



UNIVERSITI PUTRA MALAYSIA

**REMOTELY SENSED CHLOROPHYLL-A VARIABILITY IN THE
STRAITS OF MALACCA**

ABDEL GALEEL ALI YOUSIF

FPAS 2009 8



**REMOTELY SENSED CHLOROPHYLL-A
VARIABILITY IN THE STRAITS OF MALACCA**

ABDEL GALEEL ALI YOUSIF

**DOCTOR OF PHILOSOPHY
UNIVERSITI PUTRA MALAYSIA**

2009



**REMOTELY SENSED CHLOROPHYLL-A VARIABILITY IN THE
STRAITS OF MALACCA**

By

ABDEL GALEEL ALI YOUSIF

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

July 2009



DEDICATION

THIS WORK IS DEDICATED TO MY BELOVED FAMILY



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment
of the requirements for the degree of Doctor of Philosophy

**REMOTELY SENSED CHLOROPHYLL-A VARIABILITY IN THE
STRAITS OF MALACCA**

By

ABDEL GALEEL ALI YOUSIF

July 2009

Chairman : Professor Mohd Ibrahim Bin Hj. Mohamed, PhD

Faculty : Environmental Studies

Studies on the marine plankton in Malaysian waters are limited, and most of the studies have been mainly taxonomic and qualitative in nature. The present study investigates the spatial and temporal distribution of SeaWiFS derived-chlorophyll-a in the Straits of Malacca. A period of six consecutive years from 1998 to 2003 is studied. Validation of in situ chlorophyll-a measurements with their corresponding SeaWiFS chlorophyll-a data is carried out. The correlation of sea surface temperature (SST) with the temporal chlorophyll-a data is investigated. The relationship between the Southern Oscillation Index (SOI) values and chlorophyll-a data is discussed. Finally, the correlation of marine fish landings with chlorophyll-a data is revealed.



SeaWiFS Data Analysis System (SeaDAS) has been used in SeaWiFS chlorophyll-a data analysis. In its typical use for the study of chlorophyll-a variability in tropical cloudy areas, ocean colour imagery is often binned in space and time. Comparison of in situ and SeaWiFS derived chlorophyll-a reveals that there is a moderate, positive correlation ($r = 0.51$) between the in situ and SeaWiFS chlorophyll-a observations, and the correlation is significant ($P < 0.05$) at the 0.05 level. With the six years of nearly continuous monthly images from the SeaWiFS instrument, the patterns of chlorophyll-a variability at Straits of Malacca have thus been investigated.

The results show spatial variability of chlorophyll-a in the Straits of Malacca. High chlorophyll-a concentration value (4.42 mg m^{-3}) has been observed along the near coastal area. Chlorophyll-a value (0.39 mg m^{-3}) decreased towards the offshore areas. Chlorophyll-a distribution was higher in the central (2.68 mg m^{-3}) and southern parts (3.80 mg m^{-3}) of the Straits of Malacca compared to the northern parts (1.16 mg m^{-3}). The results also show seasonality of chlorophyll-a and SST variations in the Straits of Malacca. Phytoplankton bloom events were also revealed during the northeast monsoon season all over the Straits of Malacca. The peak concentrations of chlorophyll-a were prevailed during the northeast monsoon months (2.73 mg m^{-3}).

Chlorophyll-a concentration is relatively low during the southwest monsoon (1.68 mg m^{-3}) and the two inter-monsoons months and was confined to the coastal areas. SST is low during the northeast monsoon months (28.31°C) and high during the southwest monsoon (30.32°C) and the two inter-monsoon months. A negative correlation was observed between the temporal SST and chlorophyll-a. Strong

negative SOI value (-28.5) occurred in 1998 and was associated with low chlorophyll-a values. Positive SOI values observed in 1999 were associated with high chlorophyll-a values.

It was found that the monthly marine fish landings value (39,391 metric tonnes) during the northeast monsoon months is lower than the monthly marine fish landings value (45,637 metric tonnes) during the southwest monsoon months.

The research has demonstrated that satellite remote sensing is capable of identifying, quantifying and mapping chlorophyll-a in the study area. The variability between SeaWiFS and in situ chlorophyll-a data explains the typical nature of Case II waters. The spatial chlorophyll-a distribution is associated with hydrographic features of the Straits of Malacca, and the temporal variation of chlorophyll-a concentrations is related to temporal variations in SST distributions and availability of nutrients. Strong relationships exist between ocean colour and other physical parameters such as SST. The negative correlations between chlorophyll-a and fish production with the SOI are attributed to the negative effects of the El Niño in the study area.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PERUBAHAN KLOOROFIL-A SECARA PENDERIAAN JARAK JAUH DI SELAT MELAKA

Oleh

ABDEL GALEEL ALI YOUSIF

July 2009

Pengerusi : Professor Mohd Ibrahim Bin Hj. Mohamed, PhD

Fakulti : Pengajian Alam Sekitar

Kajian mengenai plankton marin di perairan Malaysia adalah terhad, dan sebahagian besar daripada kajian adalah berasaskan kajian taxonomi dan kualitatif. Kajian ini menyiasat taburan spatial dan temporal klorofil-a yang diperolehi daripada SeaWiFS di Selat Melaka. Jangka masa 6 tahun berturutan iaitu dari tahun 1998 hingga 2003 dikaji. Kesahihan sukatan in-situ klorofil-a dibandingkan dengan SeaWiFS dijalankan. Korelasi suhu permukaan laut (SST) dengan data temporal clorofil-a disiasat. Perkaitan antara nilai indeks Southern Oscillation (SOI) dan klorofil-a didincang. Akhirnya, korelasi pendaratan ikan laut dengan data klorofil-a dipaparkan.



SeaWiFS Data Analysis System (SeaDAS) telah digunakan untuk menganalisa data klorofil-a. Dalam penggunaan biasanya dalam kajian perubahan klorofil-a di kawasan tropika yang mendung, gambarajah lautan berwarna biasanya dikait dalam ruang dan masa. Perbezaan antara klorofil-a in-situ dan terbitan SeaWiFS menunjukkan terdapat korelasi positif yang sederhana ($r = 0.51$) di antara kedsa-dua pemerhatian, dan korelasinya adalah signifikan ($p < 0.05$) pada tahap 0.05. Dengan gambaran secara bulanan selama enam tahun yang diperolehi oleh peralatan SeaWiFS, corak perubahan di Selat Melaka telah disiasat.

Keputusan menunjukkan perubahan spatial klorofil-a di selat Melaka. Kepekatan klorofil-a yang tinggi (4.42 mg m^{-3}) diperhatikan di sepanjang kawasan persisiran pantai. Nilai klorofil-a (0.39 mg m^{-3}) didapati berkurangan menuju kawasan perluaran pantai. Taburan klorofil-a adalah tinggi di kawasan bahagian pertengahan (2.68 mg m^{-3}) dan bahagian selatan (3.80 mg m^{-3}) Selat Melaka berbanding bahagian utara (1.16 mg m^{-3}). Keputusan juga menunjukkan perubahan secara bermusim untuk klorofil-a dan SST di Selat Melaka. Kejadian perkembangan plankton adalah nyata semasa musim Monsun Timur Laut di keseluruhan Selat Melaka. Kepekatan puncak klorofil-a adalah lebih nyata ketika bulan-bulan Monsun Timur Laut (2.73 mg m^{-3}).

Kepekatan klorofil-a adalah rendah secara perbandingan ketika Monsun Barat Daya (1.68 mg m^{-3}) dan kedua-dua bulan perantaraan monsun dan dihadkan kepada kawasan persisiran. SST adalah rendah pada bulan-bulan Monsun Timur Laut (28.31°C), dan tinggi ketika Monsun Barat Daya (30.32°C) dan kedua-dua bulan perantaraan monsun. Korelasi negatif diperhatikan di antara SST secara temporal dan

klorofil-a. Negatif korelasi yang tinggi bagi nilai SOI (-28.5) ditunjuk pada tahun 1998 dan dikaitkan dengan nilai klorofil-a yang rendah. Nilai SOI positif diperhatikan pada 1999 adalah dikaitkan dengan nilai klorofil-a yang tinggi.

Nilai pendaratan ikan marin bulanan (39,391 tan metrik) ketika bulan-bulan Monsun Timur Laut adalah lebih rendah daripada nilai pendaratan ikan marin bulanan (45,637 tan metrik) ketika bulan-bulan Monsun Barat Daya.

Kajian jelas menunjuk bahawa penderiaan jarak jauh satelit mampu mengenalpasti, menghitung, dan memeta klorofil-a di kawasan kajian. Perbezaan antara data klorofil-a SeaWiFS and in-situ menerangkan ciri-ciri umum air Kes II. Taburan spasial klorofil-a berkait rapat dengan ciri-ciri hidrografik Selat Melaka, manakala perubahan temporal kepekatan klorofil-a adalah berkait rapat dengan perubahan SST dan kehadiran nutrien. Perhubungan yang kukuh wujud di antara warna laut dan parameter fizikal lain seperti SST. Korelasi negatif antara klorofil-a dan pengeluaran ikan dengan SOI menyumbang kepada kesan negatif daripada El Niño di kawasan kajian.

ACKNOWLEDGEMENTS

In the name of Allah, the most gracious, the most merciful, and with due blessings and peace be upon his righteous messenger Prophet Mohammed (S.A.W). With humility and faith I thank Allah (S.W.T) who has given me the capability to complete this project.

I would like to take this opportunity to express my appreciation, indebtedness and gratitude to the chairman of my supervisory committee, Professor Dr. Capt. Mohammed Ibrahim Hj. Mohamed, for his keen supervision, valuable suggestions, discussion, and patient guidance that made the realization of this thesis possible. I would also like to express my sincere gratitude to the other members of the committee, namely Professor Dr. Shattri Bin Mansor and Dr. Mohammad Firuz Ramli for their constructive comments, advice, invaluable assistance and useful suggestions.

I owe debts of acknowledgement, appreciation, and gratitude to Professor Muddathir ‘Abd al-Rahim for his encouragement, guidance and for proof reading parts of this thesis. I would like to express my sincere gratitude and appreciation to my friend Dr. Isam Eldin Mohammed Elamin for facilitating the procedure of getting the offer letter to continue my study at Universiti Putra Malaysia, and for his continuous moral support and encouragement. I would like to express my most sincere and warmest gratitude to my friends Khalid Al-Jufri and Abdul Gadir Mahmood for their unlimited technical support during my study. I am very grateful and acknowledge to



my friends Dr. Mohammed Shareef, Dr. Faiz Ahmad, Dr. Elrashied Elimam, Dr. Musse Gabobe, Dr. Tan Chun, Dr. Siddig Ibrahim, Fatima Awad Allah, L. S. Wong, and Kin Voon for their contribution to this report, and for their support and encouragement. I am also very grateful and wish to thank my friends and colleagues in Sudan, Malaysia, and overseas for their encouragement during my study.

I am very grateful and indebted to Government of Sudan, Ministry of Higher Education, and University of Juba for their valued financial support, through Sudan embassy in Malaysia, which enabled me to further my studies at Universiti Putra Malaysia. I acknowledge the contribution of MASDEC, Universiti Putra Malaysia and JICA for providing *in situ* chlorophyll-a data. In addition, I wish to acknowledge the use of some datasets on Ferret, a product of NOAA's Pacific Marine Environmental Laboratory. The authors would like to thank the SeaWiFS Project (Code 970.2) and the Distributed Active Archive Centre (Code 902) at the Goddard Space Flight Centre, Greenbelt, MD 20771, for the production and distribution of these data, respectively. These activities are sponsored by NASA's Mission to Planet Earth Program.



I certify that a Thesis Examination Committee has met on 10th July 2009 to conduct the final examination of **Abdel Galeel Ali Yousif** on his thesis entitled “Remotely Sensed Chlorophyll-a Variability in the Straits Of Malacca” in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the **Doctoral of Philosophy**.

Members of the Examination Committee were as follows:

Ahmad Makmom Abdullah, PhD

Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Kamaruzaman Jusoff, PhD

Professor
Faculty of Forestry
Universiti Putra Malaysia
(Internal Examiner)

Zelina Zaiton Ibrahim, PhD

Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Internal Examiner)

Sharifah Mastura Syed Abdullah, Ph.D.

Professor
Faculty of Social Sciences and Humanities
Universiti Kebangsaan Malaysia
Malaysia
(External Examiner)

BUJANG BIN KIM HUAT, PhD

Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 24 December 2009



This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

MOHD IBRAHIM HJ. MOHAMED, PhD

Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

SHATTRI BIN MANSOR, PhD

Professor
Institute of Advanced Technology
Universiti Putra Malaysia
(Member)

MOHAMMAD FIRUZ RAMLI, PhD

Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

HASANAH MOHD GHAZALI, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 14 January 2010



DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently submitted for any other degree at University Putra Malaysia or at any other institution.

ABDEL GALEEL ALI YOUSIF

DATE: 25 November 2009



TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	vi
ACKNOWLEDGEMENTS	ix
APPROVAL	xi
DECLARATION	xiii
LIST OF TABLES	xviii
LIST OF FIGURES	xix
LIST OF ABBREVIATIONS	xxiv
 CHAPTER	
I INTRODUCTION	1
Background	1
Ocean Colour Satellite	6
Research Problem	10
Significance of the Study	12
Objectives of the Study	16
Hypothesis of the Study	16
 II LITERATURE REVIEW	 19
Part 1: Phytoplankton and Chlorophyll-a	19
Oceanographic Factors	22
Temperature	22
Winds, Tides and Currents	25
Upwelling	27
El Niño	29
Climatic Effects	32
Case I and Case II Waters	33
Eutrophication, Remineralization and Enrichment Factors	36
Part 2: Chlorophyll-a as Indicator for Biological Processes	40
Phytoplankton and Food Chain	40
Fish Forecasting	46
Part 3: Remote Sensing of Chlorophyll-a Using SeaWiFS	48
Historical Background	55
Sea-viewing Wide Field-of-view Sensor (SeaWiFS)	53
SeaWiFS Goals	53
SeaWiFS Data Set Information	55
SeaWiFS Data Set Organization	56
Atmospheric Correction	57
SeaWiFS Chlorophyll-a Algorithm	59
The Initial Operational SeaWiFS Chlorophyll- a	
Algorithm	60
OC2v2 Algorithm	61



OC2v4 and OC4v4	61
Overview of SeaWiFS Data Processing	64
Level-0 Data	64
Level-1a Data	65
Level-2 Data	66
Level-3 Data	67
Chlorophyll-a Retrieval	68
Chlorophyll-a Variability Detection Using Satellite	
Mainly SeaWiFS	70
Limitations of Remote Sensing Application in Case II Waters	81
Future Prospects of Remote Sensing Application	85
Summary	86
III MATERIALS AND METHODS	90
The Study Area	90
Natural Environmental Conditions	92
Climatology and Oceanography	93
Coastal and Marine Ecosystems	96
Environmental Problems	98
Materials	99
Hardware and Operating System	99
Software	100
Satellite and Instrument Information	100
SeaWiFS Data Analysis System (SeaDAS) Software	102
Data and Methods	104
The Validation of SeaWiFS Chlorophyll-a Data in the Straits of Malacca	105
MASDEC Chlorophyll-a Data	105
The Three Zones of the Straits of Malacca	106
The Classification of the Sampling Locations in the Three Zones	108
Chlorophyll-a <i>In situ</i> Data Collection	110
SeaWiFS Chlorophyll-a Validation data Collection and Processing	112
Validation of <i>In situ</i> and SeaWiFS Chlorophyll-a Data	113
SeaWiFS Chlorophyll-a Data	116
Background	116
SeaWiFS Data Collection and Processing	117
SeaWiFS Data Processing Sequence	118
SeaWiFS Processing Steps	120
SeaWiFS True Colour Image Production	123
A Dark Correction is applied to the Data	123
The Data are calibrated	124
A Rayleigh Correction is applied to the Data	124
The Data are geolocated	124
The Data are co-registered	125
The Data are displayed as an RGB Image	125
Sea Surface Temperature Data Collection and Analysis	126

El Niño Southern Oscillation Index (SOI) Data	
Collection and Analysis	128
Fish Landings Data Collection and Analysis	128
Summary	129
IV RESULTS AND DISCUSSION	132
Part 1: Chlorophyll-a Variability in the Straits of Malacca (1998-2003)	132
Qualitative Distribution of Chlorophyll-a in the Straits of Malacca	132
Quantitative Spatial Distribution of Chlorophyll-a in the Straits of Malacca	141
Average Spatial Distribution of Chlorophyll-a in the Straits of Malacca	142
Temporal Distribution of Chlorophyll-a in the Straits of Malacca	143
Average Temporal Distribution of Chlorophyll-a in the Straits of Malacca	144
Annual Spatial Distribution of Chlorophyll-a in the Straits of Malacca	145
Annual Temporal Distribution of Chlorophyll-a in the Straits of Malacca	146
Yearly Distribution of Chlorophyll-a in the Straits of Malacca	147
Factors Affecting Chlorophyll-a Variability in the Straits of Malacca	148
Discussion	149
Summary	155
Part 2: SST Distribution in the Straits of Malacca (1998-2003)	157
Monthly SST Distribution in the Straits of Malacca	157
Cumulative Monthly SST Distribution in the Straits of Malacca	158
Monthly Annual SST Distribution in the Straits of Malacca	159
Yearly SST Distribution in the Straits of Malacca	160
The Relationship between the SST and Chlorophyll-a in the Straits of Malacca	161
The Scatter Plot, the Trendline, and the R-squared of the SST and Chlorophyll-a in the Straits of Malacca	163
Discussion	164
Summary	174
Part 3: The El Niño Southern Oscillation Index (SOI) Variations in the Study Area (1998-2003)	175
The Monthly Variations of the Mean Southern Oscillation Index (SOI) in the Study Area	176
The Relationship between Monthly Variations of the Mean Southern Oscillation Index (SOI) and Monthly Chlorophyll-a Concentration in the Study Area during the Period from 1997 to 1999	178
Discussion	179
Summary	184

Part 4: Marine Fish Landings in the Straits of Malacca (1998-2003)	186
The Monthly Landings of Marine Fish in the Straits of Malacca	187
The Average Monthly Landings of Marine Fish in the Straits of Malacca	188
The Relationship between the Monthly Landings of Marine Fish and Monthly Chlorophyll-a Concentration in the Study Area	189
The Scatter Plot, the Trendline, and the R-squared of the Marine Fish Landings and Chlorophyll-a in the Straits of Malacca	191
The Annual Landings of Marine Fish in Straits of Malacca	195
The Relationship between the Annual Landings of Marine Fish and the Annual Chlorophyll-a Concentration in Straits of Malacca	197
Discussion	198
Summary	202
V SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH	
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH	205
Summary	205
Conclusions	207
Recommendations for Future Research	208
REFERENCES	210
BIODATA OF STUDENT	225
LIST OF PUBLICATIONS	228



LIST OF TABLES

Table	page
1. Orbit parameters for the OrbView-2 satellite. (Source: SeaWiFS, 2007).	101
2. Operating parameters for SeaWiFS. (Source: SeaWiFS, 2007).	101
3. Radiometric parameters for SeaWiFS. (Source: SeaWiFS, 2007).	101
4. Hardware requirements for SeaDAS 4.3. (Source: SeaDAS, 2005).	103
5. Software requirements for SeaDAS 4.3. (Source: SeaDAS, 2005).	103
6. Compile-from-scratch support. (Source: SeaDAS, 2005).	103
7. Descriptive statistics of chlorophyll-a, SST, SOI, and marine fish landings data	104
8. The sampling stations in the Straits of Malacca with their corresponding latitude, longitude and depth profile. (Source: MASDEC, 2003).	107
9. The location of stations in the three zones of the Straits of Malacca. (Source: MASDEC, 2003).	109
10. MASDEC cruises in the Straits of Malacca at different monsoons. (Source: MASDEC, 2003).	110
11. The sampling stations in the Straits of Malacca with their corresponding pixel and line. (Source: MASDEC, 2003).	111
12. An overview of SeaWiFS data processing.	119
13. The frequency of chlorophyll-a <i>in situ</i> (black x) and SeaWiFS (red x) data collection and extraction at sampling stations in Straits of Malacca for the four cruises.	121
14. The four factors affecting chlorophyll-a in the Straits of Malacca.	148
15. Analysis of variance for chlorophyll-a concentration in the Straits of Malacca.	148
16. The SST (°C) distributions of five MASDEC cruise expeditions in the Straits of Malacca. (Source: MASDEC, 2003 cited by Hassan, 2004).	170



LIST OF FIGURES

Figure	Page
1. The map of Peninsular Malaysia. (Source: Mohsin and Ambak, 1996).	2
2. Annual landings of marine fish in various regions of Malaysia 1997-2003. (Source: Department of Fisheries, 1997-2003).	13
3. Surface productivity of Malaysian waters ($\text{g C/m}^2/\text{yr}$). (Source: Mohsin and Ambak, 1996).	45
4. Atmospheric transmission as a function of wavelength within electromagnetic spectrum employed for satellite oceanography. (Source: Miller <i>et al.</i> , 2005).	50
5. Some examples of remote-sensing reflectance spectra from different types of waters. The figure shows (a) waters with very high sediment and gelbstoff concentrations, (b) high sediment and gelbstoff concentrations, (c) moderate sediment and gelbstoff with some phytoplankton, (d) clear water, (e) waters with moderate chlorophyll and sediment concentrations, (f) waters with moderate chlorophyll concentration. a, b, c and e are Case 2 waters; d and f are Case 1 waters. (Source: IOCCG, 2003).	70
6. Seasonal patterns in the Canary Islands region of the persistence of (a) low SST and (b) high chlorophyll-a concentration from autumn (OND) 1997 at the top to winter (JFM) 1999. The colour scale indicates the temporal density of such conditions for each season according to the definitions given in Fig. 7. Note the offshore extent of cooler upwelled water in summer (JAS) 1998 through autumn (OND) 1998 in relation to the three stations at EBC, ESTOC and LP. (Source: Davenport <i>et al.</i> , 2002).	76
7. Monthly average SeaWiFS Chl-a images in 2000. spatial resolution is 4 km. Color bar indicates Chl-a concentrations. Lands and clouds are shown in blackcolour and coastal lines in white colour. (Source: Tang <i>et al.</i> , 2003a).	78
8. Monthly average of SeaWiFS derived Chl-a concentrations in the center part of the gulf obtained during January 1999 to December 2000. (Source: Tang <i>et al.</i> , 2003a).	78
9. The Arabian Sea and the Bay of Bengal. (Source: Dey and Singh, 2003).	80
10. Chlorophyll concentrations in coastal part of the Arabian Sea and the Bay of Bengal. (Source: Dey and Singh, 2003).	81



11. Bathymetry and topology of the Straits of Malacca and its surrounding areas. Shaded areas on land show the mountain ranges in both Sumatra and Malay Peninsular. SEAFDEC cruise stations 58–63 are marked. Dark dotted lines show the boundary of the Straits of Malacca. Gray dotted line at the middle of the Straits of Malacca shows the division of the northern and southern areas. (Source: Tan *et al.*, 2006). 91
12. Current and water masses distribution in the Straits of Malacca and South China Sea during the northeast monsoon season. (Source: Mohsin and Ambak, 1996). 94
13. Current and water masses distribution in the Straits of Malacca and South China Sea during the southwest monsoon season. (Source: Mohsin and Ambak, 1996). 94
14. MASDEC 24 sampling stations of the Straits of Malacca, the blue line bordering the study area. (Source: MASDEC, 2003). 108
15. Comparison between *in situ* chlorophyll-a and SeaWiFS-derived chlorophyll-a data for the 24 sampling stations in the Straits of Malacca. 114
16. The relationship between SeaWiFS and *in situ* chlorophyll-a data in the Straits of Malacca during the period of MASDEC cruises from 1998 to 2000. 115
17. SeaWiFS monthly chlorophyll-a Standard Mapped Images of 9-km resolution in the Straits of Malacca for 1997. The land areas are shown in red colour, clouds in black colour, and coastal lines in blue colour. The colour bar indicates chlorophyll-a concentration in mg m^{-3} . 133
18. SeaWiFS monthly chlorophyll-a Standard Mapped Images of 9-km resolution in the Straits of Malacca for 1998. The land areas are shown in red colour, clouds in black colour, and coastal lines in blue colour. The colour bar indicates chlorophyll-a concentration in mg m^{-3} . 134
19. SeaWiFS monthly chlorophyll-a Standard Mapped Images of 9-km resolution in the Straits of Malacca for 1999. The land areas are shown in red colour, clouds in black colour, and coastal lines in blue colour. The colour bar indicates chlorophyll-a concentration in mg m^{-3} . 136
20. SeaWiFS monthly chlorophyll-a Standard Mapped Images of 9-km resolution in the Straits of Malacca for 2000. The land areas are shown in red colour, clouds in black colour, and coastal lines in blue colour. The colour bar indicates chlorophyll-a concentration in mg m^{-3} . 137



21.	SeaWiFS monthly chlorophyll-a Standard Mapped Images of 9-km resolution in the Straits of Malacca for 2001. The land areas are shown in red colour, clouds in black colour, and coastal lines in blue colour. The colour bar indicates chlorophyll-a concentration in mg m^{-3} .	138
22.	SeaWiFS monthly chlorophyll-a Standard Mapped Images of 9-km resolution in the Straits of Malacca for 2002. The land areas are shown in red colour, clouds in black colour, and coastal lines in blue colour. The colour bar indicates chlorophyll-a concentration in mg m^{-3} .	139
23.	SeaWiFS monthly chlorophyll-a Standard Mapped Images of 9-km resolution in the Straits of Malacca for 2003. The land areas are shown in red colour, clouds in black colour, and coastal lines in blue colour. The colour bar indicates chlorophyll-a concentration in mg m^{-3} .	140
24.	Spatial Chlorophyll-a Distribution in the 24 stations in the Straits of Malacca during the period from 1998 to 2003.	141
25.	Average spatial chlorophyll-a distribution of SeaWiFS SMI in the Straits of Malacca during the period from 1998 to 2003.	142
26.	Temporal chlorophyll-a distribution of SeaWiFS SMI in the Straits of Malacca (1998-2003).	143
27.	Average temporal chlorophyll-a distribution of SeaWiFS SMI in the Straits of Malacca during the period from 1998 to 2003.	144
28.	Annual spatial chlorophyll-a distribution of SeaWiFS SMI in the Straits of Malacca (1998-2003).	145
29.	Annual temporal chlorophyll-a distribution of SeaWiFS SMI in the Straits of Malacca during the period from 1998 to 2003.	146
30.	Yearly chlorophyll-a concentration of SeaWiFS SMI in the Straits of Malacca during the period from 1998 to 2003.	147
31.	Monthly rainfall (mm) in Six Stations in the Straits of Malacca (1997-2003). (Source: Malaysian Meteorological Services, 2004).	153
32.	Monthly SST distribution in the Straits of Malacca (1998-2003).	157
33.	Cumulative monthly SST distribution in the Straits of Malacca (1998 to 2003).	158
34.	Monthly annual SST distribution in the Straits of Malacca (1998-2003)	159
35.	Yearly SST distribution in the Straits of Malacca (1998-2003).	160

36.	The relationship between the SST and chlorophyll-a distribution in the Straits of Malacca (1998-2003).	162
37.	The relationship between the monthly cumulative SST and monthly Cumulative chlorophyll-a distribution in the Straits of Malacca (1998-2003).	162
38.	The yearly relationship between the SST and chlorophyll-a distribution in the Straits of Malacca (1998-2003).	163
39.	The scatter plot, the trendline, and the R-squared of the SST and chlorophyll-a distribution in the Straits of Malacca during the year 1998.	165
40.	The scatter plot, the trendline, and the R-squared of the SST and chlorophyll-a distribution in the Straits of Malacca during the year 1999.	165
41.	The scatter plot, the trendline, and the R-squared of the SST and chlorophyll-a distribution in the Straits of Malacca during the year 2000.	166
42.	The scatter plot, the trendline, and the R-squared of the SST and chlorophyll-a distribution in the Straits of Malacca during the year 2001.	166
43.	The scatter plot, the trendline, and the R-squared of the SST and chlorophyll-a distribution in the Straits of Malacca during the year 2002.	167
44.	The scatter plot, the trendline, and the R-squared of the SST and chlorophyll-a distribution in the Straits of Malacca during the year 2003.	167
45.	The scatter plot, the trendline, and the R-squared of the monthly cumulative SST and the monthly cumulative chlorophyll-a distribution in the Straits of Malacca (1998-2003).	168
46.	The scatter plot, the trendline, and the R-squared of the yearly SST and the yearly chlorophyll-a distribution in the Straits of Malacca (1998-2003).	168
47.	The monthly variations of the mean Southern Oscillation Index (SOI) in the Straits of Malacca (1997-2003).	177
48.	The relationship between monthly variations of the mean Southern Oscillation Index (SOI) and monthly chlorophyll-a concentration in the Straits of Malacca (1997-1999).	178
49.	The monthly landings of marine fish in the Straits of Malacca (1997-2003).	187
50.	The average monthly landings of marine fish in the Straits of Malacca (1998-2003).	188



51.	The relationship between the monthly landings of marine fish and monthly chlorophyll-a concentration in the Straits of Malacca (1998-2003).	190
52.	The relationship between the average monthly landings of marine fish and the average monthly chlorophyll-a concentration in the Straits of Malacca (1998-2003).	190
53.	The scatter plot, the trendline, and the R-squared of the marine fish landings and chlorophyll-a distribution in the Straits of Malacca during the year 1998.	192
54.	The scatter plot, the trendline, and the R-squared of the marine fish landings and chlorophyll-a distribution in the Straits of Malacca during the year 1999.	192
55.	The scatter plot, the trendline, and the R-squared of the marine fish landings and chlorophyll-a distribution in the Straits of Malacca during the year 2000.	193
56.	The scatter plot, the trendline, and the R-squared of the marine fish landings and chlorophyll-a distribution in the Straits of Malacca during the year 2001.	193
57.	The scatter plot, the trendline, and the R-squared of the marine fish landings and chlorophyll-a distribution in the Straits of Malacca during the year 2002.	194
58.	The scatter plot, the trendline, and the R-squared of the marine fish landings and chlorophyll-a distribution in the Straits of Malacca during the year 2003.	194
59.	The scatter plot, the trendline, and the R-squared of the average monthly marine fish landings and the average monthly chlorophyll-a concentration in the Straits of Malacca during the period from 1998 to 2003.	195
60.	The annual landings of marine fish in the Straits of Malacca (1998-2003).	197
61.	The relationship between the annual landings of marine fish and the annual chlorophyll-a concentration in the Straits of Malacca (1998-2003).	198

