

**ANALYSIS OF CHLOROPHYLL
PIGMENT CONCENTRATION IN THE
NORTHERN ARABIAN SEA USING
REMOTE SENSING AND GIS**

SHIVANI THAPA
February 2007

**ANALYSIS OF CHLOROPHYLL PIGMENT
CONCENTRATION IN THE NORTHERN
ARABIAN SEA USING REMOTE SENSING
AND GIS**

A DISSERTATION

*Submitted in partial fulfillment of the requirement for the award of the
degree*

Of

MASTER OF SCIENCE AND TECHNOLOGY

In

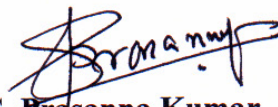
REMOTE SENSING AND GIS

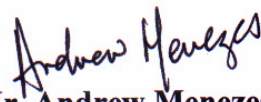
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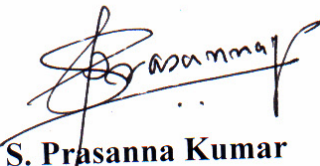


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CERTIFICATE

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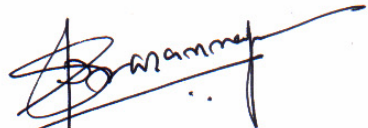
I here by, declare that the work which is being presented in dissertation work entitled **“ANALYSIS OF CHLOROPHYLL PIGMENT CONCENTRATION IN THE NORTHERN ARABIAN SEA USING REMOTE SENSING AND GIS”** in partial fulfillment of requirement for the award of degree of **Master of Science and Technology in Remote Sensing and GIS** and submitted in Department of Applied Geology, Barkatullah (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. Andrew Menezes**, Scientist, MID, at National Institute of Oceanography (NIO) , Goa.

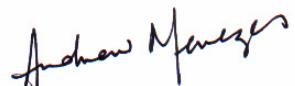
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*DEDICATED TO MY
BELOVED PARENTS*

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CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

The ocean covers 70% of total earth surface and plays a vital role in sustaining the life on our planet. The upper layer of ocean plays an important role in regulation of ocean biology. There is evidence that life existed on earth in form of blue algae, which were first detected in the oceans. The photosynthesizing microscopic organisms containing chlorophyll, referred to as phytoplankton, are a diverse group of single-celled algae. This tiny phytoplankton is the building blocks of biological system, which depend upon sunlight and nutrients for their growth. They fix about 1/3 of atmospheric carbon dioxide and act as a reservoir of carbon, apart from increasing the oxygen levels which is of immense important to other forms of life. The nutrient concentration in upper layer of ocean is least due to photosynthesis and hence concentration goes on increasing towards the mid depth. The green pigment (chlorophyll) in the phytoplankton absorbs blue and red light, and reflects green light. Hence, more the phytoplankton present, greener the ocean appears.

In Northern Arabian Sea, the growth of Phytoplankton cell is controlled by nutrient availability rather than light, while inhibition of photosynthesis near the surface is negligible (Tang et al., 2002). The boundary and the open

ocean process of Arabian Sea is influenced by upwelling during summer and cooling in winter that brings in higher amount of nutrients into the upper ocean enhancing primary productivity and ultimately fisheries (Madhupratap et al., 2001). In addition, cold-core eddies are also capable of increasing the biological productivity and known to occurrence in Arabian Sea during winter monsoon (Bohm et al., 1999). In general, Eddies appears to have appreciable deep vertical extension (Qasin, 19982) and the eddy circulation is attributed to the influence of bottom topography that is marked by depression and rise (Dasetal.1980). The Northern Arabian Sea is distinguished by its many features that make it an ideal place to study changes in physical parameters brought about by seasonally driven atmospheric forcing. The response of thermo-haline structure to momentum and heat flux and associated changes in water-column nutrient and chlorophyll structure are key to the understanding of primary, secondary and tertiary production in the ocean. The chemical and biological data are of critical importance in building models for forecasting global carbon cycles and predicting climate changes. The present project is aimed at understanding the chlorophyll *a* distribution in Northern Arabian Sea using satellite derived pigment concentrations.

1.2 STUDY DOMAIN

The Arabian Sea is situated in the western part of northern Indian Ocean. The maximum width of Arabian Sea is approximately 2,400km and maximum depth is 4,652mt. The monsoon of Arabian Sea, with extreme strong southwesterly winds during June to September and comparatively weak and steady northeasterly winds during November to February, is the major atmospheric forcing that influences the oceanic processes on a

seasonal scale. The Arabian Sea is the largest productive region of the world and results in large fish production, which feeds the billion people of this continent.

In order to understand the environmental factor responsible for the distribution and variability of chlorophyll in northern Arabian Sea, the study area chosen extended from 15°N to 25°N latitude and 45°E to 75°E longitudes.

1.3 ABOUT THE PROJECT AND MOTIVATION

Since Phytoplankton forms the basis of ocean life and also has the potential to regulate the CO₂ and oxygen levels in the atmosphere with its implication to climate of the earth system, it has been a topic of immense interest to many of researchers. In view of this, the present study aims at understanding the distribution of chlorophyll pigment concentration in the Northern Arabian Sea. Since the winds over the Northern Indian Ocean reverse semi-annually, from southwest during June to September to Northeast during November to February, it is natural to expect a similar variation in the chlorophyll pigment concentration in the northern Arabian Sea. While understanding the pattern of variability in the chlorophyll pigment concentrations, possible factors that are responsible for the observed variability is also explored through this project work.

1.4 OBJECTIVES

The main objective of this study is to use GIS and Remote sensing tools for analysis of the oceanic parameters along with its statistics in the North Arabian Sea.

The specific observations of this study are

- 1) To analyses the seasonal and inter-annual variability of chlorophyll pigment concentration, aerosol and diffuse attenuation coefficient in the northern Arabian Sea.
- 2) To analyses the correlation between chlorophyll and other parameters such as aerosol and diffuse attenuation coefficient.

CHAPTER 2

ABOUT PHYTOPLANKTON AND CHLOROPHYLL

2.1 PHYTOPLANKTON

Phytoplanktons are group of microscopic, single-celled algae. The word “Phyto” means, “plant”, and plankton means “at the mercy of the currents”. About ninety-nine percent of the biosphere is marine and most of this is supported by the photosynthetic activity of phytoplankton. Although phytoplankton supports marine life, they also have the ability to destroy it. Some species have the ability to produce neurotoxins that enter the food web and endanger both marine and human life. As stated earlier, phytoplankton strongly influences ocean color. Phytoplankton is more abundant closer to the shore because they receive everything they need to grow. To be able to grow, phytoplankton needs light, water, CO₂, and nutrients. Water and CO₂ are readily available, so phytoplankton is limited by light and nutrients. Light is available near the surface, but nutrients are removed from the surface and sink. When ocean circulation moves nutrients to shallow water, phytoplankton is able to grow.

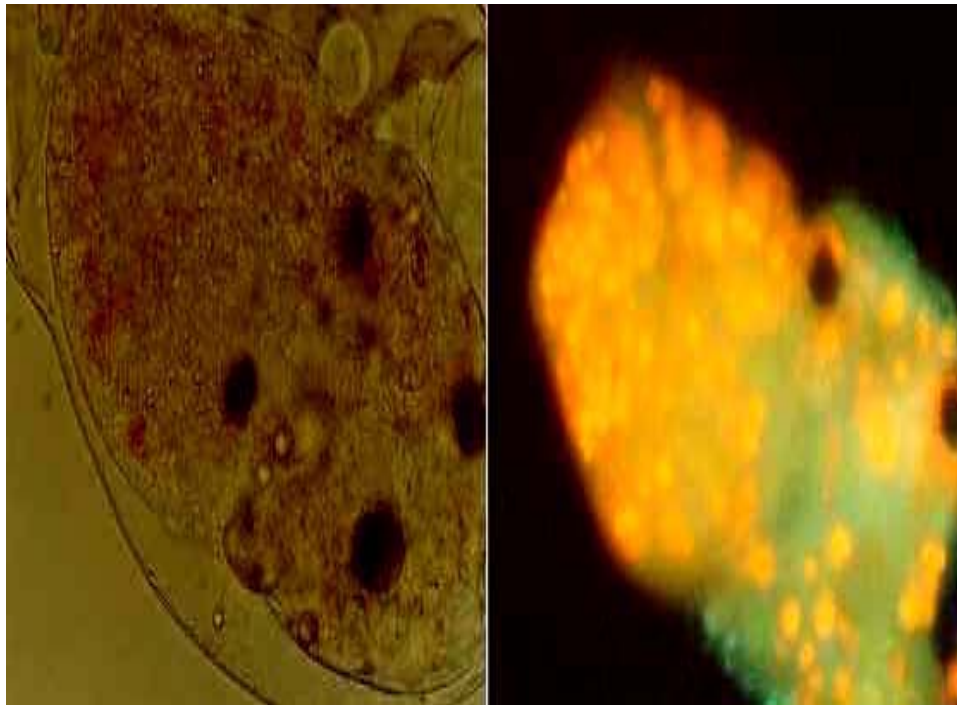


Fig. 1 Phytoplankton

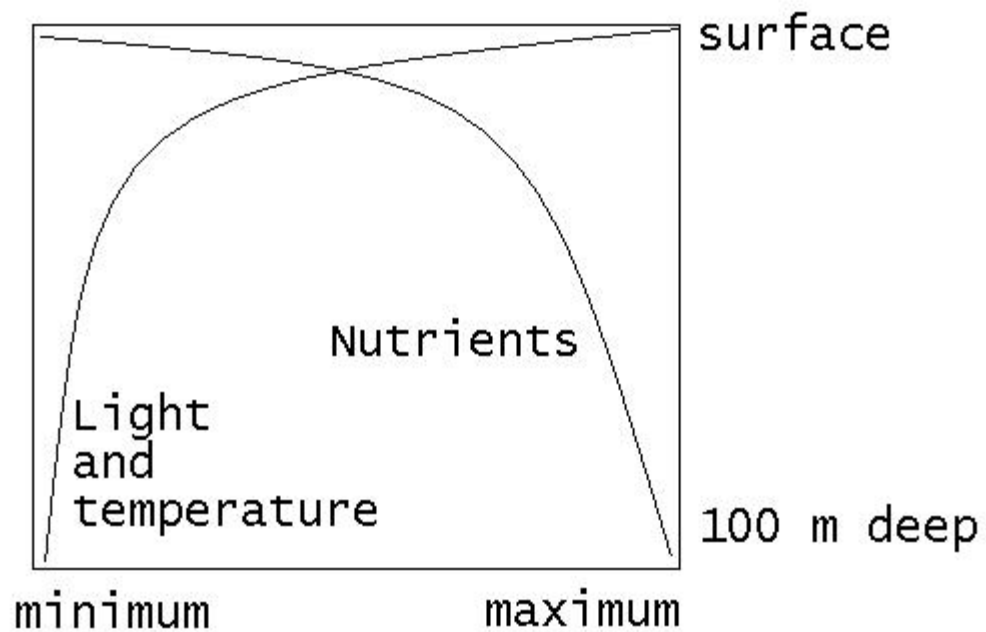


Fig. 2 Relationship between light nutrients and temperature in the upper ocean

2.2 CHLOROPHYLL

Light absorption is accomplished through the use of pigments such as carotenoids, and photosynthetic pigments called chlorophyll. Two of the types of chlorophyll in autotrophic life are called chlorophyll *a* and chlorophyll *b*. Chlorophyll absorbs different wavelengths of light. This is used to help different species of plant and phytoplankton to survive in different environments by absorbing different magnitudes of light wavelength to execute photosynthesis. Chlorophyll absorbs very little green light. This is what makes chlorophyll green. White light from the sun is a combination of every color ranging from violet to red. When white light hits a phytoplankton, all of the light except the green wavelengths is absorbed. All light, which is not absorbed by chlorophyll, is transmitted back to the human eye, which is why chlorophyll appears to be green. Chlorophyll *a* absorbs maximally at 440 and 675nm.

Using this principle of light absorption by phytoplankton, it is possible to detect them from space using satellite and remote sensing technique.

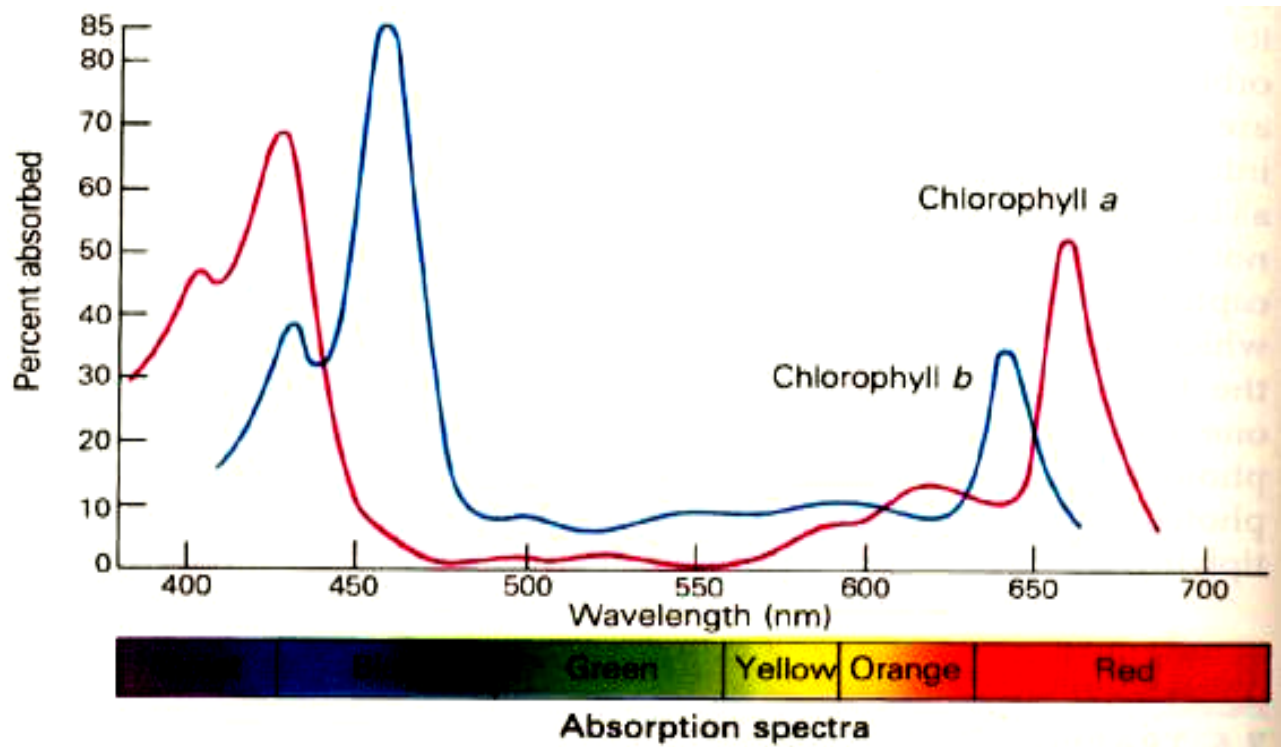


Fig. 3 Absorption spectra of chlorophyll pigment

2.3 IMPORTANCE OF CHLOROPHYLL IN CARBON CYCLE

Phytoplankton use carbon dioxide, a greenhouse gas, for photosynthesis to produce glucose and plays an important role in the regulation of global CO₂ balance. The larger the world's phytoplankton population, the more carbon dioxide gets absorbed from the atmosphere; this will lower the average temperature due to lower volumes of this greenhouse gas. The effect of a reduction of phytoplankton on the Earth's ecosystem has serious consequences.

- 1) Phytoplankton is the primary source of food for the oceanic food chain, which includes fish and the marine birds that feed on them.
- 2) Phytoplankton play an important role in removing carbon dioxide from atmosphere, by converting inorganic CO₂ into organic carbon through photosynthesis, the principal cause of global warming.

The effect of a reduction in phytoplankton means less fish to feed, less carbon dioxide removed from the atmosphere and increased global warming. Rising levels of carbon dioxide in the atmosphere play a big part in global warming. The warming of the oceans near the surface creates a barrier between the warm surface and colder lower regions, which cuts off the access of phytoplankton to essential nutrients below that they need to grow.

2.4 ABOUT AEROSOL

An aerosol is a dispersion of solid and liquid particles suspended in gas. Atmospheric aerosols are defined as solid and liquid particles suspended in air. Aerosols occur in troposphere as well as in stratosphere. Aerosol occurs on land and water surfaces and in the atmosphere also. They are produced by different processes that occur on land and water surfaces, and in the atmosphere. Aerosols are usually divided into three size categories.

Aitkin particles, or nucleation mode: (0.001 - 0.1 μm radius)

Large particles, or accumulation mode: (0.1 - 1 μm radius)

Giant particles, or coarse particle mode: (> 1 μm radius)

Aerosols are the black carbon (BC) that affects the climate by absorbing solar energy that in turn heats up the atmosphere. There is considerable difference in chemical nature and sources of

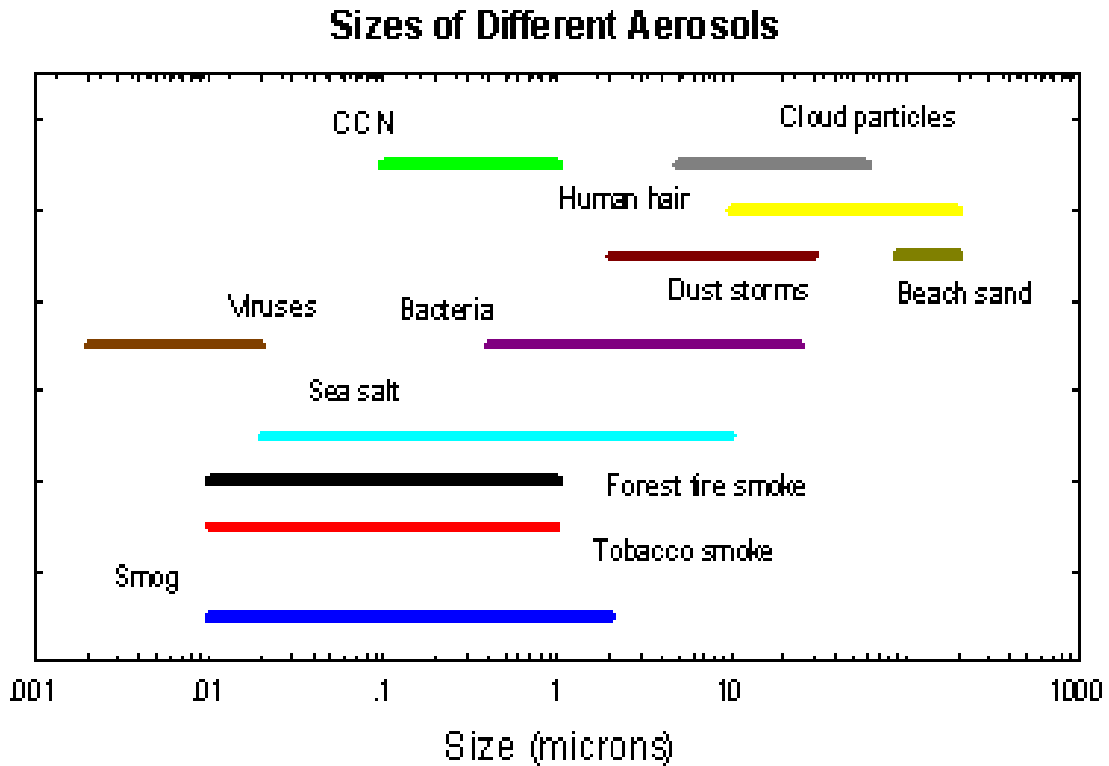


Fig. 4 Size category of different aerosol particle

the aerosols that occur in these two atmospheric layers. This is because aerosols have important consequences for global climate, ecosystem processes, and human health. The amount of solar radiation reaching the surface of the earth, known as radiative forcing is influenced by aerosol. Radiative forcing is usually expressed in units of W/m^2 , and can be a positive or negative term. A reduction of solar radiation reaching the earth is considered a negative forcing. Aerosols both absorb and scatter solar

radiation. Most of the light extinction caused by aerosols is due to scattering. Aerosols are transported by prevailing winds and convection once they are in the atmosphere.

2.5 ABOUT DIFFUSE ATTENUATION COEFFICIENT

The light field in the ocean or in any absorbing and scattering medium changes with depth. The diffuse attenuation coefficient for down welling irradiance, K_d (in inverse meters) determines the optical properties of seawater. It is defined as

$$K_d = -1/E_d * dE_d/ dz$$

Where, E_d (watts per square meter) is planar down welling irradiance and z (in meters) is depth (positive downward from the sea surface).

K_d is an indicator of the penetrative component of solar radiation. Approximately 90% of the diffuse reflected light from a water body comes from a surface layer of water of depth $1/ K_d$. Thus K_d is an important parameter for remote sensing of ocean color. K_d is not a property of the water itself but this is a descriptor of the underwater light field that varies with depth, solar altitude, and time.

Underwater solar light plays an important role in the formation of vertical distribution and abundance of phytoplankton as well as bottom vegetation. The interactions of light availability, its spectral distribution, and the physiology of phytoplankton impose fundamental constraints on the rate of primary production of a water column (Platt et al., 1984; Gallegos et al., 1990; Kirk, 1996).

CHAPTER 3

INTRODUCTION TO REMOTE SENSING

3.1 INTRODUCTION

Remote sensing has been defined as “a technique used to gather information about an object or an area without actually coming into physical contact with it ” Our eyes, ears, and skin, as well as more sophisticated instruments, all aid us in remote sensing. These sensors provide information about size, color, location, temperature, and other conditions. Remote sensing is the science of acquiring, processing and interpreting images that record the interaction between electromagnetic radiation and matter. Electromagnetic radiation, which is reflected or emitted from the object, is the usual source of remote sensing data. However any media such as gravity or magnetic field can be utilized in remote sensing. In remote sensing electromagnetic radiation (EMR) is used to transfer the information. When the sunlight falls on ocean, some part of light is scattered and some part of light get absorbed. These scattered EMR are captured by remote sensing satellites and then collected by the sensor.

3.2 ELECTROMAGNETIC SPECTRUM

Based on wavelength, remote sensing is classified into three types.

1. Visible and reflective Infrared Remote Sensing
2. Thermal Infrared Remote Sensing
3. Microwave Remote Sensing

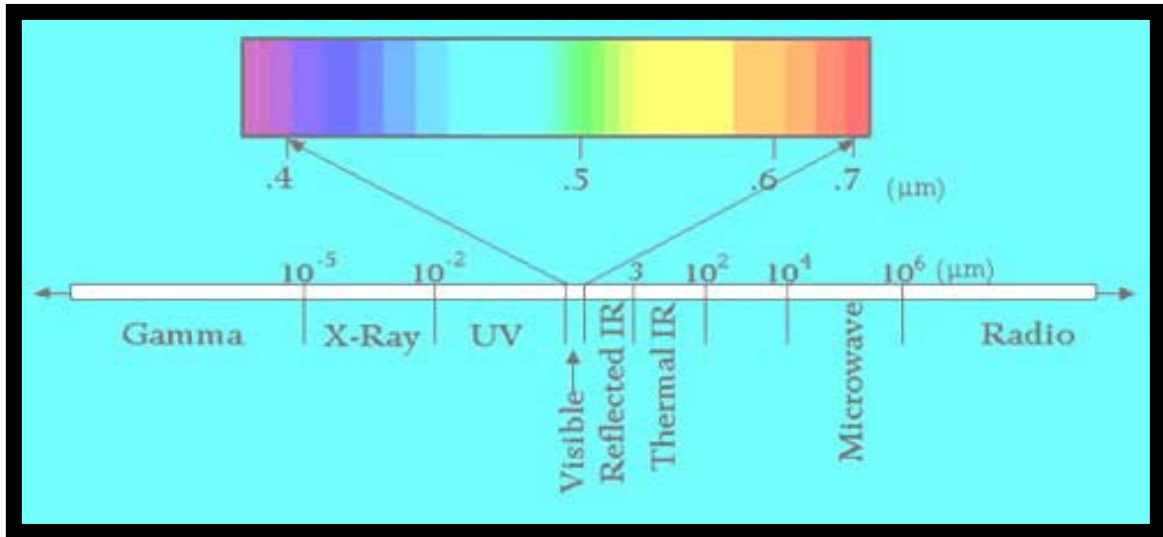


Fig. 5 Electromagnetic spectrum

The energy source used in visible and reflected infrared remote sensing is sun and mainly depends upon reflectance of object on the ground surface. Therefore information about the object can be obtained from the spectral reflectance. In thermal infrared the source of radiant energy is the object itself. Because any object with a normal temperature will emit electromagnetic radiation with a peak.

In Microwave region, there are two type of Microwave Remote Sensing - Passive and Active. In Passive Microwave Remote Sensing, the microwave radiation emitted from the object is detected, while the back scattering coefficient is detected in Active Microwave Remote Sensing.

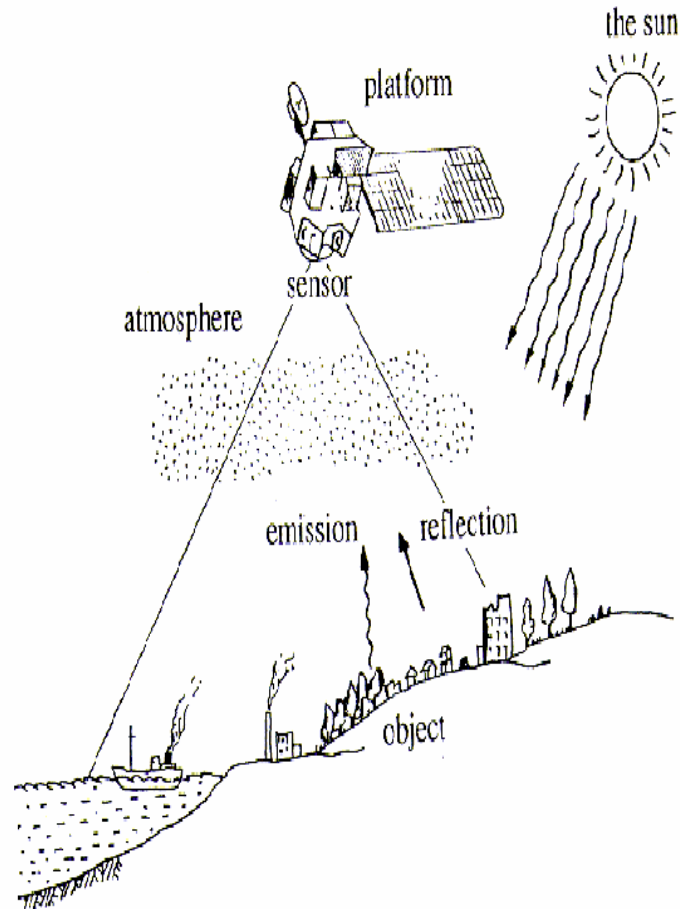


Fig. 6 Schematic of data collection by remote sensing

3.3 TYPES OF REMOTE SENSING SATELLITES

Polar-orbiting Satellite: Polar orbits are useful for viewing the planet's surface. As a satellite orbits in a north-south direction, Earth spins beneath it in an east-west direction. As a result, a satellite in polar orbit can eventually scan the entire surface. Satellite that monitor the global environment, like remote sensing satellites and certain weather satellites, are almost always in polar orbit.

Geosynchronous-orbiting Satellite: They orbit at a rate that matches the Earth's rotation, so they are always above the same spot and scan the same region. From an altitude of about 36,000km, each geosynchronous satellite monitors almost one-third of the Earth's surface and has a "full-disk" view of the Earth from pole to pole.

Geostationary-orbiting Satellite: A satellite that appears to remain in the same position above the Earth. The orbit is circular and its inclination is zero degrees, which means that it is above the Earth's Equator. The altitude is about 36,000 kilometers, and the satellite travels at 3 kilometers per second. The satellite's orbital period is about the same as the Earth's rotation period, roughly 24 hours. From Earth the satellite appears to be stationary and is called a geostationary satellite.

Synchronous-orbiting Satellite: A satellite said to be synchronous orbit that goes around the Earth once a day and returning to its original position. An orbit in which the satellite completes one circuit around the Earth in one day, and then appears in the same position above the Earth's surface, is known as a "synchronous orbit".

Recurrent-orbiting Satellite: A satellite said in a recurrent orbit that returns to its starting point above the Earth's surface within one day. A recurrent orbit is an orbit in which the satellite returns to the same position over the surface of the Earth within 24 hours, regardless of how many orbits it has made in that time. The orbital period of the satellite is an integral fraction of the Earth's rotation period.

Sub-recurrent-orbiting Satellite: In sub-recurrent orbit, the satellite returns to the same point above the Earth's surface a number of days later. Although orbiting the Earth several times a day, the satellite returns regularly after a set time to its starting position above the surface of the Earth.

Sun-synchronous-orbiting Satellite: In a sun-synchronous orbit, the direction of rotation of the orbital plane and the period (the rotation angle per day) are the same as the Earth's orbital period (the rotation angle per day).

Sun-synchronous sub-recurrent-orbiting Satellite: A sun synchronous sub-recurrent orbit is an orbit that combines a sun-synchronous orbit with a sub-recurrent orbit. Satellites launched into this kind of orbit appear in the sky over a certain point every few days. Because they repeatedly pass the same point in the same time zone, they can observe the point many times under the same conditions.

3.4 TYPES OF REMOTE SENSING SENSOR

PASSIVE SENSOR: Passive Sensor is those, which are designed to detect natural occurring energy i.e. passive sensor, detect the reflected or emitted electromagnetic radiation from natural sources. In remote sensing, mostly passive sensor is used. The sun's energy is either reflected, as it is for visible wavelengths, or absorbed and then re-emitted, as it is for thermal infrared wavelengths. Most often, the source of radiative energy is the sun. This sensor is capable of detecting radiation in several different portions of the

electromagnetic spectrum. The Thematic Mapper, the primary sensor on the Landsat satellites, is a good example of a passive sensor.

ACTIVE SENSOR: Active sensors are those that provide their own energy source for illumination of the target i.e. active sensors detect reflected responses from the object, which are irradiated from an artificially generated energy source. Doppler radar is an example of an active remote sensing technology. A Doppler radar device is a ground-based system that emits radio energy in a radial pattern as the transmitter rotates.

Passive, non-scanning and non-imaging methods are 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 laser spectrometer and laser altimeter. An active, scanning and imaging sensor is radar, for e.g. Synthetic Aperture Radar (SAR), which can produce high-resolution imagery during day or night, even under cloud cover. The most popular sensors used in remote sensing are the camera, solid-state scanner, such as the CCD (charge coupled device) images, the multi-spectral scanner and in the future the passive synthetic aperture radar.

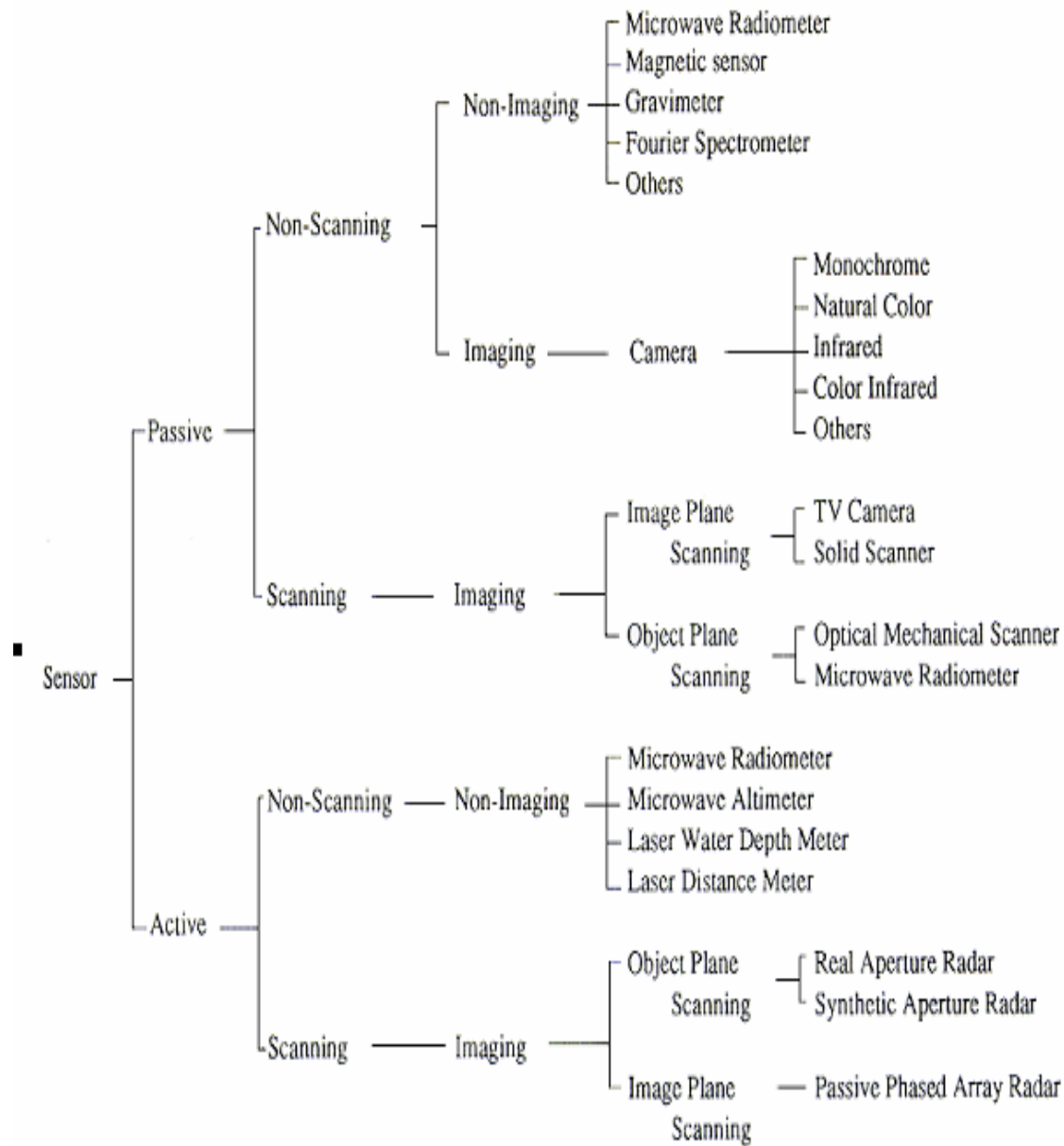


Fig. 7 Diagram showing Sensor classification

3.5 REMOTE SENSING FOR OCEAN

Conventionally, ships were used to make measurements of ocean parameters, which provided us the information regarding ocean currents, property distribution as well as the diversity of life within. As the technology advanced, remote sensing became a powerful tool in modern oceanography, which is capable of providing a synoptic view of the oceans. Satellites are able to sense an array of parameters such as ocean color, Sea Surface Temperature (SST), Sea Surface Height (SSH) anomalies and Sea Surface Winds (SSW). Monitoring of ocean environment through remote sensing provides better understanding of the marine processes, ecology and the ocean environmental changes.

3.6 REMOTE SENSING OF CHLOROPHYLL PIGMENT CONCENTRATION

Remote sensing of ocean color gives the information on the constituents of seawater such as the concentration of phytoplankton pigments, suspended sediments and yellow substance. The aim of remote sensing of Ocean color is to derive quantitative information on the types and concentrations of substances present in the water from variations in spectral form. It has become a powerful tool in oceanography. Ocean color is determined by remote sensing reflectance (R_{rs}); the ratio of water leaving radiance (L_u) to down welling irradiance (Kirk, 1994). This is a measure of down welling light that is incident onto the water surface then 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 determine the magnitude and variability of primary production, and timing of phytoplankton blooms. Routine monitoring of the regional and temporal variability of ocean chlorophyll provides information on primary production and subsequent assessment of secondary and higher order production processes such as zooplanktons and marine fisheries.

3.7 ABOUT SeaWiFS

The SeaWiFS is Sea-viewing Wide Field-of-view Sensor. The purpose of the SeaWiFS Project is to provide useful data on ocean color to the Earth science community. The SeaWiFS consists of an optical scanner. SeaWiFS flies on the OrbView-2 satellite, The OrbView-2 satellite with the SeawiFS sensor launched in 1st August 1997, which provides multispectral imagery of the Earth's land and ocean surface every day, Swath of this is 2801km, Resolution is 1.1km and Number of bands is 8.

3.8 SeaWiFS AND MODIS-AQUA FOR CHLOROPHYLL CONCENTRATION

The Sea-viewing Wide Field-of-view Sensor and MODIS (Moderate Resolution Imaging Spectroradiometer) are placed on two satellites (Terra

and Aqua). The **Terra** satellite is the first EOS (Earth Observing System) platform and provides global data on the state of the atmosphere, land, and oceans, as well as their interactions with solar radiation and with one another. The **Aqua** Project is the multi-disciplinary study of the Earth's interrelated processes (atmosphere, oceans, and land surface) and their relationship to Earth system changes. MODIS measure the photosynthetic activity of land and marine plants (phytoplankton) to yield better estimates of how much of the greenhouse gas is being absorbed and used in plant productivity. The 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.

CHAPTER 4

INTRODUCTION OF GIS

4.1 DEFINITION OF GIS

Like the field of geography, the term Geographic Information System (GIS) is hard to define. It is the integration of many subject areas. Because of which there is no absolute definition of a GIS (deMers, 1997). 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. A broadly accepted definition of GIS is the one provided by the National Center of Geographic Information and Analysis.

A GIS is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modeling, representation and display

of georeferenced data to solve complex problems regarding planning and management of resources. (NCGIA, 1990)

Geographic information systems have emerged in the last decade as an essential tool for urban and resource planning and management. Their capacity to store, retrieve, analyses, model and map large areas with huge volumes of spatial data has led to an extraordinary growth of applications. Geographic information systems are now used for land use planning, utilities management, ecosystems modeling, landscape assessment and planning, transportation and infrastructure planning, market analysis, visual impact analysis, facilities management, tax assessment, real estate analysis and many other applications.

4.2 FUNCTIONS OF GIS

Data entry

Data display

Data management

Data Output

4.3 COMPONENTS OF GIS

GIS consists of five key components:

Hardware

Software

Data

People

Methods

Hardware - Hardware is the computer on which GIS works. GIS runs on the wide range of the hardware types, from centralized computer servers to desktop computers.

Software - GIS software gives the functions and tools needed to store, analyze, and display geographic information.

Key software components are

1. A database management system (DBMS)
2. Tools for the input and manipulation of geographic information
3. Tools that support geographic query, analysis, and visualization
4. A Graphical User Interface (GUI) for easy access to tools

Data - The most important component of a GIS is the data. Geographic data and related tabular data can be collected in-house or bought from a commercial data provider. Most GIS employ a DBMS to create and maintain a database to help organize and manage data.

People - GIS technology is of limited value without the people who manage the system and to develop plans for applying it. GIS users rang from technical specialists who design and maintain the system to those who use it to help them do their everyday work.

- A database management system (DBMS)
- Tools for the input and manipulation of geographic information
- Tools that support geographic query, analysis, and visualization
- A Graphical User Interface (GUI) for easy access to tools

- A database management system (DBMS)
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- Tools that support geographic query, analysis, and visualization
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Methods - A GIS operates according to a well-designed plan and business rules.

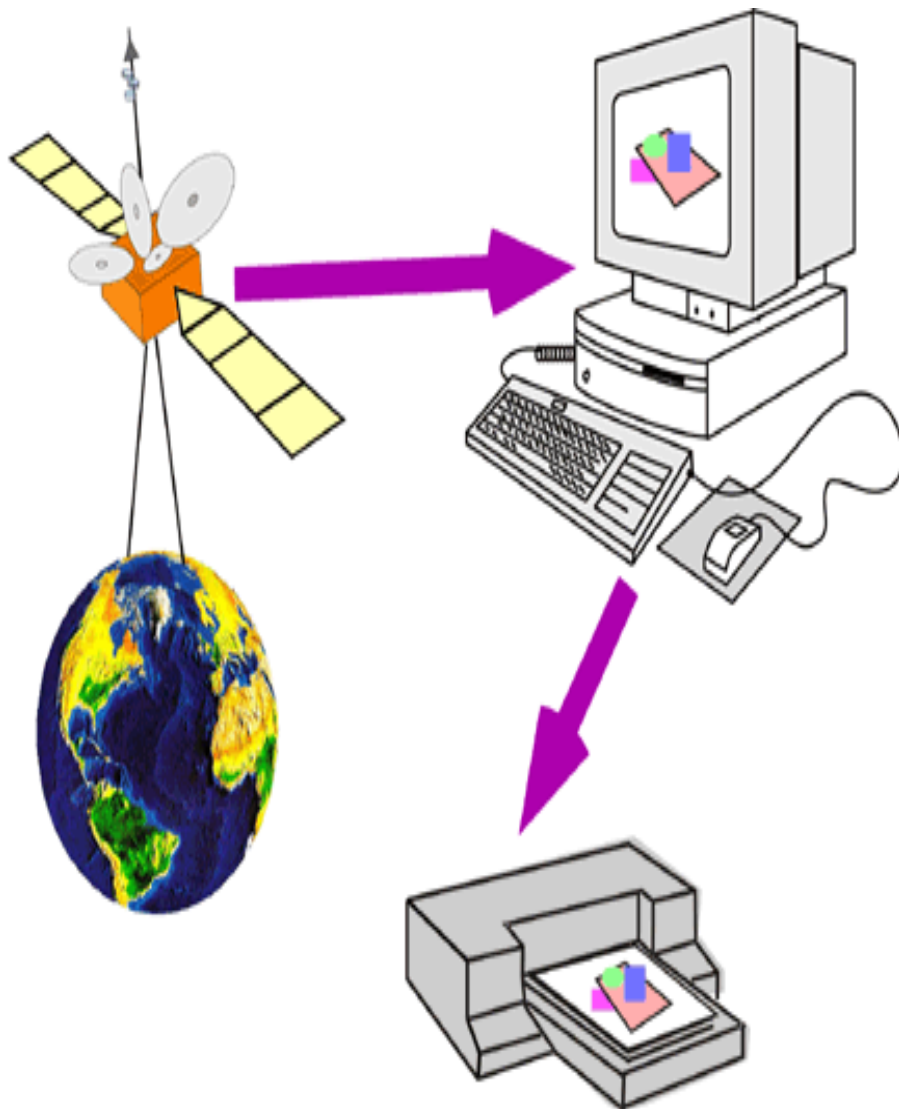


Fig.8 Component of GIS

4.4 APPLICATION OF GIS

The rapidly growth associated with of industrialization has increased the need of geographical information and its management for the understanding and sustainable use of the Earth's natural resources. The uses for geographical information are extensive. A few specific examples are:

Land use and resource management

Forestry

Teaching and education

Marketing and Business location

Natural Hazard

Disaster Management

Oceanography

Environmental monitoring

Geology

Urbanization

Rural Development

Infrastructure and Utilities

Health and Healthcare

4.5 GIS FOR OCEANIC STUDY

Applications of GIS technology in the various oceanographic disciplines are multifaceted. They deal with data acquired with a variety of different methods and integration of principles from different technological disciplines in an attempt to facilitate the resolution of the dynamics of the marine environment. Oceanographic GIS is capable of finding solution to an ever-increasing number of marine problems and at the same time provides new insights to the unknown oceanographic processes. 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. 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. In recent years, the applications of GIS increased in the studies of oceanic process such as ocean surface processes, environmental and bioeconomic characterizations 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.

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.

CHAPTER 5

METHODOLOGY

Processing of remote sensing data involves several steps, which are listed below. The satellite remote sensing data, which is in the form of binary system and compressed, are converted to the uncompressed file for easy data analysis.

5.1 PARAMETERS USED

Chlorophyll concentration from SeaWifs

Aerosol from SeaWifs

Diffuse Attenuation from SeaWifs

5.2 SOFTWARE USED

Arc /view 3.2

MS-Excel

Grapher

5.3 DATA SOURCE

The data on Chlorophyll, Aerosol and Diffuse Attenuation coefficient were extracted from the following website:

<http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.swf8D.2.shtml>

From this site, the weekly data on Chlorophyll Concentration, Aerosol and Diffuse Attenuation coefficient for 10 years, from August 1997 to September 2006, were downloaded. These data were processed following the procedure given below to create individual distribution maps. These were further processed to obtain the statistics.

5.4 VARIOUS STEPS APPLIED

Remotely sensed ASCII data is converted in the text file format in WordPad. Subsequently, added all the text file data in tabular form in the Arc view. The text file of each of the three parameters such as chlorophyll concentration, Aerosol optics And Diffuse Attenuation was converted into the point map (shape files) using option “Theme” in Arc/View 3.2. From the shape file, using the option “Theme “and “Query”, removed all the Abnormal Value of these three parameters. Finally, statistics such as Mean, Maximum, and Minimum value of each parameter was obtained. These were then used for preparing graphs using MS EXCEL and GRAPHER packages.

CHAPTER 6

RESULT AND DISCUSSION

In this chapter analysis of the data on chlorophyll pigment concentrations, aerosol and diffuse attenuation coefficient were examined to understand the following:

1. Seasonal variability
2. Inter-annual variability
3. Relationship of chlorophyll pigment concentration with aerosol and diffuse attenuation coefficient

The objective of the analysis is to see if there exist any relationship between chlorophyll pigment concentrations and aerosol, which could potentially supply nutrients for phytoplankton growth by way of dust input.

6.1 SPATIAL VARIABILITY ON A SEASONAL SCALE

Spatial Distribution of Chlorophyll pigment

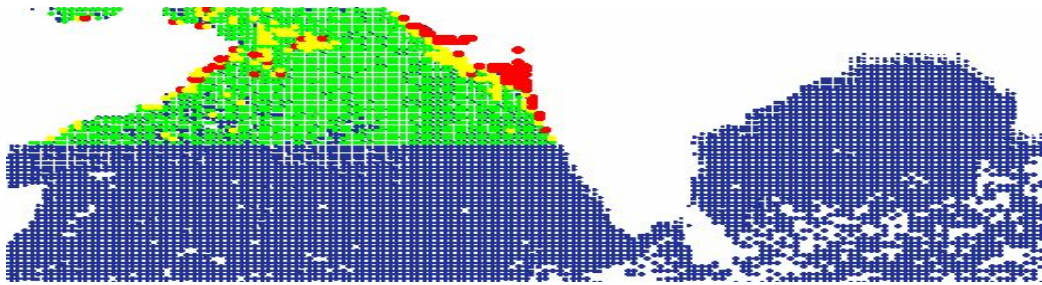


Fig.9 Chlorophyll Pigment Concentrations for the first week of January 2004 (8-day composite). The color coding - Red pertains to high concentration, Yellow to medium while Green to low concentration.

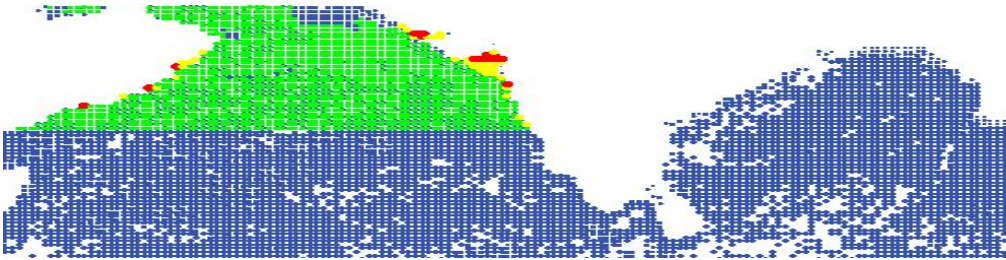


Fig.10 Chlorophyll Pigment Concentrations for the first week of **April 2004** (8-day composite). The color coding - Red pertains to high concentration, Yellow for medium concentration while Green for low concentration.

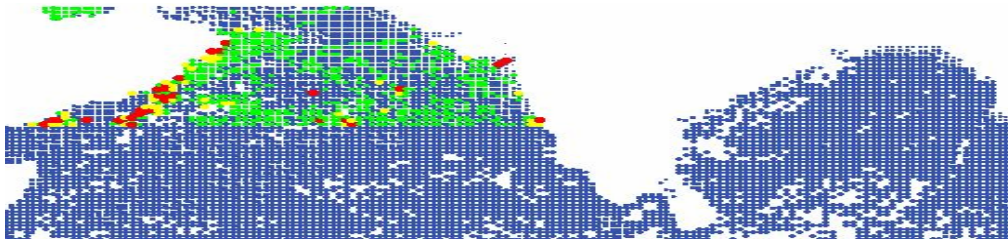


Fig.11 Chlorophyll Pigment Concentrations for the first week of **August 2004** (8-day composite). The color coding - Red pertains to high concentration, Yellow to medium concentration while Green to low concentration.

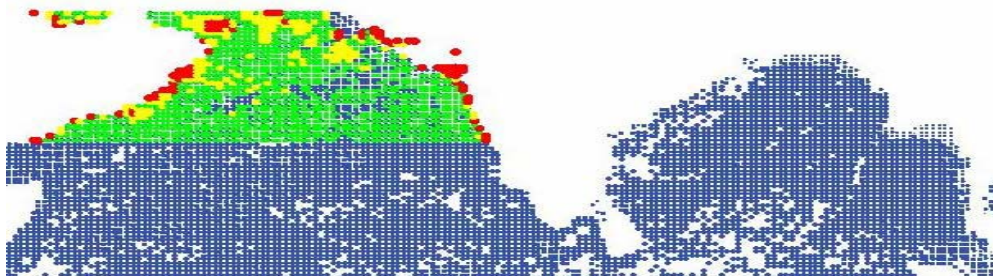


Fig.12 Chlorophyll Pigment Concentrations for the first week of **October 2004** (8-day composite). The color coding - Red pertains to high concentration, Yellow to medium concentration while Green to low concentration.

Spatial Distribution of Aerosol

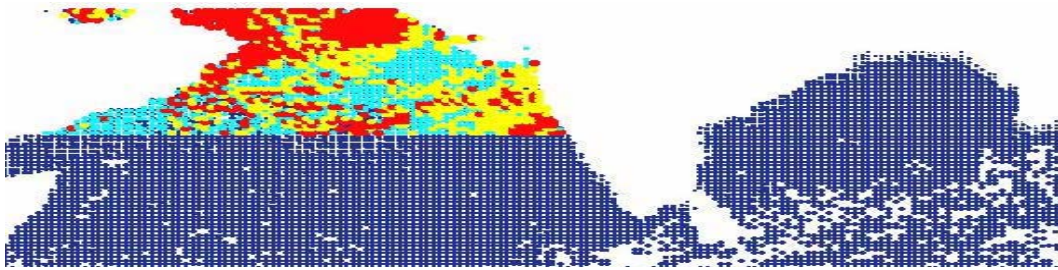


Fig.13 Spatial Distribution of Aerosol for the first week of **January 2004**. The color coding - Red pertains to high concentration, Yellow to medium concentration while Cyan to low concentration

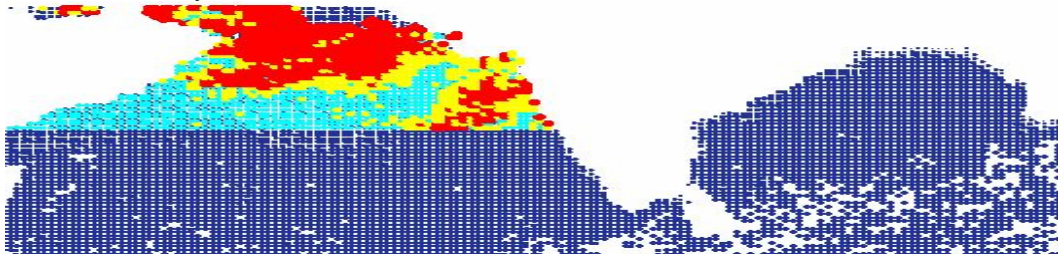


Fig.14 Spatial Distribution of Aerosol for the first week of **April 2004**. The color coding - Red pertains to high concentration, Yellow to medium concentration while Cyan to low concentration

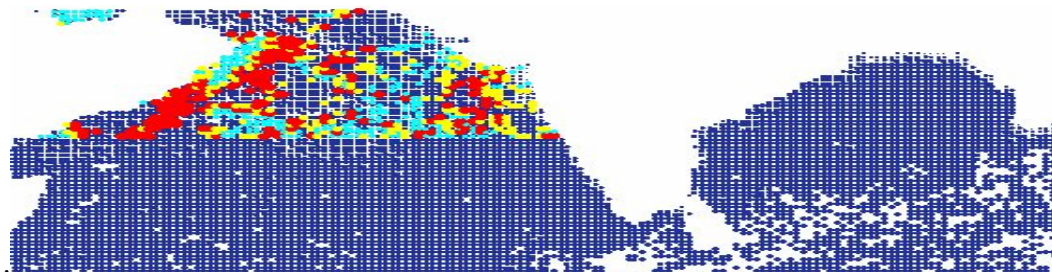


Fig.15 Spatial Distribution of Aerosol for the first week of **August 2004**. The color coding - Red pertains to high concentration, Yellow to medium concentration while Cyan to low concentration

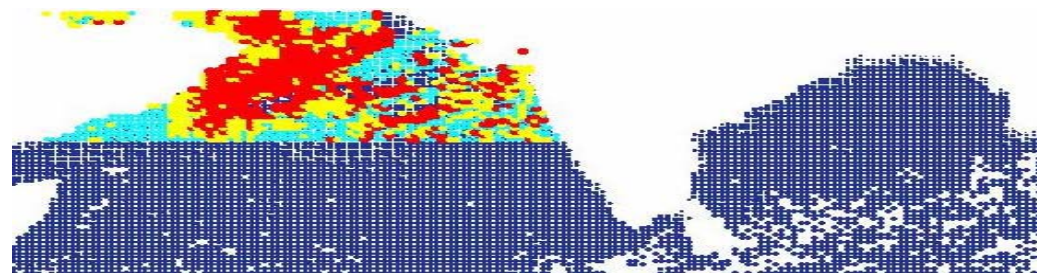


Fig.16 Spatial Distribution of Aerosol for the first week of **October 2004**. The color coding - Red pertains to high concentration, Yellow to medium concentration while Cyan to low concentration

Spatial Distribution of Diffuse Attenuation

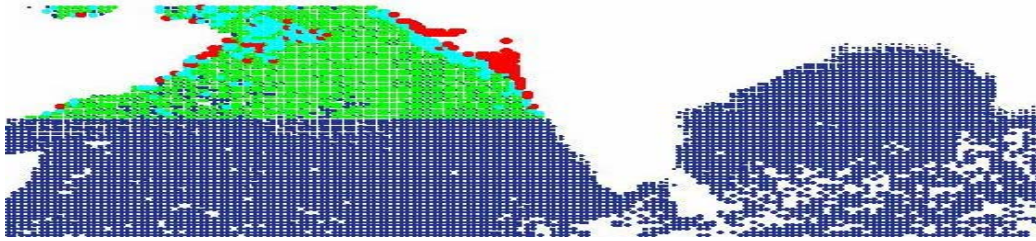


Fig.17 Spatial Distribution of Diffuse Attenuation for the first week of **January 2004**.The color coding - Red pertains to high value, Cyan to medium value while Green to low value

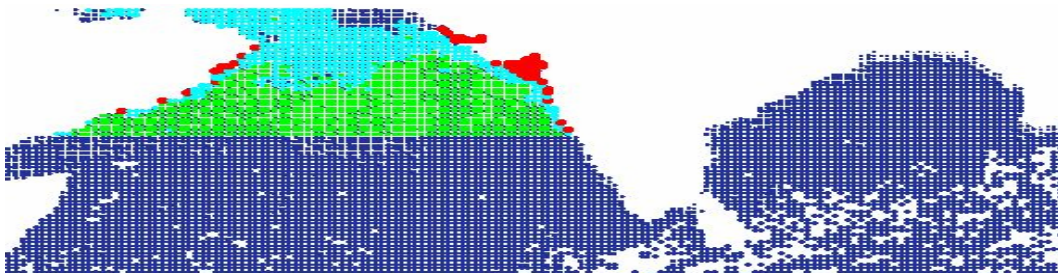


Fig.18 Spatial Distribution of Diffuse Attenuation Coefficient for the first week of **April 2004**. The color coding - Red pertains to high concentration, Cyan to medium concentration while Green to low concentration

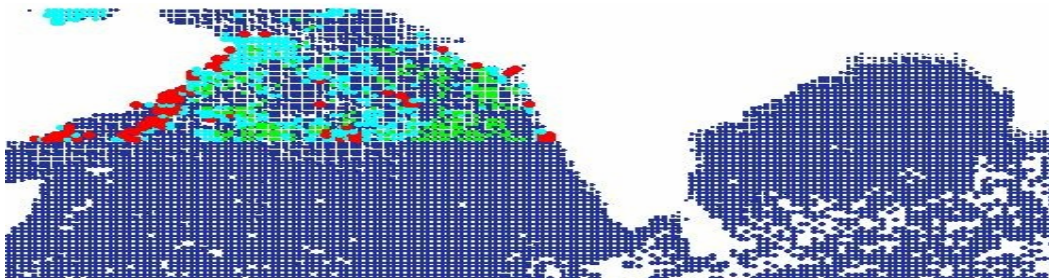


Fig.19 Spatial Distribution of Diffuse Attenuation Coefficient for the first week of **August 2004**. The color coding - Red pertains to high concentration, Cyan to medium concentration while Green to low concentration

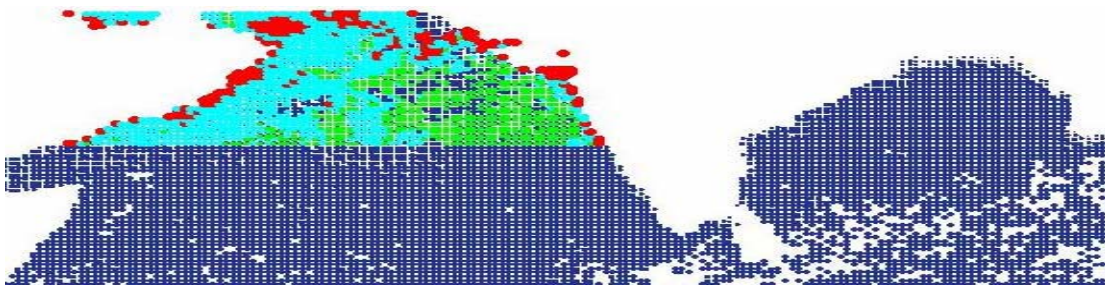


Fig.20 Spatial Distribution of Diffuse Attenuation Coefficient for the first week of **October 2004**. The color coding - Red pertains to high concentration, Cyan to medium concentration while Green to low concentration.

The spatial distribution of chlorophyll pigment concentrations, aerosol and diffuse attenuation coefficient showed pattern suggesting seasonal variability. For example, in the year 2004, the maximum chlorophyll concentration occurred during October. The range was maximum from 3.54 to 12.73, medium from 1.71 mg/m³ to 3.54 mg/m³, minimum from 0.12 mg/m³ to 1.71 mg/m³ followed by January when the range was, maximum from 3.31 to 19.95, medium ranges from 1.7 mg/m³ to 3.31 mg/m³, minimum from 0.20 mg/m³ to 1.70 mg/m³ and the least was in April which was 5.95 mg/m³ to 21.38 mg/m³. During August, due to cloud cover there were not enough data, but the available values indicate that the chlorophyll concentrations were high. Similar was the distribution pattern of aerosol as well as diffuse attenuation coefficient. This pattern could be understood in the context of prevailing atmospheric forcing over the northern Arabian Sea. Over the Arabian Sea the winds reverse semi-annually, with strong (~15m/s) southwesterly winds during summer monsoon (June-September) followed by comparatively weak (~5m/s) northeasterly winds during winter monsoon (November-February). Between the monsoons we have weak and variable winds during spring (April-May) and October when the incoming solar radiation warms the surface ocean and makes it highly stratified. During summer upwelling takes place along the Somalia as well as the Arabian coasts, which brings nutrient rich subsurface cold waters to the surface, and help fertilize the upper ocean where enough sunlight is available. The observed high chlorophyll pigment concentration during August and October is the result of this. Though October is the period of secondary heating in the Arabian Sea, in the northern Arabian Sea, the upwelled waters from Arabian upwelling system keeps this region fertile till October. During winter, the dry northeast trade winds from the continent

cools the surface waters by way of evaporative cooling as well as cooling due to net heat loss. This will initiate convective mixing and brings nutrients from deeper waters to the surface and help in fertilizing the ocean. The lowest chlorophyll pigment concentration during April is because the upper ocean is heated to its maximum during this period. This will make the ocean strongly stratified and will not allow mixing of deeper water with surface waters. So the lack of nutrients will limit the biological production during this period.

The diffuse attenuation coefficient shows almost same pattern of distribution as that of chlorophyll pigment concentrations. This is expected, as the diffuse attenuation coefficient is strongly related to the particle present in the water column. In the absence of any major river supplying sediment to the region, the chlorophyll pigment concentrations will decide the diffuse attenuation.

The aerosol showed highest concentrations during April the range was maximum from 0.23 to 0.38, medium from 0.19 to 0.23 and minimum from 0.23 to 0.38 followed by October (maximum 0.22-0.39, medium from 0.17 to 0.22 and minimum from 0.03 to 0.17), while the least occurred in August. Note that there are missing data due to cloud cover. As the spring (April) is the period of highest heating, the dry conditions are favorable for generating large amount of dust, especially from adjoining desert areas of Middle East. Once the southwest monsoon sets-in, the rain will remove atmospheric dust through precipitation and hence the amount of dust in the atmosphere will be least towards the end of summer monsoon as noticed during August.

6.2 SEASONAL OF NORTHERN ARABIAN SEA DURING 1997-2006

Year 1997

Chlorophyll: The area averaged chlorophyll pigment concentrations in the northern Arabian Sea during 1997 showed increase in concentration in the last week of August. A steep decrease in chlorophyll concentration occurred in the month of September which was $\sim 0.5 \text{ mg/m}^3$. After that there was a gradual increase in pigment concentration in the month of November, which was more than 0.5 mg/m^3 . In the month of December it again showed a decreasing trend.

Aerosol: There was an increase in concentration in the month of August. The graph showed decrease in aerosol concentration in the month of September followed by an increase in the first week of November, which was more than 0.5.

Diffuse Attenuation Coefficient: In the first week of August there was increase in the diffuse attenuation coefficient, which decreased from the last week of August till the first week of September. The value of diffuse attenuation coefficient was less than 0.08 m^{-1} in the month of September. In the month of October the graph showed slight increase in the diffuse attenuation coefficient.

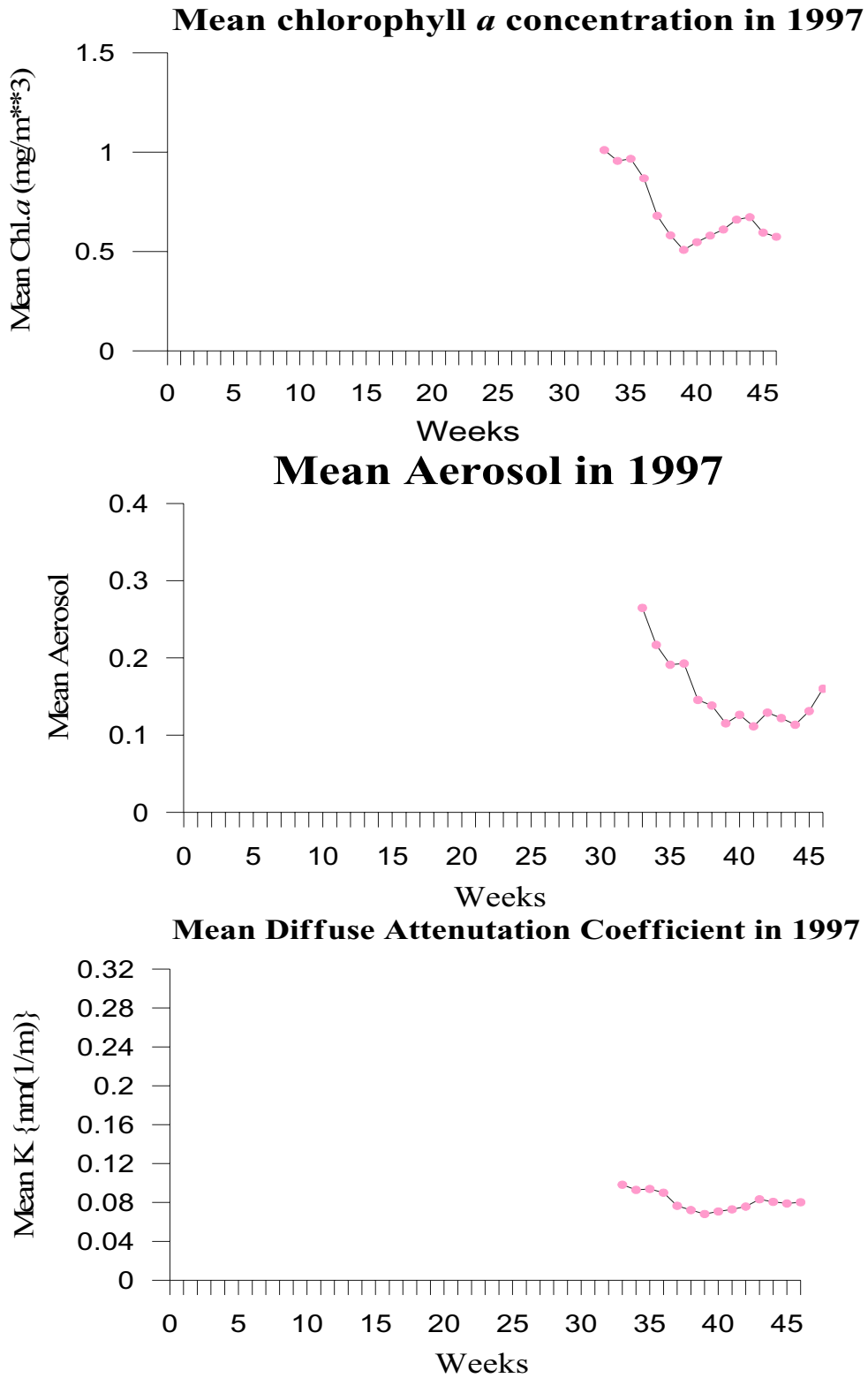


Fig.21 Time- series of 8-day mean Chlorophyll pigment concentration (top panel), Aerosol (middle panel) and Diffuse attenuation (bottom panel) for 1997.

Year 1998

Chlorophyll: The area averaged chlorophyll pigment concentrations in the northern Arabian Sea during 1998 showed a primary peak during June-July with concentrations of about 2.5 mg/m^3 followed by another small peak during January-February with concentrations less than 1.0 mg/m^3 . In the first week of August, the graph showed a small increase in the chlorophyll pigment concentration. From the month of September there was a decrease in the concentration. In the month of October the chlorophyll concentration showed a decrease and then gradual increase in the first week of November. In the month of February and March there was decrease in the concentration, followed by an increase from the first week of May.

Aerosol: The month of January has got a very low level of aerosol concentration less than 0.02. From the week of April there was an increase in aerosol concentration near about 0.03 followed by a decrease in the month of June. In the month of July the graph showed an increase and then decrease from the last week of July. The month of August showed a decreasing trend from 0.3 to 0.1.

Diffuse Attenuation Coefficient: In the month of June, diffuse attenuation coefficient showed a peak with concentration of about 0.18 m^{-1} during the year 1998. Then there was a decrease in it. The graph showed a small increase in the value of diffuse attenuation coefficient in the month of July, which was more than 0.12 m^{-1} followed by decrease in the last week of September.

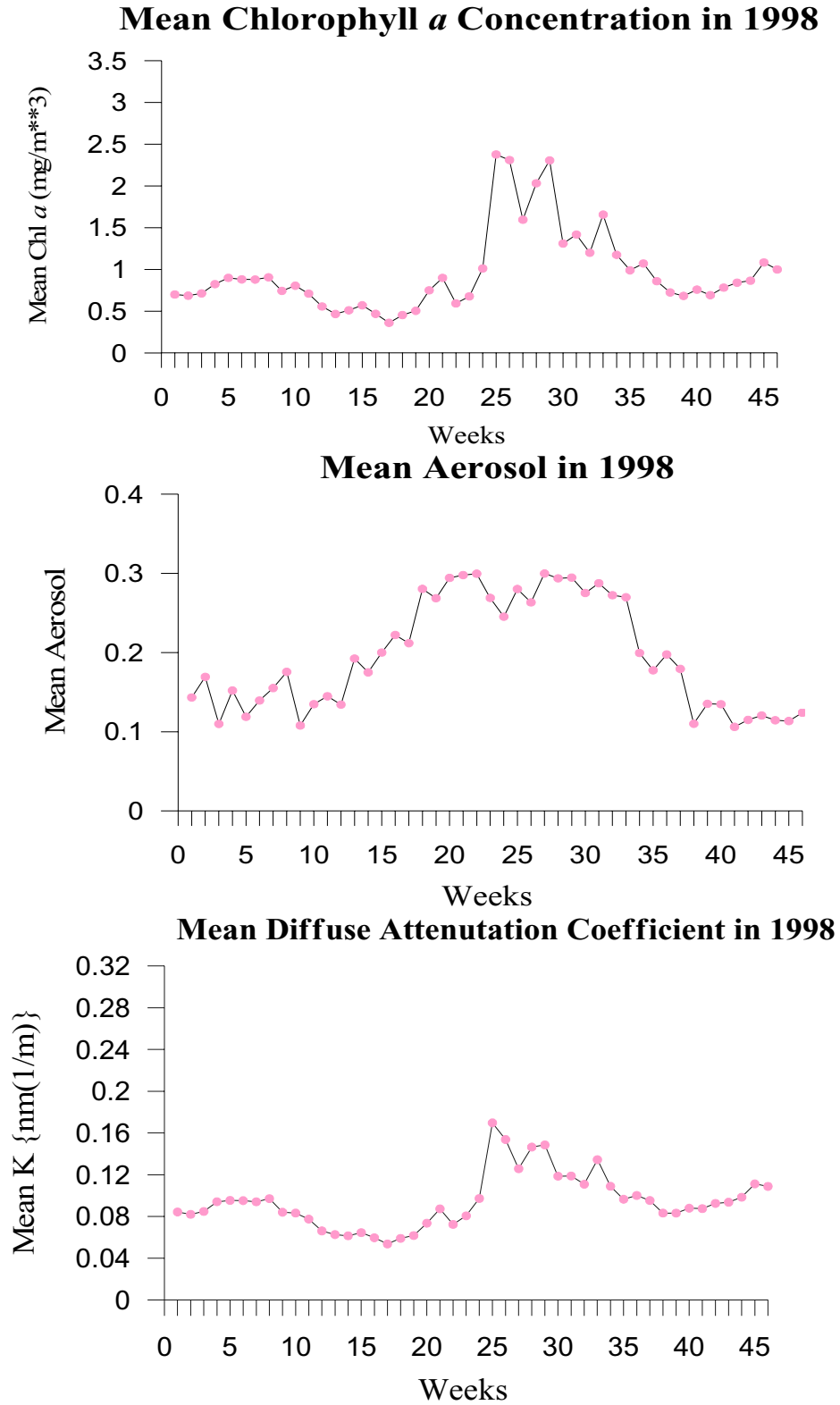


Fig.22 Time- series of 8-day mean Chlorophyll pigment concentration (top panel), Aerosol (middle panel) and Diffuse attenuation (bottom panel) for 1998.

From the first week of October there was an increase in diffuse attenuation coefficient. During December it started increasing at the rate of more than 0.12 m^{-1} attaining a secondary maximum in February, and thereafter showed a decreasing trend. In the month of April the concentration was about 0.06 m^{-1} . From the first week of May the graph showed an increase in trend of the diffuse attenuation coefficient.

Year 1999

Chlorophyll: The area averaged chlorophyll pigment concentrations in the northern Arabian Sea during 1999 showed two peaks in the month of June and July with a concentration of about 3.4 mg/m^3 and 3.5 mg/m^3 respectively. There was a steep decrease in chlorophyll concentration in the month of August. In the month of September the pigment concentration was less than 1 mg/m^3 . In the first week of October, there was slight increase in the concentration level, which decreased in the month of December. As the month of January approached the concentration increased to about 1.5 mg/m^3 . There was gradual decrease in the concentration from the first week of February to the last week of March. In the first week of May the graph showed an increase in the pigment concentration of more than 2.0 mg/m^3 . From the last week of May the concentration started decreasing. The chlorophyll pigment was $\sim 2.2 \text{ mg/m}^3$ in the month of June, which showed a small increase in the concentration.

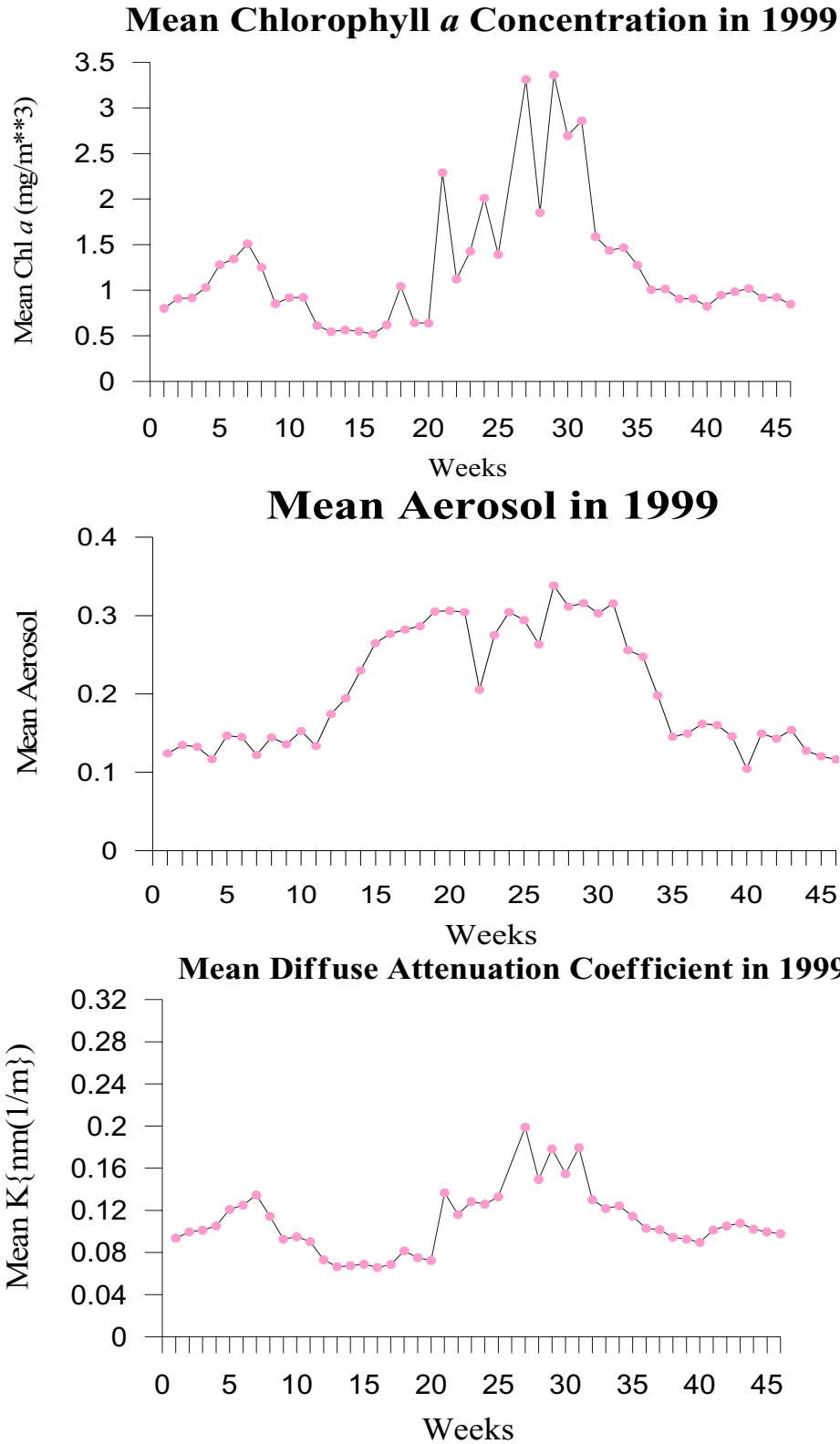


Fig.23 Time- series of 8-day mean Chlorophyll pigment concentration (top panel), Aerosol (middle panel) and Diffuse attenuation (bottom panel) for 1999.

Aerosol: There was a decrease in the aerosol concentration from January to February. But from the last week of February there was rapid increase in the aerosol concentration about 0.3 in the month of May. Then there was steep decrease in the month of June. The aerosols concentration level was more in the month of July i.e. more than 0.4. from the month of August there was steep decrease in aerosol concentration till the month of November.

Diffuse Attenuation Coefficient: In the month of December there was decrease in the diffuse attenuation coefficient. As the month of January approaches there was an increase in the value of diffuse attenuation, which was more than 0.12 m^{-1} . From the month of February this value started decreasing till the last week of April, followed by an increase in the first week of April. In the first week of June there was decrease in the diffuse attenuation coefficient. But in the last week of June there was increase in the value of diffuse attenuation coefficient, which was 0.2 m^{-1} . The graph showed the decrease in diffuse attenuation from the first week of August to the last week of September, followed by the increase in the month of October.

Year 2000

Chlorophyll: From the first week of November the chlorophyll pigment concentration increased, but from the second week of November the concentration level decreased till the end of November. From the last week of January the chlorophyll pigment concentration increased with a peak concentration of about 1.8 mg/m^3 in the month of February. As the month of

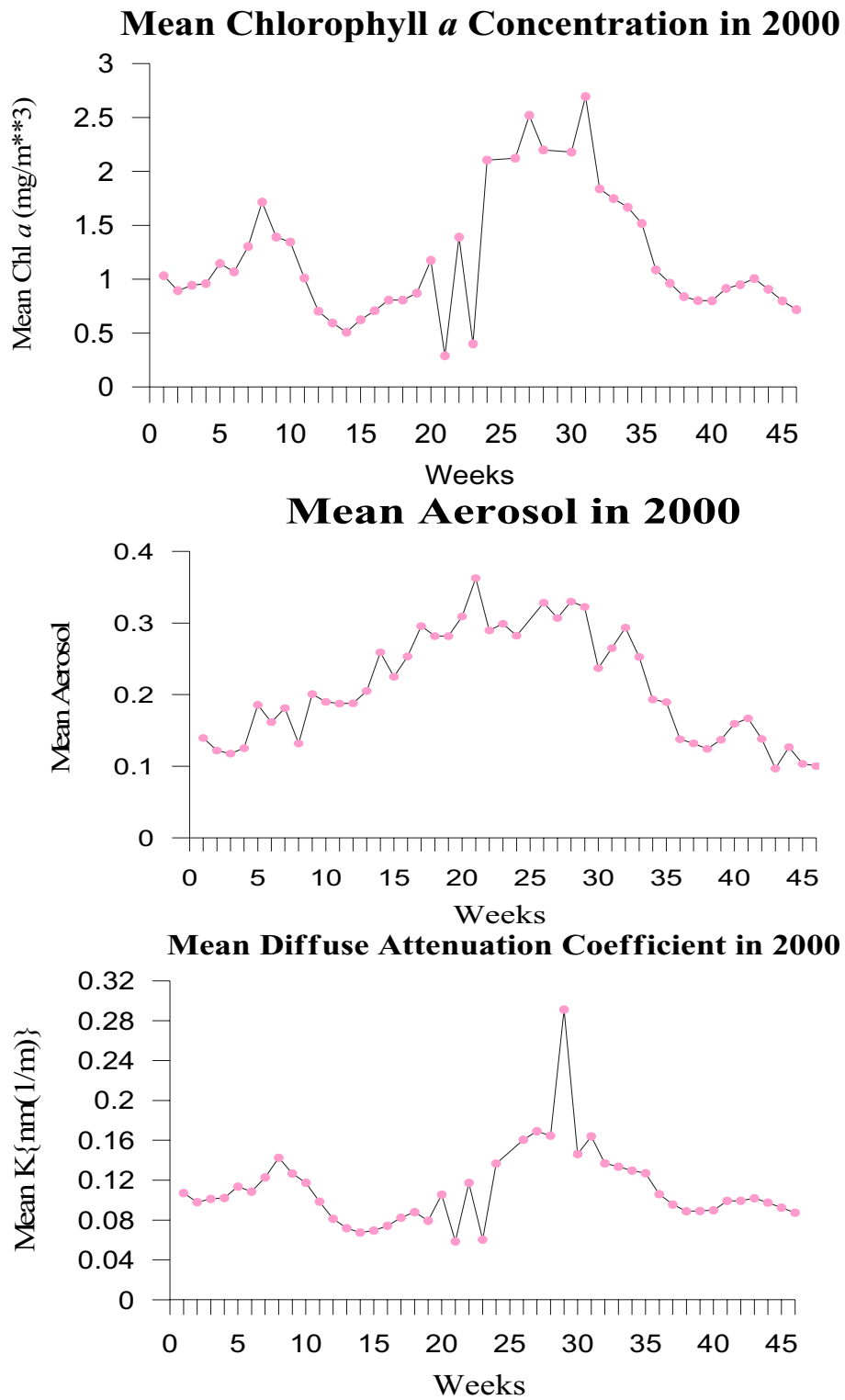


Fig.24 Time- series of 8-day mean Chlorophyll pigment concentration (top panel), Aerosol (middle panel) and Diffuse attenuation (bottom panel) for 2000.

March reaches there was a decrease in the pigment concentration followed by the increase in the month of April. A steep decrease in chlorophyll concentration was noticed in the month of May, which was less than 0.5 mg/m^3 . In the month of July and August there was an increase in chlorophyll pigment with concentration of about 2.7 mg/m^3 and 2.8 mg/m^3 respectively. Chlorophyll pigment concentration decreases from the month of September to October.

Aerosol: The month of January showed very low level of aerosol concentration, less than 0.1. From this month onwards the aerosol, concentration increased up to 0.3 in the month of May. There after till August, the graph showed an increase followed by a decrease in aerosol concentration. The month of August showed decrease in aerosol from 0.3 to 0.1 towards the last week.

Diffuse Attenuation coefficient: From the first week of October there was increase in the diffuse attenuation coefficient followed by a decrease in the month of December. In the month of January the attenuation coefficient showed an increasing trend with a small peak in the month of February and the value of diffuse attenuation was more than 0.12 m^{-1} . From the month of March to June the graph showed increase followed by decrease in diffuse attenuation coefficient. There was a primary peak of diffuse attenuation coefficient in the First week of July, which showed the value of more than 0.28 m^{-1} . From the month of August the attenuation value decreased till the last week of September.

Year 2001

Chlorophyll: From the first week of February there was an increase in chlorophyll concentration ($\sim 1.6 \text{ mg/m}^3$). In the month of March the chlorophyll concentration decreased and the value reached to less than 0.5 mg/m^3 in the month of April. From the first week of May there was gradual increase in the chlorophyll concentration. With the arrival of summer, in the month of June, the chlorophyll level increased, followed by a decrease in the last week of June. From the last week of July and first week of August the chlorophyll level reached to highest peak ($\sim 2.6 \text{ mg/m}^3$) followed by a decrease in the last week of August.

In the first week of October, the graph showed an increase in pigment concentration. The chlorophyll concentration showed a decrease in the month of December.

Aerosol: From the first week of January the aerosol concentration increased from 0.1 to 0.3 till the last week of April. There after it showed a decrease till last week of May. From the month of June the aerosol level again increased followed by the decrease in the last week of July. There was a gradual decrease in aerosol concentration from 0.3 in the month of August to 0.1 in the month of December.

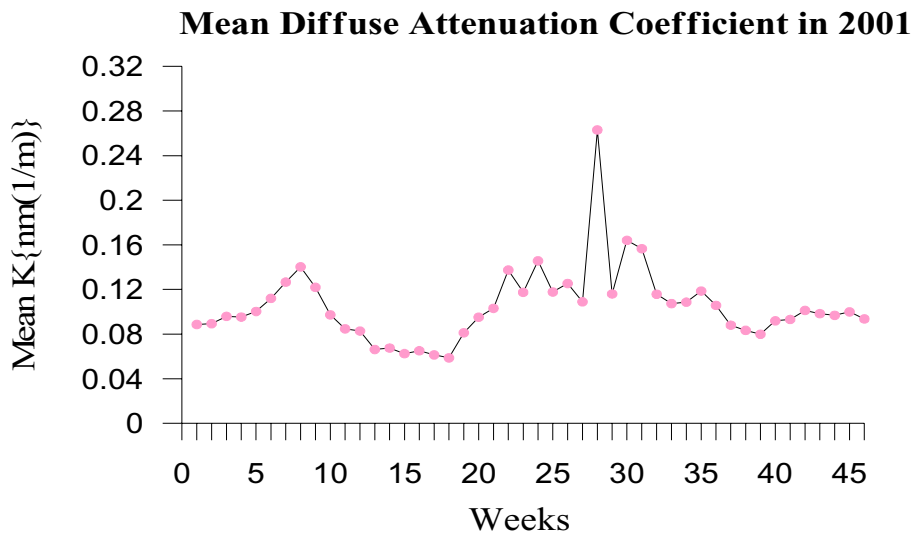
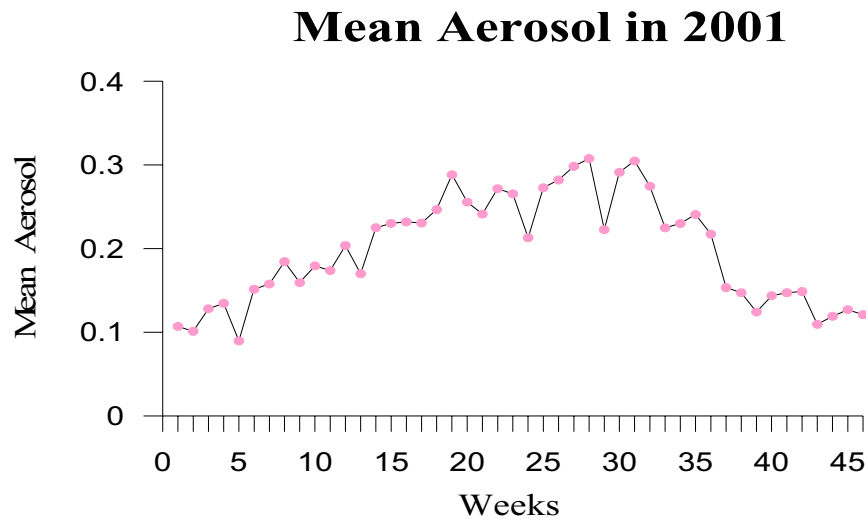
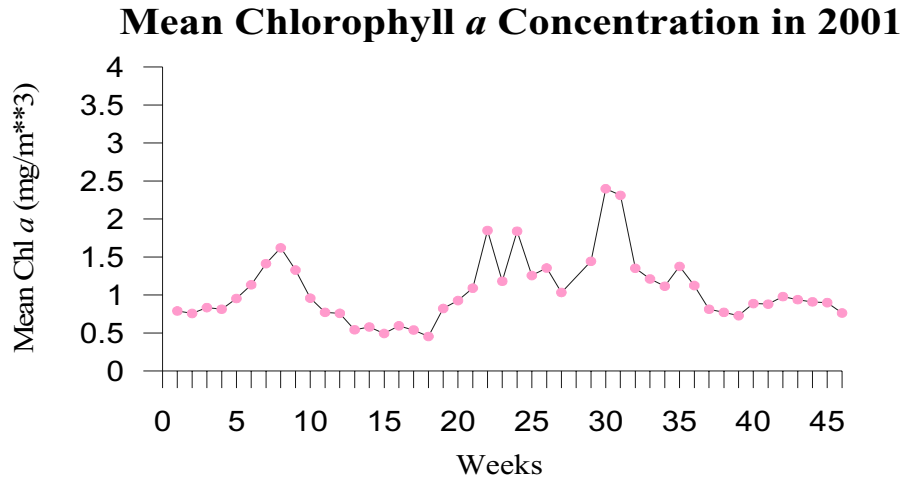


Fig.25 Time-series of 8-day mean Chlorophyll pigment concentration (top panel), Aerosol (middle panel) and Diffuse attenuation (bottom panel) for 2001.

Diffuse Attenuation Coefficient: From the first week of January there was an increase in the diffuse attenuation coefficient. There was a small peak in the month of February, with a value of more than 0.12 m^{-1} . From the last week of February the graph showed decrease in the diffuse attenuation coefficient, which reached to less than 0.08 m^{-1} in the week of April. In month of May there was again an increase in the diffuse attenuation coefficient followed by a decrease in the month of June. The graph showed the highest peak in the first week of July and decrease in the month of August. From August to December diffuse attenuation coefficient did not vary significantly.

Year 2002

Chlorophyll: The chlorophyll pigment concentration increased from less than 1.0 mg/m^3 in January to about 1.4 mg/m^3 in February, followed by a decrease to less than 0.3 mg/m^3 in the month of April. From April to August, the chlorophyll pigment concentration showed an overall increase passing through cycles of increase and decrease to attain a value of more than 2.0 mg/m^3 . From August to October, the pigment concentration showed a steep decrease to about 0.7 mg/m^3 , which was maintained till December.

Aerosol: From the first week of January there was an increase in aerosol concentration to more than 0.1 but in the last week of January this concentration went on decreasing. As the month of February approaches the

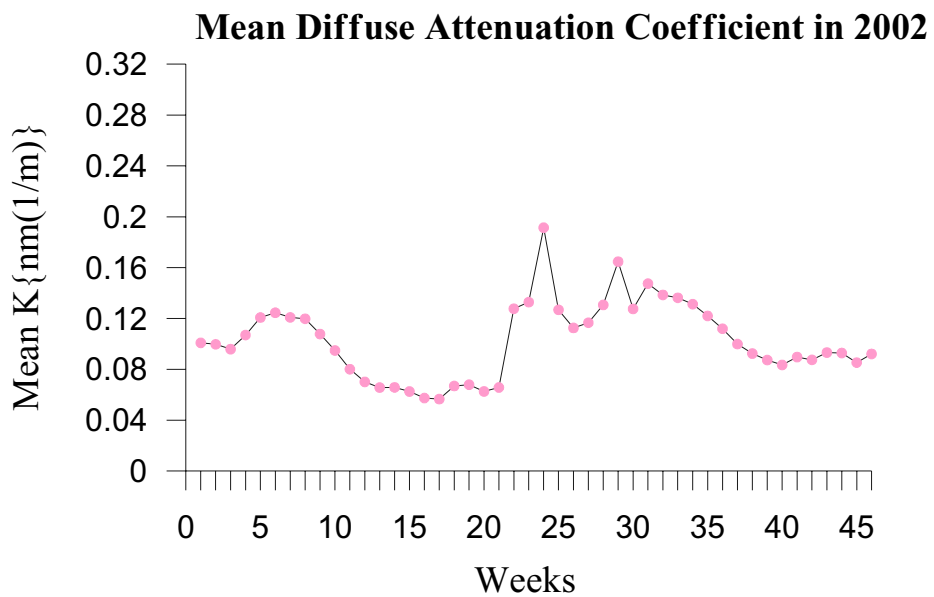
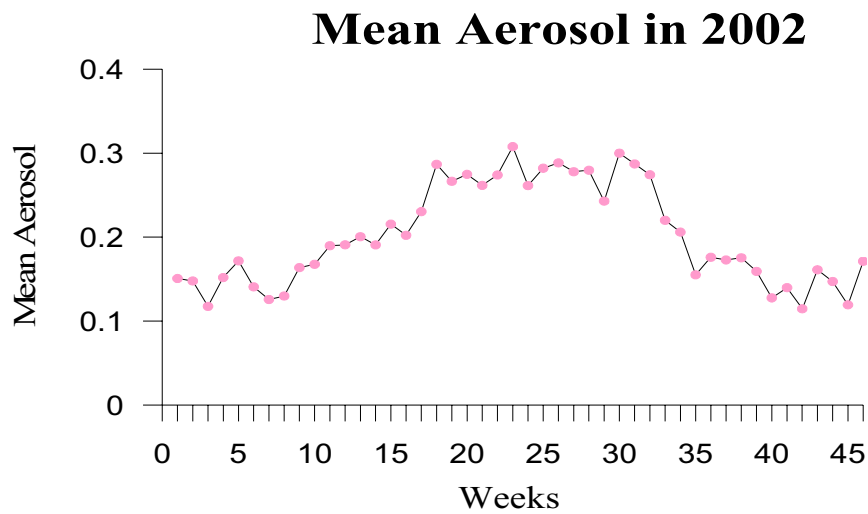
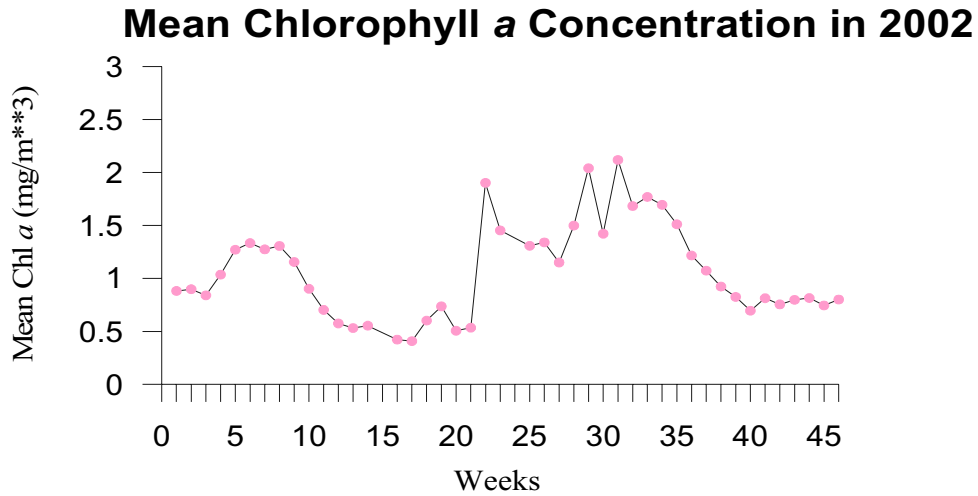


Fig.26 Time- series of 8-day mean Chlorophyll pigment concentration (top panel), Aerosol (middle panel) and Diffuse attenuation

(bottom panel) for 2002.

Concentration gradually increased. The aerosol concentration reached to 0.3 in the month of June. Again there was decrease in aerosol concentration in the month of June.. The aerosol concentration once again increased in the month of July followed by the decrease form the first week of August. This decrease was accompanied by cycles of ups and downs in the aerosol concentration.

Diffuse Attenuation Coefficient: The graph showed an increase in diffuse attenuation coefficient in the month of January and February. But from the last week of February to April there was decrease in the attenuation coefficient value i.e. less than 0.08 m^{-1} . From the first week of May there was steep increase in the value of diffuse attenuation coefficient. The value of diffuse attenuation coefficient reached to more than 0.2 m^{-1} in the first week of June followed by a decrease in the last month of June. From June to August the diffuse attenuation coefficient passes through a cycle of increase and decrease, and from August to December it showed a steady decrease.

Year 2003

Chlorophyll: From the first week of January to the mid week of February the chlorophyll level increased to 2.0 mg/m^3 . There was sharp decrease in pigment concentration in the month of March. As the month of May approached, the concentration reached to a peak ($\sim 3 \text{ mg/m}^3$). In the month of June the concentration level decreased to less than 1.0 mg/m^3 . By the last

week of July and first week of August, the concentration increased to more than 2.0 mg/m^3 . From the month of September, the chlorophyll concentration decreased. There was slight increase in concentration in the month of October ($\sim 1.0 \text{ mg/m}^3$) followed by a decreased in the month of December.

Aerosol: The concentration of aerosol in January was less than 0.2. From this month onwards the aerosol concentration increased up to more than 0.3 in the month of August. After that there was a steep decrease in the aerosol concentration up to the last week of October, followed by the slight increase in the month of December.

Diffuse Attenuation Coefficient: In the month of January and February there was increase in the diffuse attenuation coefficient, which was more than 0.12 m^{-1} . But the value of diffuse attenuation coefficient decreased from the last week of February to April. In the month of May there was increase in the value of diffuse attenuation coefficient to more than 0.16 m^{-1} followed by a decrease in the month of June. As the month of July reached diffuse attenuation coefficient level increased. The month of November and December showed the decrease in diffuse attenuation level.

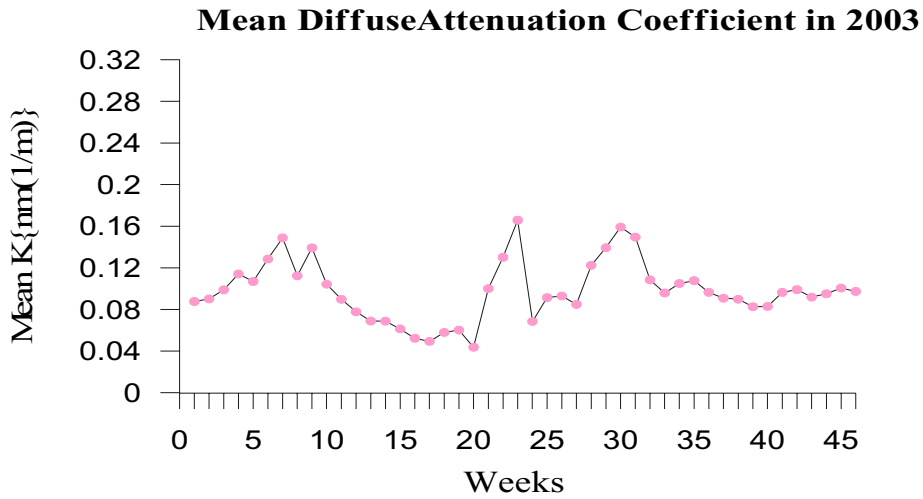
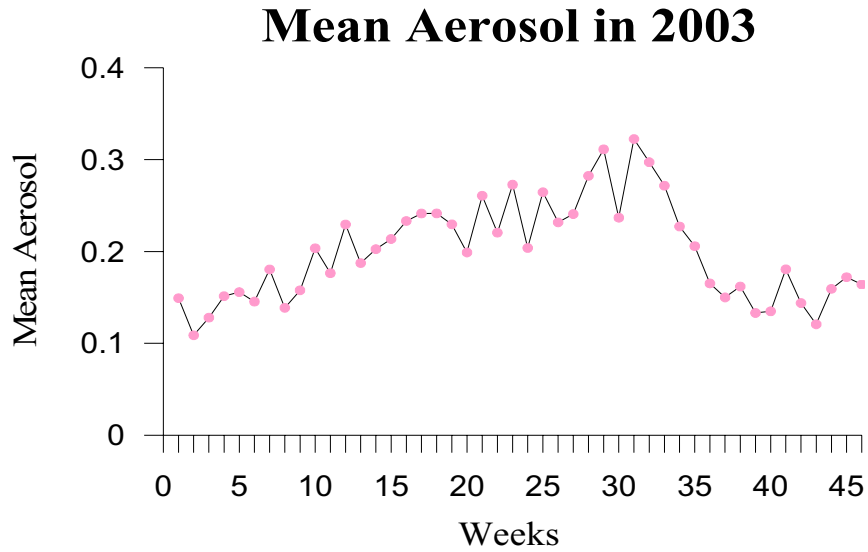
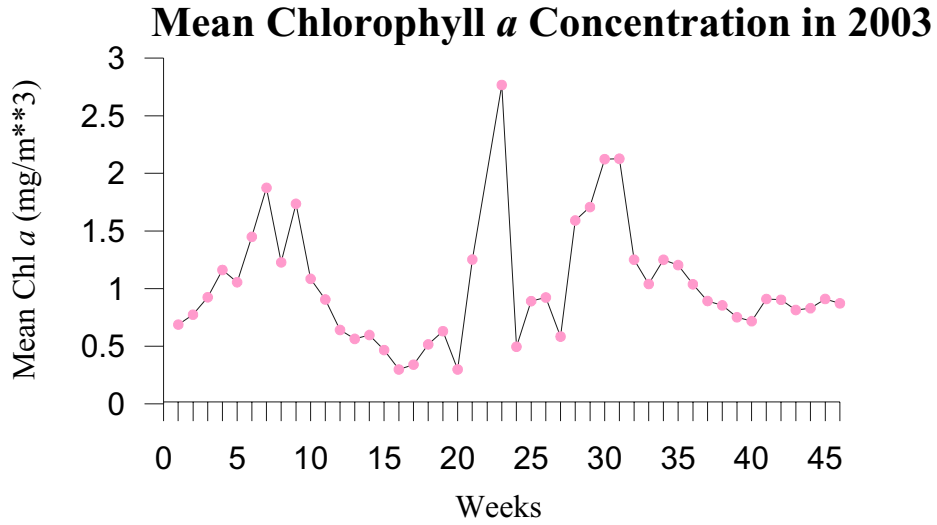


Fig.27 Time- series of 8-day mean Chlorophyll pigment concentration (top panel), Aerosol (middle panel) and Diffuse attenuation (bottom panel) for 2003.

Year 2004

Chlorophyll: With the arrival of summer, in the month of May, the chlorophyll concentration levels increased rapidly ($\sim 2.8 \text{ mg/m}^3$) but in the last week of May the pigment concentration decreased. In June there was again an increase in chlorophyll pigment concentration and the value reaches to 2.5 mg/m^3 . The concentration decreased in the last week of June and increased gradually from the first week of July. The chlorophyll pigment concentration in the month of July was 3.0 mg/m^3 which showed a gradual decrease from the month of August to September. In January there was slight increase in the chlorophyll concentration level, which decreased from the last week of February to the month of April.

Aerosol: The month of January showed very low level of aerosol concentration i.e. less than 0.1. From this month onward the aerosol concentration increased to 0.3 in the month of May. There was an increase in aerosol concentration in the month of July to than 0.3 followed by the decrease from the month of August.

Diffuse Attenuation Coefficient: In January diffuse attenuation coefficient increased but from the last week of February there was decrease in the attenuation level. As the month of May reached the attenuation level increased to 0.16 m^{-1} . The graph showed lot of variation and ups and down in the level of diffuse attenuation coefficient in the month of June and July. From the last week of August there was decrease in diffuse attenuation coefficient. Diffuse attenuation level showed slight increase in the month of October followed by the decrease in the month of December.

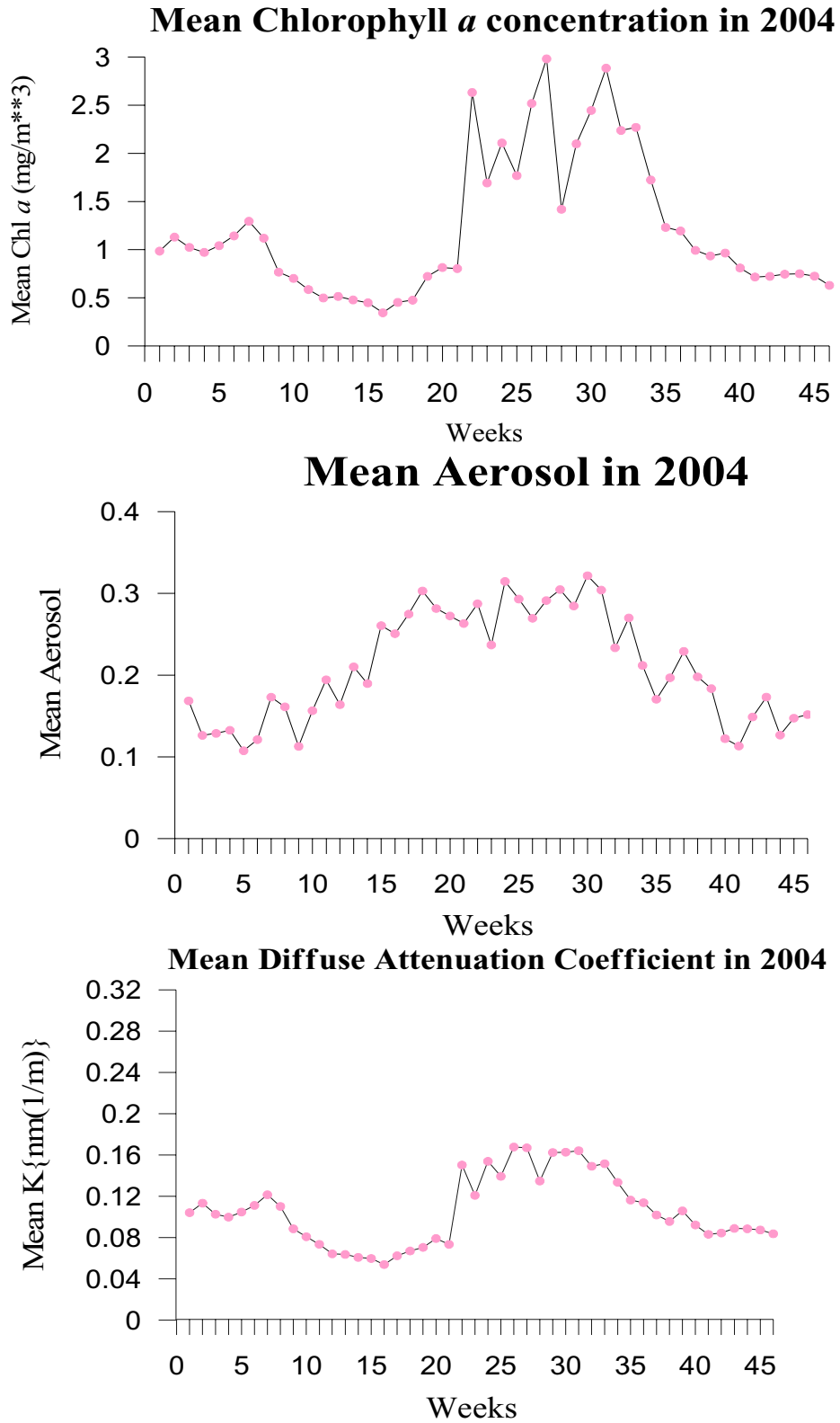


Fig.28 Time- series of 8-day mean Chlorophyll pigment concentration (top panel), Aerosol (middle panel) and Diffuse attenuation (bottom panel) for 2004.

Year 2005

Chlorophyll: The chlorophyll pigment concentration showed an increasing trend from the week of October. In the month of February the level of chlorophyll concentration approached a value of 1.5 mg/m^3 . From the last week of February the concentration level decreased till the month of April. In the month of June the chlorophyll concentration reached the peak value of $\sim 3.0 \text{ mg/m}^3$. A secondary peak was observed in the first week of August with chlorophyll concentration of $\sim 2.6 \text{ mg/m}^3$. But from the last week of August pigment concentration had been seen decreasing till the month of September

Aerosol: The area averaged aerosol concentrations in the northern Arabian Sea during 2005 showed a primary peak during June-July with concentrations of about 0.3 followed by many small peaks during January-February with concentrations less than 0.2. From the last week of July there was gradually decrease in the aerosol concentration up to the last week of November.

Diffuse Attenuation coefficient: The graph showed the increase in the diffuse attenuation coefficient from the first week of January followed by a decrease in the month of February and March. There was a certain increase in the level of diffuse attenuation i.e. more than 0.12 m^{-1} in the month of June followed by the decrease in value from the last week of August to the month of September. Once again there was an increase in the diffuse attenuation in the first week of October.

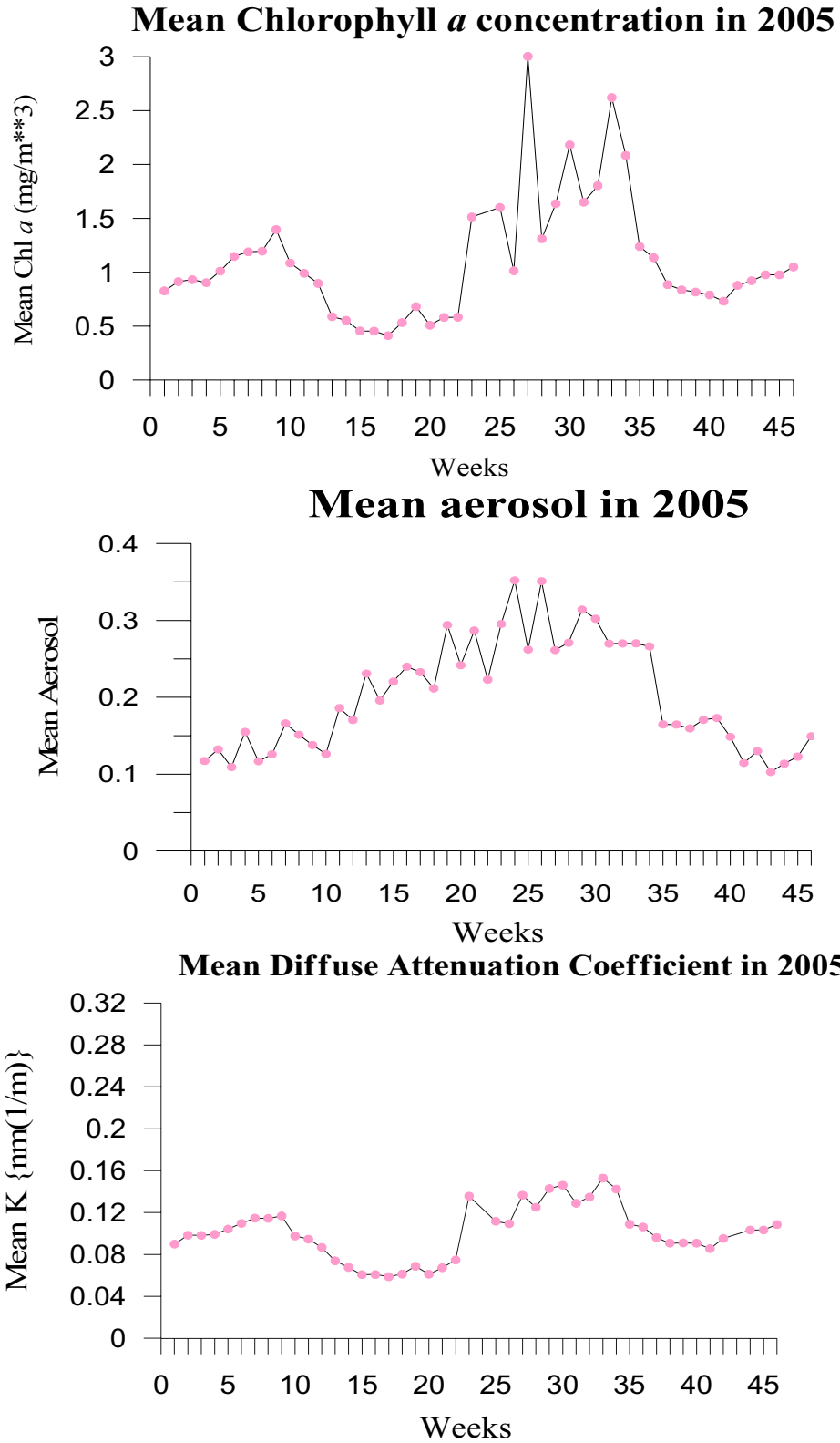


Fig.29 Time- series of 8-day mean Chlorophyll pigment concentration (top panel), Aerosol (middle panel) and Diffuse attenuation (bottom panel) for 2005.

Year 2006

Chlorophyll: In the month of January there was slight increase in the chlorophyll concentration to more than 1.5 mg/m^3 . Then the graph showed a rapid decrease in chlorophyll pigment concentration from the last week of February. In the month of June the chlorophyll concentration level increased and reached its highest peak ($\sim 2.7 \text{ mg/m}^3$) in the first week of July followed by the decrease in the last month of July. As the month of August reached, there was an increase in the chlorophyll concentration, which decreases, in the last week of August. A secondary peak in the chlorophyll pigment concentration was seen in August with a value of $\sim 2.6 \text{ mg/m}^3$.

Aerosol: There was increase in aerosol concentration in the month of January followed by the decrease in the month of February. After that there was an increase in aerosol till May. But from the last week of May it decreased once again. In the month of July the aerosol concentration reached its highest peak of more than 0.3, followed by a decrease in concentration in the month of December.

Diffuse Attenuation Coefficient: From the month of January the value of diffuse attenuation coefficient increased followed by the decrease in the month of February and March. In the month of May there was again an increase in the diffuse attenuation coefficient level. The graph showed the highest value of diffuse attenuation coefficient i.e. more than 0.16 m^{-1} in the month of July, followed by the decrease in the last week of July. Again there was another increase in the diffuse attenuation level in the month of August.

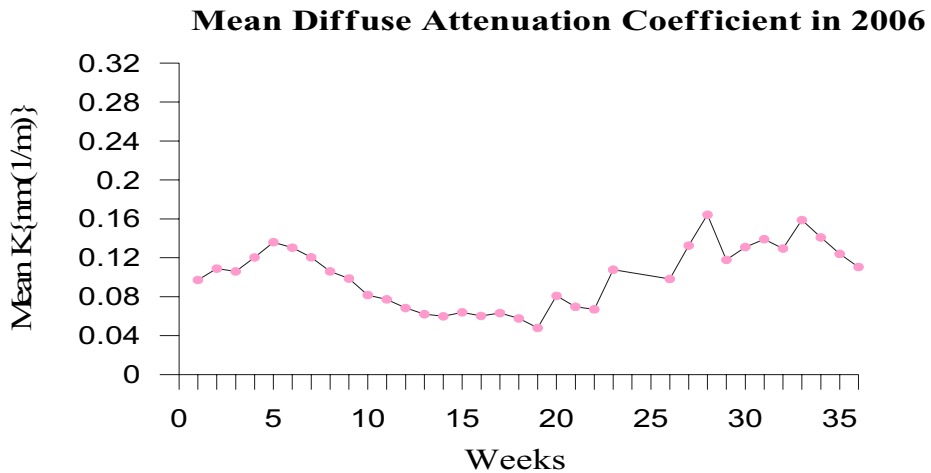
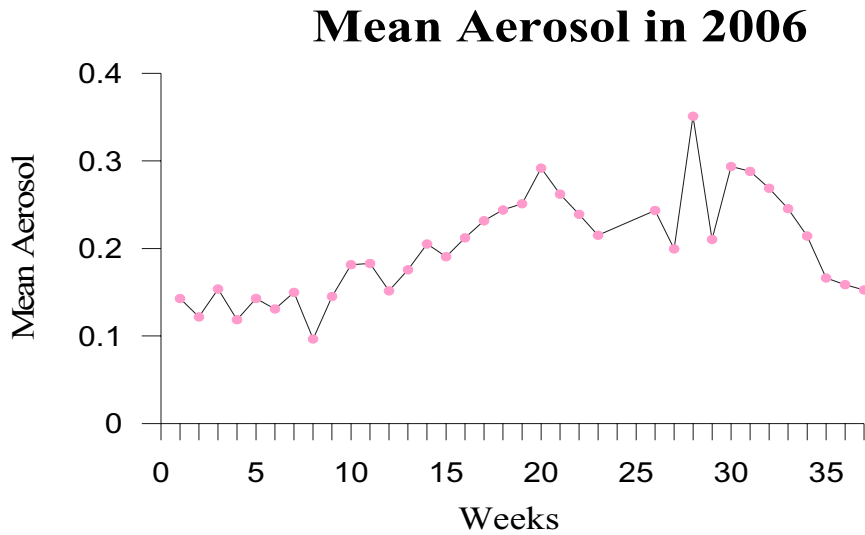
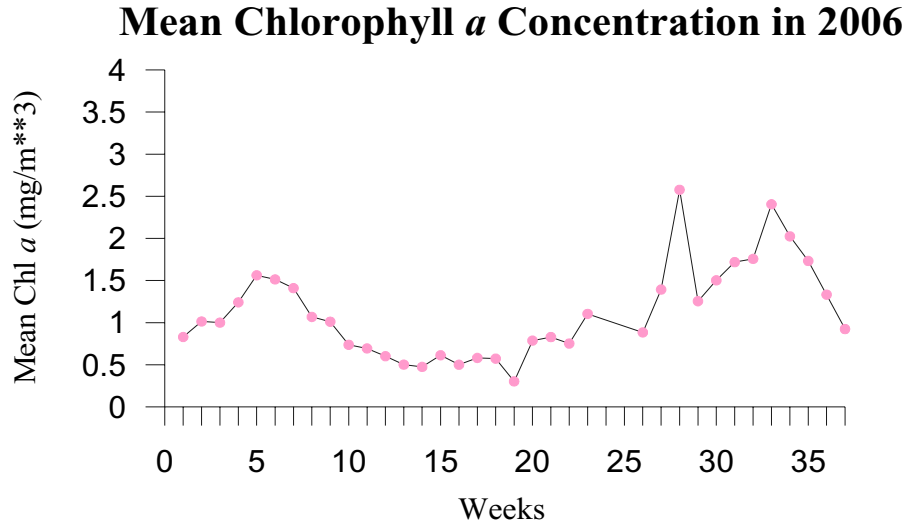


Fig.30 Time-series of 8-day mean Chlorophyll pigment concentration (top panel), Aerosol (middle panel) and Diffuse attenuation (bottom panel) for 2006.

6.3 RELATIONSHIP OF CHLOROPHYLL PIGMENT CONCENTRATION WITH AEROSOL AND DIFFUSE ATTENUATION COEFFICIENT

Having analyzed the seasonal variability of chlorophyll pigment concentration, aerosol and diffuse attenuation coefficient for 10 years from 1997 to 2006, it is important to find out if there exists any relationship between these 3 parameters obtained from satellite remote sensing. For this all the 10-year data on the above parameters was subjected to correlation

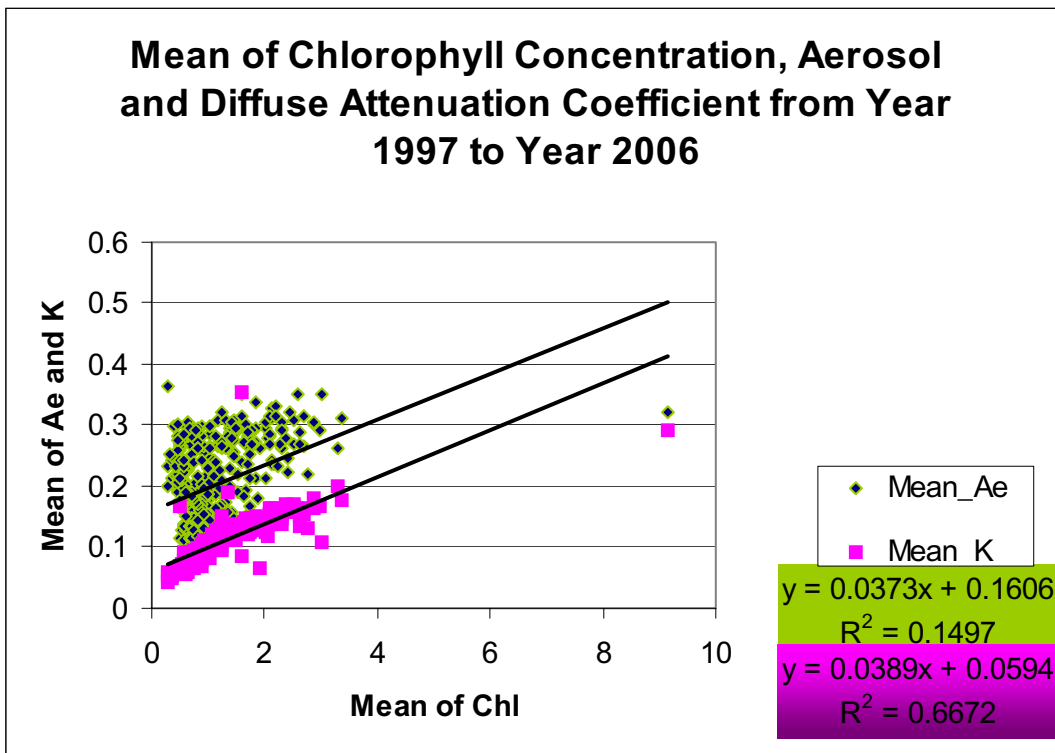


Fig.31 Correlation between 8-day mean Chlorophyll pigment concentrations and Aerosol (Green), and Chlorophyll pigment concentrations and Diffuse attenuation (Magenta) during 1997-2006.

showed better correlation with diffuse attenuation coefficient than with aerosol. This is because the diffuse attenuation coefficient, which is also known as inverse Secchi depth, is a measure of the turbidity of water. In the absence of any major sediment input through river system, the turbidity of water depends on the suspended matter present in the water column and in the open ocean region it is primarily due to the chlorophyll. This is the reason for high correlation between chlorophyll pigment concentrations with diffuse attenuation coefficient in the northern Arabian Sea, which is a typical open ocean regime with no major river input of sedimentary material. However, the weak relationship between chlorophyll pigment concentration and aerosol is because the aerosol in the atmosphere is controlled by several factors such as dust input, change in the land use pattern associated with deforestation, agriculture, human settlement and urbanization. The aerosol in the air over the Arabian Sea shows strong seasonality, as shown in the previous section. Though the aerosol could potentially influence the chlorophyll concentration by altering the sunlight reaching at the ocean surface, Arabian Sea being in the tropical region sunlight, usually is not a constrain for phytoplankton growth, except during intense clouding associated with summer monsoon which lasts only for few days at a time. Having analyzed the relationship between chlorophyll

Pigment concentration, aerosol and diffuse attenuation coefficient for 10 years, it is also important to see if the relationship shows any year-to-year change. This is presented in figures 32 to 36.

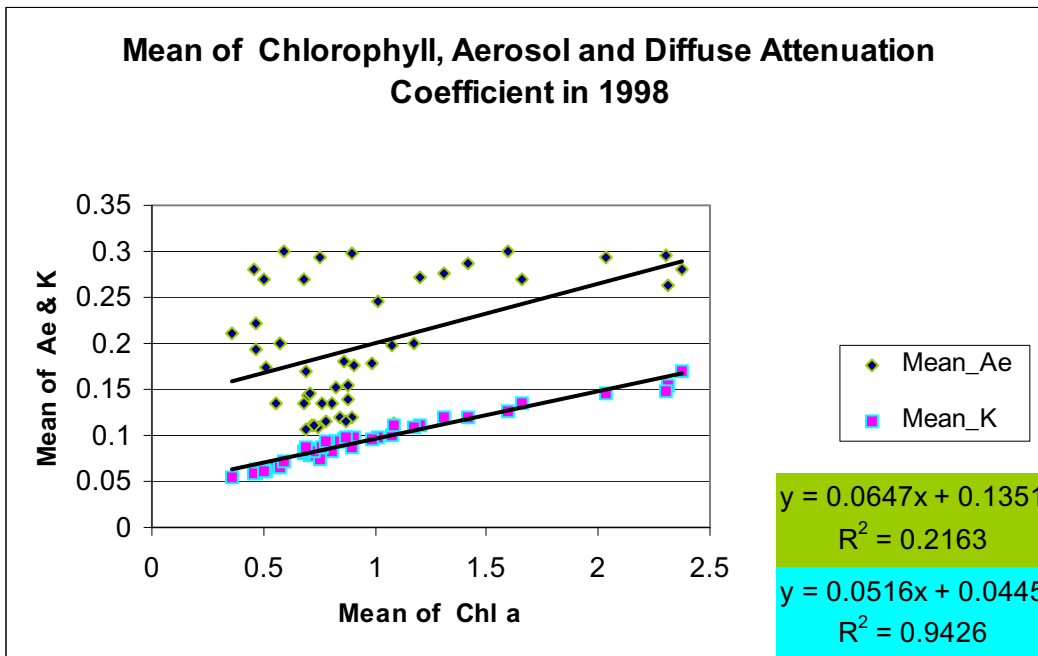
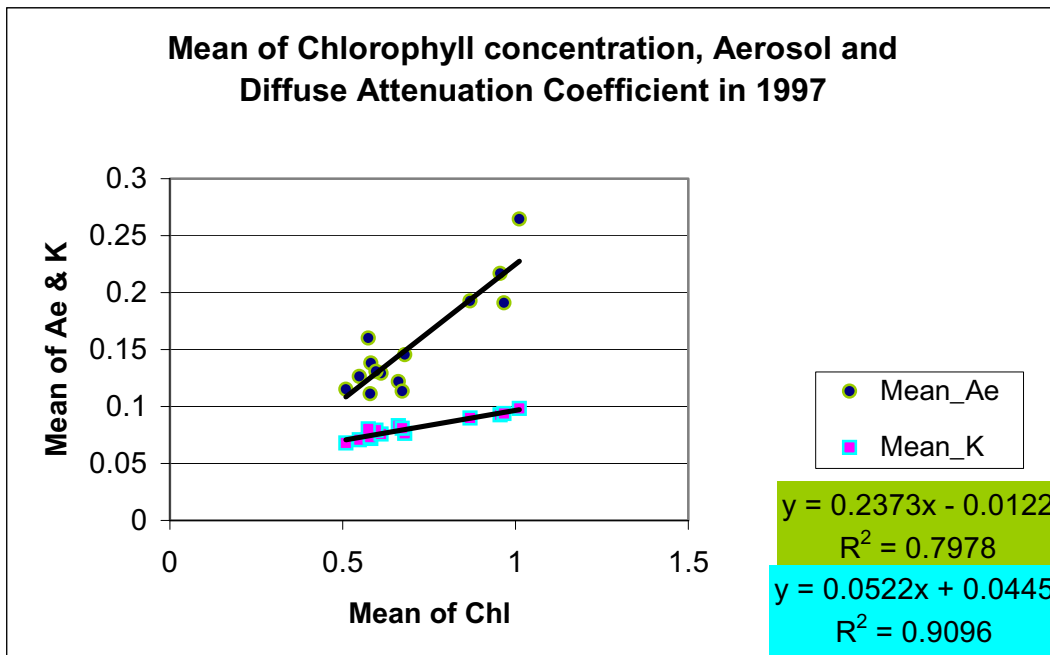


Fig. 32 Relationship of Chlorophyll Concentration (chl) with Aerosol (Ae) And Diffuse Attenuation Coefficient (K) in year **1997** and **1998**.

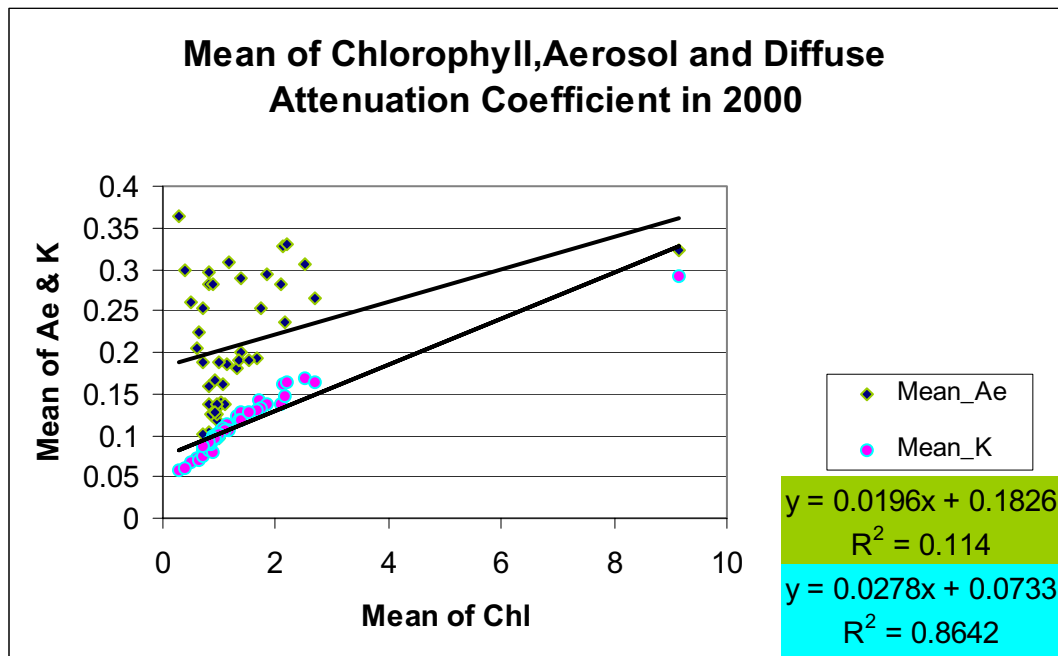
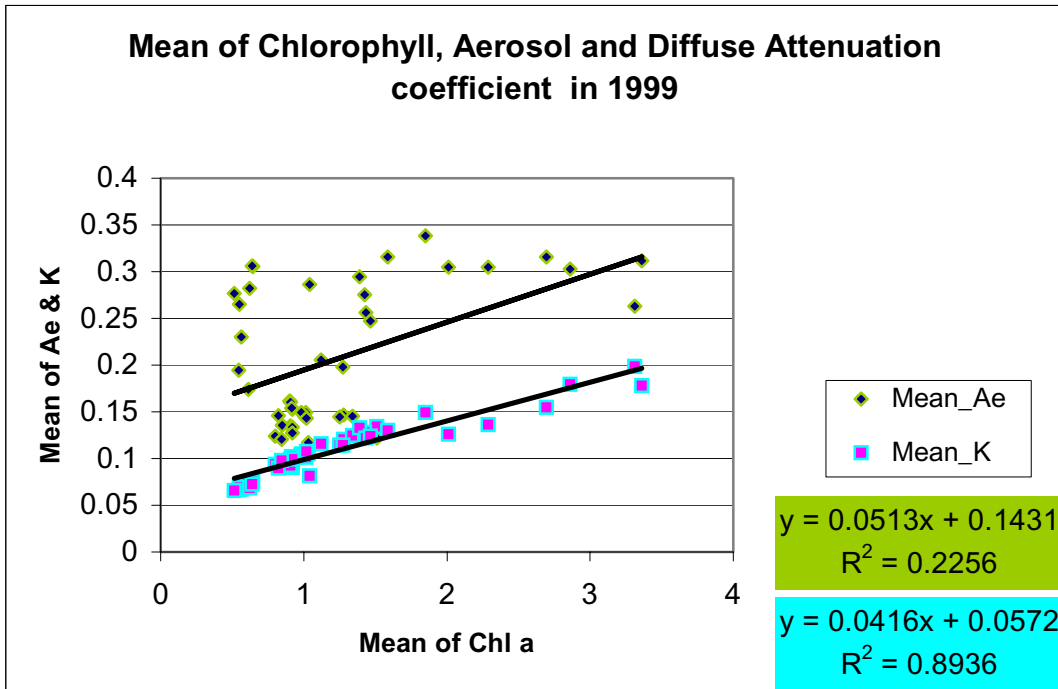


Fig. 33 Relationship of Chlorophyll Concentration (chl) with Aerosol (Ae) And Diffuse Attenuation Coefficient (K) in year **1999** and **2000**.

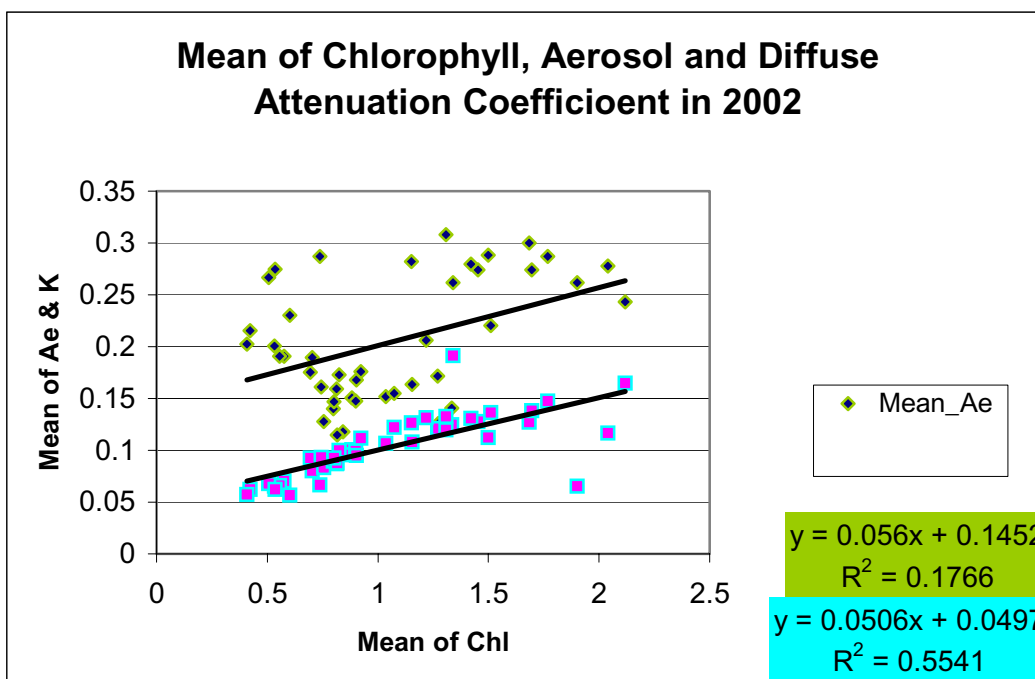
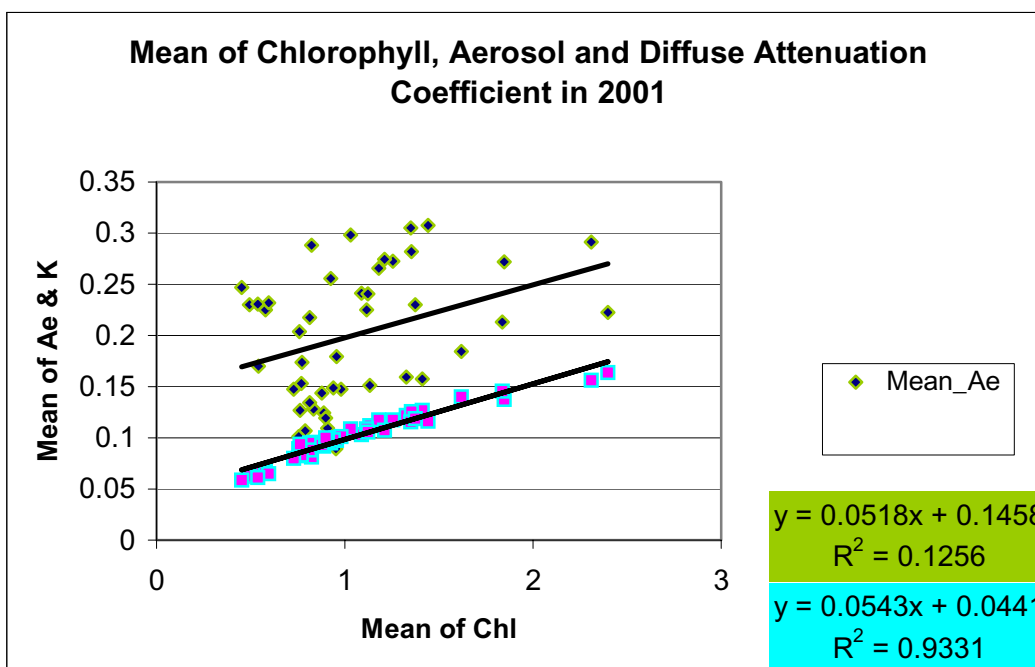


Fig.34 Relationship of Chlorophyll Concentration (chl) with Aerosol (Ae) And Diffuse Attenuation Coefficient (K) in year **2001** and **2002**

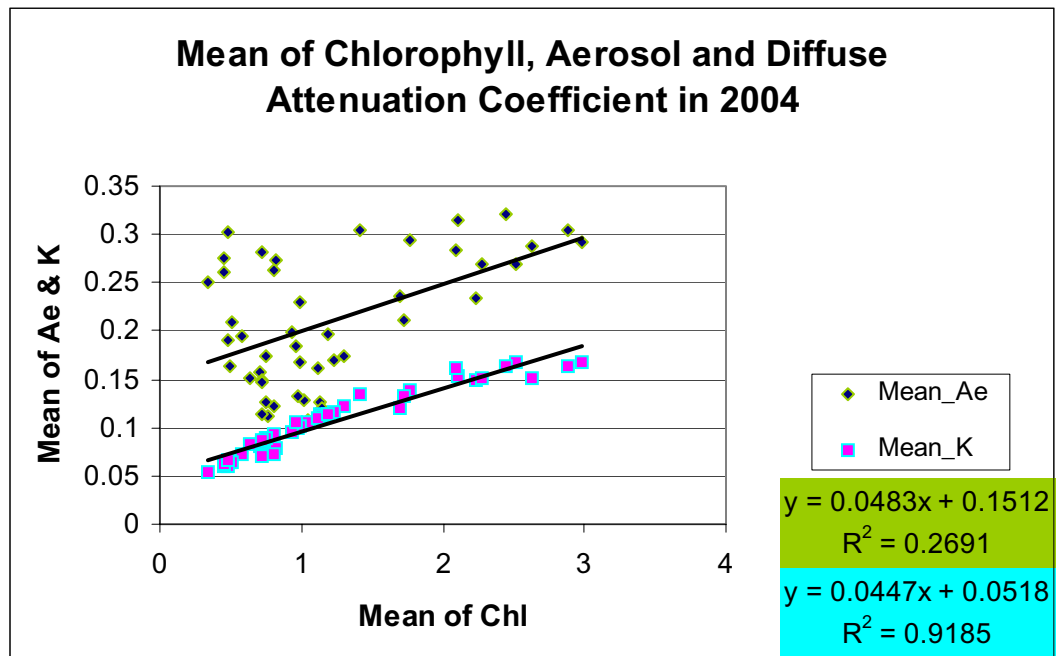
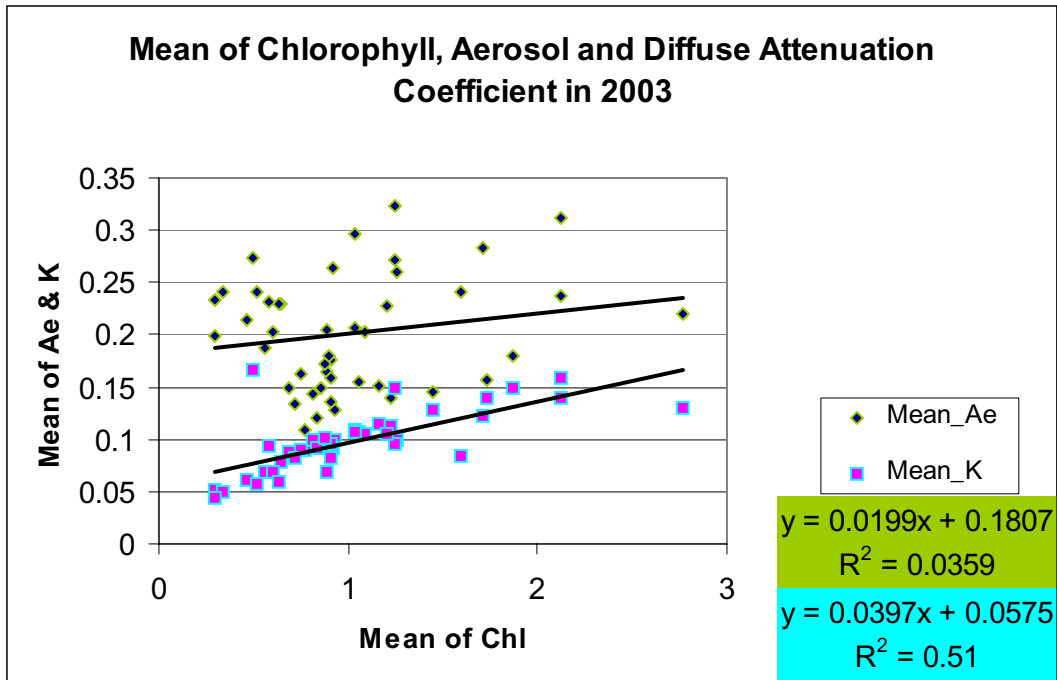


Fig.35 Relationship of Chlorophyll Concentration (chl) with Aerosol (Ae) and Diffuse Attenuation Coefficient (K) in **year 2003** and **2004**.

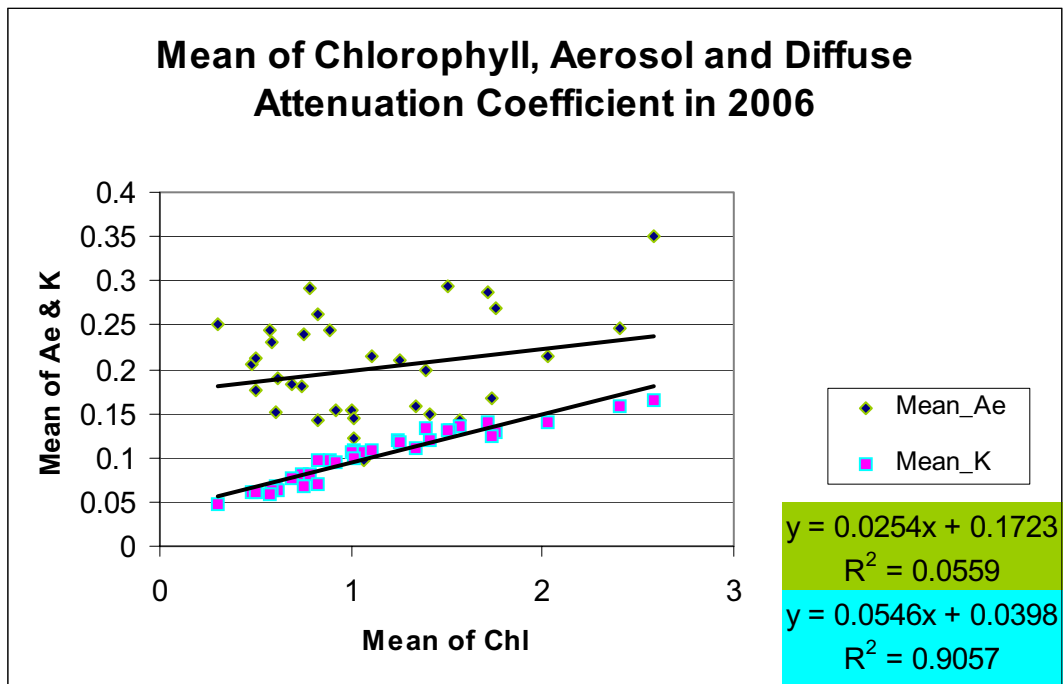
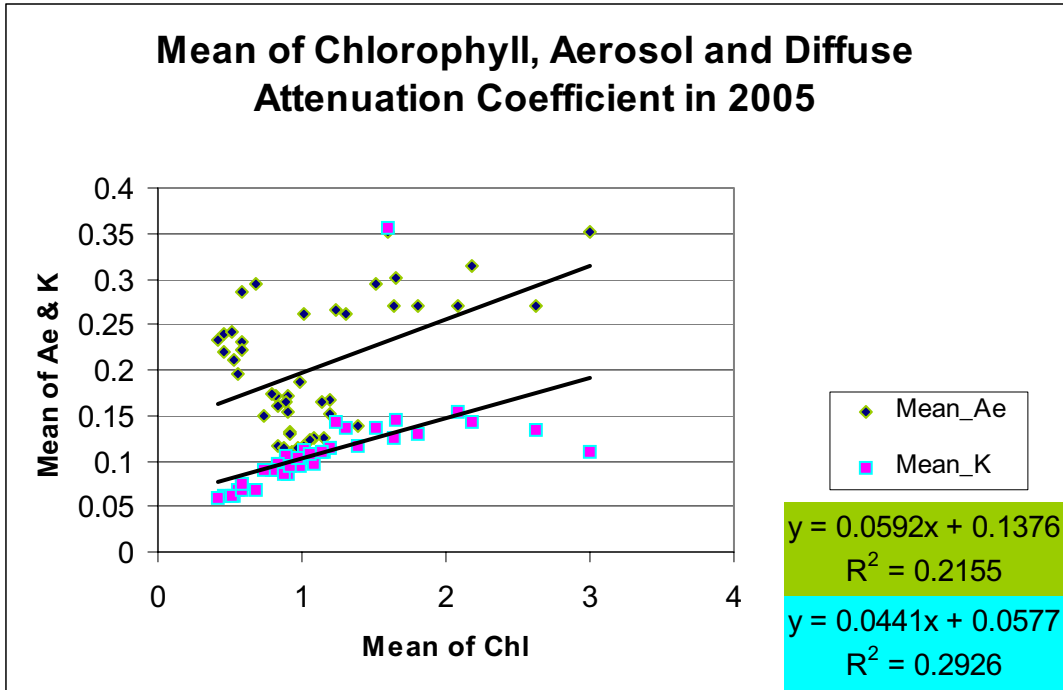


Fig. 36 Relationship of Chlorophyll Concentration (chl) with Aerosol (Ae) and Diffuse Attenuation Coefficient (K) in year **2005** and **2006**.

In all the 10 years, the chlorophyll pigment concentrations showed very strong correlation ($R^2 > 0.85$) with diffuse attenuation coefficient, except during 2002, 2003 and 2005 when R^2 was 0.55, 0.51 and 0.29 respectively. The reason for this is not clear from the analysis. The relationship between chlorophyll pigment concentrations and aerosol was consistently weak in all the years with marginal changes in R^2 values, except in the year 1997 when R^2 was 0.71.

6.4 STATISTICS

The statistics (mean, maximum and minimum values) of chlorophyll pigment concentration, aerosol and diffuse attenuation coefficient for each week for each year for the period of 10 years from 1997 to 2006 is presented in Table 1 to Table 10

Table 1. Mean, Maximum, Minimum of chlorophyll In Year 1997

Running Weeks	Mean Chlorophyll	Maximum Chlorophyll	Minimum Chlorophyll
33	1.01	22.13	0.15
34	0.96	58.21	0.06
35	0.97	21.38	0.10
36	0.87	26.30	0.10
37	0.68	27.23	0.06
38	0.58	17.38	0.11
39	0.51	11.89	0.10
40	0.55	16.22	0.10
41	0.58	12.30	0.10
42	0.61	13.65	0.10
43	0.66	14.62	0.13
44	0.67	24.55	0.13
45	0.60	12.74	0.12
46	0.57	7.85	0.12

Table 2. Mean, Maximum, Minimum of chlorophyll In Year 1998

Running Weeks	Mean Chlorophyll	Maximum Chlorophyll	Minimum Chlorophyll
1	0.70	13.65	0.14
2	0.69	11.09	0.14
3	0.71	12.30	0.16
4	0.82	14.62	0.16
5	0.9 0	19.28	0.17
6	0.88	16.79	0.13
7	0.88	19.95	0.11
8	0.91	10.35	0.16
9	0.74	16.79	0.12
10	0.81	22.13	0.10
11	0.71	11.89	0.09
12	0.56	14.13	0.10
13	0.47	11.09	0.10
14	0.51	16.79	0.06
15	0.57	35.89	0.08
16	0.47	17.38	0.07
17	0.36	24.55	0.05
18	0.45	21.38	0.08
19	0.51	31.26	0.05
20	0.75	38.46	0.09
21	0.90	12.74	0.12
22	0.59	22.13	0.09
23	0.68	5.37	0.15
24	1.01	8.41	0.19
26	2.31	14.62	0.19
27	1.60	23.71	0.24
28	2.03	20.65	0.30
29	2.31	37.15	0.15
30	1.31	14.62	0.19
31	1.42	15.14	0.19
32	1.20	13.65	0.18
33	1.66	22.91	0.19
34	1.18	16.22	0.09
35	0.99	19.28	0.14
36	1.07	41.21	0.12
37	0.86	16.79	0.14
38	0.72	35.89	0.13
39	0.68	12.74	0.13
40	0.76	25.41	0.15
41	0.69	13.65	0.14
42	0.78	22.13	0.19
43	0.84	22.13	0.17
44	0.87	18.62	0.14
45	1.08	21.38	0.27
46	1.00	15.14	0.21

Table 3. Mean, Maximum, Minimum of chlorophyll In Year 1999

Running Weeks	Mean Chlorophyll	Maximum Chlorophyll	Minimum Chlorophyll
1	0.80	13.18	0.24
2	0.91	17.38	0.24
3	0.92	15.67	0.20
4	1.03	23.71	0.20
5	1.28	15.67	0.20
6	1.34	13.65	0.20
7	1.51	19.95	0.22
8	1.25	15.67	0.19
9	0.85	19.28	0.17
10	0.92	14.13	0.18
11	0.92	17.38	0.15
12	0.61	18.62	0.15
13	0.54	21.38	0.11
14	0.56	29.17	0.10
15	0.55	11.89	0.11
16	0.52	11.09	0.10
17	0.62	25.41	0.08
18	1.04	17.38	0.12
19	0.64	10.00	0.08
20	0.64	29.17	0.10
21	2.29	27.23	0.19
22	1.12	2.88	0.57
23	1.43	11.09	0.30
24	2.01	23.71	0.24
25	1.39	3.09	0.32
27	3.31	18.62	0.61
28	1.85	18.62	0.63
29	3.36	54.33	0.35
30	2.70	38.46	0.15
31	2.86	21.38	0.32
32	1.59	29.17	0.23
33	1.44	37.15	0.19
34	1.47	23.71	0.18
35	1.27	35.89	0.10
36	1.01	14.62	0.11
37	1.01	19.95	0.17
38	0.90	14.62	0.18
39	0.91	26.30	0.19
40	0.82	18.62	0.18
41	0.95	13.65	0.19
42	0.98	15.67	0.22
43	1.02	16.79	0.22
44	0.92	13.65	0.22
45	0.92	16.22	0.20
46	0.85	10.00	0.17

Table 4. Mean, Maximum, Minimum of chlorophyll In Year 2000

Running Weeks	Mean Chlorophyll	Maximum Chlorophyll	Minimum Chlorophyll
1	1.03	29.17	0.22
2	0.89	22.91	0.19
3	0.94	35.89	0.18
4	0.96	19.95	0.18
5	1.14	14.62	0.13
6	1.07	20.65	0.14
7	1.30	11.89	0.14
8	1.71	16.79	0.14
9	1.39	12.30	0.13
10	1.34	12.74	0.13
11	1.01	14.13	0.14
12	0.70	13.65	0.14
13	0.59	22.13	0.11
14	0.51	9.33	0.11
15	0.62	21.38	0.08
16	0.71	64.57	0.11
17	0.81	14.13	0.13
18	0.81	11.48	0.15
19	0.87	47.32	0.07
20	1.18	9.33	0.15
21	0.29	0.38	0.24
22	1.39	8.71	0.20
23	0.40	2.99	0.16
24	2.11	12.74	0.26
26	2.12	15.14	0.50
27	2.52	16.22	0.33
28	2.20	8.41	0.27
30	2.18	28.18	0.25
31	2.69	32.36	0.30
32	1.84	16.79	0.25
33	1.75	48.98	0.20
34	1.67	21.38	0.12
35	1.52	22.91	0.15
36	1.09	45.71	0.14
37	0.96	48.98	0.14
38	0.84	19.28	0.18
39	0.80	17.99	0.18
40	0.80	15.67	0.15
41	0.91	15.67	0.17
42	0.95	22.91	0.16
43	1.01	20.65	0.17
44	0.91	15.14	0.19
45	0.80	14.62	0.17
46	0.72	18.62	0.19

Table 5. Mean, Maximum, Minimum of chlorophyll In Year 2001

Running Weeks	Mean Chlorophyll	Maximum Chlorophyll	Minimum Chlorophyll
1	0.79	25.41	0.22
2	0.76	22.13	0.19
3	0.83	13.65	0.19
4	0.81	19.28	0.20
5	0.95	24.55	0.16
6	1.13	17.38	0.15
7	1.41	15.14	0.18
8	1.62	14.13	0.16
9	1.33	17.38	0.11
10	0.96	19.28	0.14
11	0.77	12.74	0.12
12	0.76	16.79	0.14
13	0.54	17.99	0.12
14	0.58	20.65	0.09
15	0.49	14.13	0.10
16	0.59	42.66	0.08
17	0.54	30.20	0.06
18	0.45	20.65	0.05
19	0.82	15.14	0.15
20	0.93	5.56	0.14
21	1.09	10.00	0.13
22	1.85	13.18	0.27
23	1.18	3.09	0.22
24	1.84	6.61	0.51
25	1.26	6.17	0.22
26	1.35	4.37	0.38
27	1.03	3.67	0.35
29	1.44	27.23	0.21
30	2.40	17.38	0.31
31	2.31	20.65	0.24
32	1.35	19.95	0.23
33	1.21	22.91	0.15
34	1.11	14.13	0.13
35	1.38	60.26	0.18
36	1.12	20.65	0.10
37	0.81	20.65	0.14
38	0.77	15.67	0.19
39	0.73	24.55	0.16
40	0.89	48.98	0.18
41	0.88	37.15	0.18
42	0.98	17.38	0.19
43	0.94	22.91	0.17
44	0.91	23.71	0.18
45	0.90	17.99	0.19
46	0.76	10.00	0.19

Table 6. Mean, Maximum, Minimum of chlorophyll In Year 2002

Running Weeks	Mean Chlorophyll	Maximum Chlorophyll	Minimum Chlorophyll
1	0.88	12.30	0.22
2	0.90	16.22	0.19
3	0.84	18.62	0.15
4	1.04	24.55	0.12
5	1.27	11.89	0.19
6	1.33	17.38	0.18
7	1.27	15.67	0.19
8	1.31	12.74	0.15
9	1.16	14.13	0.14
10	0.90	19.28	0.16
11	0.70	14.13	0.11
12	0.58	18.62	0.14
13	0.53	31.26	0.12
14	0.55	19.28	0.11
16	0.42	12.74	0.05
17	0.41	14.62	0.08
18	0.60	22.13	0.08
19	0.74	30.20	0.06
20	0.51	20.65	0.07
21	0.54	6.61	0.06
22	1.90	21.38	0.15
23	1.45	4.52	0.51
25	1.31	3.67	0.20
26	1.34	12.74	0.18
27	1.15	3.20	0.32
28	1.50	6.61	0.42
29	2.04	5.19	0.65
30	1.42	10.72	0.39
31	2.12	25.41	0.34
32	1.68	17.99	0.14
33	1.77	16.79	0.19
34	1.69	27.23	0.15
35	1.51	20.65	0.16
36	1.22	25.41	0.18
37	1.07	28.18	0.16
38	0.92	23.71	0.08
39	0.83	29.17	0.14
40	0.70	16.79	0.09
41	0.81	17.99	0.14
42	0.76	15.67	0.14
43	0.80	21.38	0.16
44	0.82	16.79	0.12
45	0.74	17.38	0.14
46	0.80	17.38	0.12

Table 7. Mean, Maximum, Minimum of chlorophyll In Year 2003

Running Weeks	Mean Chlorophyll	Maximum Chlorophyll	Minimum Chlorophyll
1	0.69	15.67	0.17
2	0.77	22.13	0.21
3	0.92	20.65	0.14
4	1.16	11.89	0.14
5	1.06	16.22	0.16
6	1.45	28.18	0.14
7	1.87	15.14	0.12
8	1.23	22.91	0.12
9	1.74	15.14	0.13
10	1.08	13.65	0.11
11	0.91	12.74	0.11
12	0.64	10.72	0.11
13	0.56	13.18	0.09
14	0.60	18.62	0.10
15	0.47	12.30	0.07
16	0.30	5.96	0.07
17	0.34	16.22	0.07
18	0.52	39.81	0.05
19	0.63	26.30	0.05
20	0.30	24.55	0.03
21	1.25	22.13	0.09
23	2.77	8.41	0.22
24	0.50	4.07	0.15
25	0.89	6.84	0.14
26	0.92	5.56	0.18
27	0.58	2.60	0.21
28	1.59	12.74	0.19
29	1.71	9.02	0.30
30	2.12	13.18	0.33
31	2.13	18.62	0.32
32	1.25	37.15	0.27
33	1.04	16.22	0.15
34	1.25	54.33	0.10
35	1.20	30.20	0.15
36	1.04	22.13	0.13
37	0.89	17.38	0.14
38	0.85	24.55	0.14
39	0.75	25.41	0.14
40	0.72	18.62	0.13
41	0.91	22.13	0.16
42	0.90	16.79	0.16
43	0.81	21.38	0.16
44	0.83	15.67	0.16
45	0.91	12.74	0.18
46	0.87	19.95	0.21

Table 8. Mean, Maximum, Minimum of chlorophyll In Year 2004

Running Weeks	Mean Chlorophyll	Maximum Chlorophyll	Minimum Chlorophyll
1	0.99	19.95	0.20
2	1.13	14.13	0.21

Table 9. Mean Maximum, Minimum of chlorophyll In Year 2005

Running Weeks	Mean Chlorophyll	Maximum Chlorophyll	Minimum Chlorophyll
3	1.02	17.38	0.15
4	0.97	22.13	0.13
5	1.04	17.99	0.16
6	1.14	18.62	0.15
7	1.29	18.62	0.17
8	1.12	19.95	0.15
9	0.77	10.72	0.14
10	0.70	15.14	0.18
11	0.59	17.38	0.15
12	0.50	15.67	0.11
13	0.51	21.38	0.11
14	0.48	11.48	0.11
15	0.45	37.15	0.08
16	0.34	12.30	0.09
17	0.45	15.14	0.12
18	0.48	4.37	0.12
19	0.72	30.20	0.06
20	0.81	28.18	0.10
21	0.80	25.41	0.06
22	2.63	30.20	0.22
23	1.69	17.99	0.19
24	2.11	4.37	0.61
25	1.77	8.71	0.27
26	2.52	10.00	0.20
27	2.98	23.71	0.26
28	1.42	2.26	0.78
29	2.10	7.85	0.57
30	2.45	17.38	0.29
31	2.89	38.46	0.22
32	2.24	39.81	0.20
33	2.27	25.41	0.22
34	1.72	44.16	0.15
35	1.23	27.23	0.15
36	1.19	12.74	0.12
37	0.99	20.65	0.18
38	0.94	44.16	0.16
39	0.96	12.30	0.15
40	0.81	15.14	0.13
41	0.72	22.13	0.15
42	0.72	15.14	0.15
43	0.75	10.35	0.18
44	0.75	13.65	0.17
45	0.73	16.79	0.15
46	0.63	7.08	0.16

Table 9. Mean Maximum, Minimum of chlorophyll in Year 2005

Running Week	Mean Chlorophyll	Maximum Chlorophyll	Minimum Chlorophyll
1	0.83	41.21	0.17
2	0.91	20.65	0.15
3	0.93	16.22	0.15
4	0.90	24.55	0.12
5	1.01	19.95	0.11
6	1.15	25.41	0.12
7	1.19	17.38	0.12
8	1.20	11.89	0.15
9	1.40	15.14	0.13
10	1.09	19.95	0.14
11	0.99	16.79	0.10
12	0.90	17.38	0.13
13	0.59	15.14	0.12
14	0.55	16.22	0.09
15	0.45	13.65	0.11
16	0.45	19.28	0.06
17	0.41	6.84	0.09
18	0.53	16.79	0.07
19	0.68	42.66	0.10
20	0.51	15.67	0.04
21	0.58	10.72	0.09
22	0.58	3.94	0.16
23	1.51	3.43	0.28
25	1.60	14.13	0.16
26	1.01	1.55	0.48
28	1.31	3.94	0.31
29	1.64	2.79	0.63
30	2.18	33.50	0.19
31	1.65	27.23	0.20
32	1.80	27.23	0.22
33	2.62	37.15	0.20
34	2.08	39.81	0.17
35	1.24	22.91	0.14
36	1.13	16.22	0.10
37	0.88	11.89	0.14
38	0.84	32.36	0.15
39	0.82	22.13	0.15
40	0.79	16.22	0.19
41	0.73	18.62	0.15
42	0.88	29.17	0.13
43	0.92	17.38	0.15
44	0.98	21.38	0.17
45	0.98	20.65	0.19
46	1.05	20.65	0.22

Table 10. Mean, Maximum, Minimum of chlorophyll In Year 2006

Running Week	Mean Chlorophyll	Maximum Chlorophyll	Minimum Chlorophyll
1	0.83	10.35	0.18
2	1.01	14.13	0.21
3	1.00	15.67	0.19
4	1.24	16.79	0.19
5	1.56	19.95	0.20
6	1.51	20.65	0.19
7	1.41	27.23	0.16
8	1.07	21.38	0.12
9	1.01	13.18	0.10
10	0.74	26.30	0.11
11	0.69	15.14	0.12
12	0.60	19.28	0.12
13	0.50	20.65	0.12
14	0.48	26.30	0.09
15	0.61	29.17	0.07
16	0.50	31.26	0.08
17	0.58	25.41	0.04
18	0.57	32.36	0.04
19	0.30	4.52	0.03
20	0.79	15.14	0.12
21	0.83	31.26	0.07
22	0.75	41.21	0.04
23	1.10	3.94	0.12
26	0.88	4.52	0.31
27	1.39	3.94	0.29
28	2.58	16.22	0.30
29	1.26	16.22	0.27
30	1.50	9.02	0.19
31	1.72	25.41	0.22
32	1.76	33.50	0.19
33	2.41	47.32	0.20
34	2.03	38.46	0.14
35	1.73	35.89	0.12
36	1.33	31.26	0.11
37	0.92	25.41	0.16

Table 11. Mean, Maximum, Minimum of Aerosol In Year 1997

Running Weeks	Mean Aerosol	Maximum Aerosol	Minimum Aerosol
33	0.26	0.41	0.08
34	0.22	0.38	0.05
35	0.19	0.38	0.03
36	0.19	0.38	0.06
37	0.15	0.37	0.05
38	0.14	0.36	0.05
39	0.12	0.31	0.05
40	0.13	0.34	0.04
41	0.11	0.30	0.03
42	0.13	0.34	0.04
43	0.12	0.32	0.03
44	0.11	0.32	0.02
45	0.13	0.32	0.05
46	0.16	0.33	0.05

Table 12. Mean, Maximum, Minimum of Aerosol In Year 1998

Running Weeks	Mean Aerosol	Maximum Aerosol	Minimum Aerosol
1	0.14	0.33	0.04
2	0.17	0.35	0.05
3	0.11	0.32	0.03
4	0.15	0.32	0.05
5	0.12	0.25	0.05
6	0.14	0.32	0.04
7	0.16	0.33	0.05
8	0.18	0.35	0.05
9	0.11	0.25	0.05
10	0.13	0.35	0.05
11	0.14	0.30	0.06
12	0.13	0.39	0.06
13	0.19	0.39	0.06
14	0.17	0.38	0.05
15	0.20	0.40	0.03
16	0.22	0.41	0.07
17	0.21	0.42	0.02
18	0.28	0.44	0.09
19	0.27	0.46	0.07
20	0.29	0.43	0.11
21	0.30	0.44	0.10
22	0.30	0.43	0.09
23	0.27	0.38	0.10
24	0.25	0.40	0.09
25	0.28	0.36	0.23
26	0.26	0.45	0.07
27	0.30	0.44	0.13
28	0.29	0.46	0.11
29	0.29	0.40	0.11
30	0.28	0.46	0.12
31	0.29	0.44	0.08
32	0.27	0.43	0.15
33	0.27	0.42	0.10
34	0.20	0.40	0.07
35	0.18	0.39	0.04
36	0.20	0.37	0.03
37	0.18	0.35	0.08
38	0.11	0.26	0.03
39	0.14	0.28	0.05
40	0.13	0.31	0.05
41	0.11	0.29	0.04
42	0.11	0.24	0.04
43	0.12	0.34	0.02
44	0.11	0.32	0.03
45	0.11	0.29	0.03
46	0.12	0.29	0.04

Table 13. Mean, Maximum, Minimum of Aerosol In Year 1999

Running Weeks	Mean Aerosol	Maximum Aerosol	Minimum Aerosol
1	0.12	0.31	0.02
2	0.13	0.29	0.03
3	0.13	0.29	0.00
4	0.12	0.32	0.05
5	0.15	0.33	0.04
6	0.14	0.34	0.02
7	0.12	0.29	0.03
8	0.14	0.37	0.06
9	0.14	0.32	0.03
10	0.15	0.32	0.06
11	0.13	0.27	0.05
12	0.17	0.29	0.11
13	0.19	0.37	0.07
14	0.23	0.38	0.08
15	0.26	0.44	0.11
16	0.28	0.42	0.10
17	0.28	0.45	0.09
18	0.29	0.46	0.08
19	0.31	0.48	0.08
20	0.31	0.45	0.07
21	0.30	0.41	0.06
22	0.21	0.36	0.15
23	0.28	0.44	0.08
24	0.30	0.44	0.14
25	0.29	0.45	0.20
26	0.26	0.45	0.07
27	0.34	0.42	0.26
28	0.31	0.43	0.10
29	0.32	0.45	0.08
30	0.30	0.47	0.10
31	0.32	0.43	0.17
32	0.26	0.42	0.07
33	0.25	0.42	0.06
34	0.20	0.37	0.03
35	0.15	0.39	0.02
36	0.15	0.38	0.02
37	0.16	0.31	0.07
38	0.16	0.27	0.09
39	0.15	0.30	0.07
40	0.10	0.25	0.03
41	0.15	0.35	0.04
42	0.14	0.32	0.07
43	0.15	0.32	0.05
44	0.13	0.35	0.04
45	0.12	0.30	0.02
46	0.12	0.36	0.02

Table 14. Mean, Maximum, Minimum of Aerosol In Year 2000

Running Weeks	Mean Aerosol	Maximum Aerosol	Minimum Aerosol
1	0.14	0.27	0.04
2	0.12	0.30	0.04
3	0.12	0.28	0.02
4	0.13	0.29	0.05
5	0.19	0.32	0.07
6	0.16	0.34	0.07
7	0.18	0.29	0.10
8	0.13	0.31	0.06
9	0.20	0.34	0.10
10	0.19	0.29	0.07
11	0.19	0.31	0.08
12	0.19	0.35	0.08
13	0.20	0.40	0.09
14	0.26	0.41	0.08
15	0.22	0.45	0.07
16	0.25	0.44	0.05
17	0.30	0.44	0.08
18	0.28	0.44	0.08
19	0.28	0.44	0.05
20	0.31	0.44	0.14
22	0.29	0.45	0.08
23	0.30	0.43	0.09
24	0.28	0.43	0.13
26	0.33	0.45	0.13
27	0.31	0.45	0.09
28	0.33	0.44	0.12
29	0.32	0.37	0.17
30	0.24	0.38	0.10
31	0.26	0.44	0.13
32	0.29	0.40	0.18
33	0.25	0.40	0.11
34	0.19	0.37	0.06
35	0.19	0.39	0.05
36	0.14	0.32	0.02
37	0.13	0.30	0.05
38	0.12	0.29	0.04
39	0.14	0.29	0.04
40	0.16	0.31	0.04
41	0.17	0.30	0.06
42	0.14	0.30	0.05
43	0.10	0.33	0.01
44	0.13	0.29	0.05
45	0.10	0.34	0.02
46	0.10	0.29	0.01

Table 15. Mean, Maximum, Minimum of Aerosol In Year 2001

Running Weeks	Mean Aerosol	Maximum Aerosol	Minimum Aerosol
1	0.11	0.33	0.01
2	0.10	0.32	0.02
3	0.13	0.28	0.03
4	0.13	0.33	0.05
5	0.09	0.23	0.02
6	0.15	0.27	0.06
7	0.16	0.30	0.06
8	0.18	0.34	0.07
9	0.16	0.30	0.09
10	0.18	0.32	0.07
11	0.17	0.35	0.05
12	0.20	0.35	0.09
13	0.17	0.31	0.08
14	0.23	0.40	0.08
15	0.23	0.41	0.09
16	0.23	0.42	0.06
17	0.23	0.46	0.06
18	0.25	0.40	0.06
19	0.29	0.45	0.09
20	0.26	0.40	0.10
21	0.24	0.41	0.07
22	0.27	0.40	0.09
23	0.27	0.39	0.17
24	0.21	0.35	0.15
25	0.27	0.41	0.10
26	0.28	0.36	0.20
27	0.30	0.36	0.20
28	0.31	0.41	0.20
29	0.22	0.39	0.05
30	0.29	0.43	0.13
31	0.30	0.46	0.11
32	0.27	0.40	0.14
33	0.22	0.38	0.09
34	0.23	0.39	0.06
35	0.24	0.36	0.07
36	0.22	0.37	0.07
37	0.15	0.37	0.06
38	0.15	0.25	0.07
39	0.12	0.25	0.05
40	0.14	0.26	0.06
41	0.15	0.27	0.04
42	0.15	0.25	0.06
43	0.11	0.24	0.05
44	0.12	0.29	0.03
45	0.13	0.27	0.04
46	0.12	0.30	0.04

Table 16. Mean, Maximum, Minimum of Aerosol In Year 2002

Running Weeks	Mean Aerosol	Maximum Aerosol	Minimum Aerosol
1	0.15	0.29	0.04
2	0.15	0.33	0.07
3	0.12	0.33	0.04
4	0.15	0.35	0.05
5	0.17	0.33	0.05
6	0.14	0.36	0.06
7	0.13	0.25	0.05
8	0.13	0.28	0.04
9	0.16	0.33	0.06
10	0.17	0.34	0.06
11	0.19	0.38	0.06
12	0.19	0.31	0.05
13	0.20	0.36	0.07
14	0.19	0.36	0.08
15	0.22	0.38	0.07
16	0.20	0.39	0.04
17	0.23	0.45	0.06
18	0.29	0.44	0.07
19	0.27	0.46	0.08
20	0.27	0.46	0.08
21	0.26	0.40	0.06
22	0.27	0.41	0.07
23	0.31	0.41	0.10
24	0.26	0.42	0.08
25	0.28	0.42	0.22
26	0.29	0.43	0.17
27	0.28	0.35	0.16
28	0.28	0.36	0.20
29	0.24	0.39	0.18
30	0.30	0.45	0.12
31	0.29	0.41	0.11
32	0.27	0.44	0.10
33	0.22	0.39	0.08
34	0.21	0.39	0.06
35	0.16	0.29	0.07
36	0.18	0.33	0.09
37	0.17	0.31	0.10
38	0.18	0.32	0.08
39	0.16	0.29	0.06
40	0.13	0.28	0.04
41	0.14	0.37	0.05
42	0.11	0.35	0.05
43	0.16	0.29	0.07
44	0.15	0.35	0.04
45	0.12	0.31	0.04
46	0.17	0.30	0.05

Table 17. Mean, Maximum, Minimum of Aerosol In Year 2003

Running Weeks	Mean Aerosol	Maximum Aerosol	Minimum Aerosol
1	0.15	0.34	0.06
2	0.11	0.27	0.04
3	0.13	0.27	0.05
4	0.15	0.33	0.04
5	0.16	0.36	0.05
6	0.15	0.32	0.05
7	0.18	0.35	0.06
8	0.14	0.29	0.04
9	0.16	0.33	0.06
10	0.20	0.36	0.03
11	0.18	0.32	0.06
12	0.23	0.36	0.07
13	0.19	0.33	0.07
14	0.20	0.38	0.05
15	0.21	0.37	0.07
16	0.23	0.41	0.04
17	0.24	0.41	0.02
18	0.24	0.46	0.06
19	0.23	0.44	0.02
20	0.20	0.40	0.02
21	0.26	0.41	0.05
22	0.22	0.29	0.15
23	0.27	0.31	0.22
24	0.20	0.40	0.07
25	0.26	0.39	0.09
26	0.23	0.37	0.12
27	0.24	0.37	0.08
28	0.28	0.40	0.11
29	0.31	0.44	0.19
30	0.24	0.41	0.17
31	0.32	0.42	0.22
32	0.30	0.43	0.09
33	0.27	0.42	0.06
34	0.23	0.40	0.07
35	0.21	0.36	0.08
36	0.17	0.34	0.05
37	0.15	0.30	0.04
38	0.16	0.28	0.09
39	0.13	0.30	0.03
40	0.13	0.27	0.04
41	0.18	0.34	0.07
42	0.14	0.29	0.04
43	0.12	0.33	0.04
44	0.16	0.35	0.03
45	0.17	0.34	0.04
46	0.16	0.35	0.06

Table 18. Mean, Maximum, Minimum of Aerosol In Year 2004

Running Weeks	Mean Aerosol	Maximum Aerosol	Minimum Aerosol
1	0.17	0.36	0.06
2	0.13	0.29	0.05
3	0.13	0.35	0.03
4	0.13	0.31	0.03
5	0.11	0.27	0.04
6	0.12	0.27	0.05
7	0.17	0.36	0.06
8	0.16	0.27	0.10
9	0.11	0.30	0.05
10	0.16	0.34	0.09
11	0.19	0.32	0.06
12	0.16	0.35	0.06
13	0.21	0.39	0.07
14	0.19	0.39	0.07
15	0.26	0.42	0.08
16	0.25	0.44	0.06
17	0.27	0.44	0.04
18	0.30	0.43	0.13
19	0.28	0.43	0.09
20	0.27	0.45	0.04
21	0.26	0.41	0.09
22	0.29	0.43	0.06
23	0.24	0.40	0.10
24	0.31	0.35	0.28
25	0.29	0.40	0.13
26	0.27	0.39	0.15
27	0.29	0.42	0.12
28	0.30	0.34	0.27
29	0.28	0.36	0.15
30	0.32	0.46	0.17
31	0.30	0.45	0.11
32	0.23	0.45	0.06
33	0.27	0.40	0.15
34	0.21	0.41	0.05
35	0.17	0.43	0.04
36	0.20	0.40	0.04
37	0.23	0.37	0.09
38	0.20	0.32	0.09
39	0.18	0.32	0.05
40	0.12	0.36	0.03
41	0.11	0.29	0.03
42	0.15	0.30	0.04
43	0.17	0.33	0.05
44	0.13	0.32	0.04
45	0.15	0.30	0.04
46	0.15	0.31	0.04

Table 19. Mean, Maximum, Minimum of Aerosol In Year 2005

Running Weeks	Mean Aerosol	Maximum Aerosol	Minimum Aerosol
1	0.12	0.30	0.01
2	0.13	0.32	0.06
3	0.11	0.28	0.03
4	0.15	0.37	0.03
5	0.12	0.29	0.03
6	0.13	0.33	0.02
7	0.17	0.32	0.06
8	0.15	0.32	0.07
9	0.14	0.34	0.06
10	0.13	0.33	0.05
11	0.19	0.35	0.08
12	0.17	0.34	0.08
13	0.23	0.38	0.12
14	0.20	0.42	0.07
15	0.22	0.43	0.06
16	0.24	0.46	0.03
17	0.23	0.48	0.08
18	0.21	0.44	0.02
19	0.29	0.44	0.11
20	0.24	0.47	0.05
21	0.29	0.44	0.03
22	0.22	0.41	0.03
23	0.30	0.40	0.18
24	0.35	0.35	0.35
25	0.26	0.47	0.10
26	0.35	0.38	0.33
27	0.26	0.32	0.15
28	0.27	0.37	0.20
29	0.31	0.38	0.26
30	0.30	0.42	0.09
31	0.27	0.44	0.15
32	0.27	0.46	0.13
33	0.27	0.43	0.10
34	0.27	0.41	0.14
35	0.16	0.36	0.04
36	0.16	0.29	0.06
37	0.16	0.29	0.05
38	0.17	0.31	0.08
39	0.17	0.30	0.07
40	0.15	0.30	0.07
41	0.11	0.25	0.05
42	0.13	0.32	0.04
43	0.10	0.26	0.02
44	0.11	0.24	0.05
45	0.12	0.35	0.04
46	0.15	0.33	0.04

Table 20. Mean, Maximum, Minimum of Aerosol In Year 2006

Running Weeks	Mean Aerosol	Maximum Aerosol	Minimum Aerosol
1	0.14	0.32	0.03
2	0.12	0.25	0.05
3	0.15	0.34	0.05
4	0.12	0.28	0.05
5	0.14	0.25	0.08
6	0.13	0.29	0.05
7	0.15	0.30	0.06
8	0.10	0.32	0.03
9	0.15	0.32	0.04
10	0.18	0.35	0.04
11	0.18	0.31	0.08
12	0.15	0.32	0.04
13	0.18	0.33	0.07
14	0.21	0.40	0.08
15	0.19	0.45	0.04
16	0.21	0.44	0.03
17	0.23	0.40	0.09
18	0.24	0.44	0.07
19	0.25	0.38	0.06
20	0.29	0.47	0.12
21	0.26	0.48	0.02
22	0.24	0.47	0.08
23	0.22	0.41	0.10
26	0.24	0.45	0.12
27	0.20	0.32	0.09
28	0.35	0.45	0.21
29	0.21	0.43	0.08
30	0.29	0.49	0.11
31	0.29	0.47	0.15
32	0.27	0.46	0.12
33	0.25	0.43	0.05
34	0.21	0.44	0.04
35	0.17	0.43	0.04
36	0.16	0.38	0.04
37	0.15	0.32	0.08

Table 21. Mean, Maximum, Minimum of Diffuse Attenuation In Year 1997

Running Weeks	Mean Diffuse Attenuation	Maximum Diffuse Attenuation	Minimum Diffuse Attenuation
33	0.10	0.59	0.03
34	0.09	0.89	0.02
35	0.09	0.56	0.03
36	0.09	0.70	0.03
37	0.08	0.78	0.02
38	0.07	0.48	0.03
39	0.07	0.44	0.03
40	0.07	0.59	0.03
41	0.07	0.44	0.03
42	0.08	0.70	0.02
43	0.08	0.49	0.03
44	0.08	0.72	0.03
45	0.08	0.42	0.03
46	0.08	0.36	0.03

Table 22. Mean, Maximum, Minimum of Diffuse Attenuation In Year 1998

Running Weeks	Mean Diffuse Attenuation	Maximum Diffuse Attenuation	Minimum Diffuse Attenuation
1	0.08	0.49	0.04
2	0.08	0.41	0.03
3	0.08	0.49	0.04
4	0.09	0.53	0.04
5	0.10	0.62	0.04
6	0.10	0.55	0.03
7	0.09	0.67	0.03
8	0.10	0.41	0.03
9	0.08	0.55	0.03
10	0.08	0.53	0.03
11	0.08	0.45	0.03
12	0.07	0.55	0.03
13	0.06	0.42	0.03
14	0.06	0.74	0.02
15	0.06	0.70	0.02
16	0.06	0.55	0.02
17	0.05	0.65	0.02
18	0.06	0.62	0.02
19	0.06	0.78	0.02
20	0.07	1.03	0.03
21	0.09	0.42	0.03
22	0.07	0.49	0.03
23	0.08	0.31	0.04
24	0.10	0.38	0.04
25	0.17	0.29	0.10
26	0.15	0.48	0.05
27	0.13	0.56	0.05
28	0.15	0.69	0.06
29	0.15	0.65	0.03
30	0.12	0.48	0.04
31	0.12	0.42	0.04
32	0.11	0.46	0.04
33	0.13	0.55	0.05
34	0.11	1.00	0.02
35	0.10	0.49	0.03
36	0.10	0.80	0.03
37	0.10	0.52	0.03
38	0.08	0.62	0.03
39	0.08	0.48	0.03
40	0.09	0.69	0.04
41	0.09	0.52	0.03
42	0.09	0.48	0.04
43	0.09	0.62	0.04
44	0.10	0.56	0.03
45	0.11	0.69	0.05
46	0.11	0.55	0.05

Table 23. Mean, Maximum, Minimum of Diffuse Attenuation In Year 1999

Running Weeks	Mean Diffuse Attenuation	Maximum Diffuse Attenuation	Minimum Diffuse Attenuation
1	0.09	0.48	0.05
2	0.10	0.61	0.05
3	0.10	0.58	0.04
4	0.11	0.67	0.04
5	0.12	0.46	0.04
6	0.12	0.49	0.04
7	0.13	3.30	0.04
8	0.11	0.65	0.04
9	0.09	0.59	0.04
10	0.09	0.49	0.04
11	0.09	0.61	0.04
12	0.07	0.59	0.03
13	0.07	0.74	0.03
14	0.07	0.78	0.03
15	0.07	0.44	0.03
16	0.07	0.42	0.03
17	0.07	0.80	0.02
18	0.08	0.51	0.03
19	0.08	0.49	0.02
20	0.07	0.65	0.03
21	0.14	0.65	0.05
22	0.12	0.19	0.08
23	0.13	0.40	0.06
24	0.13	0.61	0.05
25	0.13	0.23	0.06
27	0.20	0.55	0.09
28	0.15	0.58	0.09
29	0.18	0.86	0.07
30	0.15	0.67	0.04
31	0.18	0.59	0.07
32	0.13	0.59	0.05
33	0.12	0.86	0.04
34	0.12	1.03	0.04
35	0.11	0.70	0.03
36	0.10	0.91	0.03
37	0.10	0.59	0.04
38	0.09	0.53	0.04
39	0.09	0.67	0.04
40	0.09	1.17	0.04
41	0.10	0.46	0.04
42	0.11	0.55	0.04
43	0.11	0.59	0.04
44	0.10	0.49	0.05
45	0.10	0.58	0.04
46	0.10	0.41	0.04

Table 24. Mean, Maximum, Minimum of Diffuse Attenuation In Year 2000

Running Weeks	Mean Diffuse Attenuation	Maximum Diffuse Attenuation	Minimum Diffuse Attenuation
1	0.11	0.72	0.05
2	0.10	0.72	0.04
3	0.10	0.89	0.04
4	0.10	0.61	0.04
5	0.11	0.52	0.03
6	0.11	0.67	0.03
7	0.12	0.61	0.03
8	0.14	0.58	0.04
9	0.13	0.53	0.03
10	0.12	0.49	0.03
11	0.10	0.44	0.03
12	0.08	0.49	0.03
13	0.07	0.67	0.03
14	0.07	0.42	0.03
15	0.07	0.61	0.02
17	0.08	0.48	0.03
18	0.09	0.45	0.04
19	0.08	1.11	0.02
20	0.11	0.37	0.04
21	0.06	0.07	0.05
22	0.12	0.36	0.04
23	0.06	0.20	0.04
24	0.14	0.39	0.05
26	0.16	0.47	0.08
27	0.17	0.62	0.06
28	0.16	0.38	0.05
29	0.29	1.17	0.09
30	0.15	0.64	0.05
31	0.16	0.61	0.06
32	0.14	0.46	0.05
33	0.13	1.58	0.04
34	0.13	0.56	0.03
35	0.13	0.67	0.03
36	0.11	0.65	0.03
37	0.10	0.86	0.03
38	0.09	0.61	0.04
39	0.09	0.64	0.04
40	0.09	0.51	0.03
41	0.10	0.56	0.04
42	0.10	0.72	0.04
43	0.10	0.69	0.04
44	0.10	0.53	0.04
45	0.09	0.53	0.04
46	0.09	0.64	0.04

Table 25. Mean, Maximum, Minimum of Diffuse Attenuation In Year 2001

Running Weeks	Mean Diffuse Attenuation	Maximum Diffuse Attenuation	Minimum Diffuse Attenuation
1	0.09	0.76	0.05
2	0.09	0.74	0.04
3	0.10	0.49	0.04
4	0.10	0.65	0.04
5	0.10	0.80	0.04
6	0.11	0.59	0.03
7	0.13	0.74	0.04
8	0.14	0.53	0.04
9	0.12	0.59	0.03
10	0.10	0.62	0.04
11	0.08	0.47	0.03
12	0.08	0.58	0.03
13	0.07	0.61	0.03
14	0.07	0.91	0.03
15	0.06	0.58	0.03
16	0.07	2.38	0.02
17	0.06	0.70	0.02
18	0.06	0.59	0.02
19	0.08	0.47	0.04
20	0.10	0.28	0.03
21	0.10	0.39	0.03
22	0.14	0.45	0.05
23	0.12	0.24	0.05
24	0.15	0.31	0.08
25	0.12	0.26	0.05
26	0.13	0.24	0.06
27	0.11	0.21	0.06
29	0.12	0.44	0.04
30	0.16	0.53	0.05
31	0.16	0.52	0.06
32	0.12	0.49	0.05
33	0.11	0.67	0.03
34	0.11	0.49	0.03
35	0.12	1.17	0.03
36	0.11	0.61	0.02
37	0.09	0.64	0.03
38	0.08	0.52	0.04
39	0.08	0.67	0.03
40	0.09	0.78	0.04
41	0.09	0.58	0.04
42	0.10	0.52	0.05
43	0.10	0.70	0.04
44	0.10	0.93	0.04
45	0.10	0.61	0.04
46	0.09	0.41	0.05

Table 26. Mean, Maximum, Minimum of Diffuse Attenuation In Year2002

Running Weeks	Mean Diffuse Attenuation	Maximum Diffuse Attenuation	Minimum Diffuse Attenuation
1	0.10	0.46	0.05
2	0.10	0.55	0.04
3	0.10	0.64	0.04
4	0.11	0.76	0.03
5	0.12	0.46	0.04
6	0.12	0.58	0.04
7	0.12	0.72	0.04
8	0.12	0.80	0.04
9	0.11	0.72	0.03
10	0.09	0.67	0.03
11	0.08	0.49	0.02
12	0.07	0.48	0.03
13	0.07	0.61	0.03
14	0.07	0.64	0.03
15	0.06	1.14	0.03
16	0.06	0.46	0.02
17	0.06	0.48	0.02
18	0.07	0.61	0.02
19	0.07	0.72	0.02
20	0.06	0.55	0.02
21	0.07	0.31	0.02
22	0.13	0.59	0.04
23	0.13	0.21	0.09
24	0.19	0.70	0.08
25	0.13	0.20	0.04
26	0.11	0.35	0.04
27	0.12	0.21	0.06
28	0.13	0.28	0.07
29	0.16	0.30	0.09
30	0.13	0.36	0.07
31	0.15	0.56	0.06
32	0.14	0.61	0.03
33	0.14	0.52	0.04
34	0.13	0.74	0.03
35	0.12	0.76	0.03
36	0.11	1.36	0.04
37	0.10	0.93	0.04
38	0.09	0.58	0.02
39	0.09	0.56	0.03
40	0.08	0.52	0.02
41	0.09	0.62	0.04
42	0.09	0.70	0.03
43	0.09	0.74	0.04
44	0.09	1.03	0.02
45	0.09	0.61	0.04
46	0.09	0.64	0.03

Table 27. Mean, Maximum, Minimum of Diffuse Attenuation In Year 2003

Running Weeks	Mean Diffuse Attenuation	Maximum Diffuse Attenuation	Minimum Diffuse Attenuation
1	0.09	0.38	0.04
2	0.09	0.70	0.05
3	0.10	0.72	0.03
4	0.11	0.47	0.03
5	0.11	0.55	0.04
6	0.13	1.47	0.04
7	0.15	1.03	0.03
8	0.11	1.67	0.03
9	0.14	0.93	0.03
10	0.10	0.58	0.03
11	0.09	0.49	0.03
12	0.08	0.41	0.03
13	0.07	0.51	0.03
14	0.07	0.55	0.03
15	0.06	0.48	0.02
16	0.05	0.33	0.02
17	0.05	0.61	0.02
18	0.06	1.00	0.02
19	0.06	0.95	0.02
20	0.04	0.70	0.01
21	0.10	0.59	0.03
22	0.13	0.18	0.10
23	0.17	0.36	0.05
24	0.07	0.26	0.04
25	0.09	0.28	0.03
26	0.09	0.27	0.04
27	0.08	0.18	0.05
28	0.12	0.51	0.04
29	0.14	0.36	0.06
30	0.16	0.47	0.06
31	0.15	0.56	0.06
32	0.11	0.44	0.05
33	0.10	0.47	0.04
34	0.10	1.29	0.02
35	0.11	0.72	0.03
36	0.10	0.64	0.04
37	0.09	0.80	0.03
38	0.09	0.52	0.04
39	0.08	0.59	0.03
40	0.08	0.65	0.03
41	0.10	0.59	0.04
42	0.10	0.84	0.04
43	0.09	0.82	0.04
44	0.10	0.53	0.04
45	0.10	0.64	0.04
46	0.10	0.67	0.05

Table 28. Mean, Maximum, Minimum of Diffuse Attenuation In Year 2004

Running Weeks	Mean Diffuse Attenuation	Maximum Diffuse Attenuation	Minimum Diffuse Attenuation
1	0.10	0.64	0.04
2	0.11	0.55	0.04
3	0.10	0.59	0.04
4	0.10	0.72	0.03
5	0.10	0.59	0.04
6	0.11	0.93	0.04
7	0.12	0.84	0.04
8	0.11	0.58	0.03
9	0.09	0.46	0.03
10	0.08	0.53	0.04
11	0.07	0.58	0.03
12	0.06	0.47	0.03
13	0.06	0.61	0.03
14	0.06	0.46	0.03
15	0.06	0.95	0.02
16	0.05	0.47	0.02
17	0.06	0.48	0.03
18	0.07	0.24	0.03
19	0.07	0.72	0.02
20	0.08	0.80	0.02
21	0.07	0.69	0.02
22	0.15	0.64	0.05
23	0.12	0.64	0.04
24	0.15	0.24	0.09
25	0.14	0.38	0.05
26	0.17	0.31	0.05
27	0.17	0.38	0.05
28	0.13	0.17	0.10
29	0.16	0.31	0.08
30	0.16	0.44	0.06
31	0.16	0.69	0.05
32	0.15	1.23	0.04
33	0.15	0.58	0.04
34	0.13	0.69	0.03
35	0.12	0.53	0.04
36	0.11	0.64	0.03
37	0.10	0.51	0.04
38	0.10	0.74	0.04
39	0.11	0.51	0.03
40	0.09	0.46	0.03
41	0.08	0.69	0.03
42	0.08	0.55	0.04
43	0.09	0.42	0.04
44	0.09	0.48	0.04
45	0.09	0.59	0.04
46	0.08	0.32	0.04

Table 29. Mean, Maximum, Minimum of Diffuse Attenuation In Year 2005

Running Weeks	Mean Diffuse Attenuation	Maximum Diffuse Attenuation	Minimum Diffuse Attenuation
1	0.09	0.58	0.04
2	0.10	0.69	0.04
3	0.10	0.69	0.03
4	0.10	0.72	0.03
5	0.10	0.67	0.03
6	0.11	0.78	0.03
7	0.11	0.61	0.03
8	0.11	0.86	0.03
9	0.12	0.91	0.03
10	0.10	0.80	0.03
11	0.09	0.62	0.03
12	0.09	0.62	0.03
13	0.07	0.84	0.03
14	0.07	0.52	0.02
15	0.06	0.58	0.02
16	0.06	0.59	0.02
17	0.06	0.34	0.03
18	0.06	0.51	0.02
19	0.07	0.91	0.03
20	0.06	0.44	0.02
21	0.07	0.40	0.02
22	0.07	0.24	0.04
23	0.14	0.19	0.06
25	0.11	0.49	0.04
26	0.11	0.14	0.08
27	0.14	0.95	0.06
28	0.13	0.21	0.06
29	0.14	0.19	0.09
30	0.15	0.64	0.05
31	0.13	0.64	0.04
32	0.13	0.67	0.05
33	0.15	1.14	0.04
34	0.14	1.03	0.04
35	0.11	0.62	0.03
36	0.11	0.58	0.02
37	0.10	0.58	0.03
38	0.09	1.47	0.03
39	0.09	1.00	0.04
40	0.09	0.56	0.04
41	0.09	0.61	0.03
42	0.10	0.69	0.03
44	0.10	0.62	0.04
45	0.10	0.62	0.04
46	0.11	0.91	0.05

Table 30. Mean, Maximum, Minimum of Diffuse Attenuation In Year 2006

Running Weeks	Mean Diffuse Attenuation	Maximum Diffuse Attenuation	Minimum Diffuse Attenuation
1	0.10	0.40	0.04
2	0.11	0.52	0.04
3	0.11	0.55	0.04
4	0.12	0.59	0.04
5	0.14	0.69	0.04
6	0.13	0.82	0.04
7	0.12	1.47	0.04
8	0.11	0.62	0.03
9	0.10	0.72	0.03
10	0.08	0.69	0.03
11	0.08	0.51	0.03
12	0.07	0.72	0.03
13	0.06	0.65	0.03
14	0.06	0.72	0.03
15	0.06	0.89	0.02
16	0.06	0.67	0.02
17	0.06	0.61	0.02
18	0.06	0.72	0.02
19	0.05	0.26	0.02
20	0.08	0.47	0.03
21	0.07	0.62	0.02
22	0.07	1.00	0.02
23	0.11	0.23	0.03
26	0.10	0.24	0.06
27	0.13	0.21	0.05
28	0.16	0.36	0.05
29	0.12	0.34	0.06
30	0.13	0.38	0.04
31	0.14	0.59	0.04
32	0.13	0.69	0.04
33	0.16	1.26	0.05
34	0.14	1.63	0.03
35	0.12	0.65	0.03
36	0.11	0.86	0.03
37	0.10	0.70	0.04

CHAPTER 7

SUMMARY AND CONCLUSION

The phytoplankton in the ocean plays an important role not only because it produces food that sustains the marine life, but also it is capable of regulating CO₂ and there by influencing the climate of the earth system. It is in this context that, the present thesis aims at studying the chlorophyll pigmentation concentration in the northern Arabian Sea using remote sensing and GIS. The thesis is divided into seven chapters.

The first chapter deals with the introduction of Arabian Sea and the location of the study area. The spatial domain selected for the present study is Latitude: 15°N-25°N and Longitude: 45°E-75°E. The remote sensing data used for the study is the chlorophyll pigment concentrations, aerosol and diffuse attenuation coefficient obtained from SeaWiFS during August 1997 to September 2006 were used to understand the spatial variability of these parameters in the Arabian Sea.

The second chapter describes phytoplankton, chlorophyll, aerosol and diffuse attenuation. The importance of carbon cycle is also discussed in this chapter. Phytoplankton forms the basis of ocean life and also has the potential to regulate the CO₂ and oxygen levels in the atmosphere with its implication to climate of the earth system, which it has been a topic of immense interest to many of researchers. In view of this, the present study

aims at understanding the distribution of chlorophyll pigment concentration in the Northern Arabian Sea. Since the winds over the Northern Indian Ocean reverse semi-annually, from southwest during June to September to Northeast during November to February, it is natural to expect a similar variation in the chlorophyll pigment concentration in the northern Arabian Sea. While understanding the pattern of variability in the chlorophyll pigment concentrations, possible factors that are responsible for the observed variability is also explored through this project work.

The third chapter is an introduction to satellite remote sensing and its various applications. The ocean color remote sensing to estimate chlorophyll pigment concentration is dealt in detail, as this is the main data used for analysis. The sensor SeaWiFS (Sea-viewing Wide Field-of-view) and MODIS (Moderate Resolution Imaging Spectroradiometer) used to collect the data on three parameters i.e. chlorophyll pigment concentration, Aerosol and diffuse attenuation coefficient for the present study is also described in this chapter.

The fourth and fifth chapters deal with introduction to Geographical information system (GIS) and methodology respectively. Various steps involved in the processing and analysis of the chlorophyll pigment concentration, aerosol and diffuse attenuation coefficient are listed in fifth chapter with appropriate details.

The result formed the sixth chapter wherein the seasonal and inter-annual variability was analyzed using the above mentioned 3 parameters and the relationship among them was explored. The study showed that the northern

Arabian Sea undergoes strong seasonality in its chlorophyll pigment concentrations, aerosol as well as in the diffuse attenuation coefficient. Over the Arabian Sea the wind reverses semi-annually, with strong southwesterly winds during summer monsoon (June-September) followed by comparatively weak northeasterly winds during winter monsoon (November-February). Between the monsoons the winds were weak and variable during spring (April-May) and fall (October) when the incoming solar radiation warmed the surface ocean and made it highly stratified. There were two periods of high chlorophyll concentrations, one during summer monsoon (June to September) and the other during winter (November to February). Out of the two, higher concentrations occurred in summer. During summer upwelling along the Somalia as well as the Arabian coasts bring nutrient rich subsurface cold waters to the surface, and help fertilize the upper ocean where enough sunlight was available. The observed high chlorophyll pigment concentration during August and October was the result of this. Though October was the period of secondary heating in the Arabian Sea, in the northern Arabian Sea, the upwelled waters from Arabian upwelling system keeps this region fertile till October. During winter, the dry northeast trade winds from the continent cooled the surface waters by way of evaporative cooling as well as cooling due to net heat loss. This initiated convective mixing and brought nutrients from deeper waters to the surface and helped in fertilizing the ocean.

The correlation between Chlorophyll and Diffuse attenuation coefficient was better than that with aerosol. This was because in the absence of any major sediment input through river system, the turbidity of water depends on the suspended matter present in the water column and in the open ocean region it was primarily due to the chlorophyll. This was the reason for high

correlation between chlorophyll pigment concentrations with diffuse attenuation coefficient in the northern Arabian Sea. The weak relationship between chlorophyll pigment concentration and aerosol was because the aerosol in the atmosphere was controlled by several factors such as dust input, change in the land use pattern associated with deforestation, agriculture, human settlement and urbanization. The aerosol in the air over the Arabian Sea showed strong seasonality. In all the 10 years, the chlorophyll pigment concentrations showed very strong correlation with diffuse attenuation coefficient, except during 2002, 2003 and 2005. The relationship between chlorophyll pigment concentrations and aerosol was consistently weak in all the years.

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