

**INTERANNUAL VARIABILITY
OF
CHLOROPHYLL CONCENTRATION
IN THE
EASTERN ARABIAN SEA**

A Summer Internship Report

BY
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DECLARATION

I hereby declare that the work incorporated in this dissertation (as a part of the M.Sc course) is original and carried out at National Institute of Oceanography, Dona Paula, Goa under the guidance of Dr. S. Prasanna Kumar (Senior Scientist, Physical Oceanography Department) and it has not been submitted in part or in full any degree, diploma of any other University.

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CERTIFICATE

This is to certify that the dissertation work entitled, “*INTER ANNUAL VARIABILITY OF CHLOROPHYLL CONCENTRATION IN THE EASTERN ARABIAN SEA*” is a bonafide and authentic work carried out by Miss Satlaj Karanje as a part of the summer training programme held at National Institute of Oceanography, Goa, in May-June, 2008 and is according to the results obtained bY her under my guidance and supervision.

S. Prasanna Kumar

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CONTENTS

1. INTRODUCTION

Chlorophyll and Phytoplankton in ocean and their Importance.

2. DATA DESCRIPTION

Website and system parameters

- Chlorophyll a concentration
- Diffused Attenuation Coefficient

3. RESULTS

- Chlorophyll concentration according to Time Variation
- Climatological Chlorophyll concentration
- Annual Chlorophyll concentration

1. INTRODUCTION

Introduction

The sea can be in many different colours. What colours you see depend not only on the weather and light conditions, but also on what the water contains. This is why ocean colour measurements have become an important tool for studying plant life in the ocean.

Calculating chlorophyll from measurements of watercolour is one of the successes of optical oceanography over the last 30 years or so. As a result we can now use satellite measurements to tell us how well plants in the ocean are growing.

Like plants on land, plants growing in water contain chlorophyll, a molecule that allows the plant to trap the energy in sunlight for photosynthesis. Chlorophyll absorbs blue and red light, so it looks green to us. That is why grass and leaves are green.

The most important plants in the sea are phytoplankton - microscopic plants that float suspended in the water. Where there is a lot of phytoplankton, most of the blue light is absorbed, so the water looks green. Where there are none (or very few), the blue light is not absorbed, so the water looks blue.

The balance between blue and green (the blue-green ratio) to calculate how much chlorophyll in the water contains. This allows them to create worldwide maps of chlorophyll from satellite images of ocean colour

Bright green usually tells you there are millions of microscopic plants in the water, but a very similar green can be seen where rivers wash soil into the sea. Optical oceanographers around the world are hard at work trying to tell the two apart.

In the open ocean away from land, particles that scatter light and colour the water green, are almost certainly tiny plants. In this type of water we can now calculate chlorophyll from ocean colour measurement and be confident about the results.

Near land it is not always so simple. Rivers often bring mud and the remains of dead plants into the sea. This mixture has a yellow-brown colour. Where it mixes with seawater the ocean is coloured green, a colour, which is easily mistaken for the green of chlorophyll.

Chlorophyll a concentrations change with the factors that affect phytoplankton growth. Some of those factors are:

- Amount of sunlight
- Nutrient concentrations (nitrate and phosphate)
- Amount of mixing (stratification)
- Water temperature
- Water quality

Phytoplankton

Phytoplankton is microscopic plants that live in the ocean. There are many species of phytoplankton, each of which has a characteristic shape. Collectively, phytoplankton grows abundantly in oceans around the world and is the foundation of the marine food chain. Small fish, and some species of

whales, eat them as food. Larger fish then eat the smaller fish. Humans catch and eat many of these larger fish. Since phytoplankton depends upon certain conditions for growth, they are a good indicator of change in their environment. For these reasons, and because they also exert a global-scale influence on climate, phytoplankton are of primary interest to oceanographers and Earth scientists around the world.

Like their land-based relatives, phytoplankton requires sunlight, water, and nutrients for growth. Because sunlight is most abundant at and near the sea surface, phytoplankton remains at or near the surface. Also like terrestrial plants, phytoplankton contains the pigment chlorophyll, which gives them their greenish color. Chlorophyll is used by plants for photosynthesis, in which sunlight is used as an energy source to fuse water molecules and carbon dioxide into carbohydrates—plant food. Phytoplankton (and land plants) use carbohydrates as "building blocks" to grow fish and humans consume plants to get these same carbohydrates.

Remote Sensing

Some Earth observing satellites measure the characteristics of light, or radiance, coming from the Earth's surface. To learn about what is in the water using observations from space, we must first know what influences the color of water. Samples of ocean water are taken and their concentrations of phytoplankton and their chlorophyll are analyzed; these concentrations will then be correlated with the measured radiances. As these measurements are made, researchers hope to find consistent relationships between the radiances and the surface variables that are being measured, which will allow them to construct an algorithm. The algorithm will calculate a specific variable, such as chlorophyll concentration, based solely on the radiance data. Satellite data will then be used in these algorithms to calculate the geophysical variables over large areas of the Earth

The goal of ocean color remote sensing algorithms is to distinguish different types of water, and the constituents that determine a particular color. Ideally, a useful algorithm would calculate the concentration of suspended particulates in the muddy water, and the concentration of chlorophyll in both turbid and clear water.

A part of the ocean with only one kind of phytoplankton will have a fairly uniform color. In these cases, a fairly simple relationship exists between the color that the satellite observes and the density of phytoplankton. Ratios of light intensity detected at various wavelengths of the visible and infrared spectrum have been used in algorithms to calculate vegetation density or chlorophyll concentration. However, if water contains different species of phytoplankton as well as sediments, it becomes much more difficult to find simple relationships between optical properties and geophysical characteristic.

To further complicate the matter, instruments in space tend to change over time, and they usually can't be re-calibrated. Unfortunately, algorithms such as those described above rely on very accurate measurements of radiance. Thus mission operations ensure that a very high level of precision knows calibration of the instrument. Several different ways of calibrating these sensors while the satellite is in space have been devised.

Instruments

The primary instruments NASA uses to investigate ocean color are SeaWiFS and MODIS:

- SeaWiFS

The purpose of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project is to provide useful data on ocean color to the Earth science community. SeaWiFS flies on the OrbView-2 satellite, but beyond the

instrument itself, the SeaWiFS Project has developed and operates a research data system that processes, calibrates, validates, archives and distributes data received from an Earth-orbiting ocean color sensor.

Chlorophyll

With the SeaWiFS instrument, NASA has gathered the first record of photosynthetic productivity in the oceans. The process begins with a measurement of surface chlorophyll concentration. Chlorophyll is the material that allows plant cells to convert sunlight into energy, thus enabling them to grow. It's a green substance, and thus a good indicator of overall plant health: robust forests, lush lawns and vibrant phytoplankton blooms appear green. By measuring chlorophyll concentration, scientists can determine the health and growth of plants in a given area. By extension, healthy color signatures indicate the successful use of carbon, the fundamental building block for life.

Measuring chlorophyll can identify areas rich in nutrients and monitor such processes such as upwelling. As the surface water moves offshore, cold, nutrient-rich water upwells from below to replace it. This upwelling provides nutrients needed for the growth of marine phytoplankton, which, along with larger seaweeds, in turn nourishes the incredible diversity of creatures.

Sensors such as SeaWiFS can "see" the effects of this upwelling-related productivity because the chlorophyll-bearing phytoplankton reflect predominantly green light back into space as opposed to the water itself which reflects predominantly blue wavelengths back to space.

Optical Remote Sensing

Optical remote sensing makes use of visible, near infrared and short wave infrared sensors to form images of the earth's surface by detecting the solar radiation reflected from targets on the ground. Different materials reflect and absorb differently at different wavelengths. Thus, their spectral reflectance signatures in the remotely sensed images can differentiate the targets. There are four types of optical imaging systems commonly in use:

Panchromatic imaging system: The sensor is a single channel detector sensitive to radiation within a broad wavelength range. If the wavelength range coincides with the visible range, then the resulting image resembles a "black-and-white" photograph taken from space. The physical quantity being measured is the apparent brightness of the targets. The spectral information or "colour" of the targets is lost. An example of a panchromatic imaging system is:

- SPOT HRV-PAN

Multispectral imaging system: The sensor is a multichannel detector. Each channel is sensitive to radiation within a narrow wavelength band. The resulting image is a multilayer image, which contains both the brightness and spectral (colour) information of the targets being observed. Examples of multispectral systems are:

- LANDSAT MSS
- LANDSAT TM
- SPOT HRV-XS

Superspectral Imaging Systems: A superspectral imaging sensor has many more spectral channels (typically >10) than a multispectral sensor. The bands have narrower bandwidths, enabling the finer spectral characteristics of the targets to be captured by the sensor. Examples of superspectral systems are:

- MODIS
- MERIS

Hyperspectral Imaging Systems: A hyperspectral imaging system is also known as an "imaging spectrometer". It acquires images in about a hundred or more contiguous spectral bands. The precise spectral information contained in a hyperspectral image enables better characterisation and identification of targets. Hyperspectral images have potential applications in such fields as precision agriculture (e.g. monitoring the types, health, moisture status and maturity of crops), coastal management (e.g. monitoring of phytoplanktons, pollution, bathymetry changes). An example of a hyperspectral system is:

- Hyperion on EO1 satellite

2. DATA DESCRIPTION

Ocean Biology Processing Group (OBPG) SeaWiFS global 9-km resolution data products.

- Website Name:
<http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.seawifs.shtml>
- Name Of Sensor: SeaWiFS (Sea_viewing Wide Field_of_view Sensor)
- Data Analysed: Chlorophyll-a concentration
- Selected Parameters: Diffuse_attenuation_coefficient_at_490_nm
- Selected Area: Latitude=[5.0N, 16.0N]
Longitude=[70.0E, 80.0E]
- Selected Time Period: January, 1998 to December, 2007
- Output Data Resolution: 1.0 Degree
- Undefined/Missing Value: -99999

SeaWiFS

SeaWiFS stands for Sea-viewing Wide Field-of-view Sensor. It is the only scientific instrument on GeoEye's OrbView-2 (AKA SeaStar) satellite, and was a follow-on experiment to the Coastal Zone Color Scanner on Nimbus 7. Launched August 1, 1997 on an Orbital Sciences Pegasus small air launched rocket, the

instrument began scientific operations on 18 September 1997. The sensor resolution is 1.1 km (LAC), 4.5 km (GAC). The sensor records information in the following optical bands:

Instrument Bands

Band = Wavelength

1 = 402-422 nm

2 = 433-453 nm

3 = 480-500 nm

4 = 500-520 nm

5 = 545-565 nm

6 = 660-680 nm

7 = 745-785 nm

8 = 845-885 nm

Mission Characteristics

Orbit Type: Sun Synchronous at 705 km

Equator Crossing: Noon +20 min, descending

Orbital Period: 99 minutes

Swath Width: 2,801 km LAC/HRPT (58.3 degrees)

Swath Width: 1,502 km GAC (45 degrees)

Spatial Resolution: 1.1 km LAC, 4.5 km GAC

Real-Time Data Rate: 665 kbps

Revisit Time: 1 day

Digitization: 10 bits

The instrument has been specifically designed to monitor ocean characteristics such as chlorophyll-a concentration and water clarity. The instrument is able to tilt up to 20 degrees to avoid sunlight from the sea surface. This feature is important at equatorial latitudes where glint from sunlight often obscures watercolour.

Diffuse Attenuation Coefficient

Natural waters have what are often referred to as inherent and apparent optical properties. Inherent optical properties (IOP) are a function of the water and optically active substances in it and are not influenced by the geometric structure of the light fields.

Apparent optical properties (AOP) are derived from measurements of natural light fields in a water body. They depend on the geometry of the light fields and are related to absorption and scattering. The most common of these properties is the diffuse attenuation coefficient for downwelling irradiance (K_d). Irradiance at a given depth (E_z) is a function of the irradiance at the surface (E_0), the diffuse attenuation coefficient, and the depth interval (Z) according to the following relationship, where e is the base of the natural logarithms:

$$E_z = E_0 e^{-K_d Z}$$

From this we can see that when light penetrates water its intensity decreases exponentially with increasing depth.

The diffuse attenuation coefficient can thus be estimated by taking measurements at different depths, and using the above formula to compute K_d . The units for K_d are m^{-1} .

$$K_d = \frac{\ln \left(\frac{E_0}{E_z} \right)}{Z}$$

From this we can see that when light penetrates water its intensity decreases exponentially with increasing depth.

The diffuse attenuation coefficient can thus be estimated by taking measurements at different depths, and using the above formula to compute K_d . The units for K_d are m^{-1} .

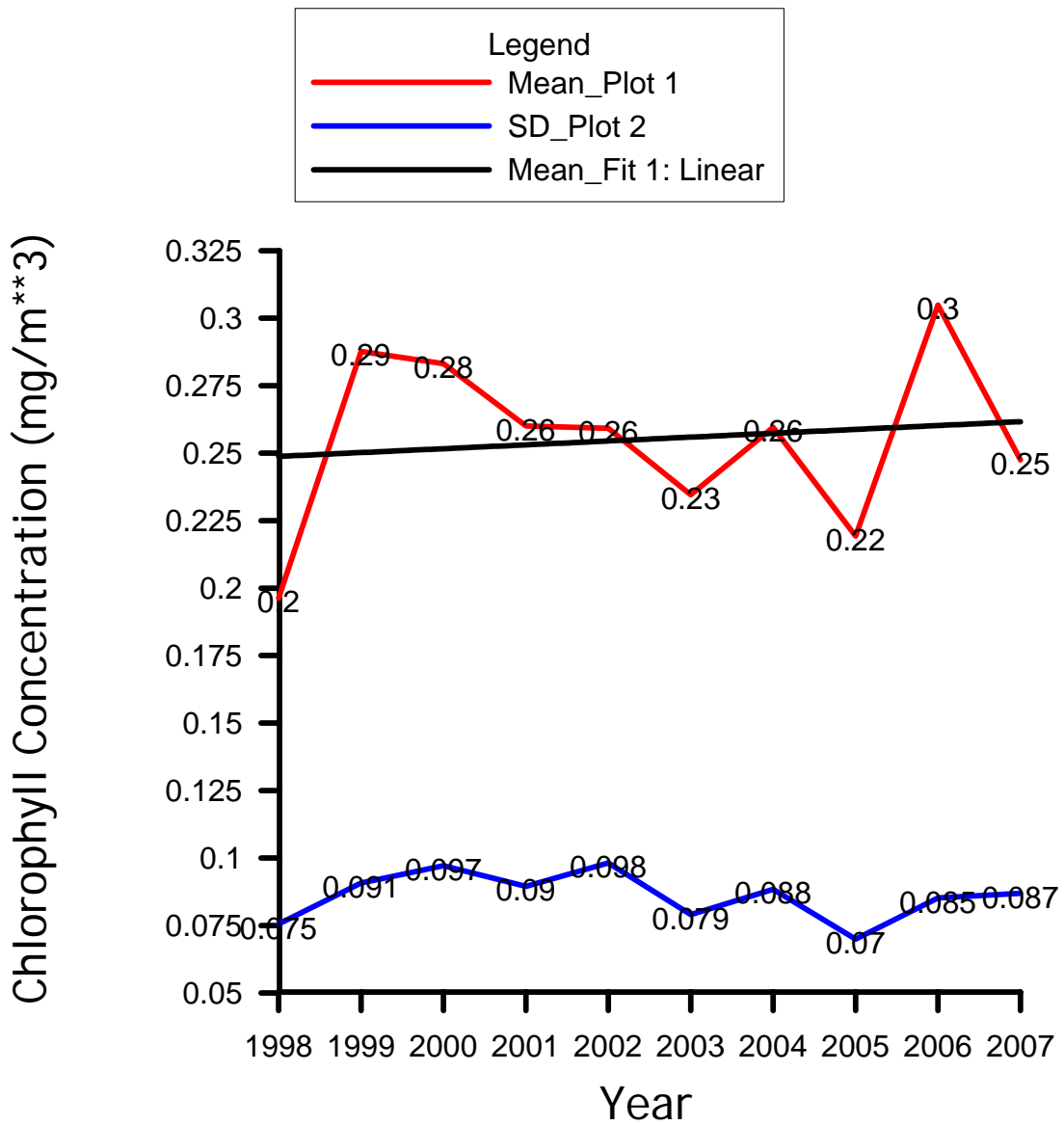
Using these diffuse attenuation coefficients (obtained from spectral irradiance measurements at different depths in the water), and using the fact that the attenuation in water decreases exponentially with respect to depth (given by the equation discussed earlier), we can plot the spectral curve for the underwater light field at various depths.

3. RESULTS

Chlorophyll Concentration

Monthly mean chlorophyll in January during 1998 to 2007

Chlorophyll Concentration (January)1998-2007

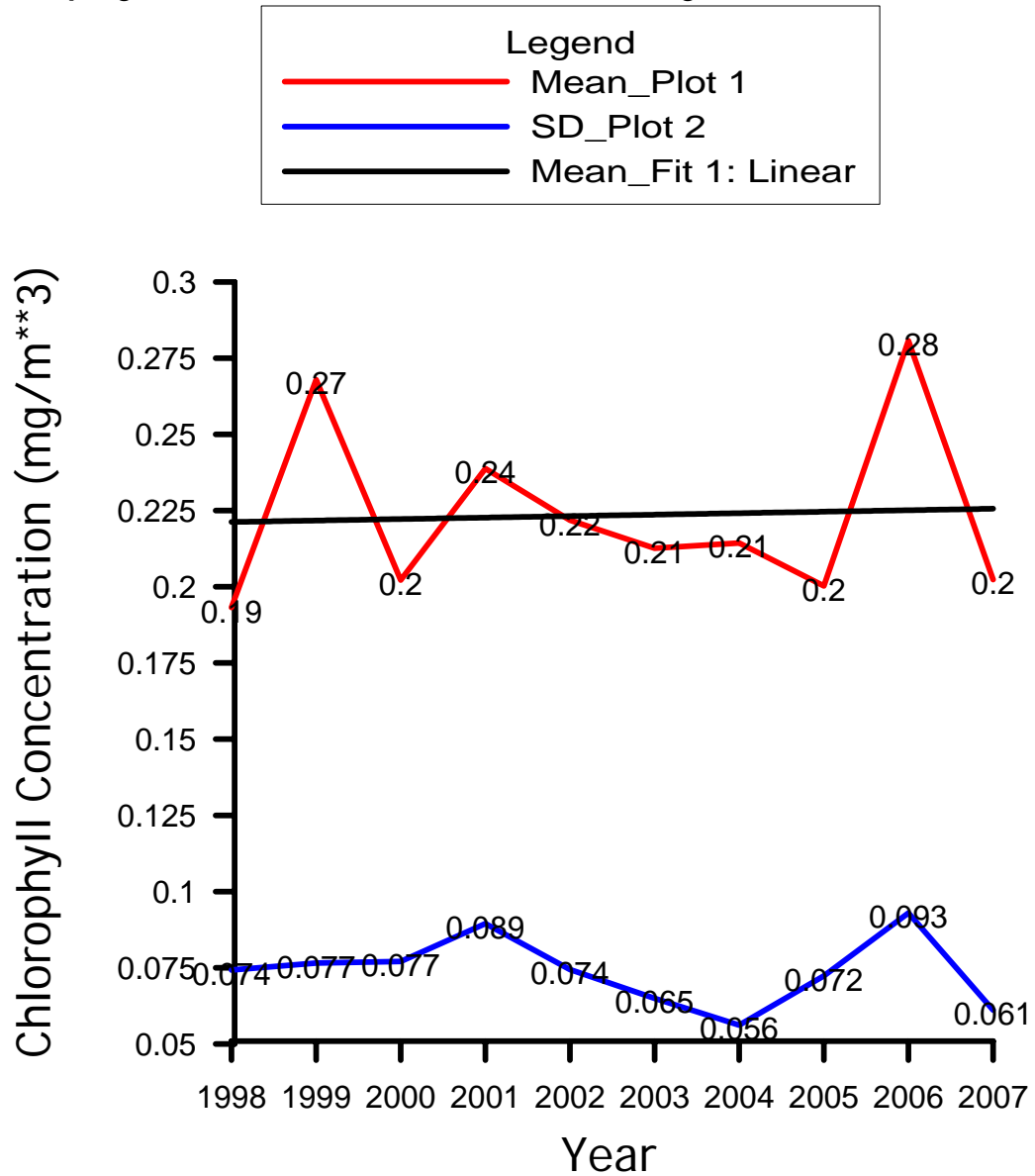


| Period | | Chlorophyll Concentration (mg/m**3) | | | |
|--------|---------|-------------------------------------|----------|-------------|-------------|
| Year | Month | Min | Max | Mean | SD |
| 1998 | January | 0.115919 | 0.506658 | 0.1962968 | 0.075480451 |
| 1999 | January | 0.152299 | 0.583982 | 0.28768289 | 0.090701973 |
| 2000 | January | 0.147365 | 0.574984 | 0.283160917 | 0.09709633 |
| 2001 | January | 0.135664 | 0.581019 | 0.260069 | 0.089526 |
| 2002 | January | 0.130446 | 0.567490 | 0.259251 | 0.098126 |
| 2003 | January | 0.128385 | 0.586411 | 0.234599419 | 0.079026732 |
| 2004 | January | 0.127870 | 0.589086 | 0.259599 | 0.088398 |
| 2005 | January | 0.121626 | 0.555613 | 0.219225 | 0.069929 |
| 2006 | January | 0.156893 | 0.528056 | 0.304912 | 0.085191 |
| 2007 | January | 0.130080 | 0.583513 | 0.247527 | 0.086869 |

Monthly mean chlorophyll in February during 1998 to 2007

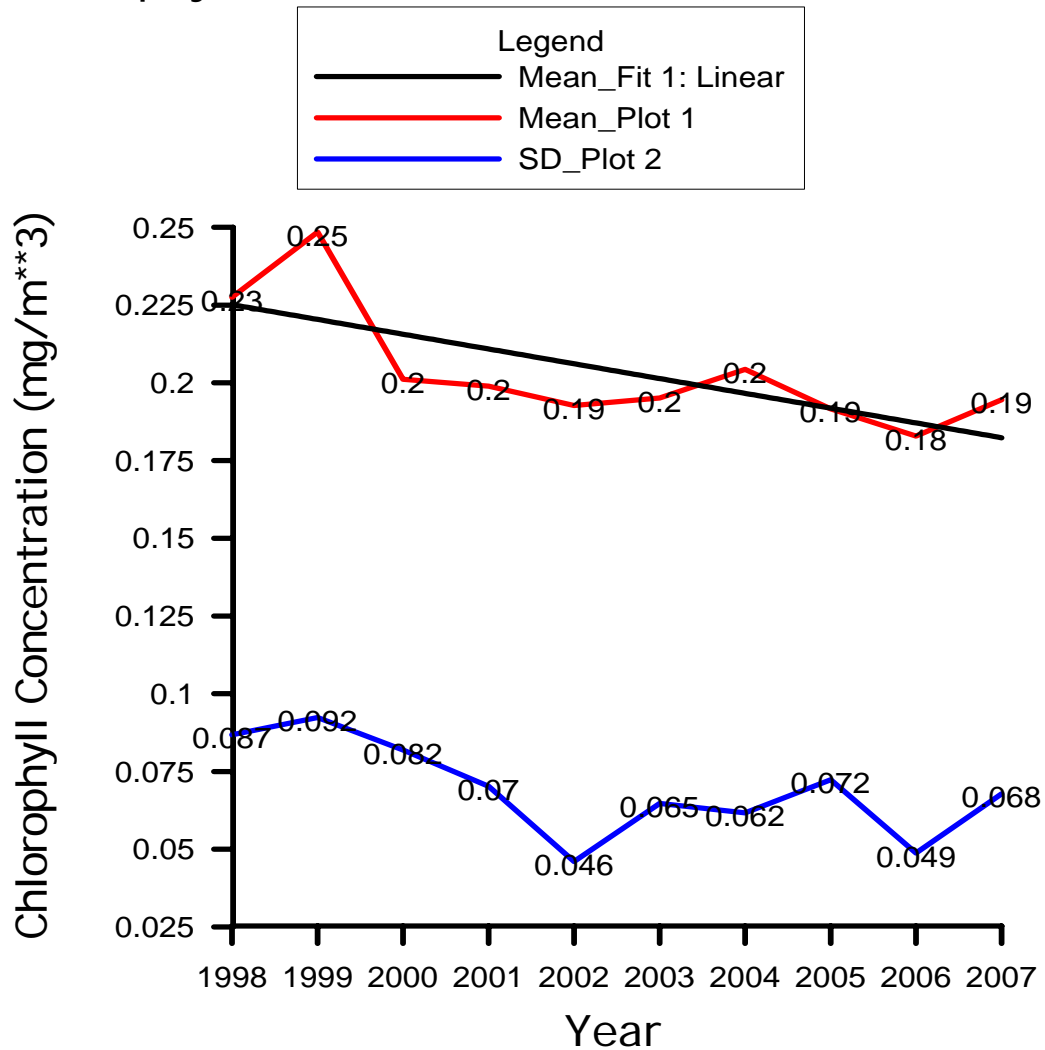
| Period | | Chlorophyll Concentration (mg/m**3) | | | |
|--------|----------|-------------------------------------|----------|----------|----------|
| Year | Month | Min | Min | Mean | SD |
| 1998 | February | 0.099486 | 0.468495 | 0.193176 | 0.074271 |
| 1999 | February | 0.168181 | 0.590033 | 0.267984 | 0.076582 |
| 2000 | February | 0.132417 | 0.598545 | 0.202186 | 0.077033 |
| 2001 | February | 0.149711 | 0.55755 | 0.238799 | 0.089441 |
| 2002 | February | 0.134327 | 0.487888 | 0.221794 | 0.074436 |
| 2003 | February | 0.142115 | 0.503548 | 0.212643 | 0.064959 |
| 2004 | February | 0.142343 | 0.480564 | 0.21437 | 0.05619 |
| 2005 | February | 0.121495 | 0.536176 | 0.200226 | 0.072346 |
| 2006 | February | 0.151242 | 0.561144 | 0.280731 | 0.092934 |
| 2007 | February | 0.109215 | 0.483597 | 0.202356 | 0.061072 |

Chlorophyll Concentration (February) 1998-2007



Monthly mean chlorophyll in March during 1998 to 2007

Chlorophyll Concentration (March) 1998-2007

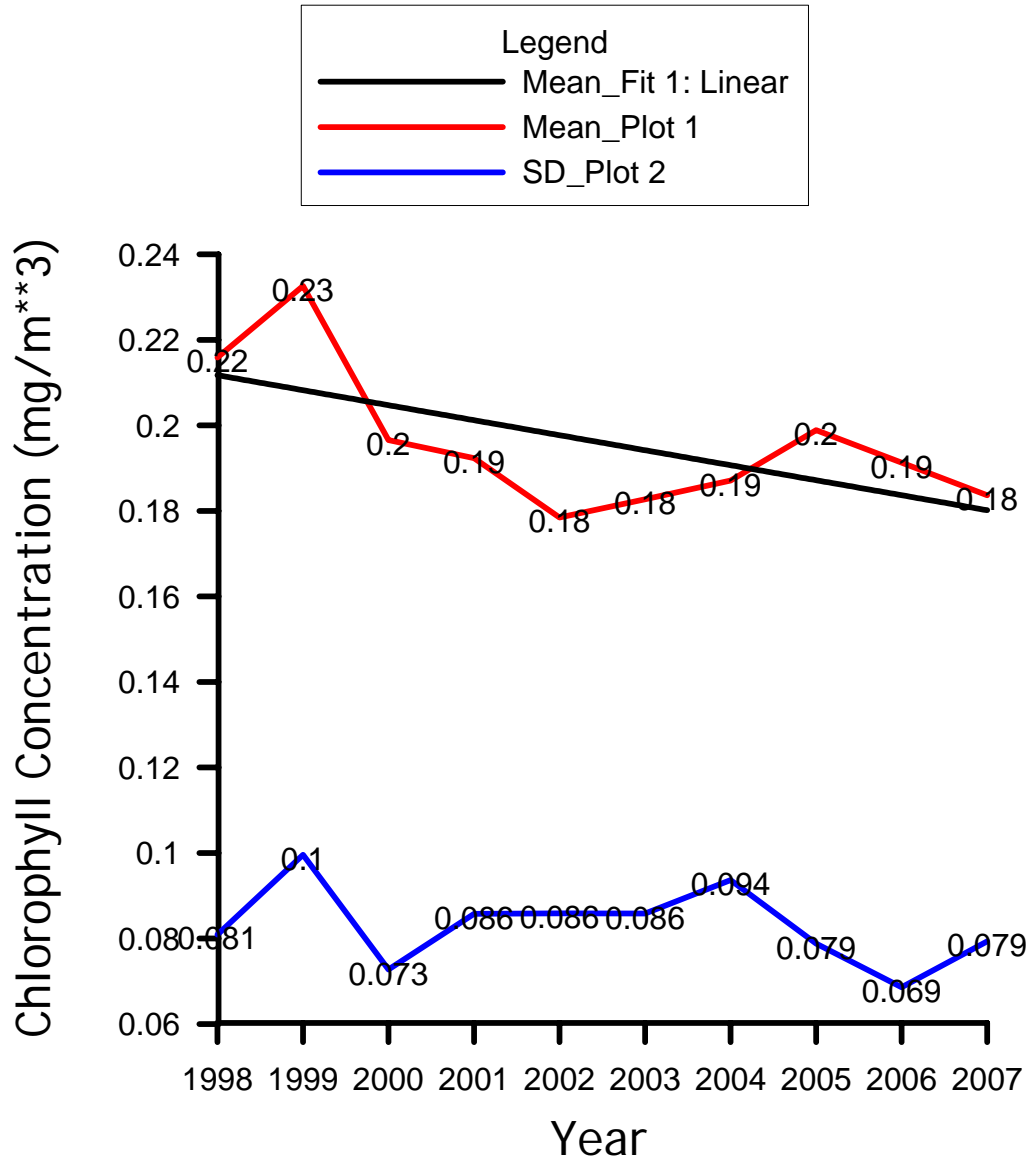


| Period | | Chlorophyll Concentration (mg/m**3) | | | |
|--------|-------|-------------------------------------|----------|-------------|-------------|
| Year | Month | Min | Min | Mean | SD |
| 1998 | March | 0.117906 | 0.585391 | 0.227546471 | 0.086823965 |
| 1999 | March | 0.145678 | 0.546686 | 0.248522 | 0.092377 |
| 2000 | March | 0.124375 | 0.586175 | 0.201137 | 0.081929 |
| 2001 | March | 0.121886 | 0.553682 | 0.19897 | 0.070214 |
| 2002 | March | 0.132701 | 0.351654 | 0.192731 | 0.046035 |
| 2003 | March | 0.130464 | 0.490705 | 0.195142 | 0.064701 |
| 2004 | March | 0.136374 | 0.529755 | 0.20434358 | 0.061691087 |
| 2005 | March | 0.128505 | 0.568783 | 0.191638 | 0.072331 |
| 2006 | March | 0.123463 | 0.444425 | 0.182925 | 0.048775 |

| | | | | | |
|------|-------|----------|----------|------------|----------|
| 2007 | March | 0.117638 | 0.573293 | 0.19459549 | 0.067791 |
|------|-------|----------|----------|------------|----------|

Monthly mean chlorophyll in April during 1998 to 2007

Chlorophyll Concentration (April) 1998-2007

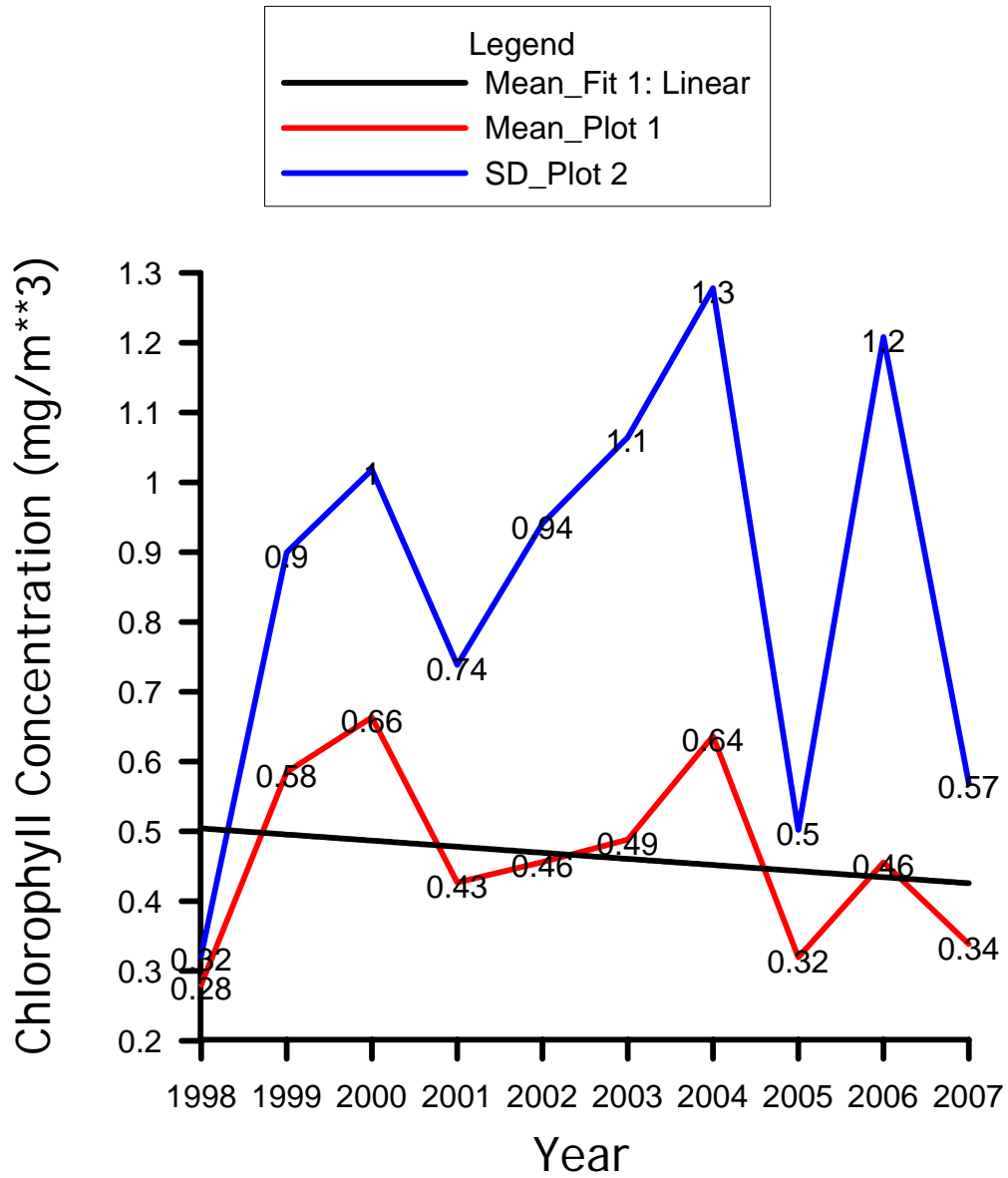


| Period | | Chlorophyll Concentration (mg/m**3) | | | |
|--------|-------|-------------------------------------|--------|-------------|-------------|
| Year | Month | Min | Min | Mean | SD |
| 1998 | April | 0.107604 | 0.5346 | 0.215881941 | 0.080923024 |

| | | | | | |
|------|-------|----------|----------|----------|----------|
| 1999 | April | 0.120475 | 0.597984 | 0.232627 | 0.099572 |
| 2000 | April | 0.090878 | 0.541587 | 0.19655 | 0.072747 |
| 2001 | April | 0.075458 | 0.570079 | 0.192323 | 0.085772 |
| 2002 | April | 0.085485 | 0.542821 | 0.178476 | 0.085874 |
| 2003 | April | 0.095608 | 0.539849 | 0.182737 | 0.085829 |
| 2004 | April | 0.099326 | 0.570689 | 0.18707 | 0.093668 |
| 2005 | April | 0.171202 | 0.543039 | 0.198874 | 0.078795 |
| 2006 | April | 0.117151 | 0.451380 | 0.191284 | 0.068602 |
| 2007 | April | 0.068534 | 0.549694 | 0.18369 | 0.079331 |

Monthly mean chlorophyll in May during 1998 to 2007

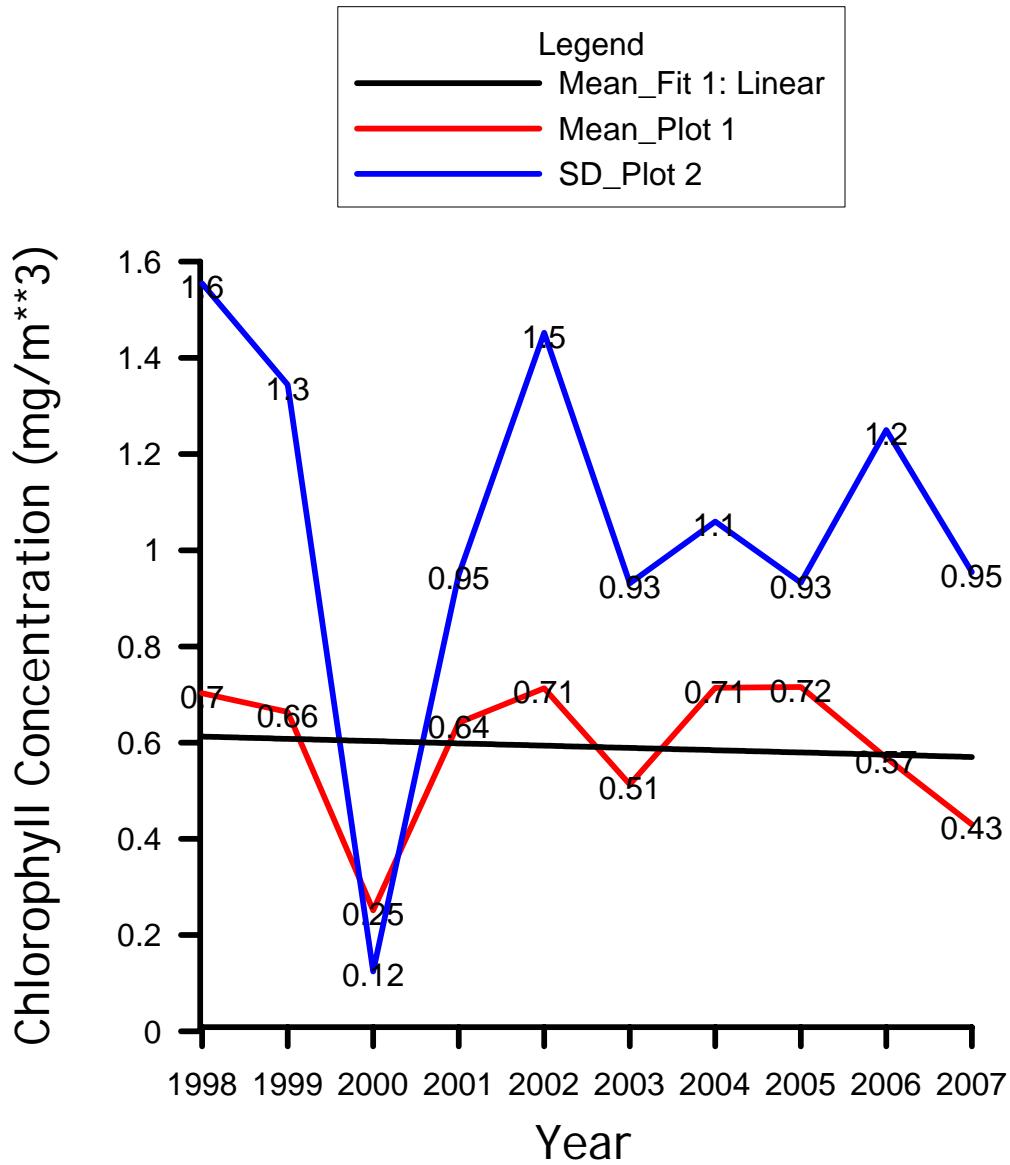
Chlorophyll Concentration (May) 1998-2007



| Period | | Chlorophyll Concentration (mg/m**3) | | | |
|--------|-------|-------------------------------------|----------|------------|------------|
| Year | Month | Min | Min | Mean | SD |
| 1998 | May | 0.049635 | 2.179220 | 0.28035445 | 0.32225755 |
| 1999 | May | 0.105960 | 5.217650 | 0.584843 | 0.899697 |
| 2000 | May | 0.108675 | 5.894390 | 0.663268 | 1.018087 |
| 2001 | May | 0.098163 | 4.151780 | 0.426751 | 0.738455 |
| 2002 | May | 0.088288 | 5.467930 | 0.455939 | 0.940941 |
| 2003 | May | 0.072984 | 6.954060 | 0.488321 | 1.064592 |
| 2004 | May | 0.127921 | 7.644380 | 0.636307 | 1.278236 |

| | | | | | |
|------|-----|----------|----------|----------|----------|
| 2005 | May | 0.096611 | 3.353550 | 0.319542 | 0.502388 |
| 2006 | May | 0.074505 | 9.699940 | 0.455594 | 1.20824 |
| 2007 | May | 0.078687 | 3.264950 | 0.338383 | 0.569012 |

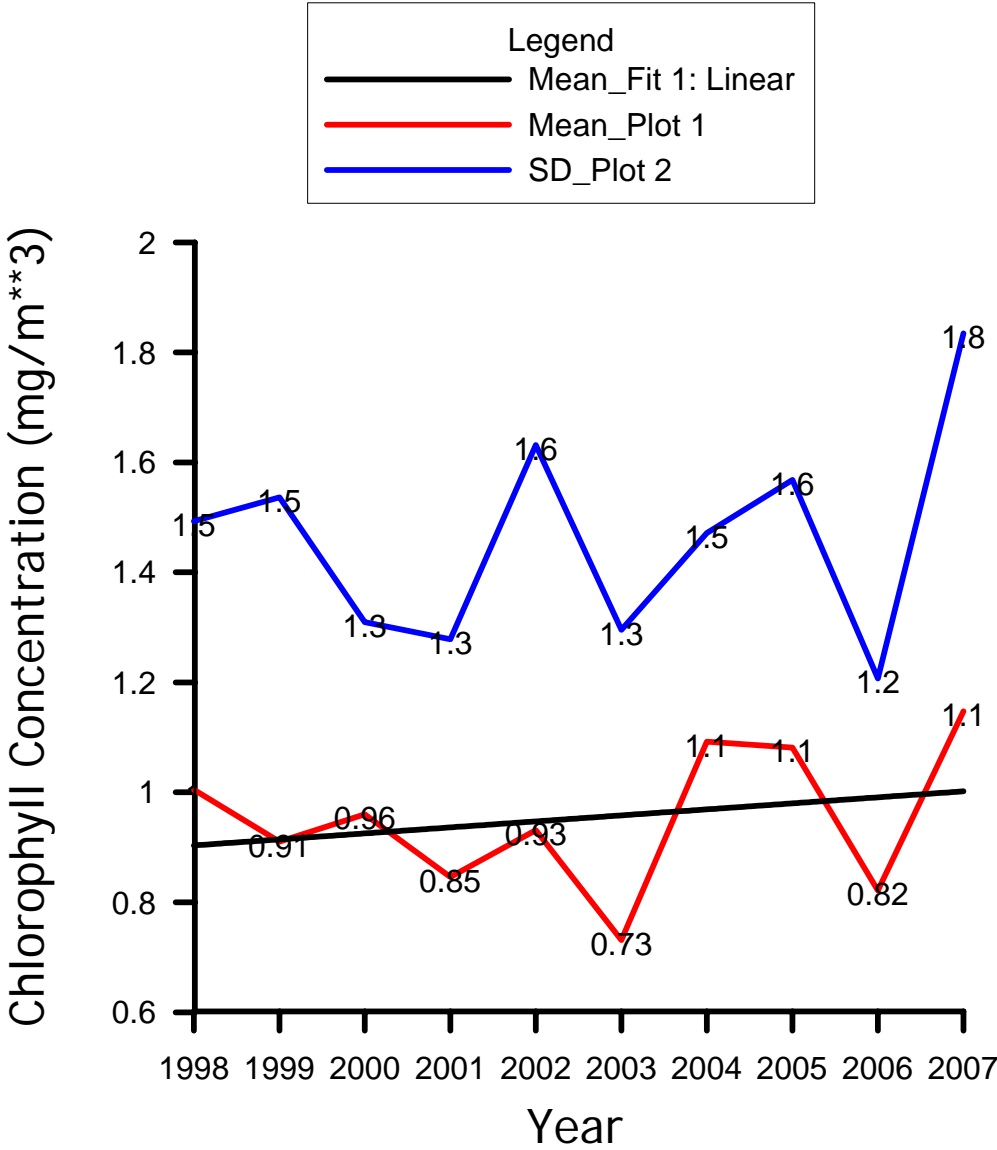
Chlorophyll Concentration (June)1998-2007



| Period | | Chlorophyll Concentration (mg/m**3) | | | |
|--------|-------|-------------------------------------|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | June | 0.116510 | 9.960480 | 0.702551 | 1.554645 |

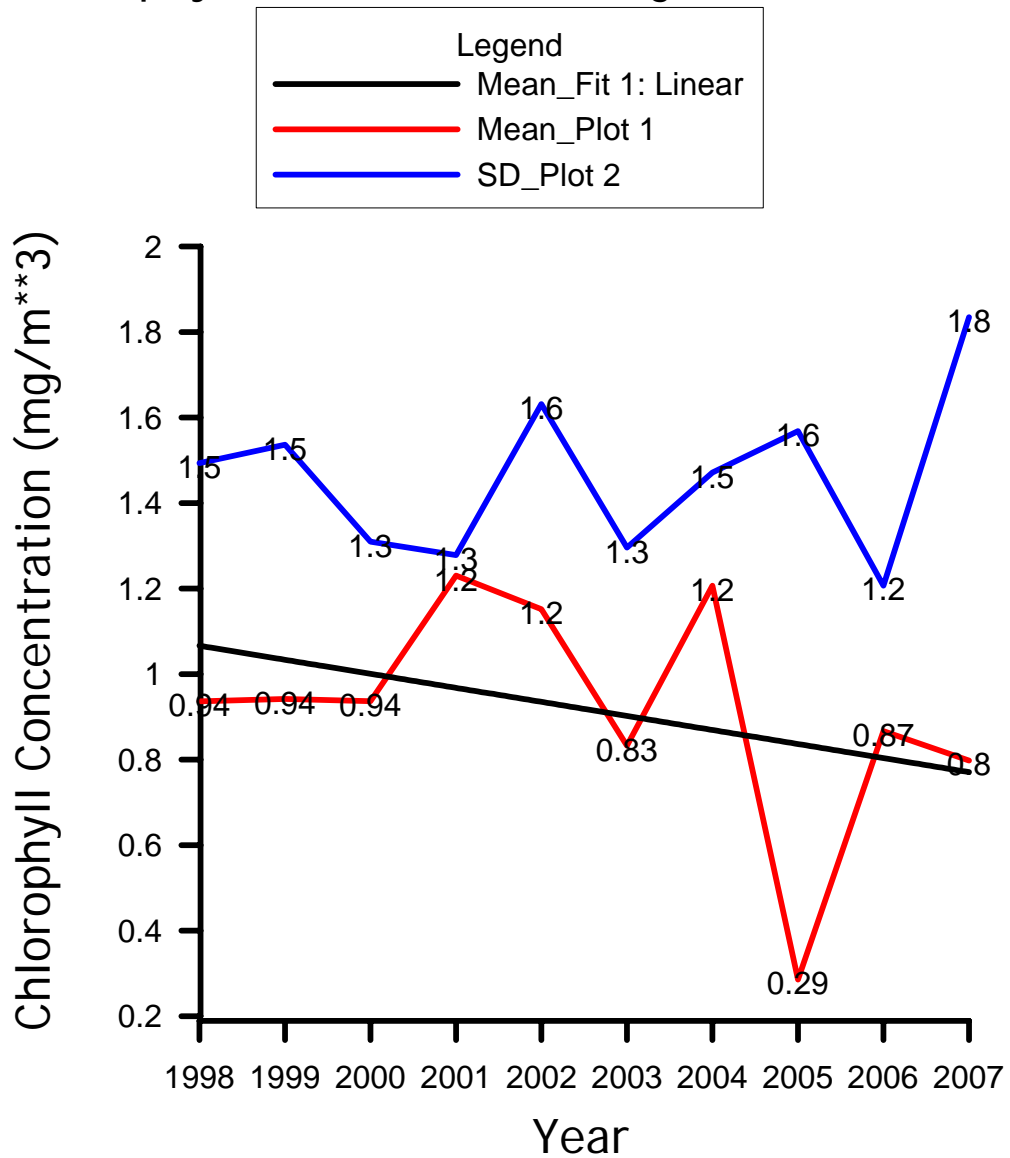
| | | | | | |
|------|------|----------|----------|----------|----------|
| 1999 | June | 0.101980 | 7.909830 | 0.663969 | 1.343921 |
| 2000 | June | 0.124359 | 5.983430 | 0.251472 | 0.124357 |
| 2001 | June | 0.124926 | 4.257020 | 0.641499 | 0.949435 |
| 2002 | June | 0.124475 | 9.447480 | 0.713138 | 1.45223 |
| 2003 | June | 0.079407 | 5.504660 | 0.513164 | 0.931152 |
| 2004 | June | 0.145367 | 6.338600 | 0.714007 | 1.059723 |
| 2005 | June | 0.106529 | 4.141230 | 0.715978 | 0.932412 |
| 2006 | June | 0.103493 | 8.941730 | 0.568587 | 1.249939 |
| 2007 | June | 0.086221 | 7.333640 | 0.430176 | 0.954468 |

Chlorophyll Concentration (Jully) 1998-2007



| Period | | Chlorophyll Concentration (mg/m ³) | | | |
|--------|-------|--|----------|-------------|-----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | July | 0.148852 | 8.927370 | 1.005028788 | 1.493174 |
| 1999 | July | 0.109993 | 9.329340 | 0.910385 | 1.536307 |
| 2000 | July | 0.150012 | 7.327600 | 0.959887 | 1.309534 |
| 2001 | July | 0.094109 | 6.102340 | 0.846229 | 1.278345 |
| 2002 | July | 0.114884 | 7.809880 | 0.931339 | 1.631558 |
| 2003 | July | 0.124559 | 7.270100 | 0.731167 | 1.295615 |
| 2004 | July | 0.140112 | 7.529610 | 1.092355 | 1.471404 |
| 2005 | July | 0.122328 | 8.365060 | 1.0813 | 1.568241 |
| 2006 | July | 0.088359 | 5.913350 | 0.821535 | 1.2070276 |
| 2007 | July | 0.118143 | 9.787330 | 1.147339 | 1.834658 |

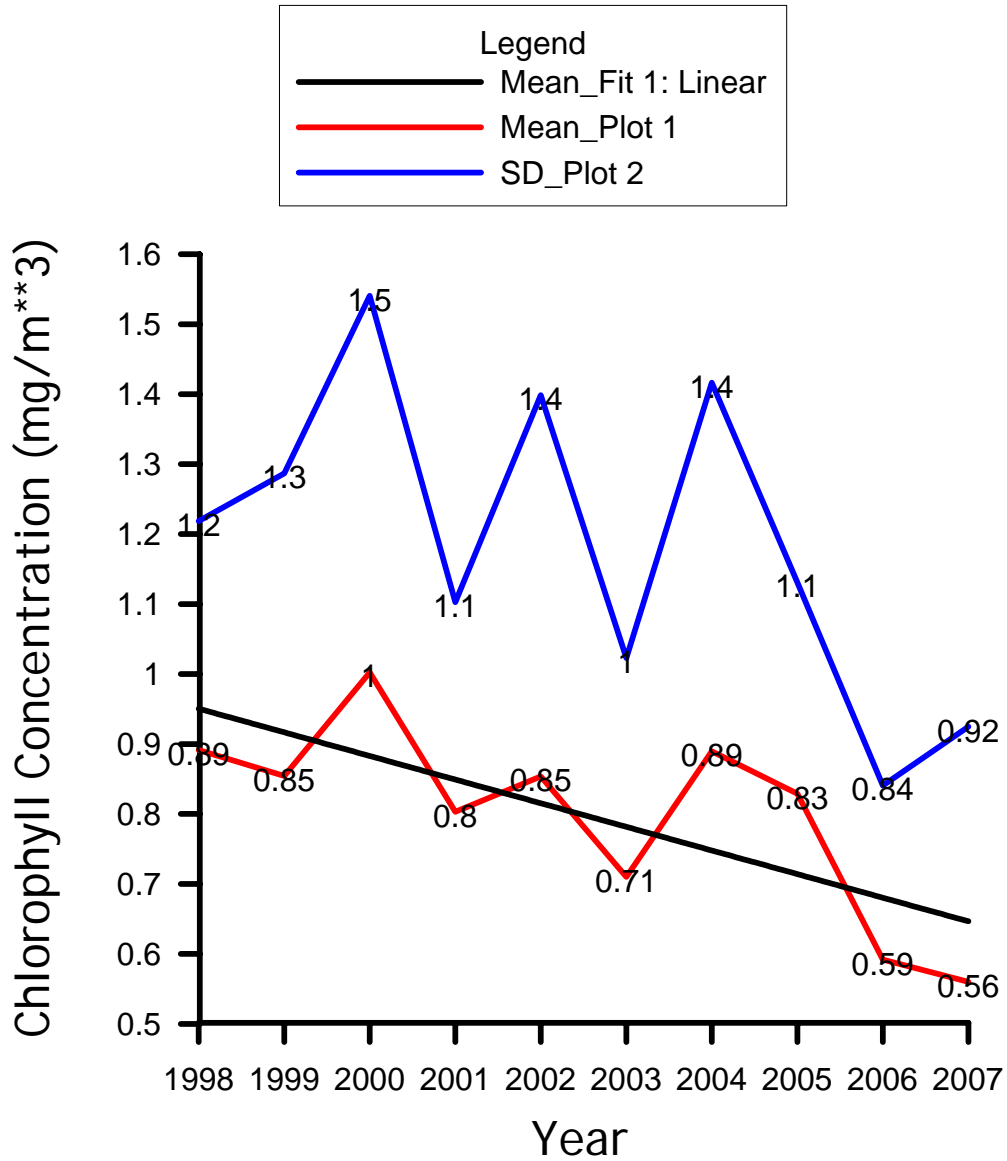
Chlorophyll Concentration (August) 1998-2007



| Period | | Chlorophyll Concentration (mg/m**3) | | | |
|--------|--------|-------------------------------------|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | August | 0.139887 | 5.772570 | 0.936042 | 1.07187 |
| 1999 | August | 0.100651 | 8.981310 | 0.941887 | 1.437711 |
| 2000 | August | 0.134453 | 6.371980 | 0.936801 | 1.195823 |
| 2001 | August | 0.140075 | 9.833300 | 1.230228 | 2.068522 |
| 2002 | August | 0.136594 | 9.810940 | 1.151681 | 1.875342 |
| 2003 | August | 0.143606 | 6.100700 | 0.832276 | 1.528585 |
| 2004 | August | 0.133824 | 8.389730 | 1.206923 | 1.939257 |
| 2005 | August | 0.113220 | 0.578148 | 0.285445 | 0.139158 |

| | | | | | |
|------|--------|----------|----------|----------|----------|
| 2006 | August | 0.089490 | 8.133170 | 0.866363 | 1.636326 |
| 2007 | August | 0.092263 | 6.878150 | 0.797671 | 1.469776 |

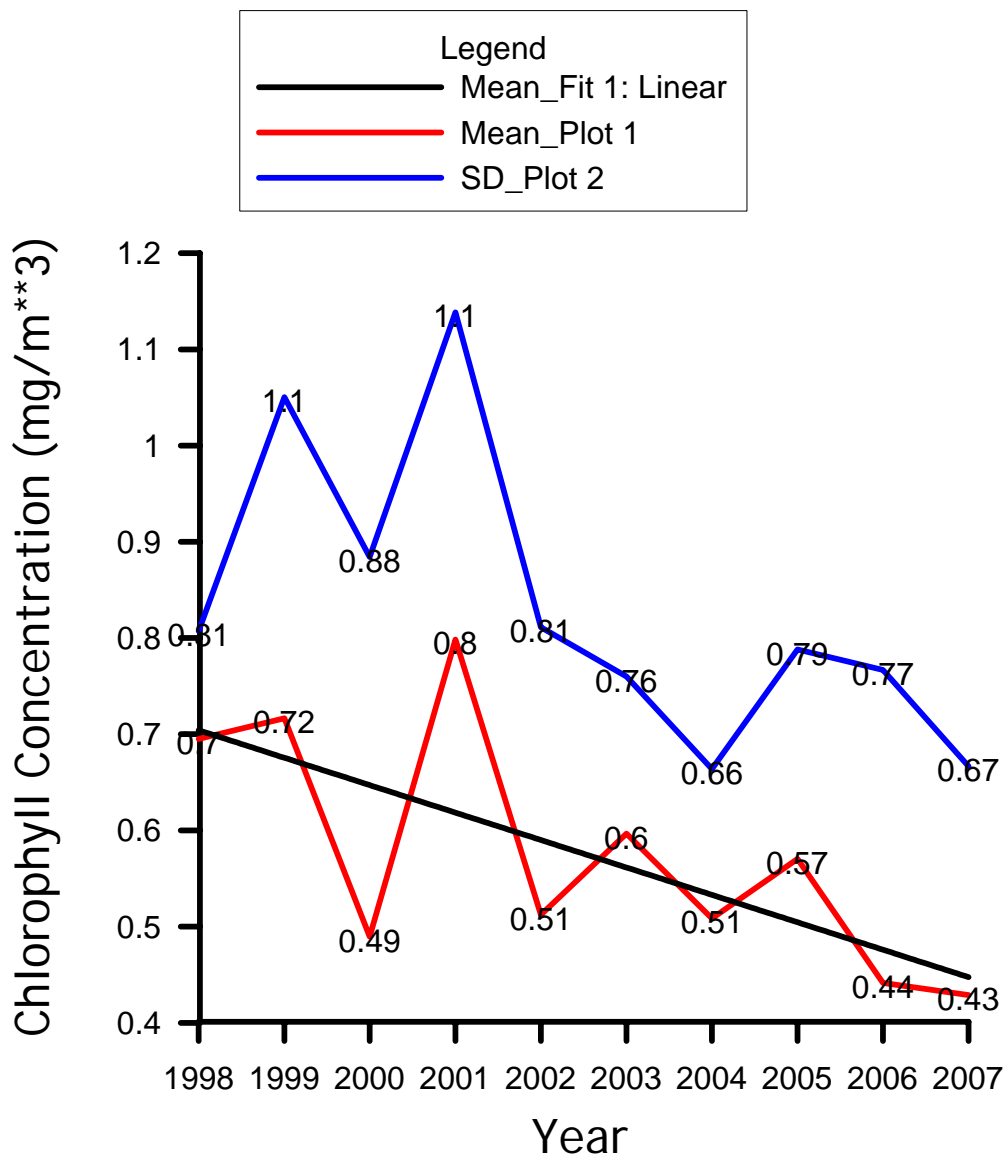
Chlorophyll Concentration (September) 1998-2007



| Period | | Chlorophyll Concentration (mg/m**3) | | | |
|--------|-----------|-------------------------------------|----------|-----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | September | 0.102363 | 5.440920 | 0.891366 | 1.218617 |
| 1999 | September | 0.083439 | 6.286410 | 0.8543951 | 1.286841 |

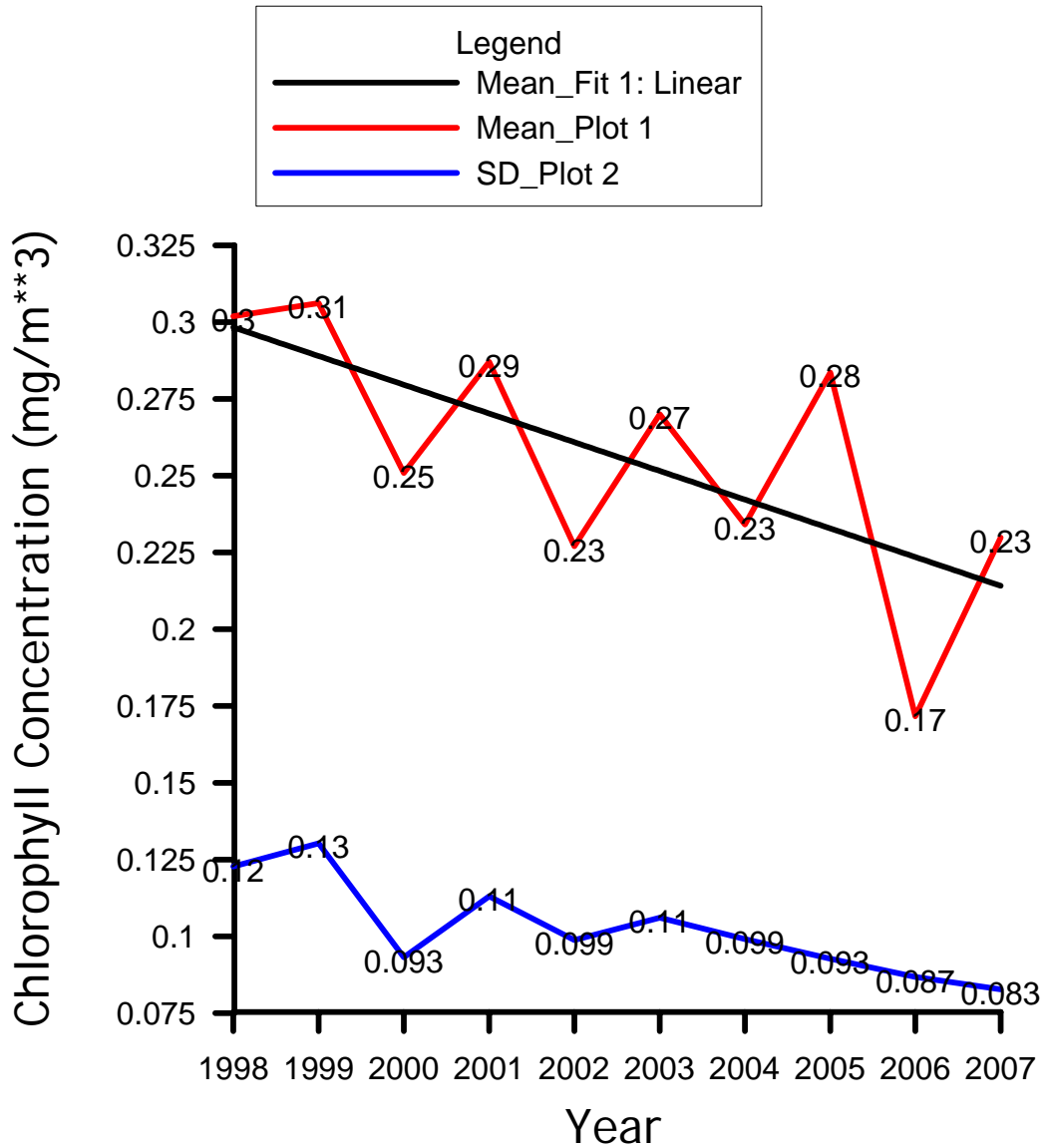
| | | | | | |
|------|-----------|----------|----------|----------|----------|
| 2000 | September | 0.125866 | 6.773980 | 1.002357 | 1.540545 |
| 2001 | September | 0.129784 | 6.266600 | 0.803025 | 1.102662 |
| 2002 | September | 0.111535 | 7.296420 | 0.853577 | 1.398779 |
| 2003 | September | 0.127340 | 5.307120 | 0.710019 | 1.022772 |
| 2004 | September | 0.139215 | 6.154840 | 0.889526 | 1.416467 |
| 2005 | September | 0.132310 | 6.508190 | 0.828887 | 1.130858 |
| 2006 | September | 0.104118 | 5.973020 | 0.591796 | 0.840731 |
| 2007 | September | 0.005900 | 4.477980 | 0.560096 | 0.924833 |

Chlorophyll Concentration (October) 1998-2007



| Period | | Chlorophyll Concentration (mg/m**3) | | | |
|--------|---------|-------------------------------------|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | October | 0.138657 | 4.282740 | 0.695143 | 0.807138 |
| 1999 | October | 0.154496 | 7.316970 | 0.716535 | 1.050352 |
| 2000 | October | 0.135048 | 7.576120 | 0.489434 | 0.884221 |
| 2001 | October | 0.177218 | 8.702010 | 0.798498 | 1.13833 |
| 2002 | October | 0.107792 | 5.785720 | 0.512367 | 0.811163 |
| 2003 | October | 0.143107 | 3.901210 | 0.596692 | 0.759909 |
| 2004 | October | 0.106060 | 3.776350 | 0.508421 | 0.663902 |
| 2005 | October | 0.142916 | 4.186940 | 0.570425 | 0.787981 |
| 2006 | October | 0.096276 | 4.796300 | 0.441425 | 0.766952 |
| 2007 | October | 0.106259 | 4.814960 | 0.428883 | 0.666792 |

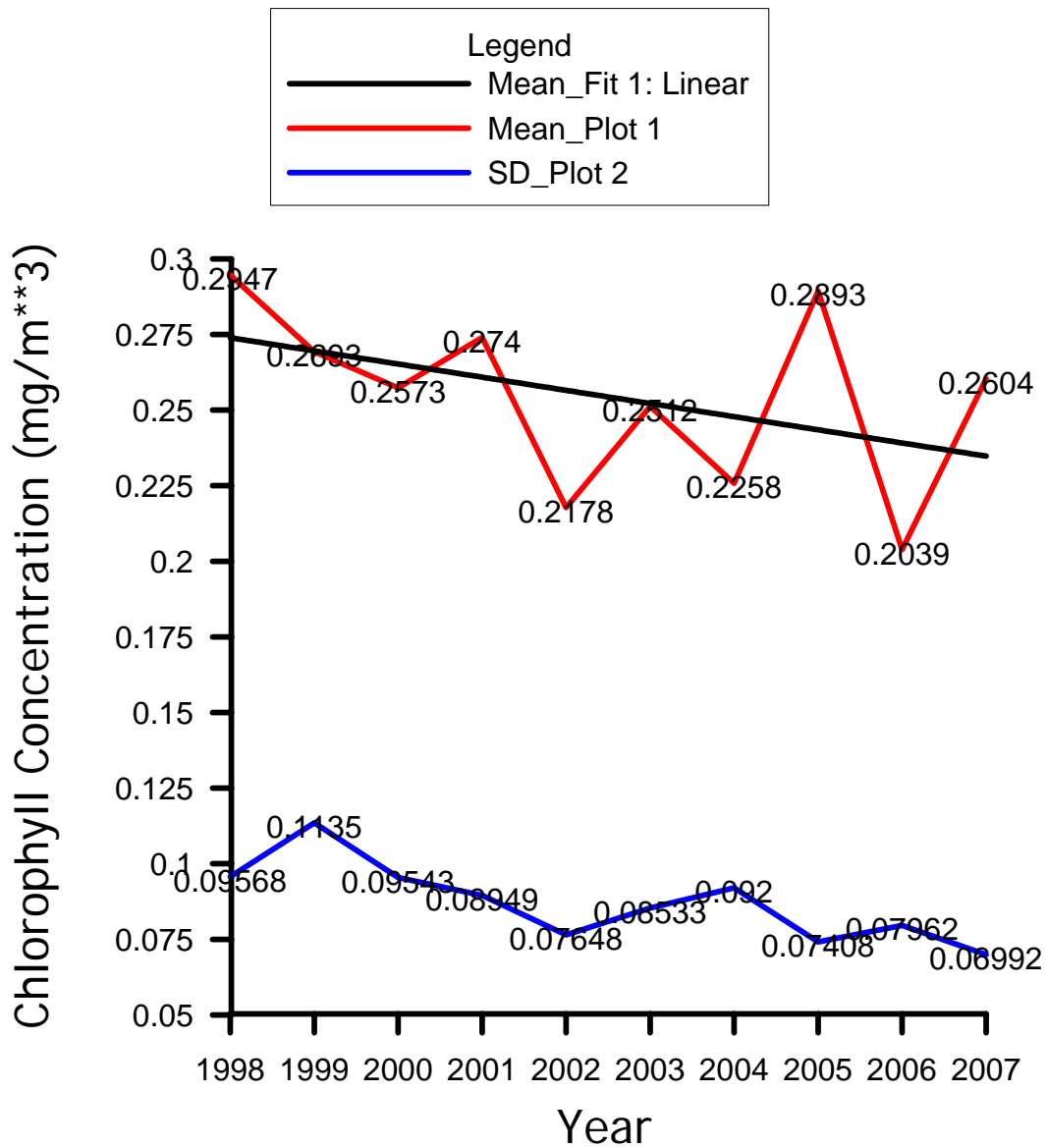
Chlorophyll Concentration (November) 1998-2007



| Period | | Chlorophyll Concentration (mg/m**3) | | | |
|--------|----------|-------------------------------------|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | November | 0.137972 | 0.598946 | 0.301951 | 0.122754 |
| 1999 | November | 0.117512 | 0.595986 | 0.306179 | 0.130291 |
| 2000 | November | 0.128041 | 0.572296 | 0.250894 | 0.093196 |
| 2001 | November | 0.137898 | 0.570460 | 0.28703 | 0.113037 |
| 2002 | November | 0.105268 | 0.546100 | 0.227066 | 0.098782 |
| 2003 | November | 0.131904 | 0.593916 | 0.27 | 0.106021 |
| 2004 | November | 0.117371 | 0.567034 | 0.234136 | 0.099109 |

| | | | | | |
|------|----------|----------|----------|----------|----------|
| 2005 | November | 0.162406 | 0.518946 | 0.283577 | 0.09271 |
| 2006 | November | 0.065441 | 0.501530 | 0.171633 | 0.08674 |
| 2007 | November | 0.134940 | 0.581641 | 0.229856 | 0.082681 |

Chlorophyll Concentration (December) 1998-2007

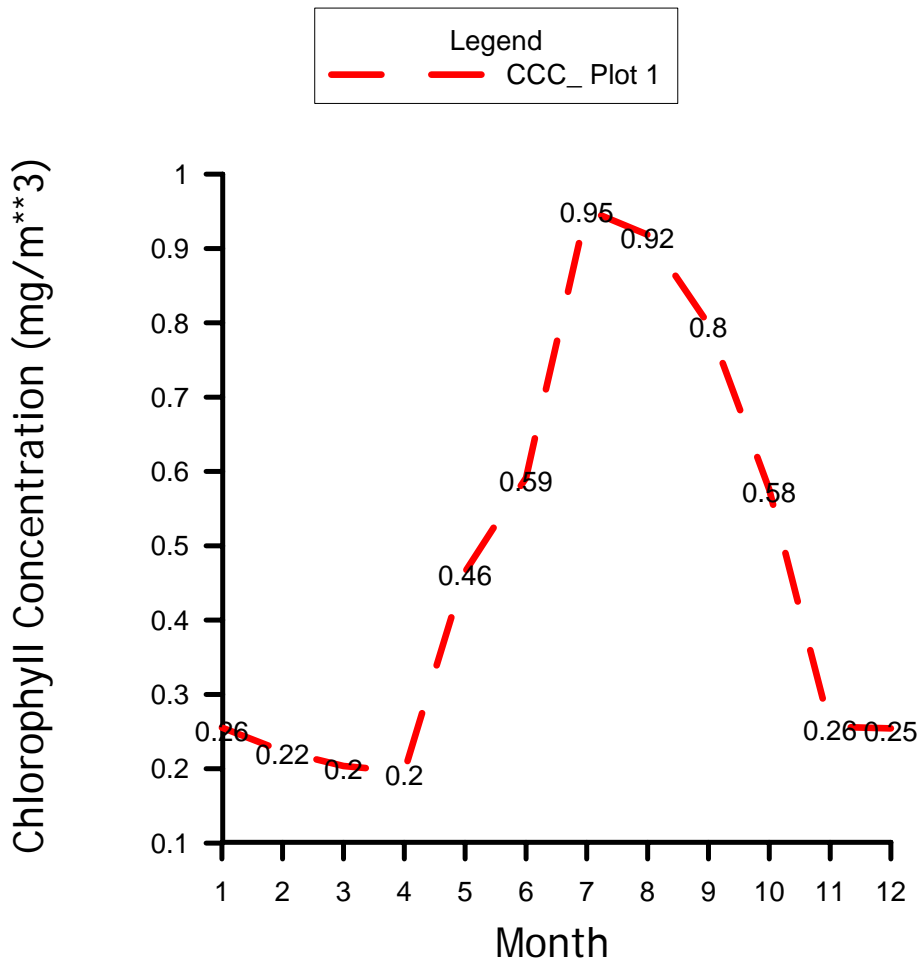


| Period | | Chlorophyll Concentration (mg/m**3) | | | |
|--------|----------|-------------------------------------|----------|----------|---------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | December | 0.124142 | 0.569240 | 0.294674 | 0.09568 |

| | | | | | |
|------|----------|----------|----------|----------|-----------|
| 1999 | December | 0.121300 | 0.597664 | 0.269298 | 0.113527 |
| 2000 | December | 0.140601 | 0.598305 | 0.257348 | 0.095433 |
| 2001 | December | 0.159178 | 0.595030 | 0.274006 | 0.089492 |
| 2002 | December | 0.122557 | 0.589638 | 0.217753 | 0.076482 |
| 2003 | December | 0.133449 | 0.583279 | 0.25119 | 0.085332 |
| 2004 | December | 0.124093 | 0.530181 | 0.225793 | 0.0920044 |
| 2005 | December | 0.183765 | 0.581953 | 0.289334 | 0.074082 |
| 2006 | December | 0.103493 | 0.517143 | 0.203881 | 0.079621 |
| 2007 | December | 0.137198 | 0.460043 | 0.260375 | 0.069918 |

Seasonal cycle of Climatological Monthly mean Chlorophyll

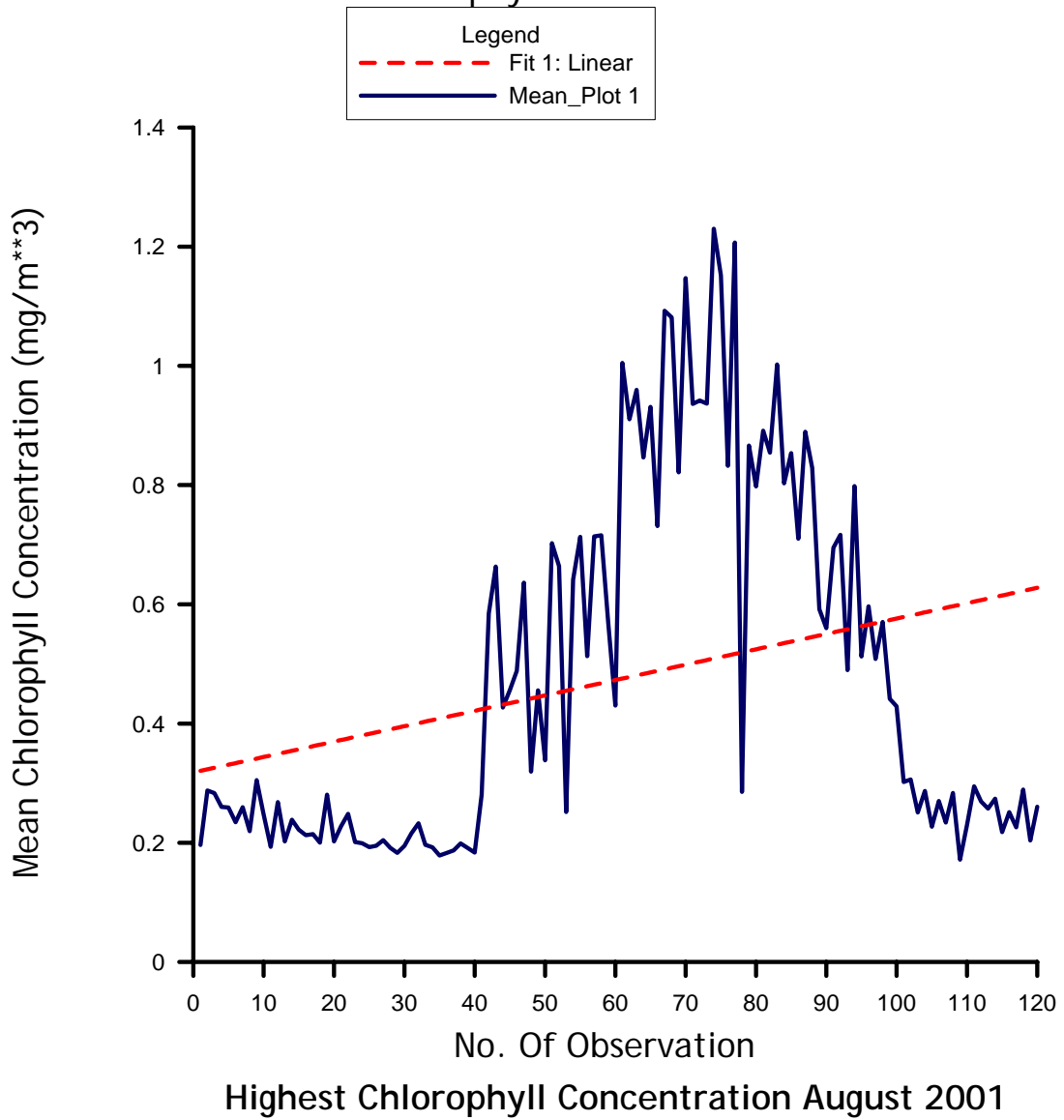
Climatic Chlorophyll Concentration



Highest Climatic Chlorophyll Concentration July=0.95266 mg/m**3

| Month_Name | Month_No. | Climatic Chlorophyll Concentration (mg/m**3) |
|------------|-----------|--|
| January | 1 | 0.255232303 |
| February | 2 | 0.2234265 |
| March | 3 | 0.203755054 |
| April | 4 | 0.195951294 |
| May | 5 | 0.464930245 |
| June | 6 | 0.5914541 |
| July | 7 | 0.952656479 |
| August | 8 | 0.9185317 |
| September | 9 | 0.79850441 |
| October | 10 | 0.5757823 |
| November | 11 | 0.2562322 |
| December | 12 | 0.2543652 |

Mean Chlorophyll Concentration



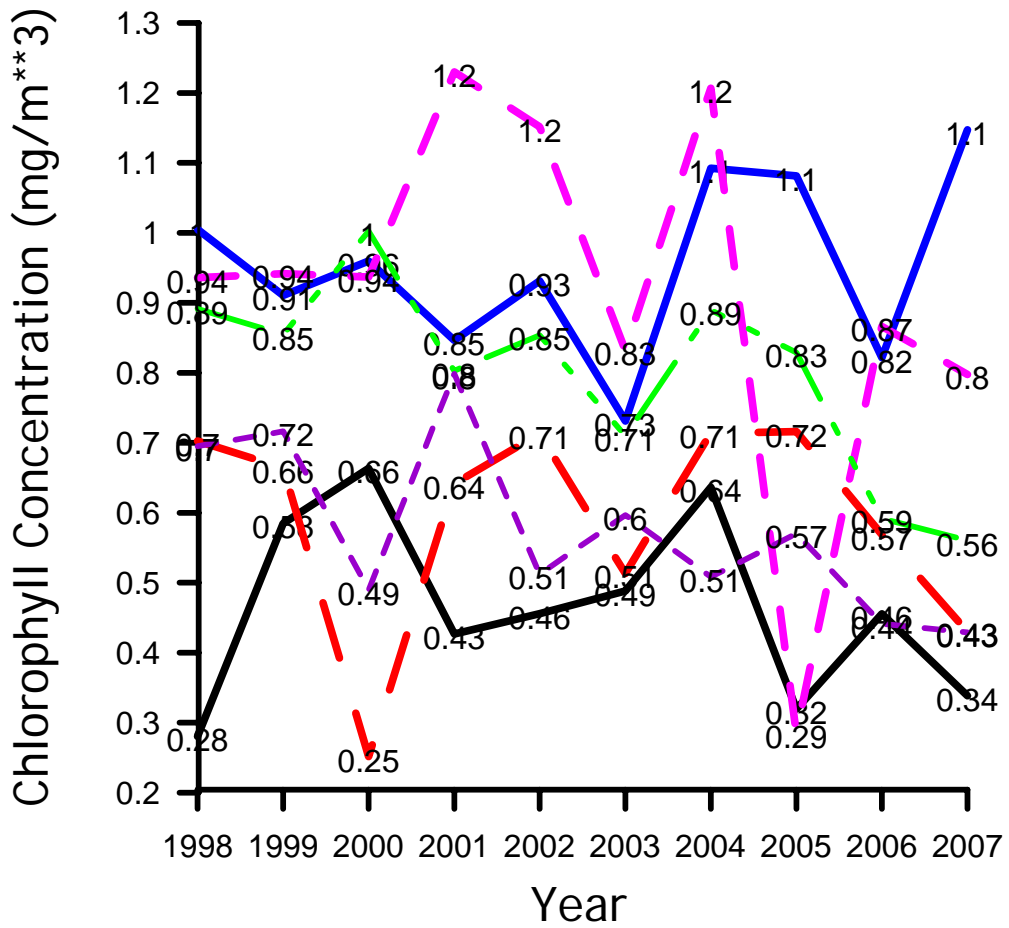
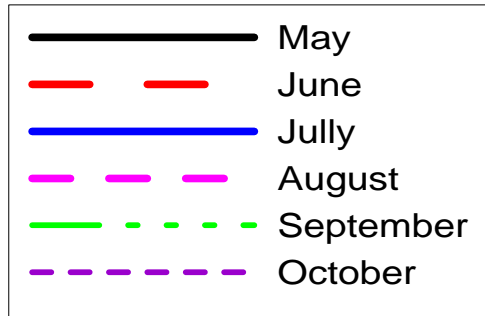
| Period | | | Chlorophyll Concentration (mg/m**3) | | | |
|--------|------|----------|-------------------------------------|----------|-------------|-------------|
| Obs. | Year | Month | Min | Max | Avg | Sd |
| 1 | 1998 | January | 0.115919 | 0.506658 | 0.1962968 | 0.075480451 |
| 2 | 1999 | January | 0.152299 | 0.583982 | 0.28768289 | 0.090701973 |
| 3 | 2000 | January | 0.147365 | 0.574984 | 0.283160917 | 0.09709633 |
| 4 | 2001 | January | 0.135664 | 0.581019 | 0.260069 | 0.089526 |
| 5 | 2002 | January | 0.130446 | 0.567490 | 0.259251 | 0.098126 |
| 6 | 2003 | January | 0.128385 | 0.586411 | 0.234599419 | 0.079026732 |
| 7 | 2004 | January | 0.127870 | 0.589086 | 0.259599 | 0.088398 |
| 8 | 2005 | January | 0.121626 | 0.555613 | 0.219225 | 0.069929 |
| 9 | 2006 | January | 0.156893 | 0.528056 | 0.304912 | 0.085191 |
| 10 | 2007 | January | 0.130080 | 0.583513 | 0.247527 | 0.086869 |
| 11 | 1998 | February | 0.099486 | 0.468495 | 0.193176 | 0.074271 |
| 12 | 1999 | February | 0.168181 | 0.590033 | 0.267984 | 0.076582 |
| 13 | 2000 | February | 0.132417 | 0.598545 | 0.202186 | 0.077033 |
| 14 | 2001 | February | 0.149711 | 0.55755 | 0.238799 | 0.089441 |
| 15 | 2002 | February | 0.134327 | 0.487888 | 0.221794 | 0.074436 |
| 16 | 2003 | February | 0.142115 | 0.503548 | 0.212643 | 0.064959 |
| 17 | 2004 | February | 0.142343 | 0.480564 | 0.21437 | 0.05619 |
| 18 | 2005 | February | 0.121495 | 0.536176 | 0.200226 | 0.072346 |
| 19 | 2006 | February | 0.151242 | 0.561144 | 0.280731 | 0.092934 |
| 20 | 2007 | February | 0.109215 | 0.483597 | 0.202356 | 0.061072 |
| 21 | 1998 | March | 0.117906 | 0.585391 | 0.227546471 | 0.086823965 |
| 22 | 1999 | March | 0.145678 | 0.546686 | 0.248522 | 0.092377 |
| 23 | 2000 | March | 0.124375 | 0.586175 | 0.201137 | 0.081929 |
| 24 | 2001 | March | 0.121886 | 0.553682 | 0.19897 | 0.070214 |
| 25 | 2002 | March | 0.132701 | 0.351654 | 0.192731 | 0.046035 |
| 26 | 2003 | March | 0.130464 | 0.490705 | 0.195142 | 0.064701 |
| 27 | 2004 | March | 0.136374 | 0.529755 | 0.20434358 | 0.061691087 |
| 28 | 2005 | March | 0.128505 | 0.568783 | 0.191638 | 0.072331 |
| 29 | 2006 | March | 0.123463 | 0.444425 | 0.182925 | 0.048775 |
| 30 | 2007 | March | 0.117638 | 0.573293 | 0.19459549 | 0.067791 |
| 31 | 1998 | April | 0.107604 | 0.5346 | 0.215881941 | 0.080923024 |
| 32 | 1999 | April | 0.120475 | 0.597984 | 0.232627 | 0.099572 |
| 33 | 2000 | April | 0.090878 | 0.541587 | 0.19655 | 0.072747 |
| 34 | 2001 | April | 0.075458 | 0.570079 | 0.192323 | 0.085772 |
| 35 | 2002 | April | 0.085485 | 0.542821 | 0.178476 | 0.085874 |
| 36 | 2003 | April | 0.095608 | 0.539849 | 0.182737 | 0.085829 |
| 37 | 2004 | April | 0.099326 | 0.570689 | 0.18707 | 0.093668 |

| | | | | | | |
|----|------|--------|----------|----------|-------------|------------|
| 38 | 2005 | April | 0.171202 | 0.543039 | 0.198874 | 0.078795 |
| 39 | 2006 | April | 0.117151 | 0.451380 | 0.191284 | 0.068602 |
| 40 | 2007 | April | 0.068534 | 0.549694 | 0.18369 | 0.079331 |
| 41 | 1998 | May | 0.049635 | 2.179220 | 0.28035445 | 0.32225755 |
| 42 | 1999 | May | 0.105960 | 5.217650 | 0.584843 | 0.899697 |
| 43 | 2000 | May | 0.108675 | 5.894390 | 0.663268 | 1.018087 |
| 44 | 2001 | May | 0.098163 | 4.151780 | 0.426751 | 0.738455 |
| 45 | 2002 | May | 0.088288 | 5.467930 | 0.455939 | 0.940941 |
| 46 | 2003 | May | 0.072984 | 6.954060 | 0.488321 | 1.064592 |
| 47 | 2004 | May | 0.127921 | 7.644380 | 0.636307 | 1.278236 |
| 48 | 2005 | May | 0.096611 | 3.353550 | 0.319542 | 0.502388 |
| 49 | 2006 | May | 0.074505 | 9.699940 | 0.455594 | 1.20824 |
| 50 | 2007 | May | 0.078687 | 3.264950 | 0.338383 | 0.569012 |
| 51 | 1998 | June | 0.116510 | 9.960480 | 0.702551 | 1.554645 |
| 52 | 1999 | June | 0.101980 | 7.909830 | 0.663969 | 1.343921 |
| 53 | 2000 | June | 0.124359 | 5.983430 | 0.251472 | 0.124357 |
| 54 | 2001 | June | 0.124926 | 4.257020 | 0.641499 | 0.949435 |
| 55 | 2002 | June | 0.124475 | 9.447480 | 0.713138 | 1.45223 |
| 56 | 2003 | June | 0.079407 | 5.504660 | 0.513164 | 0.931152 |
| 57 | 2004 | June | 0.145367 | 6.338600 | 0.714007 | 1.059723 |
| 58 | 2005 | June | 0.106529 | 4.141230 | 0.715978 | 0.932412 |
| 59 | 2006 | June | 0.103493 | 8.941730 | 0.568587 | 1.249939 |
| 60 | 2007 | June | 0.086221 | 7.333640 | 0.430176 | 0.954468 |
| 61 | 1998 | July | 0.148852 | 8.927370 | 1.005028788 | 1.493174 |
| 62 | 1999 | July | 0.109993 | 9.329340 | 0.910385 | 1.536307 |
| 63 | 2000 | July | 0.150012 | 7.327600 | 0.959887 | 1.309534 |
| 64 | 2001 | July | 0.094109 | 6.102340 | 0.846229 | 1.278345 |
| 65 | 2002 | July | 0.114884 | 7.809880 | 0.931339 | 1.631558 |
| 66 | 2003 | July | 0.124559 | 7.270100 | 0.731167 | 1.295615 |
| 67 | 2004 | July | 0.140112 | 7.529610 | 1.092355 | 1.471404 |
| 68 | 2005 | July | 0.122328 | 8.365060 | 1.0813 | 1.568241 |
| 69 | 2006 | July | 0.088359 | 5.913350 | 0.821535 | 1.2070276 |
| 70 | 2007 | July | 0.118143 | 9.787330 | 1.147339 | 1.834658 |
| 71 | 1998 | August | 0.139887 | 5.772570 | 0.936042 | 1.07187 |
| 72 | 1999 | August | 0.100651 | 8.981310 | 0.941887 | 1.437711 |
| 73 | 2000 | August | 0.134453 | 6.371980 | 0.936801 | 1.195823 |
| 74 | 2001 | August | 0.140075 | 9.833300 | 1.230228 | 2.068522 |
| 75 | 2002 | August | 0.136594 | 9.810940 | 1.151681 | 1.875342 |
| 76 | 2003 | August | 0.143606 | 6.100700 | 0.832276 | 1.528585 |
| 77 | 2004 | August | 0.133824 | 8.389730 | 1.206923 | 1.939257 |

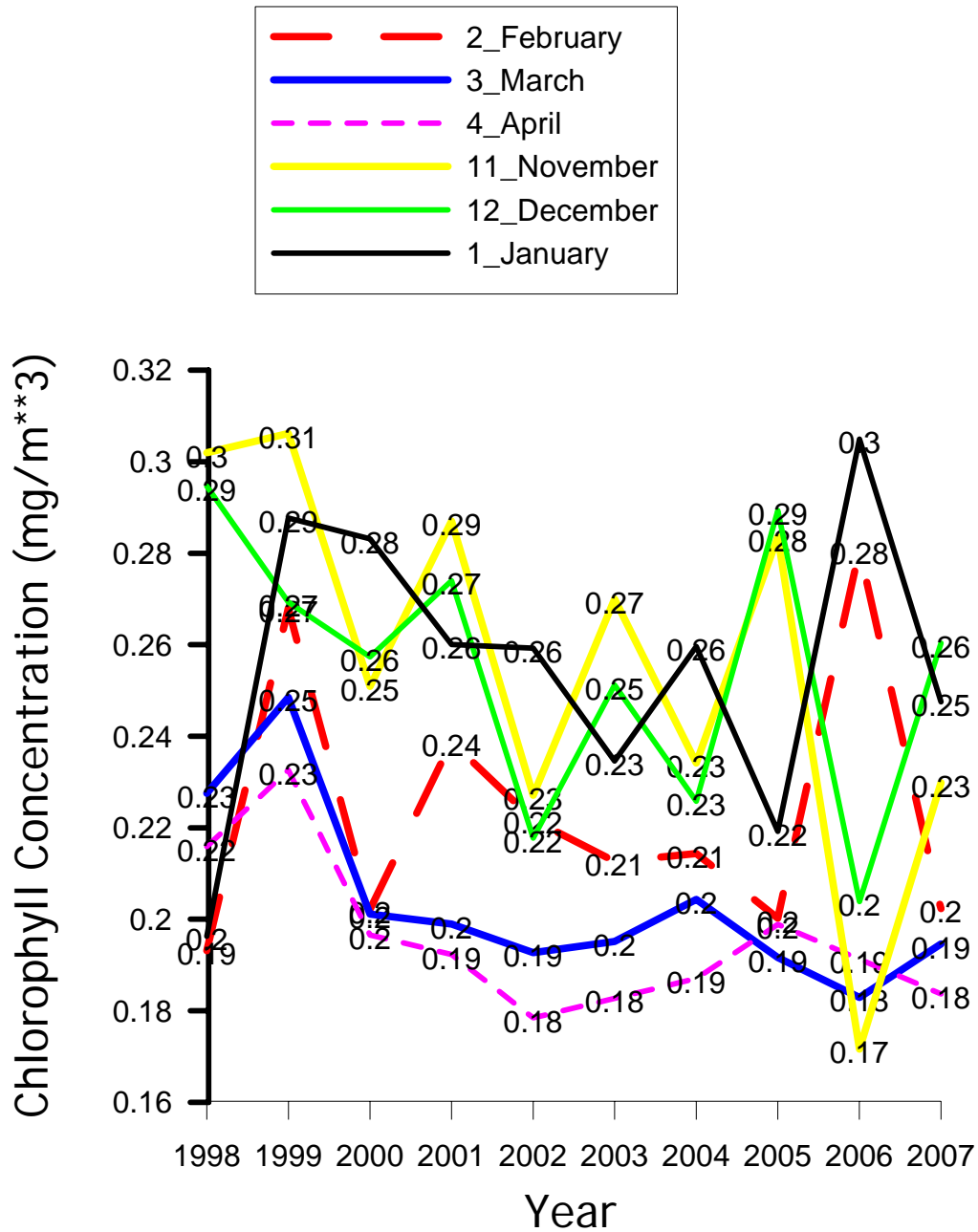
| | | | | | | |
|-----|------|-----------|----------|----------|-----------|-----------|
| 78 | 2005 | August | 0.113220 | 0.578148 | 0.285445 | 0.139158 |
| 79 | 2006 | August | 0.089490 | 8.133170 | 0.866363 | 1.636326 |
| 80 | 2007 | August | 0.092263 | 6.878150 | 0.797671 | 1.469776 |
| 81 | 1998 | September | 0.102363 | 5.440920 | 0.891366 | 1.218617 |
| 82 | 1999 | September | 0.083439 | 6.286410 | 0.8543951 | 1.286841 |
| 83 | 2000 | September | 0.125866 | 6.773980 | 1.002357 | 1.540545 |
| 84 | 2001 | September | 0.129784 | 6.266600 | 0.803025 | 1.102662 |
| 85 | 2002 | September | 0.111535 | 7.296420 | 0.853577 | 1.398779 |
| 86 | 2003 | September | 0.127340 | 5.307120 | 0.710019 | 1.022772 |
| 87 | 2004 | September | 0.139215 | 6.154840 | 0.889526 | 1.416467 |
| 88 | 2005 | September | 0.132310 | 6.508190 | 0.828887 | 1.130858 |
| 89 | 2006 | September | 0.104118 | 5.973020 | 0.591796 | 0.840731 |
| 90 | 2007 | September | 0.005900 | 4.477980 | 0.560096 | 0.924833 |
| 91 | 1998 | October | 0.138657 | 4.282740 | 0.695143 | 0.807138 |
| 92 | 1999 | October | 0.154496 | 7.316970 | 0.716535 | 1.050352 |
| 93 | 2000 | October | 0.135048 | 7.576120 | 0.489434 | 0.884221 |
| 94 | 2001 | October | 0.177218 | 8.702010 | 0.798498 | 1.13833 |
| 95 | 2002 | October | 0.107792 | 5.785720 | 0.512367 | 0.811163 |
| 96 | 2003 | October | 0.143107 | 3.901210 | 0.596692 | 0.759909 |
| 97 | 2004 | October | 0.106060 | 3.776350 | 0.508421 | 0.663902 |
| 98 | 2005 | October | 0.142916 | 4.186940 | 0.570425 | 0.787981 |
| 99 | 2006 | October | 0.096276 | 4.796300 | 0.441425 | 0.766952 |
| 100 | 2007 | October | 0.106259 | 4.814960 | 0.428883 | 0.666792 |
| 101 | 1998 | November | 0.137972 | 0.598946 | 0.301951 | 0.122754 |
| 102 | 1999 | November | 0.117512 | 0.595986 | 0.306179 | 0.130291 |
| 103 | 2000 | November | 0.128041 | 0.572296 | 0.250894 | 0.093196 |
| 104 | 2001 | November | 0.137898 | 0.570460 | 0.28703 | 0.113037 |
| 105 | 2002 | November | 0.105268 | 0.546100 | 0.227066 | 0.098782 |
| 106 | 2003 | November | 0.131904 | 0.593916 | 0.27 | 0.106021 |
| 107 | 2004 | November | 0.117371 | 0.567034 | 0.234136 | 0.099109 |
| 108 | 2005 | November | 0.162406 | 0.518946 | 0.283577 | 0.09271 |
| 109 | 2006 | November | 0.065441 | 0.501530 | 0.171633 | 0.08674 |
| 110 | 2007 | November | 0.134940 | 0.581641 | 0.229856 | 0.082681 |
| 111 | 1998 | December | 0.124142 | 0.569240 | 0.294674 | 0.09568 |
| 112 | 1999 | December | 0.121300 | 0.597664 | 0.269298 | 0.113527 |
| 113 | 2000 | December | 0.140601 | 0.598305 | 0.257348 | 0.095433 |
| 114 | 2001 | December | 0.159178 | 0.595030 | 0.274006 | 0.089492 |
| 115 | 2002 | December | 0.122557 | 0.589638 | 0.217753 | 0.076482 |
| 116 | 2003 | December | 0.133449 | 0.583279 | 0.25119 | 0.085332 |
| 117 | 2004 | December | 0.124093 | 0.530181 | 0.225793 | 0.0920044 |

| | | | | | | |
|-----|------|----------|----------|----------|----------|----------|
| 118 | 2005 | December | 0.183765 | 0.581953 | 0.289334 | 0.074082 |
| 119 | 2006 | December | 0.103493 | 0.517143 | 0.203881 | 0.079621 |
| 120 | 2007 | December | 0.137198 | 0.460043 | 0.260375 | 0.069918 |

Chlorophyll Concentration (May-October) 1998-2007



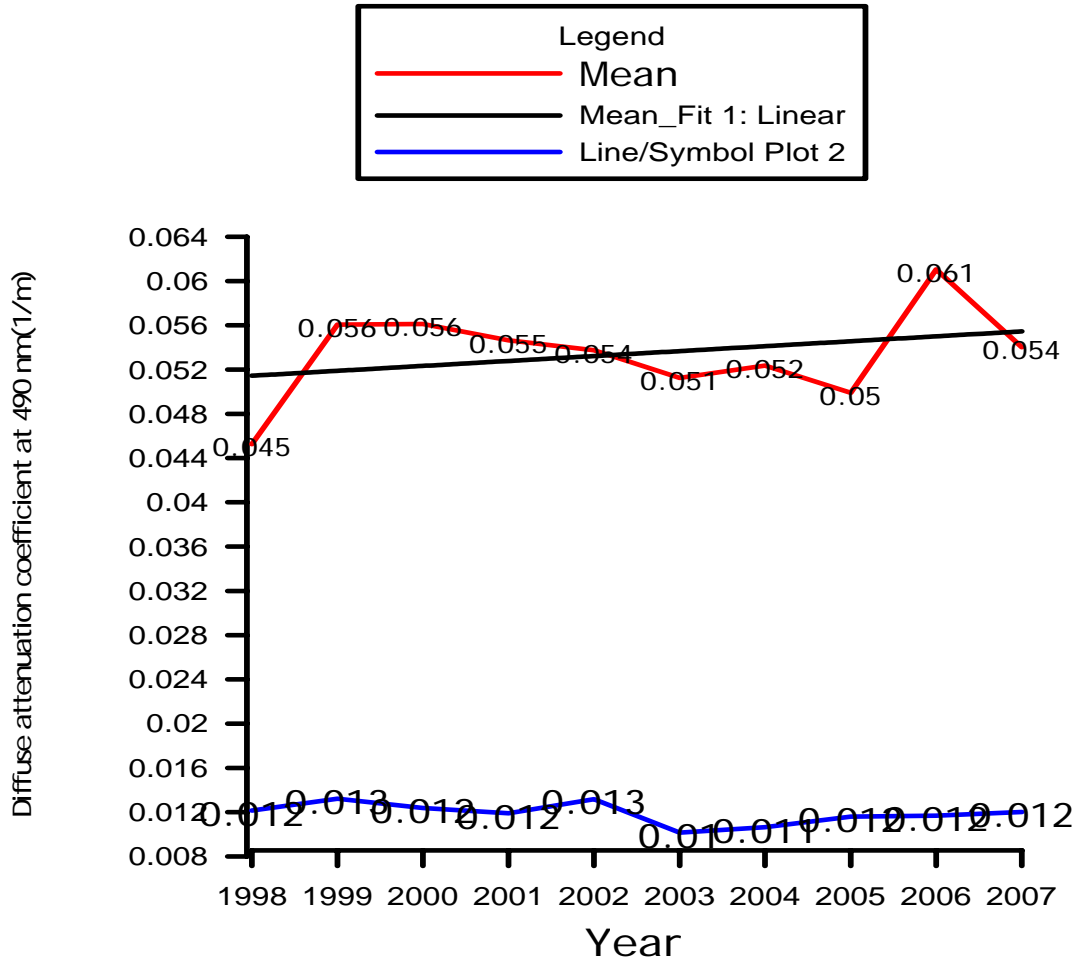
Chlorophyll Concentration (November To April) 1998-2007



Diffuse Attenuation Coefficient

Diffuse attenuation coefficient January

Diffuse_attenuation_coefficient (January) 1998-2007

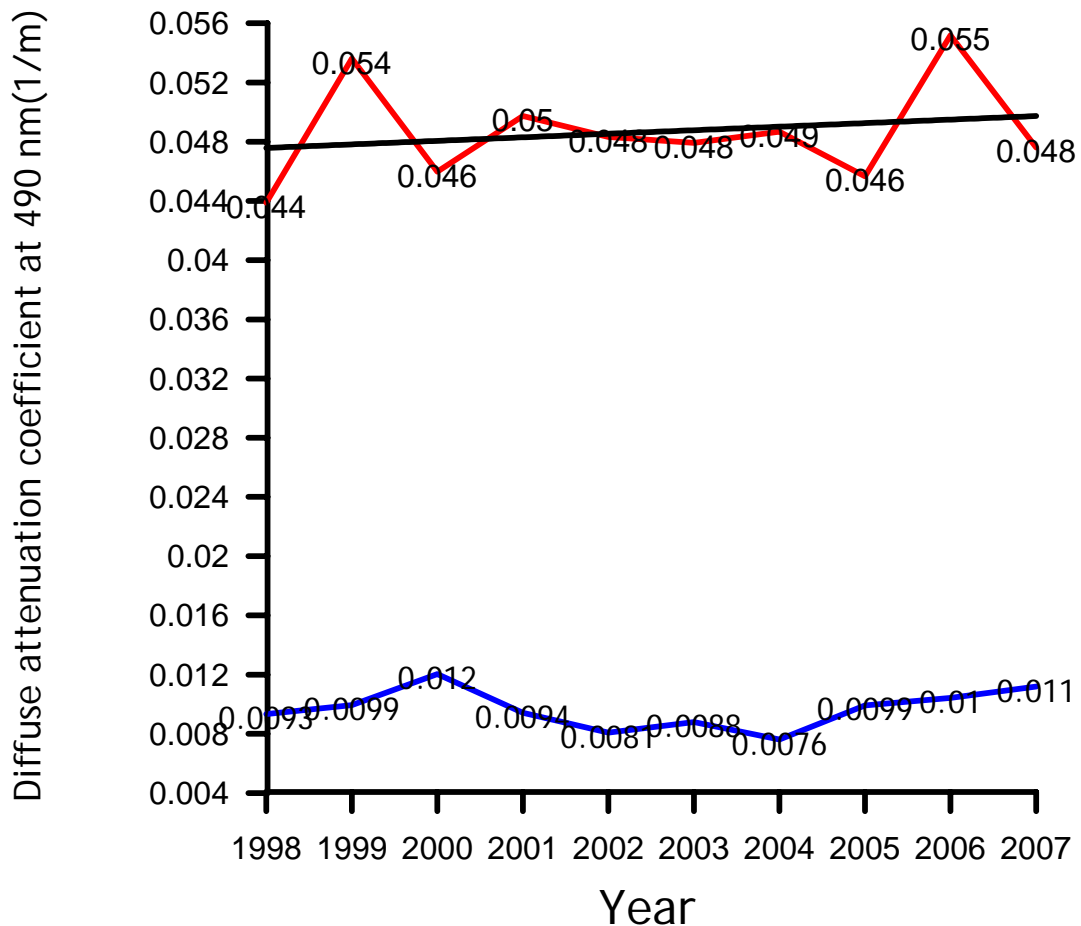
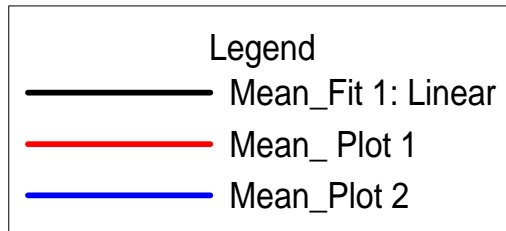


| Period | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|---------|---|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | January | 0.033516 | 0.091622 | 0.045254 | 0.012144 |
| 1999 | January | 0.036858 | 0.092091 | 0.056072 | 0.013218 |
| 2000 | January | 0.036587 | 0.093614 | 0.056118 | 0.012385 |
| 2001 | January | 0.035728 | 0.097765 | 0.054646 | 0.011911 |

| | | | | | |
|------|---------|----------|----------|----------|----------|
| 2002 | January | 0.032991 | 0.097995 | 0.053752 | 0.013187 |
| 2003 | January | 0.035396 | 0.096081 | 0.051245 | 0.010157 |
| 2004 | January | 0.034989 | 0.091911 | 0.052374 | 0.010647 |
| 2005 | January | 0.033303 | 0.090585 | 0.049904 | 0.011599 |
| 2006 | January | 0.040731 | 0.098458 | 0.061052 | 0.011682 |
| 2007 | January | 0.036191 | 0.096535 | 0.054035 | 0.012019 |

Diffuse attenuation coefficient February

Diffuse_attenuation_coefficient (February) 1998-2007

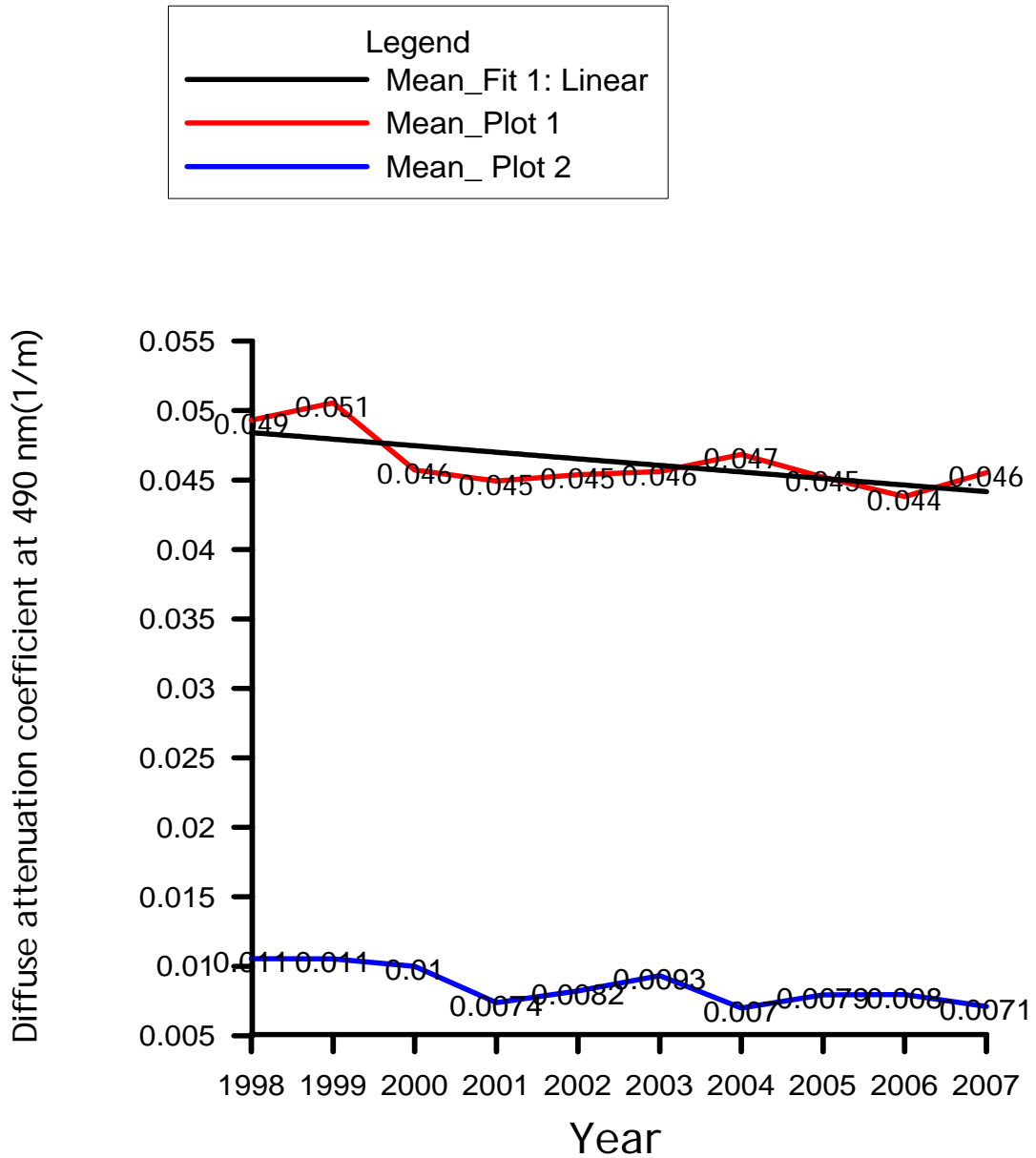


| Period | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|----------|--|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | February | 0.029388 | 0.082276 | 0.043869 | 0.009341 |
| 1999 | February | 0.041445 | 0.093926 | 0.05361 | 0.009937 |
| 2000 | February | 0.034177 | 0.095620 | 0.04597 | 0.012043 |
| 2001 | February | 0.038898 | 0.084403 | 0.049741 | 0.00942 |
| 2002 | February | 0.035574 | 0.080716 | 0.048327 | 0.008088 |
| 2003 | February | 0.037166 | 0.094000 | 0.047915 | 0.008793 |
| 2004 | February | 0.038477 | 0.088955 | 0.048668 | 0.007615 |
| 2005 | February | 0.033111 | 0.092872 | 0.045666 | 0.009929 |
| 2006 | February | 0.039340 | 0.097842 | 0.055183 | 0.010429 |
| 2007 | February | 0.031238 | 0.096430 | 0.047611 | 0.011201 |

Diffuse attenuation coefficient March

| Period | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|-------|--|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | March | 0.032518 | 0.095208 | 0.049319 | 0.010552 |
| 1999 | March | 0.036451 | 0.091847 | 0.050551 | 0.010539 |
| 2000 | March | 0.032099 | 0.088981 | 0.045725 | 0.009996 |
| 2001 | March | 0.032752 | 0.078189 | 0.044929 | 0.007379 |
| 2002 | March | 0.035651 | 0.089753 | 0.045371 | 0.008233 |
| 2003 | March | 0.034882 | 0.089674 | 0.045617 | 0.00933 |
| 2004 | March | 0.037922 | 0.081536 | 0.046849 | 0.00699 |
| 2005 | March | 0.035230 | 0.080764 | 0.045204 | 0.007937 |
| 2006 | March | 0.032544 | 0.092426 | 0.043798 | 0.007967 |
| 2007 | March | 0.034171 | 0.078335 | 0.045531 | 0.007104 |

Diffuse_attenuation_coefficient (March) 1998-2007

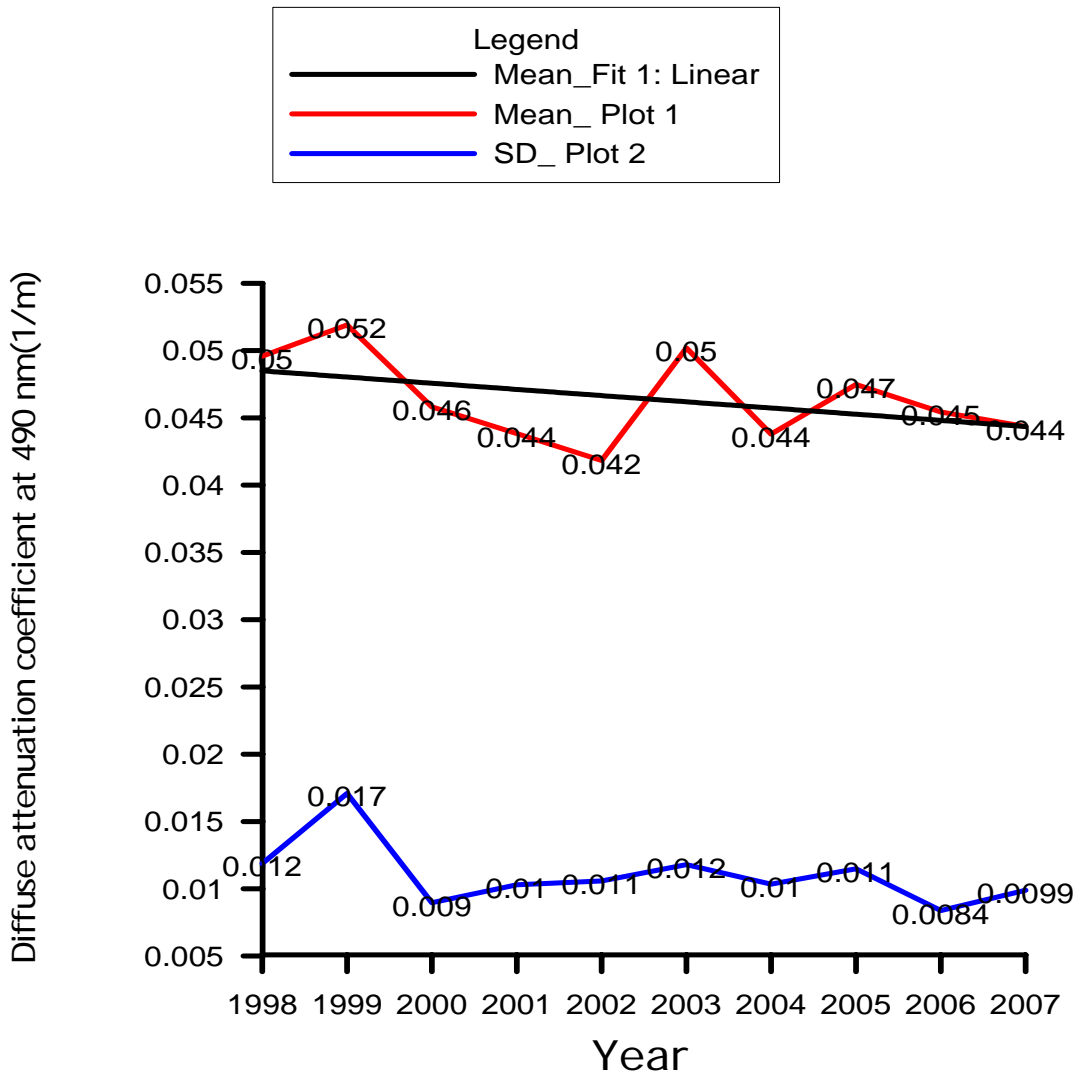


Diffuse attenuation coefficient April

| Period | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|-------|---|----------|---------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | April | 0.031085 | 0.094602 | 0.04959 | 0.011888 |

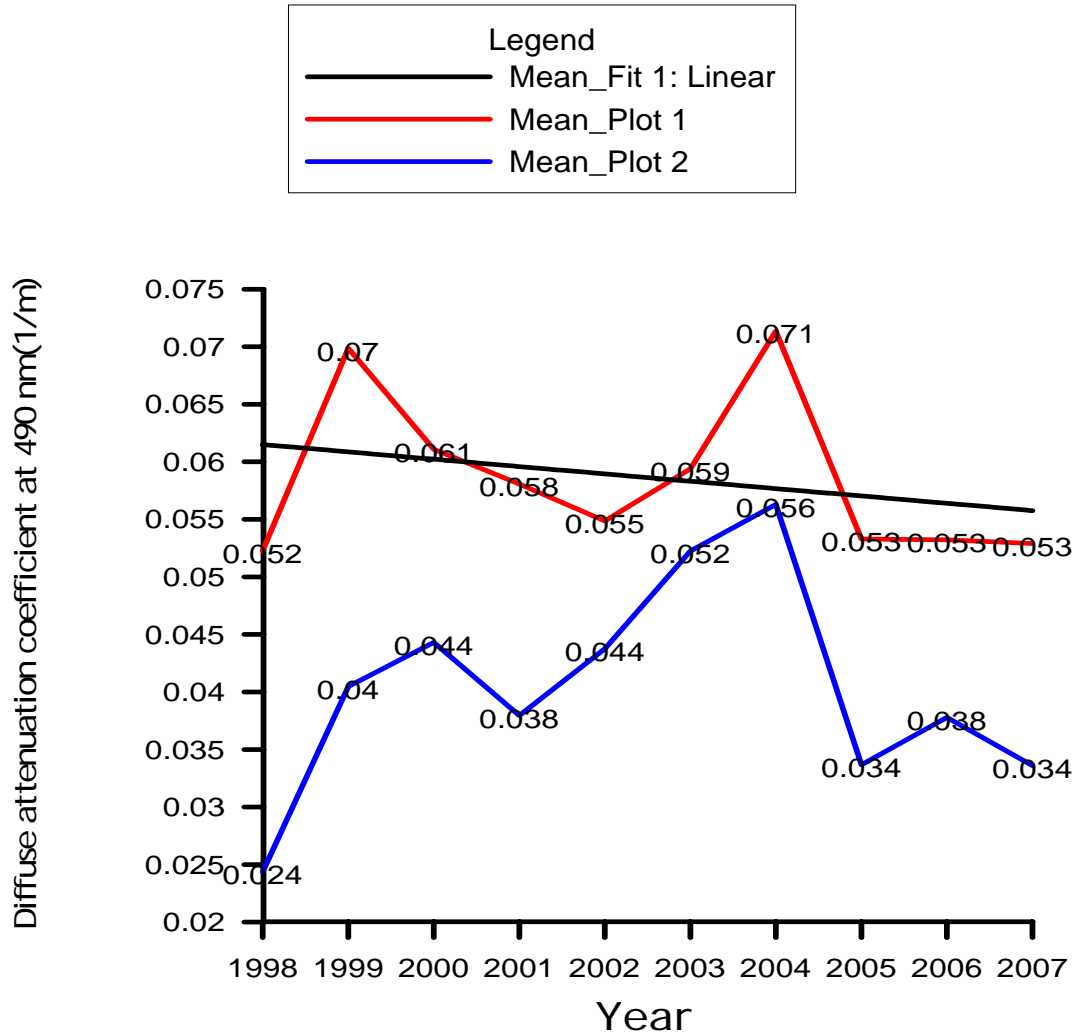
| | | | | | |
|------|-------|----------|----------|----------|----------|
| 1999 | April | 0.033595 | 0.099899 | 0.051913 | 0.017088 |
| 2000 | April | 0.024199 | 0.079724 | 0.045826 | 0.008967 |
| 2001 | April | 0.023400 | 0.080661 | 0.043827 | 0.0103 |
| 2002 | April | 0.025334 | 0.078767 | 0.041833 | 0.010591 |
| 2003 | April | 0.029414 | 0.095021 | 0.050196 | 0.011796 |
| 2004 | April | 0.029809 | 0.080962 | 0.043807 | 0.010354 |
| 2005 | April | 0.028401 | 0.091210 | 0.047484 | 0.011487 |
| 2006 | April | 0.030800 | 0.071339 | 0.045438 | 0.008378 |
| 2007 | April | 0.020600 | 0.081496 | 0.044347 | 0.009887 |

Diffuse_attenuation_coefficient (April) 1998-2007



Diffuse attenuation coefficient May

Diffuse_attenuation_coefficient (May) 1998-2007



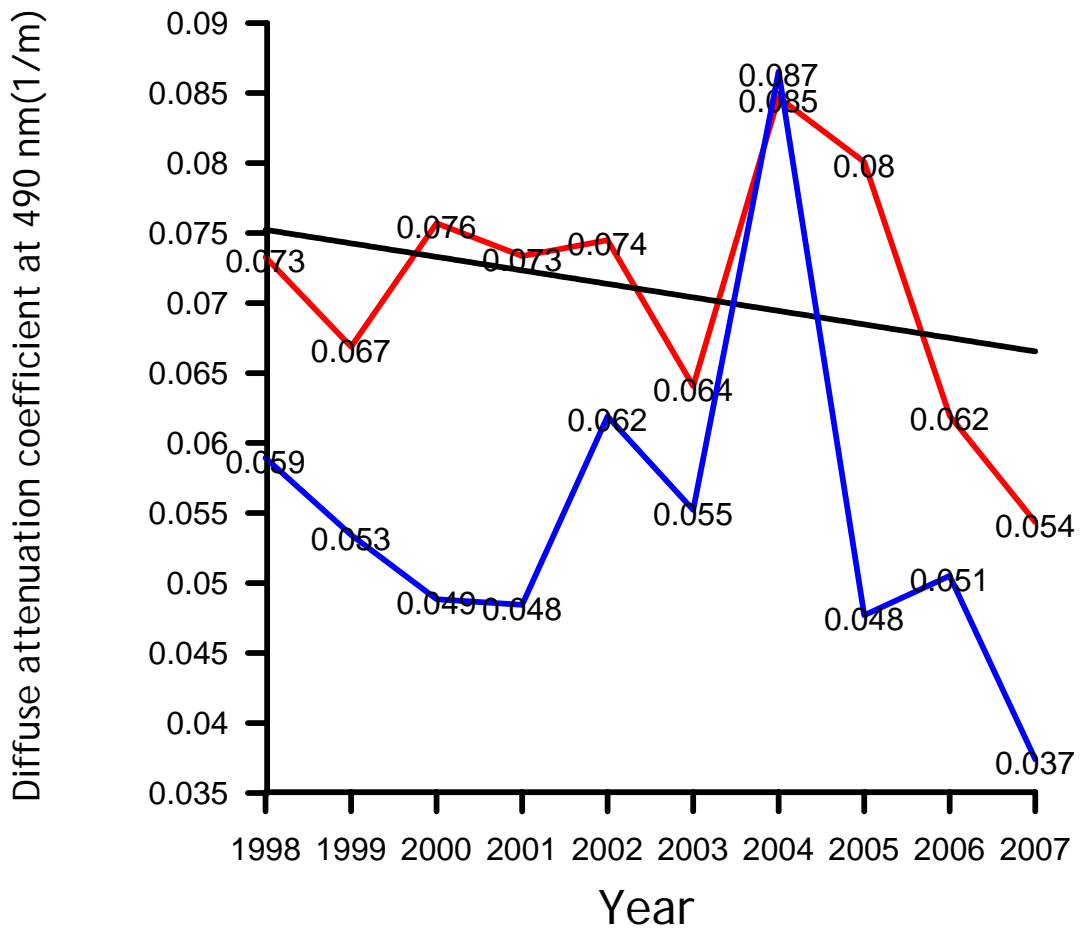
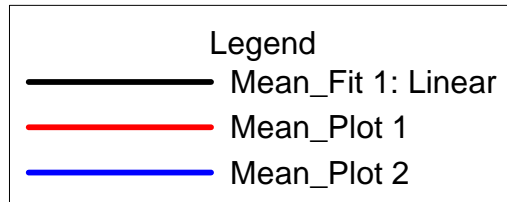
| Period | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|-------|---|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | May | 0.017801 | 0.169010 | 0.052268 | 0.024371 |
| 1999 | May | 0.027401 | 0.230912 | 0.069864 | 0.040482 |
| 2000 | May | 0.030454 | 0.250588 | 0.061086 | 0.044317 |
| 2001 | May | 0.027701 | 0.238351 | 0.058079 | 0.037954 |
| 2002 | May | 0.026795 | 0.245813 | 0.054872 | 0.043752 |
| 2003 | May | 0.023944 | 0.302476 | 0.059405 | 0.052241 |

| | | | | | |
|------|-----|----------|----------|----------|----------|
| 2004 | May | 0.034400 | 0.335812 | 0.071372 | 0.056301 |
| 2005 | May | 0.028068 | 0.246199 | 0.053282 | 0.03367 |
| 2006 | May | 0.020200 | 0.224211 | 0.053225 | 0.037789 |
| 2007 | May | 0.026726 | 0.211884 | 0.052904 | 0.033612 |

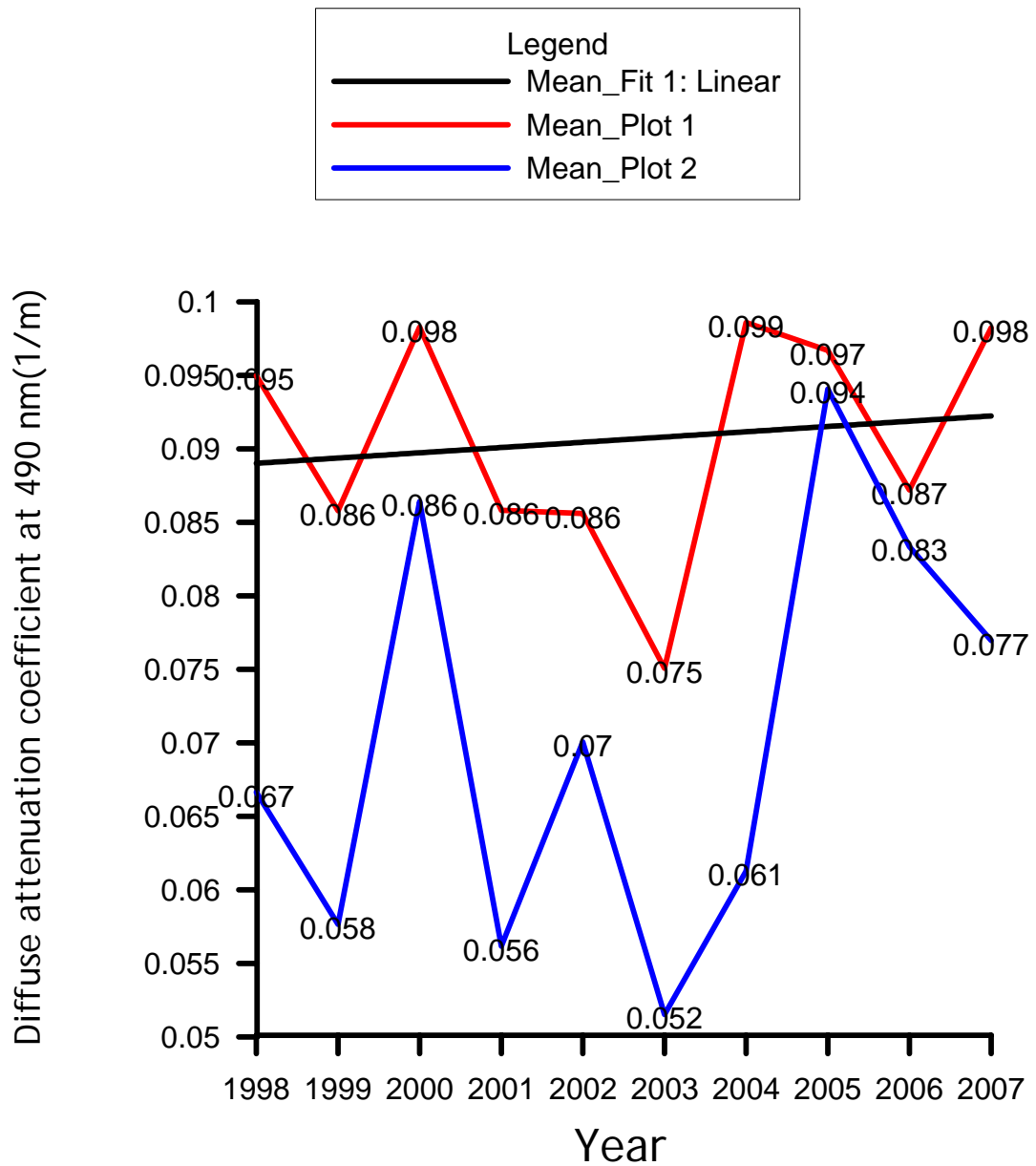
Diffuse attenuation coefficient June

| Period | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|-------|--|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | June | 0.032024 | 0.347483 | 0.073283 | 0.058932 |
| 1999 | June | 0.028401 | 0.299904 | 0.06688 | 0.053433 |
| 2000 | June | 0.029599 | 0.276301 | 0.075714 | 0.048845 |
| 2001 | June | 0.026400 | 0.237208 | 0.073358 | 0.048438 |
| 2002 | June | 0.033401 | 0.404036 | 0.074487 | 0.061917 |
| 2003 | June | 0.023201 | 0.353990 | 0.064059 | 0.055214 |
| 2004 | June | 0.035767 | 0.659813 | 0.084694 | 0.086544 |
| 2005 | June | 0.032800 | 0.216510 | 0.080089 | 0.047702 |
| 2006 | June | 0.029824 | 0.255808 | 0.061957 | 0.050515 |
| 2007 | June | 0.025725 | 0.254331 | 0.054354 | 0.037401 |

Diffuse_attenuation_coefficient (June) 1998-2007



Diffuse_attenuation_coefficient (Jully) 1998-2007



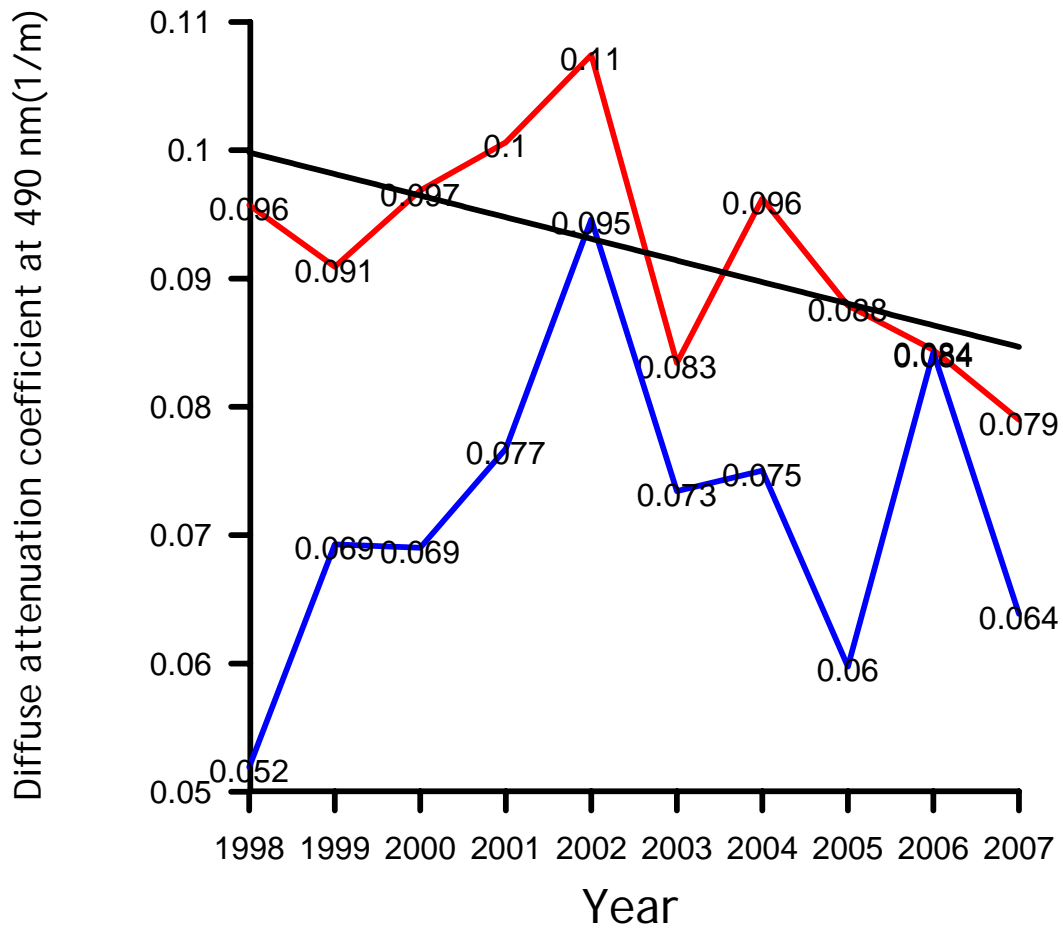
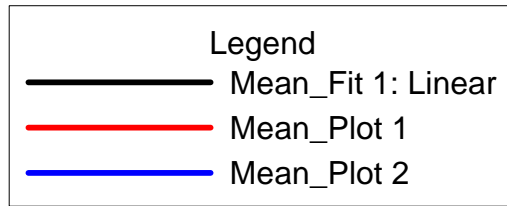
| Period | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|-------|---|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | July | 0.035452 | 0.344393 | 0.094979 | 0.066646 |
| 1999 | July | 0.031550 | 0.320324 | 0.085787 | 0.05766 |

| | | | | | |
|------|------|----------|----------|-----------|----------|
| 2000 | July | 0.036201 | 0.503557 | 0.098274 | 0.086404 |
| 2001 | July | 0.022400 | 0.276980 | 0.0858253 | 0.056168 |
| 2002 | July | 0.031000 | 0.349604 | 0.085596 | 0.070063 |
| 2003 | July | 0.032134 | 0.269576 | 0.075076 | 0.051516 |
| 2004 | July | 0.035334 | 0.308716 | 0.09859 | 0.061283 |
| 2005 | July | 0.034800 | 0.333807 | 0.096698 | 0.094063 |
| 2006 | July | 0.026695 | 0.575256 | 0.087208 | 0.083338 |
| 2007 | July | 0.031826 | 0.341732 | 0.098224 | 0.076971 |

Diffuse attenuation coefficient August

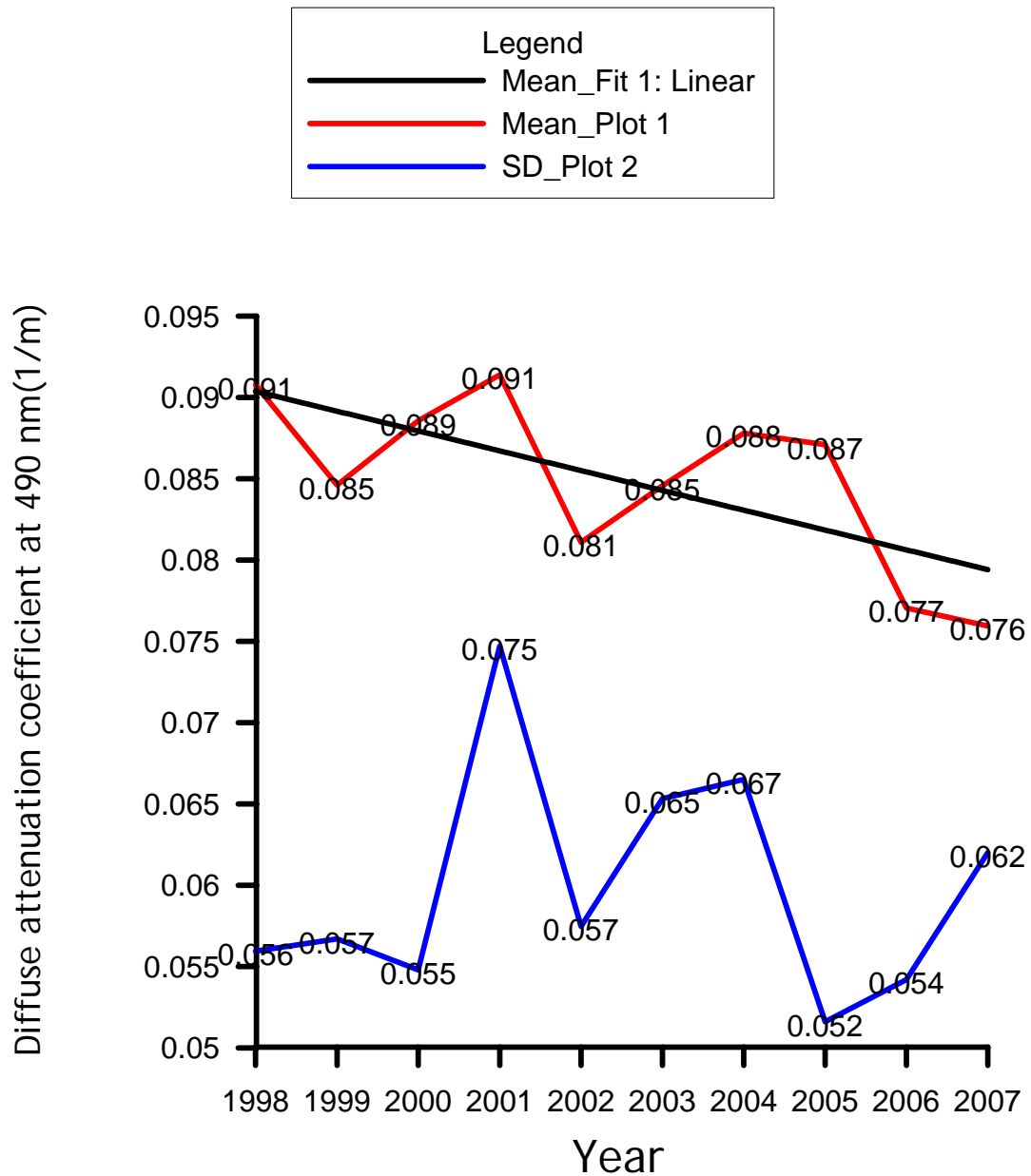
| Period | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|--------|--|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | August | 0.034948 | 0.269549 | 0.09572 | 0.051925 |
| 1999 | August | 0.027753 | 0.376944 | 0.090916 | 0.069292 |
| 2000 | August | 0.034325 | 0.373959 | 0.096862 | 0.069013 |
| 2001 | August | 0.034255 | 0.379991 | 0.100624 | 0.076741 |
| 2002 | August | 0.031500 | 0.429897 | 0.107434 | 0.094608 |
| 2003 | August | 0.031000 | 0.398130 | 0.083428 | 0.073436 |
| 2004 | August | 0.035016 | 0.338793 | 0.096233 | 0.075033 |
| 2005 | August | 0.030997 | 0.334102 | 0.087898 | 0.059761 |
| 2006 | August | 0.026473 | 0.549478 | 0.084431 | 0.084244 |
| 2007 | August | 0.026297 | 0.320450 | 0.078997 | 0.063877 |

Diffuse_attenuation_coefficient (August) 1998-2007



Diffuse attenuation coefficient September

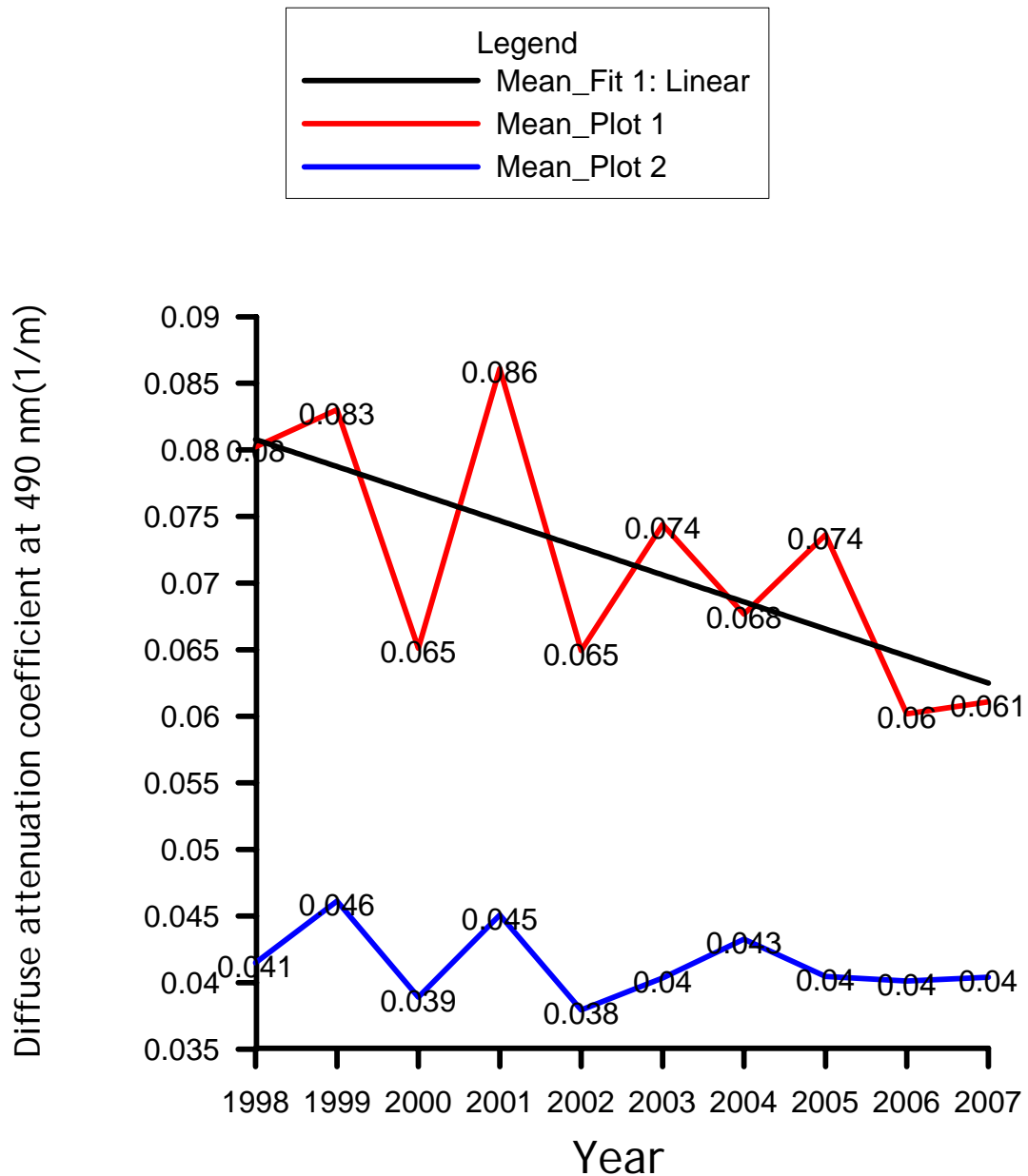
Diffuse_attenuation_coefficient (September) 1998-2007



| Period | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|-----------|---|----------|-----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | September | 0.027401 | 0.246006 | 0.090774 | 0.055942 |
| 1999 | September | 0.023201 | 0.267231 | 0.0846078 | 0.0567 |

| | | | | | |
|------|-----------|----------|----------|----------|----------|
| 2000 | September | 0.033199 | 0.275002 | 0.088561 | 0.054793 |
| 2001 | September | 0.031999 | 0.415173 | 0.091391 | 0.074713 |
| 2002 | September | 0.030921 | 0.300316 | 0.081083 | 0.057475 |
| 2003 | September | 0.034753 | 0.382686 | 0.084567 | 0.06533 |
| 2004 | September | 0.033199 | 0.360655 | 0.087799 | 0.066506 |
| 2005 | September | 0.035599 | 0.294651 | 0.08709 | 0.051599 |
| 2006 | September | 0.029187 | 0.384947 | 0.07705 | 0.054193 |
| 2007 | September | 0.031905 | 0.350051 | 0.075948 | 0.062009 |

Diffuse_attenuation_coefficient (October) 1998-2007

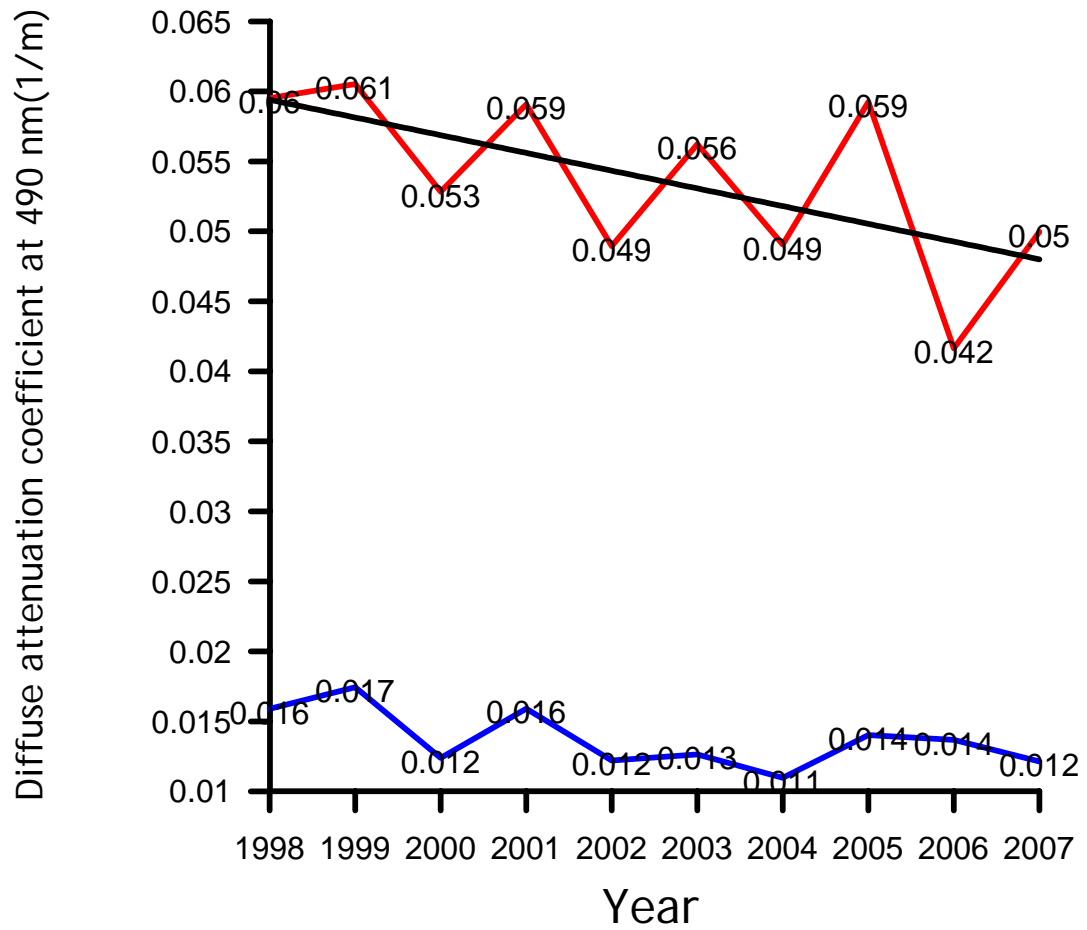
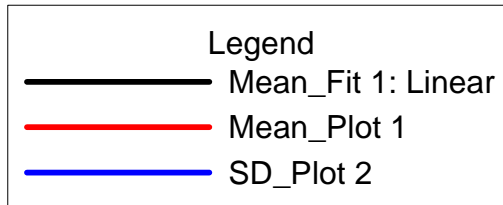


| Period | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|---------|--|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | October | 0.032232 | 0.214017 | 0.08023 | 0.041486 |
| 1999 | October | 0.038602 | 0.285230 | 0.08302 | 0.046128 |
| 2000 | October | 0.034780 | 0.296683 | 0.065106 | 0.03891 |
| 2001 | October | 0.041384 | 0.278616 | 0.086102 | 0.045082 |
| 2002 | October | 0.029874 | 0.197561 | 0.064936 | 0.037951 |
| 2003 | October | 0.036717 | 0.225159 | 0.074411 | 0.040354 |
| 2004 | October | 0.029792 | 0.228589 | 0.067665 | 0.043251 |
| 2005 | October | 0.035900 | 0.222238 | 0.073638 | 0.040456 |
| 2006 | October | 0.029135 | 0.261367 | 0.060176 | 0.040109 |
| 2007 | October | 0.028633 | 0.287988 | 0.061082 | 0.040406 |

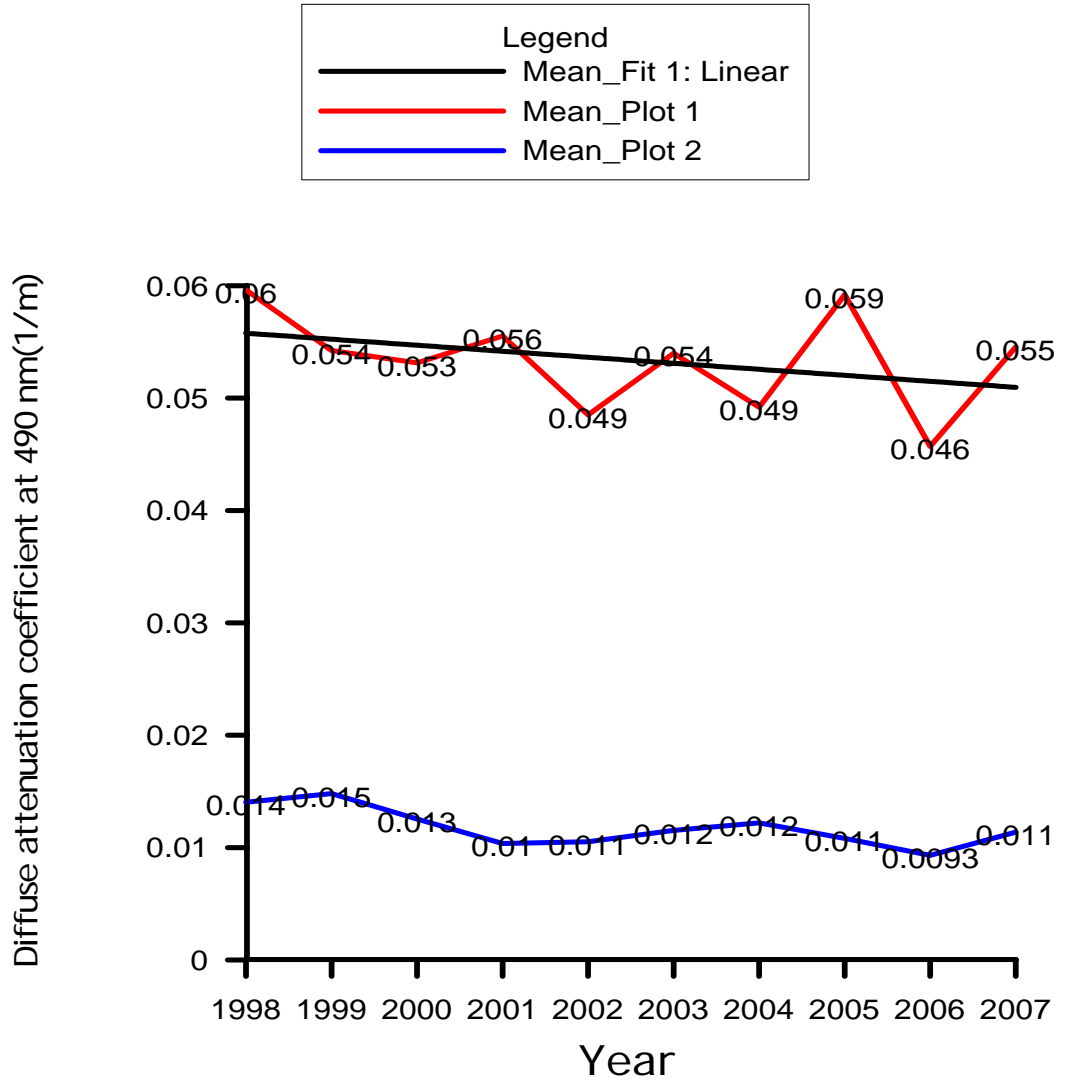
Diffuse attenuation coefficient November

| Period | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|----------|--|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | November | 0.034627 | 0.094546 | 0.059527 | 0.015895 |
| 1999 | November | 0.033313 | 0.095198 | 0.060533 | 0.017432 |
| 2000 | November | 0.032900 | 0.096222 | 0.052836 | 0.012386 |
| 2001 | November | 0.035438 | 0.097861 | 0.059072 | 0.015917 |
| 2002 | November | 0.029001 | 0.086602 | 0.04895 | 0.012214 |
| 2003 | November | 0.033980 | 0.088684 | 0.056234 | 0.012631 |
| 2004 | November | 0.032317 | 0.080266 | 0.049061 | 0.010976 |
| 2005 | November | 0.039998 | 0.095095 | 0.059248 | 0.014017 |
| 2006 | November | 0.022590 | 0.088034 | 0.041636 | 0.013682 |
| 2007 | November | 0.034800 | 0.095883 | 0.049971 | 0.012143 |

Diffuse_attenuation_coefficient (November) 1998-2007



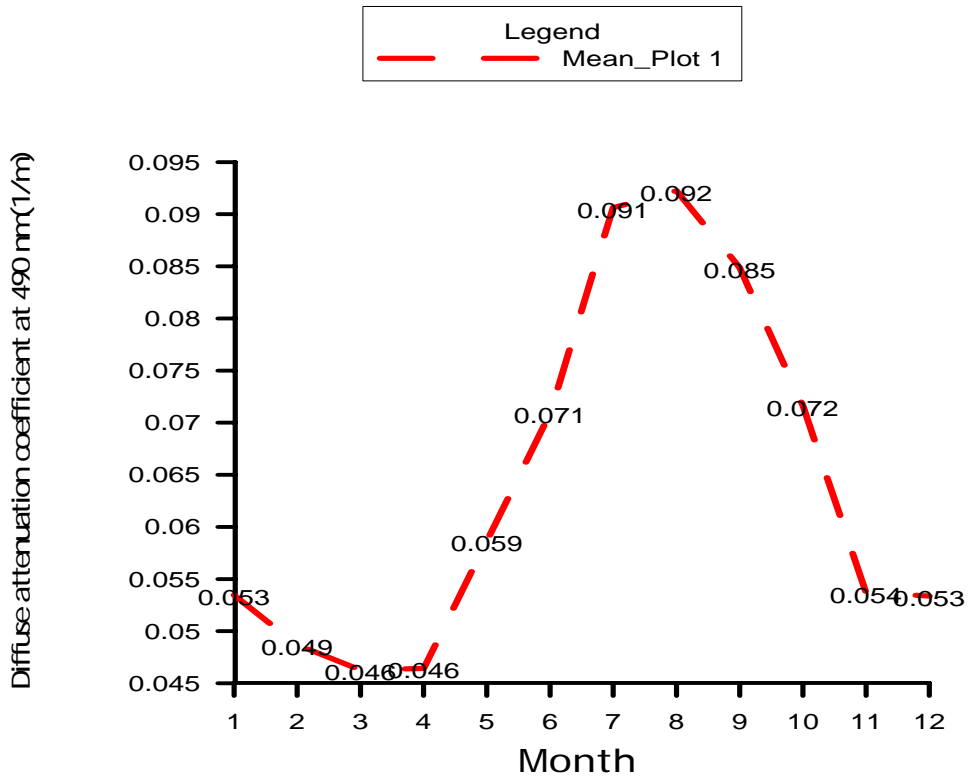
Diffuse_attenuation_coefficient (December) 1998-2007



| Period | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|----------|---|----------|----------|----------|
| Year | Month | Min | Max | Avg | Sd |
| 1998 | December | 0.032021 | 0.097967 | 0.059619 | 0.014045 |
| 1999 | December | 0.032592 | 0.095049 | 0.054238 | 0.014819 |
| 2000 | December | 0.036627 | 0.091577 | 0.053139 | 0.012558 |
| 2001 | December | 0.038975 | 0.083850 | 0.055523 | 0.010375 |
| 2002 | December | 0.033085 | 0.094695 | 0.04851 | 0.010529 |
| 2003 | December | 0.035791 | 0.093283 | 0.053997 | 0.011535 |
| 2004 | December | 0.033880 | 0.096421 | 0.049199 | 0.012203 |
| 2005 | December | 0.044176 | 0.095704 | 0.059201 | 0.010836 |

| | | | | | |
|------|----------|----------|----------|----------|----------|
| 2006 | December | 0.030439 | 0.076107 | 0.045716 | 0.009322 |
| 2007 | December | 0.035195 | 0.098207 | 0.054561 | 0.011384 |

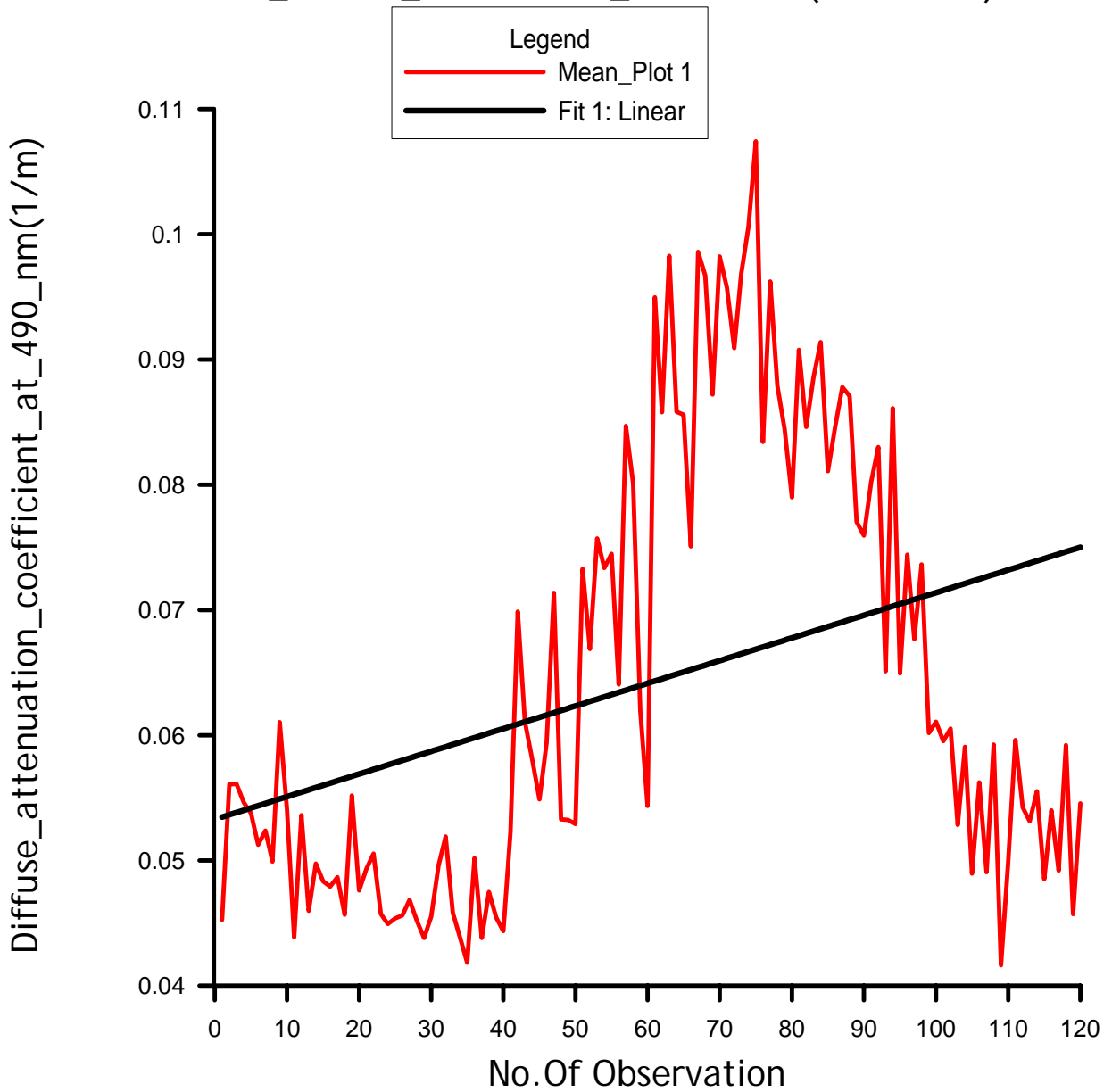
Diffuse_attenuation_coefficient (January-December)



Highest Diffuse Attenuation Coefficient at 490 nm August=0.09225(1/m)

| Month_Name | Month_no. | Diffuse Attenuation Coefficient at 490 nm (1/m) |
|------------|-----------|---|
| January | 1 | 0.05345 |
| February | 2 | 0.04866 |
| March | 3 | 0.04629 |
| April | 4 | 0.04643 |
| May | 5 | 0.05864 |
| June | 6 | 0.07089 |
| July | 7 | 0.09063 |
| August | 8 | 0.09225 |
| September | 9 | 0.08489 |
| October | 10 | 0.07164 |
| November | 11 | 0.05371 |
| December | 12 | 0.05337 |

Month_Diffuse_attenuation_coefficient(1998-2007)



Highest Diffuse Attenuation Coefficient at 490 nm August 2002

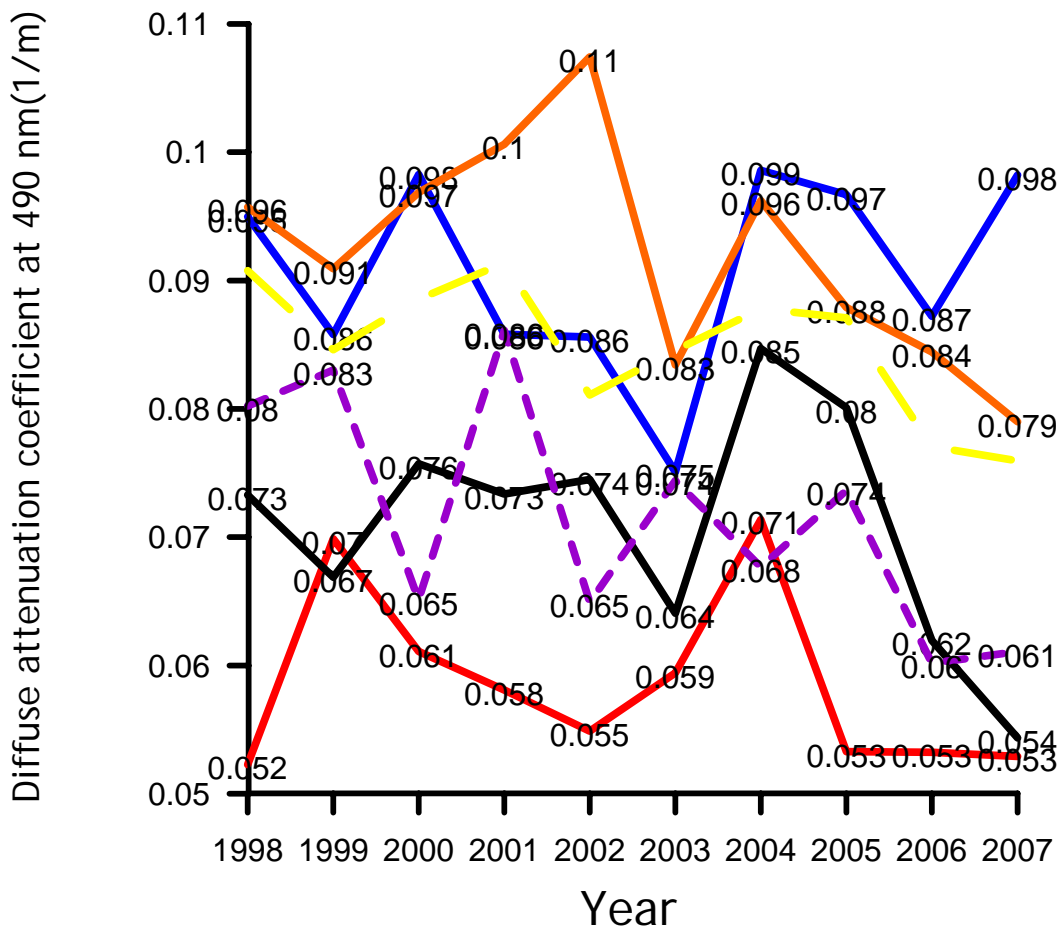
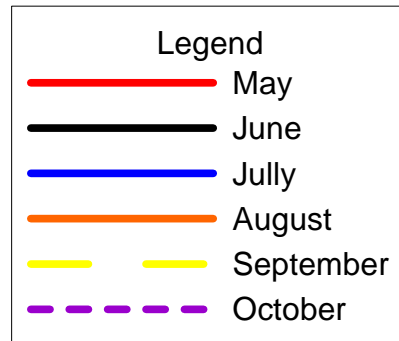
| Period | | | Diffuse_attenuation_coefficient_at_490_nm (1/m) | | | |
|--------|------|---------|---|----------|----------|----------|
| Obs. | Year | Month | Min | Max | Avg | Sd |
| 1 | 1998 | January | 0.033516 | 0.091622 | 0.045254 | 0.012144 |
| 2 | 1999 | January | 0.036858 | 0.092091 | 0.056072 | 0.013218 |
| 3 | 2000 | January | 0.036587 | 0.093614 | 0.056118 | 0.012385 |
| 4 | 2001 | January | 0.035728 | 0.097765 | 0.054646 | 0.011911 |

| | | | | | | |
|----|------|----------|----------|----------|----------|----------|
| 5 | 2002 | January | 0.032991 | 0.097995 | 0.053752 | 0.013187 |
| 6 | 2003 | January | 0.035396 | 0.096081 | 0.051245 | 0.010157 |
| 7 | 2004 | January | 0.034989 | 0.091911 | 0.052374 | 0.010647 |
| 8 | 2005 | January | 0.033303 | 0.090585 | 0.049904 | 0.011599 |
| 9 | 2006 | January | 0.040731 | 0.098458 | 0.061052 | 0.011682 |
| 10 | 2007 | January | 0.036191 | 0.096535 | 0.054035 | 0.012019 |
| 11 | 1998 | February | 0.029388 | 0.082276 | 0.043869 | 0.009341 |
| 12 | 1999 | February | 0.041445 | 0.093926 | 0.05361 | 0.009937 |
| 13 | 2000 | February | 0.034177 | 0.095620 | 0.04597 | 0.012043 |
| 14 | 2001 | February | 0.038898 | 0.084403 | 0.049741 | 0.00942 |
| 15 | 2002 | February | 0.035574 | 0.080716 | 0.048327 | 0.008088 |
| 16 | 2003 | February | 0.037166 | 0.094000 | 0.047915 | 0.008793 |
| 17 | 2004 | February | 0.038477 | 0.088955 | 0.048668 | 0.007615 |
| 18 | 2005 | February | 0.033111 | 0.092872 | 0.045666 | 0.009929 |
| 19 | 2006 | February | 0.039340 | 0.097842 | 0.055183 | 0.010429 |
| 20 | 2007 | February | 0.031238 | 0.096430 | 0.047611 | 0.011201 |
| 21 | 1998 | March | 0.032518 | 0.095208 | 0.049319 | 0.010552 |
| 22 | 1999 | March | 0.036451 | 0.091847 | 0.050551 | 0.010539 |
| 23 | 2000 | March | 0.032099 | 0.088981 | 0.045725 | 0.009996 |
| 24 | 2001 | March | 0.032752 | 0.078189 | 0.044929 | 0.007379 |
| 25 | 2002 | March | 0.035651 | 0.089753 | 0.045371 | 0.008233 |
| 26 | 2003 | March | 0.034882 | 0.089674 | 0.045617 | 0.00933 |
| 27 | 2004 | March | 0.037922 | 0.081536 | 0.046849 | 0.00699 |
| 28 | 2005 | March | 0.035230 | 0.080764 | 0.045204 | 0.007937 |
| 29 | 2006 | March | 0.032544 | 0.092426 | 0.043798 | 0.007967 |
| 30 | 2007 | March | 0.034171 | 0.078335 | 0.045531 | 0.007104 |
| 31 | 1998 | April | 0.031085 | 0.094602 | 0.04959 | 0.011888 |
| 32 | 1999 | April | 0.033595 | 0.099899 | 0.051913 | 0.017088 |
| 33 | 2000 | April | 0.024199 | 0.079724 | 0.045826 | 0.008967 |
| 34 | 2001 | April | 0.023400 | 0.080661 | 0.043827 | 0.0103 |
| 35 | 2002 | April | 0.025334 | 0.078767 | 0.041833 | 0.010591 |
| 36 | 2003 | April | 0.029414 | 0.095021 | 0.050196 | 0.011796 |
| 37 | 2004 | April | 0.029809 | 0.080962 | 0.043807 | 0.010354 |
| 38 | 2005 | April | 0.028401 | 0.091210 | 0.047484 | 0.011487 |
| 39 | 2006 | April | 0.030800 | 0.071339 | 0.045438 | 0.008378 |
| 40 | 2007 | April | 0.020600 | 0.081496 | 0.044347 | 0.009887 |
| 41 | 1998 | May | 0.017801 | 0.169010 | 0.052268 | 0.024371 |
| 42 | 1999 | May | 0.027401 | 0.230912 | 0.069864 | 0.040482 |
| 43 | 2000 | May | 0.030454 | 0.250588 | 0.061086 | 0.044317 |
| 44 | 2001 | May | 0.027701 | 0.238351 | 0.058079 | 0.037954 |

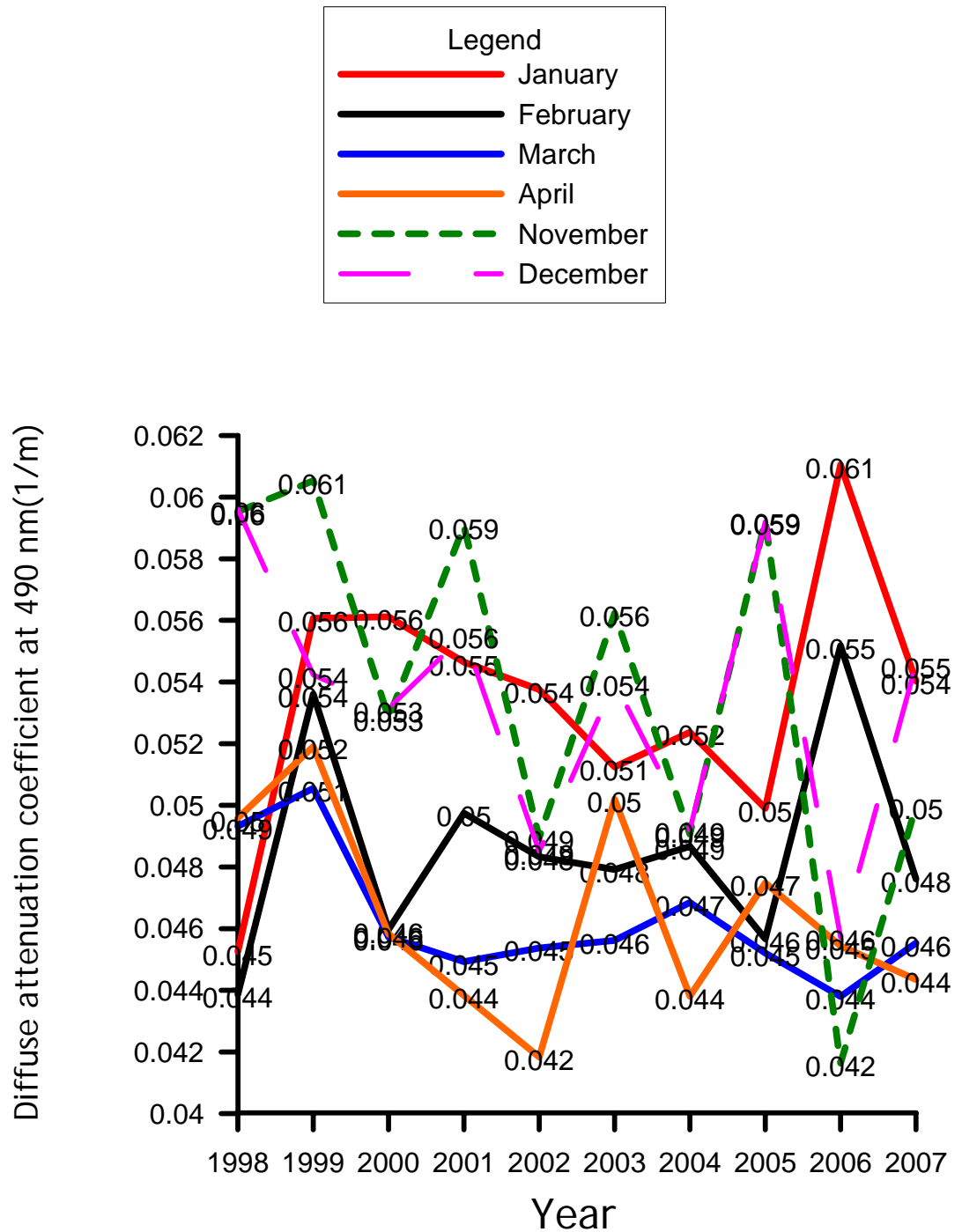
| | | | | | | |
|----|------|-----------|----------|----------|-----------|----------|
| 45 | 2002 | May | 0.026795 | 0.245813 | 0.054872 | 0.043752 |
| 46 | 2003 | May | 0.023944 | 0.302476 | 0.059405 | 0.052241 |
| 47 | 2004 | May | 0.034400 | 0.335812 | 0.071372 | 0.056301 |
| 48 | 2005 | May | 0.028068 | 0.246199 | 0.053282 | 0.03367 |
| 49 | 2006 | May | 0.020200 | 0.224211 | 0.053225 | 0.037789 |
| 50 | 2007 | May | 0.026726 | 0.211884 | 0.052904 | 0.033612 |
| 51 | 1998 | June | 0.032024 | 0.347483 | 0.073283 | 0.058932 |
| 52 | 1999 | June | 0.028401 | 0.299904 | 0.06688 | 0.053433 |
| 53 | 2000 | June | 0.029599 | 0.276301 | 0.075714 | 0.048845 |
| 54 | 2001 | June | 0.026400 | 0.237208 | 0.073358 | 0.048438 |
| 55 | 2002 | June | 0.033401 | 0.404036 | 0.074487 | 0.061917 |
| 56 | 2003 | June | 0.023201 | 0.353990 | 0.064059 | 0.055214 |
| 57 | 2004 | June | 0.035767 | 0.659813 | 0.084694 | 0.086544 |
| 58 | 2005 | June | 0.032800 | 0.216510 | 0.080089 | 0.047702 |
| 59 | 2006 | June | 0.029824 | 0.255808 | 0.061957 | 0.050515 |
| 60 | 2007 | June | 0.025725 | 0.254331 | 0.054354 | 0.037401 |
| 61 | 1998 | July | 0.035452 | 0.344393 | 0.094979 | 0.066646 |
| 62 | 1999 | July | 0.031550 | 0.320324 | 0.085787 | 0.05766 |
| 63 | 2000 | July | 0.036201 | 0.503557 | 0.098274 | 0.086404 |
| 64 | 2001 | July | 0.022400 | 0.276980 | 0.0858253 | 0.056168 |
| 65 | 2002 | July | 0.031000 | 0.349604 | 0.085596 | 0.070063 |
| 66 | 2003 | July | 0.032134 | 0.269576 | 0.075076 | 0.051516 |
| 67 | 2004 | July | 0.035334 | 0.308716 | 0.09859 | 0.061283 |
| 68 | 2005 | July | 0.034800 | 0.333807 | 0.096698 | 0.094063 |
| 69 | 2006 | July | 0.026695 | 0.575256 | 0.087208 | 0.083338 |
| 70 | 2007 | July | 0.031826 | 0.341732 | 0.098224 | 0.076971 |
| 71 | 1998 | August | 0.034948 | 0.269549 | 0.09572 | 0.051925 |
| 72 | 1999 | August | 0.027753 | 0.376944 | 0.090916 | 0.069292 |
| 73 | 2000 | August | 0.034325 | 0.373959 | 0.096862 | 0.069013 |
| 74 | 2001 | August | 0.034255 | 0.379991 | 0.100624 | 0.076741 |
| 75 | 2002 | August | 0.031500 | 0.429897 | 0.107434 | 0.094608 |
| 76 | 2003 | August | 0.031000 | 0.398130 | 0.083428 | 0.073436 |
| 77 | 2004 | August | 0.035016 | 0.338793 | 0.096233 | 0.075033 |
| 78 | 2005 | August | 0.030997 | 0.334102 | 0.087898 | 0.059761 |
| 79 | 2006 | August | 0.026473 | 0.549478 | 0.084431 | 0.084244 |
| 80 | 2007 | August | 0.026297 | 0.320450 | 0.078997 | 0.063877 |
| 81 | 1998 | September | 0.027401 | 0.246006 | 0.090774 | 0.055942 |
| 82 | 1999 | September | 0.023201 | 0.267231 | 0.0846078 | 0.0567 |
| 83 | 2000 | September | 0.033199 | 0.275002 | 0.088561 | 0.054793 |
| 84 | 2001 | September | 0.031999 | 0.415173 | 0.091391 | 0.074713 |

| | | | | | | |
|-----|------|-----------|----------|----------|----------|----------|
| 85 | 2002 | September | 0.030921 | 0.300316 | 0.081083 | 0.057475 |
| 86 | 2003 | September | 0.034753 | 0.382686 | 0.084567 | 0.06533 |
| 87 | 2004 | September | 0.033199 | 0.360655 | 0.087799 | 0.066506 |
| 88 | 2005 | September | 0.035599 | 0.294651 | 0.08709 | 0.051599 |
| 89 | 2006 | September | 0.029187 | 0.384947 | 0.07705 | 0.054193 |
| 90 | 2007 | September | 0.031905 | 0.350051 | 0.075948 | 0.062009 |
| 91 | 1998 | October | 0.032232 | 0.214017 | 0.08023 | 0.041486 |
| 92 | 1999 | October | 0.038602 | 0.285230 | 0.08302 | 0.046128 |
| 93 | 2000 | October | 0.034780 | 0.296683 | 0.065106 | 0.03891 |
| 94 | 2001 | October | 0.041384 | 0.278616 | 0.086102 | 0.045082 |
| 95 | 2002 | October | 0.029874 | 0.197561 | 0.064936 | 0.037951 |
| 96 | 2003 | October | 0.036717 | 0.225159 | 0.074411 | 0.040354 |
| 97 | 2004 | October | 0.029792 | 0.228589 | 0.067665 | 0.043251 |
| 98 | 2005 | October | 0.035900 | 0.222238 | 0.073638 | 0.040456 |
| 99 | 2006 | October | 0.029135 | 0.261367 | 0.060176 | 0.040109 |
| 100 | 2007 | October | 0.028633 | 0.287988 | 0.061082 | 0.040406 |
| 101 | 1998 | November | 0.034627 | 0.094546 | 0.059527 | 0.015895 |
| 102 | 1999 | November | 0.033313 | 0.095198 | 0.060533 | 0.017432 |
| 103 | 2000 | November | 0.032900 | 0.096222 | 0.052836 | 0.012386 |
| 104 | 2001 | November | 0.035438 | 0.097861 | 0.059072 | 0.015917 |
| 105 | 2002 | November | 0.029001 | 0.086602 | 0.04895 | 0.012214 |
| 106 | 2003 | November | 0.033980 | 0.088684 | 0.056234 | 0.012631 |
| 107 | 2004 | November | 0.032317 | 0.080266 | 0.049061 | 0.010976 |
| 108 | 2005 | November | 0.039998 | 0.095095 | 0.059248 | 0.014017 |
| 109 | 2006 | November | 0.022590 | 0.088034 | 0.041636 | 0.013682 |
| 110 | 2007 | November | 0.034800 | 0.095883 | 0.049971 | 0.012143 |
| 111 | 1998 | December | 0.032021 | 0.097967 | 0.059619 | 0.014045 |
| 112 | 1999 | December | 0.032592 | 0.095049 | 0.054238 | 0.014819 |
| 113 | 2000 | December | 0.036627 | 0.091577 | 0.053139 | 0.012558 |
| 114 | 2001 | December | 0.038975 | 0.083850 | 0.055523 | 0.010375 |
| 115 | 2002 | December | 0.033085 | 0.094695 | 0.04851 | 0.010529 |
| 116 | 2003 | December | 0.035791 | 0.093283 | 0.053997 | 0.011535 |
| 117 | 2004 | December | 0.033880 | 0.096421 | 0.049199 | 0.012203 |
| 118 | 2005 | December | 0.044176 | 0.095704 | 0.059201 | 0.010836 |
| 119 | 2006 | December | 0.030439 | 0.076107 | 0.045716 | 0.009322 |
| 120 | 2007 | December | 0.035195 | 0.098207 | 0.054561 | 0.011384 |

Diffuse_attenuation_coefficient (May-October) 1998-2007



Diffuse_attenuation_coefficient (November-April) 1998-2007



The study showed a clear seasonal variability with highest chlorophyll concentration during July-August and least in April. The inter-annual variability showed an increasing trend from 1998 to 2007.