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RESPONSE OF THE OCEAN MIXED LAYER, OFF THE EAST COAST OF PENINSULAR MALAYSIA, DURING THE NORTH-EAST AND SOUTH-WEST MONSOONS

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ABSTRACT

The behaviour of the mixed layer, off Kuala Terengganu, during the north-east and south-west monsoons is addressed. Temperature and salinity profiles, for both seasons, are analysed. The results are quite conclusive. In the mixed layer, temperature and salinity have different characteristics during each season, being lower during the north-east monsoon. The depth of the mixed layer is shallower during the south-west monsoon. Two distinctive water masses are detected during both seasons.

RESUMEN

Se estudia la respuesta de la capa de mezcla del océano a la influencia de los monzones del Noreste y del Sudoeste, en la costa este de la península Malaya. Para ello se analizan los perfiles verticales de temperatura y salinidad en ambas estaciones monzónicas. Los resultados son concluyentes. Durante el Monzón del Noreste la temperatura y la salinidad de la capa de mezcla son menores y la profundidad de la capa mezcla es mayor que durante el Monzón del Sudoeste. Se distinguen dos masas de agua de distintas características durante las diferentes estaciones monzónicas.

1. INTRODUCTION

The ocean boundary layer can be considered as an intermediate zone between the deep ocean and the atmosphere. The ocean boundary layer extends from the sea surface to a depth ranging between 10 and 150 meters. Sometimes, the depth of the mixed layer is compared with the depth of the Ekman layer. This comparison is not correct, due to the fact that the Ekman layer depth depends on the wind speed at the time of the observation. On the other hand, the mixed layer depth depends on the past history of the wind (Pond & Pickard, 1978).

Vertical exchange processes between the ocean and the atmosphere, as well as vertical mixing within the upper layers of the ocean, will affect local conditions more effectively than horizontal processes. Usually the upper ocean layers are treated as being homogeneous along the horizontal plane. Therefore, the horizontal derivatives are neglected in one-dimensional models of the mixed layer. Thus, only changes in the vertical are taken into account in such models (Niiler and Krauss, 1977). This effect has been taken into consideration in one-dimensional numerical models of the ocean mixed layer (Schopf and Cane, 1983).

The aim of this investigation is to gain some understanding of the behaviour of the mixed layer, off the east coast of Peninsular Malaysia, during both monsoon seasons. For this purpose, both the temperature and the salinity profiles, during the period ranging from October 26 to October 30, 1995, are analysed (Saadon and Yasin, 1994). Our results are compared with the results of Lokman *et al.* (1986). The mentioned authors studied the temperature and salinity profiles during a typical South-west monsoon season.

2. CLIMATOLOGY OF THE AREA

The weather pattern of the east coast of Peninsular Malaysia is greatly influenced by the monsoons. In the winter seasons, the air mass over Asia is cooler than over the surrounding areas. A high pressure system is enhanced. During the same period, November through March, the air mass over Australia is warmer than over the surrounding areas. The natural consequence is a low pressure system over Australia. A result of the combined effect of these two pressure systems is a north-easterly wind over the South China Sea. This weather system is characteristic of the north-east monsoon season.

Conversely, during the southern hemisphere winter, a high and a low pressure system over Australia and Asia, respectively, are enhanced. During May through September, these two pressure systems will produce a south-westerly wind over the South-east Asian region. This system is called the south-west monsoon season. Cloudless skies over the eastern coast of Peninsuia Malaysia are observed during this period.

Two transitional periods (usually occurring in April and October, respectively) are observed between the two monsoon seasons. These transitional periods have a duration, ranging from four to seven weeks. Heavy rainfall in the east coast of Peninsular Malaysia is usually associated to the north-east monsoon. The east coast is considered the wet belt of Peninsular Malaysia, with an annual rainfall of 2800 mm. Maximum precipitation usually occurs during the months of November and December (Chua, 1984).

3. MATERIALS AND METHODS

A cruise was conducted from October 26 to October 30, 1993. The research vessel used for the cruise was the KL. PAUS, owned by the Malaysian Department of Fisheries.

The area covered by this study was about 61,600 km^2 (Fig. 1). Temperature and salinity were measured with an Inter-ocean S4-CTD. The CTD was deployed at 33 sampling stations. However, only 12 stations were considered in our study because they were in the same study area as presented by Lokman *et al.* (1986).

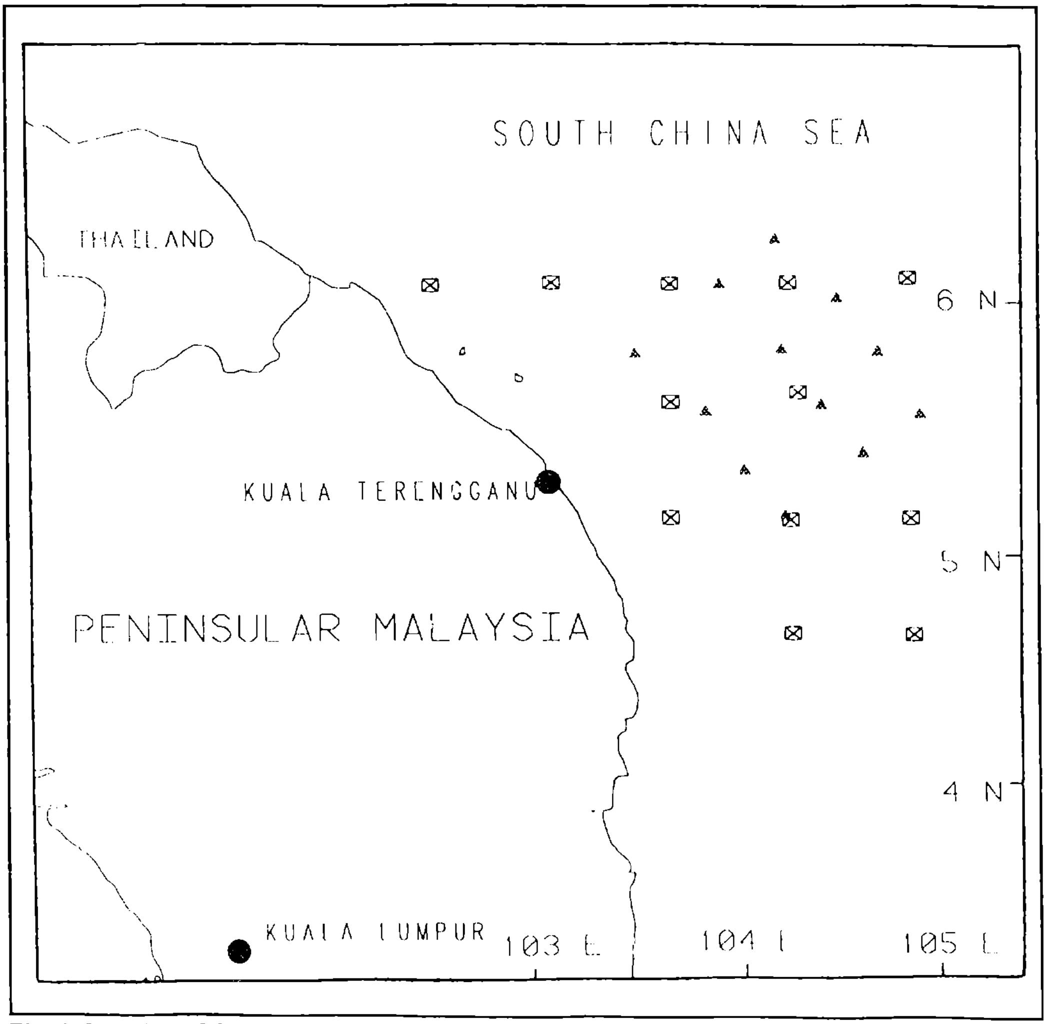

Fig. 1. Location of the study area (rectangular makers) and the area of Lokman *et al.* (1986) (triangular makers).

4. DISCUSSION AND CONCLUSIONS

In extratropical latitudes, the distributions of atmospheric wind forcing are very similar all year round. However, the intensity of the wind is greater in winter than during any other time of the year (Elsberry and Camp, 1978; Elsberry and Raney, 1978).

The source of mechanical energy is proportional to the cubic power of the friction velocity. Due to the strong wind forcing during the passage of a winter storm, an upward heat flux from the ocean to the atmosphere results. Mechanical mixing is enhanced. As a consequence of the upward heat flux, the thermocline deepens. Therefore, the depth of the mixed layer increases. Due to the entrainment from the lower layers of the sea, the cooling effect continues for approximately a week, at the wake of the storm's passage (Camerlengo, 1982).

In summer, the forcing due to atmospheric wind is weaker than in winter. Consequently, the entrainment at the base of oceanic boundary layer is almost nonexistent. As a direct consequence of the stabilising effect of the surface heating, the mixed layer becomes shallower (Elsberry and Camp, 1978; Elsberry and Raney, 1978).

In the South China Sea, the intensity of the monsoons has to be taken into consideration. Due to the fact that the north-east monsoon has stronger winds than the south-west monsoon, it is expected that greater masses of water should be entrained from the lower layers of the ocean. Therefore, the depth of the mixed layer should be greater and slightly cooler, during the north-east monsoon.

In his linear theory of the ocean's response to the displacement of a hurricane, Geisler (1970) showed the existence of inertia gravity waves at the wake of the cyclone's path. This result was confirmed by the observational study at the wake of hurricane Eloise in 1975 (Black and Whitee, 1976), and by numerical simulation (Chang and Anthes, 1978).

Geisler's theory (1970) forecasted, that very far at the rear of the storm, after the dispersion of the inertia gravity waves, the motion will be geostrophically balanced. Due to the absence of external forcing, the kinetic energy of the ocean is rapidly redistributed. Camerlengo (1982) showed that the e-folding time scale of dissipation of kinetic energy after the storm's passage, is of ten days. In the absence of any external atmospheric forcing, the kinetic energy in the ocean is rapidly redistributed. A shorter e-folding time scale would be expected if vertical mixing has been taken into consideration, in that study.

Due to overcast skies during the north-east monsoon season, the mean monthly air temperature drops by one or two degrees Celsius. During this same period, the sea surface temperature (SST) charts by Zainal (1993) and Morgan and Valencia (1983) shows a decrease of one degree Celsius, as compared to the south-west monsoon season.

All along the eastern coastline, the combined effect of freshwater discharge from rivers and heavy precipitation affects the salinity pattern. In effect, Zainal (1993) reported lower salinity water masses, all along the eastern coast of the Peninsular Malaysia. This lower salinity water mass is a natural consequence of freshwater discharge (from rivers), due to heavier precipitation in this area.

During the north-east monsoon the water mass tends to pile up against the western boundary of the South China Sea. Sea levels are higher than at any other time of the year. Due to the combined effects of geostrophy and coastal geometry the water masses tend to flow equatorwards, in a counterclockwise circulation, further reducing the salinity pattern in the area under consideration (Chua, 1984; Morgan and Valencia, 1983; Wyrtki, 1961).

Winds are stronger during the north-east monsoon (Wyrtki, 1961). These stronger winds will generate higher waves in the shallower areas of the east coast. Anon (1991) reported that during this same period, maximum wind wave heights range from three to four meters along the east coast. During the south-west monsoon, a depression of the free surface elevation at the western boundary of the South China Sea is recorded. Due to geostrophy and coastal geometry the water masses flow poleward along the east coast of Peninsular Malaysia into the Gulf of Thailand in a clockwise circulation (Chua, 1984; Morgan and Valencia, 1983; Wyrtki, 1961).

Temperature profiles of the 12 stations gathered in this investigation and in Lokman *et al.* (1986) are shown in Fig. 2. It can be readily seen that the temperature, in the mixed layer during the north-east monsoon season, ranges from 29.3 to 29.8 °C. However, for the south-west monsoon season, the temperature of mixed layer is usually greater than 30°C.

During the north-east monsoon season, skies are usually overcast. Heavy precipitation do occur within this period. Warming of the ocean surface by solar radiation is dramatically reduced. Stronger north-east winds enhances evaporation. All these factors combined explain the decrease in temperature of the mixed layer.

For the reasons explained above, the depth of the mixed layer is greater during the north-east monsoon (Fig. 2). Salinity profiles, for both seasons are shown in Fig 3. It can readily be observed that salinity values for the north-east monsoon season are lower than in its south-west counterpart. This is due to heavier precipitation and freshwater discharge from rivers along the east coast of Peninsular Malaysia and the Gulf of Thailand, which occurs during the north-east monsoon season.

During the south-west monsoon season, the halocline layer is well defined in most of the stations. This is not the case for the stations sampled during the north-east monsoon season. Fig. 4 shows the T-S diagrams for both seasons. The existence of two different water masses, for both seasons, along the east coast of Peninsular Malaysia, is clearly established.

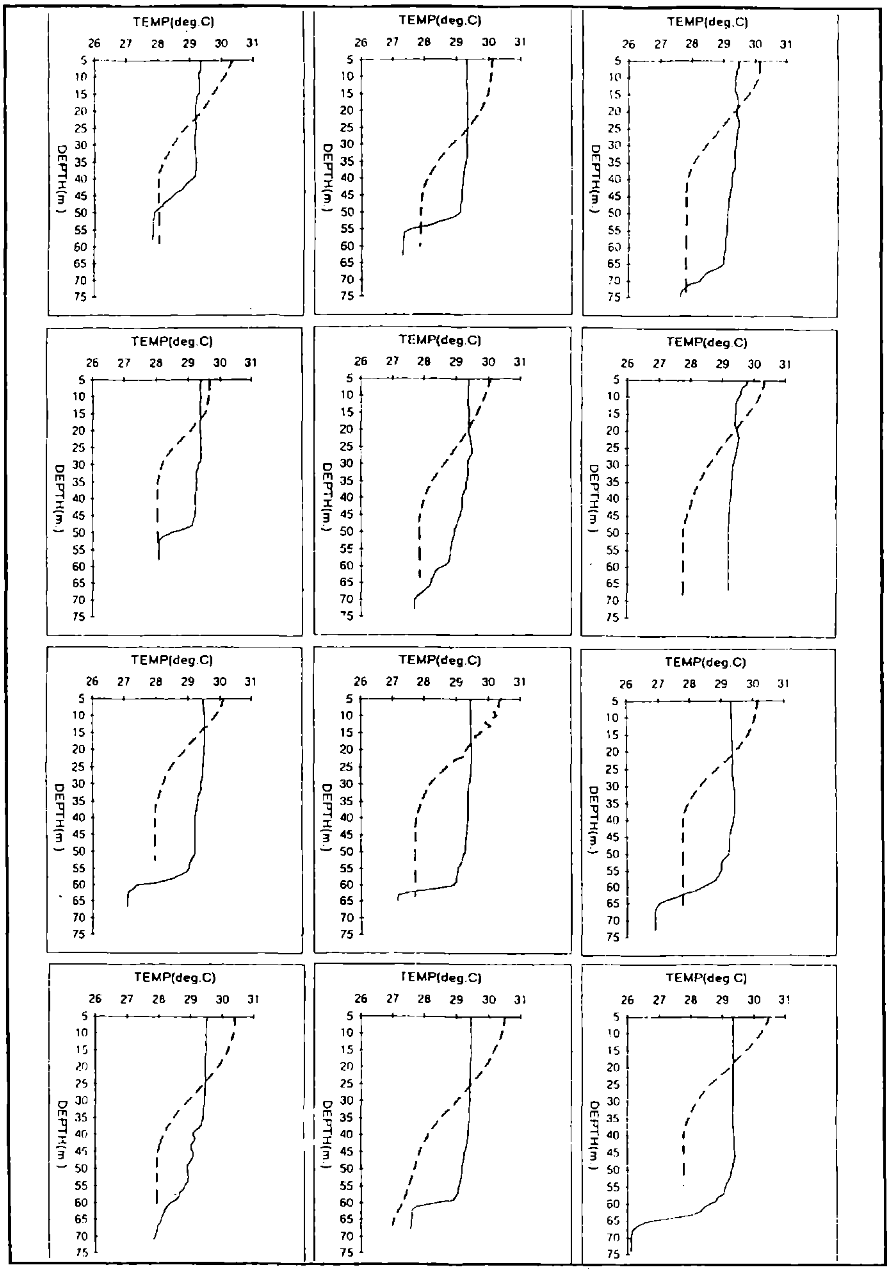

Figure: 2. Temperature profiles of 12 stations during the north-east (solid lines) and the south-west (broken lines) monsoon seasons. The stations represented in the figure, for both monsoon seasons, are not in the same location but they are in a very close proximity.

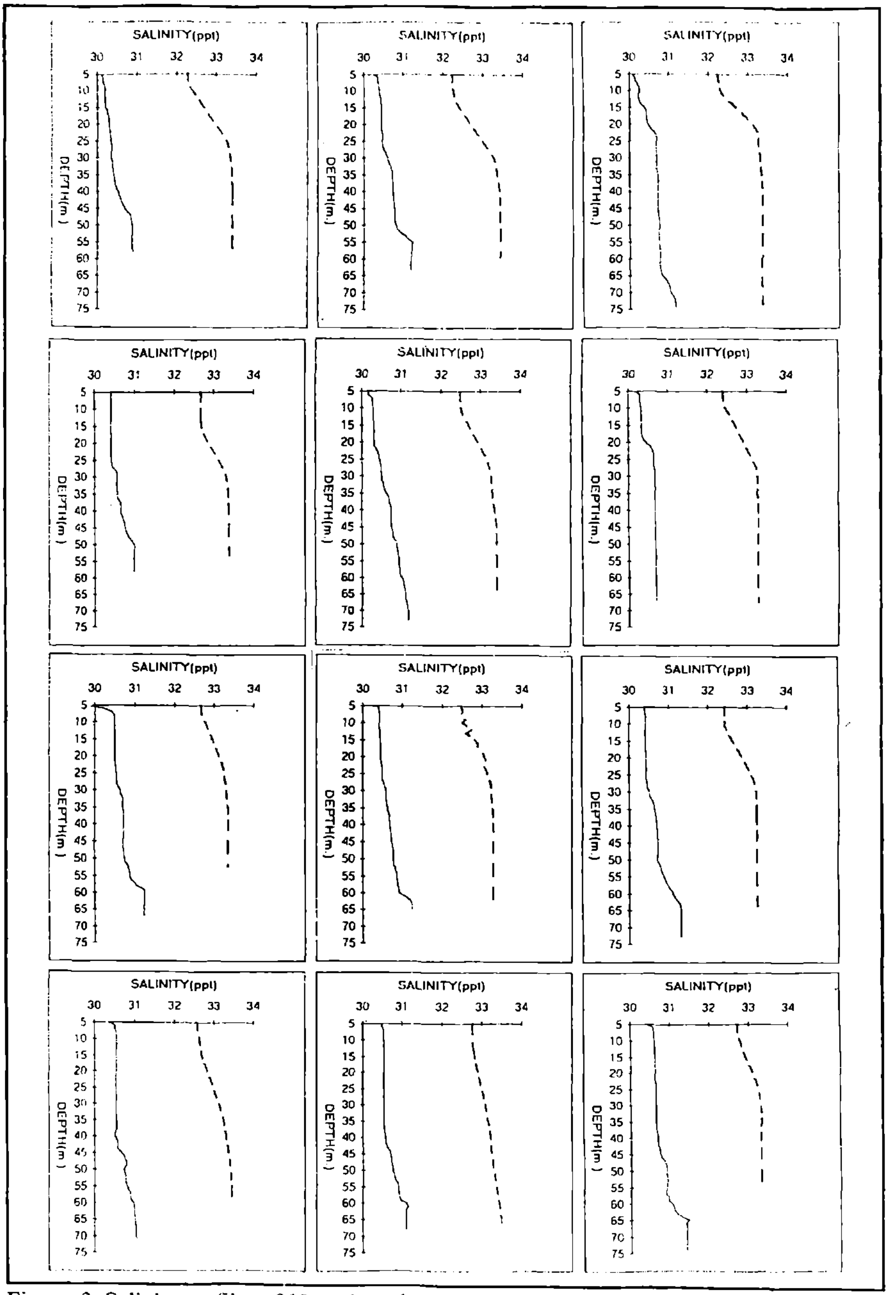

Figure: 3. Salinity profiles of 12 stations during the northeast (solid lines) and the south-west (broken lines) monsoon seasons. The stations represented in the figure, for both monsoon seasons, are not in the same location but they are in a very close proximity.

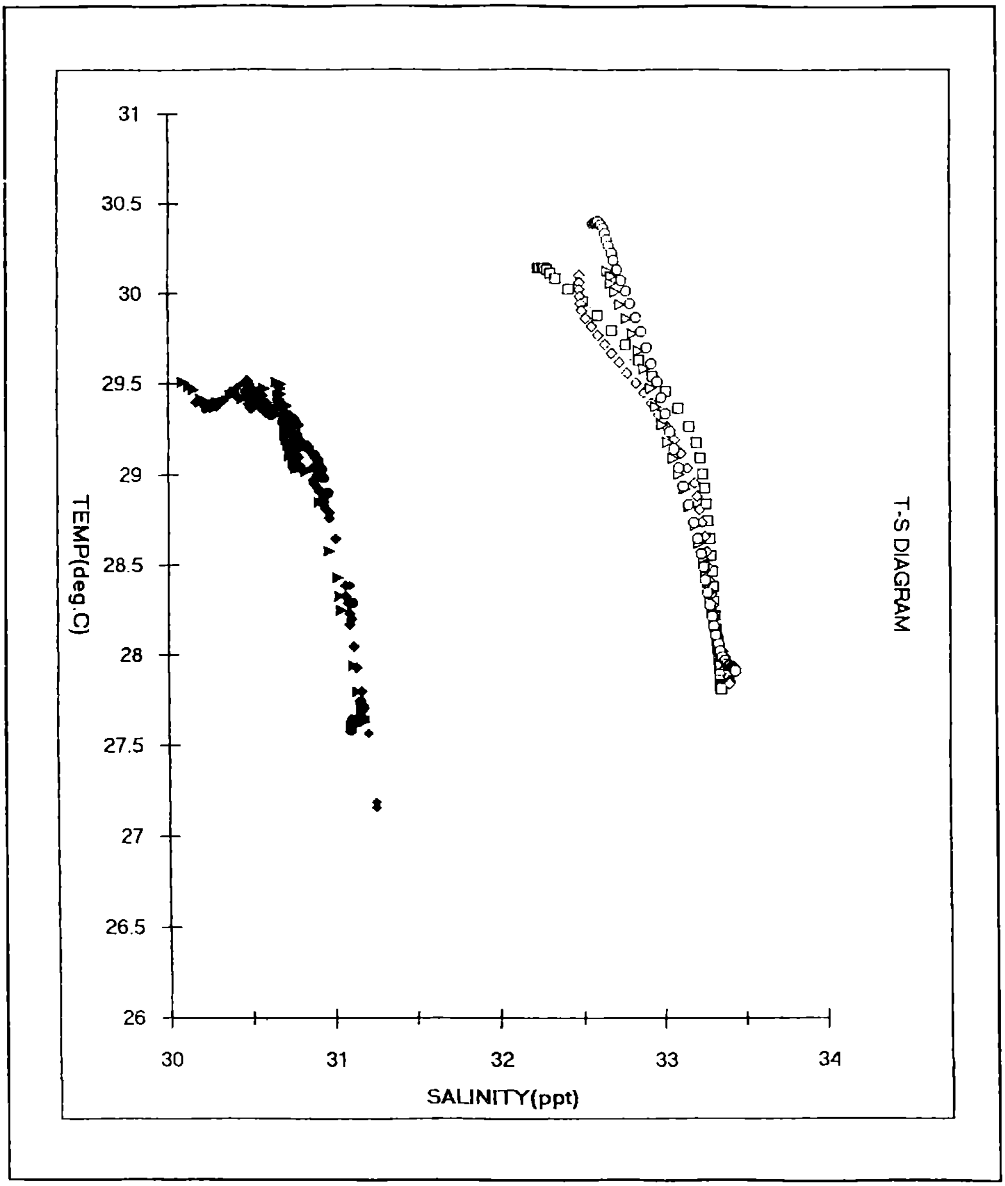

Figure: 4. T-S diagrams of four stations in the north-east monsoon season (solid markers) and four stations in the south-west monsoon season (empty markers).

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