ปัจจัยทางอุตุนิยมวิทยาที่มีผลต่อความเข้มข้นของคลอโรฟิลล์เอบริเวณอ่าวไทยจากการศึกษาด้วยเทคนิครีโมทเซนซิ่ง

นางสาววรรณรัตน์ ภูมิวงศ์พิทักษ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาวิทยาศาสตร์สิ่งแวดล้อม (สหสาขาวิชา)
บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2546

ISBN 974-17-3716-5

METEOROGICAL FACTORS ASSOCIATED WITH CHLOROPHYLL- A CONCENTRATION IN THE GULF OF THAILAND AS STUDIED BY REMOTE SENSING TECHNIQUE

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Environmental Science (Inter-Department)
Graduate School
Chulalongkorn University
Academic Year 2003

ISBN 974-17-3716-5

Thesis Title METEOROGICAL FACTORS ASSOCIATED WITH CHLOROPHYLL- A CONCENTRATION IN THE GULF OF THAILAND AS STUDIED BY REMOTE SENSING TECHNIQUE
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Field of study Environmental Science
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วรรณรัตน์ ภูมิวงศ์พิทักษ์ : ปัจจัยทางอุตุนิยมวิทยาที่มีผลต่อความเข้มข้นของคลอโรฟิลล์เอบริเวณอ่าวไทยจากการศึกษาด้วยเทคนิครีโมทเซนซิ่ง. (METEOROGICAL FACTORS ASSOCIATED WITH CHLOROPHYLL- A CONCENTRATION IN THE GULF OF THAILAND AS STUDIED BY REMOTE SENSING TECHNIQUE) อ. ที่ปรึกษา : อ. ดร. ศุภิชัย ตั้งใจตรง, อ.ที่ปรึกษาร่วม : ผศ. ดร. ไทยถาวร เลิศวิทยาประสิทธิ, 75 หน้า. ISBN 974-17-3716-5.

การศึกษารูปแบบการกระจายของของคลอโรฟิลล์เอบริเวณอ่าวไทยปี พ.ศ. 2541-2543 โดยข้อมูลดาวเทียม SeaWiFS พบว่ามีรูปแบบใกล้เคียงกับการศึกษาที่ผ่านมา โดยปริมาณคลอโรฟิลล์เอมีค่าสูงบริเวณอ่าวไทยตอนบนโดยเฉพาะบริเวณปากแม่น้ำหลัก 4 สาย ซึ่งพบได้ทุกเดือนโดยเฉพาะในช่วงฤดูฝน ส่วนบริเวณชายฝั่งทะเลตอนกลางและทางตอนล่าง พบปริมาณคลอโรฟิลล์เอมีค่าต่ำในทุกเดือน ถึงแม้จะมีการนำพาสารอาหารจากปากแม่น้ำก็ตาม และยังพบอีกว่า บริเวณกลางอ่าวไทย คลอโรฟิลล์เอในช่วงฤดูหนาวมีค่าสูงกว่าในช่วงฤดูร้อนและฤดูฝน ทั้งนี้มีสาเหตุจากลมมรสุมและการเปลี่ยนแปลงทางปัจจัยทางอุตุนิยมวิทยา และจากการศึกษาความสัมพันธ์ทางสถิติระหว่างคลอโรฟิลล์เอและปัจจัยทางอุตุนิยมวิทยาพบว่า ระยะเวลาของแสงและอุณหภูมิอากาศเป็นปัจจัยสำคัญในการควบคุมการกระจายของคลอโรฟิลล์เอในทุกฤดู ในฤดูฝน ปริมาณน้ำฝนเป็นปัจจัยสำคัญที่ควบคุมการกระจายคลอโรฟิลล์ โดยพบว่าแสงที่ลดลง อุณหภูมิเพิ่มขึ้น และ ฝนที่ตกต่อเนื่อง จะทำให้ความเข้มข้นของคลอโรฟิลล์สูงขึ้น ส่วนในฤดูร้อนและฤดูหนาว อุณหภูมิอากาศเป็นปัจจัยหลักที่ควบคุมการกระจายของคลอโรฟิลล์เอ โดยมีแสงเป็นปัจจัยร่วมต่อการกระจายของคลอโรฟิลล์เอบริเวณอ่าวไทย

สหสาขาวิชา..........วิทยาศาสตร์สิ่งแวดล้อม.........ลายมือชื่อ..
สาขาวิชา.............วิทยาศาสตร์สิ่งแวดล้อม......... ลายมือชื่ออาจารย์ที่ปรึกษา……………………
ปีการศึกษา………………..2546……………… ลายมือชื่ออาจารย์ที่ปรึกษาร่วม………………

4389095820 : MAJOR ENVIRONMENTAL SCIENCE
KEY WORD: CHLOROPHYLL-A / SeaWiFS / METEOLOGICAL FACTORS

WANNARAT PHOOMWONGPITAK : THESIS TITLE. METEOROGICAL FACTORS ASSOCIATED WITH CHLOROPHYLL- A CONCENTRATION IN THE GULF OF THAILAND AS STUDIED BY REMOTE SENSING TECHNIQUE THESIS ADVISOR : SUPICHAI TANGJAITRONG, THESIS COADVISOR : ASST.PROF. THAITAWORN LIRDWITAYAPRASITH pp. ISBN 974-17-3716-5.

The pattern of the chlorophyll *a* distribution in the Gulf of Thailand that found during 1998-2000 from SeaWiFS imagery data, described here are similar to those of previous *in situ* studies. In the upper part of the Gulf, high chlorophyll *a* concentration was detected every month espeacially in rainy season at the main four river mouths. However, high chlorophyll *a* concentration did not occur in the middle and the lower of the Gulf despite of the nutrient from the inshore discharging into the coastal sea. In winter seasons, chlorophyll *a* concentration was the higher than in summer and rainy seasons. Possible causes for this include variation in monsoon and meteorological factors. According to the statistical analysis, sunshine duration and air temperature play a major role affecting chlorophyll *a* concentration in all seasons. While in rainy season, rainfall duration is an important factor in chlorophyll *a* concentration. It was found that declined light, elevated air temperature and amount of rainfall were induced high chlorophyll *a* concentration. In addition, in summer and winter seasons, air temperature and light was a major and minor important factors affecting in chlorophyll *a* concentration, respectively.

Inter - Departmen of Environmental Science..…………………. Student’s signature………………………………

Field of study…………..… Environmental Science………….….. Advisor’s signature………………………………

Academic year ……………..2003………………………………Co-advisor’s signature………………………….…

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to Supichai Tangjaitrong, Ph.D., my thesis advisor, for his advice and opportunity and Assistant Professor Thaithaworn Lerdwithayaprasith, Ph.D., co–advisor, for his suggestion and support that I had received throughout my study. I am grateful to Assistant Professor Charnwit Kositanont, Ph.D., Darasri Dowreang, Ph.D., Associate Professor Thavivongse Sriburi, Ph.D., who served as thesis chairman and thesis committees respectively, for their suggestions. I am also thankful to Satsuki Matsumura, Ph.D. for his advice and the oppotunity to train on SEAFDEC cruises.

The supports provided by the following organizations are appreciated, namely, Graduate School for financial support; Thai Meteorological Department for meteorological data; the Department of Marine Science, Faculty of Science, Chulalongkorn University, for computer facilities; SeaWiFS project and Distributed Active Center at the Goddard Space Flight Center, Greenbelt, MD 20771 for production and distribution of the SeaWiFS data.

I would like to thank Mr. Sompop Rungsupa, Aquatic Resources Research Institue for water quality data. Ranin Suksuchano and Thitiworada Nintanawongsa for their helps and encouragements.

Lastly, I am indebted my parents and elder sisters to give a strength and the opportunity to do what I love.

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CHAPTER 1

INTRODUCTION

1.1 Importance of the study

Phytoplankton blooms occur in a wide range of locations throughout the Gulf of Thailand, as well as globally, and their influences on the ocean have been studied for several decades. They are also known as red tide, are a fairly common occurrence. Phytoplankton is the base of the marine life food chains, with indirect consequences on the fishing industry. This primary production plays also a key role for the evaluation of the global carbon cycle and is thus of great scientific concern, notably to understand the so-called greenhouse effect.

However, if conditions are right, phytoplankton can sometimes grow and reproduce at such a high rate that they create dense, highly colored patches in the water. It has colored the water reddish-brown, yellow or milky depending on the main species responsible. They deplete necessary nutrients from the water or some species have caused fish kills either by depleting the dissolved oxygen content or by forming toxic material or occasionally both. The most harmful species are poisonous and their toxin can be passed through the food chain and may cause massive fish mortalities, birds, marine mammals and even death in humans. Thus, it is important to monitor phytoplankton blooms due to their strong environmental, health, social and economic impacts.

A combination of biological, hydrographic and meteorological processes may trigger phytoplankton blooms. Although coastal pollution has enhanced phytoplankton blooms in many parts of the world, but in some areas, phytoplankton blooms represent a natural process not caused by pollution. Possible factors of the blooms include natural mechanisms of species dispersal by currents and tides to a host of human-related phenomena such as nutrient enrichment, climatic shifts, or transport of algal species via ship ballast water.

Measuring chlorophyll content is highly important in tracking with the water pollution. However, it is impractical monitor water chlorophyll distribution over a large area periodically based on a conventional water sampling and analysis method. The remote sensing technology of the ocean color has been applied widely in many countries. It permits a synoptic study in various spatial and temporal scales, as such it provide a useful database on ocean phenomena. In addition, a very rapid access to the information, almost in real time is now possible. Thus, the use of satellite remote sensing to provide synoptic measurements of the ocean is becoming increasingly important in environmental management.

1.2 Objectives

1. To study the influence of meteorological factors, amount of rainfall, sunshine duration, visibility and air temperature on chlorophyll a concentration.

2. To analyze and predict the future trends of phytoplankton bloom occurrence and thereby mitigate their effects on marine life and people, and to propose conceptual plan for environmental management in the future.

1.3 Scope of the study

1. The temporal and spatial distribution of chlorophyll *a* concentration in the Gulf of Thailand were studied.

2. The relationship between chlorophyll *a* concentration and meteorological factors was studied by using statistical analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Meteorological factors controlling phytoplankton bloom

Phytoplankton bloom is a coastal phenomena caused by environmental conditions which promote explosive growth of phytoplankton. Changing in environmental factors may increase primary productivity in the ocean. Factors that are especially favourable include temperature, rainfall duration, high nutrient content, low salinity, etc.

The patterns of seasonal variation of surface plant pigment concentration in the Newfoundland region were studied using remotely sensed data from the CZCS and SeaWiFS. It found that meteorological factors mainly influencing water stratification, which seemed to be a crucial factor in either light or nutrient limitation of phytoplankton growth (Afanasyev *et al*., 2000). In addition, the seasonal variations in wind correlated with *Gymnodinium breve* bloom occurences in the west coast of Florida USA. The bloom initially appeared in summer at the coast and continued during the fall due to weak winds and warm temperatures in the summer. Those conditions probably encourage bloom initiation by allowing concentratrion of organisms near surface, while stronger winds in the fall may help in the redistriburion of the organism to the coast (Stumpf *et al*., 1998).

Gomes *et al*. (1999) examined the seasonality of phytoplankton abundantes in the western and northern parts of Bay of Bengal using shipboard data compared with ocean colour imagery from OCTS and SeaWiFS. They found that wind driving coastal upwelling and increasing river runoff during the southwest monsoon, this increased phytoplankton biomass dramatically (92 mg.m^{-2}). However, the average productivity was only 0.3 g C m^{-2}d $^{-1}$ suggesting light limitation due to intense cloud cover. While a reduction in cloud cover and enhanced irradiance during the northeast monsoon, primary production, especially in the northern part of the bay, where phytoplankton appeared to benfit from both improved light conditions and nutrient inputs from estuarine mechanisms and river runoff. Another example is from the San Francisco Bay where estuary ligh intensity was an important factor that related environmental variations controlled changing of phytoplankton community. Diatom was most abundant in wet and normal water-year types with cook water temperature, low water transparency, low light intensity and high stream river. Flagellate groups were most abundant in dry and critically dry water-year types with high water transparency, high light intensity and low stream flow (Lehman, 2000).

In Manila Bay, Philippines, *Pyrodinium* sp. blooms formation during late March to May. It was found that the cell density was higher in June and was lower in July. Rainfall played a key role in the development of *Pyrodinium* sp. red tide because peaks of the bloom occurred in months with heavy rainfall (Bajarias and Relox, 1996). Unusually high rainfall in some areas is accompanied by resultant phytoplankton blooms of "red tides". Similarly devastating floods in the south of Thailand in 1989, resulted in phytoplankton blooms along most of the western coast of the Gulf of Thailand. Overview of *Pyrodinium* sp. in the Western Pacific, indicated that blooms incidence appear to be associated with monsoons and that upwelling caused by winds may be an important factor in the initiation of blooms (Maclean, 1989 cited in Surapol Sudara and Chou, 1999). Likewise, plankton blooms in the coastal area of Chonburi province in 1991,1992, 1995, 1997 and 1998, occurred after many days of rainfall in the rainy season. (Waewta Tongra-ar, 1998)

In years of high rainfall and high river flow in Chesapeake Bay, nutrient loads and suspended sediment carried in the freshwater flow influenced the nutrient and light conditions in the receiving water along the entire main stem of the Bay. Algal abundances in high flow-years were very high, particularly during the spring bloom period, April to mid-May, and highest chlorophyll concentrations were consistently found seaward of the peaks observed in moderate or low flow years. In years of low rainfall and low river flow, nutrient delivery is much fewer. Position of the chlorophyll maximum is related to the magnitude of flow because nutrient inputs during spring when freshwater flow is maximal, are largely derived from the Susquehanna River in the head of the Bay (CBRSP, 2003).

Nezlin *et al*. (1999) studied patterns of year-to-year discrepancies as compared with *in situ* measurements in the Black sea. The variations seem to correlate with cyclic oscillations of winter air temperature. In western shallow regions, it is also correlated with the Danube discharge intensity. More intensive winter–spring blooms and a slightly lower level of pigment concentration during warm season are typical for years with a mild winter. The causes of regularities seem to be the peculiarities of hydrology and meteorological regimes. The intensity of winter spring bloom of phytoplankton appears to depend on hydrological mechanism during winter period rather than illumination intensity. Furthermore, inter-annual variation in the timing of formation of phytoplankton bloom in Rose Sea polynya appears to be controlled by winter temperatures, which determined sea ice thickness and integrity, rather than variability or intensity in wind stress (Arrigo *et al*., 1998).

In California coastal water, offshore waters (100–1000 km from the shore) have an annual cycle of chlorophyll concentration and CDOM with a maximum in winter-spring (December–March) and a minimum in late summer. For inshore waters the maximum is more likely in spring (April–May). There was a significant increase in both chlorophyll concentration and CDOM off central and southern California during the La Nina year of 1999. The trend of increasing chlorophyll concentration and CDOM from October 1996 to June 2000 is statistically significant in many areas. The abundances of phytoplankton extended far off shore in warm waters. The increasing of Baja may be due to blooms of nitrogen-fixing cyanobacteria. Some open ocean cyanobacteria are more abundant in nutrient-depleted, strongly stratified waters because they are capable of fixing nitrogen gas into organic matter, reducing their dependence on nutrient upwelling (Kahru and Mitchell, 2001).

In the upper Gulf of Thailand, chlorophyll *a* concentration and phytoplankton density varied each year. Both values increased in winter season in 1996, 1997 and 1999 at 4 main river mouths: Chaopraya, Thachin, Bangprakong and Maeklong. On the other hand, both values were highest in summer season in 1994 and 1997. While in rainy season, highest chlorophyll *a* concentration was found in 1998 and highest phytoplankton density was found in 1995 (Sompop Rungsupa *et al.,* 1994-1999). In addition, Preecha Pacheanjai (1999) studied the diversity of phytoplankton along the lower of Bangprakong River and the east coast and the west coast of the inner Gulf of Thailand, during January-December 1999. The results from 11 stations showed that phytoplankton density was highest in November, especially at Pattaya station where high phytoplankton density was found every month.

As the season changes to summer, the amount of sunlight increases, the water heats up and the surface layer of the ocean stratifies, hence, keeping planktons near the surface. Phytoplanktons start growing again. Upwelling can also cause the population of phytoplankton to explode suddenly. Despite possible occurrence of upwelling and downwelling in some coastal areas in the Gulf of Thailand during the norteast monsoon, the data indicated a decrease in vertical mixing as compared to the South-West monsoon. That brings more stable conditions to the water column, which are more suitable for increased primary production. However, the situation is complicated by the intrusion of low-oxygen deeper water from the South China Sea into the coastal area. Low organic levels indicate relatively oxidized condition of the seabed and low productivity of the water column, except in such areas of confluence as in the vicinity of Samui Island. This is corroborated by the low primary production values measured, except in the Upper Gulf. Many seasonal variations in the distribution and concentration of trace elements both in the water column and in the sediments are also brought about by monsoon turbulence that could disturb bottom deposits. (Waleerat Musikasung *et al*., 1997)

In the west coast of Africa and South America coast near Peru, cold water is pushed up from the ocean depths and brings with it rich nutrient, the results are explosive growth in the phytoplankton population. While in Canada, phytoplankton bloom was not associated with the upwelling and fell outside the normal springtime bloom pattern.

In Indonesia, chlorophyll *a* correlated with the amount of rainfall and solar radiation in Ambon Bay and in Elpaputih Bay, chlorophyll *a* correlated best with air temperature and solar radiation. And there is no correlation between chlorophyll *a* concentration and meteorological parameters in Kayeli Bay. (Wouthuyzen, and Siahainenia, 1999)

In summary, there is no clear evidence that seasonal change plays an important role to this phenomenon.

2.2 Chlorophyll *a* detection by remote sensing of ocean color

2.2.1 Optical absorption characteristics of chlorophyll *a*

Phytoplankton contains chlorophyll *a* and other pigments that absorb sunlight, this process provides the energy needed for photosynthesis of organic carbon. Chlorophyll *a* is specific for photosynthetic organisms, mainly photosynthesis in the marine environment. Since chlorophyll *a* absorbs energy primarily in the red (650-700 nm) and blue (400-450 nm) regions of the spectrum and reflect green light (500-600 nm) (figure 2.1), there is a relationship between the spectrum of sunlight backscattered by upper ocean layers and the distribution of phytoplankton pigments in these layers.

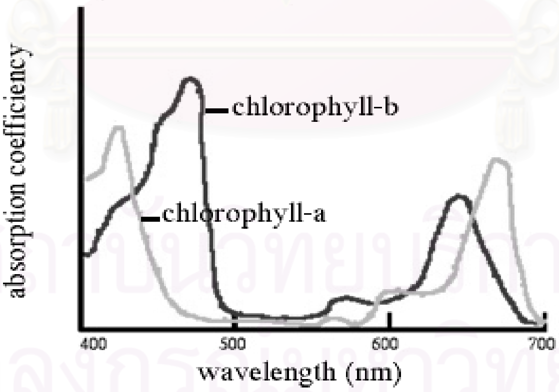


Figure 2.1 Absorption spectra of chlorophyll

2.2.2 SeaWiFS derived chlorophyll *a* concentration

Satellite ocean color algorithms involve two main steps of data processing. In the first step, the effects of the atmosphere and sea surface are removed from satellite measurement of upwelling radiance, which is commonly referred to as atmospheric correction. In the second step the semianalytical or empirical algorithms are used to derive bio-optical properties of the ocean from water-leaving radiance or remote-sensing reflectance (O'Reilly *et al.*, 1998).

The SeaStar satellite with Sea-viewing Wide Field-of-view Sensor (SeaWiFS) was launched in August 1997. It repeats the same orbit every 16 days (233 orbits) but covers the same point on the earth every 1–2 days depending on the latitude. SeaWiFS is a spectroradiometer that measures the water-leaving radiance at 6 bands in the visible light and 2 bands in the near-IR. (Table 2.1) The OC4 algorithm is an empirical algorithm based on more than 2800 bio-optical in situ measurements of chlorophyll *a* from all over the world. OC4 is a maximum band ratio algorithm where the maximum of 3 band ratios (443/555, 490/555, and 510/555) is used to predict chlorophyll concentration and the other bands are used for atmospheric correction or determination of pigment absorption, gelbstoff concentration and sediment load in the near-surface water. (O'Reily *et al.*, 2000)

Over most of the deep ocean, chlorophyll concentrations are below 0.3 mg m^{-3}, and water-leaving radiance in the 443nm band exceeds the radiance in the 490 and 510nm bands. At chlorophyll concentrations above 0.3 mg m^{-3} and below 1.5 mg m^{-3}, water-leaving radiance in the 490nm band is usually greater than the values for the 443 and 510nm bands. Finally, at chlorophyll concentrations above approximately 1.5 mg m^{-3}, frequently found near shore, water-leaving radiance in the 510nm band exceeds that measured in the 443nm and 490nm bands. In fact, in both chlorophyll-rich waters and phytoplankton blooms, the estimate of water-leaving radiance for the 443nm band can be noisy and too low to make accurate chlorophyll estimates. The OC4 algorithm takes advantage of the natural shift in the dominant radiance band, and by using the brightest band (443,490,510) in the band ratio, the algorithm is able to estimate chlorophyll concentrations with a high level of accuracy over the wide range that exists in the global ocean. (O’Reily *et al.*, 2000)

$$Chla\,(\text{mg.m}^{-3}) = 10^{a_0 + a_1 * R^1 + a_2 * R^2 + a_3 * R^3} + a_4$$

where $$R = Log_{10}\left[\frac{\max\{R_{443}, R_{490}, R_{510}\}}{R_{555}}\right]$$ and

a = [0.366,-3.067,1.930,0.649,-1.532]

Table 2.1 The SeaWiFS spectral bands

Band	Wavelength	Application
1	402-422	Colored dissolved organic matter
2	433-453	Chlorophyll absorption
3	480-500	Pigment absorption, attenuation coefficient
4	500-520	Chlorophyll absorption
5	545-565	Pigment absorption, optical properties, sediment
6	660-680	Atmospheric correction, sediment
7	745-785	Atmospheric correction, aerosol radiance
8	845-885	Atmospheric correction, aerosol radiance

Islam and Chan (2001) compared many empirical algorithms for chlorophyll concentration in Singapore regional waters. Thet reached an overall conclusion that remote sensing of ocean color using SeaWiFS satellite would greatly help in future applications on monitoring the regional water. While Liew *et al*, (2001) studied the validity of SeaWiFS chlorophyll algorithm in Singapore coastal waters. Their results showed that the OC4 algorithm is valid only for seawaters with low colored dissolved organic matter or CDOM, but the accuracy deteriorates for typical coastal waters with high dissolved organic matter.

Shen *et al*. (2001) analyzed the pattern of chlorophyll concentration and the curves of normalized water leaving radiance observed in Kimanis Bay, Sabah and Daya Bay, near Hong Kong during red tide periods. Both chlorophyll concentration and normalized water leaving radiance are considerably different from other days. Thus, they can be used as indications of red tide.

CHAPTER 3

METHODOLOGY

3.1 Data Collection

The existing data related to the study were collected as follows:

3.1.1 Meteorological data

Daily Meteorological data were provided by the Thai Meteorological Department. These data included daily amount of rainfall, daily sunshine duration, daily visibility and daily air temperature for January 1998 to February 2001 from 19 recording stations. The name, latitude and longitude coordinations are shown in table A.1 and the staion locations are present in figure A.1. Stations were selected to cover a representative range of coastal water. From the meteorological point of view, the climate of Thailand may be divided into three seasons as follows: rainy or southwest monsoon season (mid-May to mid-October), Winter or northeast monsoon season (mid-October to mid-February) and summer or pre-monsoon season, mid-February to mid-May.

3.1.2 Water quality data

Water quality data were collected by the Aquatic Resources Research Instutute with three times measurements per year, in January, March and July 1998, and in January, May and December 1999 at 21 stations along the upper of the Gulf of Thailand (Table A.2 and figure A.2). These data include chlorophyll a content, phytoplankton density, suspended solid and nutrient concentration.

3.1.3 Remotely sensed data

Recent ocean color sensors provide a capability for monitoring dynamics of phytoplankton in oceanic waters. Sea-viewing Wide Field-of view Sensor (SeaWiFS) data are useful for determining chlorophyll *a* concentration. Satellite image data were obtained from the satellite receiving station HKUS at Hong Kong University of Science and Technology and station HSNG at the National University of Singapore. The full resolution data LAC - level 1A of 1.1 km spatial resolution were obtained via the internet from the Goddard Distributed Active ArchiveCenter (GDAAC) under the auspieces of NASA. The acquired data covering the region between 6° - 13 ° N and 99° - 105 °E for the period of January 1998 to February 2001. Data covered the coordinations of Meteorological Department stations and Pollution Monitoring Program stations. They were selected for match up analysis with meteorological data and water quality data, respectively.

3.2 Software Use

All ocean color images were processed with the SeaWiFS Data Analysis System (SeaDAS) version 4.1 software package developed by NASA. SeaDAS was used for processing SeaWiFS data to create level-2 chlorophyll *a* concentration products using the bio-optical algorithm Ocean Chlorophyll 4-Band or OC4 algorithm.

Meteorological parameters and chlorophyll *a* concentration were analysed using the SPSS version 10.0 statistical analysis software package.

3.3 Methodology

3.3.1 Image analysis

3.3.1.1 SeaWiFS level-2

The level-1A SeaWiFS data give the reflectance measurements for each of the eight bands. The raw data were processed using SeaDAS software to extract normalised water leaving radiance (nLw (λ), where λ= 412, 443, 490, 510 and 555 nm) for calculating chlorophyll *a* concentration. An atmospheric correction is first carried out to reduce the errors for both the water-leaving radiance and the chlorophyll *a* concentration. The climatological meteorology and ozone ancillary data were used initially, but the imagery has been subsequently reprocessed using the daily ancillary data. Chlorophyll *a* concentration was estimated using the default SeaDAS (OC4) algorithm based on empirical method using radiance ratio of SeaWiFS channel (O'Reilly *et al.,* 2000). Bio-optical algorithms are then employed to create a level 2 end products containing chlorophyll *a* concentration. All the products were then extracted, for the area of interest.

3.3.1.2 SeaWiFS level-3

Level-2 files can be used as input to the l3bin program, and must first be spatially binned to an equal area grid before temporal binning can be perfomed. Level-2 data file will generate a single level-3 binned file, however some level-2 files will split into two level-3 binned files if the level-2 data crosses the international dateline or either pole. Next, level-3 temporal binning is performed on a set of level-3 binned files. This input set can include either spatially and/ or temporally binned level-3 binned files. Temporally gridded files are created from the summation of any number of Level-3 binned files. Typical binning periods used include "orbit", "daily", "8day", "monthly", and "yearly" products. However, SeaDAS provides the capability of producing a level-3 time-binned file of any time period. (The SeaDAS Development Group)

Both the level-3 spatially and temporally binned output files have the same logical data format, although the level-3 temporal binned files store the geophysical data values in separate physical files. However, the output-binned files are limited to fixed bin resolutions of 2km, 4km, 9km, or 36km.

In coastal water, the contribution of CDOM to the blue-green ratio is comparable or superior to that of phytoplankton pigments and the signal is very low, signal to noise ratio increases. Despite such effect, this study chosen the OC4 band ratio as it is recommended in the literature for a larger variety of waters without algorithm development.

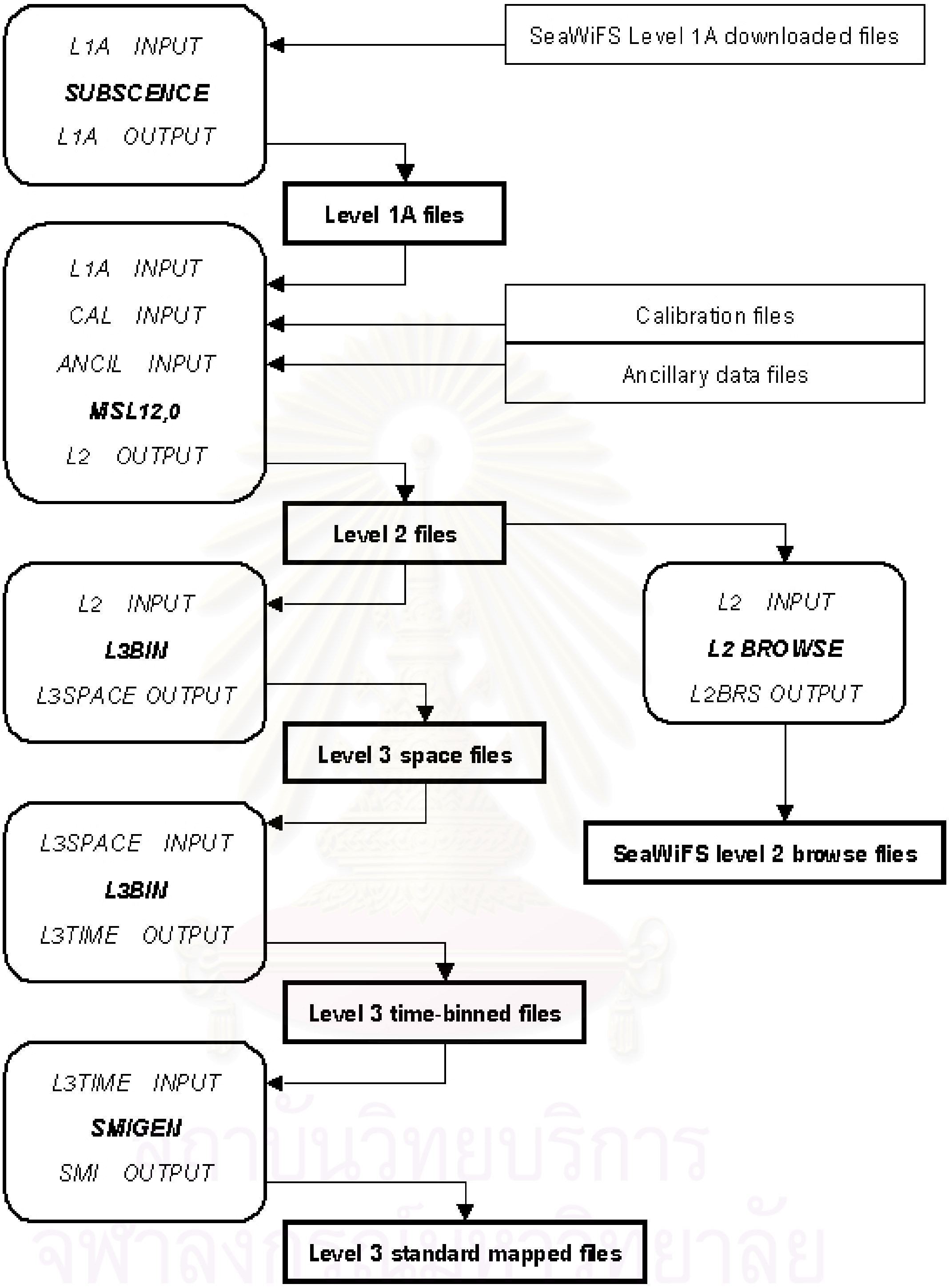


Figure 3.1 Flow chart of SeaWiFS data processing

3.3.2 Relations between SeaWiFs derived chlorophyll *a* concentration and meteorological factors

The variable list was examined for multicolinearity, and eligible variables entered stepwise into a simultaneous multiple regression model. All data were analyzed with a computer using SPSS version 10.0. Correlation procedure was used for descriptive statistics and correlation coefficients using Pearson's test. Correlation analyzes between SeaWiFS level-2 chlorophyll *a* concentration and amount of rainfall, sunshine duration, visibility and air temperature response variables were conducted using the daily data and mean monthly data from January 1998 through February 2001. In addition, correlation with *in situ* chlorophyll *a* concentration was investigated by using SeaWiFS level- 3 chlorophyll *a* concentration.

Regression procedure with the stepwise selection option was used to examine the contribution of different predictor variables on chlorophyll *a* concentration. Chlorophyll *a* concentrations were tested for normal distribution and were log-transformed prior to the statistical analysis.

The stepwise multiple regression consist of a step procedure to reduce the number of independent variables considered in an individual analysis. In the first step, meteorological factors: amount of rainfall, sunshine duration, visibility and air temperature were used as independent variables. Statistically significant variables were selected by stepwise backward variable elimination. In the second step, the statisticaly significant variables of the first were entered as the independent variables. The same variable selection procedure as above was used.

According to the yearly and seasonal variation, accumulated data from 19 stations were separated into 16 cases and data from each station were separated into 7 cases which made a total of 133 cases (19X7). The separated cases are as follows:

1. 1998-1999
2. 1998
3. 1999
4. 2000
5. Summer season 1998-2000
6. Rainy season 1998-2000
7. Winter season 1998-2000
8. Summer season 1998
9. Rainy season 1998
10. Winter season 1998
11. Summer season 1999
12. Rainy season 1999
13. Winter season 1999
14. Summer season 2000
15. Rainy season 2000
16. Winter season 2000

Case number 8-16 were not used when considered each station separately as data are insufficient for statistical analysis.

From meteorological point of view the climate of Thailand is divided into 3 seasons as follows:

1. Summer season (February, 15 to May, 14)
2. Rainy season (May, 15 to October, 14)
3. Winter season (October, 15 to February, 14)

According the current patterns and terrestrial dischages, the study devided the area in the Gulf of Thailand into 3 parts. Then relations between chlorophyll *a* concentration and meteorological factors were investigated for each area. The sub-areas and the associated meteorological stations are:

1. The upper part of the Gulf includes 7 stations: Pilot, Bangkok, Petchaburi, Hua hin, Ko sichang, Pattaya and Sattahip.
2. The middle part of the Gulf includes 6 stations: Prachuapkhirikhan, Chumphon, Ko samui, Rayong, Chantaburi and Klongyai.
3. The lower part of the Gulf includes 6 stations: Surathani, Khanom, Nakhonsithammarat, Songkla, Pattani and Narathiwat.

CHAPTER 4

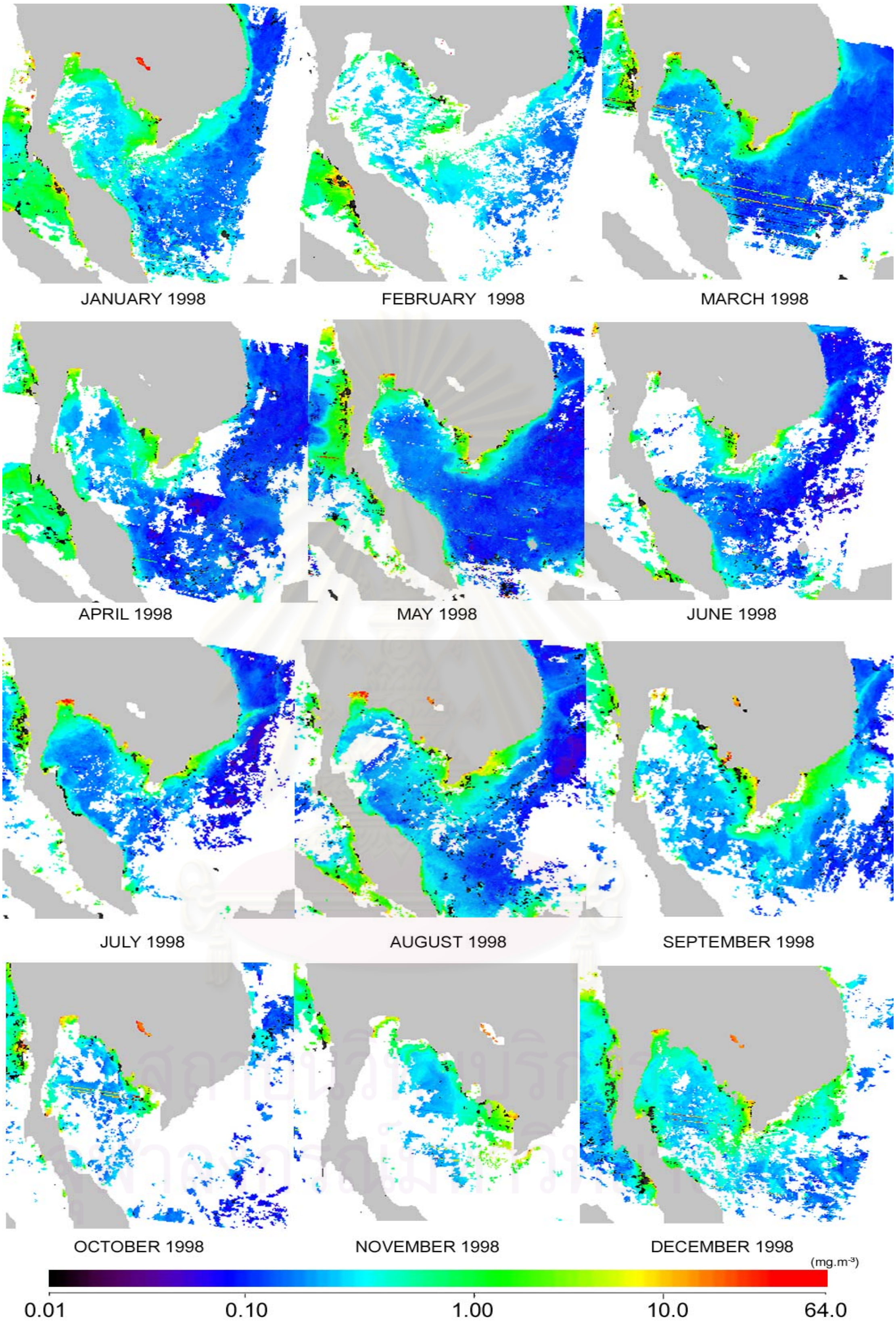
RESULTS

4.1 SeaWiFS-based estimates of chlorophyll *a* concentration distribution

Monthly mean SeaWiFS chlorophyll *a* concentration in January 1998 to July 2000 was mapped over the study area as shown in Figure 4.1, 4.2 and 4.3. Seasonal variations are easily observed in the image product, the data are displayed as an algorithm-derived pseudo color image that highlights the full range of concentrations. These images show that for every month, there was an extremely high chlorophyll *a* concentration in the upper part of the Gulf, but the concentration was quite low in the middle and lower parts of the Gulf.

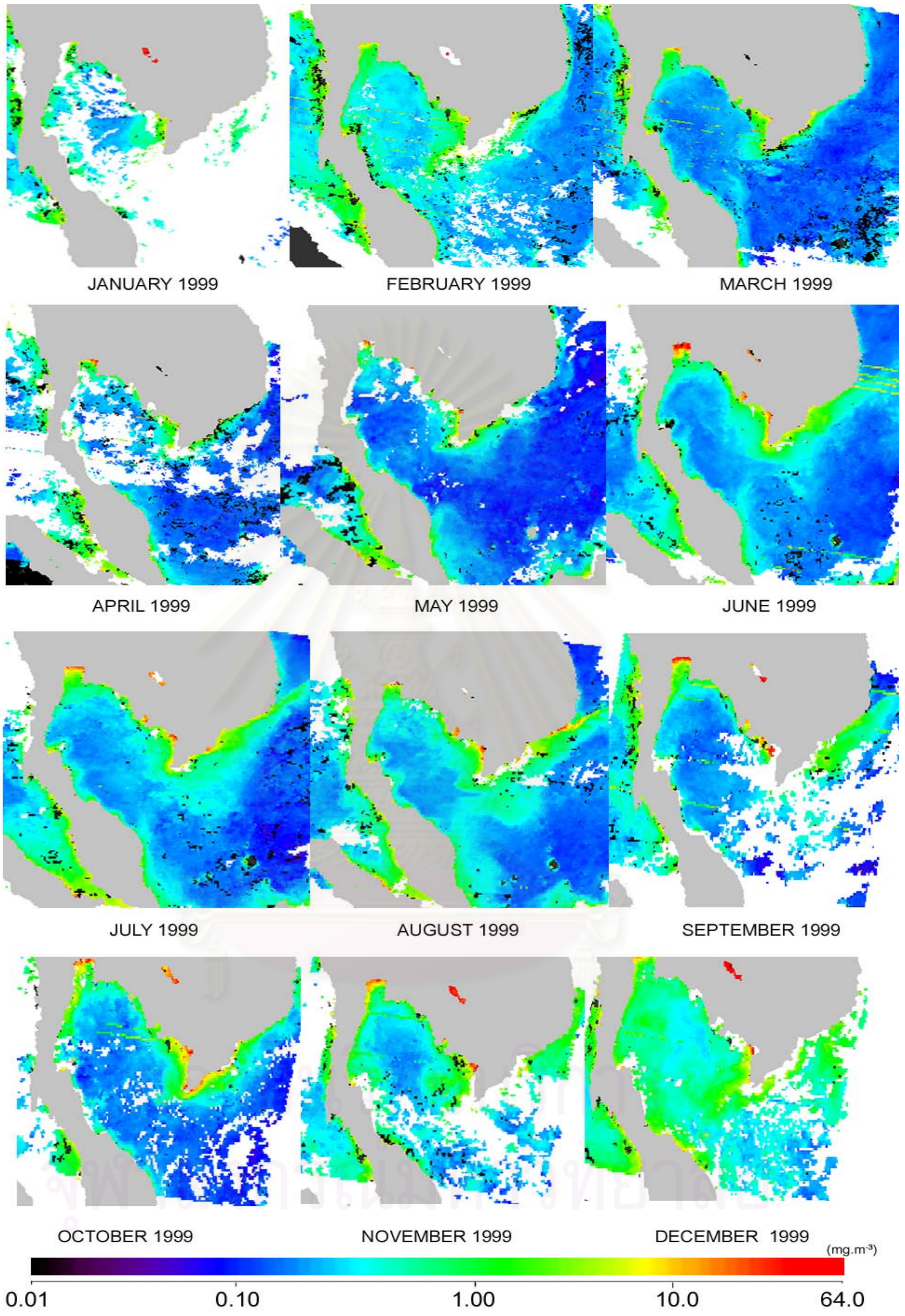
SeaWiFS image data indicated elevated chlorophyll *a* concentration starting in June to September. The maximum chlorophyll *a* concentration reached at 64.764 mg.m^{-3}. Furtermore, high chlorophyll *a* concentration that exceeds 10 mg.m^{-3} are seen in several areas in the upper part of the Gulf, especially the higest values occur in coastal shelf water. In June 1999 and 2000, high chlorophyll *a* values distribution were seen in large are and found that chlorophyll *a* values exceeded 10 mg.m^{-3}. This was in the rainy season.

Low chlorophyll *a* concentration was found in the middle part of the Gulf. However, chlorophyll *a* concentration exeeded 1 mg.m^{-1} since November through February (winter season) in the middle part of the Gulf, especially in December 1999. While in summer and rainy season, chlorophyll *a* concentration in the middle part of the Gulf was never exceeded 1 mg.m^{-3}.



JANUARY 1998
FEBRUARY 1998
MARCH 1998
APRIL 1998
MAY 1998
JUNE 1998
JULY 1998
AUGUST 1998
SEPTEMBER 1998
OCTOBER 1998
NOVEMBER 1998
DECEMBER 1998

Figure 4.1 SeaWiFS derived chlorophyll *a* concentration in 1998. Color bar indicates SeaWiFS level-3 chlorophyll *a* concentration (mg.m^{-3}) and white color represents as the cloud cover.



JANUARY 1999 FEBRUARY 1999 MARCH 1999

APRIL 1999 MAY 1999 JUNE 1999

JULY 1999 AUGUST 1999 SEPTEMBER 1999

OCTOBER 1999 NOVEMBER 1999 DECEMBER 1999

Figure 4.2 SeaWiFS derived chlorophyll *a* concentration in 1999. Color bar indicates SeaWiFS level-3 chlorophyll *a* concentration (mg.m^{-3}) and white color represents as the cloud cover.

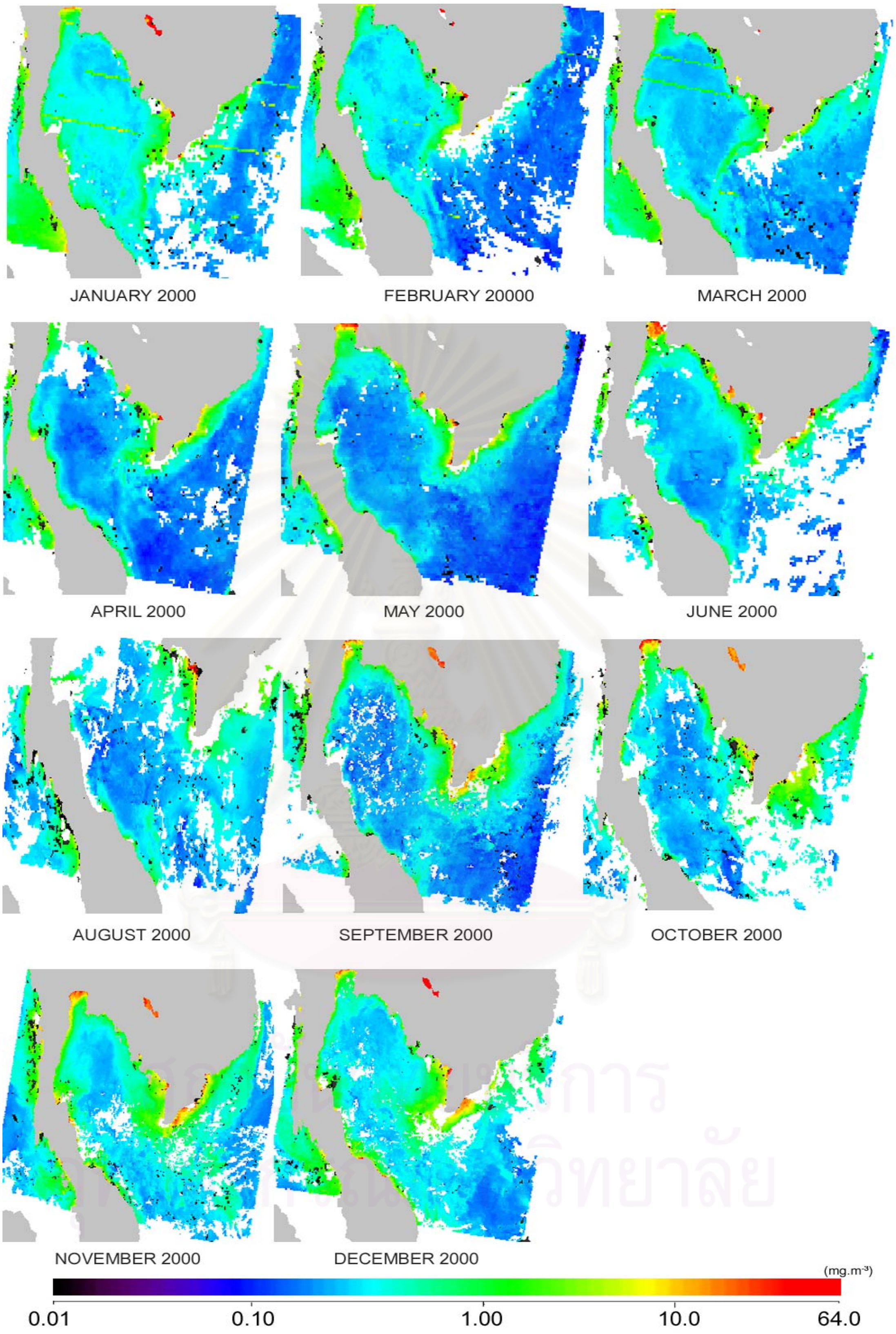


Figure 4.4 SeaWiFS derived chlorophyll *a* concentration in 2000. Color bar indicates SeaWiFS level-3 chlorophyll *a* concentration (mg.m^{-3}) and white color represents as the cloud cover.

4.2 Correlation between *in situ* chlorophyll *a* concentration and SeaWiFS derived chlorophyll a concentration

According to the data, chlorophyll *a* concentration sampling points were registered with *in situ* measurement of the Pollution Monitoring Program that consisting of 21 stations. The average of the *in situ* chlorophyll *a* concentration at every stations and the monthly level-3 chlorophyll *a* concentrations of SeaWiFS were shown in Figure 4.4. The comparison between the 2 data sets showed that most stations have similar trend. However, SeaWiFS derived chlorophyll *a* concentration generally overestimated *in situ* chlorophyll *a* concentration (Appendix B.1 and B.2). In addition, the result also found that both data have a yearly maximum mean value at Bangprakong river mouth staion. *In situ* chlorophyll *a* concentration and SeaWiFS derived chlorophyll *a* concentration is 0.515 and 12.206 mg.m^{-3}, respectively. Furthermore, a positive correlation was found in the scatter plot of logarithm chlorophyll *a* concentrations (Figure 4.5). For the performance of Pearson's correlation test, the correlation coefficient is 0.518, with a 0.01 significance level (table 4.1).

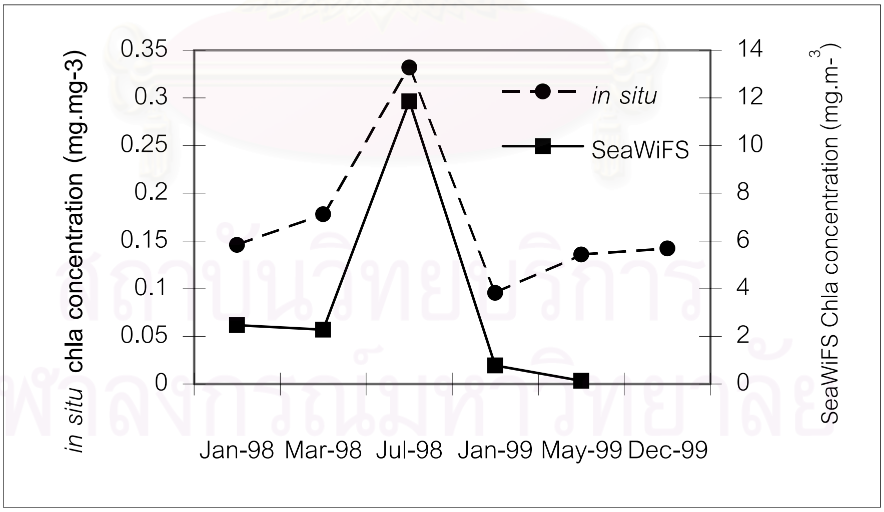


Figure 4.4 Comparison of monthly mean chlorophyll *a* concentration between *in situ* and SeaWiFS derived data.

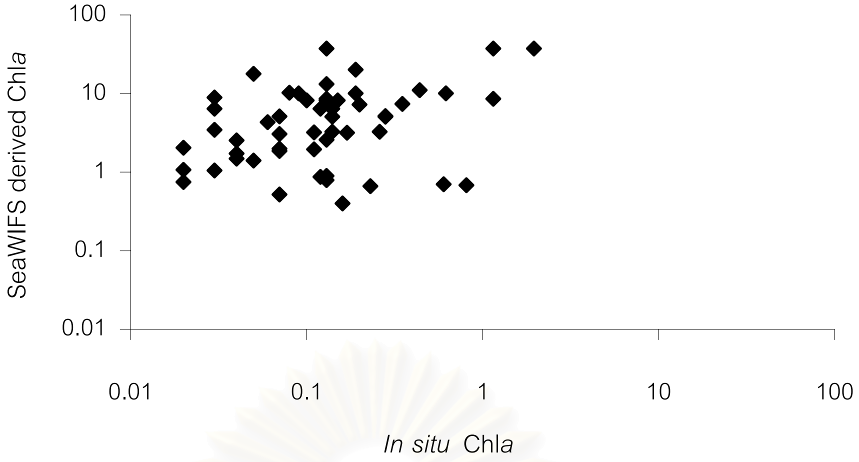


Figure 4.5 Scatter plot of logarithm *in situ* chlorophyll *a* concentration versus logarithm SeaWiFS derived chlorophyll *a* concentration

Table 4.1 Performance of Pearson's correlation test between *in situ* chlorophyll *a* concentration and SeaWiFS derived chlorophyll a concentration

		in situ Chl*a*	SeaWiFS derived Chl*a*
In situ Chl*a*	Peason 's correlation	1.000	0.518**
	Sig. (2-tailed)	.	0.000
SeaWiFS derived Chl*a*	Peason 's correlation	0.518**	1.000
	Sig. (2-tailed)	0.000	.

** Correlation is significant at the 0.01 level (2-tailed)

4.3 The relationships between SeaWiFS derived chlorophyll *a* concentration and meteorological factors

4.3.1 Phytoplankton bloom in the Gulf of Thailand

In January 3-4, 2000, phytoplankton bloom occurrence was reported at the Chaopraya River mouth, Sumutprakhan Province. It was found that a distance of this bloom was longer than 3 km and a trail of high phytoplankton density (*Ceratium* sp. = 90,375 cell/L), as well as high chlorophyll *a* concentration (300-407 mg.m^{-3}). For the comparison between *in situ* chlorophyll *a* values and SeaWiFS image at the same time, SeaWiFS derived chlorophyll *a* concentration was not found in this coordination because of the cloud cover, which is represented as white color. However, image data was found high chlorophyll *a* concentration near this area (Figure 4.6).

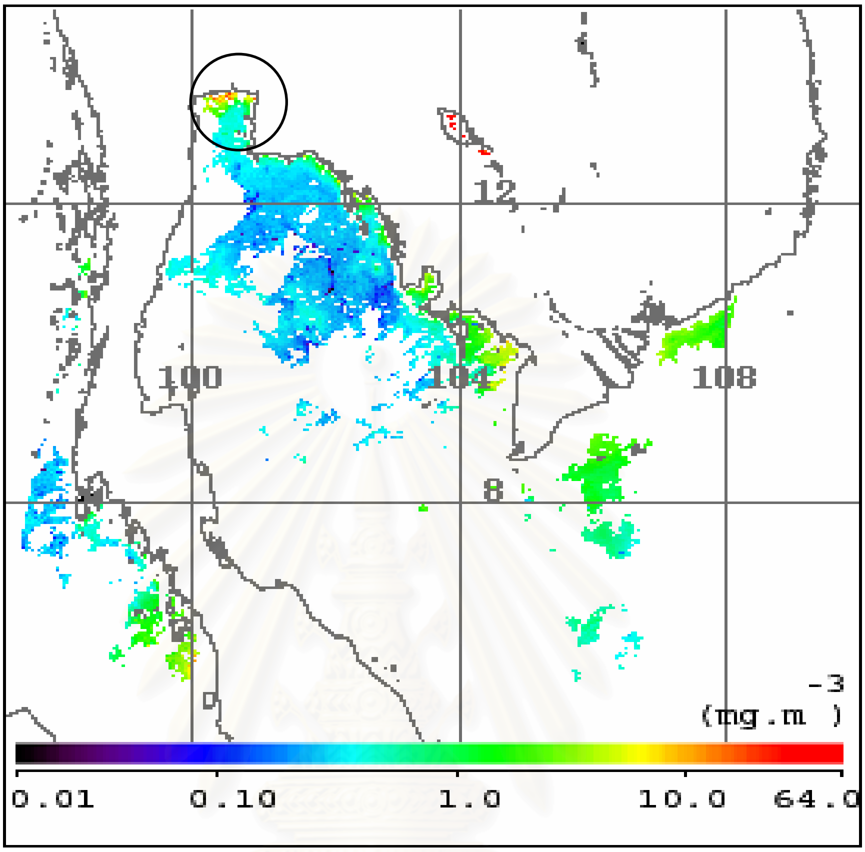


Figure 4.6 Phytoplankton bloom was observed in Chaopraya River mouth in January 3, 2000 (in a white circle). Color bar indicates SeaWiFS level-2 chlorophyll *a* concentration (mg.m^{-3})

Using daily meteorological data (December 1999 – January 2000 at Pilot station) to examined for red tide bloom ocurrence indicated that both graphs of visibility and air temperature values were elevated since December 30, 1999 until January 4, 2000. While both values have a contrary curve after this bloom period, it was also found that there was no rain in December 1999 until the timing of bloom and the data of sunshine duration was not availabled (Figure 4.7).

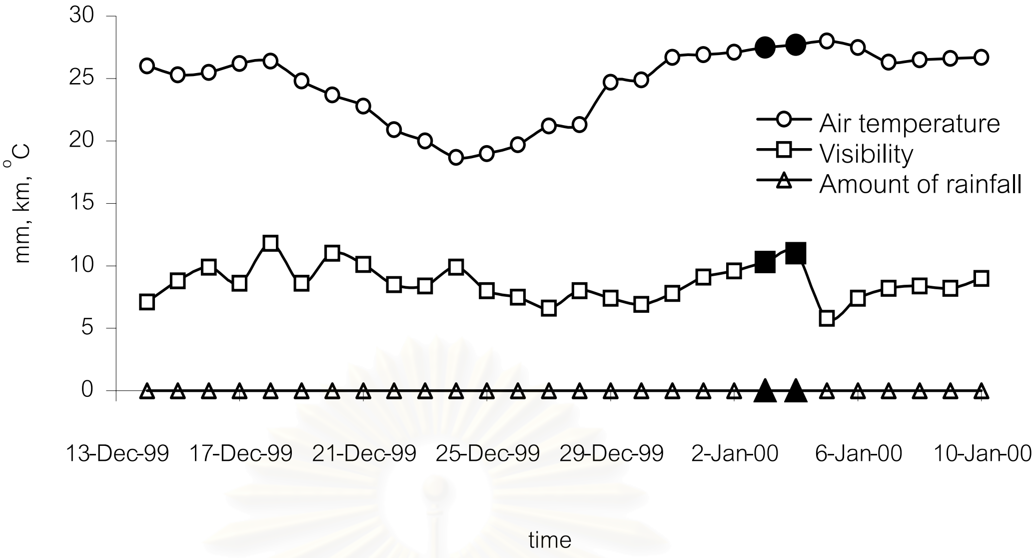


Figure 4.7 Time series of meteorological factors in December 1999 – January 2000. (The dark circle, square and triangle are the phytoplankton bloom period)

Table 4.2 SeaWiFS level-2 chlorophyll *a* concentration and meteorological factors values before phytoplankton bloom period (January 3-4, 2000) at Pilot station, Sumutprakhan Province

Date	SeaWiFS L2 (mg.m^{-3})	Amount of rainfall (mm)	Sunshine duration (hr)	Visibility (km)	Air temperature (°C)
16 Dec 1999	4.808	0	-	8.0	25.5
18 Dec 1999	3.725	0	-	11.6	26.4
21 Dec 1999	2.635	0	-	9.6	22.8
23 Dec 1999	2.826	0	-	10.8	20.0
25 Dec 1999	2.145	0	-	10.8	19.0
27 Dec 1999	3.657	0	-	0.0	21.2

- No data

Pearson‘s correlation test between chlorophyll *a* concentration and meteorological data before bloom period within 10, 8, 6 and 4 days were carried out. Table 4.3 shows that the periods may influence to the bloom occurrence. Chlorophyll *a* concentration has strongly significant positive correlation with air temperature during the period before the bloom occurrence (December 23-27, 1999) and there was no significant correlation with visibility.

Table 4.3 Pearson's correlation coefficient between SeaWiFS level-2 chlorophyll *a* concentration and meteorological factors within days before phytoplankton bloom period.

	Amount of rainfall (mm)	Sunshine duration (hr)	Visibility (km)	Air temperature ($^{\circ}$C)
16-27 Dec 99	-	-	-0.561	0.753
18-27 Dec 99	-	-	0.231	0.670
21-27 Dec99	-	-	-0.402	0.380
23-27 Dec 99	-	-	-0.893	1*

* Correlation is significant at the 0.05 level (2-tailed)

\- No data

4.3.2 SeaWiFS derived chlorophyll *a* concentration and meteorological factors

According to the estimation of chlorophyll *a* concentration by SeaWiFS image data, the maximum chlorophyll *a* concentration was found (64.764 mg.m^{-3}) in September 13, 1999, December 23, 1999 and May 28, 2000 at Bangkok station and September 27,1999 at Pilot station. In addition, the minimum chlorophyll *a* concentration (0 mg.m^{-3}) was found in December 27, 1999 at Petchaburi and Prachuapkhirikhan station (Appendix B.4).

Maximum and minimum values of SeaWiFS level-2 chlorophyll *a* concentration were analyzed with meteorological data (Figure 4.8 and 4.9). Data in September 13, 1999 (64.764 mg.m^{-3}) and May 28, 2000 (64.764 mg.m^{-3}) at Bangkok station are chosen for the analysis as they represent high chlorophyll *a* concentration. While data in November 30, 1999 (0.197 mg.m^{-3}) and February 6, 2000 (8.071 mg.m^{-3}) at Bangkok station are chosen as the representative of low chlorophyll *a* concentration, because the considering meteorological data were available.

4.3.2.1 Amount of rainfall

Figure 4.8 and 4.9 indicate that there were rainfalls within 1 week before the date of high chlorophyll *a* concentration. There was no rain in the period before date of low chlorophyll *a* concentration.

In summer and winter season, amount of rainfall factor becomes the limiting factor but chlorophyll *a* levels are high in the upper part of the Gulf.

4.3.2.2 Sunshine duration

In 2000, sunshine duration value in May 28, 2000 (date of high chlorophyll *a* concentration) was higher than previous day, while in February 6, 2000 (date of low chlorophyll *a* concentration), the data did not rather differ from the values during previous days. This is similar to the date of low chlorophyll *a* concentration in November 30, 1999.

4.3.2.3 Visibility

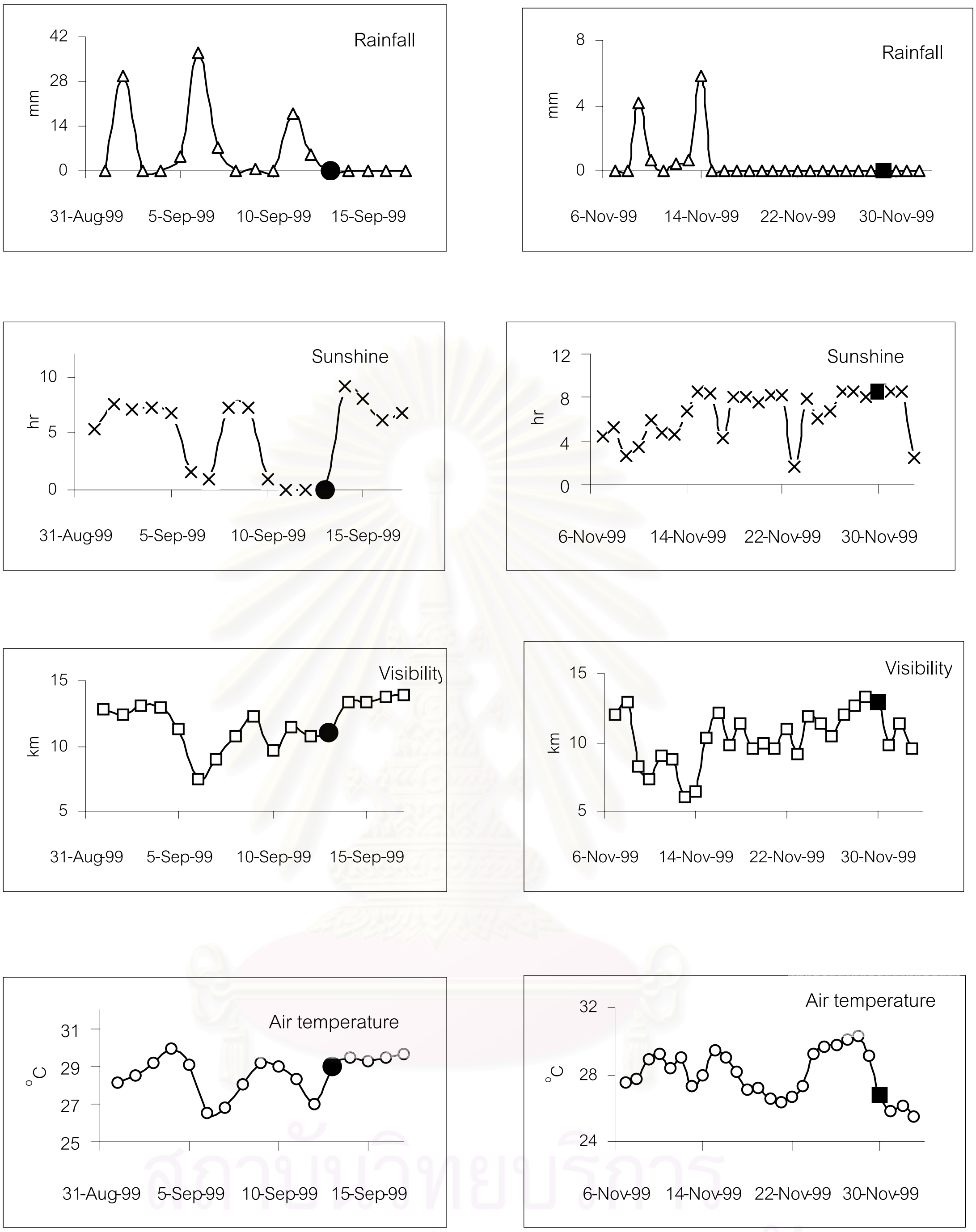
For visibility, days of high chlorophyll *a* concentration were found with different relations between 1999 and 2000. In September 13, 1999, visibility was higher than a few previous days while in November 30, 2000, it was lower than the other days (Figure 4.8a and 4.9a).

In the day of low chlorophyll *a* concentration, visibility values at that time were higher than previous and later period (Figure 4.8b and 4.9b).

4.3.2.4 Air temperature

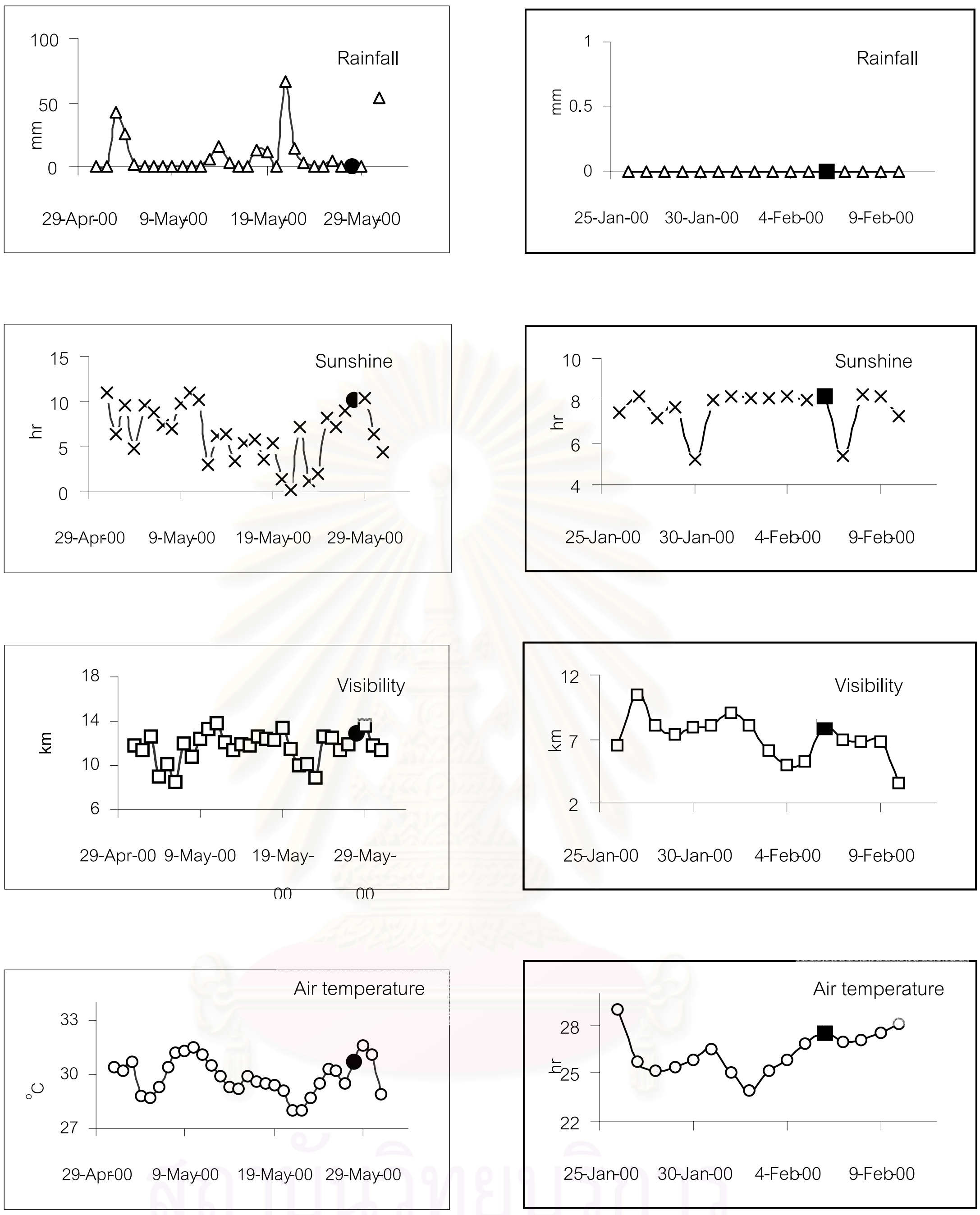
High temperature was found in date of high chlorophyll *a* concentration (higher than 28 °C). On the other hand, low temperature was found in date of low chlorophyll *a* concentration (lower than 27 °C). It should be noted that date of low chlorophyll *a* concentration in 1998-2000, was in the winter season.

To consider the different graphs of air temperature values between date of high chlorophyll a concentration and other days, in date of high chlorophyll *a* concentration (Figure 4.8a and 4.9a), air temperature values were in the increased range. While the results are dissimilar in November 30, 1999 (Figure 4.9), air temperature values are in the declined range.



(a) (b)

Figure 4.8 Time series of meteorological factors in (a) September 13, 1999 (date of high chlorophyll *a* concentration, dark circle) and (b) November 30, 1999 (date of low chlorophyll *a* concentration, dark square) at Bangkok station



(a) (b)

Figure 4.9 Time series of meteorological factors in (a) May 28, 2000 (date of high chlorophyll *a* concentration, dark circle) and (b) February 6, 2000 (date of low chlorophyll *a* concentration, dark square) at Bangkok

4.3.3 Statistical results

4.3.3.1 Pearson's correlation test

The Pearson's correlation coefficient, indicates the relationship between SeaWiFS level-2 chlorophyll *a* concentration and meteorological factors: amount of rainfall, sunshine duration, visibility and air temperature. Seasonal and yearly variation of SeaWiFS level-2 chlorophyll *a* concentration data were devided into 16 cases for all stations (Table 4.4), and 133 cases for each station (Appendix C.1). Significant levels for all cases were in the range 0.218 –0.999.

4.3.3.1.1 Amount of rainfall

Out of 16 cases, there are only 2 showed significant correlations for chlorophyll *a* concentration and amount of rainfall. Both of them exhibited a significant positive correlation. Likewise, from 133 cases, all of significant level cases exhibited positive correlation.

In the upper and lower parts of the Gulf, amount of rainfall exhibited a positive significant correlation and high correlation was found in rainy season 1998. While in the middle part of the Gulf, no significant correlation was found.

4.3.3.1.2 Sunshine duration

Four cases out of 16 cases showed significant correlation for chlorophyll *a* concentration and sunshine duration. All of them exhibited a significant negative correlation. Similarly, from 133 cases, 2 cases have a significant correlation and both of them exhibited negative correlation.

In the upper and lower parts of the Gulf, sunshine duration exhibited a significant negative correlation. While in the middle part of the Gulf, no significant correlation was found.

4.3.3.1.3 Visibility

Out of 16 cases, 4 cases showed significant correlation. Three cases exhibited a significant positive correlation. Only 1 case exhibited a significant negative correlation with higer *r* value than positive cases. ($r = -0.666$, $P<0.01$)

While in 133 cases, 11 cases showed significant correlation which most of the results were negative correlation coefficient. (8 out of 11 cases)

In the upper part of the Gulf, there was only 1 case that exhibited a significant positive correlation in winter 2000, while in the middle part of the Gulf, highly significant negative correlation was found in summer 1999. Another negative effect in the lower part of the Gulf was also found, but with a low correlation value.

4.3.3.1.4 Air temperature

Five out of 16 cases showed significant correlation, all of them exhibited a significant positive correlation. On the other hand, in 133 cases, most of the significant correlation was nagative. (8 out of 10 cases)

In the upper part of the Gulf showed significant positve correlation but in the middle and lower parts of the Gulf showed significant negative correlation. Especially, in the lower part of the Gulf, most cases were found significant correlation in winter season.

Table 4.4 Performance on correlation coefficient tested between SeaWiFS level-2 chlorophyll *a* concentration and meteorological factors from all stations.

Case	Amount of rainfall (mm)	Sunshine duration (hr)	Visibility (km)	Air temperature (°C)
1. 1998-2000	0.063	-0.232**	0.078	0.054
2. 1998	0.326**	0.189	0.260	0.085
3. 1999	-0.029	-0.439**	-0.012	-0.009
4. 2000	-0.062	-0.112	-0.666**	0.222**
5. Summer 1998-2000	-0.041	0.068	-0.076	0.224**
6. Summer 1998	-0.063	0.004	-0.181	0.008
7. Summer 1999	-0.108	0.125	0.258	0.107
8. Summer 2000	-0.017	0.004	0.063	0.364**
9. Rainy 1998-2000	0.071	-0.305*	0.111	0.137
10. Rainy 1998	0.473**	-0.596**	0.004	-0.032
11. Rainy 1999	-0.004	-0.666**	0.045	0.014
12. Rainy 2000	-0.115	0.433	0.434**	0.520**
13. Winter 1998-2000	-0.039	-0.088	0.208*	0.025
14. Winter 1998	0.170	0.091	0.0135	0.150
15. Winter 1999	-0.081	-0.353	0.110	-0. 078
16. Winter 2000	-0.050	-0.289	0.370**	0.283**

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed)

Table 4.5 Performance on correlation coefficient tested between SeaWiFS level-2 chlorophyll *a* concentration and meteorological factors in the upper part of the Gulf.

Case	Amount of rainfall (mm)	Sunshine duration (hr)	Visibility (km)	Air temperature (°C)
1. 1998-2000	0.143*	-0.306**	0.120	0.067
2. 1998	0.473**	-0.360*	0.090	0.045
3. 1999	0.049	-0.425	-0.027	0.064
4. 2000	-0.056	-0.125	0.331	0.297*
5. Summer 1998-2000	-0.073	0.077	-0.072	0.151
6. Summer 1998	-0.215	-0.128	-0.419	-0.183
7. Summer 1999	-0.231	-0.276	0.158	0.109
8. Summer 2000	-0.064	0.210	0.306	0.474
9. Rainy 1998-2000	0.191	-0.349*	-0.019	0.083
10. Rainy 1998	0.775**	-0.626*	-0.107	-0.250
11. Rainy 1999	0.020	-0.628**	-0.019	0.175
12. Rainy 2000	-0.295	0.487	0.251	0.423
13. Winter 1998-2000	0.016	-0.304*	0.277	0.030
14. Winter 1998	0.255	-0.196	0.367	0.311
15. Winter 1999	-0.073	-0.340	-0.131	0.044
16. Winter 2000	0.070	-0.373	0.472**	0.287

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed)

Table 4.6 Performance on correlation coefficient tested between SeaWiFS level-2 chlorophyll *a* concentration and meteorological factors in the middle part of the Gulf.

Case	Amount of rainfall (mm)	Sunshine duration (hr)	Visibility (km)	Air temperature (°C)
1. 1998-2000	-0.013	0.074	-0.072	-0.127
2. 1998	-0.046	-0.024	0.074	-0.026
3. 1999	0.221	-	-0.310	-0.400*
4. 2000	-0.052	-	-0.094	-0.217
5. Summer 1998-2000	-0.224	-	-0.100	0.098
6. Summer 1998	-	-	0.079	-0.224
7. Summer 1999	-	-	0.782*	-0.620
8. Summer 2000	-0.478	-	-0.324	-0.511
9. Rainy 1998-2000	-0.060	-0.038	-0.051	-0.101
10. Rainy 1998	-0.075	-0.380	0.016	-0.203
11. Rainy 1999	0.390	-	-0.158	-0.249
12. Rainy 2000	-0.370	-	-0.312	-0.719*
13. Winter 1998-2000	-0.030	-0.013	-0.041	-0.012
14. Winter 1998	-0.203	-0.269	-0.310	-0.138
15. Winter 1999	0.177	-	-0.226	0.095
16. Winter 2000	-0.091	-	0.103	-0.100

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed)

\- Not determined

Table 4.7 Performance on correlation coefficient tested between SeaWiFS level-2 chlorophyll *a* concentration and meteorological factors in the lower part of the Gulf.

Case	Amount of rainfall (mm)	Sunshine duration (hr)	Visibility (km)	Air temperature (^{o}C)
1. 1998-2000	0.070	-0.269*	-0.139*	-0.229*
2. 1998	0.366*	-0.106	-0.210	-0.411*
3. 1999	-0.072	-0.06	-0.041	-0.127
4. 2000	-0.092	0.244	-0.164	-0.451*
5. Summer 1998-2000	0.306	-0.024	-0.198	0.109
6. Summer 1998	0.270	-0.505	-0.175	-0.364
7. Summer 1999	-	-	-0.124	-0.484
8. Summer 2000	0.055	0.316	0.288	-0.355*
9. Rainy 1998-2000	-0.131	-0.393*	-0.149	-0.131
10. Rainy 1998	0.696**	-0.658	-0.387	-0.421
11. Rainy 1999	-0.090	-0.528	-0.003	-0.089
12. Rainy 2000	-0.161	0.585	-0.125	0.062
13. Winter 1998-2000	-0.132	-0.074	0.045	-0.514*
14. Winter 1998	-0.397	-0.057	-0.188	-0.658
15. Winter 1999	-0.140	0.361	-0.082	-0.660*
16. Winter 2000	-0.110	0.952	-0.072	-0.472*

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed)

- Not determined

Results of this analysis indicated that the relations between chlorophyll *a* concentration and meteorological factors are not straightforward. Positive correlations were observed between chlorophyll *a* concentration and amount of rainfall. Negative correlation was found between chlorophyll *a* concentration and sunshine duration. Surprisingly, the results in visibility and air temperature could be found both positive and negative correlation in different seasonal and yearly variation.

4.3.3.2 Stepwise multiple regression analysis

The Stepwise multiple regression analysis could estimate and defined the quantitative relationship between meteorological factors and chlorophyll *a* concentration. The results of these analyses and the best model for chlorophyll *a* concentration against predictor variables are shown in table 4.8 and 4.9, respectively.

4.3.3.2.1 Amount of rainfall

Four cases of amount of rainfall variable which were chosen into regression final model. Every case has positive effects. In case 6 (rainy season 1998-200) and 8 (rainy season 1999), there are 3 variables which are chosen into the models. Amount of rainfall variable is the third variable introduced into the model after sunshine duration and air temperature variables. While in case 2 (1998) and case 9 (rainy season 1998), it is the only one variable entered into the models.

In the upper, middle and lower parts of the Gulf, amount of rainfall factor was not entered into models.

4.3.3.2.2 Sunshine duration

There are 4 cases that sunshine duration variable are entered into the models. According to the analysis, sunshine duration was determined by all cases as negative effect to chlorophyll *a* concentration. Specifically, in case of many variables entered into the model, sunshine duration is the first variable that was selected. However, the analysis in year 1999 (case 3) was the only one case which was a second selected after the air temperature variable. It was also found that 1 out of all cases has no second selected variable into regression model.

In the upper part of the Gulf, there are 4 out of 7 cases that sunshine duration was selected into the models and all of them are negative, while in the middle part of the Gulf, the model did not choose this variable. In addition, there is only one negative influece in the lower part of the Gulf.

4.3.3.2.3 Visibility

There were two cases that visibility variable were chosen to the models with a negative effect on chlorophyll *a* concentration (case 8 :summer 1998 and case 16: winter 2000). The results showed a positive effect on chlorophyll *a* concentration. The analysis did not choose any more variable into the model.

In the upper part of the Gulf, the visibility variable did not enter into the model. In the middle part of the Gulf, only one case that this variable is selected into the model and has a posititive affect on chlorophyll *a* concentration. In the lower part of the Gulf, three models have this variables entered with negative effect.

4.3.3.2.4 Air temperature

Five cases of temperature vairiable are chosen into the regression models. The positive influence by air temperature was the second selected variable for 2 cases (case 6 and 12). The other positive case was the first selected variable. For the negative cases, first selected variable for the year 1999 and the second variable are sunshine duration (case 3), while in summer 1998-2000 (case 5), the model did not choose any second variable.

The positive effect was found in the upper part of the Gulf and one case was found for summer season, while the negative affect was found in the middle and lower parts of the Gulf and one case was found for winter season in the lower part of the Gulf.

Table 4.8 Results from the stepwise multiple regression analysis

Case	R^2	adj R^2	Sig.F	β_0	β_1	β_2	β_3	β_4
1. 1998-2000	0.086	0.008	0.000	1.191	-	-0.084	-	-
2. 1998	0.094	0.078	0.070	0.469	1.299	-	-	-
3. 1999	0.237	0.204	0.012	3.209	-	-0.097	-	-0.075
4. 2000	0.139	0.118	0.013	1.798	-	-0.139	-	-
5. Summer 1998-2000	0.296	0.279	0.000	5.298	-	-	-	-0.192
6.Rainy 1998-2000	0.346	0.306	0.011	-4.313	0.026	- 0.111	-	0.192
7.Winter 1998-2000	-	-	-	-	-	-	-	-
8. Summer 1998	0.265	0.209	0.050	1.737	-	-	-0.129	-
9. Rainy 1998	0.283	0.284	0.011	0.377	0.022	-	-	-
10.Winter 1998	-	-	-	-	-	-	-	-
11.Summer 1999	0.517	0.457	0.019	-4.957	-	-	-	0.178
12.Rainy 1999	0.569	0.505	0.035	-9.253	0.034	-0.134	-	0.365
13.Winter 1999	-	-	-	-	-	-	-	-
14.Summer 2000	-	-	-	-	-	-	-	-
15.Rainy 2000	-	-	-	-	-	-	-	-
16.Winter 2000	0.257	0.211	0.032	-0.264	-	-	-0.133	-

β_0 : constant or intercept

β_i : Regression coefficient of amount of rainfall, sunshine duration, visibility and air temperature, respectively

- Not determined

Table 4.9 Statistical final regression models

Case	Equation
1. 1998-2000	Log (Chl*a*)=1.191-0.0841X_2
2. 1998	Log (Chl*a*)=0.469+1.299X_1
3. 1999	Log (Chl*a*)=3.209-0.097X_2-0.075X_4
4. 2000	Log (Chl*a*)=1.798-0.139X_2
5. Summer 1998-2000	Log (Chl*a*)=-5.298-0.192X_4
6.Rainy 1998-2000	Log (Chl*a*)=-4.313+0.2261X_1–0.111X_2 +0.192X_4
7.Winter 1998-2000	-
8. Summer 1998	Log (Chl*a*)=1.737-0.129X_3
9. Rainy 1998	Log (Chl*a*)=0.283+0.222X_1
10.Winter 1998	-
11.Summer 1999	Log (Chl*a*)=-4.957+0.178X_4
12.Rainy 1999	Log (Chla)=-9.253+0.03415X_1-0.134X_2+0.365X_4
13.Winter 1999	-
14.Summer 2000	-
15.Rainy 2000	-
16.Winter 2000	Log (Chl*a*)=-0.264-0.133X_3

X_1: Amount of rainfall, X_2 : Sunshine duration, X_3 : Visibility, X_4 : Air temperature

- Not determined

Table 4.10 Results from the stepwise multiple regression analysis in upper part of the Gulf of Thailand

Case	R^2	adj R^2	Sig.F	β_0	β_1	β_2	β_3	β_4
1. 1998-2000	0.064	0.055	0.011	1.242	-	-0.073	-	-
2. 1998	0.011	0.085	0.042	1.336	-	-0.094	-	-
3. 1999	-	-	-	-	-	-	-	-
4. 2000	0.150	0.119	0.038	-2.767	-	-	-	0.128
5. Summer 1998-2000	0.142	0.2111	0.040	-3.686	-	-	-	0.142
6.Rainy 1998-2000	0.107	0.082	0.045	1.140	-	- 0.066	-	-
7.Winter 1998-2000	0.103	0.083	0.028	2.212	-	-0.171	-	

β_0 : constant or intercept

β_i : Regression coefficient of amount of rainfall, sunshine duration, visibility and air temperature, respectively

\- Not determined

Table 4.11 Final regression models for variable prediction in upper part of the Gulf of Thailand

Case	Equation
1. 1998-2000	Log (Chl*a*) = $1.242-0.073X_2$
2. 1998	Log (Chl*a*) = $1.336-0.094X_2$
3. 1999	-
4. 2000	Log (Chl*a*) = $-2.767+0.128X_4$
5. Summer 1998-2000	Log (Chl*a*) = $-3.686+0.142X_4$
6.Rainy 1998-2000	Log (Chl*a*) = $1.140-0.066X_2$
7.Winter 1998-2000	Log (Chl*a*) = $2.212-0.171X_2$

X_1: Amount of rainfall, X_2 : Sunshine duration, X_3 : Visibility, X_4 : Air temperature

\- Not determined

Table 4.12 Results from the stepwise multiple regression analysis in middle part of the Gulf of Thailand

Case	R^2	adj R^2	Sig.F	β_0	β_1	β_2	β_3	β_4
1. 1998-2000	0.064	0.056	0.005	0.013	-	-	-	-0.044
2. 1998	0.797	0.729	0.042	-1.564	-		0.264	-
3. 1999	0.206	0.181	0.007	2.159	-	-	-	-0.077
4. 2000	-	-	-	-	-	-	-	-
5. Summer 1998-2000	-	-	-	-	-	-	-	-
6.Rainy 1998-2000	-	-	-	-	-	-	-	-
7.Winter 1998-2000	-	-	-	-	-	-	-	-

β_0 : constant or intercept

β_i : Regression coefficient of amount of rainfall, sunshine duration, visibility and air temperature, respectively

- Not determined

Table 4.13 Final regression models for variable prediction in middle part of the Gulf of Thailand

Case	Equation
1. 1998-2000	Log (Chl*a*) = $0.013-0.044X_4$
2. 1998	Log (Chl*a*) = $-1.564+0.264X_3$
3. 1999	Log (Chl*a*) = $2.159-0.077X_4$
4. 2000	-
5. Summer 1998-2000	-
6.Rainy 1998-2000	-
7.Winter 1998-2000	-

X_1: Amount of rainfall, X_2 : Sunshine duration, X_3 : Visibility, X_4 : Air temperature

- Not determined

Table 4.14 Resuts from the stepwise multiple regression analysis in lower part of the Gulf of Thailand

Case	R^2	adj R^2	Sig.F	β_0	β_1	β_2	β_3	β_4
1. 1998-2000	0.345	0.330	0.000	2.731	-	-	-0.246	-
2. 1998	0.496	0.462	0.002	2.987	-	-	-0.244	-
3. 1999	0.310	0.261	0.025	5.001	-	-	-	-0.183
4. 2000	-	-	-	-	-	-	-	-
5. Summer 1998-2000	-	-	-	-	-	-	-	-
6.Rainy 1998-2000	0.576	0.537	0.023	3.372		-0.126	-0.215	
7.Winter 1998-2000	0.456	0.388	0.032	10.312	-	-	-	-0.365

β_0 : constant or intercept

β_i : Regression coefficient of amount of rainfall, sunshine duration, visibility and air temperature, respectively

- Not determined

Table 4.15 Final regression models for variable prediction in lower part of the Gulf of Thailand

Case	Equation
1. 1998-2000	Log (Chl*a*) = 2.731-0.246 X_3
2. 1998	Log (Chl*a*) = 2.987-0.244X_3
3. 1999	Log (Chl*a*) = 5.001-0.183X_4
4. 2000	-
5. Summer 1998-2000	-
6.Rainy 1998-2000	Log (Chl*a*) = 3.372-0.126X_2-0.215X_3
7.Winter 1998-2000	Log (Chl*a*) = 10.312-0.365X_4

X_1: Amount of rainfall, X_2 : Sunshine duration, X_3 : Visibility, X_4 : Air temperature

From the analysis of all staion, the maximum R^2 value was found in case 12 ($R^2 = 0.569$, SigF = 0.035). Results from case 7, 10, 13, 14 and 15 do not enter into the regression equation for logarithm chlorophyll *a* concentration. This suggests that four independent variables have a multicolinearlity or it do not have significant influence on the logarithm chlorophyll a concentration.

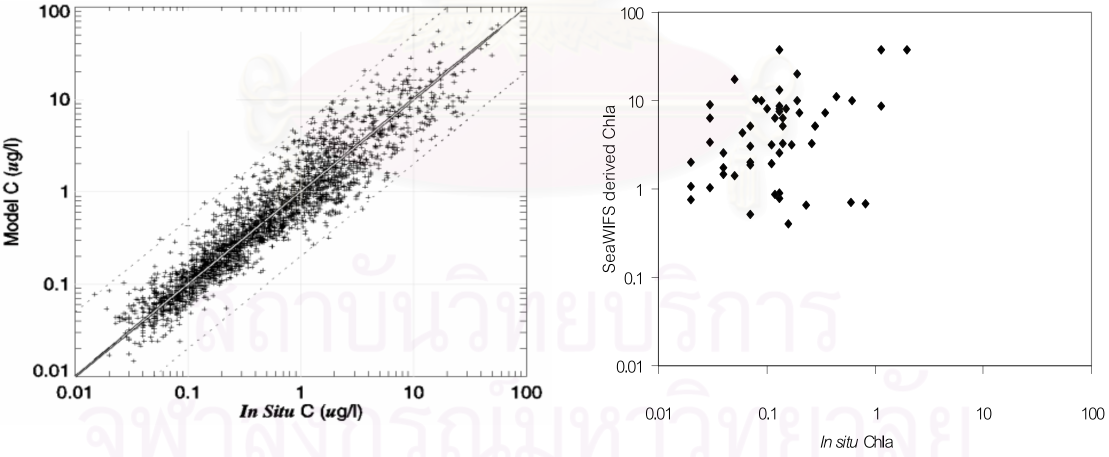
The analysis from the upper part of the Gulf, showed that low R^2 values from all cases were found and there was only sunshine duration and air temperature variables selected into the regression model. In the middle of the Gulf, the maximum R^2 value was found in case 1998 (R^2=0.797). In addition, there were only visibility and air temperature variables selected into the regression model. In the lower of the Gulf, there were 3 variables selected into the regression model (sunshine duration, visibility and air temperature). As the results of 3 parts in the Gulf, it is noted that in the rainy season, amount of rainfall was not entered into the regression model.

CHAPTER 5

DISCUSSION

5.1 *In situ* chlorophyll *a* concentration and SeaWiFS derived chlorophyll *a* concentration

Figure 5.1a shows scatter plot of OC4 model versus *in situ* chlorophyll *a* concentration. It is clear that the OC4 model is able to estimate low and high chlorophyll *a* concentration as well as medium range of chlorophyll *a* values. The correlation of the *in situ* chlorophyll *a* concentration and SeaWiFS derived chlorophyll *a* concentration is statistical fit. In this study, SeaWiFS derived chlorophyll *a* concentration was very high because the effect of suspended sediment. Thus, these values became higher than *in situ* measurement. However, the trend of SeaWiFS derived chlorophyll *a* concentration is agree with *in situ* chlorophyll *a* concentration.



(a) (b)

Figure 5.1 Scatter plot the relation between logarithm *In situ* chlorophyll *a* concentration and logarithm SeaWiFS derived chlorophyll *a* concentration (a) O'Reilly *et al*., 1998 (b) this study

5.2 The meteorological factors influence chlorophyll *a* distribution in the Gulf of Thailand

According to the results, the trend observed over the whole period (1998-2000) showed chlorophyll *a* concentration was most limited by seasonal variation and meteorological factors. The monsoon of southwest and northeast has as great of an effect as one might expect.

From the SeaWiFS image data, the chlorophyll *a* distribution pose a similar pattern from 1998 to 2000. The images confirmed the highest chlorophyll *a* concentration are found in nearshore in the upper part of the Gulf and decreased toward offshore, with maxima during rainy season. This is because the monsoon was an important period for phytoplankton abundant, distribution and species composition. The previous study by Sopana Boonuapiwat (1997) showed that the southwest monsoon is more suitable conditon for increase primary production as it brings about more stable conditions in the water column and the abundance of runoff nutrient which may be related to rainfall. In addition, images showed the spatial and temporal variability of chlorophyll *a* concentration. Generally, the concentration was high in east coast in January and shifted to west coast toward the end of the year. For the statistical analysis in the upper part of the Gulf, there are only two regression models:

$$\text{Log (chl}a\text{)} = \beta_0 - \beta_2 \text{ Sunshine duration,}$$

and

$$\text{Log (chl}a\text{)} = \beta_0 + \beta_4 \text{ Air temperature}$$

From the above eqations, amount of rainfall in the rainy season was not effect on chlorophyll *a* concentration. This suggests that high nutrient from the river discharge is a limiting factor. Therefore, air temperature and sunshine duration play an important role in chlorophyll *a* concentration directly. However, this evidence was not always effected on chlorophyll *a* concentration in every part of the Gulf. It was found positive effect in the upper part of the Gulf but in the middle and lower parts of the Gulf was found negative effect. As the results from the regression analysis, it is noted that air temperature factor was influence negatively on chlorophyll *a* concentration in the middle and lower parts of the Gulf. In the middle part of the Gulf, the regression models is:

$$\text{Log (chl}a\text{)} = \beta_0 + \beta_3 \text{ Visibility,}$$

and $$\text{Log (chl}a\text{)} = \beta_0 - \beta_4 \text{ Air temperature}$$

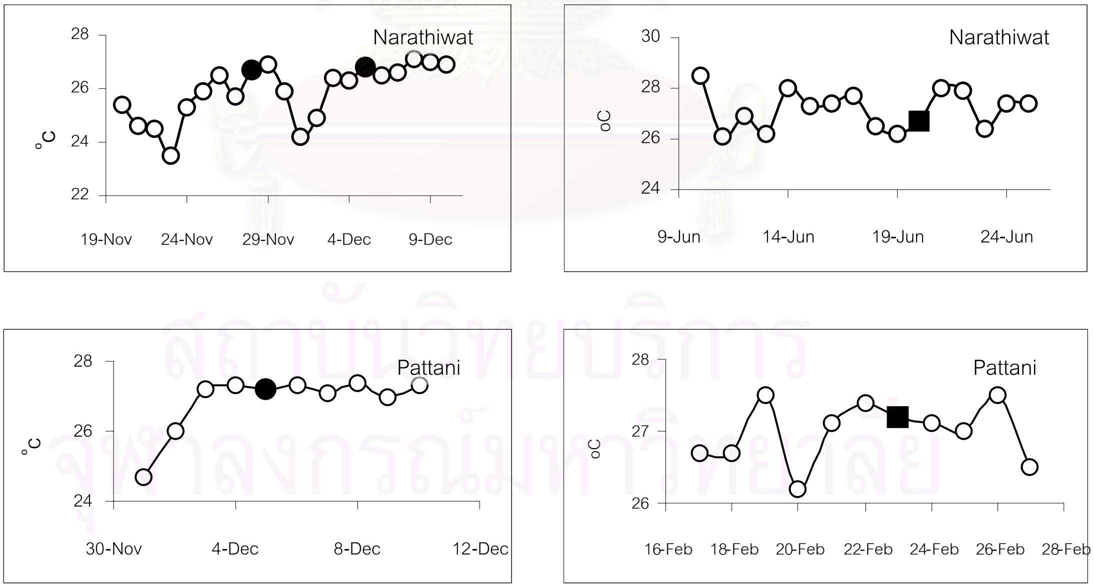
In the lower part of the Gulf, there are three pattern of the regression model is:

$$\text{Log (chl}a\text{)} = \beta_0 - \beta_3 \text{ Visibility,}$$

$$\text{Log (chl}a\text{)} = \beta_0 - \beta_4 \text{ Air temperature,}$$

and $$\text{Log (chl}a\text{)} = \beta_0 - \beta_2 \text{ Sunshine duration} - \beta_4 \text{ Air temperature}$$

Even though a significant negative correlation was found in the regression model but the elevated air temperature was observed in date of low and high chlorophyll *a* concentration in the lower part of the Gulf (Figure 5.2a and 5.2b).



(a) (b)

Figure 5.2 Time series of air temperature in (a) December 5, 2000 (date of high chlorophyll *a* concentration, dark circle) and (b) June 20, 2000 (date of low chlorophyll *a* concentration, dark square) at Narathiwat and Pattani airport station

For the entire regression models for the whole Gulf, sunshine duration had negative effect on chlorophyll *a* concentration and visibility factor had both negative and positive effect on chlorophyll *a* concentration. Theoretically, phytoplankton cells need light to survive, but light above the level they need for growth can also be a major stress for them, forcing them to metabolize more rapidly, thus higher light is not necessarily better. The concentration of chlorophyll *a* in phytoplankton cells is known to reflect their light history. Low light conditions can lead to significantly elevated concentration of chlorophyll per unit cell biovolume (Philips, 2000). The significant negative correlation between sunshine duration, visibility and chlorophyll *a* concentration provide support for the importance of light limitation.

In the winter, even less duration of sunshine means that the surface waters cool further, increasing their density. This allows the surface waters to mix with the waters below. This mixing brings deep-water nutrients back to the surface. Although there are plenty of nutrients, there isn't enough light for phytoplankton to photosynthesis effectively, so not much growth could be expected. The contribution of daily primary production in the Gulf of Thailand could be high, and it occurred along water cloumm when sunlight was generally abundant, the very low concentration of phytoplankton in the mixed surface layer allowed light to penetrate to the pycnocline (Snidvongs and Rochana-anawat, 1995). However, from the SeaWiFS images, it is important to note that high chlorophyll *a* concentration was not occurred in all coastal parts. In the middle part of the Gulf, chlorophyll *a* concentration in winter season was higher than in rainy and summer seasons, it is may indicated low freshwater discharged into the sea and possible cause includes variation in meteorological factors or the influence of monsoon.

In additon, during the northwest monsoon (winter season) and pre-monsoon period (summer season), amount of rainfall factor becomes the limiting factor but it was found high chlorophyll *a* concentration in the upper part of the Gulf (Figure 5.3). Thus, high chlorophyll *a* concentration in summer season is likely associated with light and air temperature.

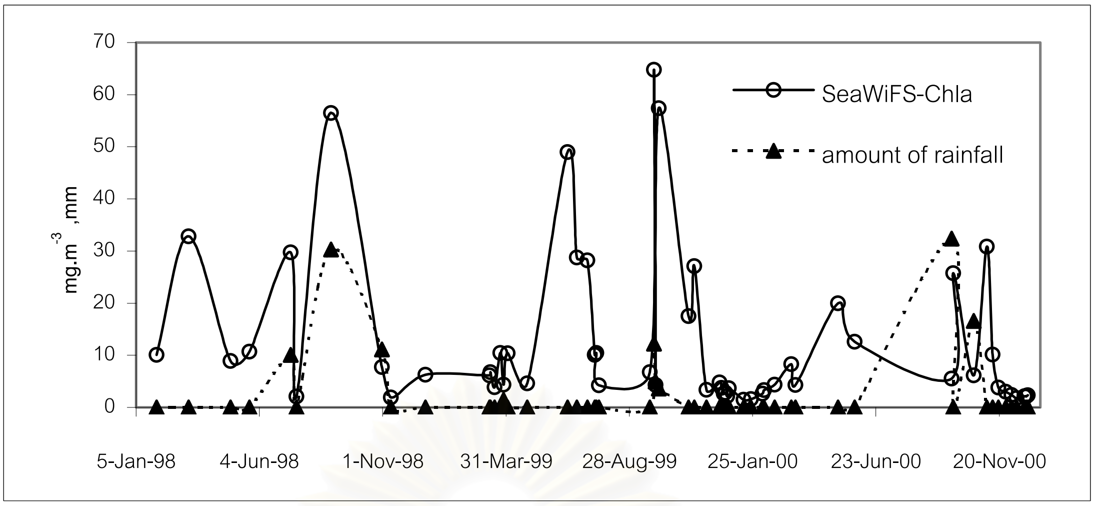


Figure 5.3 Time series of SeaWiFS derived chlorophyll *a* concentration (mg.m^{-3}) and amount of rainfall (mm) at Pilot station 1998-2000

According to overall regression model chlorophyll *a* concentration correlated with amount of rainfall positively, but negatively with sunshine duration and visibility. Surprisingly, it is also found chlorophyll *a* concentration correlated with air temperature both positively and negatively. The overall regression model for the Gulf of Thailand is:

$$\text{Log (chl}a) = \beta_0 + \beta_1 \text{ Amount of rainfall} - \beta_2 \text{ Sunshine duration}$$

$$- \beta_3 \text{ Visibility} \pm \beta_4 \text{ Air temperature}$$

It is notice that air temperature factor may both has positive and negative effects on chlorophyll *a* concentration. For the analysis of daily meteorological factors before phytoplankton bloom period indicates that phytoplankton bloom developed as soon as the air temperature elevated within a few days, may contribute to phytoplankton cell. In additon, the results from the statistical analysis apparently confirm amount of rainfall influence on chlorophyll *a* concentration especially in rainy season. Despite lack of statistical significance in some cases, the analysis of daily amount of rainfall before the date of high chlorophyll *a* concentration indicated that chlorophyll *a* concentration could be developed after the continued raining earlier.

Determining meteorological factors for early warning of potential blooms is an important objective. It is clear that one possibility to determine the bloom initiation is the influence of increased rainfall during rainy season. However, when rainfall dropped, air temperature and light dropped and increased immediately within a few days, these changing conditions are significant parameters that lead to the bloom ocurrence in the Gulf of Thailand.

Furthermore, basing on the results obtained from the regression model can be used to predict the phytoplankton bloom occurrence under the scenario:

In the upper part of the Gulf: If the air temperature increases and sunshine duration decrease, phytoplankton density will increase.

In the middle part of the Gulf: If visibility and air temperature decrease, phytoplankton density will increase.

In the lower part of the Gulf: If sunshine duration, visibility and air temperature decrease, phytoplankton density will increase.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The study of meteorological factor influence to chlorophyll *a* concentration in the Gulf of Thailand can be detected and explained reasonably.

6.1 Conclusions

1. This study compared *in situ* chlorophyll *a* concentration and SeaWiFS derived chlorophyll *a* concentration. These 2 data sets fited and showed the same tendency of chlorophyll *a* concentration in the study region that including coastal water.

2. Long term chlorophyll *a* concentration study indicated the increasing of chlorophyll *a* concentration is subject to the elevated amount of rainfall, air temperature and the declined of sunshine duration and visibility.

3. According to the seasonal variation, in summer and winter season, air temperature was a major important factor affecting chlorophyll *a* concentration and light has less influence on the concentration. While in rainy season, amount of rainfall, sunshine duration and air temperature were major important factors.

6.2 Recommendations

The study proved that remote sensing technique is a useful tool for studying the distribution of chlorophyll *a* concentration. In this work, correlation analysis between remotely sensed data and chlorophyll *a in situ* data has indicated the possibility of mapping chlorophyll *a* concentration with some degrees of success. However, the use of satellite remote sensing for mapping chlorophyll *a* concentration is limited by the presence of cloud cover. Despite these advantages, satellite data are preferable to field measurements if one aim is to follow the temporal of phytoplankton over large area.

The accuracy of the sea truth data played a very important role in determining the reliability of the calibrated algorithm and the quality of the generated water quality maps. The feasibility of applying the present techniques for operational use has to be further validated. Therefore, more data will be required for this verification analysis. However, the specific conditons in phytoplankton blooms are difficult to discriminate but this study can identify some important foctors.

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APPENDICES

APPENDIX A

Location of Meteorological recording stations and Pollution Monitoring Program station

Table A.1 List of Meteorological recording stations

Station	Latitude (^{o}N)	Longitude (^{o}E)
1. Pilot	13.216	100.36
2. Bangkok	13.4398	100.3402
3. Petchaburi	13.09	100.138
4. Hua Hin	12.3498	99.5802
5. Prachuapkhirikhan	11.4998	99.5502
6. Chumphon	10.289	99.1098
7. Suratthani	9.0702	99.210
8. Ko samui	9.2802	100.0198
9. Khanom	9.1398	99.51
10. Nkhonsithammarat	8.2802	99.5802
11. Songkhla	7.120	100.36
12. Pattani airport	6.4698	101.06
13. Narathiwat	6.2502	101.4902
14. Ko sichang	13.1002	100.48
15. Phattaya	12.5502	100.5202
16. Sattahip	12.4098	101.0102
17. Rayong	12.3798	101.210
18. Chantaburi	12.3702	102.0702
19. Klongyai	11.4602	102.5298

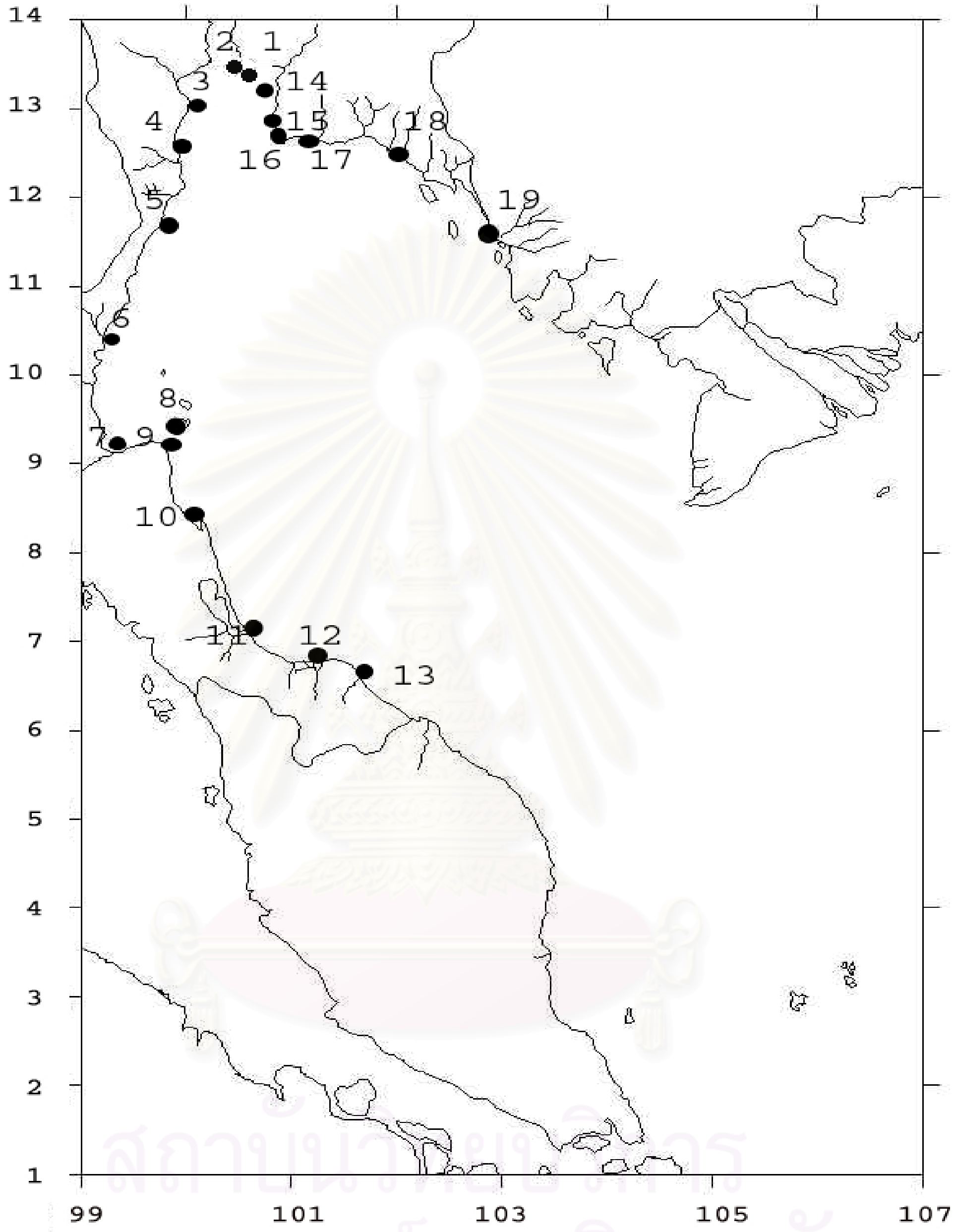

Figure A.1 Location of meteorological stations (dark circle)

Table A.2 List of Pollution Monitoring Program Stations

	Station	Location	Latitude ($^{\circ}$N)	Longitude ($^{\circ}$E)
1	MKRM	Mekong river mouth	13.14	100.03
2	TCRM	Tachin river mouth	13.238	100.538
3	CPRM	Chaopraya river mouth	13.238	100.531
4	SKCN	Sakuna chanel	13.1185	100.438
5	BPRM	Bangprakong river mouth	13.25	100.531
6	BSAN	Bangsaen	13.168	100.548
7	BPRA	Bangpra	13.14.4	100.548
8	SIRA	Sriracha	13.099	100.5105
9	SCIN	Sichang island (north)	13.113	100.4812
10	SCIE	Sichang island (east)	13.089	100.4981
11	SCIW	Sichang island (west)	13.087	100.471
12	SCIS	Sichang island (south)	13.07	100.497
13	LCHH	Laemchabang	13.55	100.5007
14	PTYA	Pattaya	12.574	100.53.1
15	KLAI	Klam island	12.385	100.49
16	MTPH	Mabtaput	12.313	101.12
17	RYRM	Rayong river mouth	12.356	101.175
18	HUHA	Hua Hin	12.55	100.10
19	PETC	Petchaburi	13.14	100.05
20	CTG1	Center of Thai Gulf1	13.10	100.30
21	CTG2	Center of Thai Gulf2	12.38.5	100.30

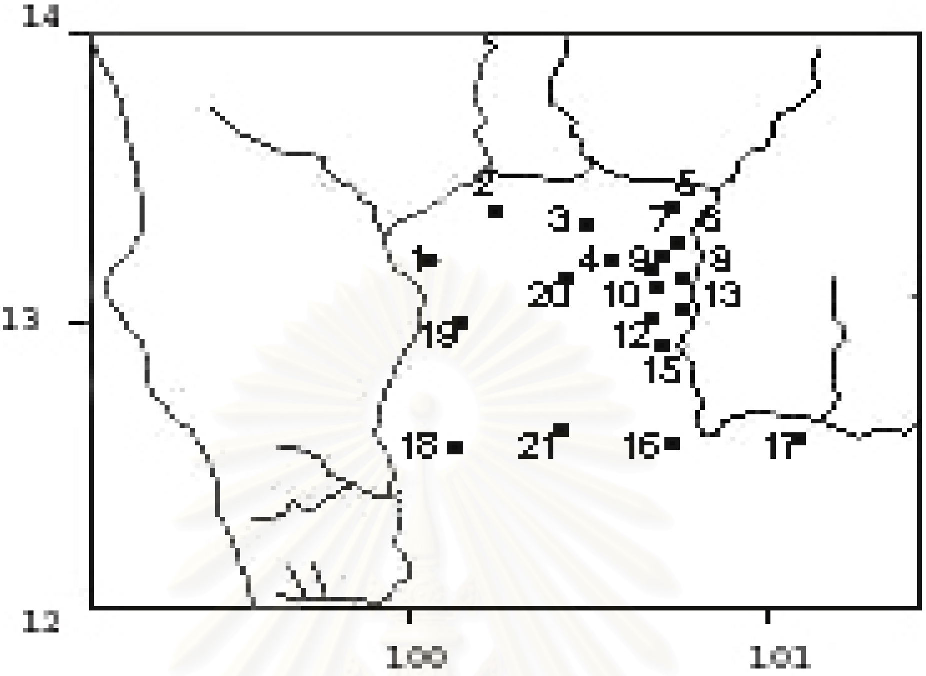

Figure A.2 Pollution Monitoring Program stations (dark square)

APPENDIX B

SeaWiFS derived chlorophyll *a* concentration

Table B.1 Chlorophyll *a* concentration (mg.m^{-3}) from Pollution Monitoring Program and SeaWiFS level-3 data at the same coordination in 1998

	January 1998		March 1998		July 1998	
Station	*In situ*	SeaWiFS	*In situ*	SeaWiFS	*In situ*	SeaWiFS
1. MKRM	0.031	0	0.839	0	1.145	8.546
2. TCRM	0.191	10.057	0.032	6.397	1.145	37.254
3. CPRM	0.624	10.057	0.119	6.397	0.127	37.254
4. SKCN	0.126	7.610	0.199	7.258	0.052	17.753
5. BPRM	0.088	10.057	0.144	6.398	1.956	37.215
6. BSAN	0.075	0	0.078	0	0.075	10.265
7. BPRA	0.091	0	0.024	0	0.191	20.172
8. SIRA	0.267	0	0.041	0	0.444	11.057
9. SCIN	0.275	5.145	0.032	8.901	0.095	8.162
10. SCIE	0.134	0	0.045	0	0.148	8.162
11. SCIW	0.075	0	0.043	2.530	0.134	8.162
12. SCIS	0.111	3.203	0.061	4.302	0.139	5.082
13. LCHH	0.131	0	0.029	2.041	0.283	5.082
14. PTYA	0.255	0	0.290	0	0.263	3.252
15. KLAI	0.110	1.940	0.600	0.704	0.134	0.786
16. MTPH	0.031	1.051	0.812	0.679	0.067	0.524
17. RYRM	0.024	1.072	0.019	0	0.067	5.125
18. HUHA	0.068	3.048	0.041	1.479	0.128	2.572
19. PETC	0.109	0	0.054	0	0.128	8.546
20. CTG1	0.170	3.175	0.002	0	0.127	13.233
21. CTG2	0.072	1.990	0.022	0.752	0.134	0.891
Average	0.146	2.474	0.178	2.278	0.332	11.858

Table B.2 Chlorophyll *a* concentration (mg.m^{-3}) from Pollution Monitoring Program and SeaWiFS level-3 data at the same coordination in 1999

	January 1999		May 1999		December 1999	
Station	*In situ*	SeaWiFS	*In situ*	SeaWiFS	*In situ*	SeaWiFS
1. MKRM	0.006	0	0.226	0.655	0.030	-
2. TCRM	0.269	0	0.278	0	0.140	-
3. CPRM	0.060	0	0.181	0	0.550	-
4. SKCN	0.350	1.735	0.159	0.399	0.110	-
5. BPRM	2.208	3.760	0.463	0	0.091	-
6. BSAN	0.162	0	0.143	3.247	0.056	-
7. BPRA	0.037	0	0.121	0.865	0.088	-
8. SIRA	0.047	0	0.100	-	0.220	-
9. SCIN	0.053	1.404	0.044	-	0.289	-
10. SCIE	0.037	0	0.135	-	0.110	-
11. SCIW	0.014	0	0.056	-	0.056	-
12. SCIS	0.410	0	0.088	-	0.350	-
13. LCHH	0.060	0	0.165	-	0.123	-
14. PTYA	0.148	0	0.126	-	0.211	-
15. KLAI	0.074	0	0.120	0.655	0.110	-
16. MTPH	0.004	0.563	0.052	0	0.031	-
17. RYRM	0.020	0	0.035	0	0.021	-
18. HUHA	0.016	0	0.052	0.399	0.054	-
19. PETC	0.073	0	0.102	0	0.102	-
20. CTG1	0.029	3.438	0.171	3.247	0.180	-
21. CTG2	0.069	1.861	0.037	0.865	0.066	-
Average	0.957	0.779	0.136	0.740	0.142	-

- No data

Table B.3 Mean chlorophyll *a* concentration from Pollution Monitoring Program and SeaWiFS level-3 data at the same coordination in 1998-1999

	Mean chlorophyll *a* concentration in 1998-1999 (mg.m^{-3})	
Station	*In situ*	SeaWiFS
1. MKRM	0.379	1.840
2. TCRM	0.347	10.734
3. CPRM	0.277	10.734
4. SKCN	0.115	6.951
5. BPRM	0.515	12.206
6. BSAN	0.098	2.702
7. BPRA	0.092	4.207
8. SIRA	0.187	2.764
9. SCIN	0.131	5.903
10. SCIE	0.101	2.041
11. SCIW	0.063	2.673
12. SCIS	0.193	3.147
13. LCHH	0.130	1.781
14. PTYA	0.172	0.183
15. KLAI	0.191	0.857
16. MTPH	0.166	0.704
17. RYRM	0.031	1.550
18. HUHA	0.060	1.775
19. PETC	0.176	2.136
20. CTG1	0.113	4.961
21. CTG2	0.067	1.373

Table B.4 Maximum and minimum SeaWiFS level-2 chlorophyll *a* concentration values at meteorological stations in 1998

	SeaWiFS L2 chlorophyll *a* concentration (mg.m^{-3})			
	Maximum value		Minimum value	
Station	Date	Value	Date	Value
1. Pilot	30 Aug	56.456	11 Nov	1.888
2. Petchaburi	25 Aug	27.063	30 Aug	1.567
3. Hua hin	23 Dec	9.850	1 Jan	0.666
4. Prachuapkhirikhan	25 Dec	2.249	25 Aug	0.293
5. Chumphon	28 Sep	4.574	19 Jul	0.716
6. Suratthani	13 Oct	15.545	29 Nov	5.309
7. Ko samui	21 Dec	1.595	19 Jul	0.384
8. Khanom	30 Jan	3.655	8 mar	1.362
9. Nakhonsithammarat	10 Aug	2.330	8 mar	0.825
10. Songkhla	30 Jan	6.422	13 oct	0.346
11. Pattani airport	5 Jun	4.639	14 Jan	1.379
12. Narathiwat	1 Jan	3.113	28 Aug	0.583
13. Bangkok	10 Mar	27.13	8 Mar	6.013
14. Ko sichang	30 Aug	9.413	29 Nov	0.694
15. Sattahip	13 Oct	2.415	29 Nov	0.793
16. Pattaya	30 Aug	6.988	29 Nov	0.842
17. Rayong	25 Dec	3.904	21 Dec	0.607
18. Chantaburi	12 Jul	16.508	11 Nov	1.694
19. Klongyai	19 Jul	1.837	8 Mar	0.811

Table B.5 Maximum and minimum SeaWiFS level-2 chlorophyll *a* concentration values at meteorological stations in 1999

	SeaWiFS derived chlorophyll *a* concentration (mg.m^{-3})			
	Maximum value		Minimum value	
Station	Date	Value	Date	Value
1. Pilot	27 Sep	64.767	25 Dec	56.456
2. Bangkok	13 Sep	64.767	11 Mar	5.924
	23 Dec	64.764		
3. Petchaburi	12 Nov	32.731	27 Dec	0
4. Hua hin	16 Dec	24.295	22 Aug	0.700
5. Prachuapkhirikhan	24 Nov	4.862	27 Dec	0
6. Chumphon	27 Dec	2.728	29 Jun	0.182
7. Suratthani	9 Jul	20.612	18 Aug	4.365
8. Ko samui	13 Aug	1.143	7,8 Jul	0.213
9. Khanom	10 Oct	1.528	21 Jun	0.695
10. Nakhonsithammarat	2 Aug	1.954	22 Jun	0.471
11. Songkhla	24 Nov	3.400	29 Jun	0.245
12. Pattani airport	24 Nov	4.585	5 Jun	0.932
13.Narathiwat	10 Oct	1.063	29 Jun	0.183
14. Ko sichang	7 Jul	101.037	18 Aug	3.374
15. Sattahip	-	-	-	-
16. Pattaya	12 Jul	2.975	9 May	1.312
17. Rayong	-	-	-	-
18. Chantaburi	-	-	-	-
19. Klongyai	11 Jul	2.735	29 Sep	1.853

- No data

Table B.6 Maximum and minimum SeaWiFS Level-2 chlorophyll *a* concentration values at meteorological stations in 2000

	SeaWiFS derived chlorophyll *a* concentration (mg.m^{-3})			
	Maximum value		Minimum value	
Station	Date	Value	Date	Value
1. Pilot	5 Nov	30.860	14 Jan	1.455
2. Bangkok	28 May	64.767	6 Feb	8.071
3. Petchaburi	7 Nov	13.601	10 Jan	1.349
4. Hua hin	7 Nov	14.937	8 May	0.278
5. Prachuapkhirikhan	7 Nov	11.265	19 Jan	0.960
6. Chumphon	28 Nov	5.567	17 Mar	0.736
7. Suratthani	6 Feb	16.772	17 Mar	10.529
8. Ko samui	28 Nov	1.619	12 Nov	0.412
9. Khanom	28 Nov	4.513	12 Nov	0.773
10. Nakhonsithammarat	10 Jan	2.842	10 Mar	0.686
11. Songkhla	4 Dec	2.399	13 Sep	0.375
12. Pattani airport	5 Dec	4.328	23 Feb	0.667
13. Narathiwat	5 Dec	6.707	20 Jun	0.233
14. Ko sichang	-	-	-	-
15. Sattahip	5 Dec	2.515	3 Feb	0.578
16. Pattaya	-	-	-	-
17. Rayong	-	-	-	-
18. Chantaburi	-	-	-	-
19. Klongyai	23 Jan	3.007	5 Dec	0.799

- No data

APPENDIX C

Statistical analysis

Statistical model

Pearson's correlation

The Pearson correlation coefficient (*r*) measures the strength and direction of a linear relationship between two variables. It is useful to use a statistical tool known as correlation to help in the interpretation. Values for *r* in a correlation, can predict what kind of change will occur in the dependent variable because of a particular change in independent variables. If the association between these variables is strong, then we can feel confident that a given change in independent variable will be associated with a given change in dependent variable. Pearson's correlation coefficient can range from +1 to –1. A correlation of +1 means that there is a perfect positive linear relationship between variables (Kalaya Wanichbancha, 2001). It is also usually reported in terms of its square (R^2), interpreted as percent of variance explained. The formula for the sample correlation coefficient is :

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{\left(\sum X^2 - \frac{\left(\sum X\right)^2}{N}\right)\left(\sum Y^2 - \frac{\left(\sum Y\right)^2}{N}\right)}}$$

Where r is the Pearson correlation coefficient, X is the independent variableand Y is the dependent variable.

Multiple regression model

Multiple correlation or the coefficient of multiple determination, R^2 is the percent of the variance in the dependent explained uniquely by the independents. R^2 can also be interpreted as the proportionate reduction in error in estimating the dependent when knowing the independents. That is, R^2 reflects the number of errors made when using the regression model to guess the value of the dependent, in ratio to the total errors made when using only the dependent's mean as the basis for estimating all cases. Mathematically, R^2 is the ratio of the sum of square Regression (SSR) to the sum square of Total (SSE):

$$SST = SSR + SSE$$

$$R^2 = \frac{SSR}{SST}$$

Where $0 \leq R^2 \leq 1$, if model has perfect predictability, $R^2 = 1$. If $R^2 = 0$, model has no predictive capability.

As additional variables are added to a regression equation, R^2 increases even when the new variables have no real predictive capability. When variables are added to the equation, the adjust R^2 doesn't increase unless the new variables have additional predictive capability. Computer software also provides the adjusted R^2 that takes into account sample size and number of explanatory variables. The adjusted R^2 is an unbiased estimate of explained variation ratio:

$$Adjust\ R^2 = 1 - SSE\frac{(n-k-1)}{SST(n-1)} = 1 + \frac{(n-1)}{(n-k-1)}(R^2 - 1)$$

Both $R^2$and the adjusted R^2 will be accepted as correct answers for percent of variation explained by regressionmodel.

Multiple regression is used to account for the linear relationship between the dependent and independent variables. The result is an equation that can be interpreted as a prediction equation if the independent variables precede the dependent variable. A multiple regression allows the simultaneous testing and modelling of multiple independent variables. The model for a multiple regression takes the form:

$$Y \quad = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + e$$

Where where Y is the estimate dependent, the β 's are the regression coefficients for the corresponding X (independent) terms, β_0 is constant or intercept and e is the residual or error.

Specifically, in a stepwise multiple regression, if a variable no longer contributes significantly to prediction, it is eliminated from the equation.

Stepwise regression

There are three basic approaches:

1.) Forward Selection

Start by choosing the independent variable, which explains the most variation in the dependent variable. Choose a second variable, which explains the residual variation, and then recalculate regression coefficients. Continue until no variables significantly explain residual variation.

2.) Backward Selection

Start with all the variables in the model, and drop the least significant,one at a time, until you are left with only significant variables.

3.) Mixture of the two

Perform a forward selection, but drop variables that become no longer significant after introduction of new variables.

Table C.1 Performance on correlation coefficient tested between SeaWiFS level-2 chlorophyll *a* concentration and meteorological factors.

Station	Amount of rainfall (ml)	Sunshine duration (hr)	Visibility (km)	Air temperature (°C)
1. Pilot				
1998 -2000	0.349**	-	0.012	0.252
1998	0.794*	-	0.425	0.219
1999	0.609**	-	-0.369	0.328
2000	-0.062	-	0.258	0.264
Summer 1998-2000	-0.194	-	-0.575*	0.183
Rainy 1998-2000	0.259	-	-0.221	-0.184
Winter 1998-2000	0.031	-	-0.013	0.247
2. Bangkok				
1998-2000	-0.118	-0.293	0.257	-0.101
1998	-0.064	-0.312	0.582	0.234
1999	0.239	-0.296	-0.085	-0.028
2000	-0.145	0.231	0.231	0.422
Summer 1998-2000	-	0.198	-0.211	-0.526
Rainy 1999-2000	1	-0.461	0.121	-0.232
Winter 1999-2000	-0.172	-0.057	0.161	-0.232
3. Petchaburi				
1998 -2000	0.379	-	0.036	0.113
1998	0.977**	-	0.253	0.068
1999	-0.125	-	-0.115	0.195
2000	-0.146	-	0.008	-0.545**
Summer 1998-2000	-	-	0.723	0.244
Rainy 1998-2000	0.453	-	-0.102	-0.148
Winter 1998-2000	0.120	-	-0.053	0.247

Station	Amount of rainfall (mm)	Sunshine duration (hr)	Visibility (km)	Air temperature (°C)
4. Hua Hin				
1998-2000	-0.060	0.024	-0.396**	-0.322*
1998	-0.176	-0.057	-0.539**	-0.510
1999	-0.041	0.158	-0.334	-0.219
2000	-0.120	-0.207	-0.324	-0.324
Summer 1998 -2000	0.350	0.290	0.190	-0.204
Rainy 1998 –2000	0.133	-0.360	-0.475	-0.275
Winter 1998 –2000	-0.175	0.266	-0.016	0.049
5. Prachuapkhirikan				
1998-2000	0.181	-	-0.263	-0.408*
1998	-0.022	-	-0.594**	-0.351
1999	0.539*	-	-0.198	-0.478**
2001	-	-	-0.439	-0.325
Summer 1998-2000	-0.453	-	-0.401	0.144
Rainy 1998-2000	0.690	-	-0.102	-0.297
Winter 1998-2000	0.032	-	-0.090	-0.181
6. Chumphom				
1998-2000	-0.126	-	-0.118	0.056
1998	-0.326	-	0.166	-0.254
1999	0.054	-	-0.521	-0.801*
2000	0.597**	-	-0.045	0.219
Summer 1998-2000	-	-	-0.297	0.247
Rainy 1998- 2000	-0.209	-	-0.035	-0.095
Winter 1998- 2000	-0.099	-	0.149	0.461

Station	Amount of rainfall (mm)	Sunshine duration (hr)	Visibility (km)	Air temperature (°C)
7. Suratthani				
1998-2000	0.164	0.259	-0.435*	0.049
1998	0.421	0.264	-0.343	-0.252
1999	0.349	-	0.140	0.390
2000	-	-	-	-
Summer 1998-2000	-0.659	-	-0.952	-0.991
Rainy 1998-2000	0.327	0.115	-0.300	0.332
Winter 1998-2000	-0.702	0.729	-0.488	-0.686
8. Ko samui				
1998-2000	0.009	-	-0.421	-0.453
1998	-0.590	-	-0.595	-0.428
1999	-	-	-0.264	-0.999*
2000	0.193	-	0.094	-0.528
Summer 1998-2000	-	-	-0.061	0.986
Rainy 1998-2000	0.281	-	-0.159	-0.457
Winter 1998-2000	-	-	0.104	-0.730
9. Khanom				
1998-2000	-0.323	-	0.108	-0.480
1998	0.957	-	-0.945	-0.893
1999	-0.661	-	0.830**	0.373
2000	-0.389	-	0.508	-0.394
Summer 1998-2000	-	-	0.302	-0.675
Rainy 1998-200	-0.807	-	0.932	0.885
Winter 1998-200	-0.420	-	0.425	0.422

Station	Amount of rainfall (mm)	Sunshine duration (hr)	Visibility (km)	Air temperature ($^{\circ}$C)
10. Nakhomsithammarat				
1998-2000	-0.021	-	-0.094	-0.214
1998	0.470	-	0.901**	-0.359
1999	0.105	-	0.105	0.194
2000	-0.092	-	-0.128	-0.477
Summer 1998-2000	-0.313	-	0.592	-0.229
Rainy 1998-2000	0.368	-	0.326	0.165
Winter 1998-2000	-0.552	-	0.029	0.333
11. Songkhla				
1998-2000	0.026	0.046	-0.116	-0.384*
1998	0.001	0.155	-0.188	0.294
1999	-0.017	-0.206	-0.300	-0.753**
2000	-0.046	0.244	0.165	-0.279
Summer 1998-2000	0.018	0.270	0.505	0.618*
Rainy 1998-2000	0.621**	-0.044	-0.064	0.271
Winter 1998-2000	-0.385	0.365	-0.170	-0.791
12. Pattani				
1998-2000	-0.012	-	-0.361*	-0.095
1998	-0.186	-	-0.292	0.004
1999	-0.220	-	-0.389	-0.591**
2000	0.176	-	-0.157	0.022
Summer 1998-2000	-	-	0.056	0.425
Rainy 1998-2000	-0.225	-	-0.505*	0.183
Winter 1998-2000	0.002	-	-0.102	-0.123

Station	Amount of rainfall (mm)	Sunshine duration (hr)	Visibility (km)	Air temperature (°C)
13.Narathiwat				
1998-2000	-0.128	-	0.094	-0.092
1998	0.711	-	-0.208	-0.086
1999	-0.358	-	-0.206	0.090
2000	-0.152	-	0.056	-0.294
Summer 1998-2000	-	-	-	-
Rainy 1998-2000	-	-	-	-
Winter 1998-2000	-	-	-	-
14. Ko sichang				
1998-2000	0.122	-0.469	0.694	0.327
1998	0.243	0.243	0.952**	0.330
1999	-0.186	-0.333	0.816	-
2000	-	-	-	-
Summer 1998-2000	-	-	-	-
Rainy 1998-2000	0.475	-0.683	-	-0.486
Winter 1998-2000	0.901	-	0.597	0.962
15. Pattaya				
1998-2000	0.785**	-0.668*	0.250	0.182
1998	0.782	-0.683**	0.347	0.081
1999	0.570	-	0.067	-0.200
2000	-	-	-	-
Summer 1998-2000	-	0.476	-0.164	-0.329
Rainy 1998-2000	0.973	-0.869	0.987	0.472
Winter 1998-2000	-	-0.794	0.019	0.196

Station	Amount of rainfall (mm)	Sunshine duration (hr)	Visibility (km)	Air temperature (°C)
16. Sattahip				
1998-2000	0.357	-	0.120	0.027
1998	0.302	-	0.142	-0.216
1999	-	-	-	-
2000	0.405	-	0.220	0.290
Summer 1998-2000	-	-	-0.953	0.375
Rain 1998-2000	0.476	-	-0.481	-0.381
Winter 1998-2000	-	-	0.090	-0.053
17. Rayong				
1998-2000	0.246	-0.320	0.401	-
1998	0.273	-0.412	0.401	-
1999	-	-	-	-
2000	0.007	-0.166	-	0.028
Summer 1998-2000	-	-	-	-
Rainy 1998-2000	-	-	-	-
Winter 1998-2000	-	-0.484	0.668	-
18. Chantaburi				
1998-2000	-0.181	-0.682	0.964	0.938
1998	-0.101	-0.697	0.917**	0.683
1999	-	-	-	-
2000	-	-	-	-
Summer 1998-2000	-	-	-	-
Rainy 1998-2000	-	-	-	-
Winter 1998-200	0.652	-0.963	-0.343	-0.416

Station	Amount of rainfall (mm)	Sunshine duration (hr)	Visibility (km)	Air temperature (°C)
19. Klongyai				
1998-2000	0.100	-	0.032	-0.162
1998	-0.283	-	0.374	0.488
1999	-	-	-	-
2000	-	-	-	-
Summer 1998-2000	-	-	-0.998*	-0.980
Rainy 1998-2000	0.428	-	-0.315	-0.195
Winter 1998-2000	-0.445	-	-0.032	-0.441

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

- Not determined

BIOGRAPHY

Wannarat Phoomwongpitak was born on May 5, 1978 in Sisaket. She received a Bachelor degree of Science in Microbiology from Chulalongkorn University in 2000. Thereafter persued her graduate study in Inter-department in enviromental science.