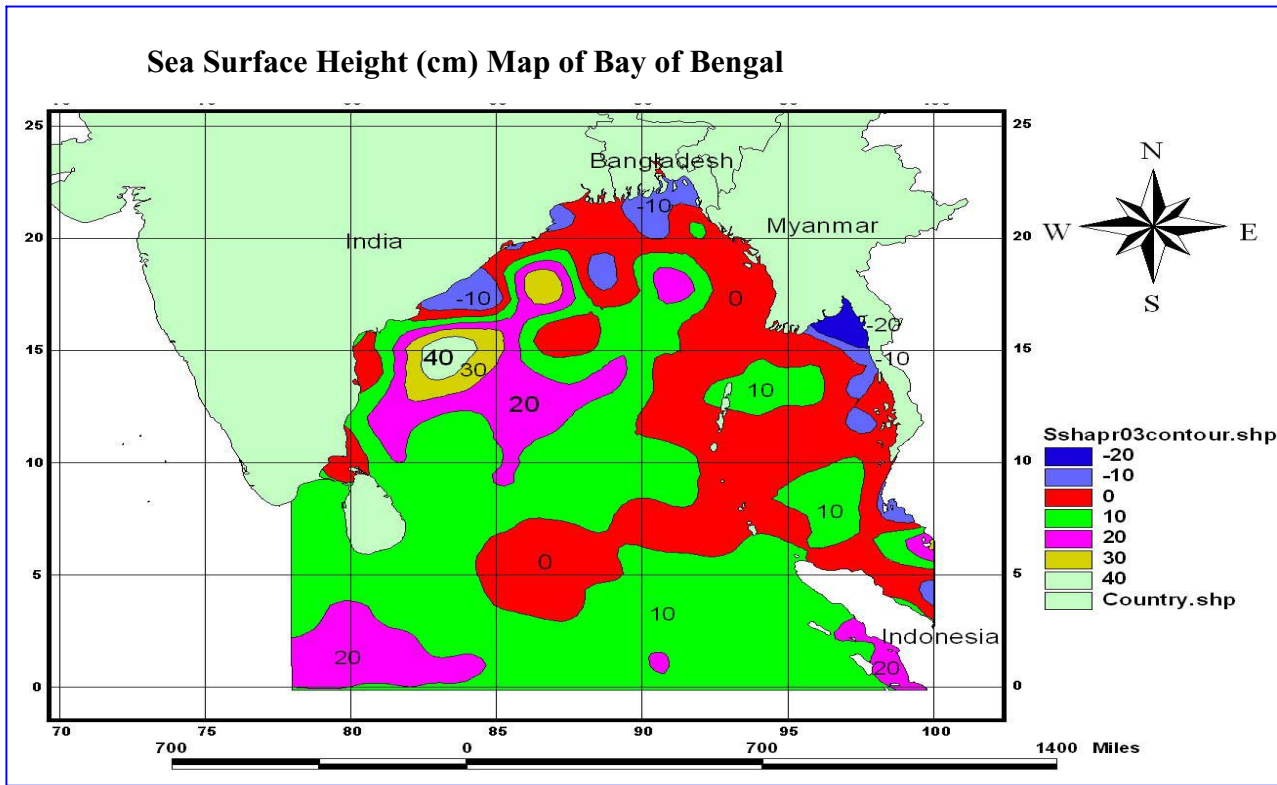


Fig. 17. Monthly mean SSH (cm) distribution in April 2003 in Bay of Bengal

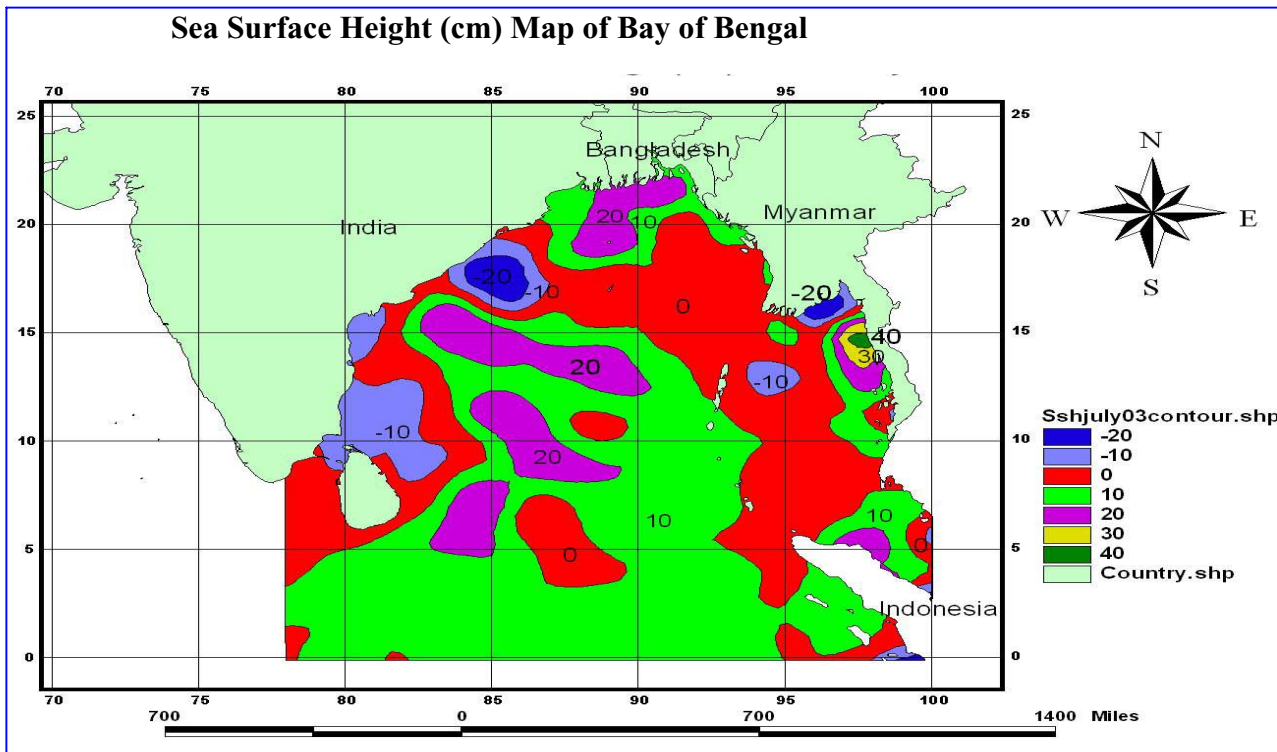


Fig. 18. Monthly mean SSH (cm) distribution in July 2003 in Bay of Bengal

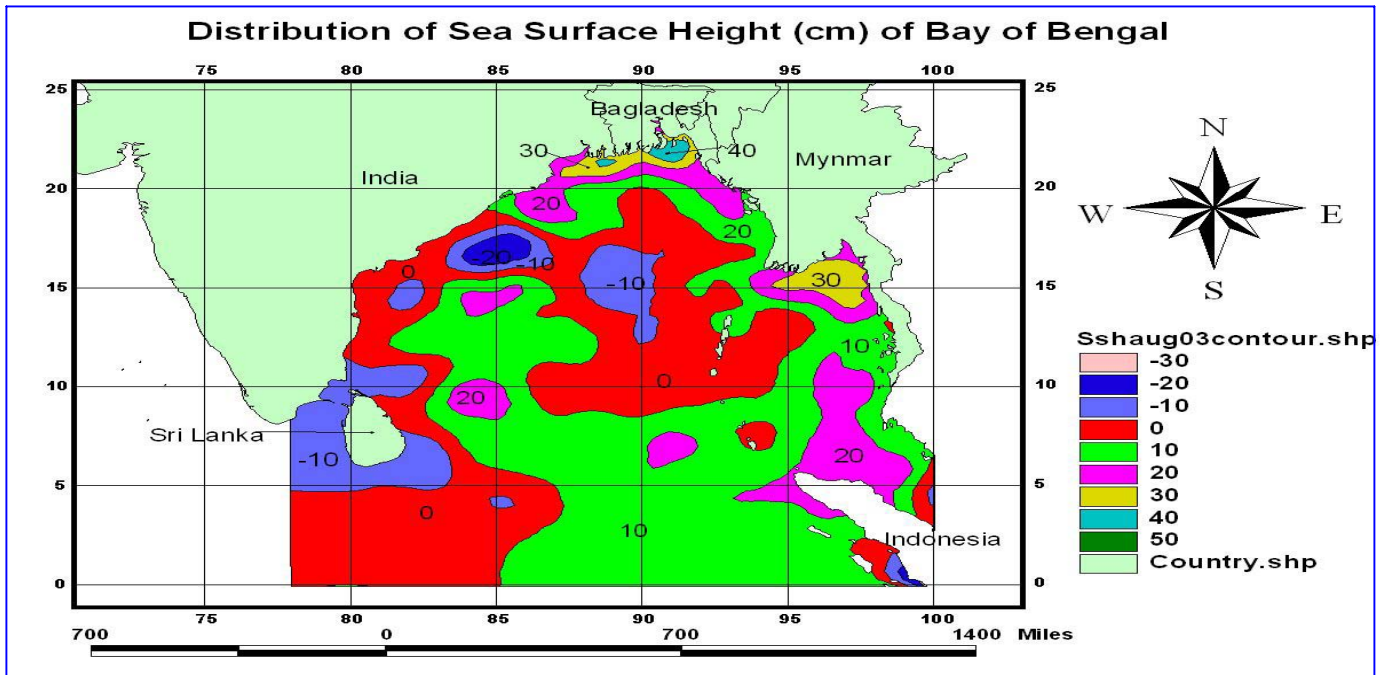


Fig. 19. Monthly mean SSH (cm) distribution in August 2003 in Bay of Bengal

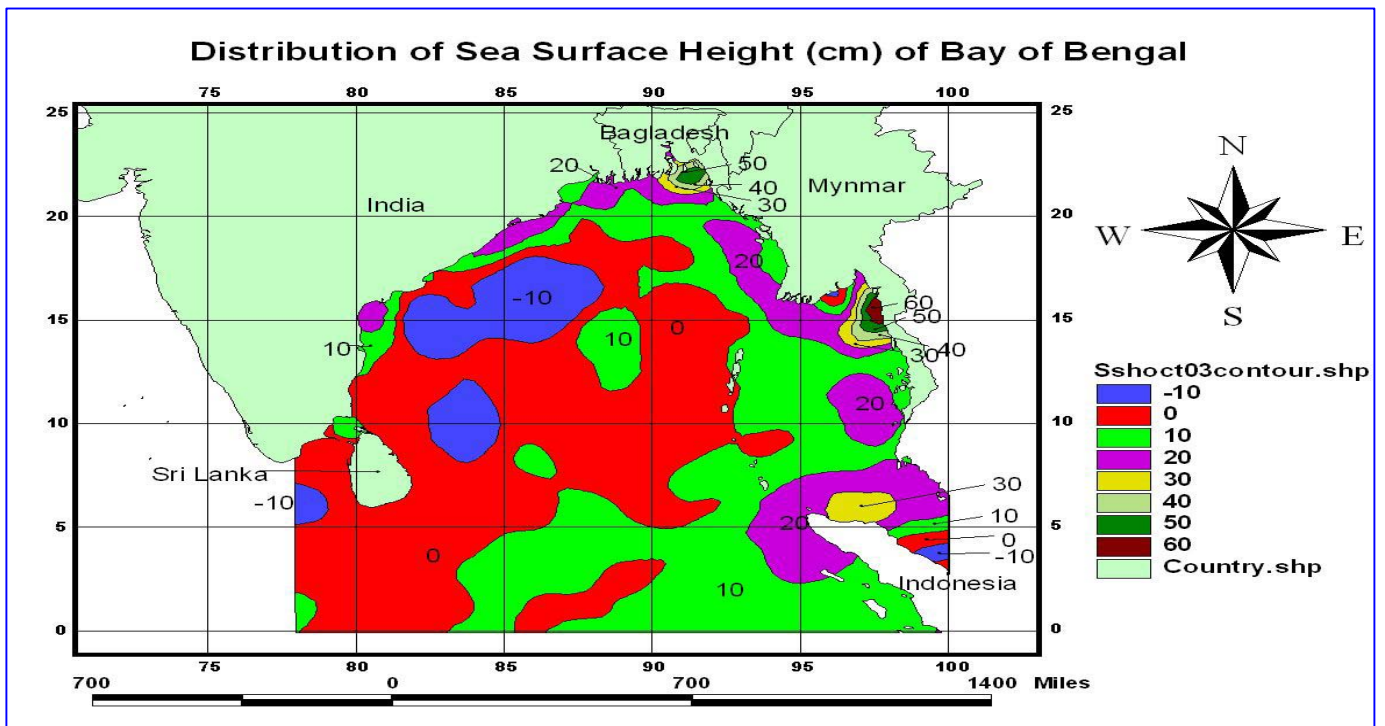


Fig. 20. Monthly mean SSH (cm) distribution in October 2003 in Bay of Bengal

Seasonal cycle of sea surface wind

For the analysis of variability of sea surface winds the U-component of the wind (zonal wind, East-West) and V-component of the wind (meridional wind, North-South) were analyzed.

The sea surface wind (SSW) was northeasterly in January in the entire Bay with maximum velocity in the central region. In April the SSW was northeasterly in the eastern Bay while it was southwesterly towards the western boundary with small magnitude (Fig.21a and 21b). In fact this showed that the Bay experiences light and variable winds during this time of the year. By July the entire Bay is under the influence of strong southwesterly monsoon winds with maximum speed of about 10-11m/s. In August also the SSW pattern was similar to that of July with wind speed of 10m/s. However, near the southeastern and southwestern parts the wind speed was less (Fig.22a and 22b). In October the southwesterly wind with stronger zonal component was confined to the southern Bay and the wind speed showed a gradual decrease towards north. In the north the westerly component is replaced by easterly component.

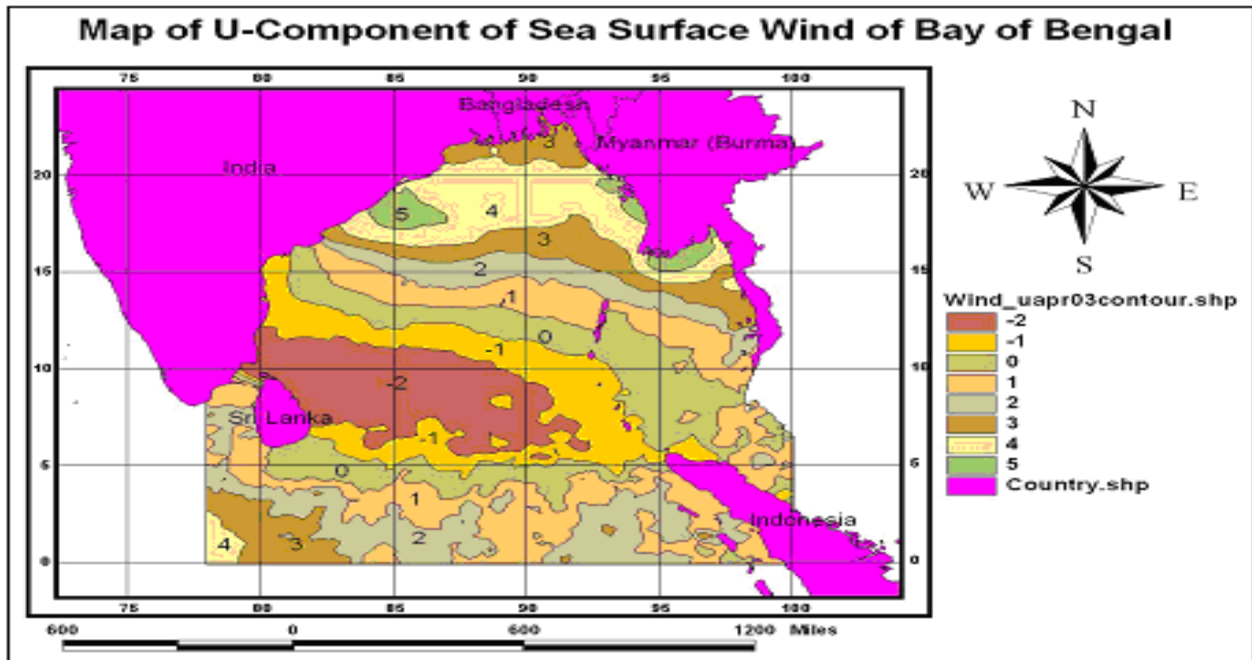


Figure 21a Distribution of monthly mean U-component (m/s) of SSW in April 2003

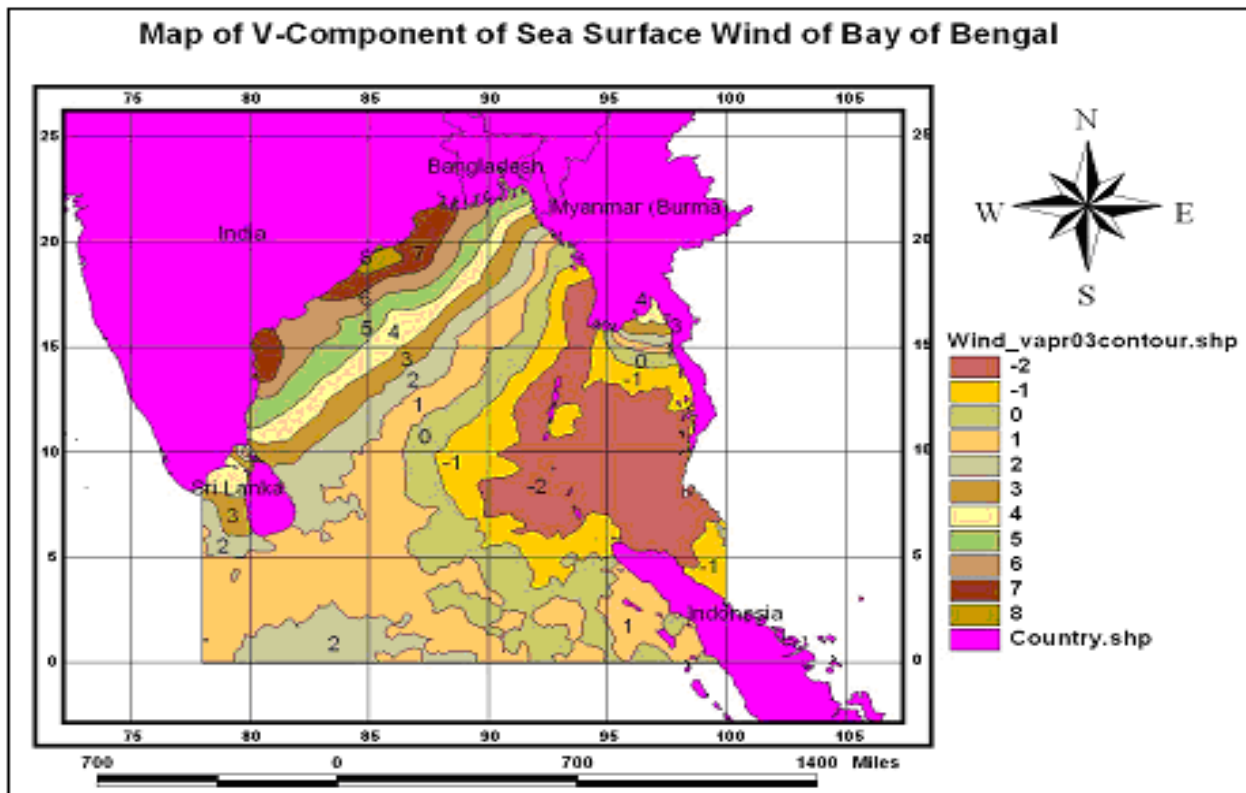


Figure 21b Distribution of monthly mean V-component (m/s) of SSW in April 2003

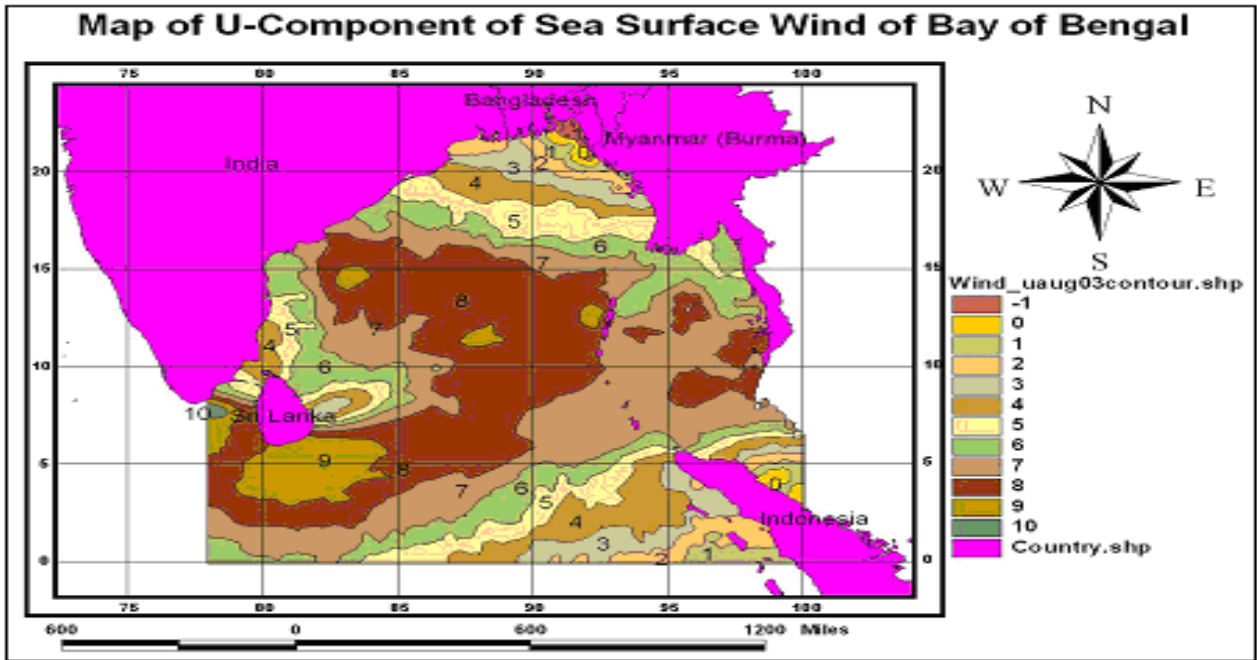


Fig. 22a Distribution of monthly mean U-component (m/s) of SSW in August 2003

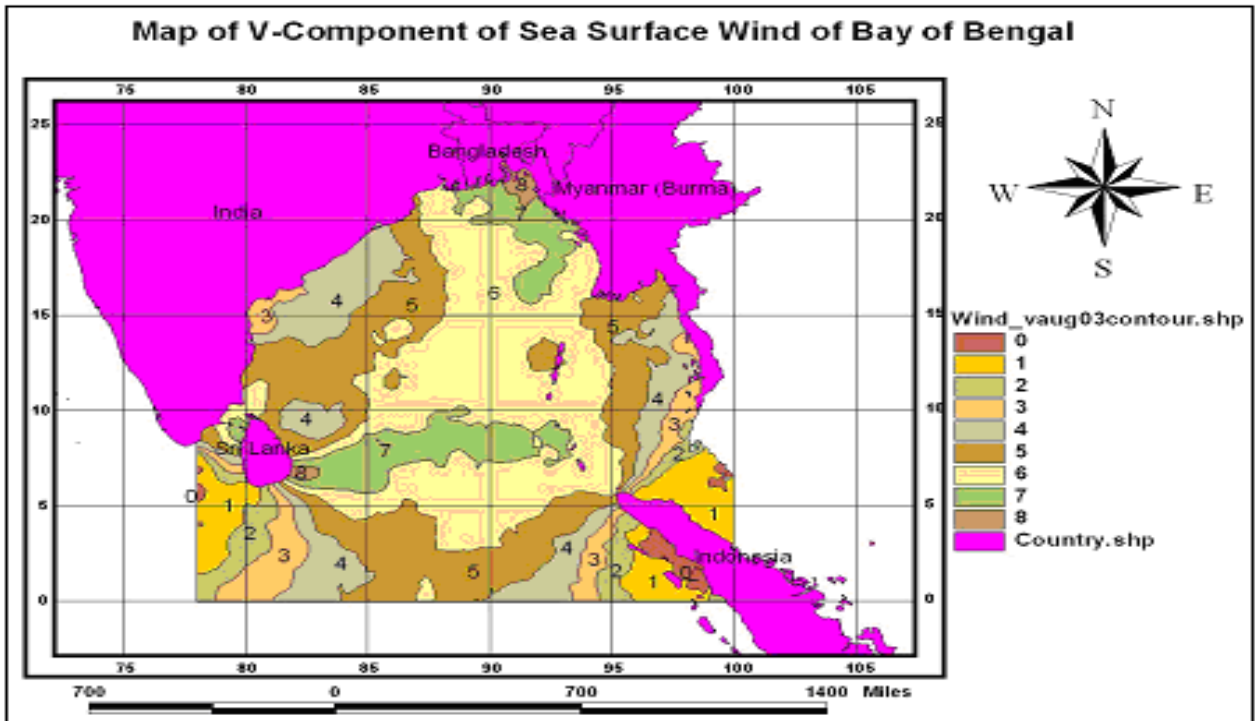


Fig 22b Distribution of monthly mean V-component (m/s) of SSW in August 2003

Inter-annual variability during 2002-2005

To understand the inter-annual variability we selected the month of January and August during 2002 to 2005. The reason for selecting January and August is the following. The month of January represents the peak winter, which is reflected in the property distribution such as SST, SSW, SSH, and chlorophyll pigment concentrations. Similarly, the analysis of seasonal variability showed that Chlorophyll concentration, SST and SSH showed maximum variability in the month of August, while SSW was strongest in July. Since the wind being the forcing for oceanic variability, and there exists time lag between the forcing and response, we thought it may be a good idea to choose the month of August to track inter-annual variability in chlorophyll concentration, SST and SSH while July for SSW.

Inter-annual variability of Sea surface temperature

January 2002 - 2005

The distribution of SST during January 2002 showed very cold temperature in the northern Bay of Bengal, as low as 17°C while the southern Bay was warm with temperature 29°C (Figure 23). The northern Bay, north of 15°N showed large thermal gradient, about 9°C, while that in the southern bay was only about 3°C. In January 2003 the northern Bay was much less colder compared to 2002 with the lowest temperature of 21°C. In the south, Bay was about 2°C warmer in 2003 compared to 2002 (Figure 24). Thus, in general, January 2002 was colder much colder than 2003. SST magnitude and distribution pattern of January 2004 was similar to that of 2003 (Figure 25). SST in January 2005 was slightly colder than that of 2004 in the southern Bay (Figure 26).

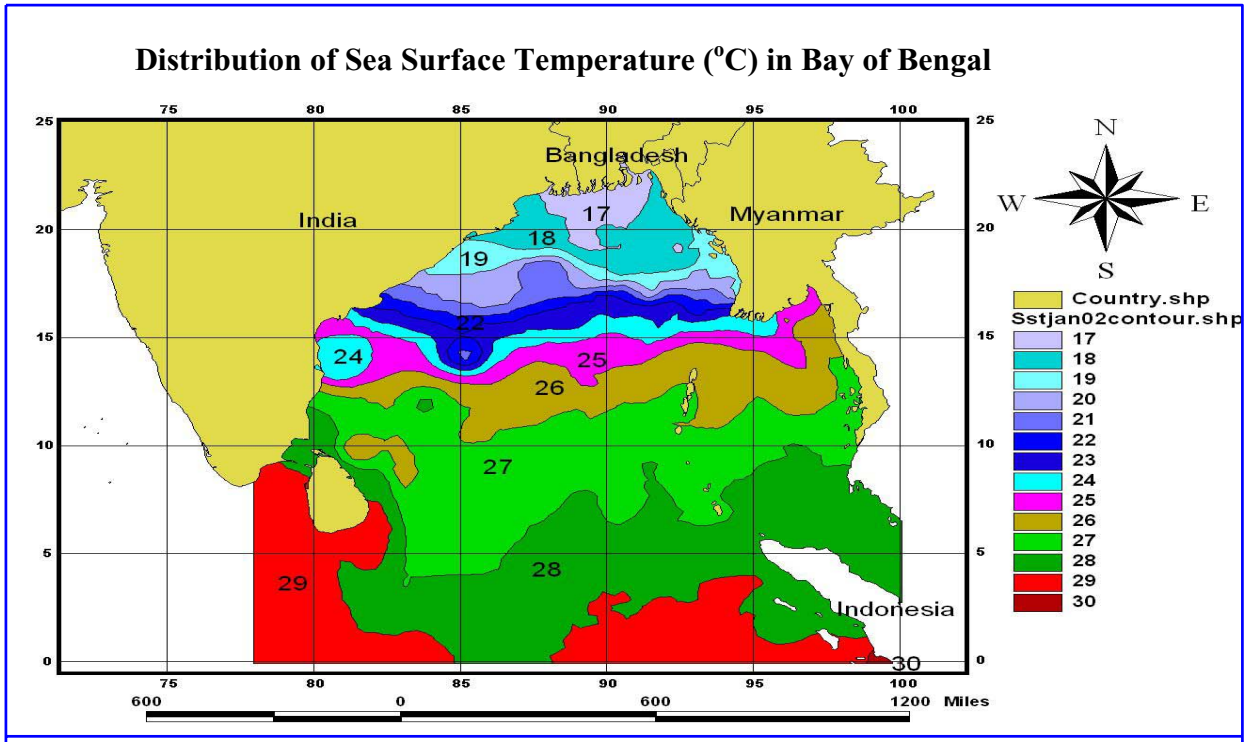


Fig.23 Monthly mean SST (°C) distribution in Bay of Bengal in January 2002

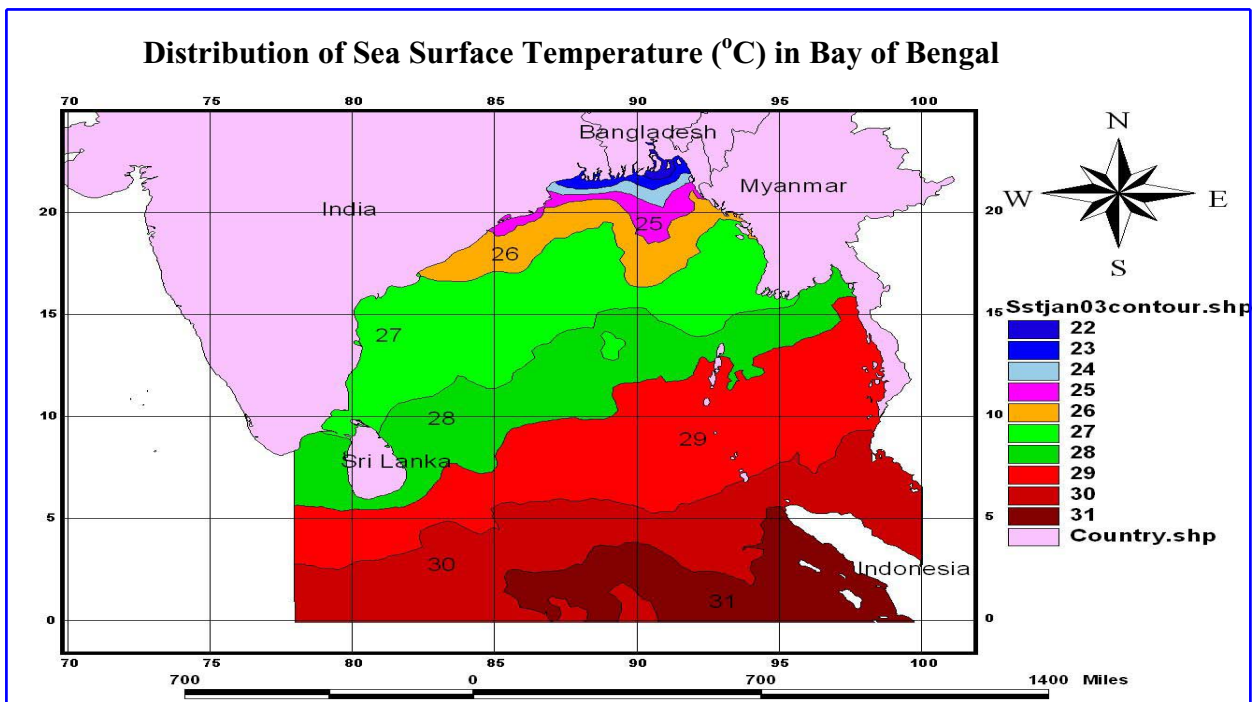


Fig.24 Monthly mean SST (°C) distribution in Bay of Bengal in January 2003

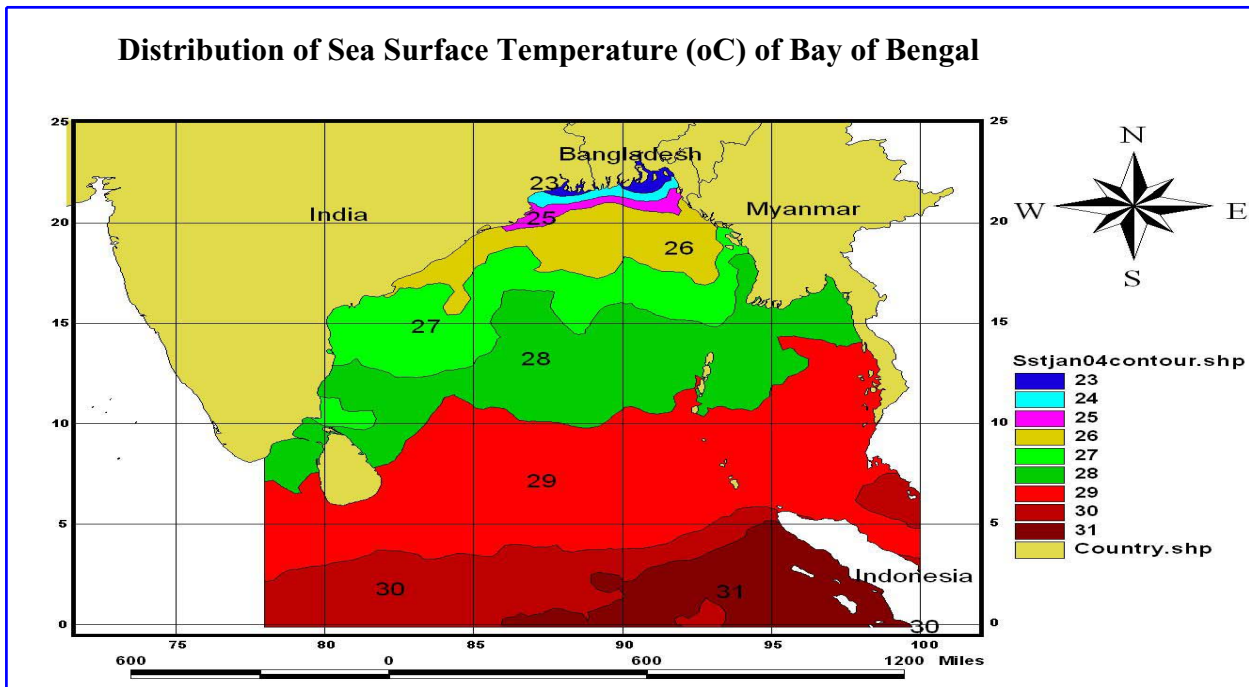


Fig.25 Monthly mean SST (°C) distribution in Bay of Bengal in January 2004

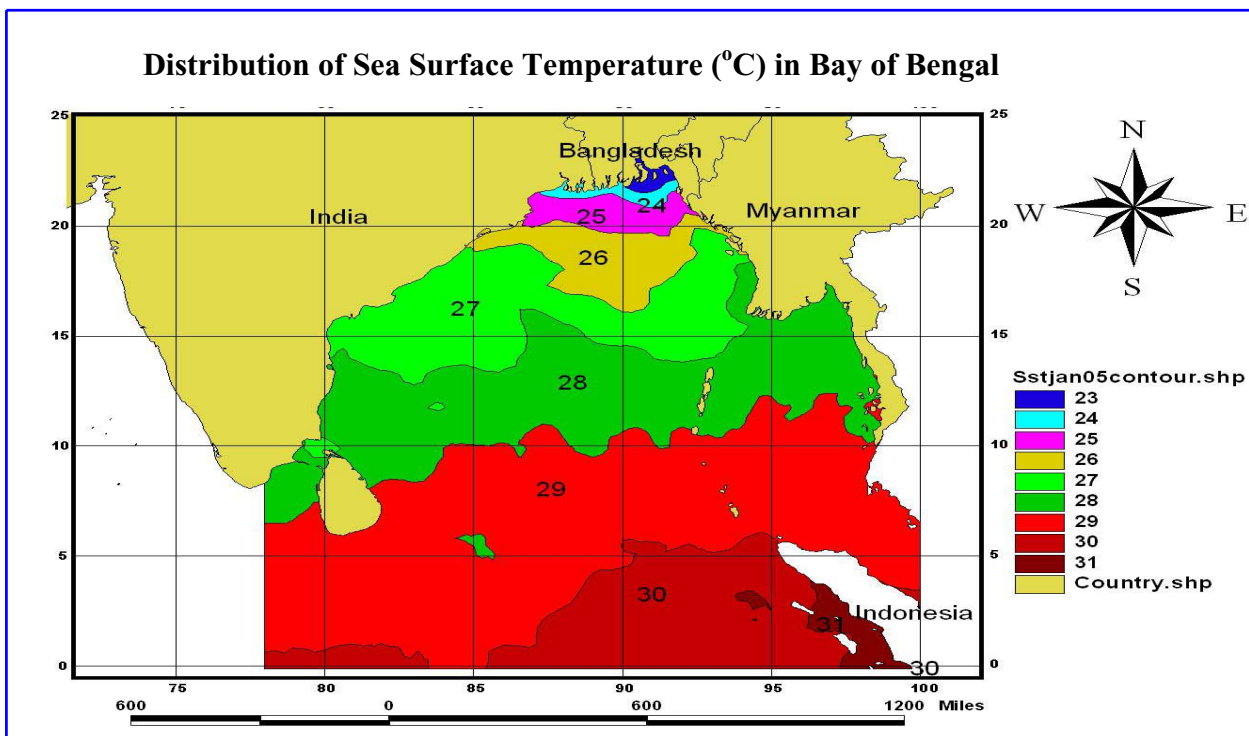


Fig.26 Monthly mean SST (°C) distribution in Bay of Bengal in January 2005

August 2002 – 2005

In the August 2002, the SST was coldest near the Indo-Sri Lanka region and near the eastern region of Bay of Bengal. Then rest of entire Bay the SST was varied between 29 to 30°C, while high near the southern region (Figure 27). In the August 2003, the area of coldest water increased from the eastern region to central Bay, and similarly near the Indo-Sri Lanka region (Figure 28). But in the August 2004, the coldest SST covered the large area of the eastern and central Bay and extended to southwest region. Then rest of southern and western region the SST was seen between 29 to 30°C (Figure 29). In August 2005, the warmer SST of 29°C again showed an increase in central to southern Bay and colder SST decreases near Indo-Sri Lanka region and near Eastern Bay (Figure 30). Near the equator SST was 39°C, while around Indonesian coastal region, SST was seen very warm about 31°C. In summary the SST of the Bay varied between 27 to 28°C in the eastern and southwest but in the rest of Bay, it was varied between 29 to 31°C.

Table 6 summarizes the basin-wide average SST during January and August of each year from 2002 to 2005.

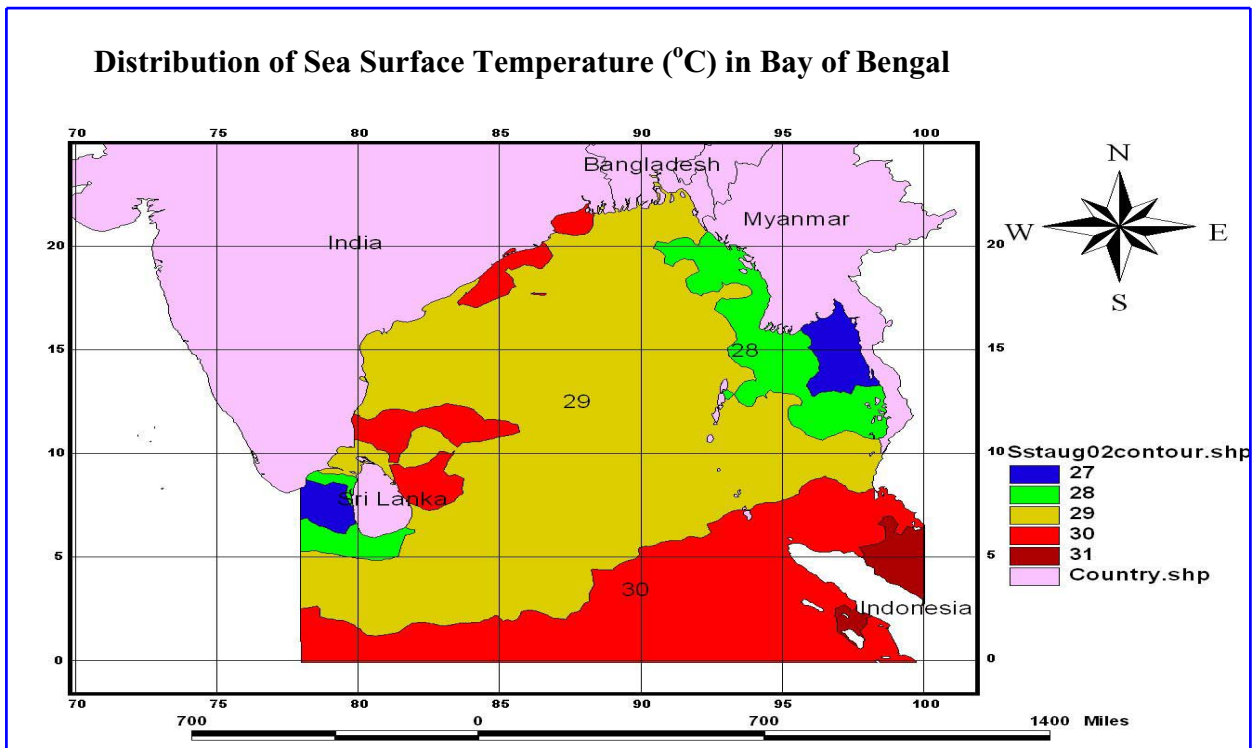


Fig.27 Monthly mean SST (°C) distribution in Bay of Bengal in August 2002

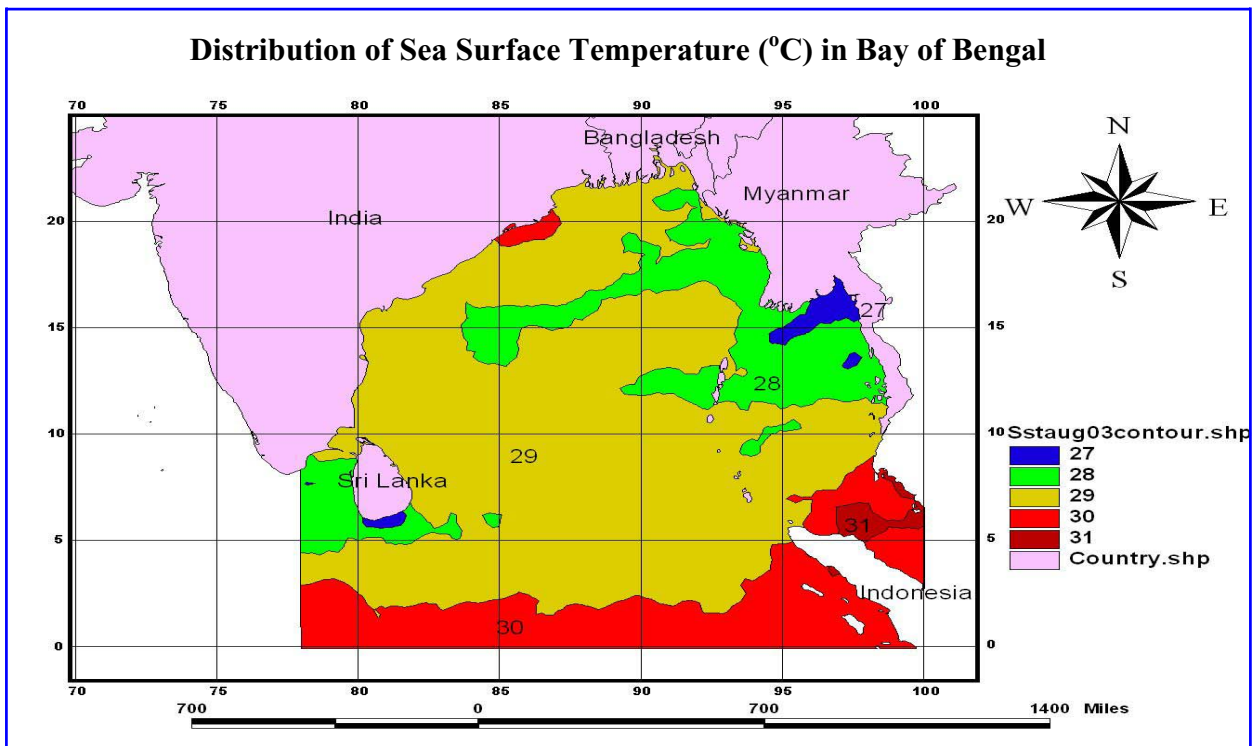


Fig.28 Monthly mean SST (°C) distribution in Bay of Bengal in August 2003

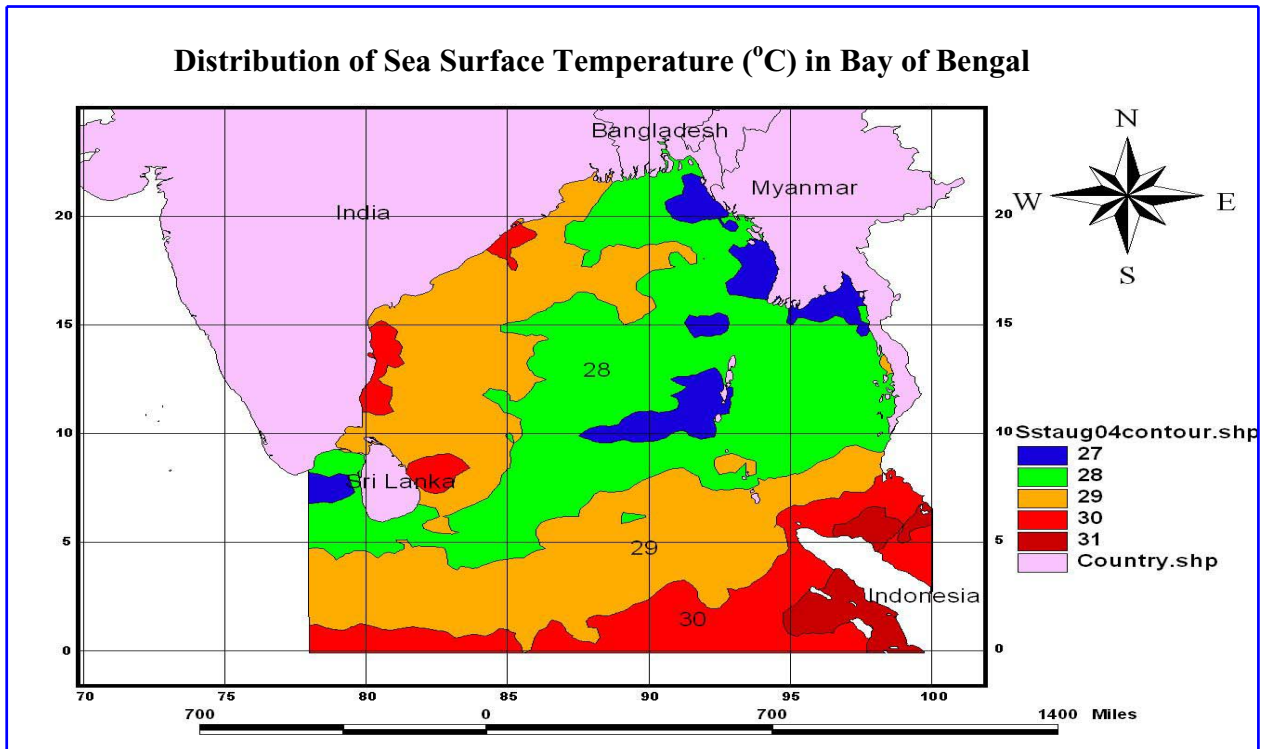


Fig.29 Monthly mean SST (°C) distribution in Bay of Bengal in August 2004

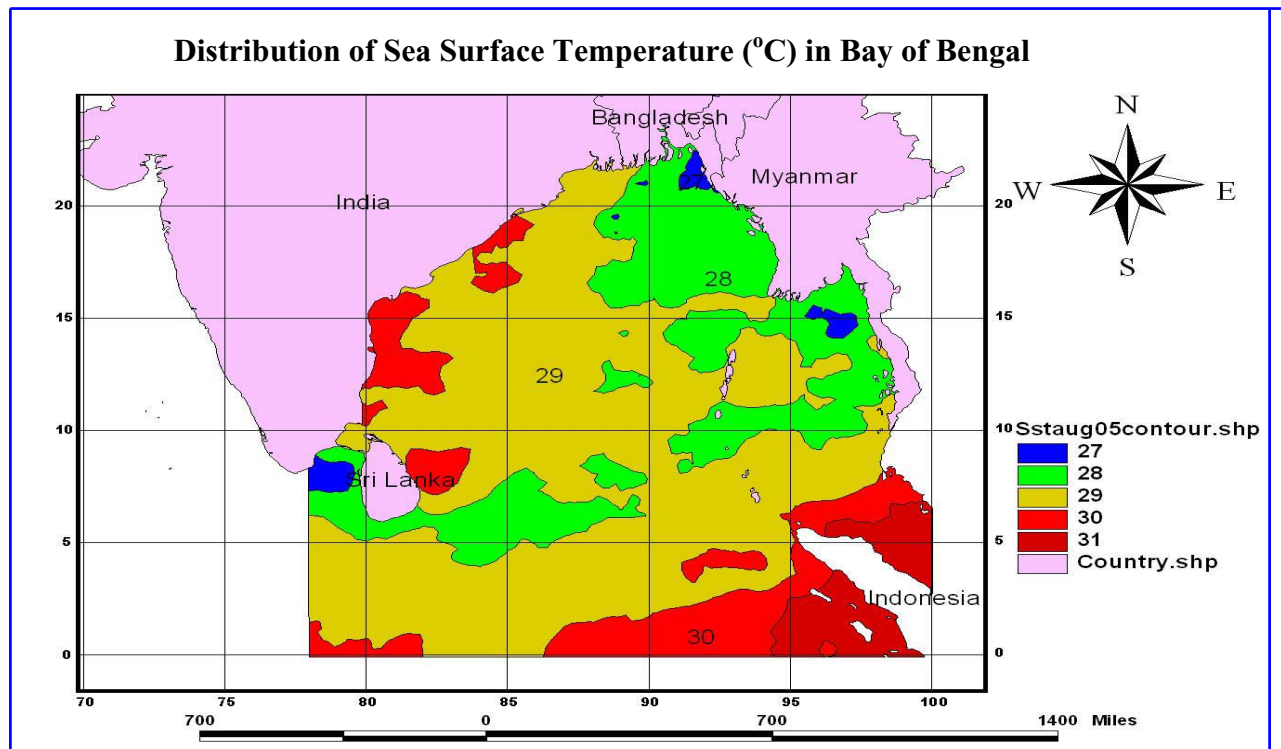


Fig.30 Monthly mean SST (°C) distribution in Bay of Bengal in August 2005

Table 6 summarizes the basin-wide average SST ($^{\circ}\text{C}$) during January and August of each year from 2002 to 2005.

Year	Sea Surface Temperature ($^{\circ}\text{C}$) in January 2002-2005			Sea Surface Temperature ($^{\circ}\text{C}$) in August 2002-2005		
	Minimum	Maximum	Average	Minimum	Maximum	Average
2002	15	30	29	26	31	29
2003	21	31	28	26	31	28
2004	22	31	28	26	31	28
2005	22	31	29	26	31	29

Inter-annual variability of chlorophyll concentration

January 2002-2005

During winter monsoon in the month of January 2002, the chlorophyll concentrations varied between 0.2 to 0.4 mg/m³ in most part of the Bay except very near to the coast. In fact large part of the Bay had a pigment concentration of about 0.3 mg/m³. In the central Bay as well as near the equatorial belt the concentrations were about 0.2 mg/m³. All along the coastal boundary the concentrations increased rapidly from 0.4 to 10 mg/m³. Maximum pigment concentrations were noticed near the coastal area of Bangladesh and Irrawadi river basin in the eastern Bay where the rivers discharge the fresh water. But these values needs to be interpreted with care as near the coast there may be large amount of suspended sediment which may introduce some errors in the pigment concentration estimation (Figure 31). In January 2003, the distribution pattern remains more or less same, but the concentrations in most part of the Bay were about 0.2 mg/m³, which is less than that of January 2002 (Figure 32). Again, in January 2004 the area of both 0.2 and 0.3 mg/m³ chlorophyll pigment concentrations showed an increase, but were much less than that of 2002 (Figure 33). Similarly in January 2005 the area of 0.2mg/m³ chlorophyll pigment concentration showed an increase, which is much more than 2004 while the area of 0.3mg/m³ chlorophyll concentrations showed a decrease. In western Bay, near the Mahanadi river basin, chlorophyll showed the poor concentration comparison to 2004 (Figure 34).

In summary, the chlorophyll concentration showed the high values between 5 to 10 mg/m³ mainly near the coastal areas of northern and eastern region due to upwelling and high sedimentation due to fresh water and showed the low value in the open Bay and southern region due to high solar heating.

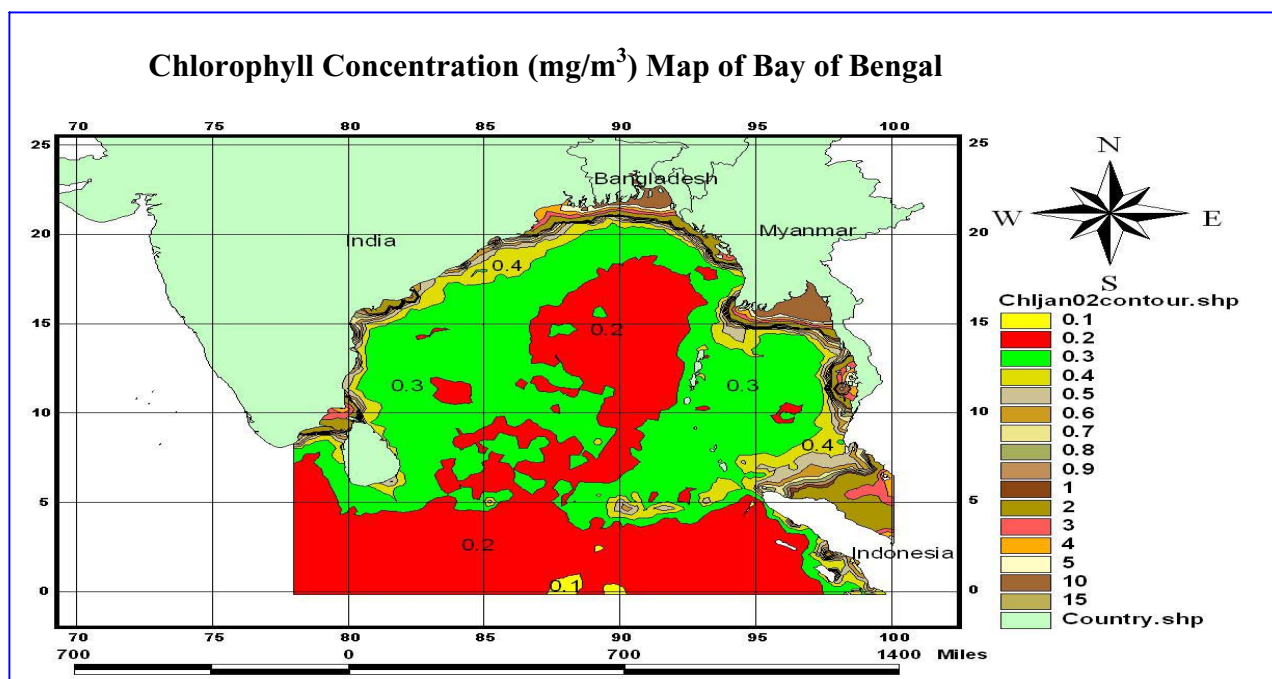


Fig. 31 Monthly mean Chlorophyll Pigment Concentration (mg/m^3) distribution in Bay of Bengal in January 2002

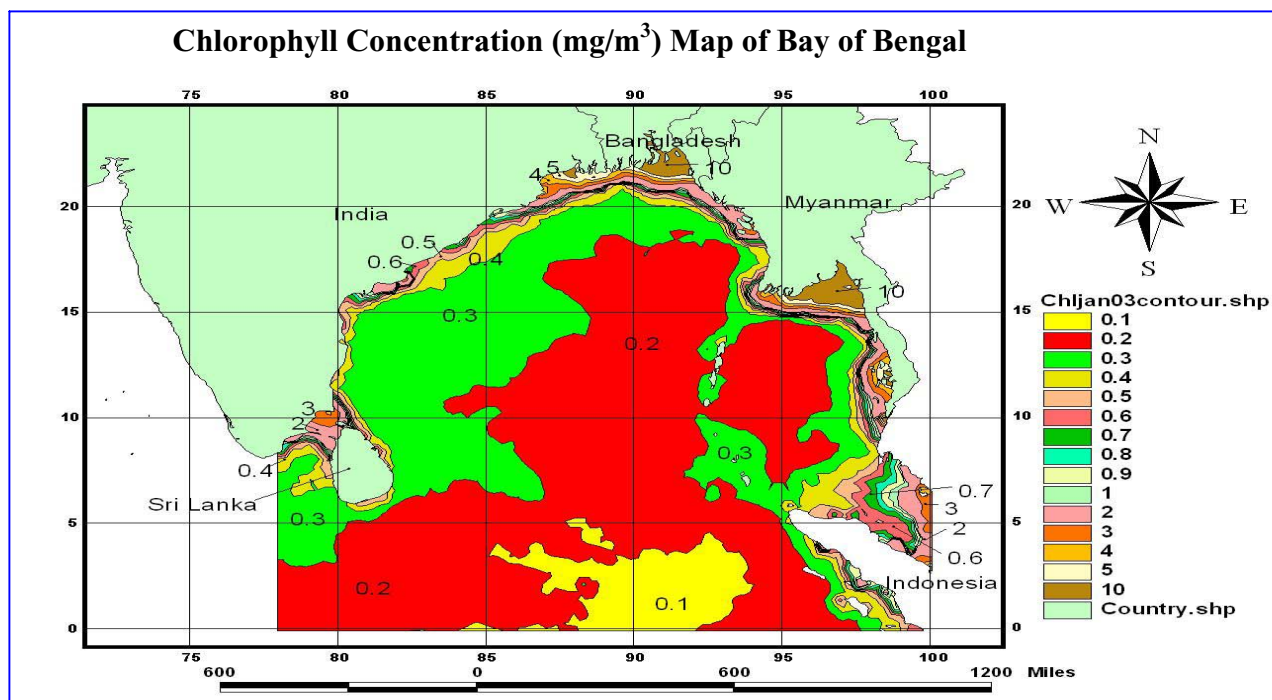


Fig. 32 Monthly mean Chlorophyll Pigment Concentration (mg/m^3) distribution in Bay of Bengal in January 2003

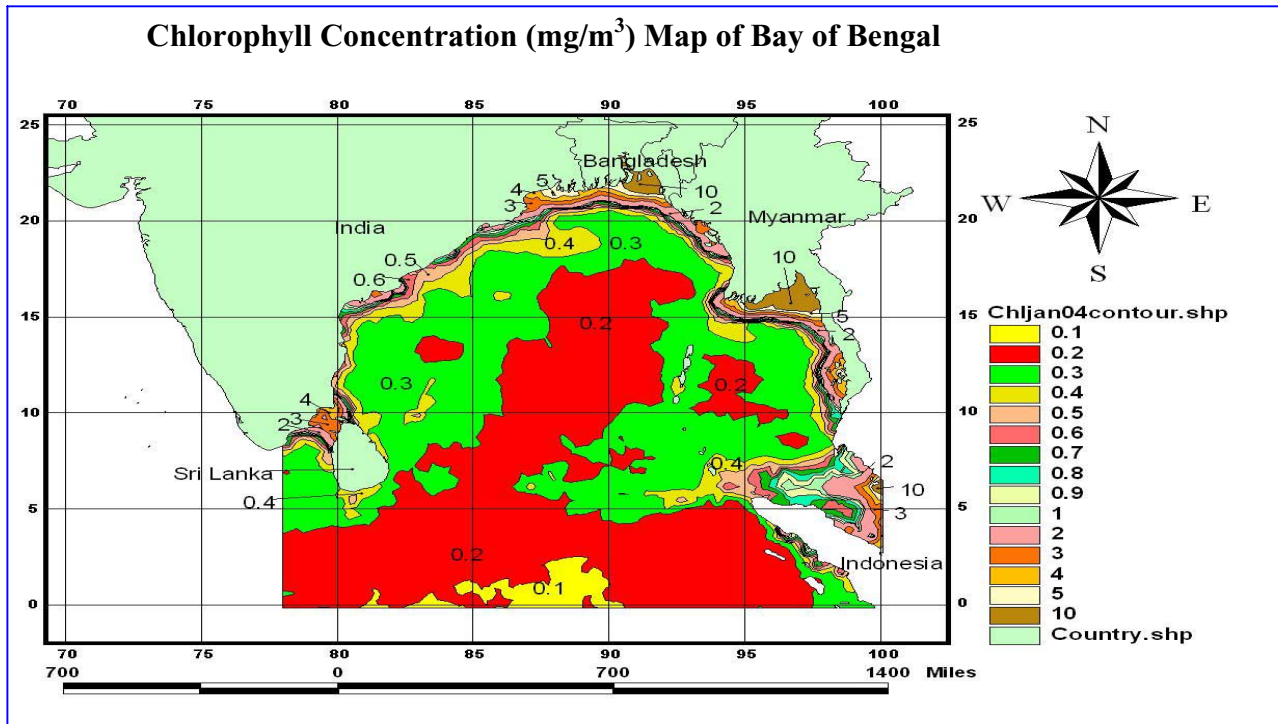


Fig. 33 Monthly mean Chlorophyll Pigment Concentration (mg/m^3) distribution in Bay of Bengal in January 2004

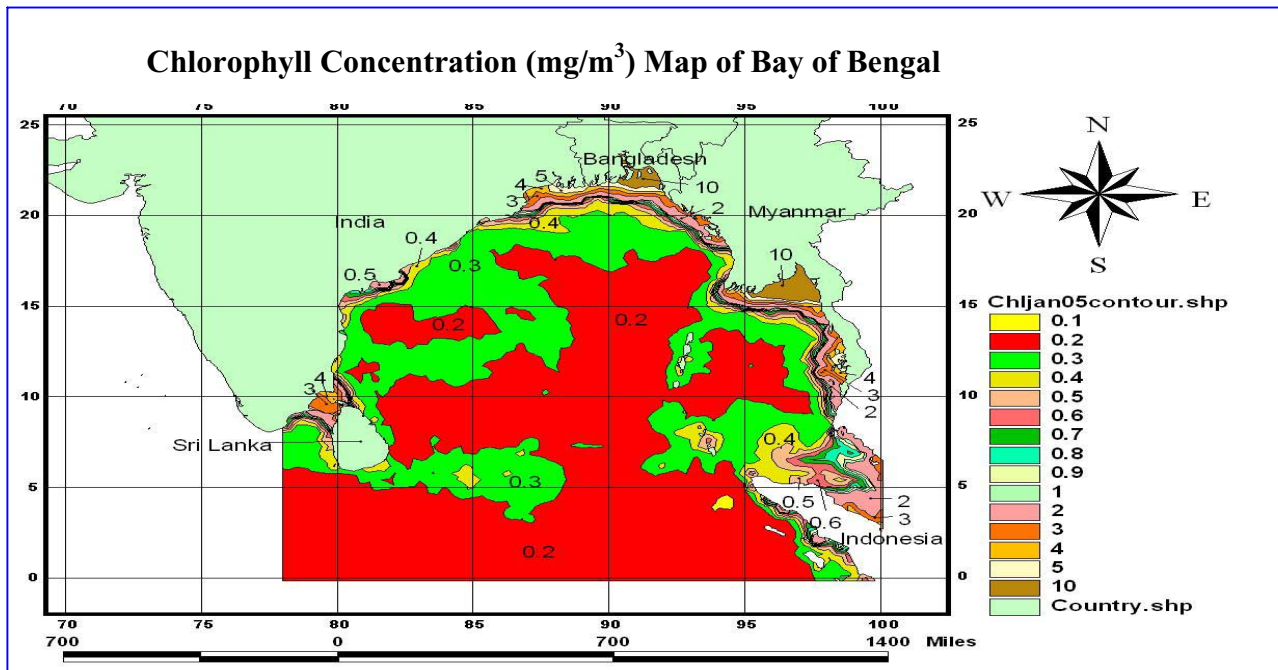


Fig. 34 Monthly mean Chlorophyll Pigment Concentration (mg/m^3) distribution in Bay of Bengal in January 2005

August 2002 to 2005

In the August 2002, the chlorophyll concentrations were seen high near the coastal areas of Ganges-Brahmaputra-Meghna deltaic and Irrawadi region. Then in the other coastal areas it varied between 0.4 to 5 mg/m³. But one patch of chlorophyll concentration greater than 0.5 mg/m³ was seen near the Indo-Sri Lanka region, which extends to central Bay. In the most part of central Bay, the chlorophyll concentration was about 0.3mg/m³ but in the southern region it was seen 0.2mg/m³ (Figure 35). In the August 2003, the chlorophyll concentration showed the low values near the coastal areas compared to August 2002. Near the Irrawady River basin it showed low concentration about 0.3mg/m³ and similar near the Indo-Sri Lanka region the area of high concentration showed a decrease. Most of the central and southern Bay, concentrations was about 0.2mg/m³ (Figure 36). But in August 2004, again it showed the high concentration near the coastal areas. The chlorophyll concentration was very high with the values of 0.4 to 2 mg/m³ near the Indo-Sri Lanka region which extend in the northeastward direction into the central Bay. The chlorophyll concentration was low in the southern Bay and most of central Bay, with concentration of about 0.3mg/m³ (Figure 37). In August 2005, the chlorophyll distribution pattern was similar to that of August 2004 near the coastal areas and near the Indo-Sri Lanka region, but the area of 0.2mg/m³ concentration showed an increase near the Krishna and Godavari region and in central Bay (Figure 38). Table 7 shows basin averaged chlorophyll pigment concentrations with its maximum and minimum value during January and August of each year from 2002 to 2005.

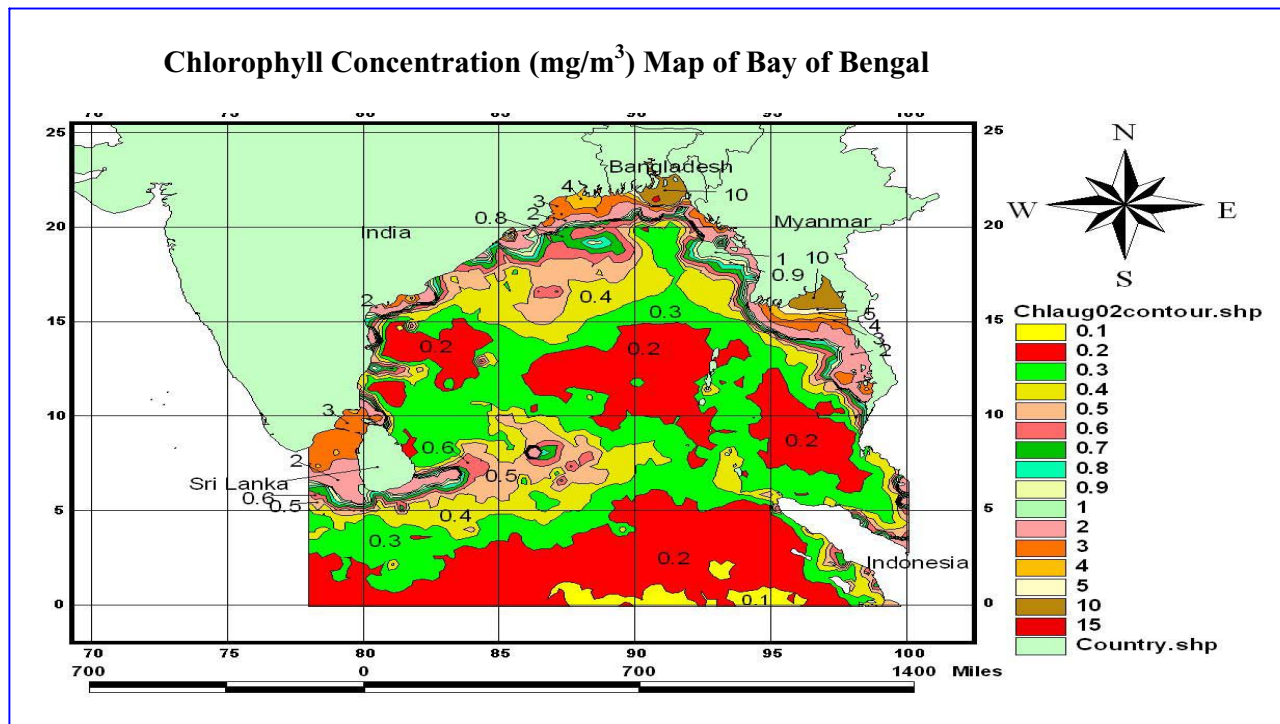


Fig. 35 Monthly mean Chlorophyll Pigment Concentration (mg/m³) distribution in Bay of Bengal in August 2002

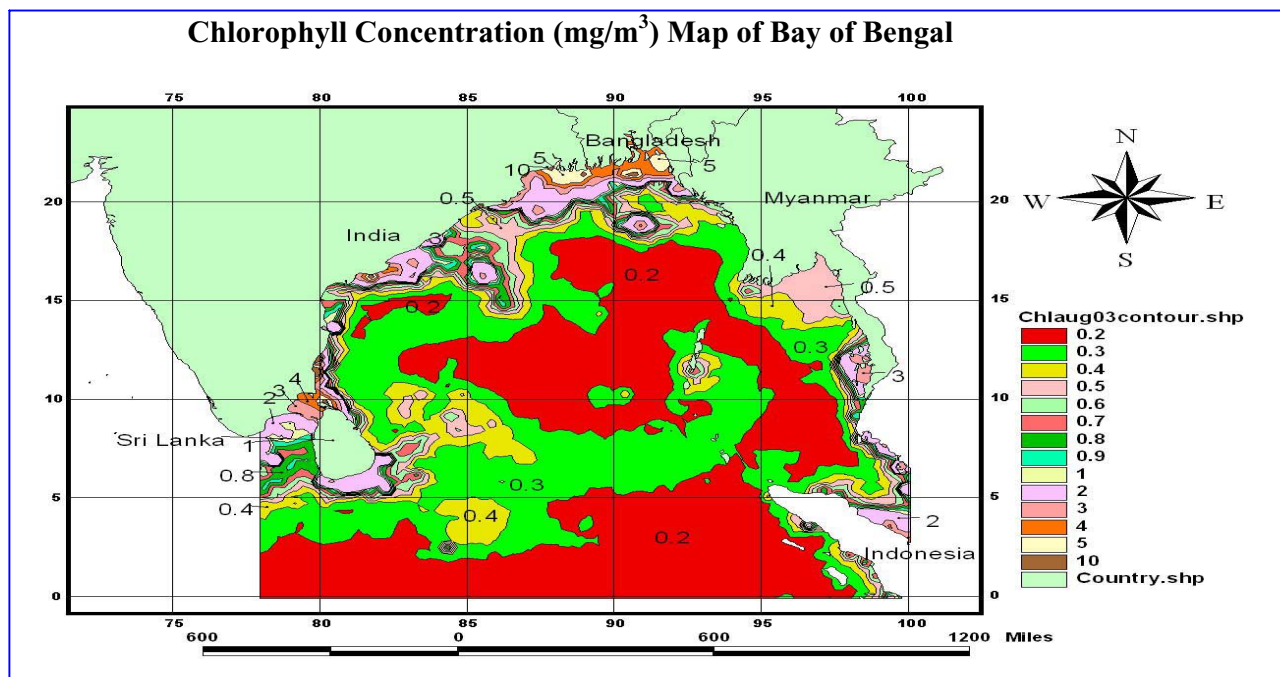


Fig. 36 Monthly mean Chlorophyll Pigment Concentration (mg/m³) distribution in Bay of Bengal in August 2003

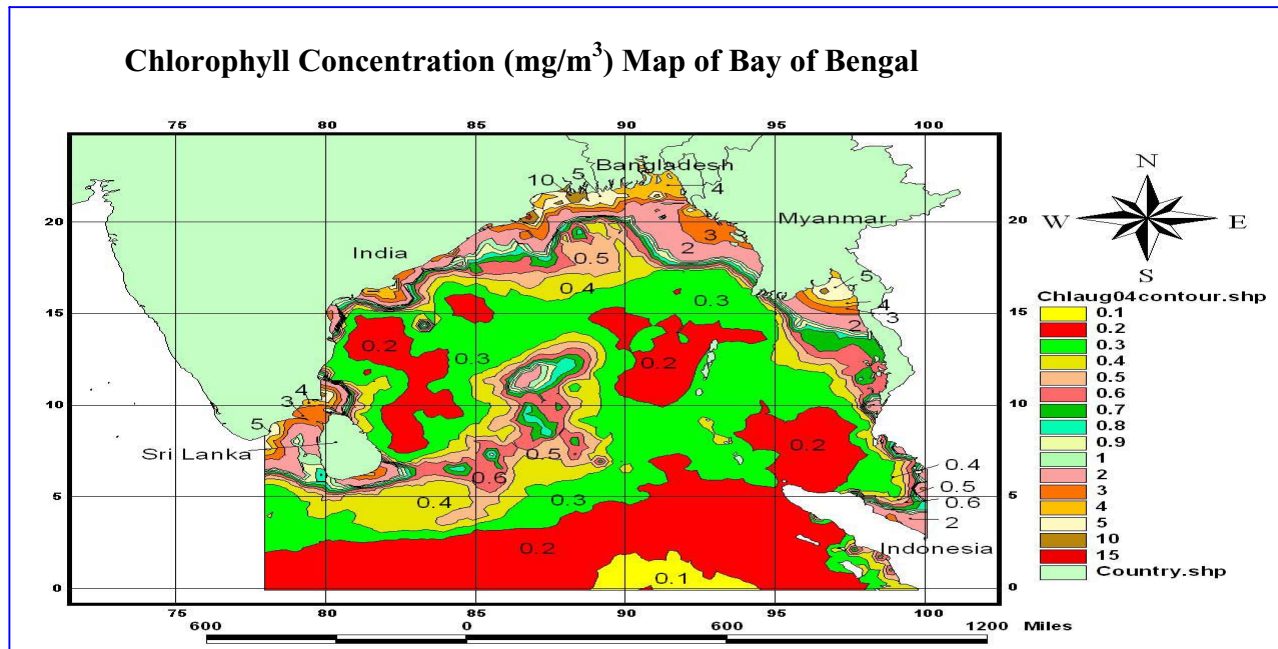


Fig. 37 Monthly mean Chlorophyll Pigment Concentration (mg/m^3) distribution In Bay of Bengal in August 2004

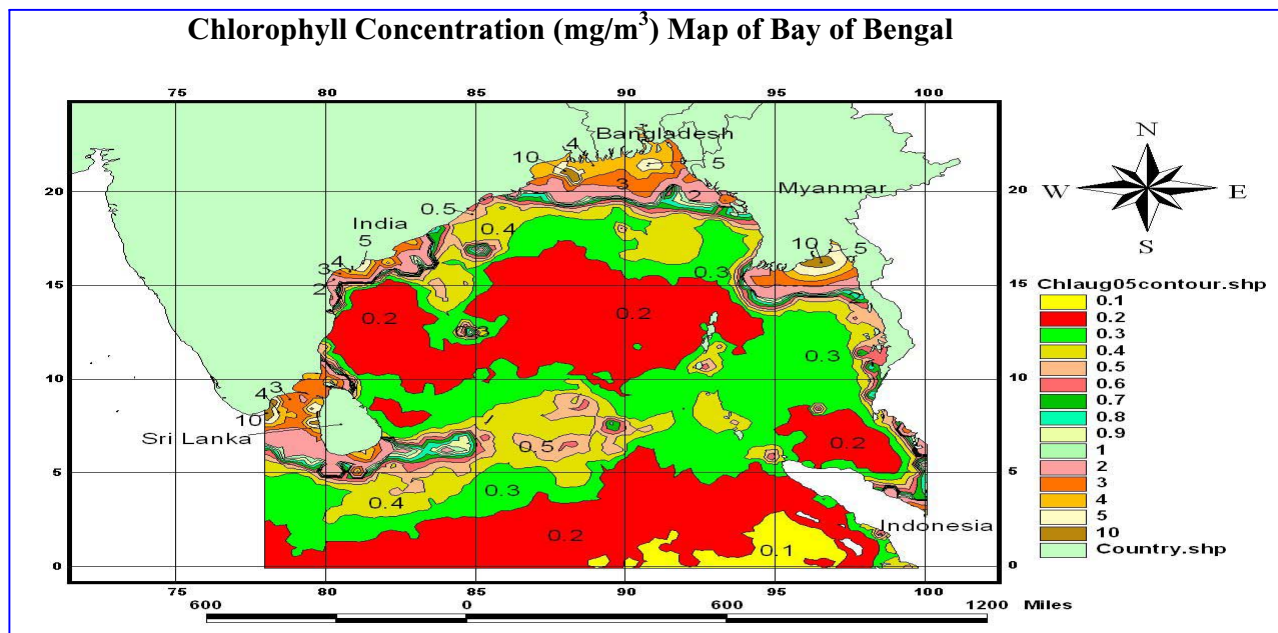


Fig. 38 Monthly mean Chlorophyll Pigment Concentration (mg/m^3) distribution In Bay of Bengal in August 2005

Table 7 Basin averaged chlorophyll pigment concentrations with its maximum and minimum value during January and August of each year from 2002 to 2005.

Year	Chlorophyll Concentration (mg/m ³) in January 2002-2005			Chlorophyll Concentration (mg/m ³) in August 2002-2005		
	Minimum	Maximum	Average	Minimum	Maximum	Average
2002	0.05	15	0.4	0.05	15	0.4
2003	0.06	10	0.4	0.03	10	0.4
2004	0.06	10	0.4	0.06	15	0.4
2005	0.05	10	0.4	0.04	10	0.4

Inter annual variability of Sea surface Height Anomalies during 2002-05

January 2002-2005

In January 2002, distribution of Sea surface height anomalies showed positive sea surface height anomaly in entire Bay, except in the region very close to the eastern boundary and head Bay. A patch of negative SSH anomaly was also seen off Indonesian region close to the equator. Near the Indo-Sri Lankan region, it showed positive SSH anomaly with values between 10 and 20 cm. In most of central part SSH was about 10cm (Figure 39). In January 2003, the height anomalies showed pattern similar to 2002, but near the Indo-Sri Lanka region it showed some decrease in positive values of SSH anomalies, which varied between 0 to 10cm (Figure 40). In January 2004, the area of negative values 10cm showed an increased near all along the coastal region of eastern boundary and near the southeast Bay. Few patches of positive anomaly of 20cm were seen in the central region and near the Indo-Sri Lanka region, and in rest of Bay, SSH anomalies varied between 0 to 10cm (Figure 41). In the January 2005, the distribution pattern was seen different from the 2004. SSH anomalies showed the highest values between 30 to 70cm near the Irrawady river basin in the eastern Bay and it showed the alternative bands of positive and negative values near the western and southern boundary (Figure 42).

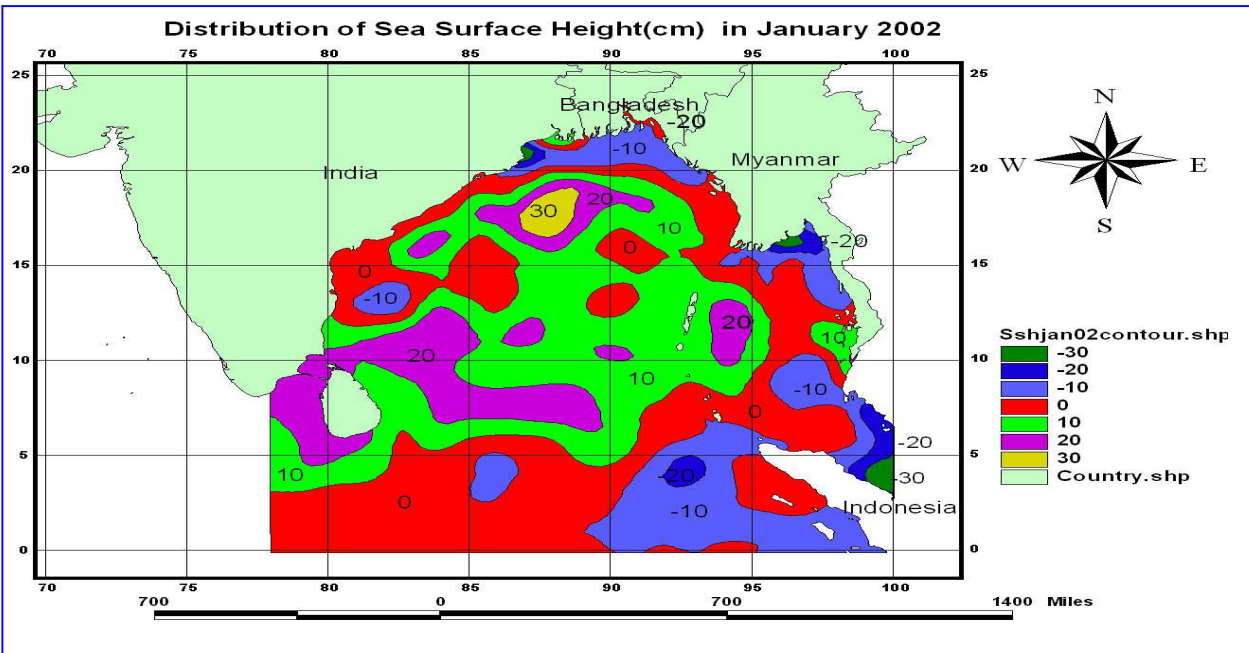


Figure 39 Monthly mean SSH (cm) distribution in Bay of Bengal in January 2002

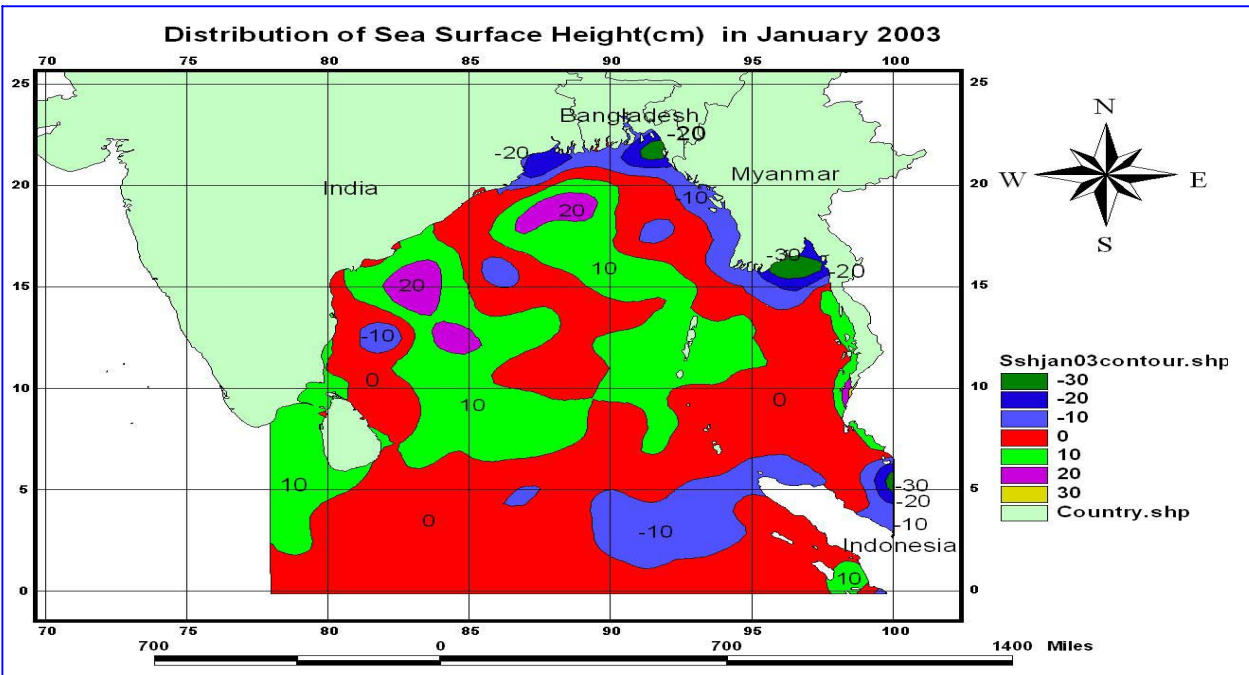


Figure 40 Monthly mean SSH (cm) distribution in Bay of Bengal in January 2003

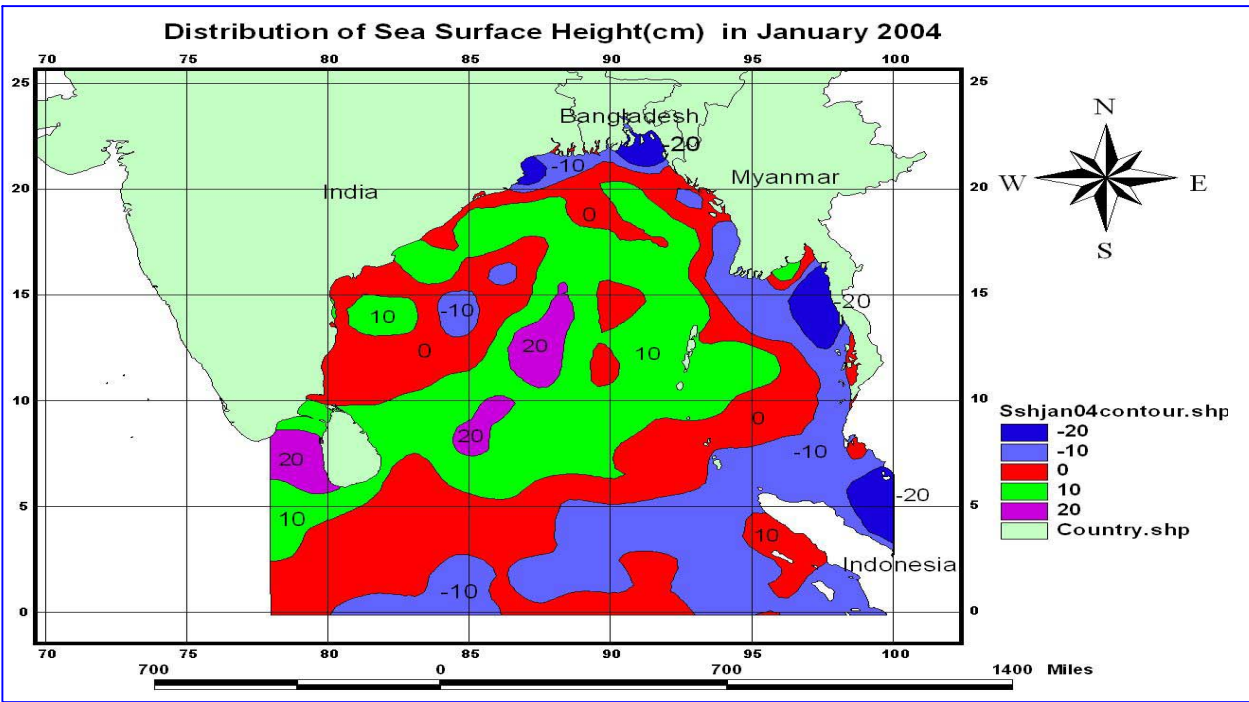


Figure 41 Monthly mean SSH (cm) distribution in Bay of Bengal in January 2004

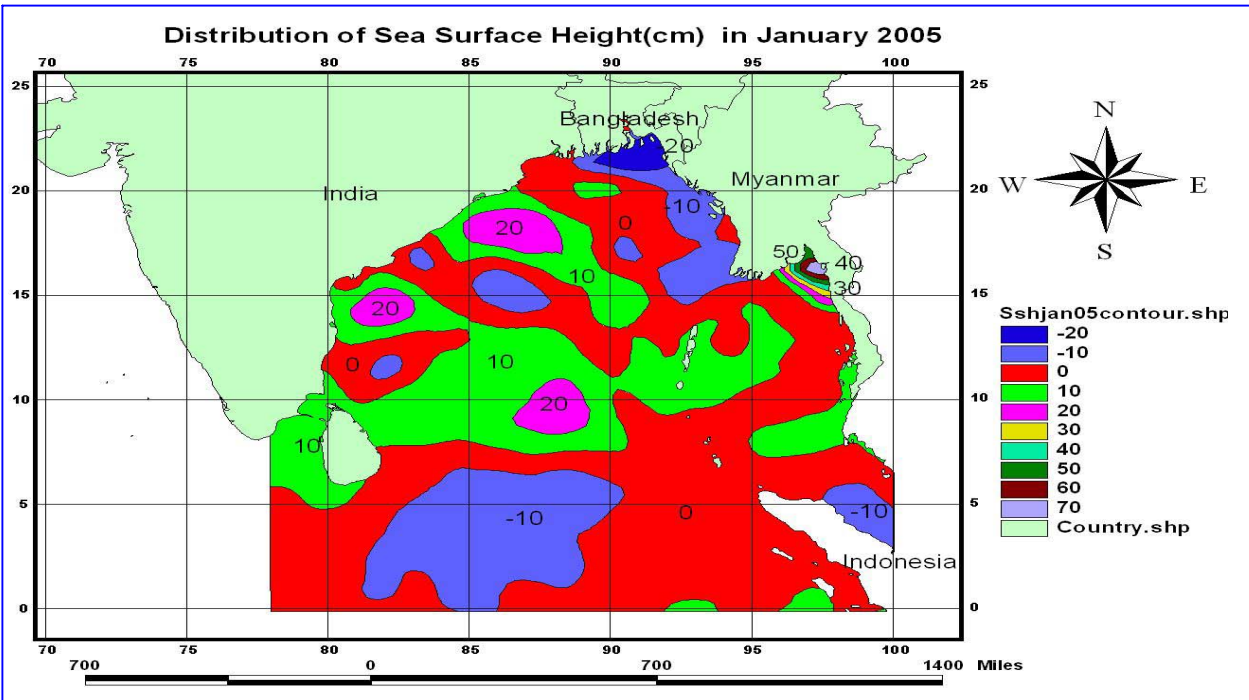


Figure 42 Monthly mean SSH (cm) distribution in Bay of Bengal in January 2005

August 2002-2005

In August 2002, the sea surface height anomaly showed high positive values near the eastern and northern boundary of the Bay, and extending to equator towards eastern boundary (Figure 43). But in the western region, near the Godavari and Krishna region negative pockets of SSH anomaly of -10 cm and same as around Sri Lanka region except one patch of -20 cm. In the August 2003, the SSH anomaly showed the similar distribution pattern to August 2002, except negative patch of -10 to -20 cm in near the Mahanadi river basin (Figure 44). In the August 2004, the negative patches of -10 cm increased in the open Bay towards the western Bay (Figure 45). In the August 2005, the negative SSH anomalies were seen in the eastern and towards the western open region. Then in the rest of part SSH anomaly showed the positive values (Figure 46). In general, negative SSH anomaly was seen near along the western boundary while it was positive in the rest of the Bay of Bengal. In particular the highest positive SSH was noticed along the eastern Bay.

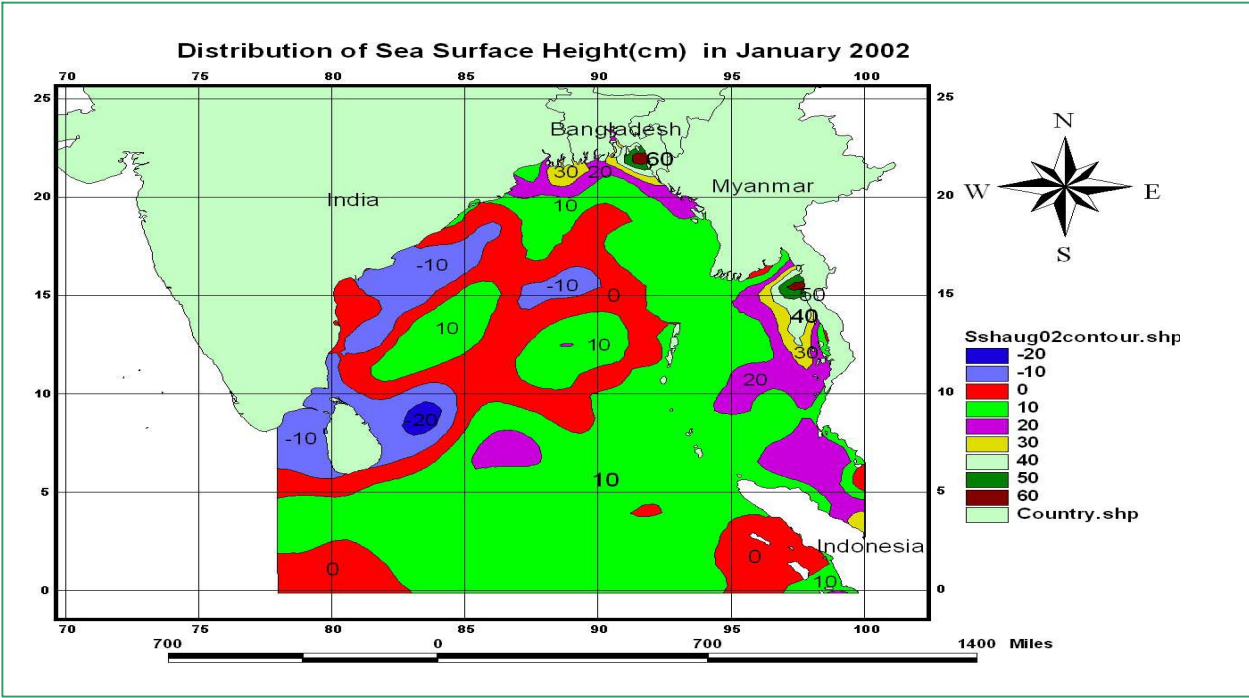


Figure 43 Monthly mean SSH (cm) distribution in Bay of Bengal in August 2002

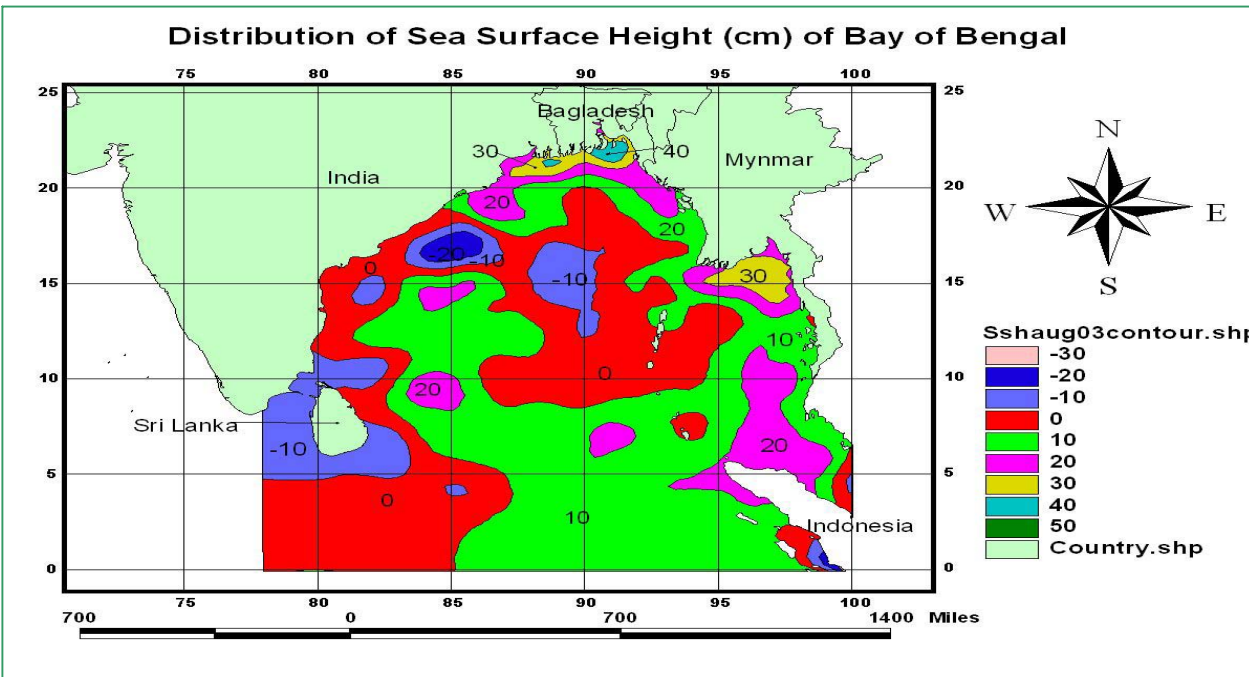


Figure 44 Monthly mean SSH (cm) distribution in Bay of Bengal in August 2003

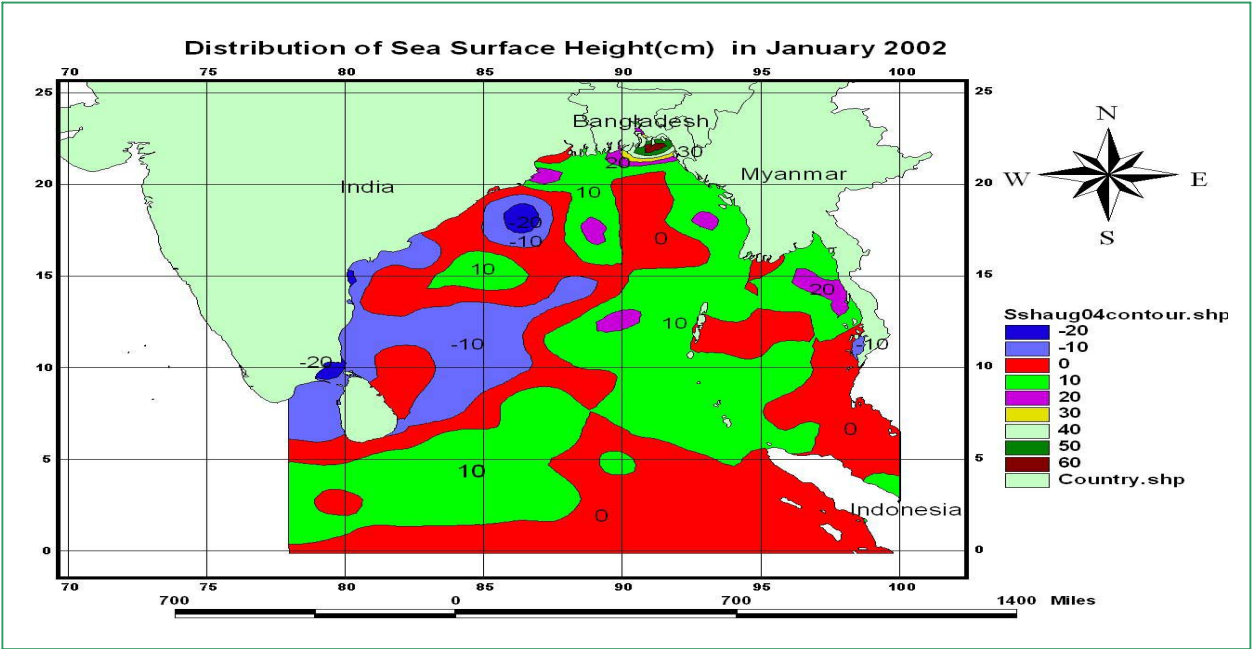


Figure 45 Monthly mean SSH (cm) distribution in Bay of Bengal in August 2004

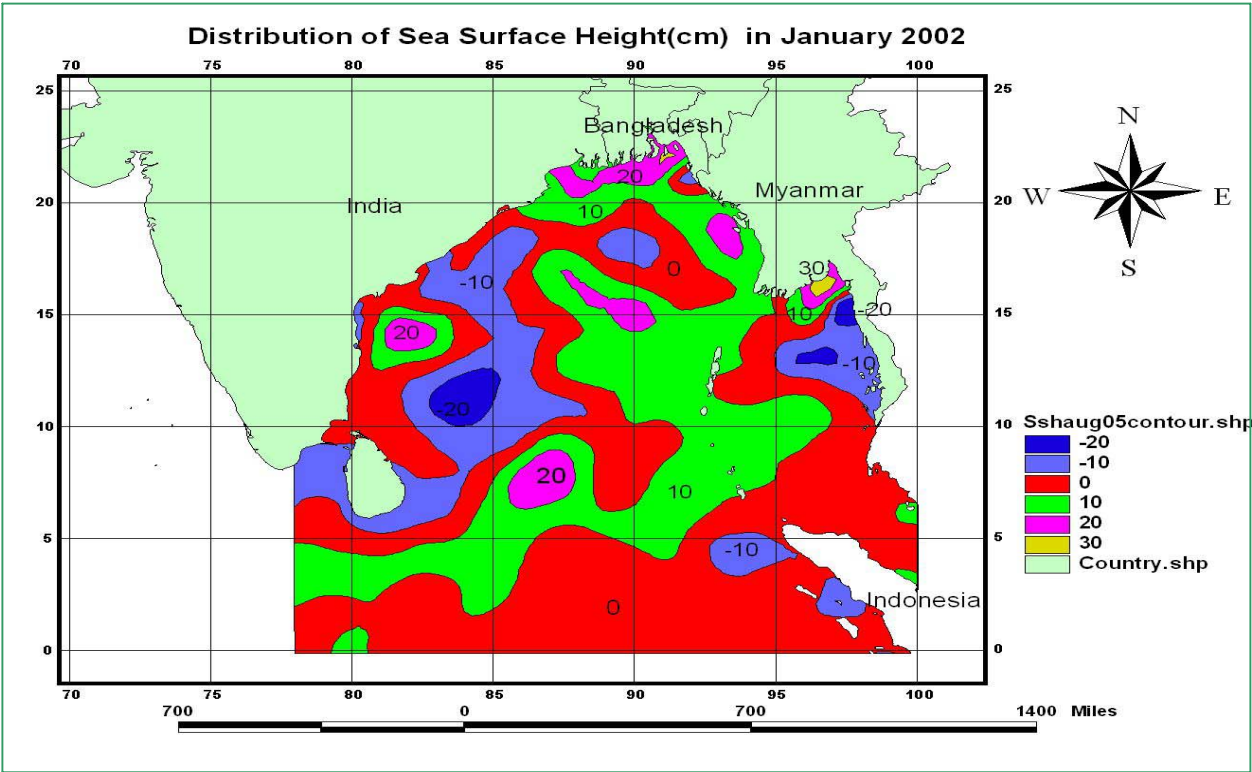


Figure 46 Monthly mean SSH (cm) distribution in Bay of Bengal in August 2005



chapter 5

summary

And

Conclusion

CHAPTER 5

Summary and Conclusion

Summary

The Bay of Bengal is a northern extended arm of the Indian Ocean, situated in eastern part between equator and 22°N latitude and 80°E and 100°E longitude. It is a tropical basin, landlocked in the north by the landmasses of India and Bangladesh and the deltaic region of the Ganges-Brahmaputra-Meghna river system, in the east by the Myanmar peninsula and Indonesian archipelago, and in the west by peninsular India and east coasts of Sri Lanka. The southern boundary of the Bay is in contact with southern ocean. The winds over the Bay of Bengal (BoB) undergo seasonal changes from north-easterly (November-February) during winter to south-westerly (June-September) during summer monsoon. In response to these winds, the environmental/oceanographic characteristics of the Bay of Bengal also will undergo seasonal changes. In addition, the large amount of refresh water brought by the rivers such as Ganges, Brahmaputra, Irawady, Mahanadi, Krishna, Godavari and Kaveri adjoining the BoB also will play a major role in the hydrographic characteristics. Hence the present study aims at understanding the seasonal variability of the environmental parameters of Bay of Bengal.

The present study utilizes the tools such as Geographical Information System (GIS) and remote sensing for the analysis of environment parameters of Bay of Bengal. The remote sensing data, used in the study, are Sea Surface Temperature (SST), Sea Surface Height (SSH) anomalies, Chlorophyll Concentration and Sea Surface Wind. The monthly mean data on SST is from Modis Aqua, chlorophyll pigment concentrations is from SeaWiFS, and sea surface winds from Quikscat. Monthly mean sea surface height anomalies were obtained merged 7-day snap shot from Topex/Posidon and ERS-1/2 series of satellites. The spatial resolution of all the data is 0.3degree in latitude and longitude. The data used for the present study is from January 2002 to December 2005.

These data were analyzed using GIS to determine the seasonal and inter-annual variability. GIS facilitates the modeling and analysis of data apart from generation of contours maps and database of these maps.

The seasonal cycle of SST in the Bay of Bengal showed two periods of warming during April and October. In this season SST was seen very warm with 29 to 30°C average in entire Bay, while it showed the cooling during winter monsoon in month of January due to reduced solar heating and upwelling near the coastal areas. The average SST was seen around 28°C with minimum 22°C in northern coastal region. In summer monsoon, SST was also seen warm with 29°C in entire Bay, while showed cooling near the eastern Bay due to upwelling of cold water with 27°C to 28°C.

Seasonal cycle of chlorophyll concentration was high during summer monsoon, in the month of July and August, and just after that in month of October and little more in January (winter). Mostly chlorophyll pigment showed the high concentration near the coastal region of the Bay and especially near the river mouths with high values about 5 to 10mg/m³. This may be to large quantity of sediments discharged from major rivers, which also brings along with them substantial quantities of nutrients, which supports the observed high pigment concentration. The average chlorophyll concentration of 0.4mg/m³ was found in open Bay, while in month of January and April; it showed low concentration in comparison to summer monsoon in the open Bay as well as near the coastal areas. As a result most of coastal areas of Bay of Bengal becomes biologically productive but in the open and southern Bay, the productivity may becomes very low due to high SST in the open Bay and southern Bay of Bengal.

Seasonal cycle of sea surface height in the Bay of Bengal showed the positive values mostly in entire Bay except near the coastal areas of Northern and eastern Bay and few patches near the western boundary. Large variation in positive and negative pockets of SSH was seen near the western and eastern boundary in all months, these could be the regions of warm (positive SSH) and cold (negative SSH) core eddies.

Seasonal cycle of sea surface wind showed the light and variable northeasterly wind in the month of January (winter) and April (spring inter monsoon) but in the summer monsoon, it was southwesterly with high speed about 10 to 11m/s. After summer monsoon, in fall inter monsoon, it showed the little decreased in speed.

The analysis of seasonal cycle showed the positive relationship between chlorophyll concentration and SST near the coastal areas of the Bay of Bengal, especially near the northern and eastern Bay in the winter monsoon and it showed the inverse relationship in the central and southern Bay of Bengal, during all the seasons, that means high SST, low chlorophyll concentrations.

The analysis of SST, chlorophyll pigment concentration, sea surface height during 2002 to 2005 showed large inter-annual variability during both winter (January) and summer (August). In general, high chlorophyll concentrations occurred during colder winter and strong summer monsoon years while the SST was colder in the winter and very warmer in the summer monsoon.

Conclusion

The study showed that the distribution of chlorophyll concentration was high near the coastal region and it showed positive relationship to sea surface temperature during winter monsoon near the northern coastal region but in the open Bay and southern Bay, inverse relationship was seen between chlorophyll concentration and SST in all the months.

The high chlorophyll concentration was seen in the summer monsoon and also in fall inter monsoon, near the coastal areas and Indo-Sri Lanka region. These regions could be the highly biologically productive in the Bay of Bengal.

These results showed the Bay of Bengal low productive in the open and southern region, but it is high biologically productive near shore region of all coastal boundaries (northern, western and eastern Bay), especially near the river mouths.

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