Faculty of Resource Science and Technology

WATER PROFILING OFF SARAWAK COASTAL AREAS

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Declaration

I hereby declare that this dissertation entitled "Water Profiling off Sarawak Coastal Waters" submitted to Faculty of Resource Science and Technology, Universiti Malaysia Sarawak (UNIMAS) is a presentation of my original work except for the citation and references which have been fully acknowledged. No portion of the work referred to in this thesis has been submitted in support of an application for another degree qualification of any other university or institution of higher learning. This work was done under the supervision of Dr Aazani Mujahid and submitted to partially fulfill the requirement for the degree qualification of Bachelor Science with Honours in Aquatic Science Resource and Management.

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Ann Aletheia A Manson

Department of Aquatic Science

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List of Abbreviations

AAIW	Antarctic Intermediate Waters
CTD	Conductivity-temperature-depth
CSW	Continental Shelf Water
DW	Deep Water
EPSP	Prime Marine Scientific Expedition
ITCZ	Intertropical Convergence Zone
m	meter
mean±std	mean ± standard deviation
MSW	Maximum Salinity Water
MKGTW	Mekong/Gulf Thailand Water
MOSTI	Malaysian Ministry of Science, Technology and Innovation
NCSW	Northern Continent Shelf Water
NOD	National Oceanographic Directorate
NPIW	North Pacific Intermediate Water
NPTW	North Pacific Tropical Water
NW	Northwest
OSW	Open Sea Water
PSU	Practical Salinity Unit
PTW	Permanent Thermocline Water
SCS	South China Sea
SCSW	Southern Continental Shelf Water
SEAFDEC	South East Asian Fisheries Development Centre

STW	Seasonal Thermocline Water
SPTW	South Pacific Tropical Water
SW	Southwest
T-S	temperature-salinity
TLDM	Royal Malaysian Navy
TSW	Tropical Surface Water
WM1	Water Mass 1
WM2	Water Mass 2
WM3	Water Mass 3
WM4	Water Mass 4
°C	Degree celcius

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Water Profiling off Sarawak Coastal Areas

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Abstract

During June 2009, Prime Scientific Sailing Expedition (EPSP) was carried out on South China Sea (SCS) along Sarawak waters. The physical properties of seawater were obtained using 'Conductivity-Temperature-Depth' (CTD) profiler. The main purpose of this present study is to construct vertical structures of temperature and salinity of Sarawak coastal waters, to construct temperature-salinity (T-S) diagram and identify the water masses, as well as to observe the features of Sarawak coastal waters. Vertical profiles of temperature, salinity and T-S diagrams were plotted and analyzed. Definitions of identified water masses in the Sarawak coastal were classified with respect to classification of previous studies done on SCS and redefined. Five water masses found exist in Sarawak water namely Continental Shelf Water (CSW), Open Sea Water (OSW), Maximum Salinity Water (MSW), Permanent Thermocline Water (PTW) and Water Mass 1 (WM1), derived from the mix of OSW and MSW. The definition of water mass is essential to understand better geographical positions of water mass to aid in the completion of water mass definitions done on SCS waters.

Keywords: vertical structures, South China Sea, water mass, temperature-salinity diagram

Abstrak

Pada Jun 2009, Perdana Saintifik Pelayaran Ekspedisi (EPSP) telah dijalankan ke atas Laut China Selatan (SCS) di sepanjang perairan Sarawak. Sifat fizikal air laut telah diperolehi dengan menggunakan 'kekonduksian Suhu Kedalaman (CTD) pemprofil. Tujuan utama kajian ini adalah untuk membina struktur menegak suhu dan kemasinan perairan pantai Sarawak, untuk membina rajah suhu kemasinan(T-S) dan mengenal pasti jisim air, dan juga untuk melihat ciri-ciri perairan pantai Sarawak. Profil menegak suhu, kemasinan dan gambar rajah T-S telah berkomplot dan dianalisis. Takrif jisim·air yang dikenal pasti di pantai Sarawak yang diklasifikasikan mengikut klasifikasi kajian sebelum ini dilakukan pada SCS dan ditakrifkan semula. Lima jisim air didapati wujud dalam air Sarawak iaitu Pelantar Benua air (CSW), Open Air Laut (OSW), maksimum Kemasinan air (MSW), Thermocline Air Tetap (PTW) dan Air Mass 1 (WM1), berasal dari campuran OSW dan MSW. Takrif massa air adalah penting untuk memahami kedudukan geografi yang lebih baik bagi jisim air untuk membantu dalam menyiapkan definisi jisim air yang dilakukan di perairan SCS.

Kata kunci: struktur menegak, Laut China Selatan, jisim air, gambar rajah suhu kemasinan

1.0 Introduction

Prime Marine Scientific Expedition (EPSP) was conducted for 44 days on June and July 2009 at the Borneo coastal waters involving South China Sea (SCS), Sulu Sea and Celebes Sea but this study focused particularly on SCS, along Sarawak coastal. Datasets comprises of ocean temperature and salinity was collected on end of June 2009 from 60 stations that were established in this study. This compilation of the data was part of the work undertaken by the National Oceanographic Directorate (NOD) under the Malaysian Ministry of Science, Technology and Innovation (MOSTI) and the Royal Malaysian Navy (TLDM) with core aim of the expedition focused entirely on physical oceanography and marine biology.

Information and knowledge regarding physical characteristics on Sarawak waters is very limited and scarce. Despite numerous studies were made on SCS waters, but there are very little understanding focusing on the features of Sarawak coastal. The most recent study done on water mass in Sarawak coastal was done by Saadon *et al.* (1998) during the South East Asian Fisheries Development Centre (SEAFDEC) cruise and one study done on temperature and salinity profiles off Sarawak coast by Nasir *et al.* (1988) during the Matahari Expedition. Yet, both of these studies have not done any water mass definition on the Sarawak waters. Hence it is very important to collect and analyze the data from time to time to update information on this water masses for better understanding. Water properties have been used as guidelines or passive tracer to provide direct pathways of water masses (Arsad and Akhir, 2013). It is necessary to compile between temperature, salinity and water depth to understand the difference of water mass. The standard method of water mass studies is based on temperature-salinity (T-S) diagram (Marghany, 2012).

In this paper, physical properties water masses of Sarawak coastal waters are presented and water mass definition will be shown with respect to classification of previous studies from Qu *et al.* (1999), Qu *et al.* (2000), Rojana-anawat *et al.* (2001) and Dippner and Loick-Wilde (2011). Classification of water masses characteristics also take into account the study of Arsad and Akhir (2013) which study were also from the same voyage expedition of EPSP 2009 but focused on Sabah coast using Argo profiling floats and Conductivity-temperature-depth (CTD) profiler cast cruises. Thus, the overall objectives of this study were:

1) To construct vertical structures of temperature and salinity of Sarawak coastal waters
2) To construct temperature-salinity diagram and identify the water masses, and
3) To observe the features of water masses of Sarawak coastal.

2.0 Literature review

2.1 South China Sea (SCS)

The SCS is the largest semi-enclosed sea in the southeastern Asian waters (Dippner *et al.*, 2007; Liu *et al.*, 2008; Qu *et al.*, 2009). SCS begins with Taiwan Strait and ends at around 700 km south of Singapore as it continuing south in the sequence of marginal seas in the western Pacific Ocean (Tomczak and Godfrey, 1994). It is located northwest of Sabah and Sarawak in Malaysia, with Brunei as well and situated northeast of the Peninsular of Malaysia and Singapore (Morton and Blackmore, 2001). The SCS ecologically is characterized by a low nutrient environment and has considerable habitat diversity and species diversity (Morton and Blackmore, 2001). The entire SCS, as mentioned by Tomczak and Godfrey (1994), is under the influence of monsoon system which can be divided into monsoon seasons of Northwest (NW) monsoon and Southwest (SW) monsoon and intermonsoon seasons (Camerlengo and Demmler, 1997; Dippner *et al.*, 2007; Marghany, 2012).

2.2 Previous studies of data collection done on South China Sea

Among the most recent physical oceanography cruises conducted on the SCS before the EPSP cruise on 2009 was the SEAFDEC cruise. Survey by SEAFDEC cruise was took place several times from the year 1995 to 1999 (Saadon *et al.*, 1998; Saadon *et al.*, 1999; Rojana-anawat *et al.*, 2000; Rojana-anawat *et al.*, 2001) provided earlier information on physical characteristics of water mass in the SCS. All the datasets from these studies was collected using Integrated CTD profiler or currently known as CTD. Saadon *et al.* (1998) reported that only little variation of physical parameters of temperature, salinity and density showed between coastal and offshore water, as well as shallow and deep waters on the SCS, along the waters of Sabah, Sarawak and Brunei, during the SW monsoon season. Another study done by Arsad and Akhir (2013) using datasets also from the KD Perantau cruise of EPSP 2009, same cruise with this research study but done in Sabah water that includes SCS, Sulu Sea and Celebes Sea showed existence of eight water masses based on dataset taken from CTD casts and Argo profiling floats.

2.3 Ocean water properties

Ocean is characterized by physical properties which represent the quantitative features of the system (Mamayev, 2010). These quantitative features are termed as water parameters or the characteristics of the system (Mamayev, 2010). Two of the most important oceanographic parameters that form the basis of ocean description are temperature and salinity (Tomczak and Godfrey, 1994).

Major variation in temperature is very typical in the upper layer of ocean because of the external environmental factors influence. Factors that affect sea water temperature is the energy transfer process that occur at the sea surface and external and internal forces that render water movement without heat transfer to or from the atmosphere (Reddy, 2001). The energy transfer processes that take place at the ocean surface are evaporation and precipitation and absorption of radiation from the sun and the sky. Reddy (2001) mentioned that the external and internal forces that occur below sea surface produces tide, current and wind which transports water from one place to another. As water body moved by influence of possible wind, tides and current, temperature gradient usually will be produced if water temperature differs with the water in the different regions (Reddy, 2001). Term used to define the ocean layers of rapidly changing temperature is called thermocline (Thurman and Trujillo, 2003).

Salinity is defined by Reddy (2001) as concentration of dissolved salt is a basic property. According to Reddy (2001), factors that affect ocean salinity is factors that can increase or decrease salinity. Factors that are responsible for increase in salinity are precipitation, evaporation, transfer of more saline water, mixing with deep water that are more saline and deposited of salt water (Reddy, 2001). Decrease in ocean salinity is by adding more freshwater to the ocean which is by processes such as runoff, decreased precipitation, melting icebergs and sea ice (Thurman and Trujillo, 2003). Lower salinity values are usually found in the coastal areas where large rivers flow into the ocean whereas higher salinity values are observed in the ocean region that resulted from high evaporation (Reddy, 2001). Seawater salinity varies with depth. Term used to define of layer rapidly changing salinity in the ocean is called halocline (Thurman and Trujillo, 2003).

Marghany (2012) pointed that coastal water physical properties and dynamical movements in Malaysian waters are influenced by monsoon winds. Such physical properties of temperature and salinity are mainly affected by the physical properties of atmospheric layer that exist exactly above the surface of the ocean. There are several studies showed that variability in the ocean water properties is driven by monsoon winds (Saadon *et al.*, 1998; Saadon *et al.*, 1999; Rojana-anawat *et al.*, 2000; Rojana-anawat *et al.*, 2001; Marghany, 2012; Roseli and Akhir, 2014).

2.4 Water mass and its definitions

Water mass is an identifiable body of ocean water with a common formation history that has distinctive narrow range of temperature and salinity from surrounding waters (Marghany, 2012) and a particular density resulting from these two parameters of temperature and salinity. Seawater density is determined by salinity and temperature that is subjected to ocean stratification, mixing, and water mass formation (Amiruddin *et al.*, 2011). A single water mass occupies a particular oceanic regions happens only in the formation region (Tomczak and Godfrey, 1994). Tomczak and Godfrey (1994) explained that that several water masses usually present at an oceanic location as the water masses mix and spread across the ocean. However, water masses occupy a measurable volume, which is the total of the volumes occupied by its entire element no matter of their current whereabouts (Tomczak and Godfrey, 1994). Tomczak and Godfrey (1994) further stated that it is also possible to determine the percentage contribution of all water masses to a given water sample, because the water mass will retain their properties of potential temperature and salinity, even when leaving the formation region. Each water mass is identified firstly by identifying its characteristics, and next step is to observe the ocean process that create that specific characteristic (Talley *et al.*, 2011). Hence, water masses can be identified by plotting temperature against salinity which is the T-S diagrams.

Earlier studies of water mass distribution done by Qu *et al.* (1999) and Qu *et al.* (2000) on SCS, along the Philippine Coast, showed relation between potential temperature versus salinity and dissolved oxygen versus salinity indicating five water masses listed in Table 1. The five water masses classified by Qu *et al.* (2000) are Tropical Surface Water (TSW), North

Pacific Tropical Water (NPTW), South Pacific Tropical Water (SPTW), North Pacific Intermediate Water (NPIW) and one water characteristic discovered earlier by Wrytki (1961) is the Antarctic Intermediate Waters (AAIW) also found in the region.

Table 1: Water mass characteristics of the different water bodies according to Qu *et al.* (1999) and Qu *et al.* (2000)

Water mass	Water depth (m)	Temperature (°C)	Salinity (PSU)
TSW	Surface layer	25-30	33.5-34.5
NPTW	120-150	17.7-18.2	34.75-35.25
SPTW	Intermediate waters	<27	>35.25
NPIW	480-500	7-9	<34.4
AAIW	500-600		<34.55

Qu *et al.* (1999) include information regarding oxygen concentration in their study other than water mass formation information. According to Qu *et al.* (1999), TSW that was found in the surface layer of Philippines Ocean was formed locally in the vicinity of the Intertropical Convergence Zone (ITCZ), with oxygen concentration of 45 ml l^{-1}. NPTW is characterized with oxygen concentration of >4.0ml l^{-1} resulted from excessive evaporation (Qu *et al.*, 1999) and SPTW with oxygen concentration of around 3.3ml l^{-1}. According to Talley (1993), NPIW is formed through the overrun of subpolar water by the saltier surface water in the region of mixing waters between the Kuroshio and Oyashio. AAIW is of Antarctic origin, derived from the Pacific Ocean Deep Water (Wrytki, 1961).

Rojana-anawat *et al.* (2001) distinguished seven different characteristic water masses in the western SCS along the Vietnamese waters. The seven water masses are the Deep Water (DW), the Permanent Thermocline Water (PTW), the Maximum Salinity Water (MSW), the Open Sea Water (OSW), the Seasonal Thermocline Water (STW), the Northern Continent Shelf

Water (NCSW) and the Southern Continental Shelf Water (SCSW). The water mass characteristics of these waters can be seen in Table 2.

Table 2: Water mass characteristics of the different water bodies according to Rojana-anawat *et al.* (2001)

Water mass	Water depth (m)	Temperature (°C)	Salinity (PSU)
DW	>900	2.5-5	34-35
PTW	180-400	10-15	34-35
MSW	100-200	15-20	>34.5
STW	50-150	20-27	34-35
OSW	>40-50	25-29	33-34
NCSW	10-<30	23-27	31-33
SCSW	10-<30	29-31	27-33

Further water mass analysis then done by Dippner and Loick-Wilde (2011) in the same area studied by Rojana-anawat *et al.* (2001) which was at the Vietnamese waters, showed a redefinition of water mass characteristics that serve as end member of mixing. The water masses are the DW, PTW, MSW, OSW, the Mekong/Gulf Thailand Water (MKGTW), the Water Mass 1 (WM1) which is the mixed waters between MSW and PTW, the Water Mass 2 (WM2) which is the mixed waters between MSW and OSW, the Water Mass 3 (WM3) which is the mixed waters between OSW and MKGTW and the Water Mass 4 (WM4) which is the mixed waters between MSW, OSW and MKGTW. These water characteristics are displayed in Table 3.

Table 3: Water mass characteristics of the different water bodies according to Dippner and Loick-Wilde (2011)

Water mass	Temperature (°C)	Salinity (PSU)
DW	<2.5	>34.6
PTW	7-9	34.4-34.5
MSW	17-19	>34.3
OSW	26-31	33.7-34.1
MKGTW	27-31	<32.9
WM1	9-17	34-35
WM2	19-28	34.1-34.6
WM3	26-31	32.9-33.7
WM4	22-26	33.3-34.1

Other than water mass characteristics that were described earlier, there were two new additions of water mass characteristics by Arsad and Akhir (2013) that was found in local upper waters exist in Sabah other than the existence of six other identified water masses. The additional water masses are Continental Shelf Water (CSW) and the other OSW almost similar but still different to water mass OSW that first identified by Rojana-anawat *et al.* (2001). The other six identified water masses found existed in Sabah water were classified with respect to previous authors (Qu *et al.*, 1999; Qu *et al.*, 2000; Rojana-anawat *et al.*, 2001; Dippner and Loick-Wilde, 2011). DW, PTW, STW and TSW in Sabah waters in study of Arsad and Akhir (2013) were identified using water mass definition of Rojana-anawat *et al.* (2001). Qu *et al.* (1999) and Qu *et al.* (2000) as well as Dippner and Loick-Wilde (2011) contributed one water mass definition each and those water masses are NPIW (Qu *et al.*, 1999; Qu *et al.*, 2000) and MSW (Dippner and Loick-Wilde, 2011). The characteristics of the water masses are listed in Table 4 shown below.

Table 4: Water mass characteristics of the different water bodies according to Arsad and Akhir (2013)

Water mass	Water depth (m)	Temperature (°C)	Salinity (PSU)
DW	>900	2.5-5	>34.5
NPIW	480-500	7-9	<34.4
PTW	180-400	10-15	34-35
MSW	100-200	17-19	>34.3
STW	50-150	20-27	34-35
TSW	Ocean surface	25-30	33.5-34.5
CSW	<40	29-31	27-33.5
OSW	>40	25-29	32.5-34

Tomczak and Godfrey (1994) pointed that common name of water masses that are known usually are related to their major area of residence. Similar name may be used for well-defined water mass or simply waters found in the area (Tomzcak and Godfrey, 1994). Similar names of water masses means it is the same water mass from different waters but the definitions of temperature and salinity may change to be in a wider range or more precise such as study done by Dippner and Loick-Wilde (2011) that redefined few water masses done by Rojana-anawat *et al.* (2001).

2.5 Temperature-salinity (T-S) diagrams

According to Marghany (2012), water mass studies are usually standardized based on T-S diagram. T-S diagram is used to identify water mass types and estimates the length of mixing in waters (Marghany, 2012). Measurements of a data are plotted from the CTD cast. Data collected produces scattered points which often produce a T-S curve. T-S curve shows the relationship between temperature and salinity of the subsurface water of that region (Talley *et al.*, 2011). The corresponding temperature and salinity values in a water column are found to arrange themselves according to depth (Talley *et al.*, 2011). The depths of the observed values can be entered along the T-S curve, which then will also give information as to variation of temperature and salinity with depth (Talley *et al.*, 2011). Emery (2001) explained that water type refers to a single point on T-S diagram whereas that water mass refers to some portion or segment of the characteristic curve, which describes the 'core properties' of that water mass. When two or more water types of different temperature and salinity are mixed, it will be shown following this rule: regardless of what portions of the water types, the points representing temperature and salinity are joined on a curve on the T-S diagram (Colling, 2001). Hence, this will determine the water masses.

3.0 Materials and methodology

3.1 Study site

The study site was located in South China Sea along Sarawak waters as shown in Figure 1. Overall, 60 stations were involved which were spread in areas from 2.8737°N to 4.4446°N and 109.9034°W to 113.3421°W . Time taken and exact coordinates of each station can be seen in Appendix 1. Indication of shallow water by stations with green color showed data taken from ocean depth less than 50 m and there were 16 stations with located in shallow waters. The other 44 stations located in the areas of deep waters with depth of more than 50 m indicated by stations with yellow color.

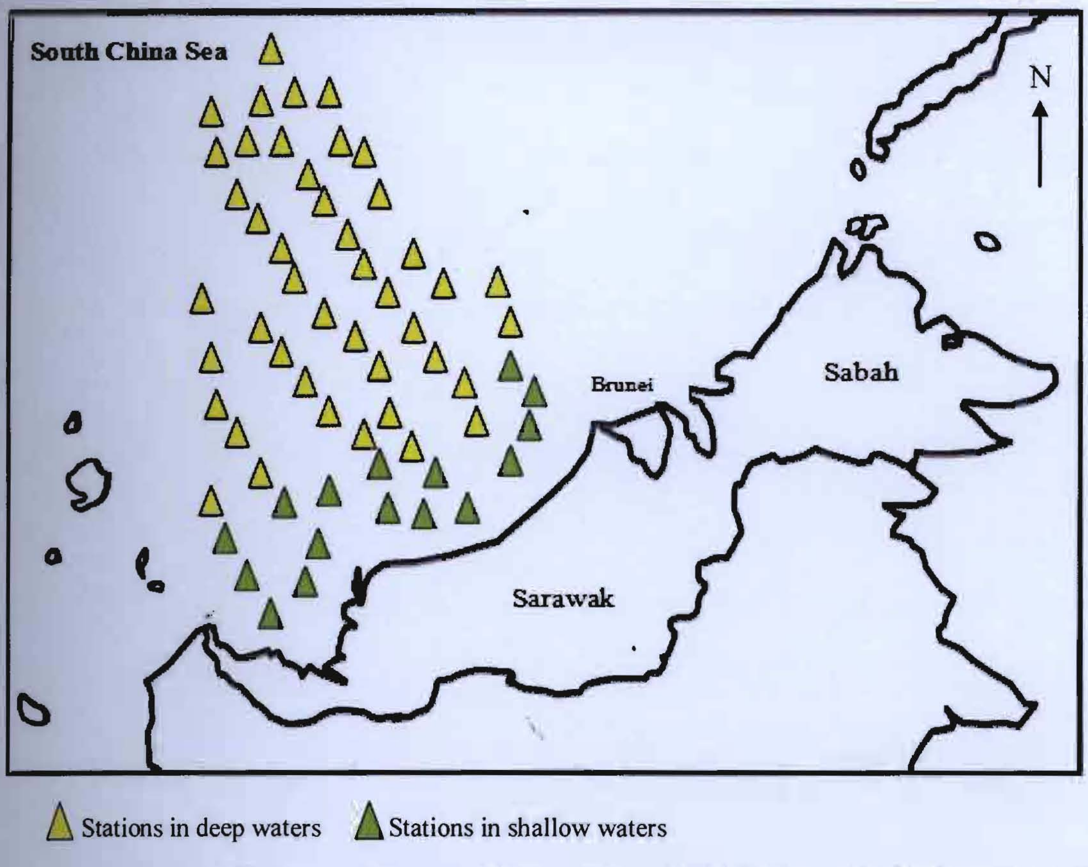

Figure 1: Distribution of 60 stations with range of longitude from 109.9034°W to 113.3421°W and range of latitude from 109.9034°W to 113.3421°W (Adapted from Google Earth 2014)

3.2 Voyage expedition

Datasets used in this study were obtained aboard Malaysia Royal Navy vessel "KD Perantau" of the EPSP 2009. This expedition was conducted by NOD and TLDM that lasted for 44 days in June and July 2009, but the data of this study was collected only on 20 June 2009 until 28 June 2009.

3.3 Conductivity-temperature depth (CTD) profiler

Temperature and salinity parameters used in this study were collected by using SBE 19Plus CTD profiler (Figure 2). CTD instrument measures the conductivity and temperature at the depth where the instrument is situated (Wurl, 2009). A CTD rosette is a framework designed to carry 12 to 36 Niskin or Go-Flo sampling bottles and the CTD sensor is mounted underneath or in the center (Wurl, 2009). The deck command unit of the rosette sampler allowed the control of the closing mechanism of the bottles electronically using a remote (Wurl, 2009). As the rosette was lowered and the data were received from the CTD, particular stratified water layers were looked and water samples were took at any depth based on the CTD profile (Wurl, 2009). CTDs were lowered and raised at 1 m per second (Wurl, 2009). The data from the CTD sensor was sent directly onboard via computer and was sent continuously (Wurl, 2009). The data produced consists of temperature and salinity.

The specifications of the profiler are listed as the following. The temperature accuracy is 0.005 °C and temperature resolution is 0.0001 °C; conductivity accuracy 0.0005 S/m and conductivity resolution 0.00005 S/m; pressure accuracy is 0.1% of full scale range and pressure resolution is 0.002% of full scale range; dissolved oxygen sensor accuracy is 2% of