THE INFLUENCE OF RIVER DISCHARGES, TIDES, AND WINDS ON ESTUARINE PLUME IN NORTHWEST PENINSULAR MALAYSIA

by

MUHAMMAD SYUKRI

Thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

December 2006

To very special people in my life:
my late mother Djuairiah Sabi,
my wife Rini Safitri
and
my son Raushan al Kasyfie Muhammad

The origins of oceanography lie in voyaging...

ACKNOWLEDGEMENTS

As a long journey and endeavour, this thesis was not a solo effort. I owe a tremendous of gratitude to the many people that assist and support me, that it is difficult to know where to begin and end this list. Even after one of the longest acknowledgments list ever written in this thesis is done, I am sure I will have forgotten some important people. To you I offer my apologies and implicit thanks. I would like to thank the University of Syiah Kuala (USK), Darussalam, Banda Aceh, Indonesia for providing the scholarship to support my study. I also wish to thank University Science Malaysia (USM), for serving and the use of all facility, where I learnt so much from being part of a graduate student here.

The very first, I want to pay special tribute to my advisor and friend Dr. Md. Noordin Abu Bakar has served as a source of inspiration since the conception of this thesis, helped me with advice, comments and suggestions. He was always available when I needed his advice or wisdom, but gave me the freedom to work independently. He has demonstrated impeccable leadership and has given me a strong foundation on which to build my own independent research program. Insya Allah, my career as an oceanographer in the future will always reflect what I have learned as a student from him. Further more, I also would like to thank to Ass. Prof. Dr. Khiruddin Abdullah as a co-supervisor for reviewing some of the results. Then I would like to extent my thanks to Dr. Zuhar Zahir Tuan Harith for guiding, suggestions and useful discussion during my study.

I would like to thanks the Malaysia Meteorological Service (MMS) for kindly providing the meteorology and hydrographic data, the Hydrology and Water Resources Division, Department of Irrigation and Drainage (DID) Malaysia for graciously providing the suspended sediment concentration, river discharge, and river stage data, the Malaysian Mapping and Survey Department (MMSD) for pleasantly providing the tide observation data, Centre for Marine and Coastal Studies (CEMAC) USM for their friendship and all those who helped me with laboratory work for the TSS analysis, Kedah Flying Club (KFC) for supplied aerial images from aerial surveys with their small aircraft. These datasets contributed significantly to the quality of the work and study presented in these pages.

I want to thank the Dean School of Physics USM, all staff of Geophysics Laboratory, School of Physics, for providing an atmosphere teeming with a collaborative spirit and enthusiasm for the research. Special thanks also to my wonderful friends and team works En. Yaakub Othman, En. Jamalludin, Uncle Abu Bakar, for their technical advice, who helped me with field surveys of the days and nights and in all weathers. They were also enthusiastic about my project and made the days I spent field surveying enjoyable. En. Zainul Abidin, Shahil Ahmad, Shaiful Mahathir, and Faisal, a very special thank you for all your help, cooperation, assistance and encouragement.

Further, I would like to express my special thanks to my parents, Usman Ismail and (late) Djuairiah Sabi, and my parents-in-law, Soewardi Soekirman and Nur Aini Umar, my sisters and brothers, k'Ina and b'Samsoel, k' Nyanyak and b'Poel, k'Ida and b'Ijal, and Ismail for their supporting and do'a during this very challenging period in my life.

Finally, especially and most importantly, to my wife and best friend Rini Safitri, and my son and sources of inspiration Raushan al Kasyfie Muhammad, for their wonderful

support, love, patience, distraction, and comfort during this trying odyssey know as graduate school, and particularly during that rather surreal period know as "writing up". I could not have done this without them, and dedicate my thesis to them.

Contents

List of Tables

List of Figures

List of Abbreviations

Name	Definition	Page
ADCP	Acoustic Doppler current profiler	29
APHA	American Public Health Association	98
AVHRR	Advanced very high resolution radiometer	34
CDOM	Coloured dissolved organic matter	38
DID	Department of Irrigation and Drainage, Malaysia	54
DNPS	Daya Bay nuclear power station	34
DOC	dissolved organic carbon	18
E	East	41
ENE	East Northeast	82
ESE	East Southeast	82
GF	Glasfaser Rundfilter	98
GIS	Geographic Information System	34
GPS	Global Positioning System	66
ICAM	Integrating cavity absorption meter	39
IPTS-68	The International Practical Temperature Scale of 1968	101
IUPAC	International Union of Pure and Applied Chemistry	103
Landsat TM	Landsat Thematic Mapper	38
LiDAR	Light Detection and Ranging	38
MMS	Malaysian Meteorological Services	58
MMSD	Malaysian Mapping and Survey Department	54
mg	Milligram	99
mg/l	Milligram per liter	99
MSL	Mean Sea Level	53
MST	Malaysia Standard Time	53
N	North	41
NE	Northeast	79
NASA	National Aeronautics and Space Administration	39
OBS	Optical backscatterance sensor	15

p	Pressure	100
POC	Particulate organic matter	18
ppt	Parts per thousand	101
PSS-78	The Practical Salinity Scale 1978	36
psu	Practical salinity units	29
ROFI	Region of Freshwater Influence	65
S	Salinity	79
S	South	28
SBS	Southern Brazilian Shelf	65
SCT	Salinity, conductivity and temperature	65
SLFMR	Scanning low frequency microwave radiometer	35
SPOT	Satellite Pour l'Observation de la Terre, is a commercial earth observation satellite	28
SW	Southwest	79
SPM	Suspended particulate matter	365
SSW	South Southwest	82
T	Temperature	65
TSS	Total suspended solids	34
W	West	79
WNW	West Northwest	82
YSI	Yellow Spring Instrument	65

List of Symbols

Name	*Definition*	*Page*
A^*	Absorption coefficient for sediment	38
a_x	Absorption coefficient for nonsediment constituents	38
B^*	Specific backscatter coefficient	38
A	Weigh of filter + residue	99
B	Weigh of filter	99
B	Buoyancy anomaly	20
C	Volume of water sample filtered	99
C'	Sediment volume concentration	19
C_D	Non-dimensional bottom drag coefficient	19
D	Depth of typical plume	11
f	Coriolis parameter	11
G	Acceleration of gravity	11
H	Depth	12
K	Kelvin number	24
K	Secant bulk modulus	100
L	Along shore length	12
γL	Across shore length	12
R_i	Richardson number	19
R_g	Richardson gradient number	106
R_L	Layer Richardson Number	107
R'_d	Reflectance	37
R_{bias}	Residual reflectance	37
r_i	Baroclinic Rossby radius	11
ρ	Average density of plume water	11
ρ_a	Density of ambient coastal water	11
ρ_s	Density of siliceous sediment	20
U	Current velocity	12
U_{max}	Total current velocity	19

U_w	RMS wave orbital velocity	20
u_g	Average current velocity in x direction	20
V	Specific volume	100
v_c	Magnitude of along shelf current	20
‰	Part per thousand (unit of salinity)	111
Φ	Diameter	98
σ_t	Density	105
$t_0(\lambda)$	Ozone and water vapor absorption optical depth for channel λ,	37
$t_r(\lambda)$	Rayleigh optical depth for channel λ	37

List of Appendices

PENGARUH LUAHAN SUNGAI, PASANG SURUT DAN ANGIN TERHADAP PLUM ESTUARI DI BARATLAUT SEMENANJUNG MALAYSIA

ABSTRAK

Tujuan thesis ini adalah untuk mengkaji struktur daripada plum estuari dan perairan pantai secara spasial dan temporal di baratlaut Semenanjung Malaysia. Pengukuran saliniti, suhu dan sedimen terampai (TSS) dijalankan bagi kawasan plum Muda, plum Prai dan dibahagian bawah Estuari Merbok. Di samping itu imej digital (imej udara) dan pengukuran arus juga diperolehi di beberapa tempat kajian yang terpilih. Luahan daripada sungai Muda adalah satu orde kali ganda lebih tinggi daripada Sungai Prai dan Sungai Merbok.

Keputusan yang diperolehi menunjukkan ciri-ciri permukaan plum bagi estuari dan perairan laut yang dipengaruhi oleh luahan air sungai, tenaga pasang surut dan juga oleh kekuatan angin. Semasa luahan tinggi, pergerakan bagi plum estuari Muda dan plum Prai ke perairan laut adalah masing-masingnya sekitar 4 km dan 2 km dari garis pantai. Keluasan permukaan yang dilitupi oleh estuari plum tersebut adalah bagi masing-masingnya sekitar 30 km^2 dan 13.5 km^2. Semasa luahan rendah, jarak plum akan berkurangan makin berdekatan sekitar 1-2 km dari garis pantai.

Pasang surut adalah penyebab kepada campuran dan penstrataan daripada plum. Plum Muda dan bahagian bawah Estuari Merbok, semasa perubahan daripada pasang surut perbani (*spring tides*) kepada pasang surut anak (*neap tides*), struktur plum bertukar daripada penstrataan separa atau homogen (pasang surut perbani) kepada penstrataan tinggi (pasang surut anak). Kepekatan TSS yang tinggi adalah konsisten bagi plum Muda dan plum Prai dan bahagian bawah Estuari Merbok semasa pasang surut perbani dibandingkan dengan semasa pasang surut anak disebabkan oleh tenaga pasang surut perbani yang lebih tinggi. Sebaliknya semasa pasang surut anak perlakuan yang sama bagi kepekatan TSS tidak diperolehi. Tiada korelasi yang jelas diperolehi diantara ciri-ciri plum dan kekuatan angin, kecuali

semasa kekuatan angin yang kencang yang menunjukkan terdapat bukti bahawa pergerakan plum adalah mengikuti arah angin.

Penderiaan jauh memberikan maklumat secara dua dimensi bagi struktur permukaan plum estuari. Imej digital jelas menunjukkan bahawa plum Prai akan terherot ke arah selatan/utara semasa luahan air sungai yang rendah/tinggi. Perlakuan ini dipengaruhi oleh pasang surut.

PENGARUH LUAHAN SUNGAI, PASANG SURUT DAN ANGIN TERHADAP PLUM ESTUARI DI BARATLAUT SEMENANJUNG MALAYSIA

ABSTRAK

Tujuan thesis ini adalah untuk mengkaji struktur daripada plum estuari dan perairan pantai secara spasial dan temporal di baratlaut Semenanjung Malaysia. Pengukuran saliniti, suhu dan sedimen terampai (TSS) dijalankan bagi kawasan plum Muda, plum Prai dan dibahagian bawah Estuari Merbok. Di samping itu imej digital (imej udara) dan pengukuran arus juga diperolehi di beberapa tempat kajian yang terpilih. Luahan daripada sungai Muda adalah satu orde kali ganda lebih tinggi daripada Sungai Prai dan Sungai Merbok. Keputusan yang diperolehi menunjukkan ciri-ciri permukaan plum bagi estuari dan perairan laut yang dipengaruhi oleh luahan air sungai, tenaga pasang surut dan juga oleh kekuatan angin. Semasa luahan tinggi, pergerakan bagi plum estuari Muda dan plum Prai ke perairan laut adalah masing-masingnya sekitar 4 km dan 2 km dari garis pantai. Keluasan permukaan yang dilitupi oleh estuari plum tersebut adalah bagi masing-masingnya sekitar 30 km^2 dan 13.5 km^2. Semasa luahan rendah, jarak plum akan berkurangan makin berdekatan sekitar 1-2 km dari garis pantai. Pasang surut adalah penyebab kepada campuran dan penstrataan daripada plum. Plum Muda dan bahagian bawah Estuari Merbok, semasa perubahan daripada pasang surut perbani (*spring tides*) kepada pasang surut anak (*neap tides*), struktur plum bertukar daripada penstrataan separa atau homogen (pasang surut perbani) kepada penstrataan tinggi (pasang surut anak). Kepekatan TSS yang tinggi adalah konsisten bagi plum Muda dan plum Prai dan bahagian bawah Estuari Merbok semasa pasang surut perbani dibandingkan dengan semasa pasang surut anak disebabkan oleh tenaga pasang surut perbani yang lebih tinggi. Sebaliknya semasa pasang surut anak perlakuan yang sama bagi kepekatan TSS tidak diperolehi. Tiada korelasi yang jelas diperolehi diantara ciri-ciri plum dan kekuatan angin, kecuali semasa kekuatan angin yang kencang yang menunjukkan terdapat bukti bahawa pergerakan plum adalah mengikuti arah angin. Penderiaan jauh memberikan

maklumat secara dua dimensi bagi struktur permukaan plum estuari. Imej digital jelas menunjukkan bahawa plum Prai akan terherot ke arah selatan/utara semasa luahan air sungai yang rendah/tinggi. Perlakuan ini dipengaruhi oleh pasang surut.

THE INFLUENCE OF RIVER DISCHARGES, TIDES, AND WINDS ON ESTUARINE PLUME IN NORTHWEST PENINSULAR MALAYSIA

ABSTRACT

The aim of the thesis was to investigate the spatial and temporal structure of estuarine plume and coastal waters in northwest Peninsular Malaysia. Measurements of salinity, temperature, and TSS were carried out at the Muda plume, Prai plume and the lower Merbok estuary. In addition, aerial images and current measurements were also obtained through several selected field surveys. The discharge of the Muda River was an order of magnitude more than Prai and Merbok Rivers. The results suggest that the surface plume characteristics of the estuaries and coastal waters are influenced by freshwater discharge, spring-neap tidal energy, and to some extent by wind forcing. During high discharge, the offshore extent of the Muda and Prai estuary plumes were approximately 4 km and 2 km respectively. The surface horizontal areas covered by these plumes were 30.0 km^2 and 13.5 km^2, respectively. During low discharge, the extent of plumes were closer to the coastline at about 1-2 km offshore. Tides were responsible for the mixing and the stratification of the plumes. The Muda plume and the lower Merbok Estuary, during the transition of spring-to-neap periods that change the plume structure from partially-mixed or homogeneous (spring tide) to highly stratified (neap tide). There were consistently higher TSS concentrations of Muda and Prai plume waters and Merbok Estuary during spring tides than at neap tides due to stronger spring tide energy. On the contrary, during neap tide a similar behavior of TSS concentration was not found. No obvious correlation was found between the plume characteristics and wind forcing, except during strong winds when there were some evidence of plume movement according to wind direction. Remote sensing provided information on the two-dimensional surface structures of the estuary plumes. For example, the aerial images clearly showed snapshots of the Prai plume being deflected to the south/north during low/high discharge. These behaviors were influenced by tides.

Chapter One
Introduction

1.0 Introduction

In studying and observing the coastal and estuary, the very first it is important to understand the basic concepts and their characteristics. The coastal area is significantly affected by various forcing mechanisms occurring over a broad range of spatial and temporal scales. The coastal ocean response to these various forcing mechanisms depends critically on the geometry and topography of the region, as well as the scale of the forcing. These relevant forcing mechanisms influencing the coastal characteristics are: river discharge, tidal range, atmospheric events (wind, waves, atmospheric temperature, rainfall, and density gradients (buoyant plumes)).

The estuary is a dynamic mixing areas for fresh and salt water, is particularly important because their high productivity. The term estuary means the lower tidal reaches of a river. Elliott and McLusky (2002) concluded that as existing definitions would never be suitable for all needs, a different approach is required. According to a contemporary definition and most scientist accept the definition of Pritchard (1967), based on physical characteristics: "an estuary is a semi-enclosed body of water having a free connection with the open sea and within which the seawater is measurably diluted with freshwater draining from the land". The estuary functions as a buffer between the ocean and the land. It can filter sediment and pollutants from the water before it flows into the oceans. Basically, all estuaries will interact physically with the open coast. This interaction is expressed in terms of both the influence of the estuary on the coast, and the influence of the coast on the estuary. It is important to understand the dynamics of estuarine systems, especially their water and sediment movement.

The movement of river waters into estuary and coastal region is part of an interconnected environmental system. Freshwater discharge is one of the most influential landscape processes affecting physical structure and function in estuaries, deltas and coastal. As a natural process, rivers drain freshwater discharge from rainfall events over land. The runoff and the downstream movement of materials is one of the primary controls over the productivity of estuarine systems and coastal waters. The river discharge collects a variety of materials as it moves through the river's catchment, lands and waterways including nutrients, sediments and contaminants depending on the catchment characteristics. Upon reaching the sea at the estuary mouth, the discharge drives a buoyant plume into coastal and shelf waters. It is an interesting phenomena that can be observed, a distinct color difference between the river and seawater. The area that appears to be extension of more brown color river water than seawater into the coastal zone is called a plume.

1.1 Motivation

The study areas are the estuaries and coastal waters of the Northwest of Peninsular Malaysia, are well known for their productive and diverse marine ecosystem, but little is known about the physical oceanography of the region. The Muda, Merbok and Prai Rivers, as a representative of tropical estuaries and coastal waters, drain into the Malacca Straits. There are some other factors deciding upon the complexity of the hydrodynamic phenomena such as: river discharges, tides, winds, atmospheric temperatures changes and sediment transport that appears in the estuaries and coastal waters.

Understanding the interactions between estuaries or coastal waters and global changes cannot be achieved through estimation or laboratory studies alone. Observational studies of key environmental processes is a significant and vital method that must be used to achieve its overall objectives, particularly in view of the fact that many of the uncertainties and real natural problems and processes occurring within the estuaries and coastal waters. This thesis is intended as a guide for those wishing to contribute to the objective of elucidating plume dynamics, suspended sediment concentration, turbidity (Secchi depth), density, salinity and temperature distribution in estuaries and coastal waters. Characteristics behavior of all these parameters directly correlated with the plume, that also as a representative of tropical plume. Figure 1.1a shows a schematics plan view of an estuary plume while Figure 1.1b illustrates a cross shore section of the plume, with the less dense river water overlying the more dense seawater. The vertical section shows how the plume floats out into the seawater, creating strong turbulence along its boundary as the fresh river water is absorbed into the seawater surroundings. The plume eventually spreads and mixes with ambient coastal waters.

This study has historically been motivated by the desire to both exploit and preserve resources in estuaries and coastal waters. It was done by the need to understand the distribution and fate of these estuarine waters, after their release into the coastal zone. The study will focus on the characteristics of the estuary plume in the study areas. The study is designed as a 1-year research for Muda coastal zone, starting in July 2001 and ending in August 2002, 6-months in Merbok River estuary, and 4-months in Prai coastal zone.

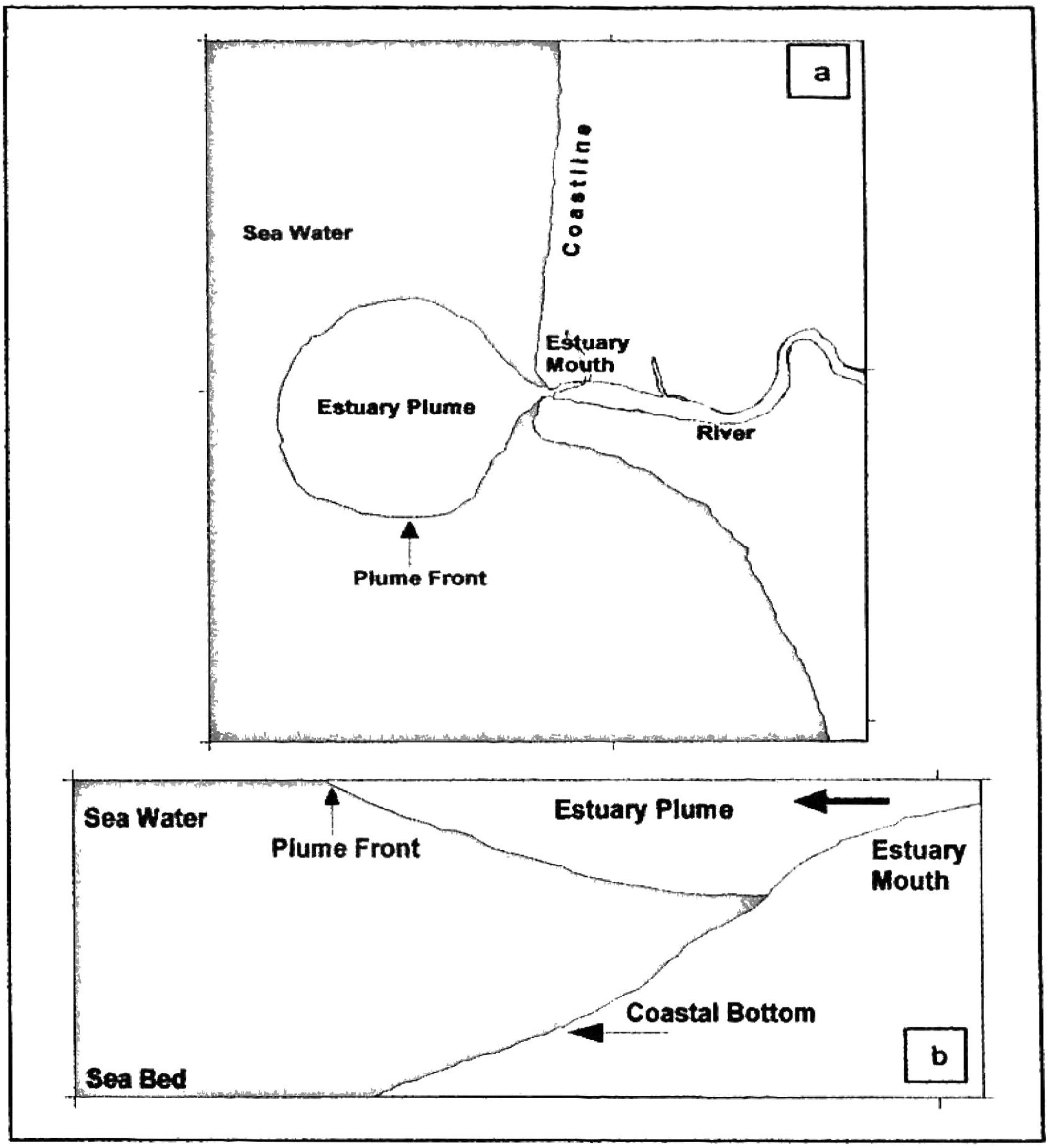


Figure 1.1 (a) A schematic plan view of an estuary plume in the coastal water, and (b). A vertical section of an estuary plume as the fresher water discharge from the estuary to coastal water.

1.2 Hypothesis

Studies on the temporal and spatial structures of the estuary plume are of considerable interest not only because of its influence on the physical processes of the shelf circulation but also because of its close relationship to environmental problems. In particular, the vast amount of land-drained materials, suspended materials, and sewage brought onto the continental shelf through the river discharge may significantly affect the formation of the estuary plume in the coastal zone. It is, therefore, important to have a general understanding of the coastal circulation as well as trace and predict the pathways and distributions of estuary plume in coastal waters.

This study demonstrates the movement of estuary plumes from the estuary mouth to inshore systems. Measurements taken near the mouth of the estuary systems are more representative of the processes that are occur in rivers that are dependent on the characteristics of that river system. Samples taken at close proximity to the mouth may generally be high in suspended matter that are related to the river source and also bottom sediment of coastal water.

The hypotheses or assumption made in this study are:

- ❑ High/low river discharge that related to the wet/dry season is one of the most influential factors affecting the physical structure of the estuary plume. As a natural process, freshwater discharge forcing and the downstream movement of sediments is one of the primary control of the characteristic of coastal sea. During high discharges (wet season) are expected well develop of estuary plume. On the other hand, from low discharges (dry season) are expected would result less or no plume.
- ❑ Tidal forces would produces cross shelf plume water movements. A mixing of sea and river water by tidal energy would determine the movement of plume water from the coastal water. During neap tides, it is expected that the plume waters would pushed landward on flood phase. While, during spring tides it is expected that the plume water would push further seaward on ebb phase. The magnitude of plume movement in spring tides would be higher than in neap tides.
- ❑ Wind force will induce a shear stress on the surface water causing the plume water to move in the general direction of the wind, and transfer energy to the

water column. During periods of strong winds, it is expected that the movement of plume water would follow the direction of the wind. In periods of weak wind, there is no significant influence on plume water movement.

1.3 Objectives and scope

The general objective of this study is to elucidate the basic physical processes associated with the characteristics of estuary plume. In particular, the study will focus on understanding river discharge, tidal, and wind forcing in determining the structure, patterns and fate of the plume. One of the key contributions of this work is quantification of both the along and cross shore motions of plume waters, and their distribution around the lower estuary.

The study have the following major objectives:

- ❑ To investigation the spatial and temporal structure of the Muda, Merbok and Prai Rivers estuary plume under a range of river discharge, tide and wind regimes.
- ❑ To carry out aerial surveys and observe their significant relationships with field measurements.
- ❑ To determine the physical mechanisms governing plume near the estuary mouth and coastal zone.

To carry out the objectives of the study, the area of observation will be established and will include: (1) the observations of salinity, temperature, density, total suspended solids (TSS), and Secchi depths near the mouths of three rivers of many tributaries flowing into coastal of Northwest Peninsular Malaysia, (2) the collection and measurement of tidal phase, rainfall, river discharge, water level, atmospheric temperature, current velocity, and wind speed and direction at specific locations inside the coast, estuary and in land.

In order to achieve the above objectives, it is need to limit the scope of study and provide some coherence. This study will focus on the theme of coastal and lower estuary processes and exchange i.e., identifying and understanding processes that are important in flowing plume water and associated seasonal, dynamical and physical oceanography across and along the shore and lower estuary. Even this is not a new problems in physical oceanography, however the objective of this study emphasis on this problem in motivated by several factors:

- ❑ To obtain a more thorough understanding of the hydrographic characteristics and dynamics of the Muda and Prai coastal waters, lower Merbok Estuary and the adjacent estuary mouth region.
- ❑ To delineate the extent and distribution (spatial and temporal distribution) of the Muda, Merbok and Prai Estuary plume in relation to the local hydrology characteristics and assesses the potential processes that might control (or have affected) the distribution of plume water in the coastal area and lower estuary.
- ❑ To use recent developments of instrumentation and techniques to gain new insights into estuary and coastal processes, wind driven over coastal and buoyant plumes associated with river discharge onto coastal waters.

1.4 Thesis outline

The study is done base on the need to understand processes occurring in estuary and coastal region arises from a variety of historic and contemporary topics in physical oceanography. It includes observation of the estuary and coastal dynamics in the Northwest Coastal of Peninsular Malaysia. In particular, the study focuses on the interactions of estuary (brackish estuarine) discharge in coastal after it leaves the estuary mouth, and also in lower estuary. It is very interesting and important role in coastal ocean and estuary dynamics because of it acts as a repository of organic matter in marine sediments, and source of nutrients and contaminants. This phenomenon is one of the interesting features to understand from this study.

The thesis is organized as follows. In Chapter 2, a brief review of the relevant theoretical and experimental investigations are presented in order to place the present work its appropriate context. In chapter 3, study sites characteristic, meteorological and hydrography data, field and laboratory works, and the methods are explained briefly. In Chapters 4, 5 and 6 present results and analysis from all observation conducted in the Muda, Merbok and Prai Rivers. Finally, Chapter 7 provides conclusions and significant findings of the results and suggests directions for future research.

Chapter Two

Literature Review

Studies of the characteristics and structures of estuary plume are very interesting not only because of its influence on the physical processes of the coastal circulation but also because of its close relationship to environmental and ecosystem problems. In particular, it is important to have a general understanding of the coastal circulation as well as to trace and to predict the trajectories and distributions of estuary plume in the coastal ocean.

2.0 Estuary plume structures

Several research and observations show that estuary plumes have different structures in different regions. In general, the plume structure is principally determined by the local conditions like the total volume of freshwater outflow, winds, tides, coastal currents and bathymetry. A review is given by Wiseman and Garvine (1995). Estuary plumes can be characterized by a Kelvin number, the ratio of the width of the river mouth to the baroclinic Rossby radius (Garvine, 1987):

$$K = w / r_i \tag{2.1}$$

and

$$r_i = \frac{\{gd(\rho_a - \rho)/\rho_a\}^{1/2}}{f} \tag{2.2}$$

where ρ is the average density of plume water, ρ_a is the density of ambient coastal water, g is the acceleration of gravity, d is the typical plume depth, and f is the Coriolis parameter. Physically for a plume with small K, the deflection of the plume alongshore tends to be dominated by motion of ambient coastal water, not by the anticyclonic turning action of Coriolis force, while for of order unity or larger effects of the earth rotation or the Coriolis force becomes important. Garvine (1995) offered a method to classify buoyancy flows in coastal waters. He considered the balance of the following forces: horizontal advection, Coriolis, pressure gradient, wind stress and bottom stress. Figure 2.1 shows an idealized buoyant plume.

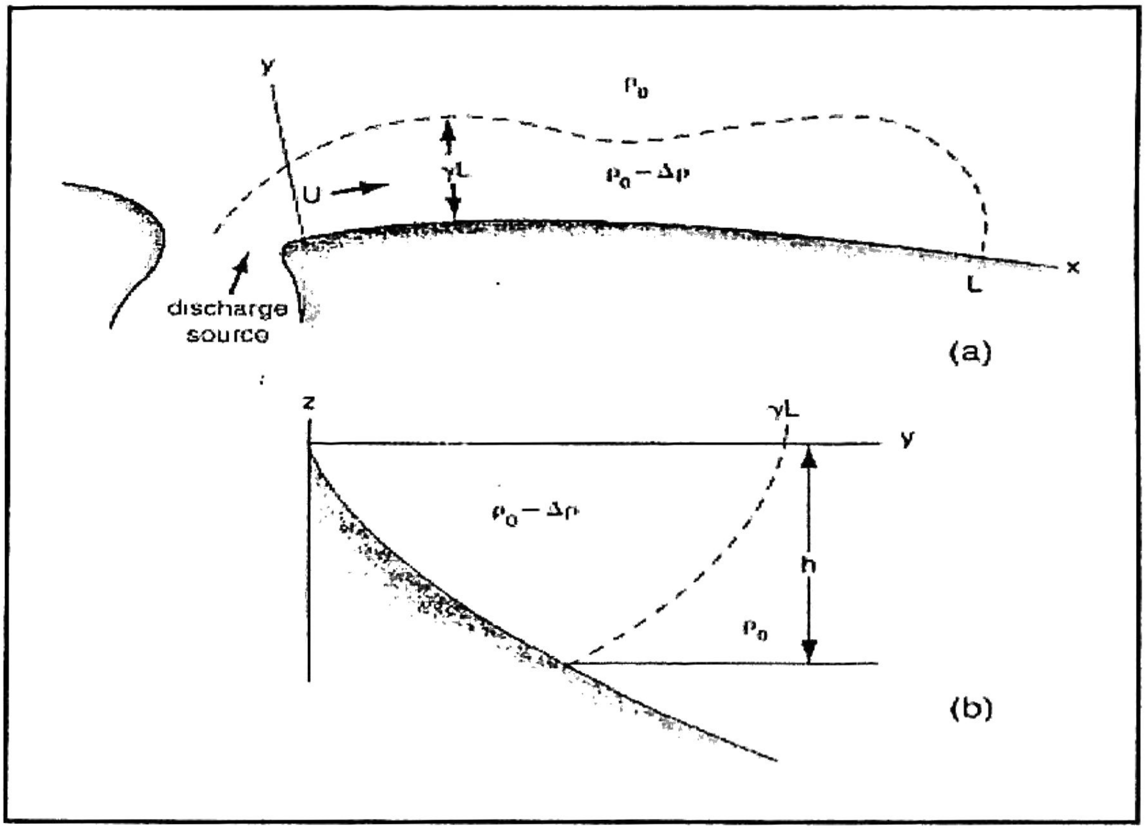


Figure 2.1 Sketch of buoyant layer scales. (a) x and y are alongshore and across-shore coordinates. Dashed line denotes a bounding isopycnal contour for the buoyant layer. U is typical alongshore buoyant water velocity. L and γL are the alongshore and the across-shore length scale, respectively. (b) A typical across-shore vertical section with vertical coordinate z. Dashed line shows typical bounding isopycnal for the buoyant of typical depth h. (from Garvine, 1995).

This kind of estuary plume is described by theoretical model to obtain approximate solutions to several problems which are interpreted to yield new insights of these phenomena (O'Donnell, 1990). However, James (1997) dealing with regions of the sea where the dynamical effect of the coastal discharge of relatively freshwater is significant by developed the anticyclonic circulation model that can change the expected direction of the discharge plume. For the mathematical description of plume structure, Poulos and Collins (1994) predicted the spread of freshwater outflow for a small river based upon a combination of frictionally-controlled and buoyant plume dispersal models. Here, the estuary plume decelerates rapidly for the first 400 m to seaward of the estuary mouth, and at the transitional zone, the plume has lost then its initial momentum and it is controlled now by buoyant forces and entrainment processes.

Fennel and Mutzke (1997) studied the initial evolution of a buoyant plume. They stated that estuary plumes are forced by two mechanisms: (i) momentum added to the ocean at the estuary mouth and (ii) intrusion of buoyancy at the estuary mouth. Several researchers such as, Ingram (1981), O'Donnell (1990), Ruddick *et al.* (1995), James (1997) and Broche *et al.* (1998) implied that the study of estuary plume is a subject related to river discharge. Since the river discharge is fairly small, mixing between river water and seawater to be extremely small, thus the estuary plume might be disturbed by turbulence advected from beyond the location. When the amount of river discharge becomes much larger, the salt water is pushed out from the estuary mouth so that the estuary plume becomes supercritical (Murota and Nakatsuji, 1988; Chao, 1998).

The freshwater inflow provides a direct input of momentum as well as a large buoyancy source, both of which contribute to the motion over the shelf. The surface salinity distribution and the suspended sediment distribution from the Eel River plume exiting the mouth of the Bay are shown in Figure 2.2 and Figure 2.3. These observations indicate that the suspended sediment was behaving nearly conservatively within the plume during the high-flow, down welling conditions, and that sediment was being lost to settling during the falling-flow, upwelling conditions. Beside that, because of high rates of particulate and river discharge, the estuarine processes usually take place on the adjacent continental shelf instead of in a physically confined estuary (Dagg *et al.*, 2004). The other results suggest that Fouha Bay (at southwest coast of Guam) is flushed annually by waves generated from typhoons passing to the

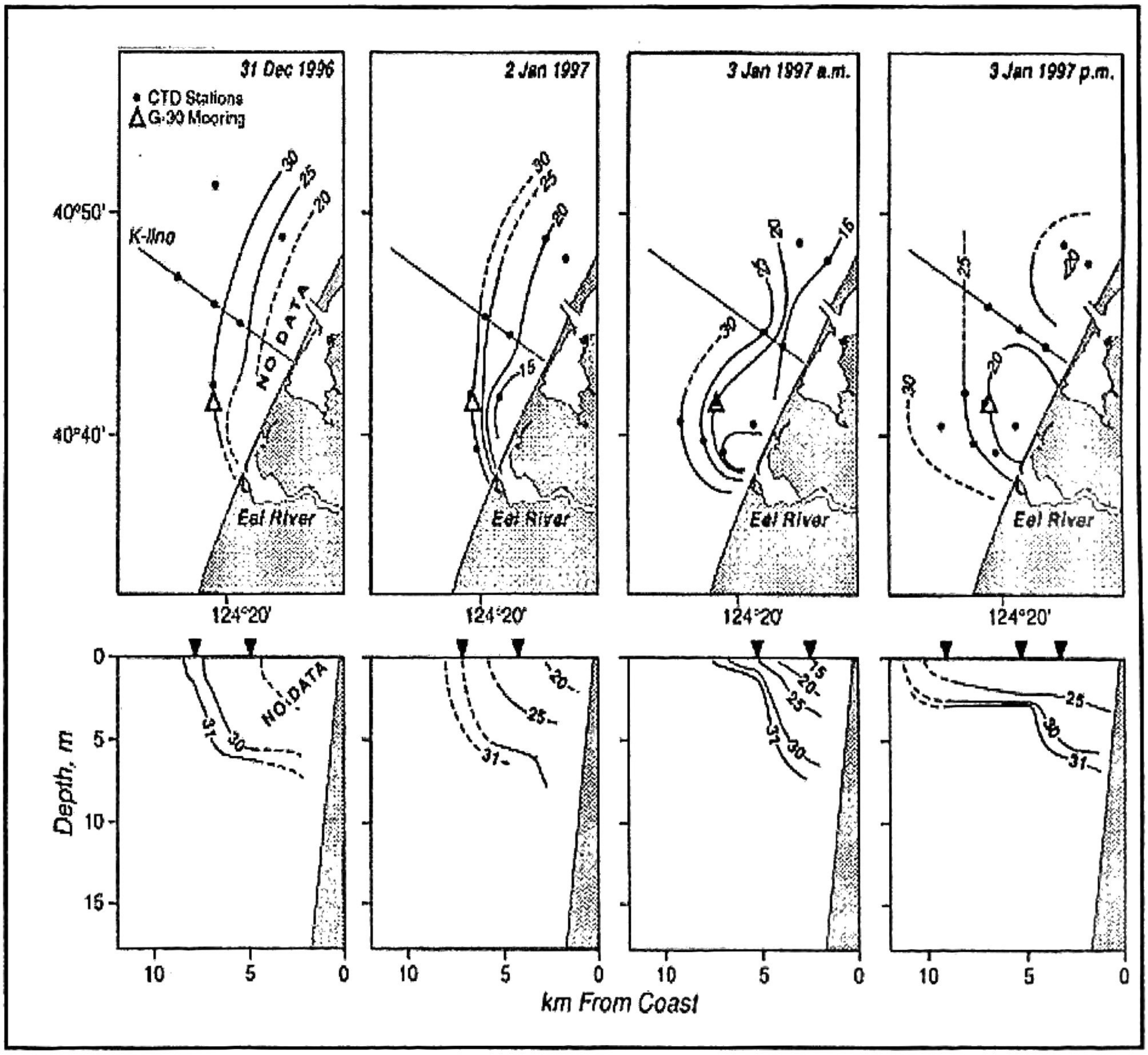


Figure 2.2 Salinity distributions during the January 1997 flood. Upper panels: near-surface (1.5m) salinity distributions; lower panel: cross-sections at river mouth (from Geyer *et al.*, 2000).

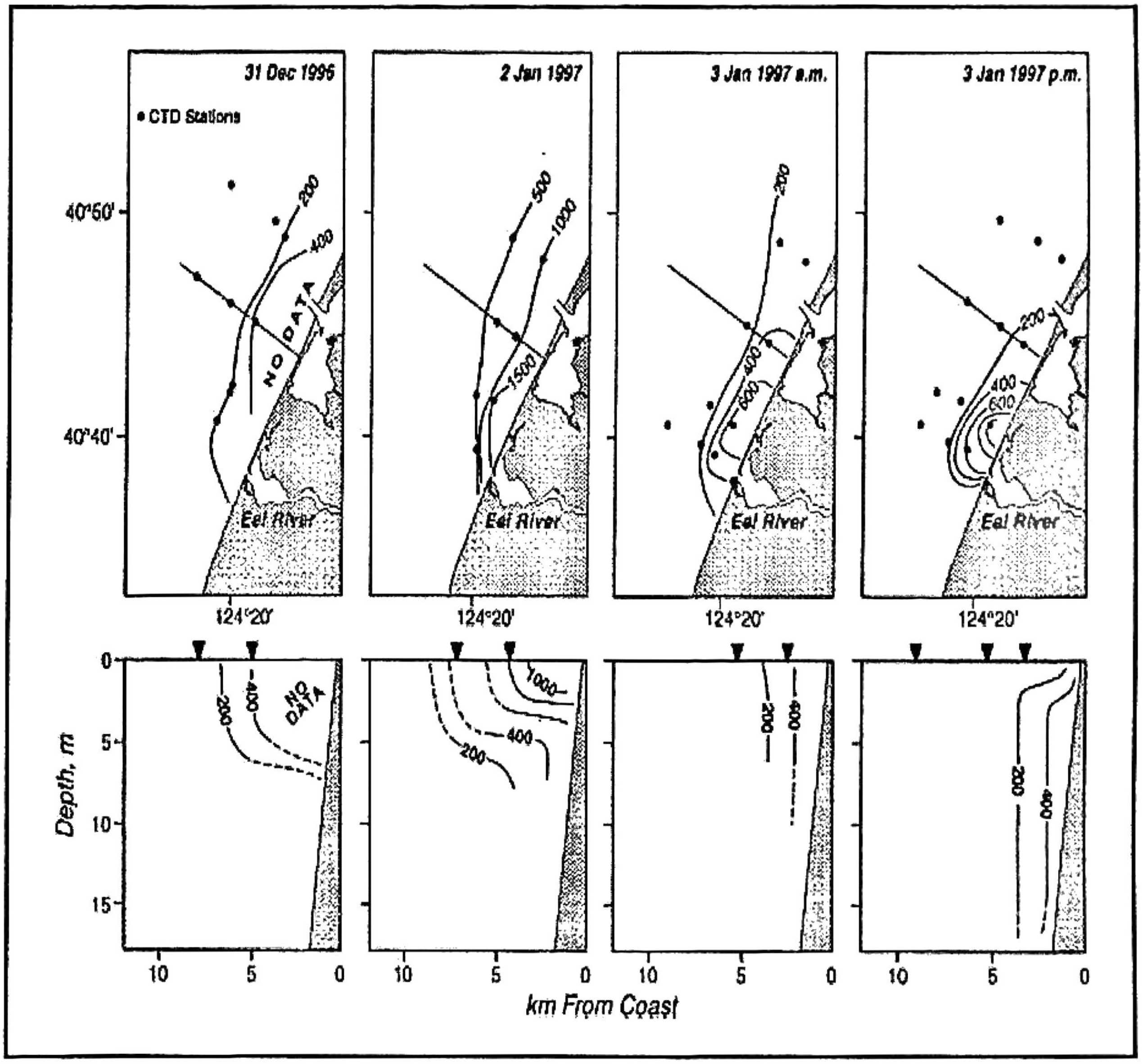


Figure 2.3 Total suspended sediment distributions during the 1997 flood. Upper panels: near-surface (1.5 m) suspended solids, based on water samples; lower panel: cross-sections at river mouth, based on water samples and optical backscatterance sensor (OBS) profiles (from Geyer *et al.*, 2000).

south of Guam. If sediment input can be substantially reduced through improved land-use practices, water and substratum quality should improve and provide the conditions for reef regeneration to occur (Wolanski *et al.*, 2005).

2.1 Sediment transport

Coastal areas and estuaries are an important element in cycle processes, because much of the sediment found on the ocean floor is derived from land and reaches the ocean through rivers and their estuaries. There are a variety of interesting and important dynamical processes that occur within the coastal regions after the modified river water leaves the estuary. A plume typically forms as the buoyant water spreads away from the mouth of the estuary.

In coastal area, sediment transport in estuary plumes is controlled not only by the trajectory of the freshwater plume, but also by rate of settling, the plume thickness and plume velocity (Geyer *et al.*, 2000). The dynamics and structure of plumes of small rivers differ considerably from those of large rivers, due to differences in the physical scales of the processes near the estuary mouth (Garvine, 1995) and relatively short duration from small (e.g., Eel and Waipaoa River), and large sediment input compared to large river (e.g., Columbia, Mississippi, and Amazon River) (Wheatcroft, 2000). The transport processes of sediment from the small river to the coastal ocean occurs in freshwater plume, whose trajectories may strongly depend on discharge magnitude and sediment load, the rate of flocculation of particles within the plume, and the ambient oceanic conditions (currents and density structure) (Morehead and Syvitsky, 1999) and a region's climate and local drainage-basin characteristics (e.g., headwater elevation) (Syvitsky and Morehead, 1999).

On the contrary, transport processes of estuary plume for large rivers cannot be understood by simply scaling up the magnitudes and impacts of dominant processes in smaller rivers. Time and space scales over which these transport and transformation processes occur vary greatly, depending on factors such as scales of discharge, suspended sediment loads, latitude of discharge, and winds and tides, which affect plume behavior, and also affected by meteorology and climatology, bottom topography of the receiving site and orientation of plume (Dagg *et al.,* 2001) and planetary rotation (Simpson and Sharples, 1994; O'Donnell, 1990). For examples, these effects (river discharge and the amount of sediment loads) for the world's largest river are summarized in Table 2.1.

Buoyancy is a key mediating factor in the transports and transformations of estuary plume in the coastal margin. The expansion, contraction, and alongshore orientation of surface plumes are often influenced by tide and wind conditions (Davies and Xing, 2001; Schallenberg and Krebsbach, 2001; Joordens *et al.*, 2001), besides river discharge and wave conditions (Scully *et al.*, 2004; Wright *et al.*, 2002; Aubertot and Echevin, 2002; Durand *et al.*, 2002; Wheatcroft, 2000; Mullenbach and Nittrouer, 2000).

Table 2.1 Discharge data for the world's largest rivers (from Dagg *et al.*, 2001).

River (Country)	Water discharge 10^9 m^{3}y^{-1}	Sediment discharge 10^9 m^{3}y^{-1}	Drainage basin 10^6 km^2	POC 10^6 ty^{-1}	DOC 10^6 ty^{-1}
Amazon (Brazil)	6300	1150	6.15	13.0	19.1
Zaire (Zaire)	1250	43	3.82	2.8	10.15
Orinoco (Venezuela)	1200	150	0.99	2.0	4.5
Ganges-Brahmapura (Bangladesh)	970	1050	1.48	nd	nd
Yangtze (China)	900	480	1.94	4.4	11.8
Yenisey (Russia)	630	5	2.58	0.17	4.86
Mississippi (USA)	530	210	3.27	0.8	3.5
Lena (Russia)	510	11	2.49	0.46	3.38
Mekong (Vietnam)	470	160	0.79	nd	nd
Parana/Uruguay (Brazil)	470	100	2.83	1.3	5.9
St. Lawrence (Canada)	450	3	1.03	0.31	1.55
Irrawaddy (Burma)	430	260	0.43	nd	nd
Ob (Russia)	400	16	2.99	nd	3.69
Amur (Russia)	325	52	1.86	nd	nd
Mackenzie (Canada)	310	100	1.81	1.8	1.3
Xi Jiang (China)	300	80	0.44	nd	nd
Salween (Burma)	300	100	0.28	nd	nd
Columbia (USA)	250	8	0.67	nd	0.5
Indus (Pakistan)	240	50	0.97	nd	0.75
Magdalena (Columbia)	240	220	0.24	nd	nd
Zambezi (Mozambique)	220	20	1.2	nd	nd
Danube (Romania)	210	40	0.81	nd	nd
Yukon (USA)	195	60	0.84	nd	nd
Niger (Africa)	190	40	1.21	0.66	0.53
Purani/Fly (New Guinea)	150	110	0.09	nd	nd

Notes: POC: particulate organic matter; DOC: dissolved organic carbon, nd: no data.

Water temperature changes with the depth of water and season of the year. Because the Merbok Estuary is relatively shallow, there can be considerable diurnal and seasonal temperature variation. The surface of the water is likely to be warmer than the deeper water because the surface water gets more heat from the sun. It is often part of the natural cycle of the system. Wind is one of the important factors as apart of natural cycle that influence the estuary temperature. Variability in wind stress is likely responsible for the variability in the coastal environment. A stronger wind speed increased surface mixing, thus decreasing temperatures at the surface water. Conversely, a lower wind speed increased surface temperatures.

Generally, seasonal weather changes have the greatest effect on water temperature, but the mixing of the water in the estuary will also cause the temperature to fluctuate in the study area. In shallow estuary and adjacent coastal water, there is less likely to be any temperature change from surface to bottom.

c. Density pattern

During survey with relatively strong wind speed, it was examined wind effect the brackish water pattern. The observation was obtained during a period of wind blowing to the north and south parallel with the coastline. Wind forcing produces a shear stress on the water surface causing it to move in the general direction of the wind, and transfer energy to the water column. Also the spring tide energy causes mixing in the estuary that tends to reduce horizontal gradients of density.

During weak wind stress survey, a weaker gradient of horizontal density can be observed, corresponding to the mixing between the freshwater and the saltwater. Beside that, this weak density gradient also related to the mixing process coincided with the neap tide condition. This shows that low wind did not induce the flow of brackish water at the lower estuary and adjacent coastal water. The different pattern of both density distributions indicated a different conditions that probably resulted by river discharge or tidal condition and wind forcing.

The plume waters have means densities less than that of ambient seawater and were typically disperse mixing processes produced by spring-neap tidal energy and possibly enhancing the rapid movement of estuarine water by wind forcing. Based on an observation by Yankovsky *et al.* (2000), they demonstrated that there are two forcing (wind and buoyancy) that influence the plume water. It was opposed each other: upwelling-favorable wind acted northward (upshelf) while the buoyant intrusion propagated southward (downshelf). Wind forcing had a large spatial scale, while buoyancy forcing was confined to the plume.

d. Total suspended solids pattern

Only during strong wind condition, the higher value of TSS was evident in the coastal water. The distribution of high TSS corresponds to the highly turbid waters due to fluctuation of wind speed and direction. This was speculated in a way so that strong winds were eroding more sediment from the bottom.

Generally, the results show that the TSS patterns in the study area was slightly determined by the wind direction, while the size of the concentrations was determined by the wind speed. During the field surveys period, the highest values in turbidity (high TSS concentrations) were found in the shallow water regions off the north and south side of estuary mouth. This suggests that significantly larger tidal energy or higher river discharge over the study area may have had a great effect on the pattern of turbidity, supporting by the wind energy. Relatively higher winds over the study area would produce a relatively high wave, while the lower winds might explain the smaller disturbing those estuary and coastal waters.

e. Secchi depth pattern

Observation the water clarity in estuary and coastal water is one of the important factor in the assessment and determine the physical aspects of the estuary. As TSS concentrations increase in the water, the amount of light traveling through the water column is reduced. The Secchi depth record provides a convenient method for measuring light penetration below the water surface. Material that becomes mixed and suspended in water will reduce its clarity and make the water turbid. In shallow areas, wind generated waves wakes interact with the bottom to stir up sediments. Wind generated waves breaking on shore also contribute to turbidity.

Similarly, Secchi depth values could indicate appreciably different TSS concentrations. The higher value of Secchi depth can be explained by lower concentrations of TSS in the estuary. So, only during strong wind condition, the lower value of Secchi depth was evident in the study area. The TSS concentrations and Secchi depth values within the study area were significantly different, in all surveys. Regression analysis indicated that a greater TSS concentration corresponds to a lower Secchi depth value (Figure 5.41).

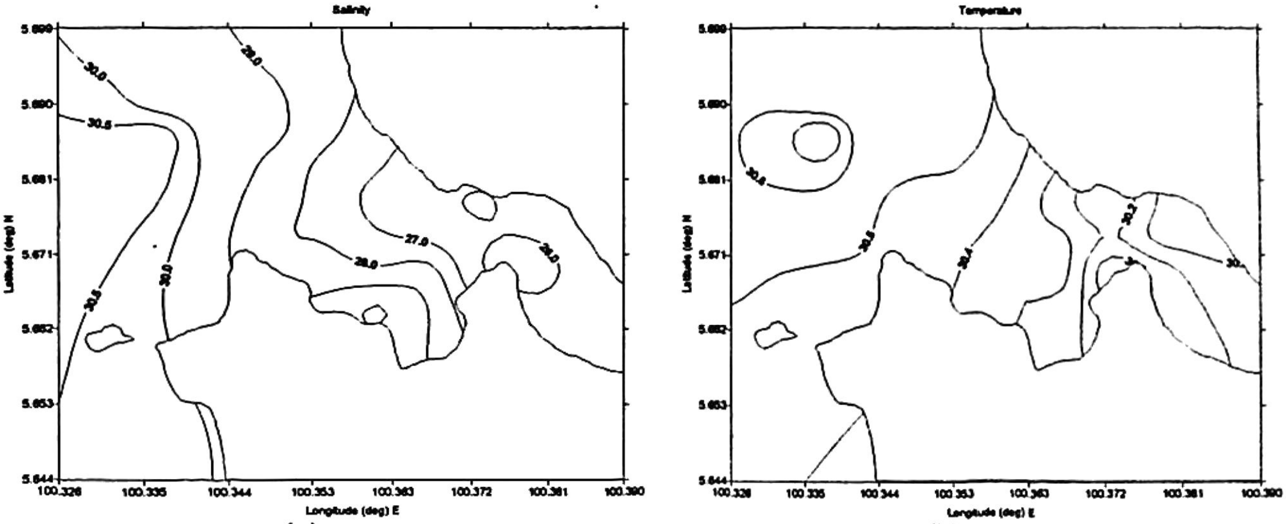
Direct observations in the study area during surveys seem to be dominating the wind speed variability with very low intensity during daytime and high intensity in nigh. All of the surveys of this study were conducted during the daytime. Although wind forcing was observed, there was no corresponding change in characteristics of the estuary, because of this low intensity. This suggests that wind forcing was not large enough to significantly influence the bottom shear stresses and the resuspension of bottom sediments in the estuary. The lack of correlation between winds and salinity, temperature, density, TSS and Secchi depth record of brackish water pattern also suggests that winds do not have a significant affect on the axial position of physical factors of the estuary.

5.5.5 Monsoon variability and atmospheric temperature

The study area is located in the Malaysia Peninsular where the climate is governed by tropical monsoons-steady winds that blow alternately from the northeast (NE) and the southwest (SW), each for about half of the year. The SW monsoon begins in late May and continues until September. The NE monsoon is from November to March. April and October are transitional periods with unstable wind speed and direction. This tropical monsoonal pattern is sensitive to a variety of environmental change and would influence the physical characteristics in estuary and coastal zone. However, unlike any places in West Malaysia, the catchment area of Merbok River that located in the north experience a rather different monsoonal effect compared with the east coast and other west coast region. It is due to sheltering effect of the central mountain ranges running from north to south in Peninsular Malaysia and Sumatera Island (Ismail, 1992). The means rainfall for NE monsoon was lower than the SW monsoon.

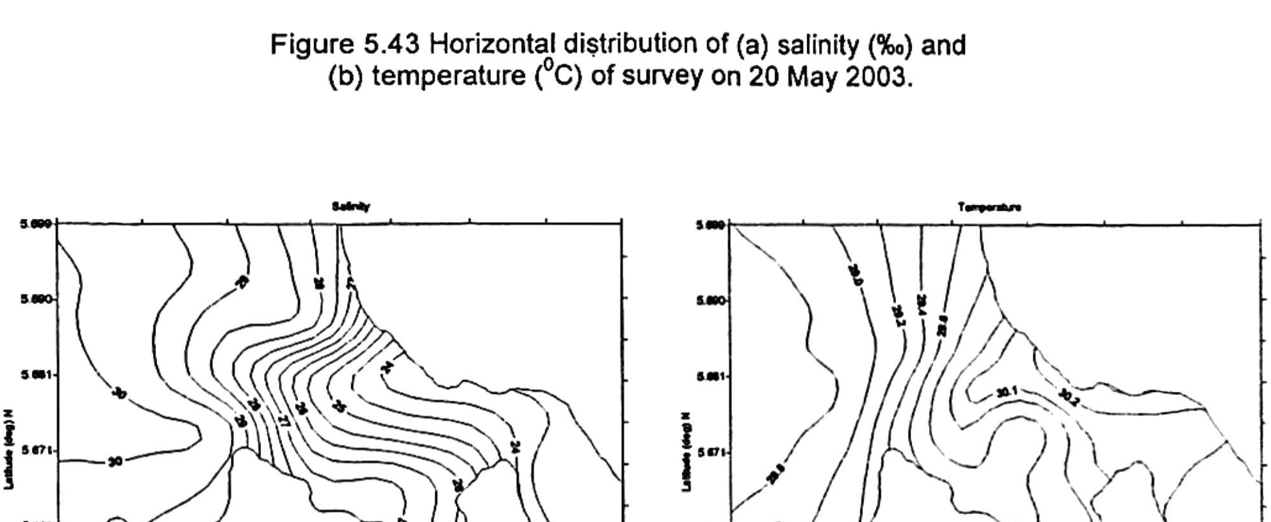
Salinity and temperature of water are the two prime physical quantities that must always be determined in coastal and estuarine investigations. Because of the salinity difference between ocean water and freshwater, it proved to be the best indicator of plume waters. During field surveys in NE monsoon period, on 20 May 2003 (Figure 5.43), salinity decrease throughout the lower estuary. This lower salinity value was caused by wet season characterized by higher rainfall, coinciding with the NE monsoon. During this season, the river basin received greater amounts of rainfall than the long term average corresponding to the rainy season. The temperatures recorded were above long-term average temperatures. The study area, in general, also recorded higher than average amounts of solar radiation and higher than average rates of evaporation during the month.

Survey during inter-monsoon period, on 26 October 2002 (Figure 5.44), salinity increased gradually from about 24.0 ‰ inside the lower estuary to about 30.3 ‰ at coastal zone, while temperature decreased gradually with almost the same patterns with salinity from 30.0 to 28.8 °C (Figure 5.44b). This fact was strongly influenced the wettest month, coinciding with the inter-monsoon period. October was the wettest month of the year. The obvious difference of salinity and temperature indicate the episodic nature of the rainfall pattern. During this period the winds were light, hot and



(a) (b)

Figure 5.43 Horizontal distribution of (a) salinity (‰) and (b) temperature (°C) of survey on 20 May 2003.



(a) (b)

Figure 5.44 Horizontal distribution of (a) salinity (‰) and (b) temperature (°C) of survey on 26 October 2002.

humid, and there was little seasonal variation in temperature. The results are nearly consistent well with the other studies of monsoonal influence to the plume water by Ilahude *et al.* (2004) and Jilan (2004).

Compared to the salinity values for both cases, the variation of salinities for wet season were smaller than wettest season. But, the weather condition revealed the recorded temperature was generally higher than the long-term averages. Solar radiation varied from below average to above average and evaporation rates were generally near average (www.kjc.gov.my). Overall, distribution of surface salinity obtained exhibited consistent salinity levels and features in lower Merbok Estuary, a low salinity field in the middle and northern region of the lower estuary that increased seaward into the coastal zone where the Merbok River waters influenced the field.

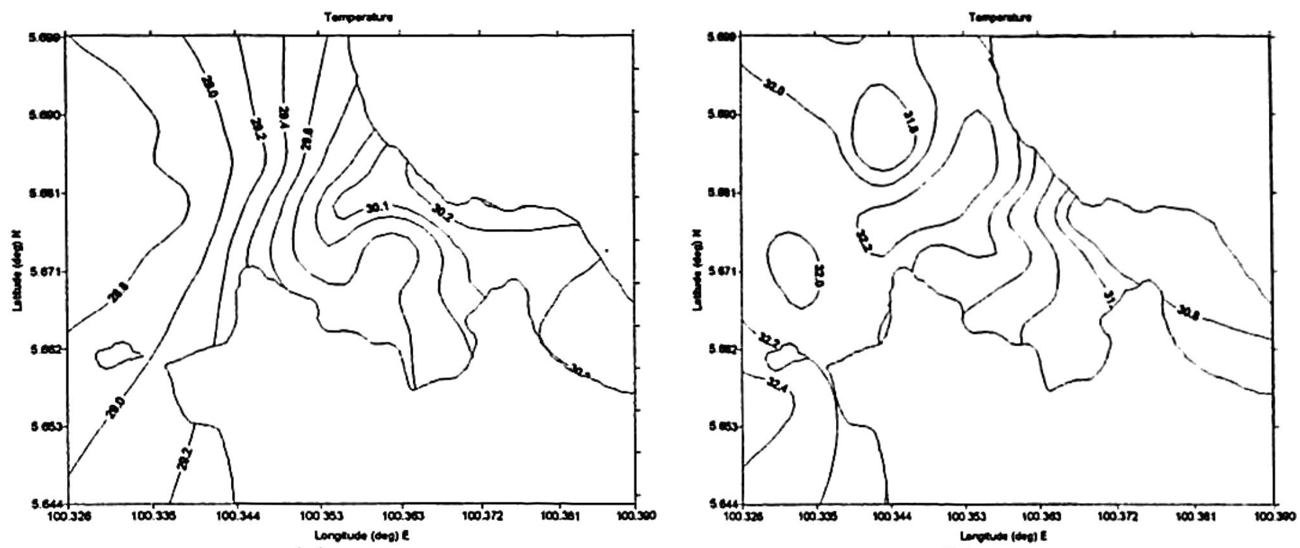
Generally, the Merbok River strongly influenced by the monsoonal climate. It representing the variation of monsoonal zones shows that the morphodynamics at the coastal and estuary conditions are closely dependent on the local climatic conditions and associated environmental features. The rainfall characteristics of the basin have two peaked distributions. First, it was in April and May, and second was in October and November. The minimum rainfall was occurred in January (Figure 3.19 and 3.20, in sub section 3.4.2). The rainfall levels were reflected in the river discharge on the basin. The influence of freshwater discharge disturbs the hydrography and circulation of these waters. In both NE and SW monsoon seasons, the winds are predominantly light and steady. During the transitional periods winds are light and more variable as a result of local land and sea breezes, which are then influential. The effect of Coriolis is negligible and less important than the monsoon driven flow influence in the study area.

Monitoring of atmospheric temperature different, temporal and spatial distribution of the estuary and sea surface temperature can be extremely valuable for observation of oceanography applications. The atmospheric thermal cycle is responsible for the temperature differences, especially in the sea surface. Despite the strong vertical stratification induced by salinity on the density field, the temperature distribution in the estuary remains almost vertically homogeneous. Probably the waters of the mixed layer due to mixing process of sea and freshwater at the lower estuary reach a thermal equilibrium with the atmosphere before flowing upstream underneath the estuarine waters. This mixing process, partly driven by global radiation and winds, alters the energy transfer process in the uppermost layer of the water bodies, and can explain in this case higher variation of the surface water temperature. The transitional periods (cooling and warming phases) were expected to present a horizontal thermal contrast between estuarine and coastal waters, induced by the different thermal inertia between both regimes, and consequently a thermocline at the estuary should be expected.

Local mixing of the upper ocean is predominantly forced from the state of the atmospheric temperature directly above it. The variations of atmospheric temperatures (maximum and minimum) during the month of surveys are shown in Figure B-28 (in Appendix B). The daily cycle of heating and cooling, wind, rain, and changes in temperature associated with weather features produce a hierarchy of physical processes that act and interact to stir the surface water.

Related to the monsoonal effect, it was observed in both inter-monsoon cases in April and October. The observed temperature was lower at survey on 26 October 2002 (Figure 5.45a), there has an associated atmospheric temperature of 25.0 - 31.0 ^{0}C, which corresponds well not only with the observed temperature (28.8 - 30.3 ^{0}C) at the field, but also with cold and the wettest season during this survey. It was related to the SW to NE inter-monsoonal period. In tropical monsoonal area, the monthly temperature is influence cumulatively to the estuary and coastal water. Climatological changes and atmospheric temperature condition led to surface warming at surface water in this region.

However, the temperatures increased following the climate shift in the study area, while observed of sea water temperatures also increase. It can be seen at survey on 10 April 2003, with obtained higher temperature of 30.7 - 32.5 ^{0}C (Figure 5.45b). It has a significant influence on regional climatic conditions. That was related to NE to SW inter-monsoonal effect, after warmer and drier period. This temperature apparently sensitive in upper layer, and their changes would be apparently dictated by variations in atmospheric temperature by the natural wandering of the climate system.



(a) (b)

Figure 5.45 Horizontal distribution of temperature (^{0}C) of survey on (a) 26 October 2002 and (b) 10 April 2003.

In general, the principal factors controlling estuarine water temperatures are energy-transfer processes. These processes include radiation inputs (atmospheric temperature), convection/advection (vertical and horizontal mixing), evaporation, and mixing of water of different temperature. In the matter of monsoonal influences, temperature in the estuary and coastal waters from surface down to the bottom has relatively stronger different in inter-monsoon period.

The temperature is lower in SW-NE inter-monsoon period and is higher in NE-SW inter-monsoon period. The analyses of this temperature pattern changes demonstrated the essential influences of atmospheric temperature on temporal distributions of temperature in the study area. It is revealed that the tropical monsoonal effect represent a natural factor causing the renewal temperature of the estuary and coastal waters. The atmospheric temperature in the study area is remarkably uniformed with small variations due to elevation and seasonal and maritime influences. Temperature is relatively high except during the end of NE monsoon when winds from Central Asia bring somewhat cooler air. Then the temperature gradually rises up until April when, under the influence of light southerly winds, the weather becomes very hot. This high temperature last until SW monsoon commences in May.

5.5.5 Water masses

In order to describe oceanographic mixing processes, it is important to define water types that have extreme water properties and that mix together to create the observed temperature and salinity properties in study area (the water masses). Water types in the Merbok River and adjacent ocean waters were defined as seawater and brackish estuary plume water. To identify particular water masses were obtained from T-S diagrams plot, similar with Matsuno *et al.* (1999), Soares and Moller Jr (2001), and Omsteadt and Axell (2003). However, in coastal waters, water mixing is very strong and complicated, therefore the T-S diagram includes many kinds of water masses and mixtures. Omsteadt and Axell (2003) divided the water masses in three parts: the surface water, with varying temperatures and only small variations in salinity; the halocline water, with small variations in temperature and salinity; the deepwater with small variations in temperature but with large variations in salinity. The T-S diagrams for each survey is presented in Figure B-29 (in Appendix B) illustrate many of the features of the hydrography of the study area. Seasonal variations of freshwater contributions to seawater are indicted in these diagrams. Two distinct water masses were identified: seawater and brackish water, although some of the diagrams were not so clear.

Based on an examination of the T-S properties, it was found that the patterns which revealed that differed primarily in salinity and temperature resulted by different season, that conforming the characteristic of tropical monsoonal effect. The pattern analysis water masses based on T-S properties identified two major patterns. From these two T-S patterns, there were two different characterized of seawater. First, the sea water warmer than estuary water and another seawater cooler than estuary water. In wet and cold season, the estuary plume spread over the coastal near the estuary and the scatter plot show descend pattern, survey on 26 October 2002, 7 and 17 June 2003 (Figure B-29, Appendix B). The values of salinity and temperature were 30.1 - 31.0 ‰ and 30.0 - 30.3 ^{0}C, respectively in the upper layer coastal waters which surrounded the estuary plume. These distributions that characterized by cooler seawater associated with the wet and cold season during NE monsoon and inter-monsoon period.

In the dry and warm season, the estuary plume was near the shoreline of the estuary the distributions show ascend patterns (22 and 23 March, 10 April, 19 and 20 May 2003). It was characterized by warmer seawater than estuarine water. The structures of salinity and temperature show the higher values, in which the maximum salinity and temperature were about 29.8 – 31.0 ‰ and 30.1 - 31.1 ^{0}C, respectively. These structures were related to the dry and warm season. In general, both pattern of T-S diagrams show significant relationships and supporting to the previous results in section 5.5.1.

5.5.6 Mixing processes

The Richardson gradient number relates the existent equilibrium across the interface between the buoyancy forces that produce the interface stability, and the characteristic shear (du/dz) that produce mixing due to the energy transfer. This number is represented as equation (3.17) in sub section 3.6.4. In practice the density gradient is difficult to quantify therefore it is often easier to use the Layer Richardson Number (R_L) as equation (3.18) in previous sub section 3.6.4.

Calculation of R_L allows a qualitative estimate to be made of the intensity of mixing at different stage of the tide in a partially mixed estuary. Dyer and News (1986) observations indicate when $R_L < 2$ that bed generated turbulence is the main mixing process, and for $R_L > 20$, the water column is stable, and bottom turbulence is not effective in mixing. The vertical density gradient will affect the turbulence characteristics in the same way that salinity or temperature would, and be expressible in terms of a gradient Richardson number (Dyer, 2004).

At the lower Merbok Estuary, a characteristics RMS current speed of 0.2 m/s at neaps and 0.7 m/s at springs is adopted from previous studies at the same area by Uncles *et al.*, (1990). This current speed was measured at five depths using calibrated current vanes in the lower Merbok Estuary (Figure 5.46). Then, this value is used as depth mean velocity in equation 5.3, with the constant value of g (9.80665 ms^{-2}). The R_L value for each station along the lower estuary in various field surveys are presented Table 5.2-5.5.

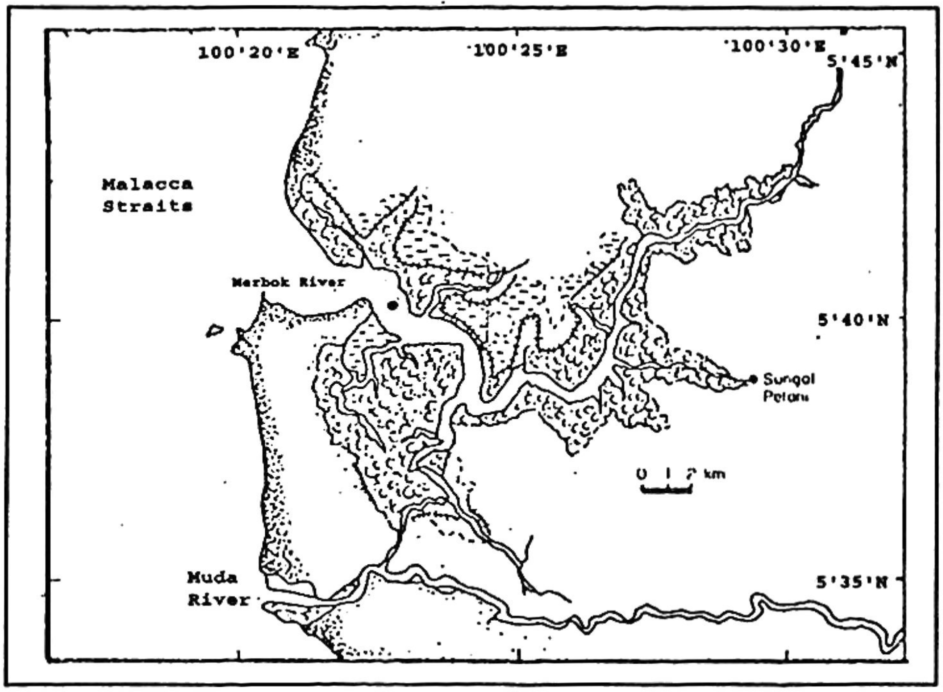


Figure 5.46 Location map (▪) showing the current speed measurement in the lower Merbok Estuary (from Uncles *et al.*, 1990).

Table 5.2 The R_L values for survey on 23 March 2003.

No.	*Tide Condition*	*Station*			*R_L Value*
		Number	Depth (m)	Distance (km)	
1.	Spring	1	9.8	1.27	2.740
2.		2	5.8	1.82	7.796
3.		3	5.4	2.42	1.715
4.		4	6.7	3.13	3.497
5.		5	3.3	3.80	0.922
6.		6	1.7	4.34	0.271

Table 5.3 The R_L values for survey on 19 May 2003.

No.	*Tide Condition*	*Station*			*R_L Value*
		Number	Depth (m)	Distance (km)	
1.	Spring	1	8.3	1.14	17.904
2.		2	6.7	1.54	11.309
3.		3	4.3	1.99	6.893
4.		4	4.8	2.42	8.167
5.		5	6.2	2.84	13.793
6.		6	6.3	3.41	16.447
7.		7	5.7	3.97	17.404
8.		8	4.8	4.40	13.561
9.		9	4.3	4.86	8.658
10.		10	3.7	5.42	8.406
11.		11	3.4	5.99	7.021
12.		12	3.3	6.68	5.647

Table 5.4 The R_L values for survey on 20 May 2003.

No.	*Tide Condition*	*Station*			*R_L Value*
		Number	Depth (m)	Distance (km)	
1.	Spring	2	8.3	1.51	27.530
2.		3	6.8	1.79	22.931
3.		5	8.8	2.14	27.112
4.		8	7.4	2.62	18.712
5.		14	6.2	3.11	18.088
6.		16	5.3	3.57	14.950
7.		22	2.8	4.29	5.368
8.		23	0.9	4.78	0.346
9.		24	0.9	4.44	0.834
10.		25	0.8	5.99	0.674

Table 5.5 The R_L values for survey on 7 June 2003.

No.	*Tide Condition*	*Station*			*R_L Value*
		Number	Depth (m)	Distance (km)	
1.	Neap	1	1.9	1.24	19.036
2.		2	5.3	1.39	165.031
3.		4	1.8	2.00	26.282
4.		5	8.3	2.18	342.409
5.		8	5.4	2.63	146.560
6.		14	1.9	3.72	32.064
7.		15	5.3	3.80	159.226
8.		21	1.9	5.51	21.951
9.		22	1.9	6.02	13.037
10.		23	2.2	6.14	30.271

Figures 5.47 - 5.50 shows the variation of the layer Richardson number R_L along the lower estuary to the river mouth. The results show clear visual of turbulence characteristics in two groups. First, spring tide pattern, with strong current led to increased turbulence and mixing processes. In this condition, the vales of R_L (Figure 5.47 - 5.49) reach a minimum for springs, with the value generally $R_L < 20$. This may have been due partly to a decrease in locally-generated turbulence, and partly to advection of more stratified water from river discharge. Secondly, neap tide pattern showed the value of $R_L > 20$ (Figure 5.50). This was shows the more stratified condition, and bottom turbulence was not effective in mixing. This result was in accordance with observation made by MacKay and Schumann (1990) in Sundays River Estuary.

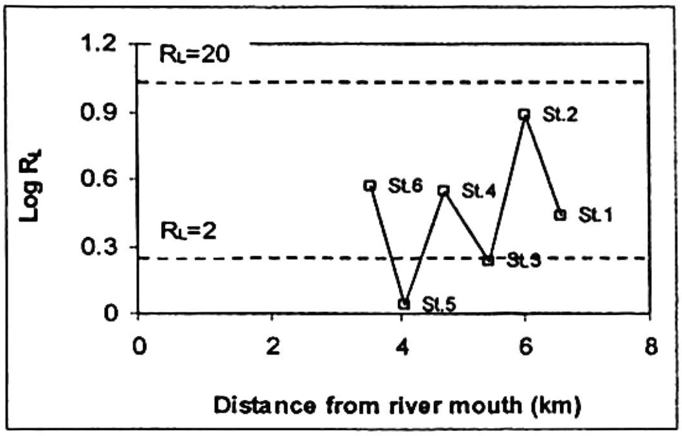


Figure 5.47 Variation of the layer Richardson number, R_L, in 23 March 2003 (spring tide).

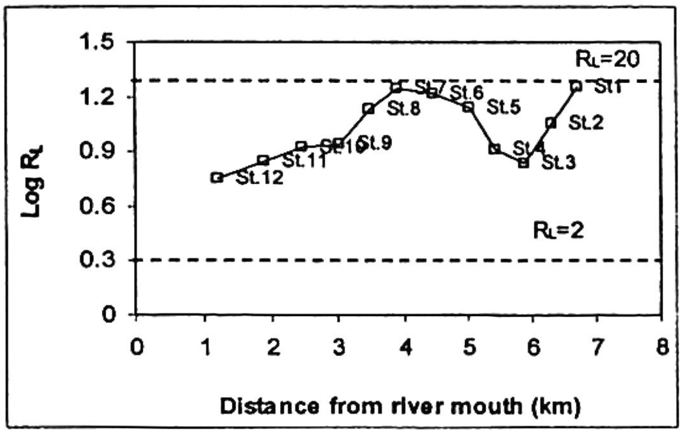


Figure 5.48 Variation of the layer Richardson number, R_L, in 19 May 2003 (spring tide).

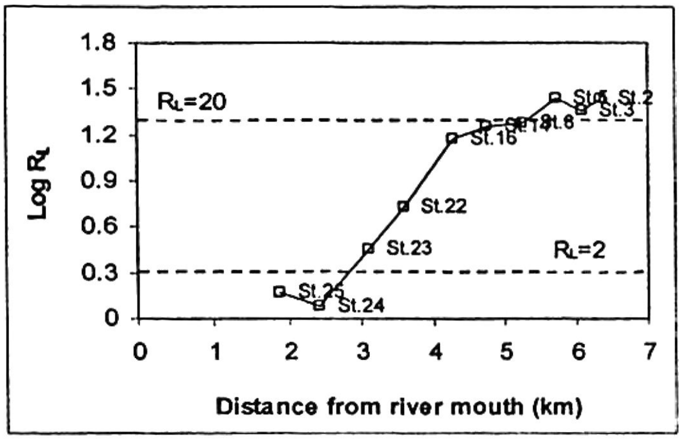


Figure 5.49 Variation of the layer Richardson number, R_L, in 20 May 2003 (spring tide).

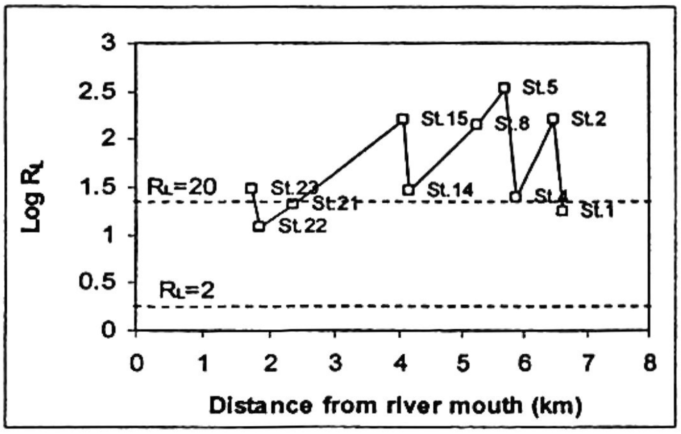


Figure 5.50 Variation of the layer Richardson number, R_L, in 7 June 2003 (neap tide).

The mixing process plays an essential role in both the tidal circulation and the salinity distribution. It is important to know both the dependence of turbulent mixing on stratification and under what circumstances other processes may be responsible for momentum exchange. In case of vertical mixing process and vertical tidal salt transport transfer momentum and salt without a net movement of water. There is a connection between the horizontal and vertical salt transport in an estuary. Water enters the estuary along the bottom (because of the baroclinic pressure gradient), is entrained into the surface layer, and is carried out of the estuary, diluted by river runoff. There will be substantial horizontal and vertical advective salt transports, both driven by the mean circulation. The results observation suggests that both horizontal and vertical salt transport in the Merbok River Estuary should be dominated by tidal processes rather than the river discharge processes. The increase in tidal range on a spring tide that accompanies the increase in vertical mixing decreases the stratification. Decreasing tidal ranges decrease vertical mixing and increase stratification.

5.5.7 Aerial surveys

Two sets of aerial digital images were obtained from the study area. The first set was taken on 09 March 2002, and the second was taken on 23 March 2003, with different tide condition (Figure 5.51). Figure 5.53 and Figure 5.55 present a sequence of airborne images of a front which regularly forms off of lower estuary, until the outer side of the estuary mouth. The two dimensional morphology of surface water can clearly be seen in the aerial digital images. Both figures were illustrates the distribution and pattern of brackish water in lower Merbok Estuary. Examination of a number of airborne images showed that the area of the highly turbid zone varies significantly and appears to be strongly related to spring-neap tidal cycles. Observation of the plume water in Moriches shallow bay, south of Long Island New York by using the analysis of aerial photograph was also used by Conley (1999). Observations of estuary plumes which occur on the continental shelf from ebb tidal flow through inlets show a thin estuarine layer advecting over a denser oceanic layer with a thicker roller region at the leading edge of the estuarine plume. The roller is a location of strong convergence where most of the entrainment is assumed to take place. Tidal exchange through inlets is the mechanism through which saline ocean water is mixed into bays, and the balance between this exchange and any fresh water input determines the estuary plume salinity.

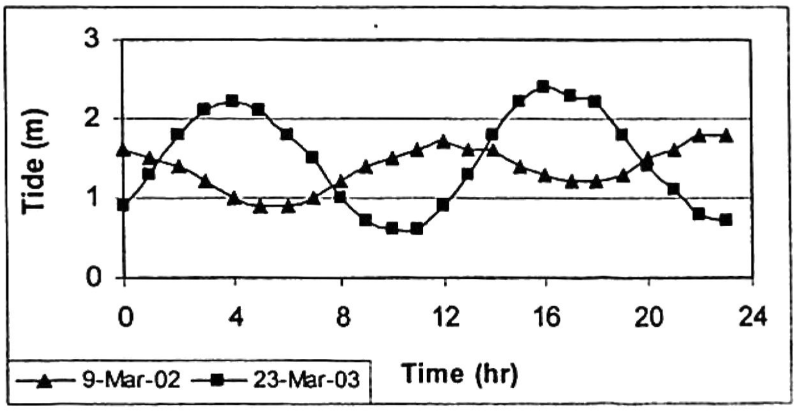


Figure 5.51 Tide condition in both flight surveys on 9 March 2002 (neap tide) and 23 March 2003 (spring tide).

First, the sequence of approximately occurred during the ebb to flood (spring tide) portion of the semidiurnal tidal cycle on 23 March 2003 (Figure 5.53). Figure 5.52 shows the average coverage area of segmentation from this period. During this period, the dominant wind over the study area was north-western of relatively weak wind, with mean speed of 2.2 m/s (maximum speed of 6.1 m/s). Two salient features of this development are the sharp bend near southern coast in outer side and inside the lower estuary, and the bulge which forms initially near the Pantai Merdeka at central region, and subsequently expands following the shape of coast. During this time, the plume was constrained relatively close to the coast (Figure 5.53c) moving north and was distinctly visible at least as far north as outer side of the estuary. After reaching the coastal area, the leading edge of the plume was still quite distinct, with highly coloured plume water. This brackish plume water was caused by freshwater discharge that characterized by rain falling of 24.4 mm a day before survey over the catchment area. The overall scenery shows the less turbid water (bright areas) meet the more turbid water (darker areas) in the estuary, while the patchy structure indicates intense mixing area. The arrows in images indicate the apparent surface flow. By similar method of aerial image interpretation observed by Arnau *et al.* (2004), estuary plume-dispersion patterns near the estuary mouth can be now observed with unprecedented resolution in the northwestern Mediterranean. In the Gulf of Lions, estuary plumes usually expand over a wide continental shelf at a relatively short distance from the coast. Due to the low density of fluvial discharge, sediment-laden plumes can deviate toward the shoreline, where they can accumulate as lenses of relatively low-salinity water.

From the contrast in colors it appears the flowing of the brackish plume water in the lower estuary seaward. Plume frontal boundaries were clearly visible in the images near the northern end of the estuary mouth, inner side, and in the south arm of the estuary. The sandbar in the middle of estuary was cusped on the Pantai Merdeka arm in south and north side, giving the impression that this section was accumulating sediment (Figure 5.53a and 5.53d, circle sign). Combined with filed survey of TSS data, it was assessed and the pattern of orientation of the estuary plume (insert image in Figure 5.53). The field data show the TSS concentrations of plume water in some small part of the study has nearly pattern with the digital images data.

The distribution of estuary plume that was observed in the lower estuary and adjacent coastal water that show in the field surveys can not observed clearly in digital images. It was due to the lower estuary was relatively wide compare to the Muda and Prai Estuary. However the digital images give significant features of some small part of the study area. This exemplifies the plume waters and identifies the complex problem of bigger scale of estuary plume dynamics. This result showed the limitation of digital image that could be suitable in observation of small scale estuary plume.

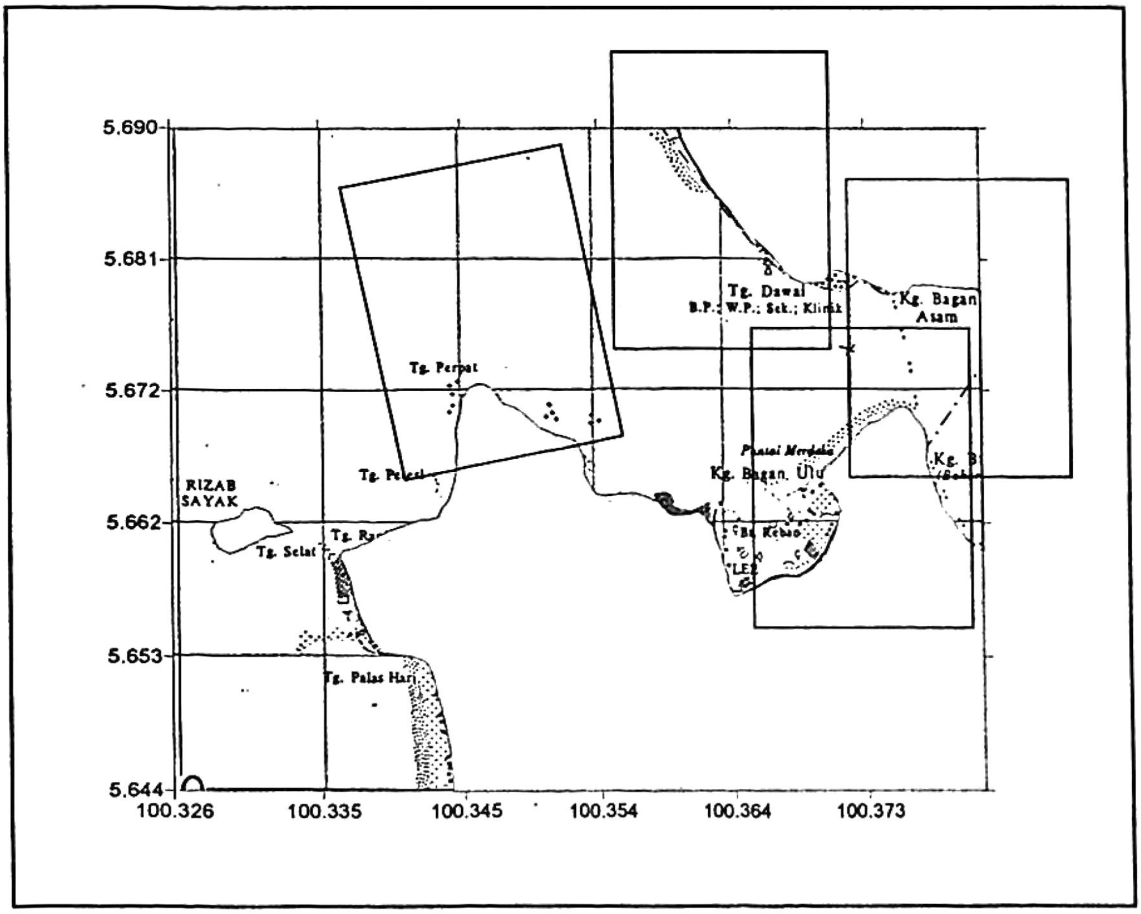
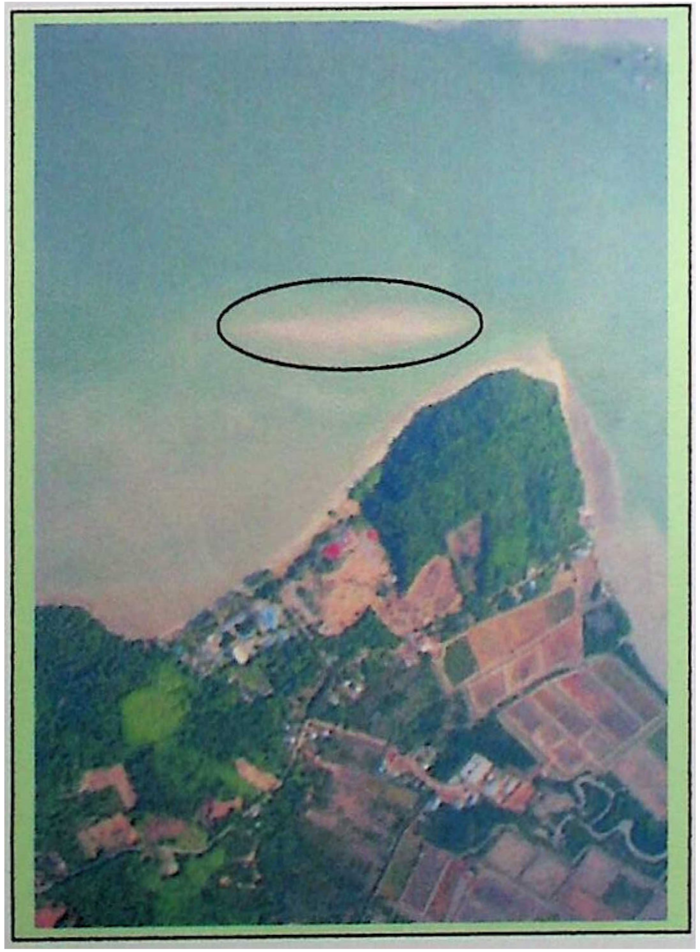
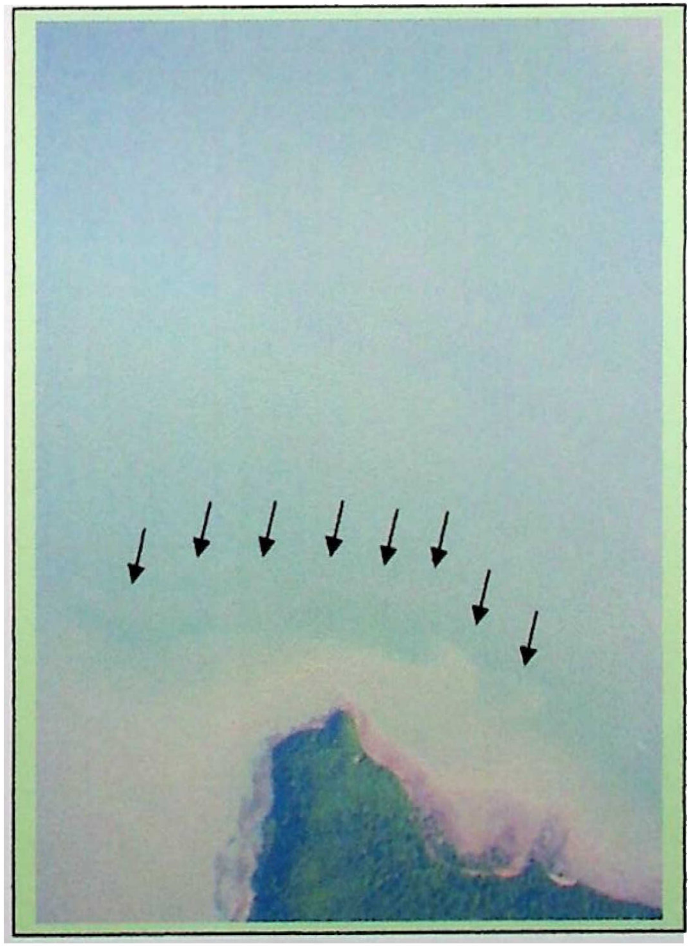


Figure 5.52 Approximate coverage area of segmentations captured on 23 March 2003 (spring tide).

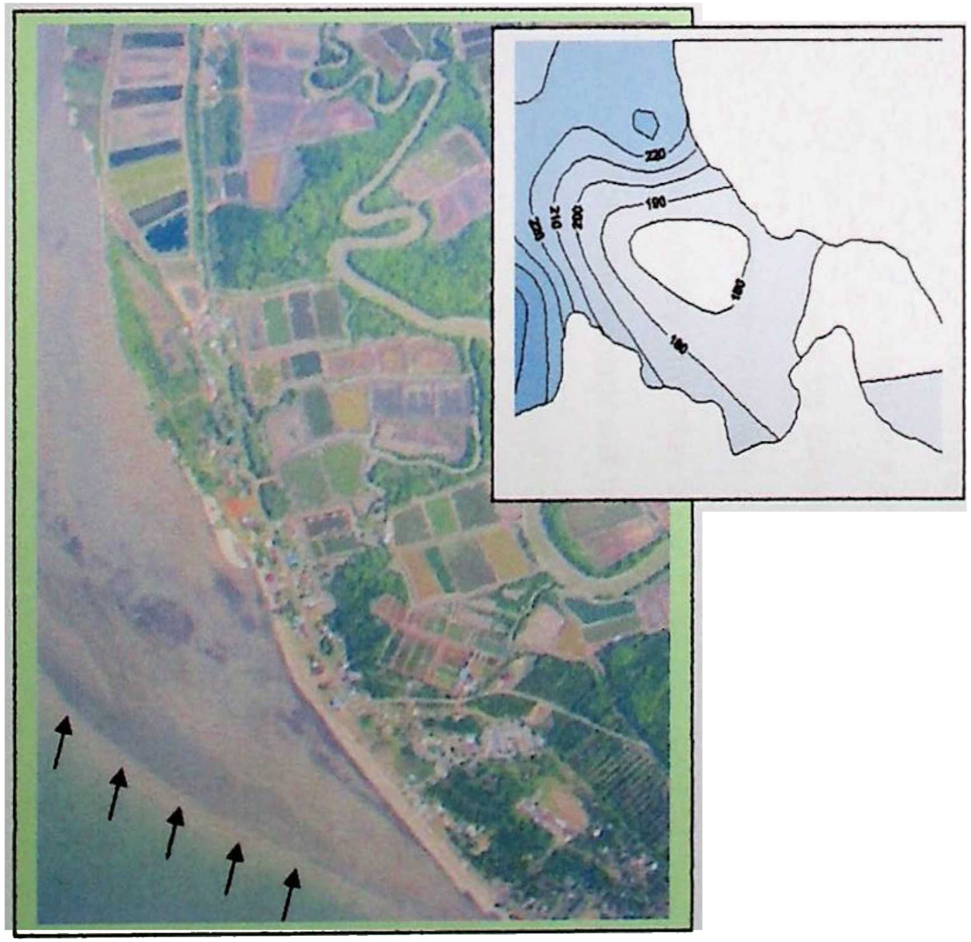


(a)

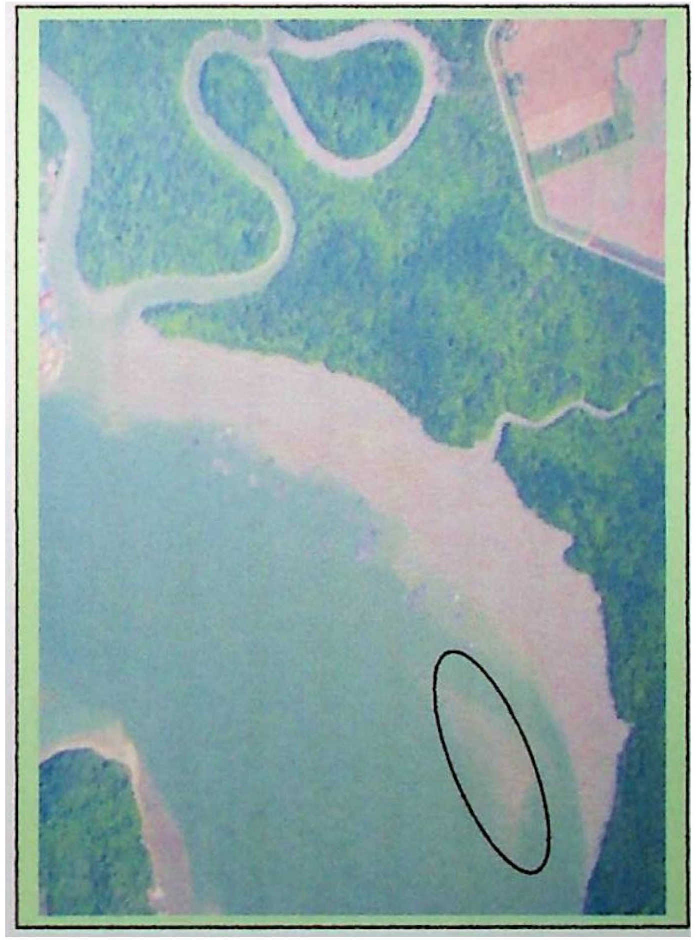


(b)

Figure 5.53 (*continued next page*).



(c)



(d)

Figure 5.53 Sequence of digital images over the lower Merbok Estuary captured on 23 March 2003, and the filed survey of TSS in similar date (insert image).

A second sequence containing surface brackish water evolution is presented in Figure 5.55, with the approximate coverage area of segmentation show in Figure 5.54. This sequence occurred during the slack of the tidal cycle (neap tide) on 09 March 2002. During the period of low discharge and no rains falling over the study area, the dominant wind over the study area was north-eastern of moderate strength wind, with mean speed of 2.5 m/s (maximum speed of 8.9 m/s). For clarity, line segments are shown, with each segment indicates the position and shape of the front as determined by a particular airborne image in the sequence. Plumes were readily observable as darker turbid water masses contrasting with cleaner seawater. A bulge of plume water can be observed near the southern coast, in the middle of mouth (Figure 5.55a, b, c). The arrows in the images indicate the apparent surface flow. This structure was emphasized by delineating it with a distinct line (or color). As is generally observed, the morphology is oriented in a way that leaves the bulge always pointing toward the less dense plume water. By following the trajectory of this feature, it may estimate that the bulge appears to originate over a region with steep and deep bottom topography. While bathymetry may play a role in the generation of these features, this identifying a generation mechanism will be one of important factors that affected the plume water. Using the similar field survey and supported by image interpretation by Black *et al.* (2004), in relation to land sources of sediment, the nearby Ashtamudi Estuary, India appears to be providing no significant quantities of sediment, even though the delta may be responsible for the rotated coastline to the south. The entrance to the estuary is presently filled with sediments which appear to come from the open coast, not from the rivers draining into the estuary.

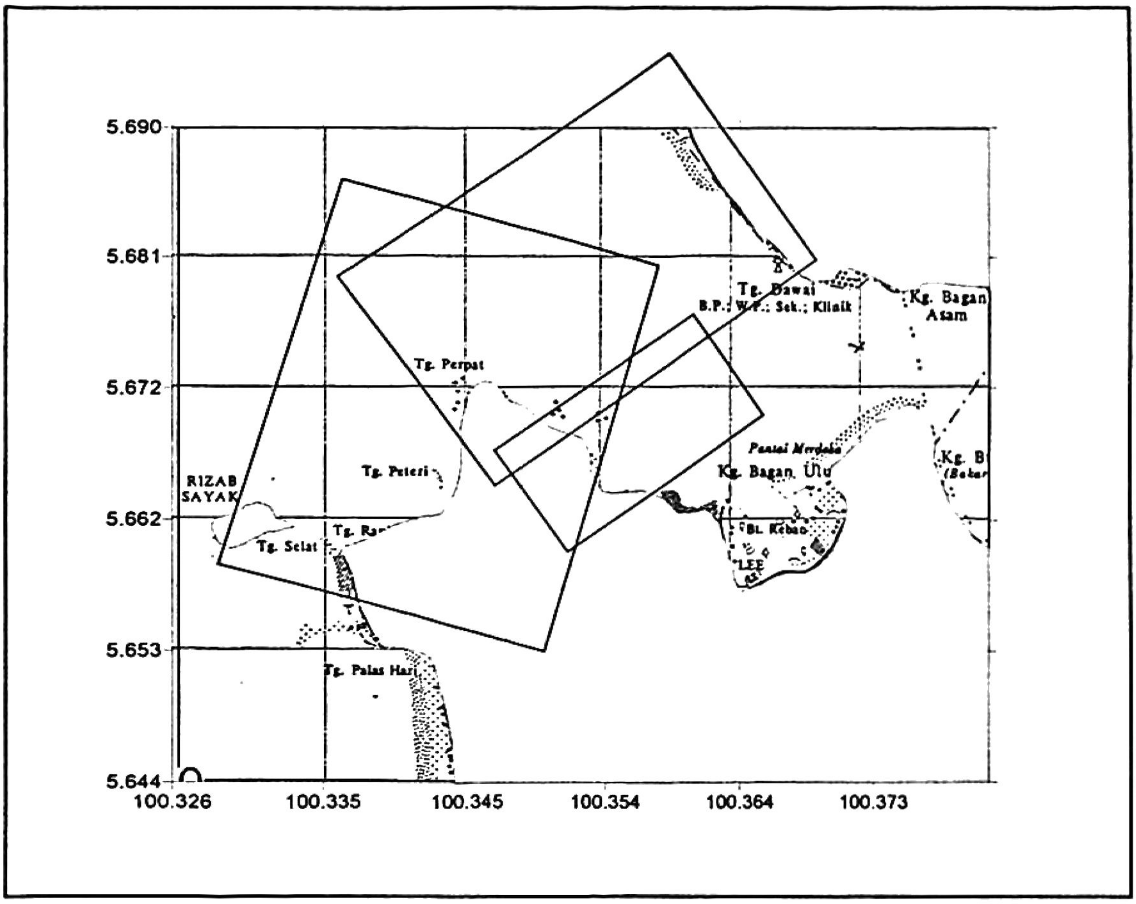
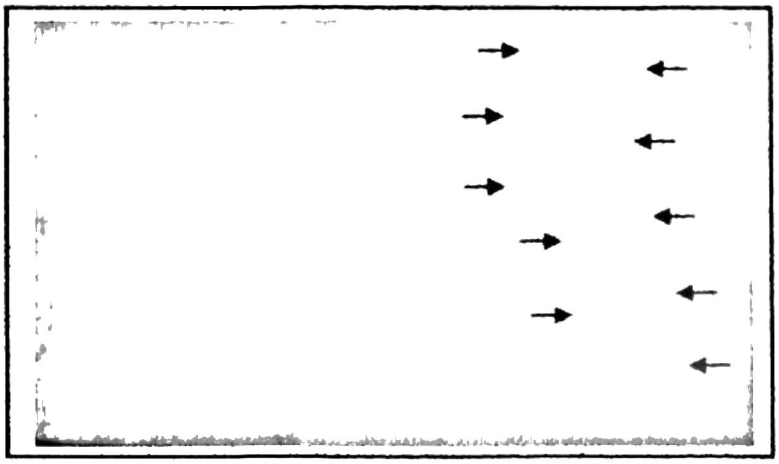
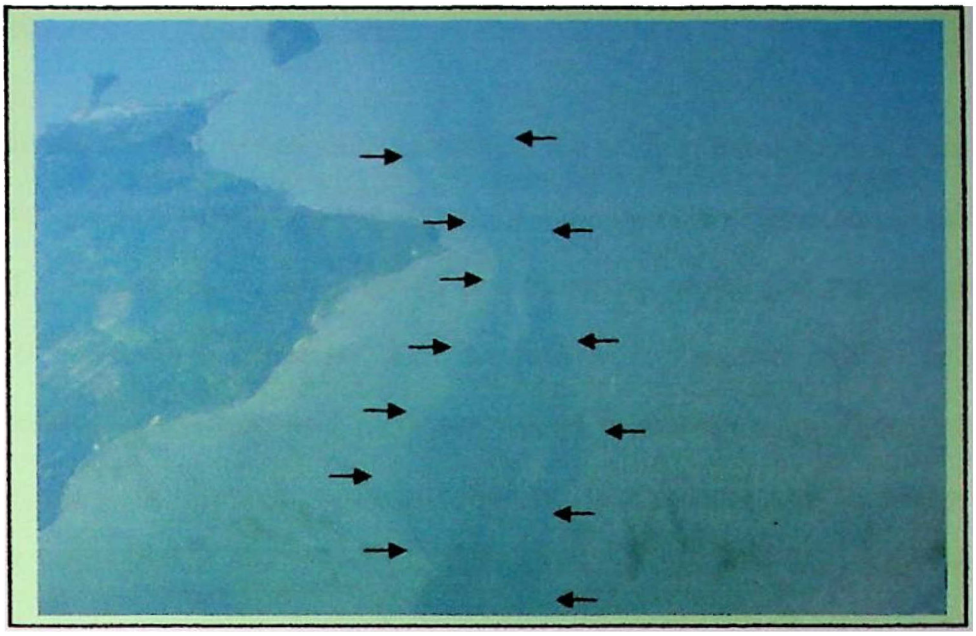


Figure 5.54 Approximate coverage area of segmentations captured on 09 March 2002 (neap tide).



(a)

Figure 5.55 (*continued next page*).



(b)

(c)

Figure 5.55 Sequence of digital images over the lower Merbok Estuary captured on 09 March 2002.

5.6 Summary of field surveys

The following section presents the results of the study in lower Merbok Estuary. Table 5.7 shows a summary of characteristics for the parameters measured in each survey, including tidal condition, wind speed and direction, rainfall and number of stations. Table 5.8 presents a summary of data measured in the lower Merbok Estuary. The table provides maximum and minimum values of salinity, temperature and density. Concentrations of water turbidity parameters, Secchi depth and TSS were collected and later analysed in the laboratory. These Secchi depth and TSS data were always collected from the same stations with the salinity and temperature data for each survey. Contour maps and cross sections of salinity, temperature, and density, contour of TSS and Secchi depth, including the survey stations are presented and reported, for each month in the Appendix B.

Table 5.6 Details of meteorological data to lower Merbok Estuary during study period.

No.	Date dd/mm/yy	Tide	Tidal ranges (m)	Wind*			Rainfall** (mm)
				Speed (m/s)		*Direction (deg)*	
				mean	*max*		
1.	26/10/02	Neap (flood)	1.7	1.7	8.2	NW (290)	16.6
2.	22/03/03	Spring (flood)	2.2	2.7	10.4	N (360)	24.4
3.	23/03/03	Spring (ebb)	1.8	2.2	6.1	NNE (30)	1
4.	10/04/03	Neap (ebb)	0.6	2.0	11.4	NE (50)	10.7
5.	19/05/03	Spring (flood)	2.1	2.2	7.4	NW (300)	0
6.	20/05/03	Spring (flood)	1.7	2.3	7.9	NW (300)	0
7	07/06/03	Neap (ebb)	1.2	2.4	9.7	W (270)	0
8	17/06/03	Spring (flood)	2.1	2.3	10.7	SSW(190)	0.1

Notes: * Base on observation at Butterworth meteorological station.
** Total rainfall in mm received on survey date, based on observation at Sungai Petani meteorological station

Table 5.7 Data measured (date ordered) on the lower Merbok Estuary during study period.

No.	Date dd/mm/yy	Salinity (‰)		Temperature (^0C)		Density (kgm^{-3})		TSS (mgl^{-1})	Secchi depth (cm)
		min	*max*	*min*	*max*	*min*	*max*		
1.	26/10/02	22.8	30.1	28.8	30.3	13.22	18.28	101-324	40-110
2.	22/03/02	29.4	31	29.7	30.6	17.48	18.65	175-366	10-80
3.	23/03/03	29.3	30.2	29.3	30.1	17.63	18.46	174-262	50-100
4.	10/04/03	24.2	29.8	30.7	32.5	13.35	17.11	120-201	50-120
5.	19/05/03	26	30.7	30	31.1	14.97	18.12	122-247	20-100
6.	20/05/03	25.1	30.9	29.7	30.7	14.41	18.31	112-247	20-100
7	07/06/03	26.5	30.9	29.2	30.1	15.96	18.99	133-189	30-120
8	17/06/03	28.5	31.0	29.1	30.0	16.86	18.87	142-204	20-100

Chapter Six
Prai Surveys

6.0 Introduction

Estuary plumes associated with estuary outflow are characterized by strong horizontal and vertical salinity gradients. The characteristics of surface estuary plume can be defined as regions where a maximum in the horizontal gradient of one or more physical characteristics of the surface water exists. The existence of these surface features, which seem to be ubiquitous in the surface waters, can be caused by a great variety of physical processes like, for example, freshwater discharge from the estuary on the top of the heavier ambient ocean, differential tidal mixing in coastal areas, and variability of wind stress. The movement of estuary plumes into the marine environment is an important part of the physical process that drives productivity in the coastal area. Liu *et al.* (2002) states that the estuary plume is determined by the interplay of the buoyancy of the effluent, the turbulent mixing by tide-dominated coastal flows in the lower part of the water column, and the turbulent mixing by the wind field in the upper part of the water column. The grain-size composition of the river effluent also plays a role in the plume-related sediment transport because it not only determines the total amount of sediment dispersal, but also the temporal and spatial characteristics of the sediment flux associated with the plume.

The estuarine water mass discharge from the river is mixed by diffusion with seawater. This estuarine water mass can be identified when entering the sea because of its different color and composition. The estuary plume eventually disappears into the sea by dilution. In this dilution process, the importance of tidal energies and waves are prominent, since they contribute to mixing and entrainment and control the fate and trajectory of the plume.

The important reasons contribute to determine the importance of studying surface estuary plumes: often their presence reveals regions where two different water masses meet. Moreover, they can contribute to the determination of the environmental equilibrium of coastal region, as they are often linked to an increased concentration of sediments. This surface estuary plumes can also be linked to different phenomena occurring at the sea surface, for example, variations in water salinity, temperature, density, or TSS concentrations.

6.1 River discharge influence

6.1.1 Salinity

The horizontal distribution of salinity in high and low river discharge is shown in Figure 6.5. Survey of high river discharge on 9 April 2003 (Figure 6.1a), the higher salinity value for the coastal region was 30.0 ‰, and a lower salinity (23.0 ‰) was observed close the estuary mouth. The map shows the estuary plume (salinity value of ≤ 30.0 ‰) more offshore about 1 km before being deflected in the NW direction. The pattern showed strong horizontal gradient of salinity, with the strongest closer to the estuary mouth. It was caused by high river discharge that characterized by

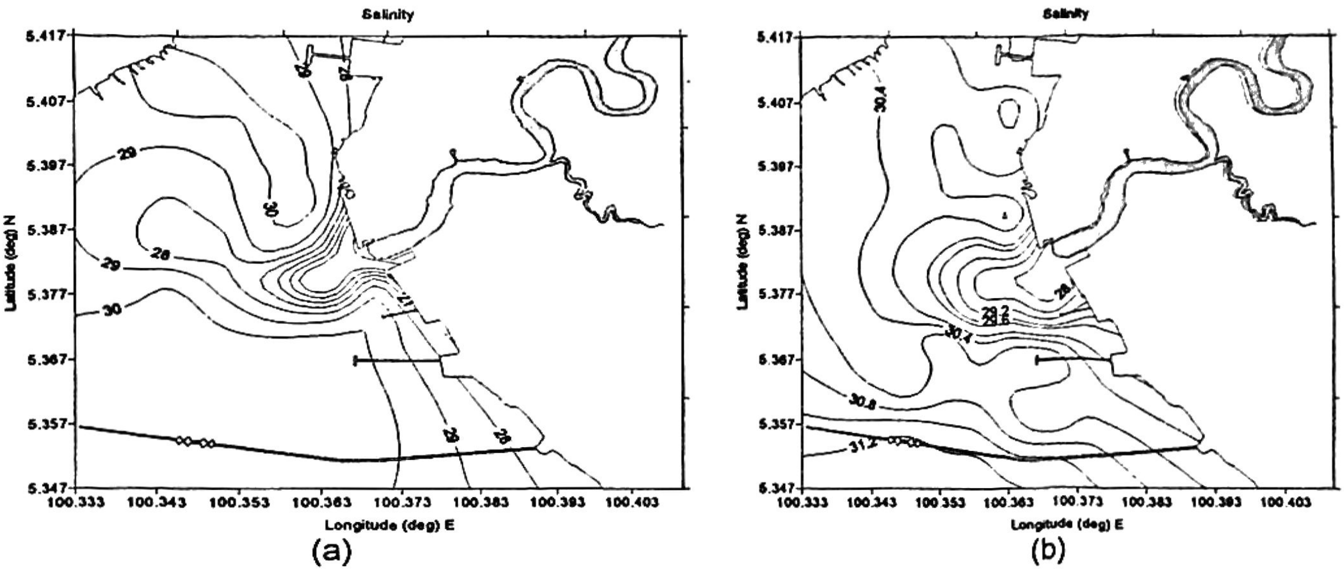


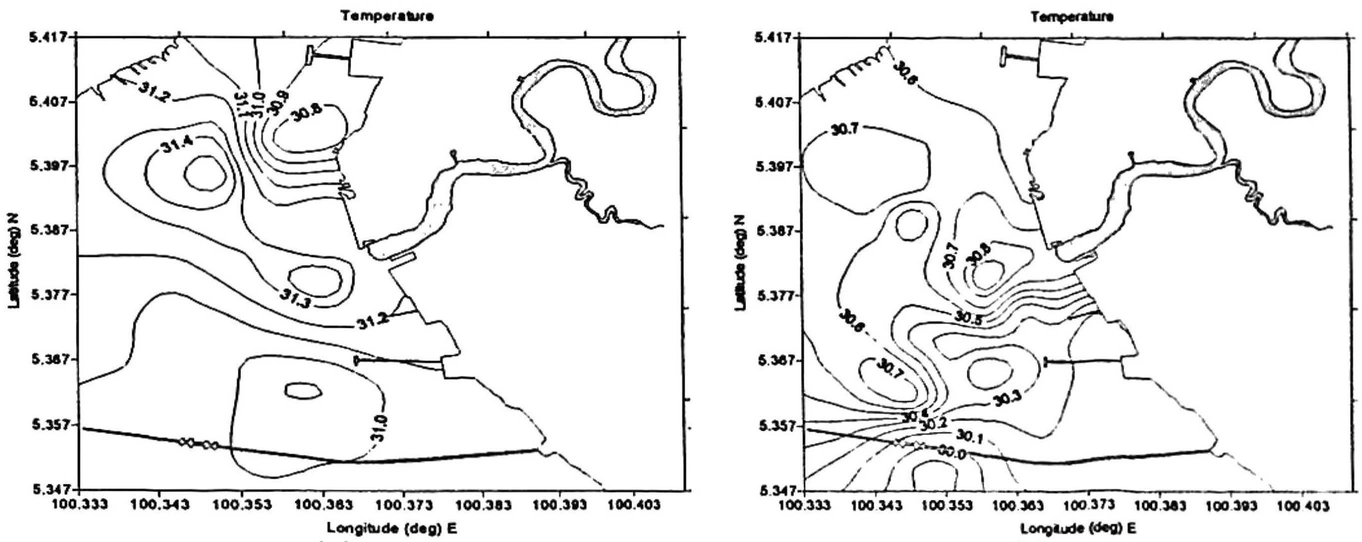
Figure 6.1 Horizontal distributions of surface salinity (‰) during (a) high river discharge survey on 9 April 2003 and (b) low river discharge survey on 14 March 2002.

higher rainfall of about 34.7 mm during this survey and totally about 66.6 mm for four days.

Figure 6.1b shows a distinctly surface salinity distribution in low river discharge condition, survey on 14 March 2002 with estuary plume development in coastal waters. The less saline waters at the estuary mouth and the most saline waters further seaward at the north and south side of the estuary mouth. The influence of estuarine water input was only detected close to the estuary mouth. It can be seen as plume water that detected about 1.5 km in front of the estuary mouth. Further in the coastal region along channel the salinity exceeds 31.0 ‰. The estuary plume was distributed in shorter area due to low river discharge, characterized by no rainfall measured during this survey.

6.1.2 Temperature

On 9 April 2003, under high river discharge condition, the observed sea surface temperature was about 30.8 to 31.3 ^{0}C (Figure 6.2a). The influence of high river discharge from the Prai Estuary on surface temperature was not so clear. Figure 6.2b shows the horizontal distribution of temperature during low river discharge, survey on 14 March 2002. During this survey, the surface temperature was lower than high river discharge, with the value of 30.0 - 30.8 ^{0}C. The warmest water was observed close the estuary mouth and the coolest water further seaward at south channel. This area of plume water showed inversions of temperature due to the presence of warmer, lower salinity estuarine waters related to river discharge. The direct influence of plume water inputs from the estuary was spread in quite limited area near the estuary mouth.



(a) (b)

Figure 6.2 Horizontal distributions of surface temperature (^{0}C) during (a) high river discharge survey on 9 April 2003 and (b) low river discharge survey on 14 March 2002.

6.1.3 Density

The horizontal density distribution derived from the above temperature and salinity data is shown in Figure 6.3. The survey on 9 April 2003 of high discharge condition is shown in Figure 6.3a. The maximum density observed was about 18.0 kgm^{-3} further seaward at southern side of the estuary mouth. The minimum density observed was about 14.0 kgm^{-3} at the estuary mouth. The plume water spread to the entirely survey area then gradually merges into the seawater, that pushed by high river discharge.

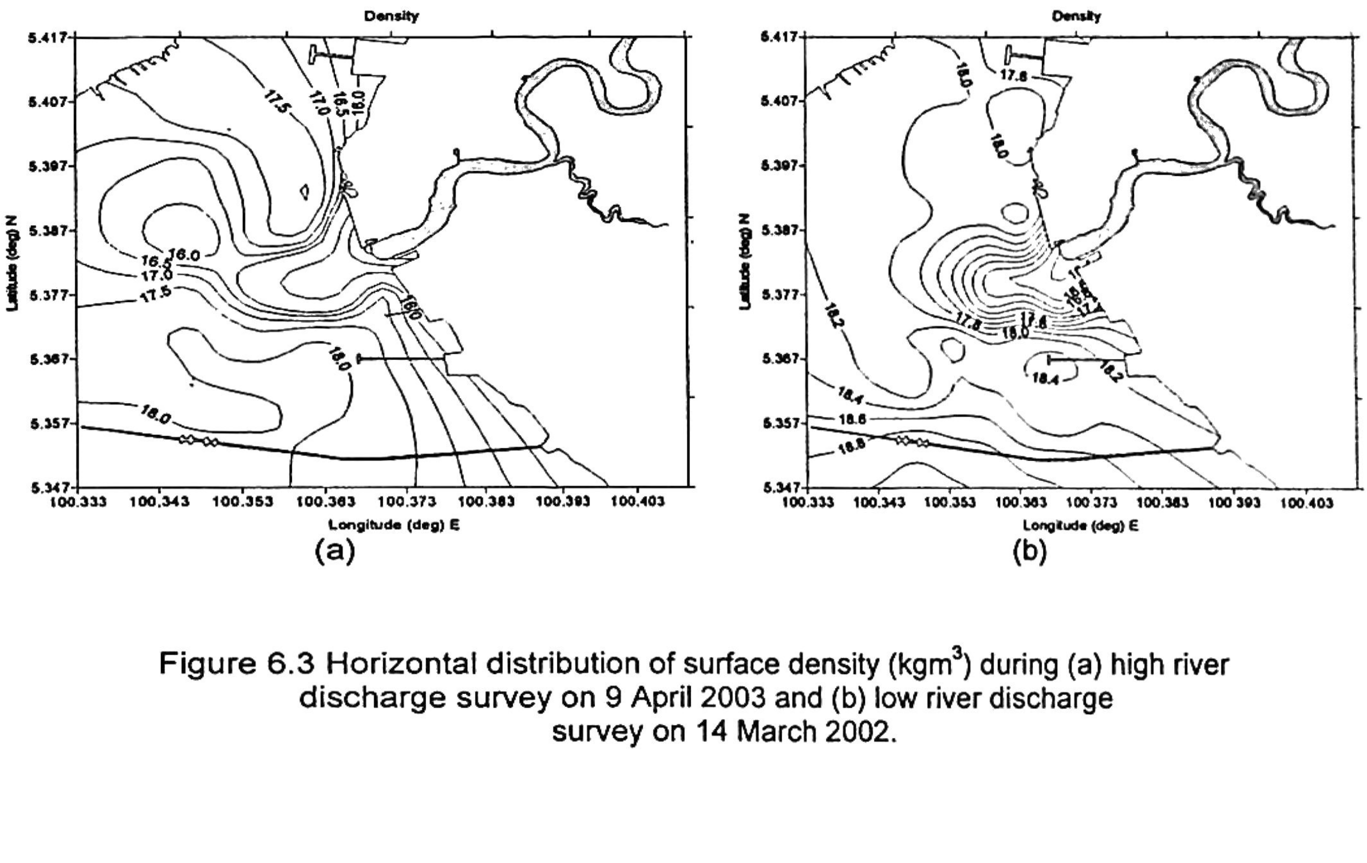


Figure 6.3 Horizontal distribution of surface density (kgm^{3}) during (a) high river discharge survey on 9 April 2003 and (b) low river discharge survey on 14 March 2002.

In low river discharge condition, on 14 March 2002, the horizontal density distribution is shown in Figure 6.3b, with density range from 16.6 to 18.8 kgm^{-3}. The density gradient was smaller than first case, due to lower variations of density plume water and seawater. The pattern of density was similar with high river discharge case, but with higher density value. The surface estuarine water formed between the lower salinity tongue in the estuary mouth and its surrounding seawater. Less dense plume water was distributed near the estuary mouth and observed in smaller area. As the estuary plume exits into the coastal water from the estuary mouth, a bulge of plume water was formed near the mouth of the estuary due to low river discharge.

6.1.4 Total suspended solids

The spatial distribution of the TSS plume water was studied under varying conditions river discharge. Under high river discharge condition, survey on 9 April 2003, the stronger plume water spread on the entire the survey area, and slightly confined to the south side of the estuary mouth (Figure 6.4a). The concentrations of TSS show a decrease from the estuary mouth down seaward in coastal zone, where the highest TSS concentration was found about 215 mgl^{-1} near the estuary mouth and at the southern side, and the lowest value of 165 mgl^{-1} further seaward.

Under low river discharge condition survey on 14 March 2002, the plume water covered a wider area of the coastal water reaching 1.5 km seaward (Figure 6.4b). The highest TSS concentration of 245 mgl^{-1} was observed at the estuary mouth and slightly at north side. It reflects the high turbidity generated as a result of tidal energy and combined with wave action by strong wind forcing with mean value about 2.5 m/s. The lowest concentrations (195 mgl^{-1}) were observed further seaward.

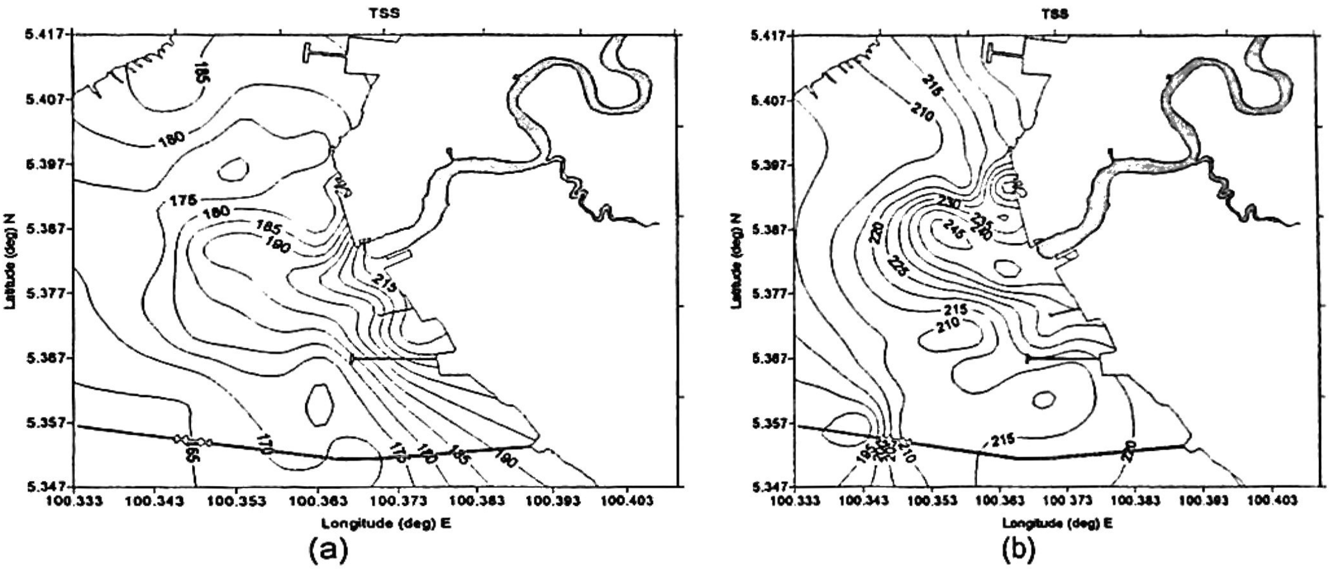


Figure 6.4 Horizontal distribution of surface TSS (mgl^{-1}) during (a) high river discharge survey on 9 April 2003 and (b) low river discharge survey on 14 March 2002.

6.2 Tidal influence

6.2.1 Salinity

Observation of horizontal salinity distributions (Figure 6.5) showed the estuary plume offshore existing at the Prai Estuary mouth as suggested by the tidal forcing. The amplitude of the surface salinity variation was related to the amplitude of the semidiurnal tidal forcing. In spring tide condition survey on 14 March 2002 (Figure 6.5a), the salinity range was greatest (28.4 - 31.2 ‰ at flood tide) with the least saline water at the estuary mouth and the most saline water in the middle channel at southern side of the estuary mouth. The stronger gradients occur near the estuary mouth and gradually weaker further seaward. It characterized with sharp fronts around the estuary mouth delineating the boundary between freshwater and seawater masses.

In neap tide condition survey on 3 September 2003 (Figure 6.5b), the average salinity ranged from 20.0 ‰ at the estuary mouth which was exposed to freshwaters from the Prai River to 32.0 ‰ at about 2 km from estuary mouth. There was an extended surface water mass of low salinity (20.0 – 22.0 ‰), spreads at northern and southern side. The extent of estuary plume was increased to coastal zone and along the coastline. The spread of the estuary plume water has the similar distance of about 2 km from estuary mouth in both cases. But, the salinity gradient of survey on 3 September was much stronger than in survey 14 March. This great difference was caused by different tidal energy in the study area.

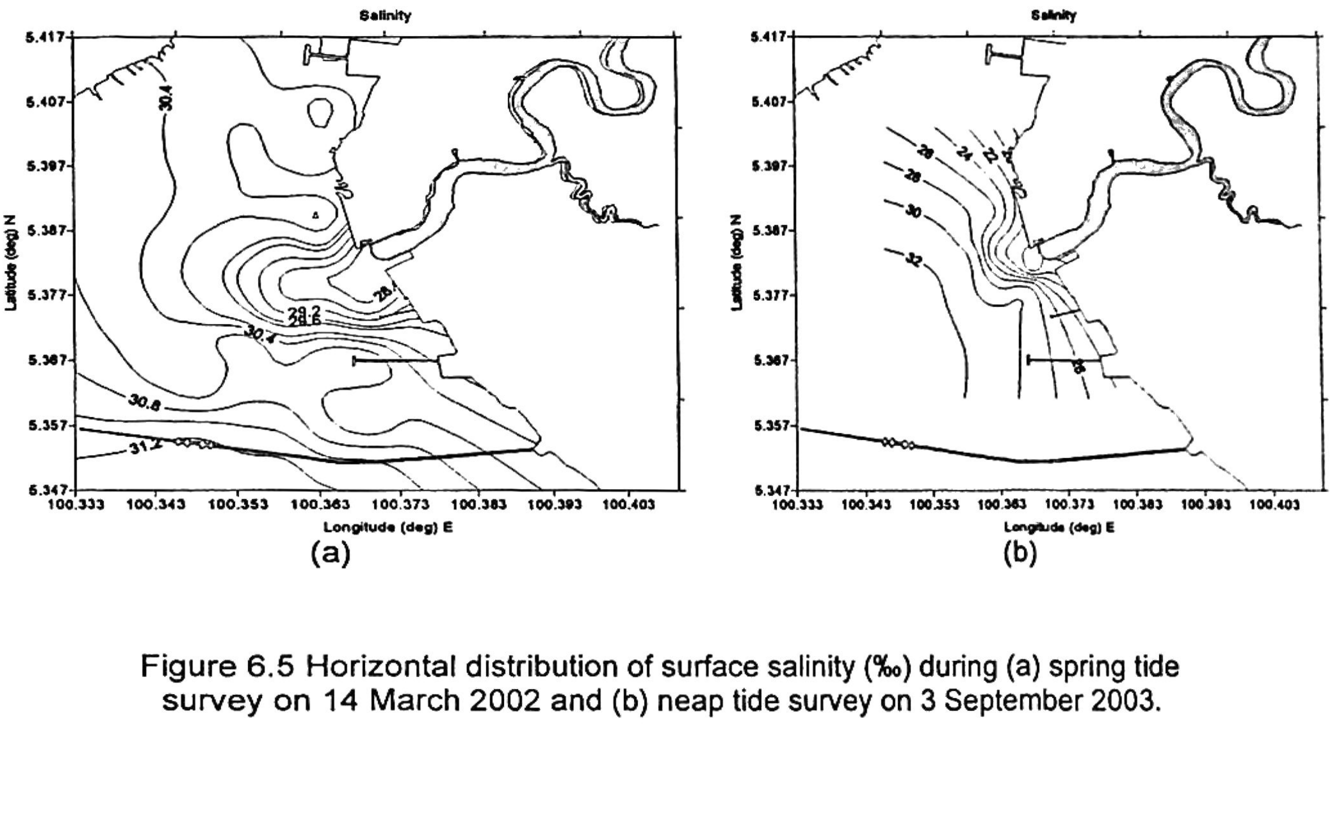
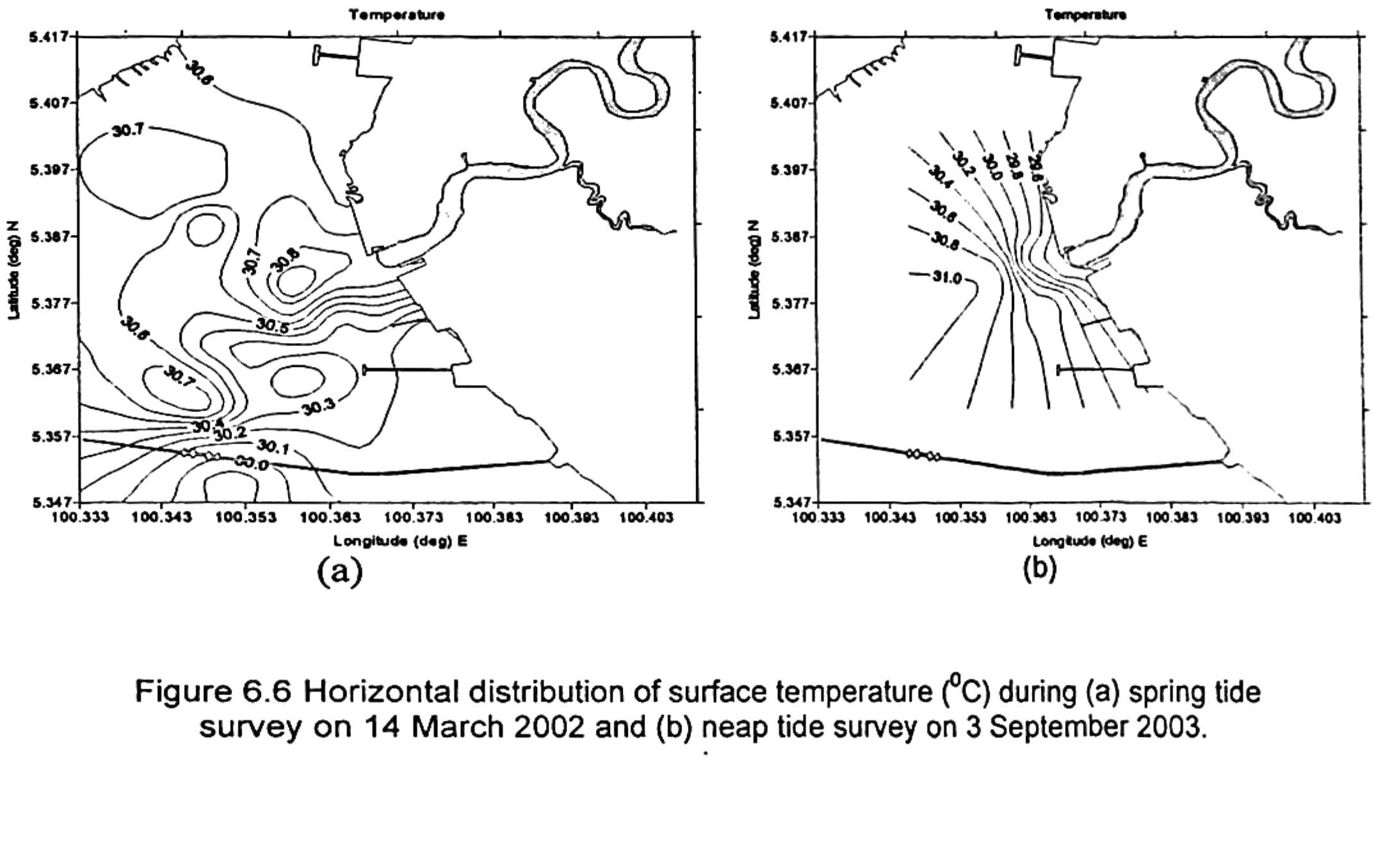


Figure 6.5 Horizontal distribution of surface salinity (‰) during (a) spring tide survey on 14 March 2002 and (b) neap tide survey on 3 September 2003.

6.2.2 Temperature

The horizontal distribution of temperature in spring tide condition, survey on 9 March 2002 is shown in Figure 6.6a. The higher temperature (30.8 ^{o}C) was observed at the estuary mouth, and the lower temperature (30.0 ^{o}C) was observed in the middle channel at southern side of the estuary mouth. The pattern shows colder seawater separated by stronger gradients from the warmer freshwater.

The temperature range in neap tide condition, on 3 September 2003 (Figure 6.6b) was around 29.6 - 31.0 ^{0}C at ebb tide period, with the coolest water at the estuary mouth and the warmest water further seaward. The greatest temperature gradient was found at estuary mouth, which was the boundary between the freshwater and seawater mixing. Similar with salinity pattern above, the temperature gradient of survey on 3 September was also much stronger than in survey 14 March.



(a) (b)

Figure 6.6 Horizontal distribution of surface temperature (^{0}C) during (a) spring tide survey on 14 March 2002 and (b) neap tide survey on 3 September 2003.

6.2.3 Density

Horizontal distribution of density at spring and neap tide around the estuary mouth is presented in Figure 6.7. In spring tide survey on 14 March 2002 (Figure 6.7a), the lower density value (16.4 kgm^{-3}) was observed at the estuary mouth, and the higher density value (18.8 kgm^{-3}) was observed in middle channel at the southern side of the estuary mouth. These density distributions show strong resemblance with surface salinity distributions.

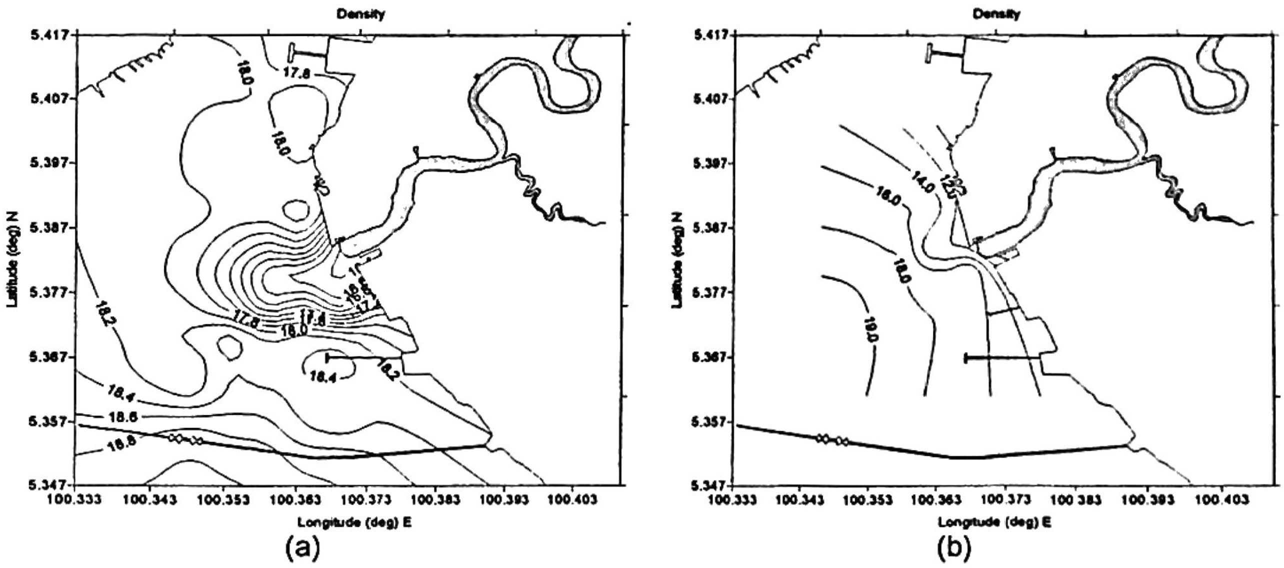


Figure 6.7 Horizontal distribution of surface density (kgm^{-3}) during (a) spring tide survey on 14 March 2002 and (b) neap tide survey on 3 September 2003.

At neap tide survey, on 3 September 2003 (Figure 6.7b), an extremely well developed horizontal density gradient was apparent, with a low density plume waters around the estuary mouth. There was a pronounced density difference between the estuarine water at the mouth (about 16.4 kgm^{-3}) and coastal water (about 18.8 kgm^{-3}). The density gradient was also much stronger than first case due to different tidal energy. The density patterns were very close to the salinity patters.

6.2.4 Total suspended solids

The TSS concentration within the study area varied from 190 - 240 mgl^{-1} as measured in 14 March 2002 during flood-spring tide (Figure 6.8a) and 100 - 170 mgl^{-1} in 3 September 2003 during ebb-neap tide (Figure 6.8b). In spring tide survey the concentration pattern of TSS had an obvious structure with TSS concentrations decreased as the estuary plume diluted into the sea. The TSS was decreasing progressively from estuary mouth to coastal region. Tidal resuspension was likely to be active in this area, when enhanced by wave action.

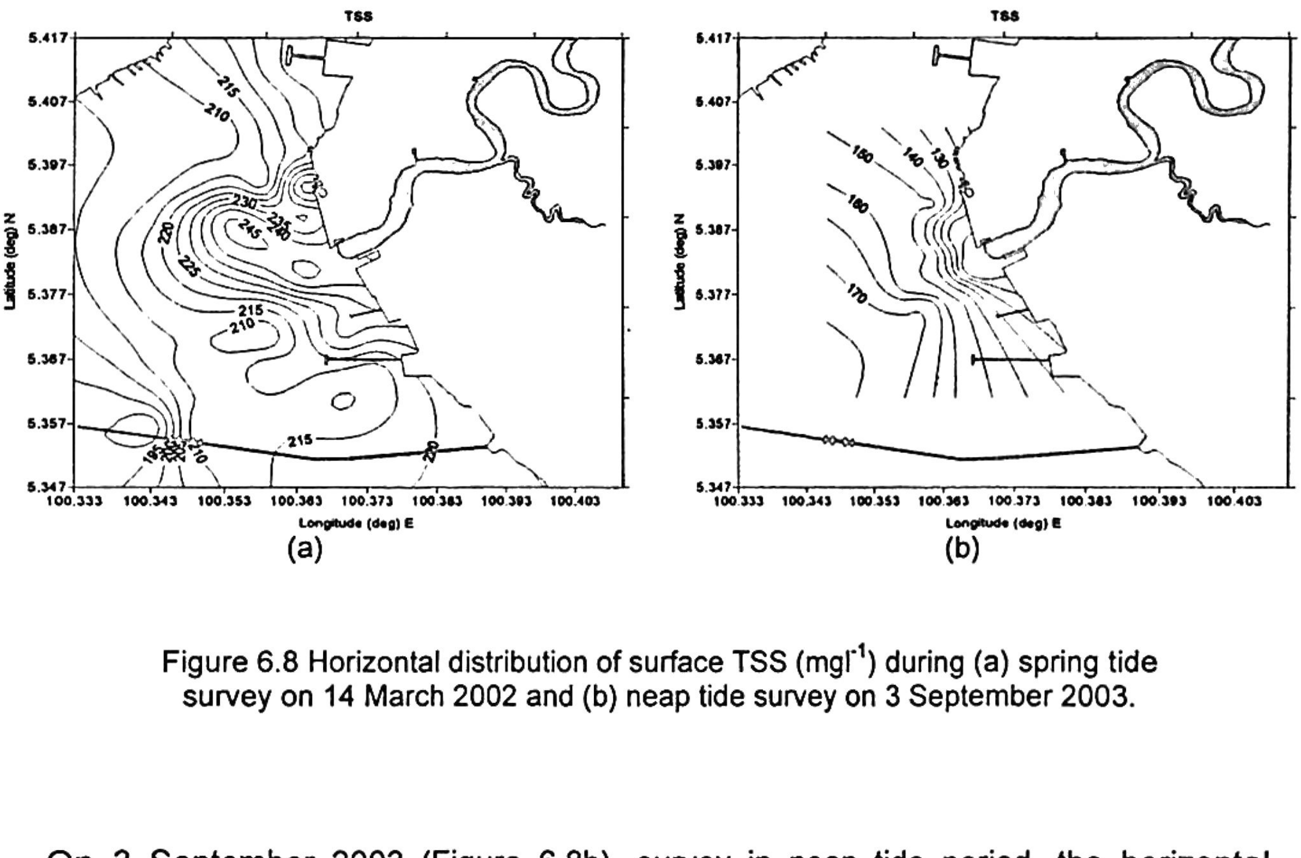


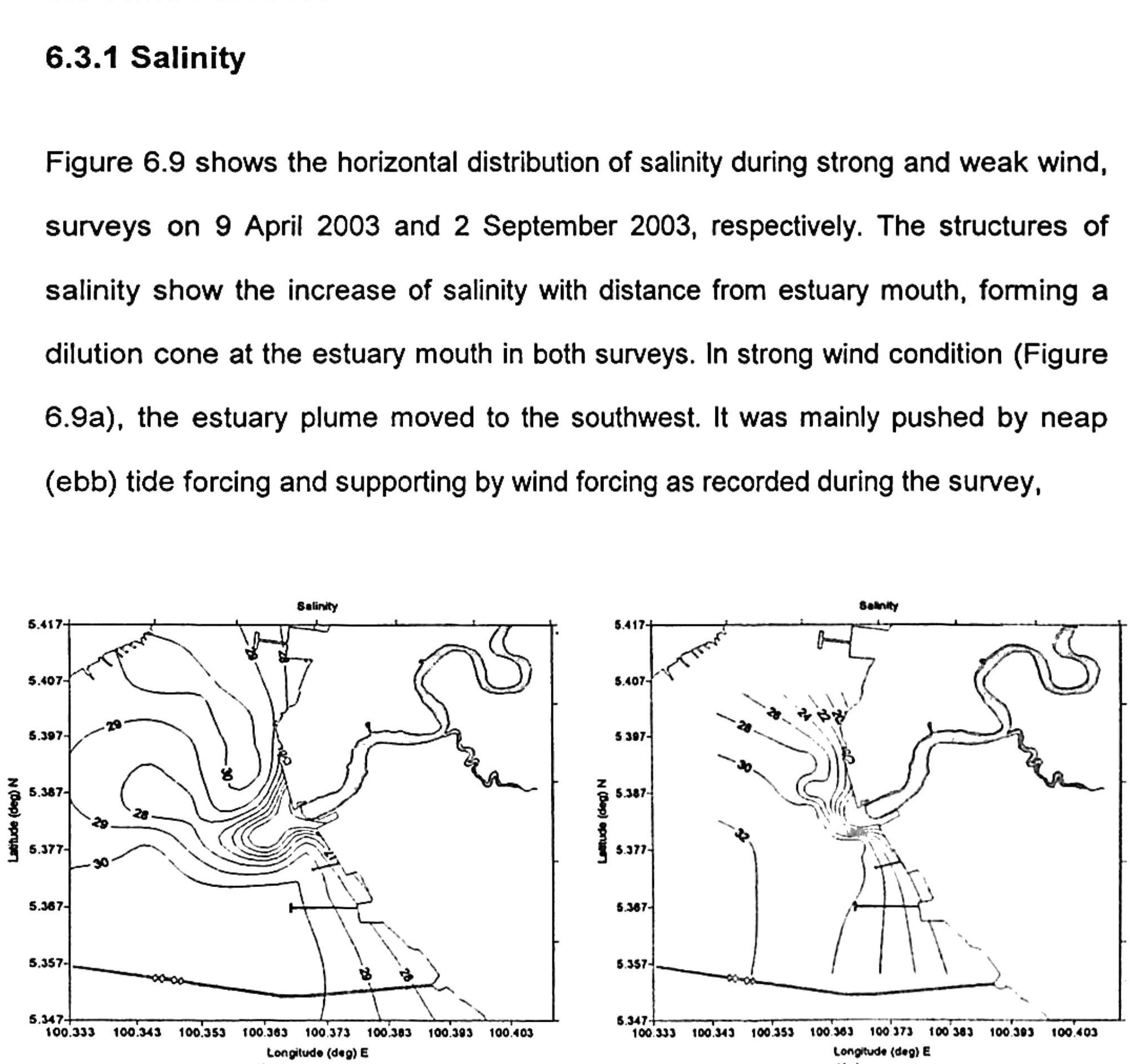
Figure 6.8 Horizontal distribution of surface TSS (mgl^{-1}) during (a) spring tide survey on 14 March 2002 and (b) neap tide survey on 3 September 2003.

On 3 September 2003 (Figure 6.8b), survey in neap tide period, the horizontal structure of TSS shows also significant increases in surface waters with maximum values at the middle channel. On this survey, relatively clearer freshwater enters the study area at the surface and along the coast. A zone of low TSS value (low turbidity) was located at the estuary mouth, indicating possibly (1) bottom coastal source of sediments up to surface layer, and (2) low TSS carried by high discharge. Beside that, the TSS concentrations during this survey were much lower than first case, due to weak neap tidal energy to resuspend the bottom coastal sediment.

6.3 Wind influence

6.3.1 Salinity

Figure 6.9 shows the horizontal distribution of salinity during strong and weak wind, surveys on 9 April 2003 and 2 September 2003, respectively. The structures of salinity show the increase of salinity with distance from estuary mouth, forming a dilution cone at the estuary mouth in both surveys. In strong wind condition (Figure 6.9a), the estuary plume moved to the southwest. It was mainly pushed by neap (ebb) tide forcing and supporting by wind forcing as recorded during the survey,



(a) (b)

Figure 6.9 Horizontal distribution of surface salinity (‰) during (a) strong wind survey on 9 April 2003 and (b) weak wind survey on 2 September 2003.

which had an average direction of 140^0 (SSE). The wind speed oscillated with an average value of 2.3 m/s during this survey. The salinity value ranged form 24.0 ‰ from estuary mouth to 30 ‰ further seaward. The estuary plume spread showing a narrower and longer shape in coastal region.

In weak wind condition, the estuary plume initially moved northwards (Figure 6.9b). The smaller extension occupied by the plume water was also noticeable during this day. The salinity value ranged from 20.0 to 30.0 ‰. The influence of weak wind forcing do not clearly in affected the spreading of the plume water.

6.3.2 Temperature

Horizontal temperature distribution during strong and weak wind is shown in Figure 6.10, survey on 9 April 2003 and 2 September 2003, respectively. The distribution showed a pattern of estuary plume distribution in study area. In strong wind condition (Figure 6.10a), with the temperature between 30.8 and 31.4 ^{0}C, the plume water from the estuary covers the surface waters from the estuary mouth to northern side, goes further seaward. The estuary plume can be separated into two distinct areas, a bulge area in front of estuary mouth and a coastal area.

During weak wind condition, the temperature vales in ranged of 28.0 - 29.8 ^{0}C (Figure 6.10b). The estuary mouth discharge direction was westward. The relatively fresher, lower temperature plume water, spread over the coastal water. During this survey, the plume water temperature was generally smaller than above (9 April) case, but it has similar small temperature variations.

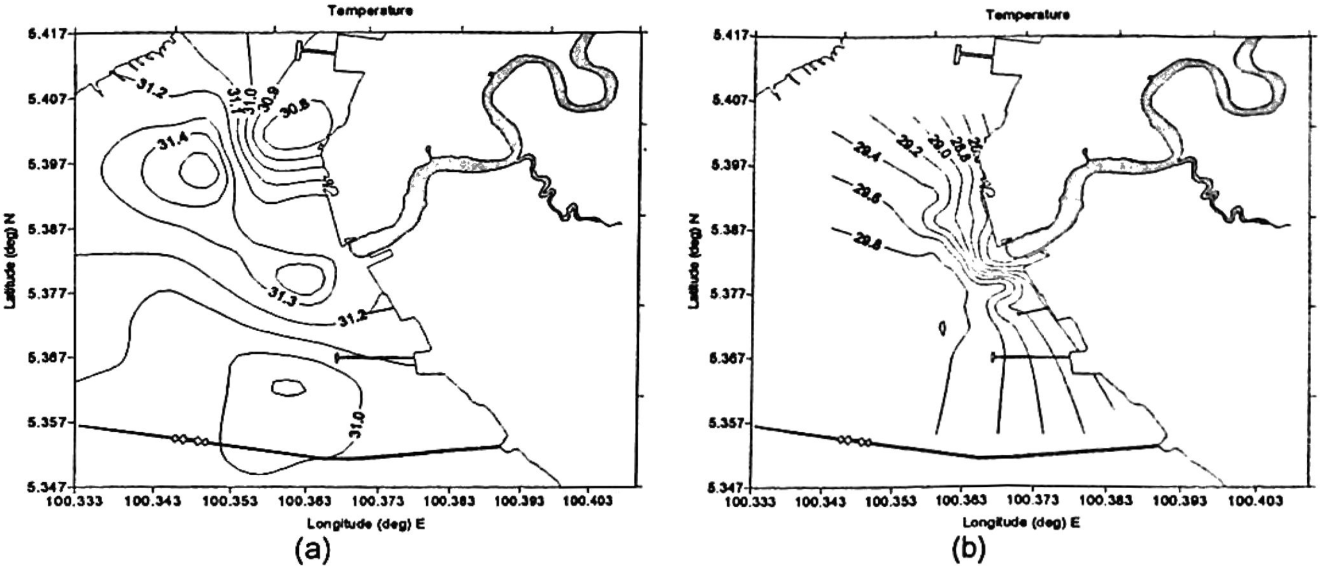


Figure 6.10 Horizontal distribution of surface temperature (^0C) during (a) strong wind survey on 9 April 2003 and (b) weak wind survey on 2 September 2003.

6.3.3 Density

The distribution of surface water density during strong and weak wind is shown in Figure 6.11, survey on 9 April 2003 and 2 September 2003, respectively. In strong wind condition (Figure 6.11a), it can be detected the mixing area of estuary water and further seaward, but with smaller density variations. The density varied between 15 kgm^{-3} at the estuary mouth and 19 kgm^{-3} further seaward at the northern and southern side of the channel. It can be seen that the influence of strong wind slightly disturbed the plume water distribution.

In weak wind condition, the surface water density increases gradually from around 10 kgm^{-3} at estuary mouth to about 19 kgm^{-3} in the middle channel at coastal region (Figure 6.11b), with the strongest gradient at the estuary mouth. During this survey, the density distribution shows stronger variation than strong wind case. This strong density variation was mainly attributed by strong tidal energy to disturbed plume water.

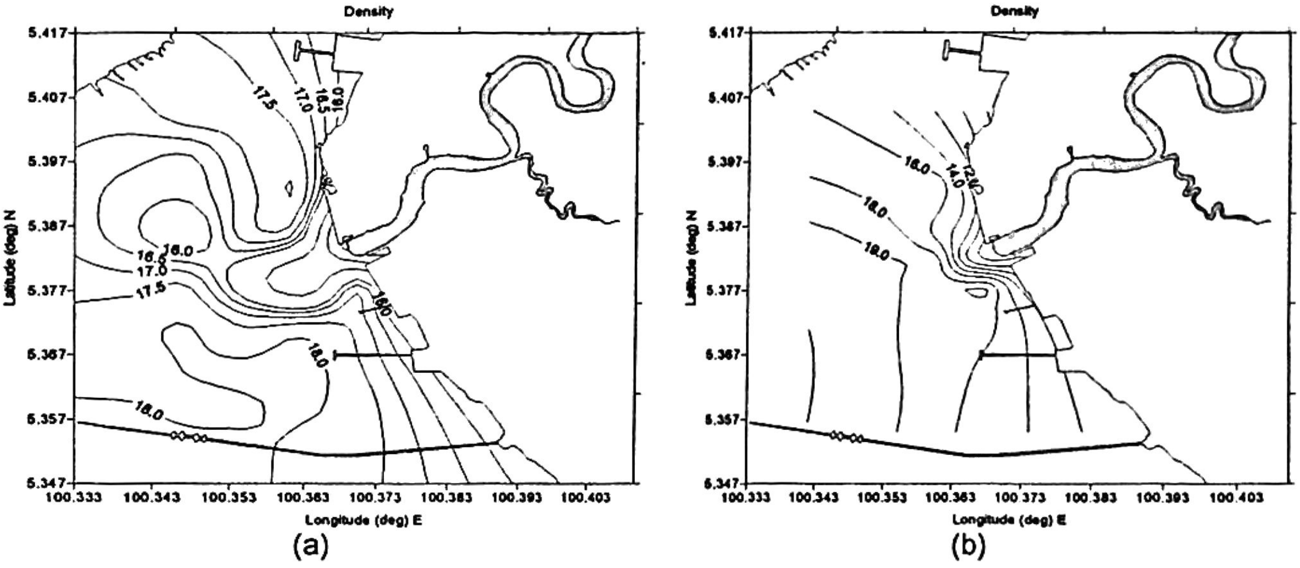


Figure 6.11 Horizontal distribution of surface density (kgm^{-3}) during (a) strong wind survey on 9 April 2003 and (b) weak wind survey on 2 September 2003.

6.3.4 Total suspended solids

TSS concentrations in the study area showed an obvious distribution of estuary plume from the river. Figure 6.12 shows the horizontal distribution of TSS concentrations in the surface water during the strong and weak wind condition, surveys on 9 April 2003 and 2 September 2003, respectively. It can be observed that the plume water decreasing with distance from the estuary mouth and further seaward.

In strong wind condition (Figure 6.12a), the observed TSS concentrations in the surface water varied between 165 and 215 mgl^{-1}. The patterns are characterized by high turbidity in the proximity of the estuary mouth. The plume emanating from the river had a reduced extent and composition but did merge with seawater in a northerly direction in a very constrained near shore area. It can be observed that the strong wind influencing the estuary plume distribution at the coastal water.

In weak wind condition (Figure 6.12b), TSS concentration in surface waters varied between 78 and 252 mgl^{-1} with highest values in river waters at estuary mouth, and a general decrease in offshore direction. The high TSS concentration (high turbidity) of the surface water that connects with the coastal zone of the middle channel shows several continuously seaward extended plume water masses, with markedly undulated boundary at the estuary mouth.

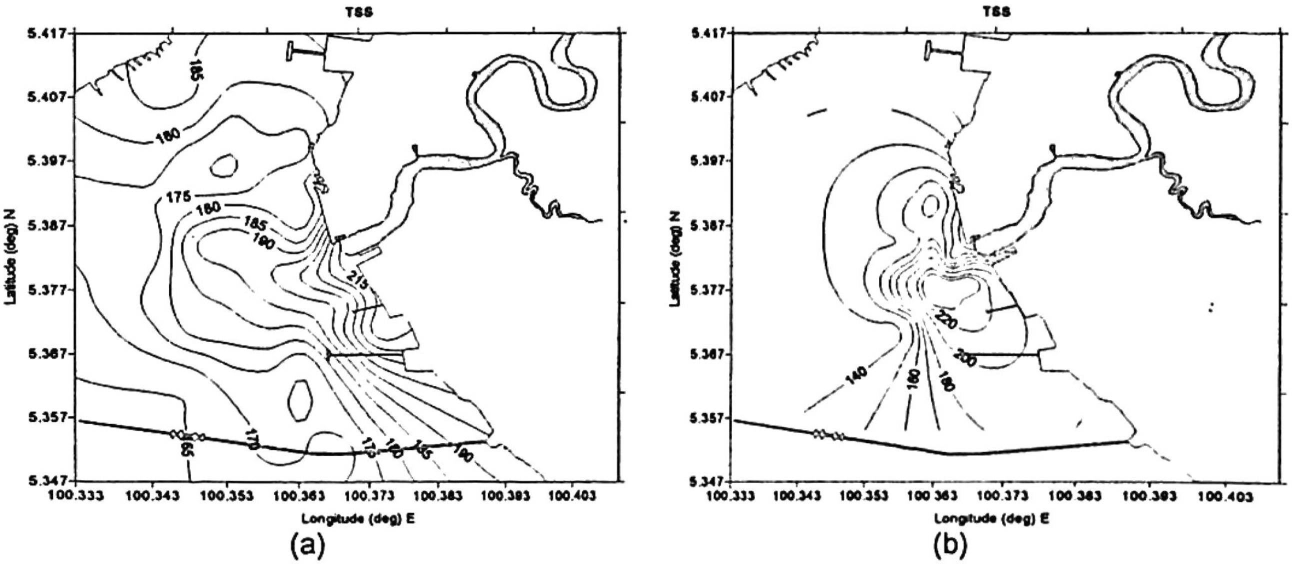


Figure 6.12 Horizontal distribution of surface TSS (mgl^{-1}) during (a) strong wind survey on 9 April 2003 and (b) weak wind survey on 2 September 2003.

6.4 Discussion

The general meteorology and hydrographic of the Prai coastal water under various river discharge (and rainfall condition), spring-neap tidal variation and different wind conditions, are discussed with respect to all the data collected of about six months field surveys, from October 2001, March 2002, April and September 2003 (Table 6.1 and 6.2, in section 6.5). The average monthly trends of the main physical water parameters that allow us to identify and to characterize Prai coastal systems on the basis of physical factors are described below.

6.4.1 River discharge influence

River discharge and rainfall condition is one of the most influential factor affecting physical structure in the Prai coastal water. The amount of rainfall that falls over catchment area can have a marked effect on the condition of river discharge. Therefore, definition of the seasonal cycle of Prai River freshwater discharge is essential to the understanding of physical processes and characteristics of the coastal water. Horizontal distributions of salinity, temperature, density, TSS and Secchi depth record for the low and high river discharge condition are shown in Appendix C.

a. Salinity pattern

The horizontal distribution of salinity shows the estuary plume development near the Prai Estuary mouth and adjacent coastal water. It was shown stronger horizontal gradient of salinity near the estuary mouth. The low salinity region of estuary plume was separated from the seawater. The only reasonable low salinity plume water source would be from the higher freshwater discharge from the Prai River into the Penang Channels. This high discharge event was strong enough to push the estuarine water out of the estuary further seaward.

In low river discharge case, the influence of estuarine water input was only detected closer to the estuary mouth. The less saline waters at the estuary mouth and the most saline waters detected seaward at the north and south side of the estuary mouth. The influence of shallow area near the estuary mouth and low river discharge result in this low salinity plume water close to the coastal edge near estuary mouth. The results of surface salinity herein are nearly consistent with those obtained in the other studies of the Yangtze River, East China Sea (Delcroix, 2002), and in the Chesapeake Bay (Guo and Levinson, 2004). In addition, Li *et al.* (1999) observed in Strait of Georgia and Juan de Fuca Strait, Canada using a Box Model. The seasonal sea surface salinity shows a minimum in salinity value during the months when the river discharge is maximum.

Generally, the horizontal distribution of salinity at surface layer in the coastal water reflects the freshwater discharge from the Prai Estuary that varies seasonally in its location along the coastal water. However, the variation of salinity, as indicated by differences between near estuary mouth and further seawater, were noticeable at high river discharge. The extent of the low salinity plume water also depended on the quantity of freshwater discharge from the river. The greater the discharge, the further downward the low salinity would occur.

b. Temperature pattern

Horizontal distribution of temperature across the channel showed cooler water temperatures near the estuary mouth during high river discharge, and vice versa. As revealed, the spatial distribution temperature was mainly affected by the spatial distributions of freshwater and intruded seawater in the estuary mouth. Beside that, there was a consistent increase in temperature associated with the offshore extension of the higher river discharge and a warming associated with the atmospheric temperature condition. Relatively higher rainfall in catchment area, would bring the cooler fresh river water. It would significantly reduce the surface temperature at the study area. The direct influence of high river discharge from the Prai River was detected near the estuary mouth, and adjacent coastal water.

During low river discharge, temperature distribution shows the warmer water at the estuary mouth and the cooler water further seaward in the channel. This water temperature pattern area showed inversions of warmer estuarine water temperature at surface, related to low river discharge conditions. The results of surface water temperature herein are closely with the results observed by Johnson *et al.* (1997) in the Kara Sea, Russia and contrary to those obtained in the other studies of the Yangtze River, East China Sea observed by Delcroix, 2002. The results indicate that the dynamic and thermodynamic effects of the freshwater input from the river may be phase lagged by up to a season with maximum surface warming occurring in the months when the river discharge is maximum.

From the results analysis suggests that the temperature characteristics of estuary plume during low and high river discharge periods can contribute significantly. Similar condition with catchment area of Muda River, during low discharge (dry seasons) the heating effect from the sun could be much more influencing at surface catchment area and river water. However, during high discharge (wet seasons) with high rainfall reduces the surface heating processes from the sun and the river water temperature would be cooler. The intense rainfalls tend to reinforce condition until the minimum effect of solar radiation in the region. Then, this high volume of cooler freshwater would strongly influence the estuary plume water temperature, as it discharged from the estuary and mixed in the coastal water.

c. Density pattern

The horizontal distribution of density during high river discharge shows pronounced gradient. The lower density plume water was observed near the estuary mouth and higher density value further seaward. The estuary plume water extends along most of the coast, especially when the discharge was high. Then, this plume water gradually merges into the seawater at coastal region that pushed by high river discharge. The water density appears to mirror that of the salinity and therefore it is suggested that the density distribution is primarily controlled by the salinity.

In low river discharge, the horizontal distribution of density shows similar pattern with above case. The surface plume water formed between the low salinity tongue in the estuary mouth and its surrounding oceanic water. The lower density plume water was closest to the coastline and near the estuary mouth. Generally the density values were lower than high discharge case. This fact confirms further the occurrence of the contribution of freshwater entering the river as explained for salinity earlier. Overall, the water density appears to mirror that of the salinity in both low and high river discharge conditions. Therefore it was suggested that the density distribution was primarily controlled by the salinity.

d. Total suspended solids pattern

During high river discharge case, the distribution of TSS plume water was distributed wider at the coastal water. However, the bigger volumes of estuarine water from high river discharge do not show clearly contribute to the quantity of TSS concentrations in the study area. The concentration of TSS near the estuary mouth was consistently higher than in seawater. This area of high TSS value (turbid water) may have resulted primarily from resuspension of sediments by the prevailing of tidal energy and slightly by high river discharge.

During low river discharge conditions, the higher TSS concentration of plume water still observed near the estuary mouth and become lower further seaward. This pattern reflects the high turbidity generated by mixing processes that resuspended bottom sediment to surface layer due to tidal energy, combined with wave action by stronger wind forcing. In surface water, wind-generated waves and wakes interact with the bottom to stir up sediments. In coastal water, the estuary plumes that becomes mixed and suspended in water will reduce its clarity and make the water turbid.

The seasonal changes in TSS patterns between both surveys high and low river discharge were surprisingly do not clearly shows significant influence in affecting the TSS concentrations in the study area. Since the high and busy activities of fisherman boats, ships, and ferryboat at the port that were located around the study area, the effects appear slightly significant contribution as progressive wave.

TSS results were statistically compared and calibrated to Secchi depth records that taken at the same stations in each survey. By combine the TSS concentrations and Secchi depth (turbidity) measurements can produce a significant correlation. Linear regression analysis found excellent correlations between TSS data and Secchi depth record. The linear regressions are shown in Figure 6.13 and statistical properties of the regressions are given. All regressions are significant and show strong linear relationship Secchi depth and TSS. R-square coefficients of correlation ranged from 0.96 to 0.84, with the lowest correlation occurring on 28 October 2001.

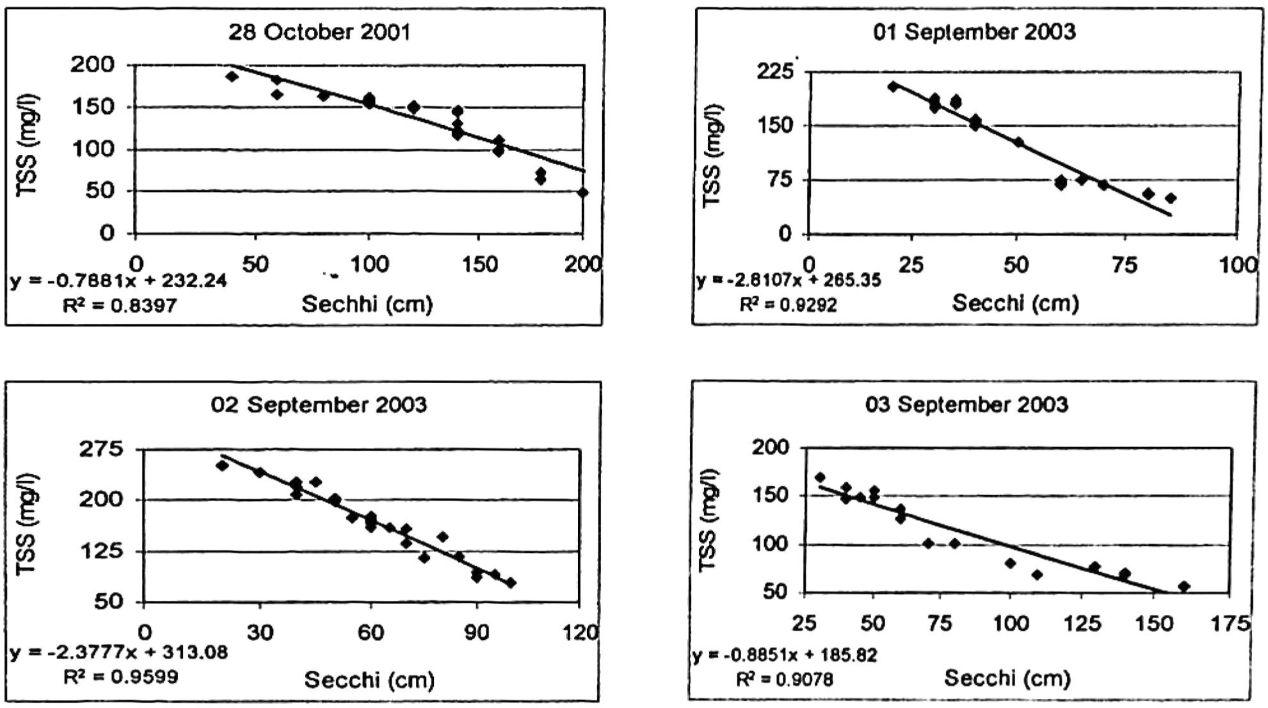


Figure 6.13 TSS-Secchi depth diagrams along the date of surveys.

6.4.2 Tidal influence

Intensive field surveys were undertaken in coastal water of Penang Channels to examine the patters of buoyant surface plumes originating from the Prai River estuary on each outgoing tidal cycle. Tides in the study area are semidiurnal with mean neap and spring tide ranges of 0.9 - 1.9 m and 2.1 m during the field surveys (Figure C7 and C8 in Appendix C).

a. Salinity pattern

The amplitude of the surface salinity variation was related to the amplitude of the semidiurnal flow. In spring tide survey, the low salinity plume water was distributed closer the coastline. The least saline water was observed near the estuary mouth and the most saline water further seaward at the middle channel. The plume water was generally well mixed, with sharp fronts around the estuary mouth delineating the boundary between freshwater and seawater masses. This salinity map shows a localized tidal energy, causing local salinity minimum at the estuary mouth.

In neap tide condition, it was occurred larger horizontal gradient of salinity value. The lower salinity values of plume water were detected around the estuary mouth and gradually increase further in seawater. There was an extended surface water mass of low salinity plume water, lying in wider area that appears seaward. This structure shows a general trend of increasing salinity away from the estuary mouth, indicating that water mixing processes have been occurring between freshwater and seawater. There are nearly similar results observed here with the other observation by Mao *et al.* (2004). Tides and tidal currents are a major source of energy for turbulence and mixing in estuaries and coastal water and they play an important role in the movement plume water. The dissipation of tidal energy causes changes in the vertical stability of the water column.

In general, by observation the salinity values during different tide conditions, it was found that the salinity value of spring tide survey was higher than equivalent values found in the plume survey in neap tide survey. The easiest explanation for this contrast was the presence of different energy of spring and neap tide. The stronger spring tide energy pushed seawater landward that would increased the salinity value in the mixing area. On the other hand, the weaker neap tide energy would decreased the salinity value by pushed the plume water further seaward. These patterns agree with the other studies such as Orton and Jay (2005). Their observations of intense localized mixing behind the tidal plume front of a surface-advected estuary plume confirm that these tidal energy play a major role in the vertical transfer of buoyancy and other constituents.

b. Temperature pattern

The horizontal temperature distribution of spring tide shows that the higher temperature was observed near the estuary mouth, and lower temperature was observed in the middle channel. The pattern shows colder seawater separated by a stronger gradient from the warmer freshwater water. In this situation, the warmer estuarine water was resulted mainly by fresher water discharge from the river. However, it could be suggesting that the cooler water was advected from the seawater pushed by spring tide forcing.

In neap tide condition, the temperature ranges was relatively higher that above case, with the temperature of plume water depend on the estuarine water discharged from the river. However, the greatest temperature gradient was found near the estuary mouth, which was the strongest mixing area.

The seasonal cycle of tidal phase and wind in this region is determined by the processes of heating and cooling over the study area. The processes of surface heating and cooling that occur in and affect the atmosphere are similar in many ways to the processes that occur in and affect the surface seawater. The influence of surface heating and cooling is illustrated using the atmospheric temperature data (Figure C-12, in Appendix C). The results from observed data indicate the importance of mixing process and variable freshwater and seawater temperature relative to surface heat exchange.

c. Density pattern

Horizontal distribution of density at surface layer for spring tide condition shows elevated value from the estuary mouth to further seaward in the middle channel. This density distribution show strong resemblance with surface salinity. The appearance of a spring tide intrusion of higher density seawater can be seen at surface water just outside the mouth of the estuary, with the weakening of density water in this area. However, the mixing processes that occur between the freshwater and saltwater depend on the tidal energy and the relative volume of freshwater that confined by the river sides and of saltwater that confined more by depth.

At neap tide condition, the horizontal distribution of density at surface layer also shows elevated density, with a lower density value of plume waters around the estuary mouth. The less dense surface water at estuary mouth was generated mainly by neap tide energy. The density difference was greater than spring tide period. Hence, the resulting density difference in Prai coastal zone was mainly determined by salinity. It was depend on the dynamical balance between buoyancy and mixing forces.

d. Total suspended solids pattern

The TSS concentration exhibited significant spatial variability related to the phase of the tide. In the spring tide survey the concentration pattern of TSS had an obvious structure with higher TSS concentrations and it decreased as the plume water diluted into the sea at middle channel. It was observed that the highest concentration of TSS near the estuary mouth and decreasing progressively in the coastal region. Spring tide resuspension was likely to be active and strong in this area, when enhanced by wave action.

On neap tide period, the horizontal structure shows significant decreases of TSS in surface waters, with the highest values still near the estuary mouth. During this period, the weaker neap tide energy do not strong enough to disturbed the bottom sediment that characterized by lower TSS concentration at surface water. Beside that, this weaker neap tidal energy pushing the muddy waters into the seawards and then mix with clearer seawater resulted lower TSS concentration. This general pattern reflects the fact that the spatial variations of TSS indicated that highly correlated with the different tidal energy. The results are consistent well with the other studies by Alvarez and Jones (2002), eventhough with different mechanism. The suspended sediment observed at shallow water over a spring to neap tidal cycle. These revealed contrasting dynamic conditions in which gravity current events produced significant lower values of suspended sediment during neap tides. Beside, higher values of suspended sediment during spring tides due to tidal resuspension.

The correlation among TSS concentration, tidal range and shallow coastal water leads to the conclusion that tidal energy combined with shallow water depths remobilize and resuspend bottom sediments, enhancing the concentration of TSS and generating, therefore, the higher turbidity water. TSS plume water was moved in the direction of the strongest tidal energy, and consequently were moved specifically in either ebb or flood directions. As observed by Mantovanelli *et al.* (2004) in Paranagua Bay estuary, Brazil, they shows that the sediment dynamics was intrinsically related to cyclical processes of erosion, resuspension and deposition driven by tidal energy. Resuspension and vertical mixing were conspicuous in spring cycles, while the horizontal advection preponderated in the neaps. On the other hand, the Penang Channels at the cross road of several major shipping route, is one of the busiest shipping links in Malaysia and hosts the port. As a consequence of increased industrial and shipping activities in the channel, marine pollution has become an important concern. Then, it was slightly contributed to influencing the TSS concentrations in the study area.

6.4.3 Wind influence

Generally, the study area experiences very light winds due to of its close proximity to the equator. Hence, wind forcing play not so important roles in determining the characteristics of buoyant estuary plumes. The evolution of the estuary plume was highly dependent on the variability inherent with the others coastal features and acted as a good indicator of the mixing and exchange of offshore waters with shallow waters.

a. Salinity pattern

The structures of salinity show the increase of salinity with distance to the estuary mouth in both strong and weak wind surveys. The lower salinity plume water moved down seaward pushed by river discharge or neap tide forcing and combination of strong wind forcing. The estuary plume spread showing a narrower and longer shape in coastal region. It was clear that strong wind forcing was slightly related to movement of estuary plume.

The smaller extension occupied by the plume water was not noticeable during weak wind condition. The lower salinity plume water can not be qualitatively explained by weak wind conditions, which were very variable. Indeed, after spreading offshore, the estuary plume was pushed down seaward by the river discharge or tidal forcing. It was found that the weak wind forcing do not give significant result in influencing the plume water spreading in coastal water. The importance of wind forcing has been shown by Fernandes *et al.* (2005) that observed at the Patos Lagoon, in the southern Brazilian coastline. Wind in dominated in the study area, where the effects tend to force saltwater penetration and accumulation inside the lagoon. It is also evident that the system responds quickly to variations in the magnitude and/or direction of the wind.

b. Temperature pattern

In strong wind condition, the plume water from the estuary covers the wider surface waters from the estuary mouth, goes through the middle channel but with relatively small variation. During weak wind condition, plume water can not be observed clearly. This plume pattern was presumably due to increased mixing caused by the tidal energy or river discharge in the coastal environment. During both periods, it was documented that there was small variation of temperature in the study area. The weak increase in sea temperatures were a characteristic feature of Prai coastal waters as atmospheric temperatures generally uniform in the study area. The temperature of the coastal water changes during surveys, have close relation to the mixing processes and/or to heat exchange with the atmosphere.

c. Density pattern

Similar with the structures of salinity, it was also show the increase of density with distance to the estuary mouth in both strong and weak wind surveys. During strong wind, the plume water mixing area probably extended further seaward, with strong density gradient at estuary mouth. The less dense surface water was generated mainly by river discharge and increase of the neap tide energy. However, the influence the strong have a role as supporting energy that contributed to disturbed the wave.

A plan view of the changes in the density values of both surveys indicate that there were significant in coastal zone variations associated with changes in forcing conditions. High river discharge to the coastal zone, however, will cause changes in the density through the mixing process. Then, it was supported by strong wind through the generation of waves, which can suspend sediment from the seabed, particularly in shallow water.

d. Total suspended solids pattern

In strong wind condition, the plume water has higher TSS concentration that was characterized by higher turbidity in the proximity of the estuary mouth. The plume emanating from the estuary had a reduced extent and composition but did merge with seawater in a constrained near shore area. This was most likely to be related to the movement of the plume that was pushed by high discharge or neap tide forcing and combination of wind forcing. During weak wind period, the TSS concentration in surface waters was smaller than above case, and a general decrease in offshore direction. This was also influenced by river discharge or tidal forcing. However, weaker wind forcing does not enough energy to generates of wave and disturbed the plume water.

From the observed dynamics of TSS concentration of plume water, it can be concluded that due to resuspend of sediment by tidal energy, and highly estuarine discharge were generally confined close inshore. Therefore, significant quantities of estuarine discharge were likely to be deposited on coastal water. From this finding, it was clear that the wind forcing was not the main factor and has minimal effect in influence the rotational veering of the estuary plume to coastal water. By direct observations in the study area during field surveys seem to be dominating the wind speed variability with very low intensity during daytime and high intensity in nigh. It was confirm with the daily pattern in the wind is calm in the mornings until afternoon and stronger in the afternoons until morning. All of the surveys of this study were conducted during the morning. Although wind forcing was observed, there was no corresponding change in characteristics of the costal water, because of this low intensity.

6.4.4 Aerial surveys

Estuary plume dispersion characteristic was also observed at the Prai coastal area, that was mapped and interpreted by aerial digital images resulted from aerial surveys. This information can be obtained on their spatial and temporal variability that can lead to determine coastal dynamic, control the dispersion patterns of estuary plumes within the study area. The mixing processes of estuarine water and seawater become relevant factors that interact with estuary plumes and largely influence their spreading and movement.

The results obtained clearly the seasonal difference in the extent of the plume water. Figure 6.14 shows the digital image captured on 28 July 2001. The images showed the dominant plume water that was flows northward and clearly detectable. The wind speed was relatively strong with mean value of 2.5 m/s toward the SW (220^0). River discharge was relatively small, that indicated from event of no rainfall during this survey. During the neap (ebb) tide, with the observation value in rages of 2.14 - 3.23 m, the estuary plume can be seen as a patch of darker water near estuary mouth. The detected darker plume water, associated to the neap tide energy, showed mostly stripe-like appearance, oriented parallel from the estuary mouth to the northern shore of the island. The origin of the main plume water was detected at a shorter distance from the coast. The patch of relatively more turbid water within the relatively clear water zone may be due to the discharge of turbid river waters or rapid settling of suspended sediments due to decrease in neap tidal energy.

Figure 6.14 Sequence of aerial digital images over the Prai coastal water, showing the distinct edge of estuary plume, captured on 28 July 2001.

The other digital image capture on 28 October 2001 (Figure 6.15) showed the plume pattern in the Prai coastal area, with the dominant plume water flows southward was clearly detectable. Estuary plume water was clearly observable as brown turbid water masses contrasted very distinctly against the clearer seawater. Estuary plumes expand over a wide coastal water at a relatively short distance from the coast. Due to the low density of plume water discharge, sediment laden plumes can deviate toward the shoreline, where they can accumulate as lenses of relatively low salinity water. It shows a plume water (dark region) discharge from the Prai River covering the central part of the coastal water just offshore of the estuary mouth. The plume water structure illustrates such a situation higher discharge and neap tide period during this survey. Higher discharge in this area was a consequence of rain event in relatively wide area that record in both Butterworth and Prai meteorological stations. Similar with the situation in the northwestern Mediterranean, In the Gulf of Lions, estuary plumes usually expand over a wide continental shelf at a relatively short distance from the coast. Due to the low density of fluvial discharge, sediment-laden plumes can deviate toward the shoreline, where they can accumulate as lenses of relatively low-salinity water. It was observed with similar technique of aerial image interpretation observed by Arnau *et al.* (2004). They observed the estuary plume-dispersion patterns near the estuary mouth with unprecedented resolution. The same technique also used by Conley (1999) using aerial photograph analysis in Moriches shallow bay, south of Long Island New York. Observations of buoyant plumes which occur on the continental shelf from ebb tidal flow through inlets show a thin estuarine layer advecting over a denser oceanic layer with a thicker roller region at the leading edge of the estuarine plume. The roller is a location of strong convergence where most of the entrainment is assumed to take place. Tidal exchange through inlets is the mechanism through which saline ocean water is mixed into bays, and the balance between this exchange and any freshwater input determines the estuary plume salinity.

The distribution of estuary plume was observed in the coastal water near the estuary mouth. After spread from the estuary mouth, the plume deflected to the south and relatively close to the coastline. Combined with filed survey of TSS data, it was assessed and the pattern of orientation of the estuary plume (insert image in Figure 6.16). The field data show the TSS concentrations of plume water has similar pattern with the digital image data. The darker lines in insert figure represent the TSS value that identified about 110-170 mgl^{-1}. This TSS result feature was closely similar with digital image displayed. This small area of estuary plume was caused by relatively low discharge during the neap tide survey.

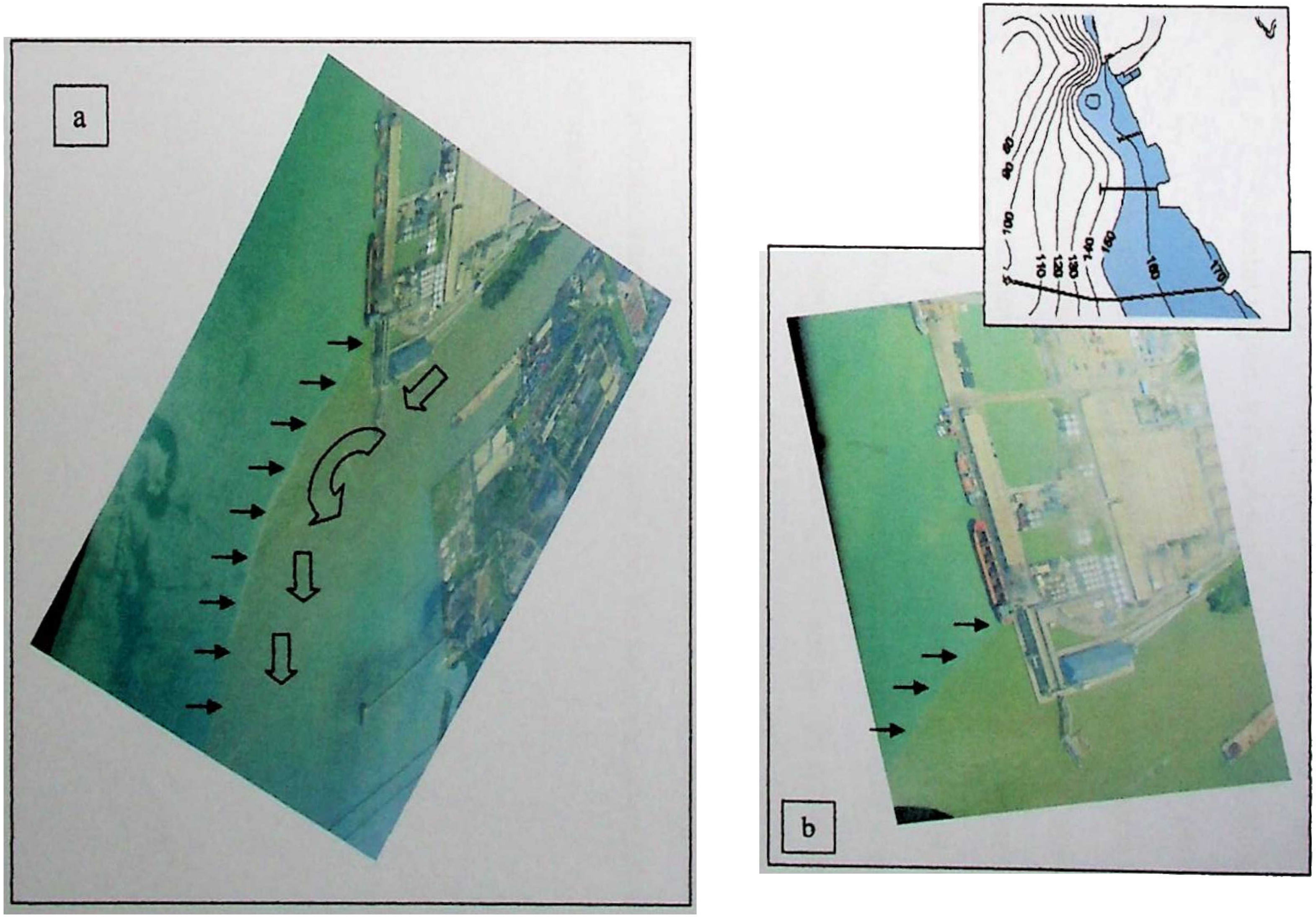


Figure 6.15 Sequence of aerial digital images over the Prai coastal water, showing the distinct edge of estuary plume, captured on 28 October 2001. The plume pattern was identified by field observation (TSS) during similar date (insert Figure).

Another plume water from the Prai River, observed on 9 March 2002 with aerial images is shown in Figure 6.16. The structure of plume water was not so clearly during this survey. The structure was more prominent in the estuary mouth rather than in coastal region. It was indicate a less extended plume waters and practically no plume outside the estuary mouth. Instead, the edge of plume water was located inside the estuary mouth. Under neap tides condition, when the observation tidal ranges was about 2.0 -3.3 m, and the dry seasons that characterized by no rain during this month, the aerial extent of the high turbid zone was drastically reduced. With reducing distance of estuary plume from the coast and only accumulated in estuary mouth, the tidal forcing weakens and was unable to pushing plume water further. Most commonly, the strong wind energy can transfer and push the plume water from the estuary further seaward. But with weak wind speed (maximum wind speed of 8.9 m/s and blow to NW (300^0)), therefore, this wind forcing do not cause significant transport of plume water from the estuary to coastal water and the middle channel.

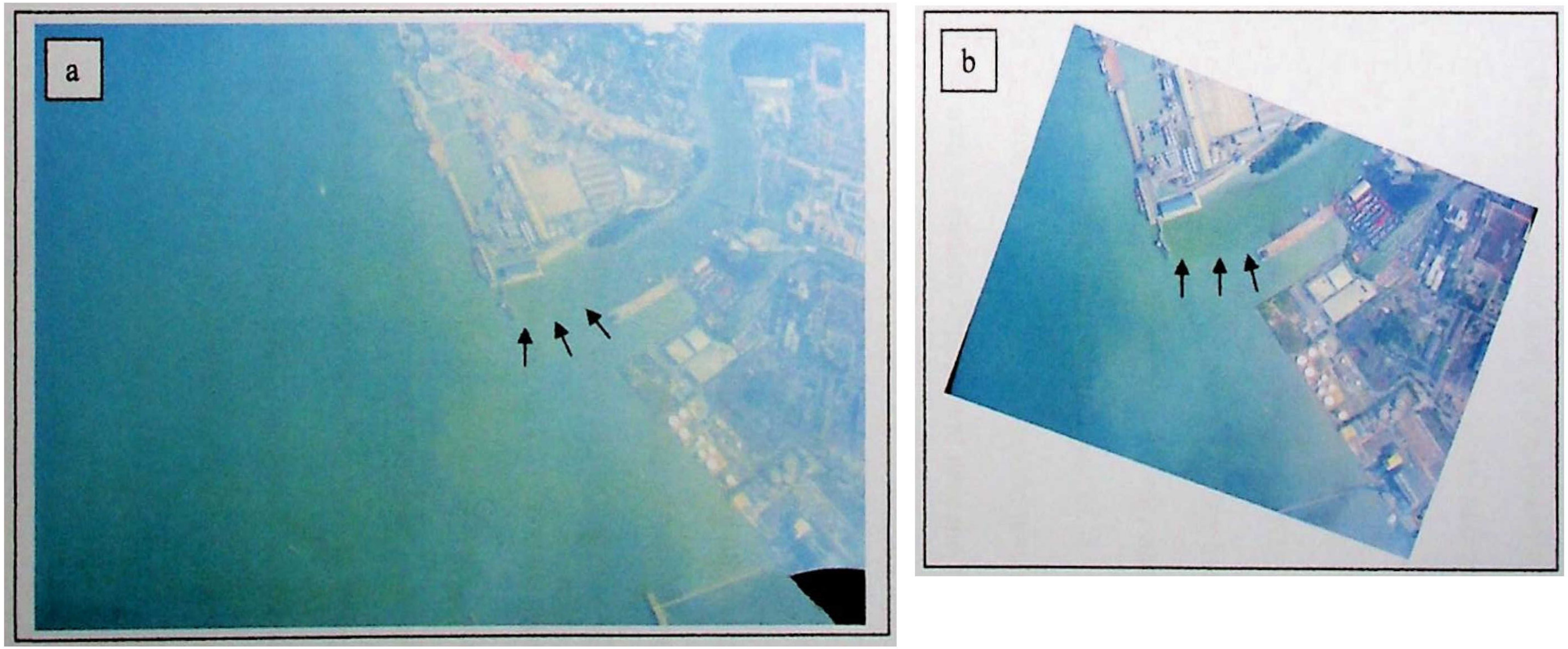


Figure 6.16 Sequence of aerial digital images over the Prai coastal water, captured on 9 March 2002.

Figure 6.17 show the aerial digital images captured on 1 September 2003. The most characteristic feature of the estuary plume distribution was large highly turbid zone in the coastal water and off the mouth of the Prai River. It flowing northward of the estuary mouth, bordered by highly turbid water along the coastline. The main factor for the mixing of the turbid plume water was variation in tidal energy due to change in tidal range, and the seasonal change. The maximum southward extent of the high turbid zone was during the neap tide. The seasonal behavior was related to changes in the wind regime and in the freshwater discharge. The mean wind speed during this survey was about 2.1 m/s and blew to NNW (320^0). The rainfall events leading to the river discharge of 1 September 2003 were relatively small occurrences. Rainfall for this period was about 9.7 mm at station Butterworth, and 10.5 mm at station Prai. At the time the picture was captured, the relatively strong wind was moving the plume water in same direction as wind blow, and influenced by high river discharge and by neap tidal energy.

The distribution of estuary plume was observed in small area on the coastal water near the estuary mouth. After spread from the estuary mouth, the plume deflected to the north and relatively close to the coastline. The digital image was assessed and combined with field survey of TSS concentration (insert image in Figure 6.18). The field data show the TSS concentrations of plume water also observed in small area in front of the estuary mouth that also deflected to the north side, as showed in digital image. The darker lines in insert figure represent the TSS value that identified about 130-170 mgl^{-1}. This TSS result feature was slight similar with digital image displayed. The result of small plume from the Prai Estuary in this survey was caused by low discharge due small rainfall during the survey and some days before.

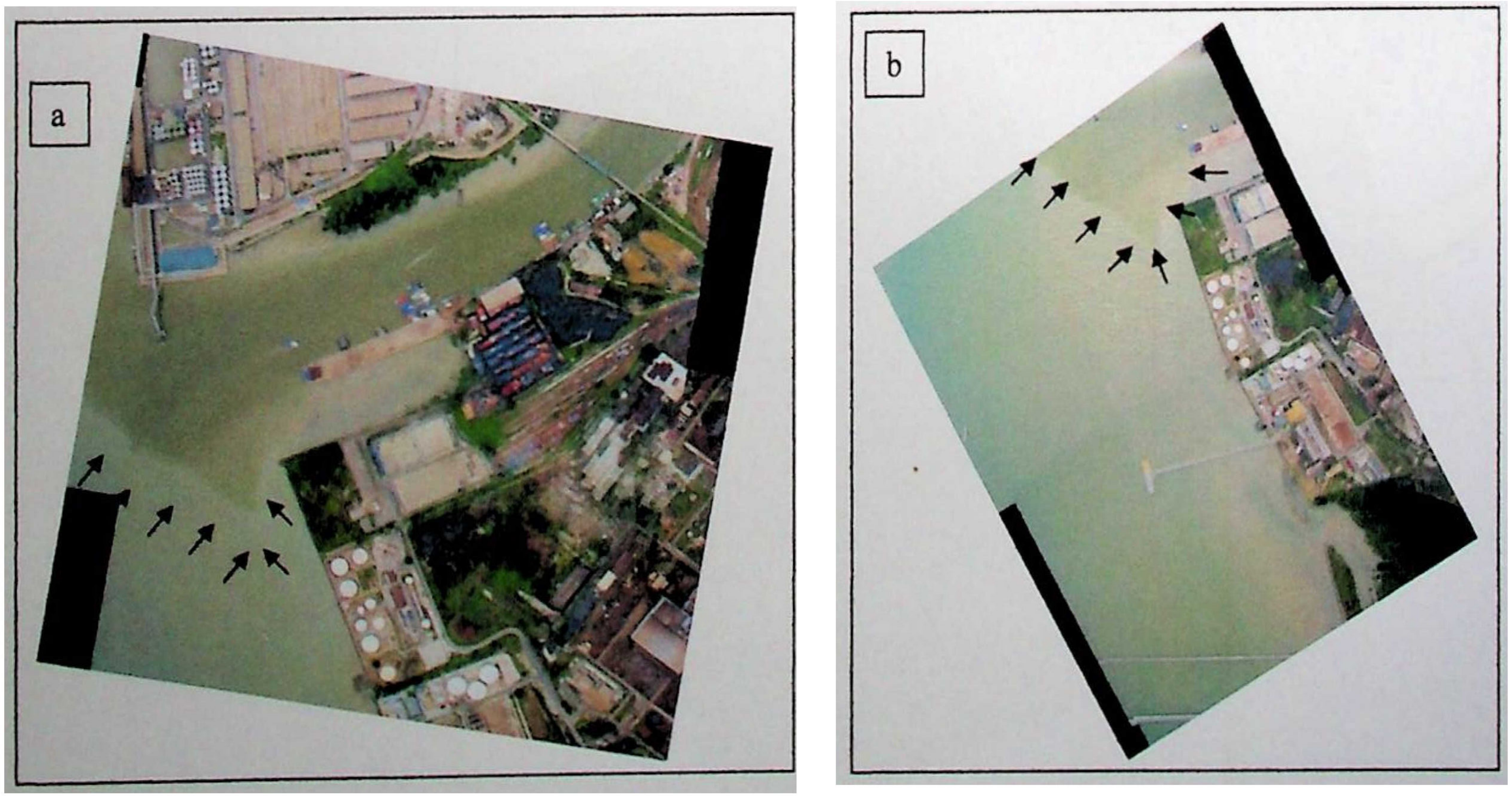


Figure 6.17 Sequence of aerial digital images over the Prai coastal water, showing the distinct edge of estuary plume, captured on 1 September 2003. The plume pattern was identified by field observation (TSS) during similar date (insert Figure).

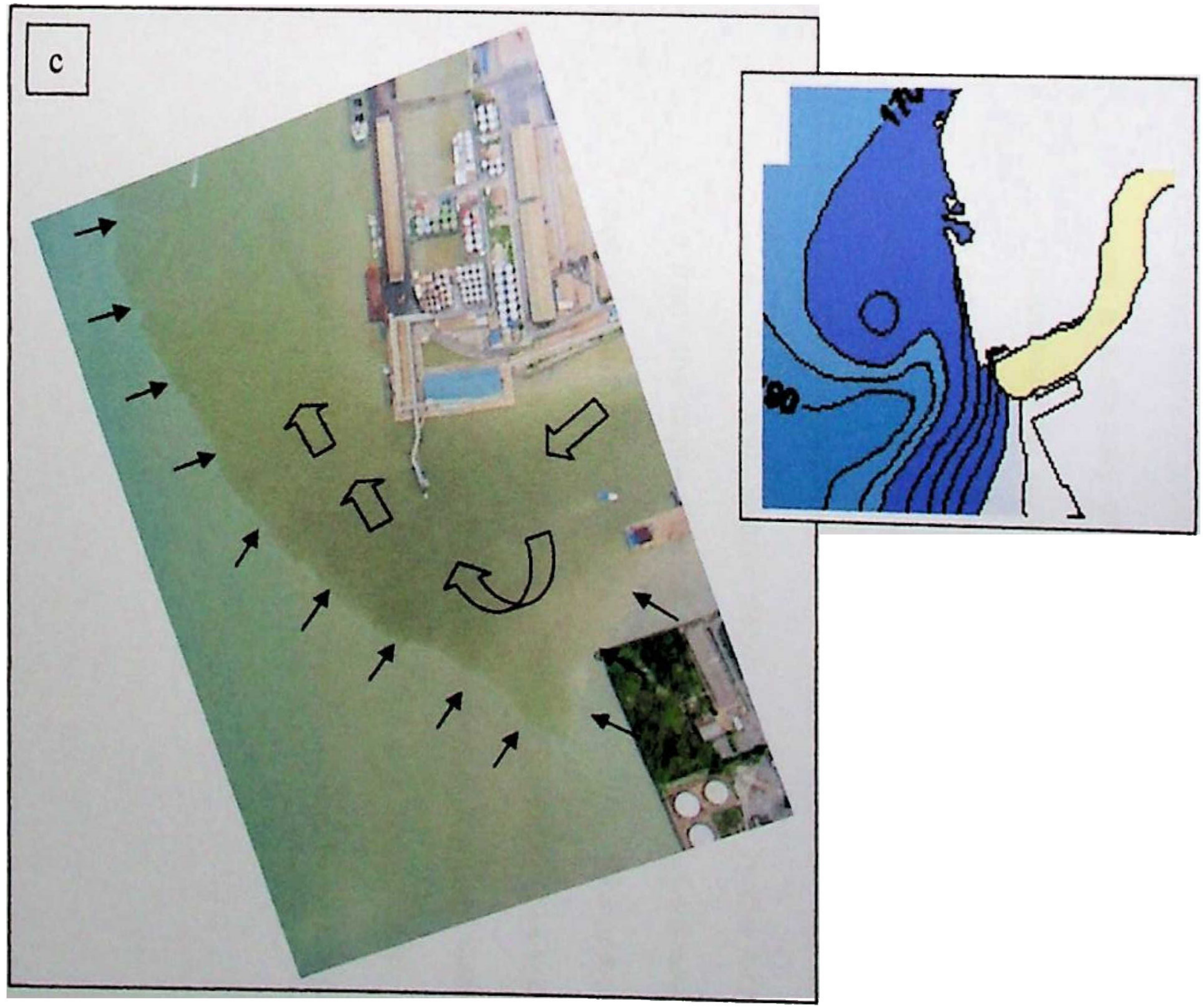


Figure 6.17 (*Continued*).

6.5 Summary of field surveys

The following section presents the results of the study in Prai coastal region. Table 6.1 shows a summary of characteristics for the parameters measured in each survey, including tidal condition, wind speed and direction, and rainfall condition. Tables 6.2 present data measured and collected in the coastal area and around the Prai Estuary mouth. This provides a good contrast of salinity, temperature and density between maximum and minimum values. Concentrations of water turbidity parameters, TSS and Secchi depth measured in the laboratory were always collected from the same stations in each survey with the salinity and temperature data that concentrated near the estuary mouth. Measurements taken near the estuary mouth were more representative of the processes that are occurring in the estuary and dependent on the characteristics of that river system. Contour maps of surface salinity, temperature, density, TSS and Secchi depth, including the survey station are presented and reported, for each survey in the Appendix C.

Table 6.1 Details of surveys to Prai coastal area (Penang Channels) during study period.

No.	Date dd/mm/yy	Tide	Wind*			Rainfall** (mm)	
			Speed (m/s)				
			mean	*max*	*Direction (deg)*	*Station BW*	*Station Prai*
1.	28/10/01	Neap (flood)	2	8.2	350 (NNW)	6.6	2.4
2.	14/03/02	Spring (flood)	2.5	10.1	310 (WNW)	0	0
3.	09/04/03	Neap (ebb)	2.3	11.6	140 (SSE)	34.7	0
4.	01/09/03	Neap (ebb to flood)	2.1	9	320 (NNW)	9.7	10.5
5.	02/09/03	Neap (ebb to flood)	1.9	11.5	310 (WNW)	13.7	1
6.	03/09/03	Neap (ebb)	1.9	6.2	300 (WNW)	0	0

Notes: * Base on observation at Butterworth meteorological station.
** Total rainfall in mm received on survey date, based on observation at Butterworth (*BW*) and Prai meteorological station

Table 6.2 Data measured (date ordered) on the Prai coastal area (Penang Channels) during study period.

No.	Date dd/mm/yy	Salinity (‰)		Temperature (^0C)		Density (kgm^{-3})		TSS (mgl^{-1})	Secchi depth (cm)
		min	*max*	*min*	*max*	*min*	*max*		
1.	28/10/01	18.0	29.5	29.8	31.6	8.0	17.0	80-170	80-220
2.	14/03/02	28.0	31.2	30.0	31.0	16.4	18.8	190-245	ND
3.	09/04/03	22.0	30.0	30.8	31.4	10.0	18. 0	165-215	ND
4.	01/09/03	12.0	32.0	28.8	30.0	6.0	19.0	51-205	30-70
5.	02/09/03	18.0	32.0	28.0	29.8	8.0	19.0	140-240	30-100
6.	03/09/03	16.0	32.0	28.8	31.0	7.0	19.0	80-170	30-90

ND : No data

Chapter Seven

Conclusions and Future Works

7.0 Conclusions

This chapter conclude important findings from the study of the physical characteristics in the Muda, Merbok and Prai estuaries and coastal waters. The all three study areas are located at the northwest of Peninsular Malaysia. The study describes surface and vertical distribution of several parameters namely salinity, temperature, density, TSS concentration, and Secchi depth record, in addition to a number of aerial imageries.

River discharge would produce fresher and less saline water at estuaries and coastal waters and the resulting estuary plume in the coastal water. The greater the discharge, the further seaward the low salinity plume would occur (see Table 7.1). Because of its larger catchment area, Muda River's discharge is larger than Prai and Mebok River. During field surveys, the lowest discharge of Muda River was about 15 m^3/s and the highest of about 210 m^3/s. The results demonstrate that during high discharge, the estuary plume can extend more than 4 km offshore and covered the area ≈ 30.0 km^2 for the Muda plume. However, Prai plume only extend about 2 km offshore with covered smaller plume area ≈ 13.5 km^2. This different distance and area of Muda and Prai plume is associated with different quantity of river discharge. The Muda plume horizontal extent, in low discharge cases were less than 1.5 km and reach ≈ 4 km for one case. In other cases there were no plume detected. Generally, the estuary plume water was confined to the surface layer of < 1.0 m water depth. Exceptional case in the Muda coastal water of survey on 8 November 2001, with the second highest survey on 8 November 2001, with the second highest discharge (> 170 m^3/s) during field surveys, the plume reached a maximum thickness of 5 m water depth. However, in the lower Merbok Estuary the lower salinity water (isohalines) was more evident near the estuary mouth due to the high river discharge. During low discharge, the invasion of freshwater in the lower Merbok Estuary was much less pronounced. Without the influence of tidal energy, the vertical patterns of salinity did not showed significant influence of river discharge in affected the water column stratification. The found results for the river discharge influences in the study areas are however very appropriate to the first hypothesis.

Table 7.1 The general results of area (km^2) and offshore extend (km) of estuary plume in the study areas.

River	Plume area (km^2)		Plume offshore extend (km)	
	High river discharge	*Low river discharge*	*High river discharge*	*Low river discharge*
Muda	≈ 30.0	< 10.0	≈ 4.0	< 1.5
Prai	≈ 13.5	< 5.0	≈ 2.0	< 1.0
Merbok	≈ 8.0	no plume	≈ 2.0	no plume

Temperature at the Muda plume, during high river discharge, the plume was consistently lower than that of the coastal seawater. Beside this, the temperature of the plume surface layer was higher than that at the bottom of the sea water. During low river discharge, the behavior of the Muda plume temperature could be both higher or lower than the coastal water temperature. Similar temperature trends was observed for the Merbok Estuary and Prai plume possibly due to low discharge phenomenon. Bigger amount of freshwater can dictate plume temperature compare to smaller amount of freshwater.

The results indicate that there is no clear correlation between river discharge and TSS concentrations in the Muda plume, Prai plume and Merbok Estuary. This suggests that the TSS concentrations at coastal water or lower estuary were not strongly associated with sediments discharge from the rivers. However, the other important factors could be more important that influences the TSS concentration and formation in the Muda and Prai plume, and Merbok Estuary.

Tides are responsible for the mixing, resuspension, or exchange processes of salt and freshwater in the study areas, combined with complex bathymetry and slightly by strong wind forcing. In the Muda and Prai plume waters, distributions of salinity varies according to spring-neap tidal cycle. During spring tide, the plume water was confined closer to the estuary mouth and further seaward during the neap tide. In the lower Merbok Estuary, isohaline were shifted upstream during the flood phase and shifted downstream during the ebb phase of the spring tide. The magnitude of the shifting was much less during the neap tides. The variations in the observed plume patterns, at least during ebb phase of spring tide are opposite with the postulation of the second hypothesis.

In the Muda coastal water and in the lower Merbok Estuary, during periods of low river discharges there is a spring-to-neap transition that changes the salinity structure from partially-mixed or homogenous (spring tide) to highly stratified (neap tide). This transition is less prominent under high river discharge conditions. The transition may be abrupt because of the interaction of vertical mixing and stratification; increased stratification during periods of decreasing tidal range before the neap tide inhibits mixing which, in turn, allows further increases in stratification. The process is reversed as tidal range increases after the neap.

TSS concentrations in all three study areas are closely related to the tidal forcing that resuspended the bottom sediments. There were consistently higher TSS concentrations of Muda and Prai plume waters and that of the Merbok Estuary during spring tides than in neap tides due to stronger spring tide energy. Except one neap tide case of survey on 28 October 2002 in Merbok Estuary, the higher TSS concentration could be caused by the other important factors. During spring tides, the Muda plume has maximum TSS concentration of about 260-440 mgl^{-1} and only 180-290 mgl^{-1} during neap tides. Beside, the Merbok Estuary has maximum TSS concentrations of about 204-366 mgl^{-1} during spring tide and during neaps were about 189-201 mgl^{-1}. However, the higher increasing of TSS concentration during spring tides may also lead to significant sediment export, if the spring tides correspond to periods of high river discharge. With relatively shallow depth coastal of the study areas, tidal energy mixes the waters and bring the bed material to the surface. During neap tide periods, the concentration of TSS in the coastal waters and estuaries were less than during spring tides periods. The intrusion of clear offshore waters and/or rapid settling of sediments due to decrease in tidal energy may be responsible for this difference.

The wind forcing within the study areas are generally very light and not particularly energetic. The daily mean wind speed was only 1.2 – 2.8 m/s in the study areas. No obvious correlation was found between the plume characteristics and the wind forcing, except for several cases during strong wind. The effect of mixing due to winds was limited to mainly surface layer. This is evident form the marked vertical salinity stratification that was observed at the subsurface layer, even during strong wind events. Under the influence of strong winds, in several cases the Muda plume can even reach further seaward i.e. several kilometres away from the estuary mouth and follow the wind direction. But in few strong wind cases, the Muda plume flows in the different (or opposite) direction with the wind direction. It was similar with Prai plume, but the plume spread closer to coastline. In the lower Merbok Estuary, even at strong wind speed only occasionally the brackish water direction in the coastal zone was consistent with the wind direction. During weak wind blow, the result shows a behaviour of brackish water movement independent from wind influence. In view of the above results and findings that shows the movement of the Muda and Prai plumes, and Merbok Estuary, the wind forcing was not the main factor and has minimal effect in influence the rotational veering of the plumes. As mention in the third hypothesis, the role that wind and variability play in the movement of a plume was not so significant in the study areas. It was most likely due to the other important factors and the wind forcing can be considered as supporting energy.

Remote sensing provides information on the two dimensional, surface structures of the estuary plumes. For case of Muda plume survey on 20 July 2001 with higher discharge of about 46 m^3s^{-1}, the plume develops into a large area that characterized by turbid water as seen from the digital image. Combined with field survey (TSS concentration), it was found similarly plume pattern. The plume has a TSS concentration of about 210-230 mgl^{-1} on the coastal water. In another field survey, both aerial image and TSS data shows the formation a small estuary plume in front of the estuary mouth, with turbid water having a TSS value of 280-290 mgl^{-1}. Survey of Prai plume in low discharge (on 28 October 2001), the digital image showed the movement of the plume that spread to coastal water and deflected to the south. The field data also showed similar pattern, with the plume represent the TSS value about 110-170 mgl^{-1}. The other closely pattern of Prai plume in aerial and field data also found in high discharge survey on 1 September 2003, the plume deflected to the north side instead. In the lower Merbok estuary, the pattern of the brackish and turbid water can not observed by digital camera due to limited spatial resolution it offers.

7.1 Recommendations and future work requirements

- The results presented in this thesis demonstrate that the characteristics of Muda, Merbok and Prai estuaries and coastal waters have an inter-dependent relationship with physical processes in the study areas and with hydrography conditions. Measurements taken in the study of the characteristics of estuary plume allow the relationship to be established between instantaneous changes to long term patterns. Based on the findings of this study, it is recommend additional long term monitoring for 12 hours, 24 hours and monthly to evaluate the performance of the methods.

- Several studies were conducted in order to achieve this overall objective, including field surveys, laboratory experiments, data evaluation and interpretation, aerial surveys and the review of the published literature. It is also recommend that the numerical model be further developed in terms of the sophistication of the modeling. It would be possible to have models for ever consented general conditions incorporated in the system.
- It is recommended that in future field research sediment-induced buoyancy effects on the turbulence be also investigated at their higher levels in the water column. Assessment of vertical and horizontal mean velocity and mean TSS profiles is also recommended if the detailed turbulence measurements are to be related to the overall properties of the tidal flow. Measurements of TSS upstream of the measuring location, for example, may aid in discriminating between temporal variations in TSS caused by local sediment-bed exchange processes and those caused by advective transports.
- The characteristics of turbidity related to environmental studies records have provided proof that the use of TSS concentrations and Secchi depth can provide a detailed picture of the sediment and pollution history within the estuaries and coastal waters. It is recommend that the analysis is extended to cover a wider area and included the subsurface layer in order to quantify the higher degree of pollution contained within the sediments and to enhance our understanding of the relationship between pollution and physical processes.

References

Alvarez, L.G. and Jones, S.E. (2002). Factors influencing suspended sediment flux in the upper Gulf of California. *Estuarine, Coastal and Shelf Science*, 54, 747-759.

Apan, A.A., Raine, S.R. and Paterson, M.S. (2002). Mapping and analysis of changes in the riparian landscape structure of the Lockyer Valley catchment, Queensland, Australia. *Landscape and Urban Planning*, 59, 43-57.

Arnau, P., Liquete, C. and Canals, M. (2004). River mouth plume events and their dispersal in the Northwestern Mediterranean Sea. *Oceanography*, 17, 22-31.

Atkinson, L.P., Levinson, A.V., Figueroa D., De Pol-Holz, R., Gallardo, V.A., Schneider, W., Blanco, J.L. and Schmidt, M. (2002). Oceanographic observations in Chilean coastal waters between Valdivia and Concepcion. *Journal of Geophysical Research*, 107, 6-7.

Aubertot, P.B. and Echevin, V. (2002). The influence of the coast on the dynamics of upwelling fronts. Part II. Numerical simulations. *Dynamics Atmospheres and Oceans*, 36, 175-200.

Bakar, M.N.A., Abdullah. K., Rahman, A.H.A. and Jafri, M.Z.M. (2004). Estuarine variability in the Merbok Estuary, Malaysia. *ISG-3 Egypt, April 2004*, 470-473.

Basnyat, P., Teeter, L.D., Lockaby, B.G. and Flynn, K.N. (2000). The use of remote sensing and GIS in watershed level analyses of non-point source pollution problems. *Forest Ecology and Management*, 128, 65-73.

Bean, J.H. (1969). The iron-ore deposits of West Malaysia. *Geological Survey West Malaysia*. Economic Bulletin 2.

Black, K.P., Kurian, N.P., Mathew, J. and Baba, M. (2004). Open tropical beach dynamics. *Journal of Coastal Research*, Summer 2004, 1-12.

Blanton, J.O., Alber, M. and Sheldon, J. (2001). Salinity response of the Satilla River estuary to seasonal changes in freshwater discharge. *Proceedings of the 2001 Georgia Water Resources Conference*, the University of Georgia. Kathryn J. Hatcher, *editor*, Institute of Ecology, The University of Georgia, Athens, Georgia.

Blanton, J.O., Lin, G. and Elston, S.A. (2002). Tidal current asymmetry in shallow estuaries and tidal creeks. *Continental Shelf Research*, 22, 1731-1743.

Bowden, K.F. and El Din, S.H.S. (1966). Circulation, salinity and river discharge in the Mersey Estuary. *Geophys. J. R. A. S.*, 10, 383-399.

Bowers, D.G., Boudjelas, S. and Harker, G.E.L. (1998). The distribution of fine suspended sediments in the surface waters of the Irish Sea and its relation to tidal stirring. *Int. Journal of Remote Sensing*, 19, 2789-2805.

Broche, P., Devenon, J.L., Forget, P., de Maistre, J.C., Naudin, J.J. and Cauwet, G. (1998). Experimental study of the Rhone plume. Part I: physics and dynamics. *Oceanologica Acta*, 21, 725-738.

Burrage, D.M., Heron, M.L., Hacker, J.M., Miller, J.L., Steglitz, T.C., Steinberg, C.R. and Prytz, A. (2003). Structure and influence of tropical river plumes in the Great Barrier Reef: application and performance of an airborne sea surface salinity mapping system, *Remote Sensing of Environment*, 85, 204-220.

Carstensen, J., Conley, D.J., Andersen, J.H. and Aertebjerg, G. (2006). Coastal eutrophication and trend reversal: A Danish case study. *Limnology Oceanography*, 51, 398-408.

Chao, S.Y. (1998). Hyperpycnal and buoyant plumes from a sediment-laden river. *Journal of Geophysical Research,* 103 (C2), 3067-3081.

Chen, J.C., Li, D.J., Chen, B., Hu, F., Zhu, H. and Liu, C. (1999). The processes of dynamic sedimentation in the Chiangjiang Estuary. *Journal of Sea Research*, 41, 129-140.

Chiavassa, S.A., Durand, N., Rey, V. and Fraunie, P. (1995). Three dimensional modeling of the Rhone deltaic fringe. Proceedings of 2nd International Conference on the Mediterranean Coastal Environment. Tarragona, Spain.

Christiansen, C., Edelvang, K., Emeis, K., Graf, G., Ja¨hmlich, S., Kozuch, J., Laima, M., Leipe T., Loffler, A., Lund-Hansen, L. C., Miltner, A., Pazdro, K., Pempkowiak, J., Shimmield, G., Shimmield, T., Smith, J., Voss, M. and Witt, G. (2002). Material transport from the nearshore to the basinal environment in the southern Baltic Sea: Processes and mass estimates. *Journal of Marine Systems*, 35, 133-150.

Cobby, D.M., Mason, D.C. and Davenport, I.J. (2001). Image processing of airborne scanning laser altimetry data for improved river flood modeling. *ISPRS Journal of Photogrammetry & Remote Sensing*, 56, 121-138.

Conley, D.C. (1999). Observations on the impact of a developing inlet in a bar built estuary. *Continental Shelf Research*, 19, 1733-1754.

Courtier, D.B. (1974). Geology and mineral resources of the neighbourhood of Kulim, Kedah, Geology Survey of Malaysia. Map Bulletin 3.

Cummins, P.F. and Oey, L.Y. (1997). Simulation of barotropic and baroclinic tides off Northern British Columbia, *Journal of Physical Oceanography*, 27, 762-781.

Curran, K.J., Hill, P.S. and Milligan, T.G. (2002). Fine-grained suspended sediment dynamics in the Eel River flood plume. *Continental Shelf Research*, 22, 2537–2550.

D'Sa, E.J. and Miller, R.L. (2003). Bio-optical properties in waters influenced by the Mississippi River during low flow conditions. *Remote Sensing of Environment,* 84, 538-549.

D'Sa, E.J., Zaitzeff, J.B. and Steward R.G. (2000). Monitoring water quality in Florida Bay with remotely sensed salinity and in situ bio optical observations. *International Journal of Remote Sensing*, 21, 811-816.

Da Silva, J.F., Duck, R.W., Anderson, J.M., McManus, J. and Monk, J.G.C. (2001). Airborne observations of frontal systems in the inlet channel of the Ria de Aveiro, Portugal. *Phys. Chem. Earth (B),* 26, 713-719.

Dagg, M., Benner, R., Lohrenz, S., Donnell, J.O. and Lawrence, D. (2001). Transport and transformation of dissolved and particulate materials on continental shelves influenced by large rives: plume processes. *Louisiana University Marine Consortium.* Chauvin LA.

Dagg, M., Benner, R., Lohrenz, S. and Lawrence, D. (2004). Transformation of dissolved and particulate materials on continental shelves influenced by large rives: plume processes. *Continental Shelf Research*, 24, 833-858.

Davies, A.M. and Xing, J. (2001). Modelling processes influencing shelf edge currents, mixing, across shelf exchange, and sediment movement at the shelf edge. *Dynamics of Atmospheres and Oceans*, 34, 291-326.

Davies, P.A. and Ahmed, I. (1996). Laboratory studies of a round, negatively buoyant jet discharged horizontally into a rotating homogeneous fluid. *Fluid Dynamics Research*, 17, 137-274.

Delcroix, T. (2002). Sea surface salinity changes in the East China Sea during 1997–2001: Influence of the Yangtze River. *Journal of Geophysical Research.* 107, C-12. 9-1–9-12.

Dellapenna, T.M., Kuehl, S.A. and Schaffner, L.C. (2003). Ephemeral deposition, seabed mixing and fine-scale strata formation in the York River estuary, Chesapeake Bay. *Estuarine, Coastal and Shelf Science.* 58, 621-643.

Devlin, M.J. and Brodie J. (2005). Terrestrial discharge into the Great Barrier Reef Lagoon: nutrient behavior in coastal waters. *Marine Pollution Bulletin*, 51, 9-22.

De Ruijter, W.P.M., Visser, A.W. and Bos, W.G. (1997). The Rhine outflow: A prototypical pulsed discharge plume in a high energy shallow sea. *Journal of Marine System*, 12, 263-276.

DiGiacomo, P.M., Washburn, L., Holt, B. and Jones, B.H. (2004). Coastal pollution hazards in southern California observed by SAR imagery: stormwater plumes, wastewater plumes, and natural hydrocarbon seeps. *Marine Pollutant Bulletin.* 49, 1013-1024.

Dippner, J.W. (1993). A frontal-resolving model for the German Bight. *Continental Shelf Research*, 13, 49–66.

Dong, L., Su, J., Wong, L.A., Cao, Z. and Chen, J.C. (2004). Seasonal variation and dynamics of the Pearl River plume. *Continental Shelf Research*, 24, 1761–1777.

Durand, N., Fiandrino, A., Fraunie, P., Ouillon, S., Forget, P. and Naudin, J.J. (2002). Suspended matter dispersion in the Ebro ROFI: an integrated approach. *Continental Shelf Research*, 22, 267–284.

Dyer, K.R., Christie, M.C. and Manning, A.J. (2004). The effects of suspended sediment on turbulence within an estuarine turbidity maximum. *Estuarine, Coastal and Shelf Science*, 59, 237-248.

Dyer, K.R., Gong, W.K. and Ong, J.E. (1992). The cross sectional salt balance in a tropical estuary during a lunar tide and a discharge event. *Estuarine, Coastal and Shelf Science*, 34, 579-591.

Dymond, C.C. and Johnson, E.A. (2002). Mapping vegetation spatial patterns from modeled water, temperature and solar radiation gradients. *ISPRS Journal of Photogrammetry & Remote Sensing*, 57, 69-85.

Elliott, M. and McLusky, D.S. (2002). The need for definitions in understanding estuaries. *Estuarine, Coastal and Shelf Science*, 55, 815-827.

Emeis, K., Christiansen, C., Edelvang, K., Jahmlich, S., Kozuch, J., Laima, M., Leipe, T., Loffler, A, L.C. Lund-Hansen, L. C., Miltner, A., Pazdro, K., Pempkowiak, J., Pollehne, F., Shimmield, T., Voss, M. and Witt, G. (2002). Material transport from the near shore to the basinal environment in the southern Baltic Sea: Synthesis of data on origin and properties of material. *Journal of Marine System*, 35, 151-168.

Estournel, C., Broche, P., Marsaleix, P., Devenon, J.L., Auclair, F. and Vehil, R. (2001). The Rhone River plume in unsteady conditions: numerical and experimental results. *Estuarine, Coastal and Shelf Science*, 53, 25-38.

Fennel, W. and Mutzke, A. (1997). The initial evolution of a buoyant plume. *Journal of Marine System*, 12, 53-68.

Fernandes, E.H.L, Dyer, K.R. and Moller, O.O. (2005). Spatial gradients in the flow of southern Patos Lagoon. *Journal of Coastal Research*, 21, 759-769.

Foda, M.A. and Hill, D.F. (1998). Nonlinear Energy Transfer from semidiurnal barotropic motion to near-inertial baroclinic motion. *Journal of Physical Oceanography*, 28, 1865-1872.

Fofonoff, N.P. and Millard, Jr. R.C. (1983). Algorithms for computation of fundamental properties of seawater. *UNESCO technical papers in marine science*, 44.

Fugate, D.C. and Friedrichs, C.T. (2003). Controls on suspended aggregate size in partially mixed estuaries. *Estuarine, Coastal and Shelf Science*, 58, 389-404.

Garvine, R.W. (1999). Penetration of buoyant coastal discharge onto the continental shelf: a numerical model experiment. *Journal of Physical Oceanography*, 29, 1892-1909.

Garvine, R.W. (1995). A dynamical system for classifying buoyant coastal discharges. *Continental Shelf Research*, 15, 1585-1596.

Garvine, R.W. (1987). Estuary plumes and fronts in shelf waters: a layer model. *Journal of Physical Oceanography*, 17, 1877-1896.

Garvine, R.W. (1986). The role of brackish plumes in open shelf waters, In: *The role of freshwater outflow in coastal marine ecosystem. NATO ASI Series*, G7, 47-66.

Garvine, R.W. (1984). Radial spreading of buoyant, surface plumes in coastal waters. *Journal of Geophysical Research*, 89, 1989-1996.

Gelfenbaum, G. and Stumpf, R.P. (1993). Observations of currents and density structure across a buoyant plume front. *Estuaries*, 16, 40-52.

Geyer, W.R., Hill, P. S. and Kineke, G.C. (2004). The transport, transformation dispersal of sediment by buoyant coastal flows. *Continental Shelf Research*, 24, 927-949.

Geyer, W.R., Hill, P., Milligan, T. and Traykovski, P. (2000). The structure of the Eel River plume during floods. *Continental Shelf Research*, 20, 2067-2093.

Giardino, C., Pepe, M., Brivio P.A., Ghezzi, P. and Zilioli, E. (2001). Detecting chlorophyll, Secchi disk depth and surface temperature in a sub-alpine lake using Landsat imagery. *The Science of the Total Environment*, 268, 19-29.

Goni, M.A., Teixeira, M.J. and Perkey, W.W. (2003). Sources and distribution of organic matter in a river-dominated estuary (Winyah Bay, SC, USA). *Estuarine, Coastal and Shelf Science*, 57, 1023-1048.

Greenberg, A.E., Clesceri, L.S. and Eaton, A.D. (1992). Standard Methods for the Examination of Water and Wastewater. *American Public Health Association (APHA)*, Washington.

Gross, B.D. (1997). The Effect of Compressibility on barotropic and baroclinic instability. *Journal of Atmospheric Sciences*, 54, 24-31.

Guo, X. and Levinson, A.V. (2004). Tidal effects on estuarine circulation in the Chesapeake Bay. *Center for Marine Environmental Studies*, Ehime University, Matsuyama, Japan.

Gustafsson, O., Widerlund, A., Andersson, P.S., Ingri, J., Roos, P. and Ledin, A. (2000). Colloid dynamics and transport of major elements through a boreal river - brackish bay mixing zone. *Marine Chemistry*, 71, 1-21.

Hakvoort, H., de Haana, J., Jordansa, R., Vosb, R., Petersb, S. and Rijkeboerb, M. (2002). Towards airborne remote sensing of water quality in The Netherlands-validation and error analysis. *ISPRS Journal of Photogrammetry & Remote Sensing*, 57, 171– 183.

Haren, H.V. (2001). Estimates of sea level, waves and winds from a bottom-mounted ADCP in a shelf sea. *Journal of Sea Research*, 45, 1-14.

Harms, I.H., Karcher, M.J. and Dethleff, D. (2000). Modelling Siberian river runoff - implications for contaminant transport in the Arctic Ocean. *Journal of Marine Systems*, 27, 95-115.

Hearn, C.J. and Robson, B.J. (2002). On the effects of wind and tides on the hydrodynamics of a shallow mediterranean estuary. *Continental Shelf Research*, 22, 2655-2672.

Hill, P.S., Milligan, T.G. and Geyer, W.R. (2000). Controls on effective settling velocity of suspended sediment in the Eel River flood plume. *Continental Shelf Research*, 20, 2095-2111.

Hitchcock G.L., Wiseman Jr. W.J., Boicourt W.C., Mariano A.J., Walker N., Nelsen T.A. and Ryan E. (1997). Properties fields in an effluent plume of the Mississippi River. *Journal of Marine System*, 12, 109-126.

Hossain, S., Eyre, B. and McConchie, D. (2001). Suspended sediment transport dynamics in the sub-tropical micro-tidal Richmond River estuary, Australia. *Estuarine, Coastal and Shelf Science*, 52, 529-541.

Hu, C., Carder, K.L. and Karger, F.E.M. (2000). Atmospheric correction of SeaWiFS imagery over turbid coastal waters: a practical method. *Remote Sensing and Environment*, 74, 195-206.

Huyer, A., Fleischbein, J.H., Keister, J., Kosro, P.M., Perlin, N., Smith R,L. and Wheeler P.A. (2005) Two coastal upwelling domains in the northern California Current system. *Journal of Marine Research*, 63, 901-929.

http://www.wetlands.org/wiseUse/ WW/past/ wwvol-2/spotlight

Ilahude, A.G., Hortle, K., Kusmanto, E. and Amiruddin. (2004). Oceanography of coastal and riverine waters around Timika, West Central Irian Jaya, Arafura Sea. *Continental Shelf Research*, 24, 2511-2520.

Ingram, R.G. (1981). Characteristics of the Great Whale River plume. *Journal of Geophysical Research*, 86, 2017-2030.

Islam, M.R., Begum, S.F., Yamaguchi, Y. and Ogawa, K. (2002). Distribution of suspended sediment in the coastal area off the Ganges-Brahmaputra River mouth: observation from TM data. *Journal of Marine Systems*, 32, 307-321.

Ismail, W.R. (1992). Variation of sediment yield of tropical basin: a case of Muda basin, Kedah, Malaysia. *Kajian Malaysia*, 2, 39-48.

Jacobsen, F., Azam, M.H. and ul-Kabir, M.M. (2002). Residual Flow in the Meghna Estuary on the Coastline of Bangladesh. *Estuarine, Coastal and Shelf Science*, 55, 587-597.

James, I.D. (1997). A numerical model of the development of anticyclonic circulation in a gulf-type region of freshwater influence. *Continental Shelf Research*, 17, 1803-1816.

James, I.D. (2002). Modelling pollution dispersion, the ecosystem and water quality in coastal waters: a review. *Environmental Modelling & Software*, 17, 363-385.

Jilan, S. (2004). Overview of the South China Sea circulation and its influence on the coastal physical oceanography outside the Pearl River Estuary. *Continental Shelf Research*, 24, 1745-1760.

Johnson, D.R., McClimans, T.A., King, S. and Grenness, Φ. (1997). Fresh water masses in the Kara Sea during summer. *Journal of Marine Systems*, 12, 127-145.

Joordens, J.C., A., Souza, A.J. and Visser, A. (2001). The influence of tidal straining and wind on suspended matter and phytoplankton distribution in the Rhine outflow region, *Continental Shelf Research*, 21, 301-325.

Karabashev, G., Evdoshenko, M. and Sheberstov, S. (2002). Penetration of coastal waters into the Eastern Mediterranean Sea using the SeaWiFS data. *Oceanologica Acta*, 25, 31-38.

Keller, G.H. and Richards, A.F. (1967) Sediments of the Malacca Strait, Southeast Asia. *Journal of Sedimentary Petrology*, March, 102-127.

Khondaker, A.N. (2000). Modeling the fate of drilling waste in marine environment - an overview. *Computer & Geosciences*, 26, 531-540.

Kirincich, A.R. and Hebert, D. (2005). The structure of the coastal density front at the outflow of Long Island Sound during spring 2002. *Continental Shelf Research*, 25, 1097-1114.

Kourafalou, V.H. (2001). River plume development in semi enclosed Mediterranean regions: North Adriatic Sea and Northwestern Aegean Sea. *Journal of Marine Systems*, 30, 181-205.

Lahet, F., Ouillon, S. and Forget, P. (2000). A three component model ocean color and its application in the Ebro River mouth area. *Remote Sensing of Environment*, 72, 181-190.

Levinson, A.V., Li, C., Royer, T.C. and Atkinson, L.P. (1998). Flow patterns at the Chesapeake Bay entrance. *Continental Shelf Research*, 18, 1157-1177.

Lewis, R.E. (1984). Circulation and mixing in estuary outflows. *Continental Shelf Research*, 3, 201-204.

Li, M., Gargett, A. and Denman, K. (1999). Seasonal and Internannual Variability of Estuarine Circulation in a Box Model of the Strait of Georgia and Juan de Fuca Strait. *Atmosphere Ocean*, 37, 1-19.

Liew, S.C., Kam, S.P., Tuong, T.P., Chen, P., Minh, V.Q. and Lim, H. (1998). Application of multitemporal ERS-2 synthetic aperture radar in delineating rice cropping systems in the Mekong River delta, Vietnam. *IEEE Transactions on Geoscience and Remote Sensing*, 36, 1412-1420.

Liu, J.T., Zarillo, G.A. and Surak, C.R. (1997). The influence of river discharge on hydrodynamics and mixing in a subtropical lagoon. *Journal of Coastal Research*, 13, 1016-1034.

Liu, J.T., Chao, S.Y. and Hsu, R.T. (1999). The influence of suspended sediments on the plume of a small mountainous river. *Journal of Coastal Research*, 15, 1002-1010.

Liu, J.T., Chao, S.Y. and Hsu, R.T. (2002). Numerical modeling study of sediment dispersal by a river plume. *Continental Shelf Research*, 22, 1745-1773.

Liu, J.T., Liu, K. and Huang, J.C. (2002a). The effect of a submarine canyon on the river sediment dispersal and inner shelf sediment movements in southern Taiwan. *Marine Geology*, 181, 357-386.

Liu, J.T. and Lin, H.L. (2004). Sediment dynamics in a submarine canyon: a case of river–sea interaction. *Marine Geology*, 207, 55–81.

Liu, K.K., Atkinson, L., Chen, C.T.A., Gao, S., Hall, J., Macdonald, R.W., Talaue, L., McManus. and Quinones, R. (2000). Are continental margin carbon fluxes significant to the global ocean carbon budget? *National Centre for Ocean Research*, Taipei, Taiwan.

Lohani, B. and Mason, D. C. (2001). Application of airborne scanning laser altimetry to the study of tidal channel geomorphology. *IPRS Journal of Photogrammetry & Remote Sensing*, 56, 100-120.

Luketina, D.A. and Imberger, J. (1987). Characteristics of a surface buoyant jet. *Journal of Geophysical Research*, 92, 5435-5447.

MacKay, H.M. and Schumann, E.H. (1990). Mixing and circulation in the Sundays River estuary, South Africa. *Estuarine, Coastal and Shelf Science*, 31, 203-216.

Mantovanelli, A., Marone, E., da Silva, E.T., Lautert, L.F., Klingenfuss, M.S., Prata Jr, V.P., Noernberg, M.A., Knoppers, B.A. and Angulo, R.J. (2004). Combined tidal velocity and duration asymmetries as a determinant of water transport and residual flow in Paranagua´ Bay estuary. *Estuarine, Coastal and Shelf Science*, 59, 523-537.

Mao, Q., Shis, P., Yin, K., Gan, J. and Qi, Y. (2004). Tides and tidal currents in the Pearl River Estuary. *Continental Shelf Research*, 24, 1797-1808.

Marmorino, G.O., Donato, T.F., Sletten, M.A. and Trump, C.L. (2000). Observations of an inshore front associated with the Chesapeake Bay outfow plume. *Continental Shelf Research*, 20 665-684.

Matsuno, T., Shigeoka, M., Tamaki, A., Nagata, T. and Nishimura, K. (1999). Distributions of water masses and current in Tachibana Bay, West of Ari-ake Sound, Kyusu, Japan. *Journal of Oceanography*, 55, 515-529.

McCool, W.W. and Parsons, D. (2004). Sedimentation from buoyant fine-grained suspensions. *Continental Shelf Research*, 24, 1129-1142.

Mohrholz, V., Lass, H.U. and Mutzke, A. (1999). Dynamic of river plumes in the Pomeranian Bight. *ICES Journal of Marine Science*, 56 supplement, 84-86.

Morehead, M.D. and Syvitsky, J.P. (1999). River plume sedimentation modeling for sequence stratigraphy: application to the Eel margin, northern California. *Marine Geology*, 154, 29-41.

Mullenbach, B. L. and Nittrouer, C. A. (2000). Rapid deposition of fluvial sediment in the Eel Canyon, northern California. *Continental Shelf Research*, 20, 2191-2212.

Murota A. and Nakatsuji, K. (1988). Spreading of a river plume: Field observations, integral model analyes and numerical experiments. In: *Physical processes in estuaries*, Dronkers, J. and Van Leussen, W. (Eds.). Springer-Verlag, Berlin Heidelber, 110-129.

Narayanan, C. and Garvine, R.W. (2002). Formation of a shelfbreak front by freshwater discharge. *Dynamics of Atmospheres and Oceans*, 36, 103-124.

Naudin, J.J., Cauwet, G., Dinet, M.J.C., Deniaux, B., Devenon, J.L. and Pauc, H. (1997). River discharge and wind influence upon particulate transfer at the land-ocean interaction: case study of the Rhone River plume. *Estuarine, Coastal and Shelf Science*, 45, 303-316.

Naudin, J.J., Cauwet, G., Fajon C., Oriol L., Terzic S., Devenon, J.L. and Broche P. (2001). Effect of mixing on microbial in the Rhone River plume. *Journal of Marine System*, 28, 203-227.

Neill, S.P., Copeland, G.J.M., Ferrier, G. and Folkard, A.M. (2004). Observations and numerical modelling of a non-buoyant front in the Tay Estuary, Scotland. *Estuarine, Coastal and Shelf Science*, 59, 173-184.

O'Donnell, J. (1990). The formation and fate of a river plume: a numerical model. *Journal of Physical Oceanography*, 20, 551-569.

Ogston, A.S., Chacchione, D.A., Sternberg, R.W. and Kineke, G.C. (2000). Observations of storm and river flood-driven sediment transport on the northern California continental shelf. *Continental Shelf Research*, 20, 2141-2162.

Ogston, A.S., Guerra, J.V. and Sternberg, R.W. (2004). Interannual variability of nearbed sediment flux on the Eel River shelf, northern California. *Continental Shelf Research*, 24, 117-136.

Ogston, A.S. and Sternberg, R.W. (1999). Sediment-transport events on the northern California continental shelf. *Marine Geology*, 154, 69-82.

Omstedt, A. and Axell, L.B. (2003). Modeling the variations of salinity and temperature in the large Gulfs of the Baltic Sea. *Continental Shelf Research*, 23, 265-294.

Ong, J.E., Gong, W.K. and Uncles, R.J. (1994). Transverse structure of semidiurnal currents over a cross section of the Merbok Estuary, Malaysia. *Estuarine, Coastal and Shelf Science*, 38, 283-290.

Ong, J.E., Gong, W.K., Wong, C.H., Din, Z.H. and Kjerfve, B. (1991). Characterization of a Malaysian mangrove estuary. *Estuaries*, 14, 38-48.

Orton, P.M. and Jay, D.A. (2005). Observations at the tidal plume front of a high-volume river outflow. *Geophysical Research Letter*, 32, L11605.

Pinones, A., Levinson, A.V., Narvaez, D.A., Vargas, C.A., Navarrete, S.A., Yuras, G. and Castilla, J.C. (2002). Wind-induced diurnal variability in river plume motion. *Estuarine, Coastal and Shelf Science*, 65, 513-525.

Pope, R.M., Weidemann, A.D. and Fry, E.S. (2000). Integrating cavity absorption meter measurements of dissolved substances and suspended particles in ocean water. *Dynamics of Atmospheres and Oceans*, 31, 307-320.

Poulos, S.E. and Collins, M.B. (1994). Effluent diffusion and sediment dispersion at microtidal river mouths, predicted using mathematical model. *Estuarine, Coastal and Shelf Science*, 38, 189-206.

Pritchard, D.W. (1967). What is an estuary: a physical viewpoint. *American Association for the Advancement of Science*, 83, 3-5.

Pritchard, M. and Huntley, D.A. (2002). Instability and mixing in a small estuarine plume front. *Estuarine, Coastal and Shelf Science*, 55, 275-285.

Pulliainen, J., Kallio, K., Eloheimo, K., Koponen, S., Servomaa, H., Hannonen, T., Tauriainen, S. and Hailikainen, M. (2001). A semi-operative approach to lake water quality retrieval from remote sensing data. *The science of the Total Environment*, 268, 79-93.

Ramaswamy, V., Rao, P.S., Rao, K.H., Thwin, S., Rao, N.S. and Raiker, V. (2004). Tidal influence on suspended sediment distribution and dispersal in the northern Andaman Sea and Gulf of Martaban. *Marine Geology*, 208, 33-42.

Restrepo, J.D. and Kjerfve, B. (2002). The San Juan Delta, Colombia: tides, circulations, and salt dispersion. *Continental Shelf Research*, 22, 1249-1267.

Robertson, R. (2004). Baroclinic and barotropic tides in the Weddell Sea. *For submission to Antarctic Science*, July 15, 2004.

Ruddick, K.G., Deleersnijder, E., Luyten, P.J. and Ozer, J. (1995). Haline stratification in the Rhine-Meuse freshwater plume: a three dimensional model sensitivity analysis. *Continental Shelf Research*, 15, 1597-1630.

Santos, A.M.P. (2000). Fisheries oceanography using satellite and airborne remote sensing methods: a review. *Fisheries Research*, 49, 1-20.

Savory, E. and Toy, N. (2000). Estimation of total circulation within a plume in a crosswind. *Atmospheric Environment*, 34, 1655-1658.

Sayin, E. (2003). Physical features of the Izmir Bay. *Continental Shelf Research*, 23, 957-970.

Schallenberg, M. and Krebsbach, A. (2001). Salinity in the Taieri Estuary and the Waipori/ Waihola Lake-Wetland complex, summer and autumn, 2001 - A Brief Report. *Limnology Report* No. 6, Department of Zoology, University of Otago, Dunedin.

Scheunders, P. (2001). Local mapping for multispectral image visualization. *Image and Vision Computing*, 19, 971-978.

Schott, J.R., Barsi, J.A., Nordgren, B.L., Raqueno, N.G. and de Alwis, D. (2001). Calibration of landsat thermal data and application to water resource studies. *Remote Sensing of Environment*, 78, 108-117.

Schroeder, W.W., Dinnel, S.P. and Wiseman, JR. W.J. (1990) Salinity stratification in a river dominated estuary. *Estuaries*, 13, 145-154.

Scully, M., Friedrichs, C. and Brubaker, J. (2004). Control of estuarine stratification and mixing by wind induced straining of the estuarine density field. *Physics of Estuaries and Coastal Seas (PECS) Conference* 22, 1951-1974.

Scully, M.E., Friedrichs, C.T. and Wright, L.D. (2002). Application of an analytical model of critically stratified gravity-driven sediment transport and deposition to observations from the Eel River continental shelf, Northern California. *Continental Shelf Research*, 22, 1951-1974.

Seim, H.E., Blanton, J.O. and Gross, T. (2002). Direct stress measurements in a shallow, sinuous estuary. *Continental Shelf Research*, 22, 1565-1578.

Shafique, N.A., Autrey, B.C., Fulk, F. and Cormier, S.M. (2003). The Selection of narrow wavebands for optimizing water quality monitoring on the Great Miami River, Ohio using Hyperspectral Remote Sensor Data. *Journal of Spatial Hydrology*, 1-22.

Shearman, R.K. and Lentz, S.J. (2004). Observations of tidal variability on the New England shelf. *Journal of Geophysical Research*, 109, 1-16.

Siddorn, J.R., Bowers D.G. and Hoguane, A.M. (2001). Detecting the Zambezi River plume using observed optical properties. *Marine Pollutant Bulletin*, 42, 942-950

Siegel, H. and Gerth, M. (2000). Satellite-Based Studies of the 1997 Oder Flood Event in the Southern Baltic Sea. *Remote Sensing and Environment*, 73, 207-217.

Sierra, J.P., Arcilla, A.S., Del Rio, J.G., Flos, J., Movellan, E., Mosso, C., Martinez, R., Rodilla, M., Falco., S. and Romero, I. (2002). Spatial distribution of nutrients in the Ebro estuary and plume. *Continental Shelf Research*, 22, 361-378.

Simpson, J.H. and Sharples, J. (1994). Does the Earth's rotation influence the location of the shelf sea fronts?. *Journal of Geophysical Research*, 99, 3315-3319.

Smith, Jr. W.O. and Demaster, D.J. (1996). Phytoplankton biomass and productivity in the Amazon River plume: correlation with seasonal river discharge. *Continental Shelf Research*, 16, 291-319.

Smyth, T.J., Miller, P.I., Groom, S.B. and Lavender, S.J. (2001). Remote sensing of sea surface temperature and chlorophyll during Lagrangian experiments at the Iberian margin. *Progress in Oceanography*, 51, 269-181.

Soares, I. and Moller, Jr.O. (2001). Low-frequency currents and water mass spatial distribution on the southern Brazilian shelf. *Continental Shelf Research*, 21, 1785-1814.

Stanev, E.V. and Beckers, J.M. (1999). Barotropic and baroclinic oscillations in strongly stratified ocean basins numerical study of the Black Sea. *Journal of Marine System*, 19, 65-112.

Syvitski, J.P.M. and Bahr, D.B. (2001). Numerical models of marine sediment transport and deposition. *Computer & Geosciences*, 27, 617-618.

Syvitski, J.P.M. and Morehead, M.D. (1999). Estimating river-sediment discharge to the ocean: application to the Eel margin, northern California, *Marine Geology*, 154, 13–28.

Talke, S.A. and Stacey, M.T (2003). The influence of oceanic swell on flows over an estuarine intertidal mudflat in San Francisco Bay. *Estuarine, Coastal and Shelf Science*, 58, 541-554.

Tang, D.L., Kester, D.R., Ni, I.H., Qi, Y.Z. and Kawamura, H. (2003). In situ and satellite observations of a harmful algal bloom and water condition at the Pearl River estuary in late autumn 1998. *Harmful Algae*, 2, 89-99.

Tapia, F.J., Pineda, J., Tores F.J.O., Fuchs, H.L., Parnell, P.E., Montero, P. and Ramos, S. (2004). High-frequency observations of wind-forced onshore transport at a coastal site in Baja California. *Continental Shelf Research*, 24, 1573-1585.

Tattersall, G.R., Elliott, A.J. and Lynn, N.M. (2003). Suspended sediment concentrations in the Tamar estuary. *Estuarine, Coastal and Shelf Science*, 57, 679-688.

Thain, R.H., Priestley, A.D. and Davidson, M.A (2004). The formation of a tidal intrusion front at the mouth of a macrotidal, partially mixed estuary: a field study of the Dart estuary, UK. *Estuarine, Coastal and Shelf Science*, 61, 161-172.

Thill, A., Moustier, S., Garnier, J.M., Estournel, C., Naudin, J.J. and Bottero, J.Y. (2001). Evolution of particle size and concentration in the Rhone river mixing zone: influence of salt flocculation. *Continental Shelf Research*, 21, 2127-2140.

Thomas, C.G., Spearman, J.R. and Turnbull, M.J (2001). Historical morphological change in the Mersey Estuary. *Continental Shelf Research*, 22, 1775-1794.

Tillis, G.M. (2000). Flow and salinity characteristics of the upper Suwannee River estuary, Florida. *USGS Water Resources Investigation Report* 99-4268.

Torgersen, C.E., Faux, R.N., McIntosh, B.A., Poage, N.G. and Norton, D.J. (2001). Airborne thermal remote sensing for water temperature assessment in rivers and streams. *Remote Sensing and Environment*, 76, 386-398.

Uncles, R.J. (2002). Estuarine Physical Processes Research: Some Recent Studies and Progress. *Estuarine, Coastal and Shelf Science*, 55, 829-856.

Uncles, R.J., Stephens, J.A. and Smith, R.E. (2002). The dependence of estuarine turbidity on tidal intrusion length, tidal range and residence time. *Continental Shelf Research*, 22, 1835-1856.

Uncles, R.J. and Stephens, J.A. (2001). The annual cycle of temperature in temperate estuary and associated heat fluxes to the coastal zone. *Journal of Sea Research*, 143, 143-159.

Uncles, R.J., Ong, J.E. and Gong, W.K. (1990). Observation and analysis of a stratification-destratification even in a tropical estuary. *Estuarine, Coastal and Shelf Science*, 31, 651-665.

Van Haren, H. (2004). Incoherent internal tidal currents in the deep ocean. *Ocean Dynamics*, 54, 66-76.

Van Maren, D.S. and Hoekstra, P. (2004). Seasonal variation of hydrodynamics and sediment dynamics in a shallow subtropical estuary: the Ba Lat River, Vietnam. *Estuarine, Coastal and Shelf Science*, 60, 529-540.

Van Maren, D.S. and Hoekstra, P. (2005). Dispersal of suspended sediments in the turbid and highly stratified Red River plume. *Continental Shelf Research*, 25, 503-519.

Villarreal, M.R., Montero, P., Taboada, J.J., Prego, R., Leitao, P.C. and Villar, V.P. (2002). Hydrodynamic model study of the Ria de Pontevedra under estuarine conditions. *Estuarine, Coastal and Shelf Science*, 54, 101-113.

Vos, R.J., ten Brummelhuis, P.G.J. and Gerritsen, H. (2000). Integrated data modelling approach for suspended sediment transport on a regional scale. *Coastal Engineering*, 41, 177-200.

Wang, J.D., Luo, J. and Ault, J.S. (2003). Flows, salinity, and some implication for larval transport in South Biscayne Bay, Florida. *Bulletin of Marine Science*, 72 (3), 695-723.

Warrick, J.A., Mertes, L.A.K., Washburn, L. and Siegel, D.A. (2004). Dispersal forcing of southern California river plumes, based on field and remote sensing observations. *Geo-Mar Letter*, 24, 46-52.

Washburn, L., McClure, K.A., Jones, B.H. and Bay, S.M. (2003). Spatial scales and evolution of stormwater plumes in Santa Monica Bay. *Marine Environmental Research*, 56, 103-125.

West, J.R., Uncles, R.J. and Shiono, K. (1990). Longitudinal dispersion processes in the upper Tamar Estuary. *Estuaries*, 13, 118-124.

Wheatcroft, R.A. (2000). Oceanic flood sedimentation: a new perspective. *Continental Shelf Research*, 20, 2059-2066.

Wiseman, Jr. W.J. and Garvine, R.W. (1995). Plumes and coastal current near large river mouths. *Estuaries*, 18, 509-517.

Wolanski, E., Richmond, R.H., Davis, G. and Bonito, V. (2005). Water and fine sediment dynamics in transient river plumes in a small, reef-fringed bay, Guam. *Http://www.aims.gov.au/ibm/pages/research/river-sediment-01.html.*

Wolanski, E., Spagnol, S., King, B. and Ayukai, T. (1999). Patchiness in the Fly River plume in Torres Strait. *Journal of Marine Systems*, 18, 369–381.

Wong, L.A., Chen, J.C. and Dong, L.X. (2004). A model of the plume front of the Pearl River Estuary, China and adjacent coastal waters in the winter dry season. *Continental Shelf Research*, 24, 1779-1795.

Woodruff, D.L., Stumpf, R.P., Scope, J.A. and Paerl, H.W. (1999). Remote estimation of water clarity in optically complex estuarine waters. *Remote Sensing Environment*, 68, 41-52.

Wright, L.D., Friedrichs, C.T., Kim, S.C. and Scully, M.E. (2001). Effects of ambient currents and waves on gravity-driven sediment transport on continental shelves. *Marine Geology*, 175, 25-45.

Wright, L.D., Friedrichs, C.T. and Scully, M.E. (2002). Pulsational gravity-driven sediment transport on two energetic shelves. *Continental Shelf Research*, 22, 2443-2460.

Wu, Y. and Falconer, A. (2000). A mass conservative 3-D numerical model for predicting solute fluxes in estuarine waters. *Advances in Water Resources*, 23, 531-543.

Yanagi, T., Sachoemar, S.I., Takao, T. and Fujiwara, S. (2001). Seasonal variation of stratification in the Gulf of Thailand. *Journal of Oceanography*, 57, 461-470.

Yankovsky, A.E., Garvine, R.V. and Munchow, A. (2000). Mesoscale currents on the inner New Jersey Shelf driven by the interaction of buoyancy and wind forcing. *Journal of Physical Oceanography*, 30, 2214-2230.

Ye, J. and Garvine, R.W. (1998). A model study of estuary and shelf tidally driven circulation. *Continental Shelf Research*, 18, 1125-1155.

Zheng, L., Chen, C., Alber, M. and Liu, H. (2003). A modeling study of the Satilla River estuary, Georgia. II: Suspended sediment. *Estuaries*, 26, 670–679.

Zheng, L., Chen, C. and Zhang, F.Y. (2004). Development of water quality model in the Satilla River estuary, Georgia. *Ecological Modelling*, 178, 457–482.

List of Publications

1 Syukri, M., Bakar, M.N.A., and Abdullah, K. (2005). Measurement of current, salinity, and temperature in the lower Merbok Estuary. *2005 Asian Physics Symposium*, December 7-8, 2005, Bandung, Indonesia.

2 Bakar, M.N.A., Wahidon, M., Abdullah, K., Jafri M.Z.M., and Syukri, M. (2005). Preliminary study of axial convergence front in the Merbok Estuary. *2005 Asian Physics Symposium*, December 7-8, 2005, Bandung, Indonesia.

3 Syukri, M., Bakar, M.N.A., and Abdullah, K. (2005). Water Circulation and Mixing Processes in the Lower Merbok Estuary, Malaysia. *The 3rd Kentingan Physics Forum*, Sebelas Maret University, Surakarta, 24 September 2005, Indonesia.

4 Syukri, M., and Bakar, M.N.A. (2006). Salinity and temperature pattern in the lower Merbok Estuary, Kedah. In: *Models in Ecological and Environmental Studies*, Ismail, A.I.M., Lye, K.H. and Hasan, Y.A. (Eds.). Penerbit Universiti Sains Malaysia, Penang, 265-274.

5 Syukri, M., Bakar, M.N.A., and Abdullah, K. (2004). The stratification of salinity and temperature in the lower Merbok Estuary, Kedah – Malaysia. *Symposium of Physics XX, Association of Indonesian Physicist, Riau-Indonesia.*

6 Syukri, M., Bakar, M.N.A., Abdullah, K., and Jafri, M.Z.M. (2006). Field measurements of total suspended solids in the lower Merbok Estuary, Kedah. In: *Models in Ecological and Environmental Studies*, Ismail, A.I.M., Lye, K.H. and Hasan, Y.A. (Eds.). Penerbit Universiti Sains Malaysia, Penang, 413-420.

7 Affan, M., Syukri, M., and Abdullah, K. (2003). Mapping suspended sediment concentrations in the coastal area using satellite remote sensing. *International Seminar on Marine Sciences and Resources*, 12-15 March 2003, Universitas Syiah Kuala, Banda Aceh, Indonesia.

8 Syukri, M., Bakar M.N.A., and Abdullah, K. (2003). A Field Observation of Estuary Plume in Small Scale River (Case Study: Prai River Malaysia). *Jurnal Natural*, Universitas Syiah Kuala, Indonesia, 3, 39-42.

9 Syukri, M., Bakar, M.N.A., Rahman, A.H.A., Abdullah, K., and Jafri, M.Z.M. (2004). Investigation of Muda River plume structure during dry season. In: *Integrating Technology in the Mathematical Sciences*, Hasan, Y.A., Baharum, A., Ismail, A.I.M., Lye, K.H. and Chin, L.H. (Eds.). Penerbit Universiti Sains Malaysia, Penang, 267-272.

10 Syukri, M., Bakar M.N.A., and Abdullah, K. (2002). A field Observation of the Prai River plume. *Asia Pacific Conference on Marine Science and Technology*, 12-16 May 2002, Kuala Lumpur, Malaysia.

11 Bakar, M.N.A., Abdullah, F., Syukri, M., and Abdullah, K. (2002). A Study of discharge characteristics of the Muda estuary, Malaysia. *Asia Pasific Conference on Marine Science and Technology*, 12-16 May 2002, Kuala Lumpur, Malaysia.

12 Syukri, M., Bakar, M.N.A., Abdullah, K., and Jafri, M.Z.M. (2002). Studi karakteristik plum sungai Prai secara observasi lapangan dan citra digital. *Symposium of Physics XIX*, Association of Indonesian Physicist, 30-31 July 2002, Bali, Indonesia.

13 Syukri, M., Faisal, and Bakar, M.N.A. (2006). Distributions of total suspended sediment concentrations in shallow coastal water off the Muda Estuary, Malaysia. *International Conference on Mathematics and Natural Sciences (ICMNS) 2006*, 29-30 November 2006, ITB Bandung, Indonesia.