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WIND STRESS AND SEA TEMPERATURE CHANGES OFF THE WEST COAST OF THAILAND

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ABSTRACT

Weather observations collected at the Phuket International Airport during 1976-1980 was summarized for a general description of climatic conditions off the west coast of Thailand. Analysis of wind information showed the prevailing winds to be off-shore (E, NE, SE) during the northeast monsoon and on-shore (W, NW, SW) during the southwest monsoon, with the cumulative strength of the on-shore winds greater than the off-shore winds. There were considerable variations in the strength of the monsoons with the 2 most recent monsoons weaker than those of the 2 previous years. Bathythermographs were used during pole and line fishing cruises conducted from September 1979 to December 1980 to monitor sub-surface sea temperatures. Marked changes in sub-surface sea temperatures occurred over the continental shelf concomitant with shift in wind stress. Water over the shelf was strongly stratified during the northeast monsoon and homogeneous during the southwest monsoon. Upwelling off this coast is generated primarily by wind and differs from upwelling off the west coast of India and the major upwelling systems of the eastern boundary currents where the prevailing current is the principal generating force.

1. INTRODUCTION

There is little information in the literature on the oceanographic conditions off the west coast of Thailand, Malay Peninsula. Limpsaichol (1978) described the bathymetric distribution of physicochemical parameters and nutrients for a few stations around the Surin Islands. Primary production was determined throughout 1976 off the southeast coast of Phuket Island and at a few stations off the Surin and Similan Islands by Wium-Andersen (1977; 1979). These authors noted upwelling to occur off this coast during the northeast monsoon.

The present report summarizes the information for selected weather parameters (air temperatures, precipitation, wind) at the Phuket International Airport, and sea temperature changes over the continental shelf during the 1979/1980 monsoon year. Seasonal changes in wind stress and sea temperatures are discussed and a probable sequence of cause-and-effect events is proposed.

2. SOURCE OF INFORMATION

Information of weather conditions was obtained from the Department of Meteorology in Bangkok. Phuket International Airport weather station was selected as the data source for analysis because of this station's central position on the west coast as well as in the area of pole and line fishing activities. Also, this weather station is situated on the west coast of Phuket Island in an exposed location so that wind conditions here can be expected to be similar to that on the open ocean. Meteorological observations recorded at the Phuket International Airport were obtained for the period January 1976 through October 1980.

Sea temperatures were recorded during pole and line fishing cruises of the **Pramong 10**. Surface temperatures were taken since initiation of vessel operations with a small bucket thermometer every hour on the hour during the daytime while the vessel was underway. Also, surface temperatures were taken at each fishing station. A study of sub-surface temperatures was commenced in July 1979 with a 140-m bathythermograph. This study was extended to greater depths in December 1979 with acquisition of a 275-m bathythermograph. However, this bathythermograph was damaged in February 1980 so that only the 0-140 m interval could be investigated on all subsequent cruises.

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All but 5 of the 13 pole and line fishing cruises completed from September 1979 through December 1980 were accomplished in 2 phases. The first phase was exploratory in orientation to define the areas of fish school abundance. Bathythermograph casts were made for the most part during the first phase of cruises while visual searching on transect lines. A BT cast was made at the start and the end as well as at regular intervals of distance or change in depth, depending upon circumstances, along the transect lines. This more or less systematic sampling pattern required a minimum of casts to give a general picture of the distribution of sub-surface temperatures in a vertical plane at distance intervals and in a horizontal plane at depth intervals for the area of investigations.

Positions were fixed by radar when in range of landmarks. Outside radar range, positions were fixed by dead-reckoning.

3. METHODS OF ANALYSIS

The principal phenomenon influencing climate in the Southeast Asian region is the monsoons. Consequently, meteorological and sea temperature observations were considered by monsoon seasons, that is, the northeast monsoon from November to April and the southwest monsoon from May to October. Air temperatures and precipitation for a 2-year period and wind information for a 3-year period were summarized to show seasonal contrasts between monsoons and annual differences within monsoons.

Daily readings of wind direction in degrees and wind force in Beaufort number for 1,300 hours local time were copied from weather station reports. This information was analyzed as follows and summarized graphically in compass rose diagrams.

Wind direction readings for each month were grouped into 8 major compass points, of 45° The divisions and corresponding compass points were 337.5°–22.5° = N, 22.5°–67.5° = NE, etc.

Wind frequency was taken to be the number of days during the month the wind blew from each compass point.

Wind force readings were averaged for each compass point by summing the frequency times the Beaufort number. The equivalent mean velocities in knots and km/h of Beaufort scale number are:

Beaufort number	knots	km/h
0	<1	<1
1	1-3	1-5
2	4-6	6-11
3	7-10	12-19
4	11-16	20-28
5	17-21	29-38
6	22-27	39-49
7	28-33	50-61
8	34-40	62-74
9	41-47	75-88
10	48-55	89-102

Surface sea temperatures were most frequently taken off south Phuket Island in the 1°-square area bounded by the 7° and 8° latitude and 98° and 99° longitude lines. Observations taken in this area were summarized by cruise to determine seasonal changes in surface sea temperatures.

The continental shelf between 7° and 8° latitudes was transected during most cruises completed from August 1979 to December 1980. Slides for bathythermograph casts on transect lines completed in this section of the shelf were analyzed in detail to show seasonal changes in sub-surface thermal gradients.

The entire continental shelf off the west coast of Thailand from approximately the 50-m isobath to the edge of the continental shelf was transected during 2 cruises each during the northeast (January, February) and southwest monsoons (July, August). Information from bathythermograph slides for these cruises was summarized to show differences between monsoons in temperatures at 50-m depths over the mid and outer continental shelf.

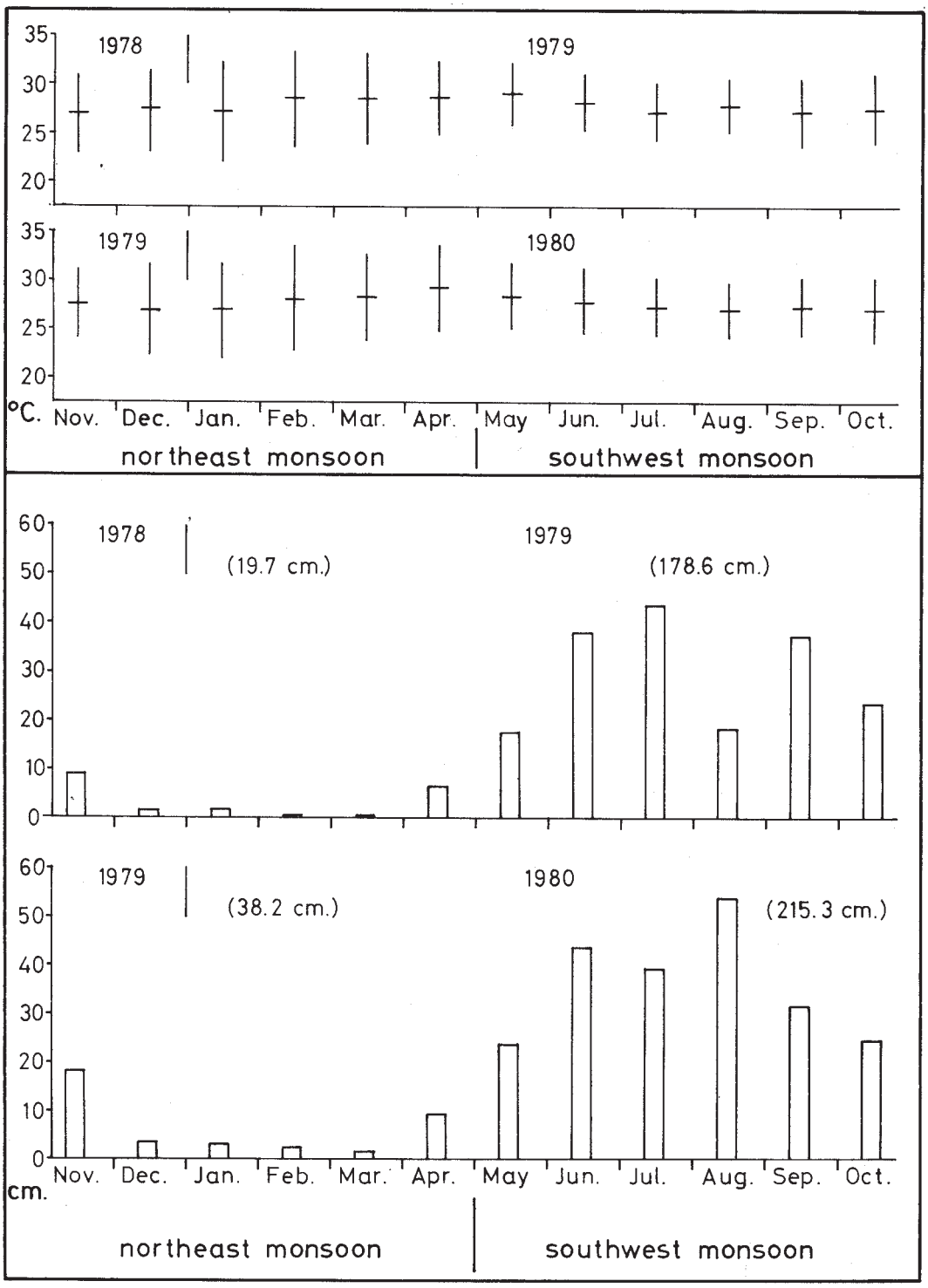

Fig. 1. (a) Monthly mean air temperatures for 2 monsoon years at the Phuket International Airport.
(b) Monthly precipitation totals for 2 monsoon years at the Phuket International Airport.

4. RESULTS

4.1 METEOROLOGICAL OBSERVATIONS

4.1.1 Air temperatures

Air temperatures are markedly constant throughout the monsoon year on the west coast of Thailand. Monthly mean temperatures ranged from 27.0° to 29.0°C during 1978/1979 and from 26.9° to 29.2°C during 1979/1980 (Fig. 1a). Highest mean temperatures occurred in May 1979 and April 1980. Air temperatures were slightly higher for the period February through June. Lowest monthly mean temperatures occurred in November 1978 and December 1979. The range in air temperatures was greater during the northeast monsoon than during the southwest monsoon.

4.1.2 Precipitation

The rainy season for the 2 monsoon years under consideration began in April and extended through to November (Fig. 1b). Rainfall increased from low levels in April to highest levels in July during 1979 and in August during 1980. There was 36.7cm more rainfall during the latter than the former southwest monsoon, primarily because of low rainfall in August 1979. The 1979/1980 northeast monsoon also was considerably wetter than the previous monsoon with 94% more rainfall.

4.1.3 Wind

The northeast and southwest monsoons are so called because of the prevailing winds during these respective monsoons However, on the west coast of Thailand and specifically at the Phuket International Airport, the predominant winds are easterly and westerly with variations within monsoons (Fig. 2 and 3). The frequency of easterly and westerly winds was higher during the 1977/1978 northeast monsoon and 1978 southwest monsoon, respectively, than during the 2 more recent monsoons. The prevailing wind system on the west coast of Thailand is off-shore (NE, E, SE) during the northeast monsoon and on-shore (NW, W, SW) during the southwest monsoon. Frequency and force of off-shore and on-shore winds were summed for an index of the relative strengths between and within monsoons (Table 1 and 2). These summations indicate the northeast monsoon to be weaker than the southwest monsoon. The average for 4 monsoon years was 432 versus 543 Beaufort force-days for these respective monsoons. Mean frequency of off-shore winds (126 days) was slightly lower than that of on-shore winds (143 days). Also, mean Beaufort force was 3.4 for off-shore winds and 3.8 for on-shore winds. The northeast and southwest monsoons of the 2 earlier years were considerably stronger than these respective monsoons of the 2 more recent years.

Of the 4 northeast monsoons under consideration, the 1977/1978 monsoon was the strongest with 574 Beaufort force-days (Table 1). Winds blew off-shore during this monsoon with high frequency and high force. The strength of the 1978/

Table 1. Number of days by Beaufort force of NE, E and SE winds (off-shore) during 4 northeast monsoons.

Northeast Monsoon	Wind force (Beaufort scale)										Total days	Mean force	Beaufort force-days
	1	2	3	4	5	6	7	8	9	10			
1976/1977	-	1	29	81	25	6	-	-	-	-	142	4.0	574
1977/1978	-	-	14	80	31	3	-	-	-	-	128	4.2	536
1978/1979	1	36	41	24	1	-	-	-	-	-	103	2.9	297
1979/1980	5	67	57	3	-	-	-	-	-	-	132	2.4	322
Mean	1.5	26.0	35.2	47.0	14.2	2.2	-	-	-	-	126.2	3.4	432.2

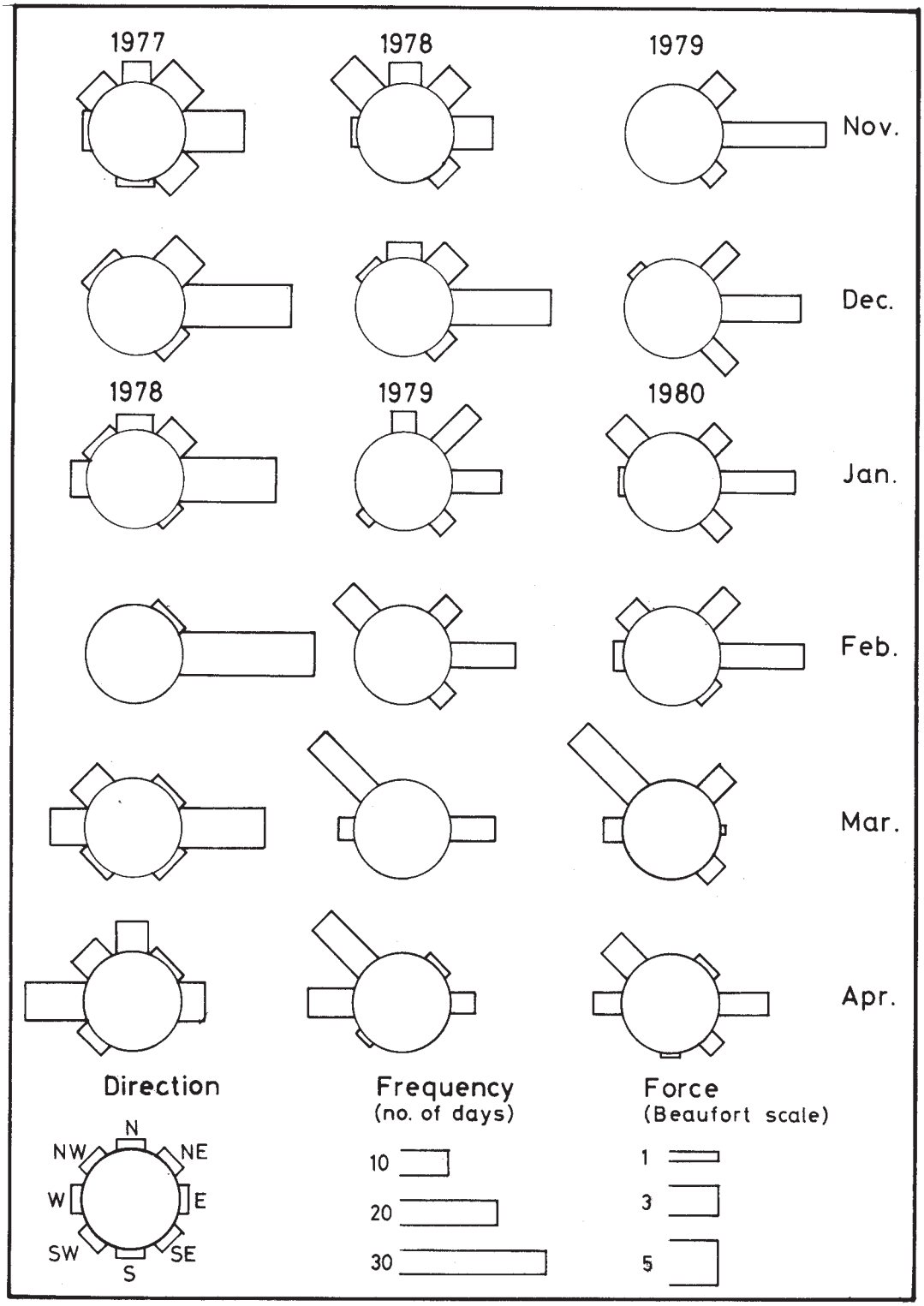

Fig. 2. Monthly wind characteristics for 3 northeast monsoons at the Phuket International Airport.

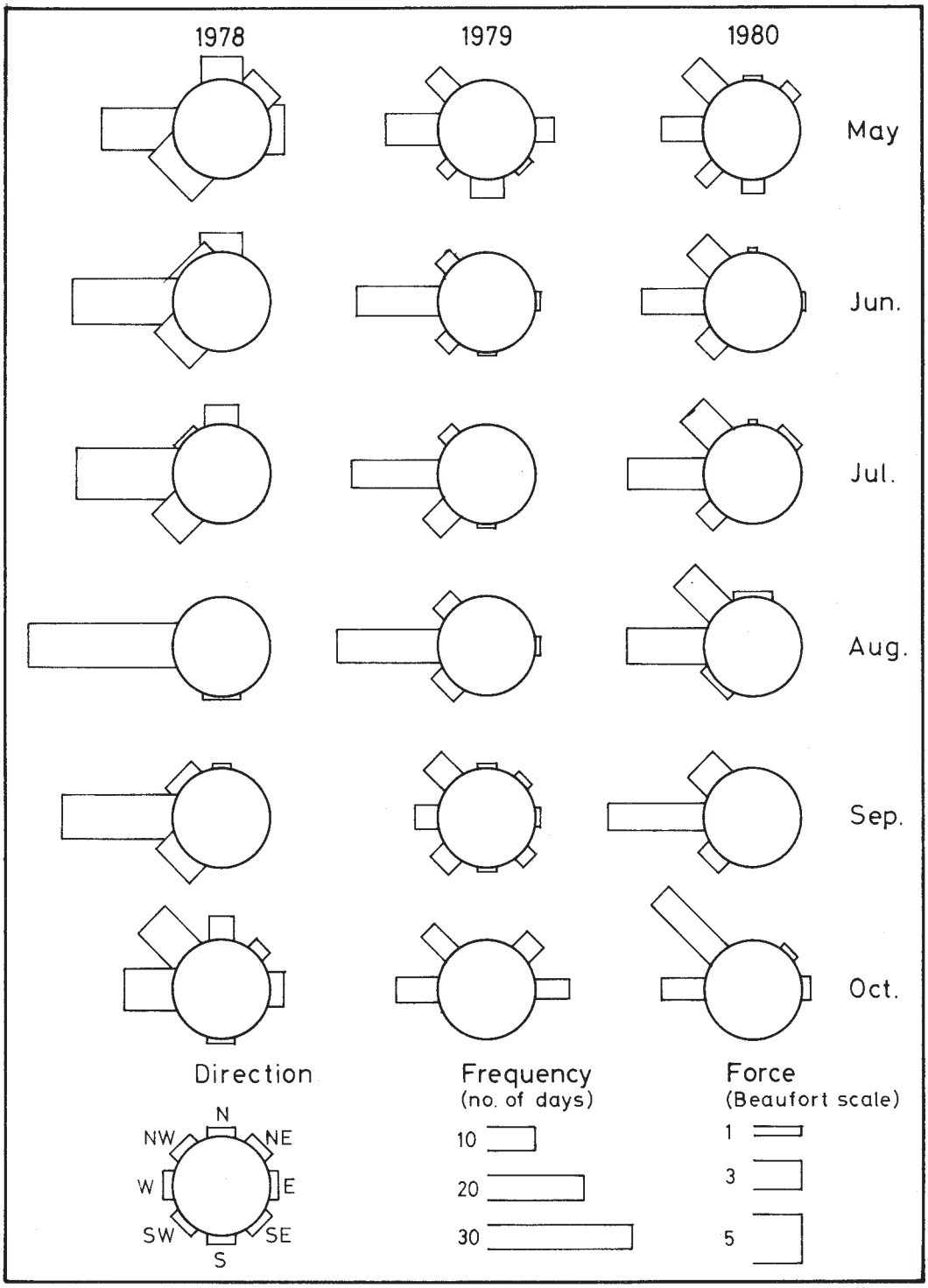

Fig. 3. Monthly wind characteristics for 3 southwest monsoons at the Phuket International Airport.

1979 northeast monsoon was half that (297 Beaufort force-days) of the previous year, resulting from low frequency and low force. Relatively high frequency of off-shore winds, but low force of these winds resulted in a weak 1979/1980 northeast monsoon (322 Beaufort force-days).

The 1978 southwest monsoon was the strongest with 719 Beaufort force-days. On-shore winds blew with high frequency and high force during this monsoon (Table 2). Frequency of on-shore winds during the 1980 southwest monsoon equalled that of the 1978 monsoon, but the low force of the winds resulted in a markedly weaker monsoon (460 Beaufort force-days). A combination of low frequency and low force resulted in the weakest southwest monsoon in 1979 (336 Beaufort force-days).

4.2 OCEANOGRAPHICAL OBSERVATIONS

4.2.1 Surface sea temperatures

Mean surface sea temperatures off south Phuket Island during 1979/1980 fluctuated from a low of 28.6° in December - January to a high of 30.2° in June and thereafter decreased again to a low of 28.6° in November (Fig. 4). Lowest surface sea temperatures occurred after the southwest monsoon with overcast skies, heavy precipitation and agitated seas. Highest surface sea temperatures occurred after the northeast monsoon with clear skies, negligible precipitation and calm seas.

Vertical plane profiles of sub-surface sea temperatures normal to the continental shelf for various months of the year showed thermal gradients to vary greatly with the monsoons. During the northeast monsoon, water over the mid and outer shelf was strongly stratified with a thin veneer of high temperatures and rapidly decreasing temperatures with depth (Fig. 5). Temperatures decreased from approximately 29°C at the surface to 16°C at 120 m during February and March. Temperatures were essentially uniform from surface to bottom over the mid and outer shelf during the southwest monsoon (Fig. 6). Temperatures during September were 29°C at the surface and 25°C at 110 m. There was an approximately 7°C increase in sea bottom temperatures over the shelf edge from March to September.

Shifts in the bathymetric displacement of isotherms can be traced through the year from the vertical plane profiles (Fig. 5 and 6). The 25° isotherm was stationary at 50 m from December to March, then retreated to 75 m in June and to 110 m in September. The 22° isotherm occurred at 100 m in December, then advanced to 70 m in February—March and returned to 95m by June. The 19° isotherm advanced from 125 m in December to 105 m in February to 90 m in March. The 16° isotherm advanced from 150 m in December to 120 m in February—March.

Horizontal plane profile at 50-m depths of sub-surface sea temperatures over the mid and outer continental shelf off the west coast of Thailand during the 1979/1980 northeast monsoon is shown

Table 2. Number of days by Beaufort force of NW, W and SW winds (on-shore) winds during 4 southwest monsoons.

Southwest Monsoon	Wind force (Beaufort scale)										Total days	Mean force	Beaufort force-days
	1	2	3	4	5	6	7	8	9	10			
1977	-	-	23	58	29	10	17	2	-	1	140	4.7	651
1978	-	-	12	68	42	16	7	7	-	-	152	4.7	719
1979	10	50	42	25	-	-	-	-	-	-	127	2.7	336
1980	6	42	67	31	4	3	1	-	-	-	154	3.0	460
Mean	4.0	23.0	36.0	45.5	18.7	7.2	6.2	2.2	-	0.2	143.2	3.8	541.5

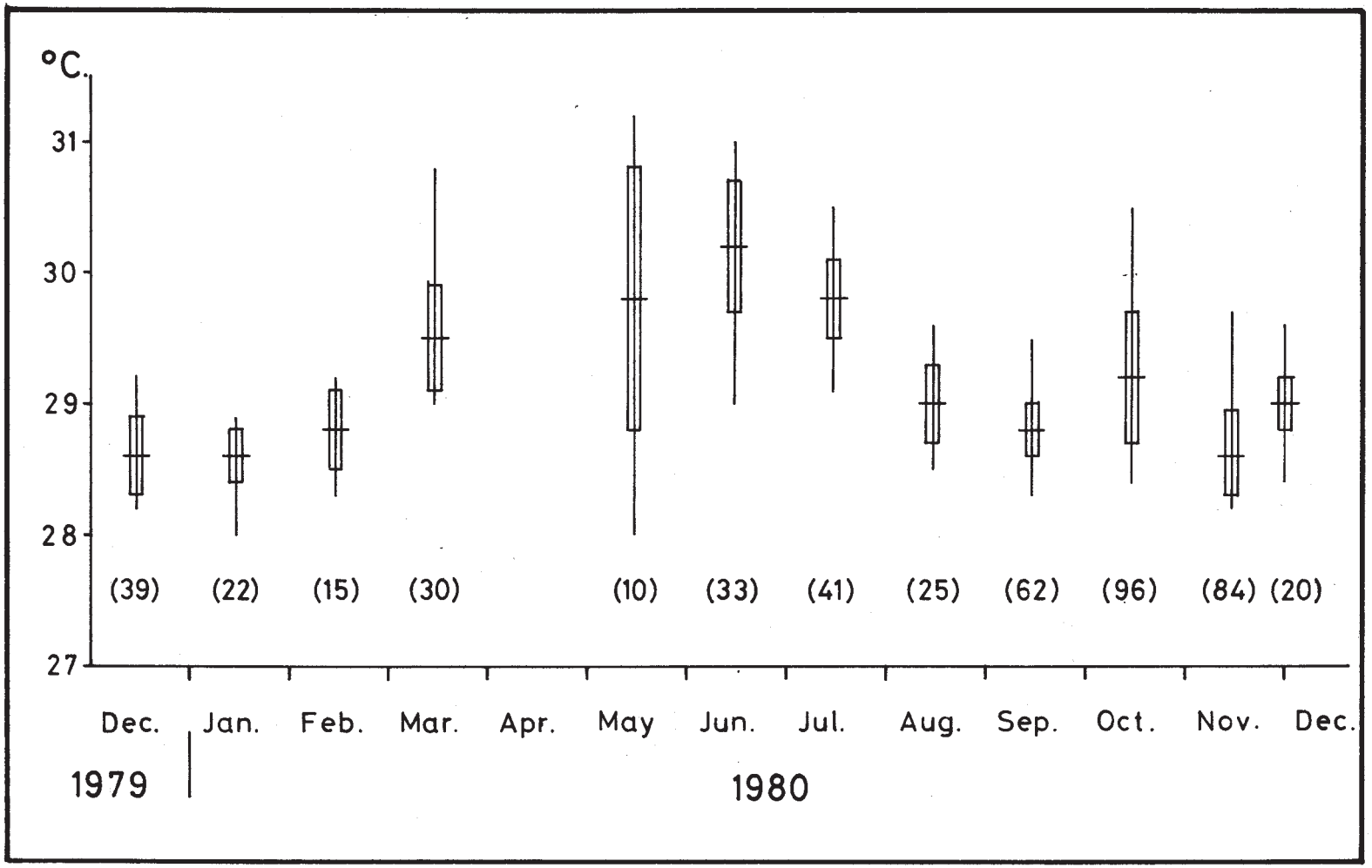

Fig. 4. Variations in surface sea temperatures off Phuket Island from December 1979 to December 1980.

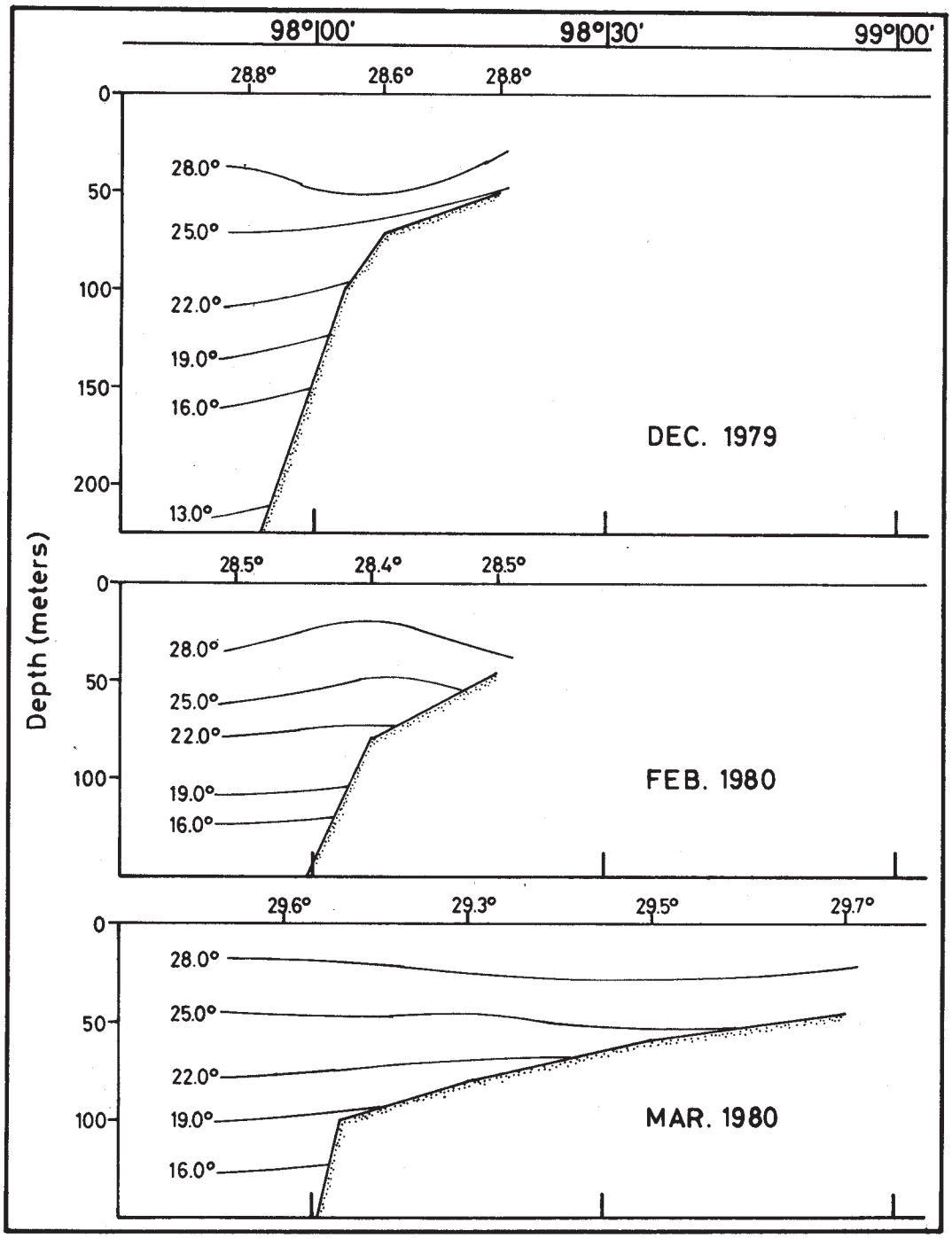

Fig. 5. Vertical plane profiles of sub-surface sea temperatures across the continental shelf south of Phuket Island for 3 selected months of the 1979/1980 northeast monsoon.

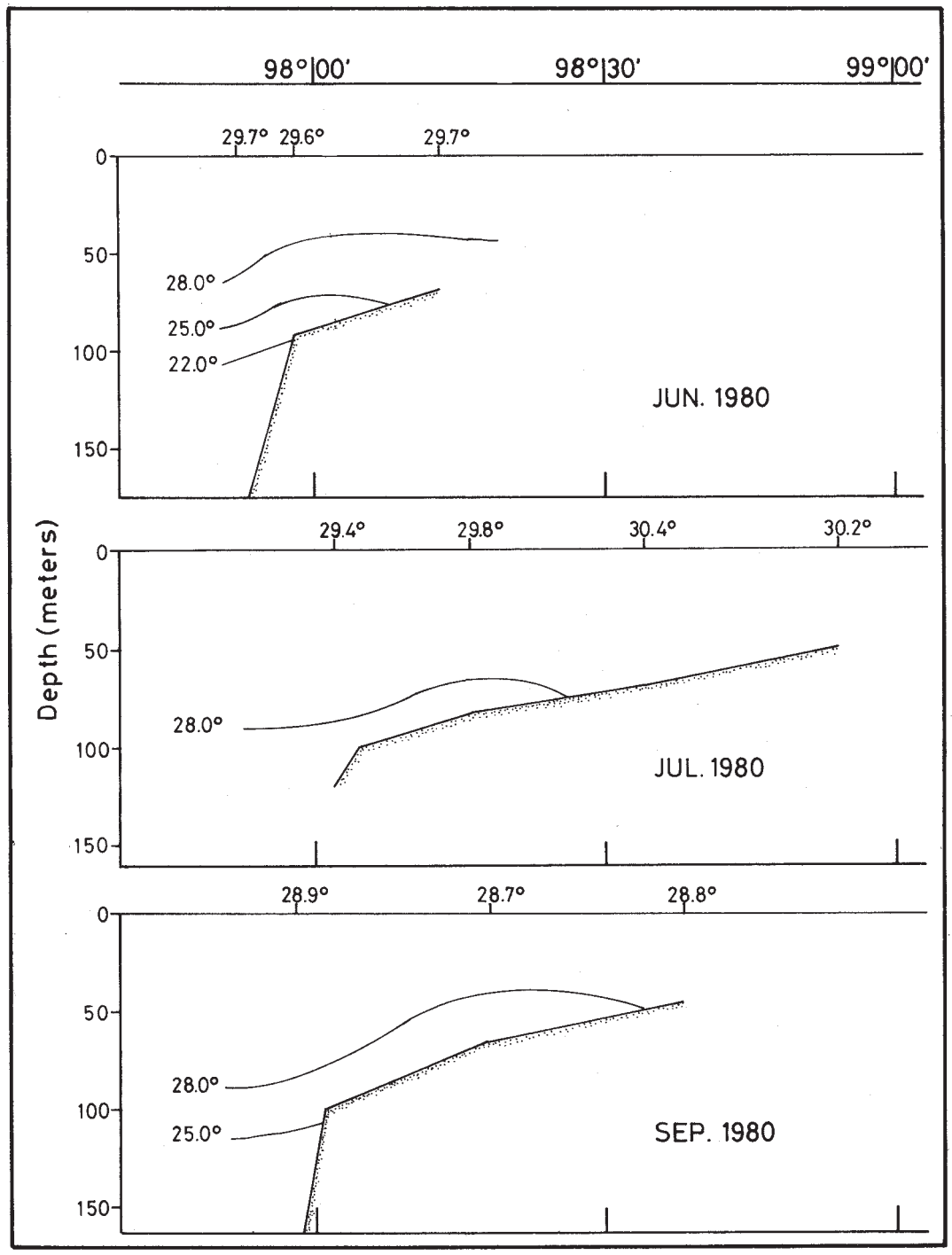

Fig. 6. Vertical plane profiles of sub-surface sea temperatures across the continental shelf south of Phuket Island for 3 selected months of the 1980 southwest monsoon.

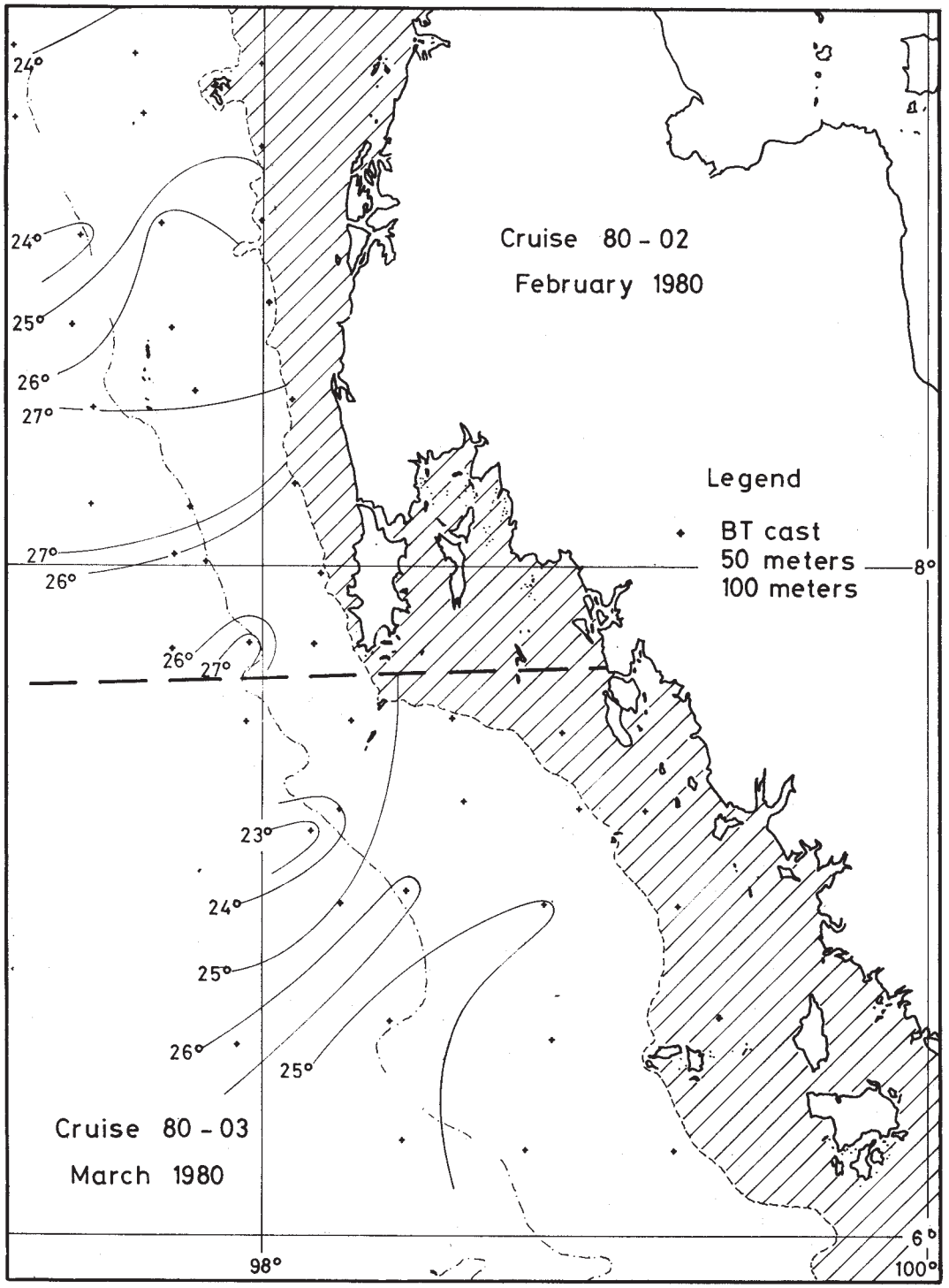

Fig. 7. Horizontal plane profiles at 50-m depths of sub-surface sea temperatures over the mid and outer continental shelf off the west coast of Thailand during the 1979/1980 northeast monsoon.

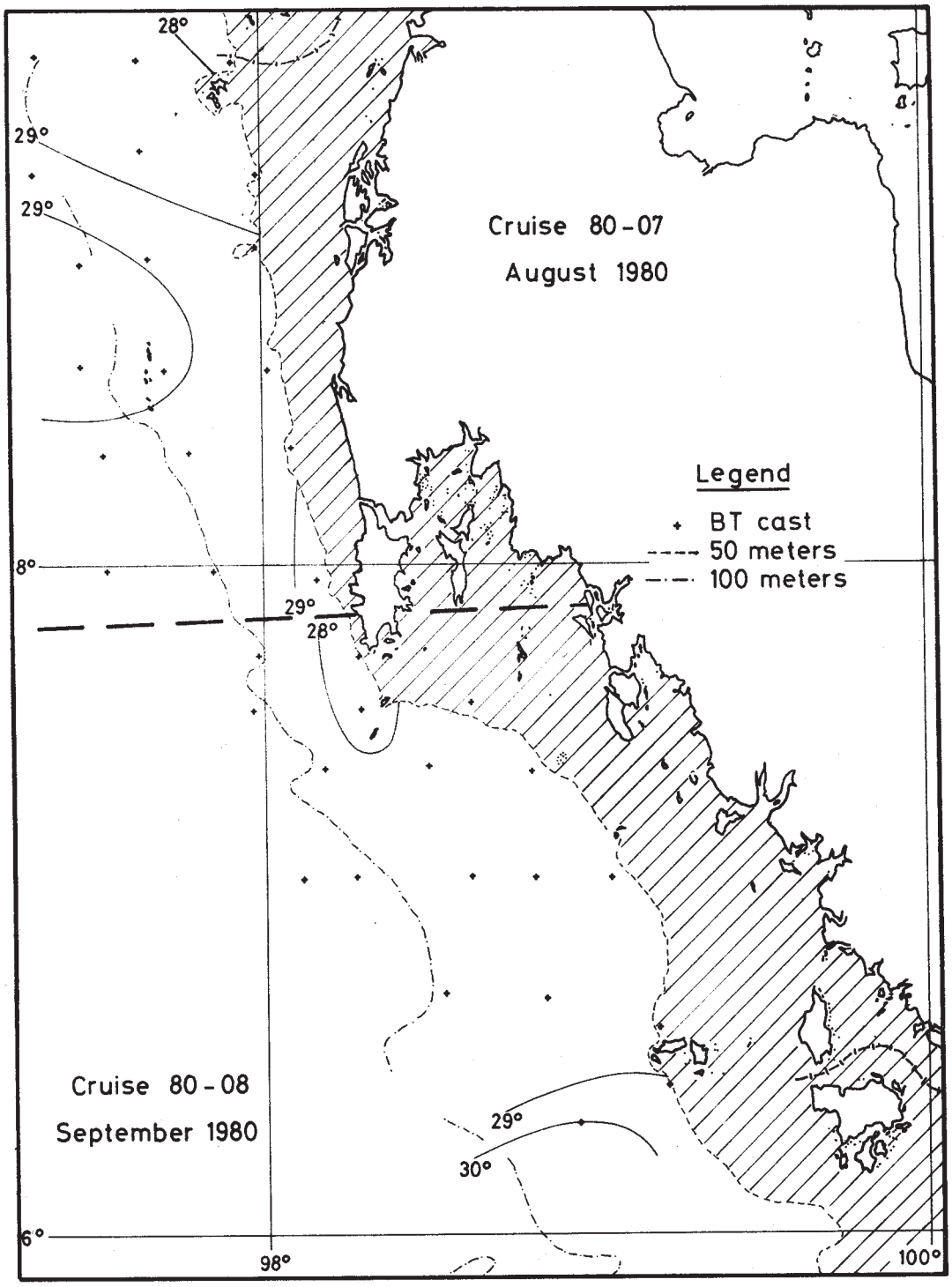

Fig. 8. Horizontal plane profiles at 50-m depths of sub-surface sea temperatures over the mid and outer continental shelf off the west coast of Thailand during the southwest monsoon.

in Figure 7. Temperatures at this depth ranged from 23° to 27° C during February—March. Tongues of cold water (less than 24°C) occurred at 2 locations near the Burmese border and another location south of Phuket Island. Masses of warm water (27° C) covered an extensive portion of the shelf around the Similan Islands and a small area of the shelf edge west of Phuket Island. The irregular distribution of isotherms suggests the intrusion of cold, deep water onto the continental shelf to be most intense near the Burmese border and south of Phuket Island and least intense around the Similan Islands.

Sub-surface temperatures at 50-m depths during the southwest monsoon are essentially uniform over the entire mid and outer shelf (Fig. 8). Coldest water (less than 28° C) occurred at the Burmese border in August and around the southern end of Phuket Island in September. Warmest water (30° C) was present at the Malaysian border in September.

5. DISCUSSION

The present analysis of 4 monsoon years shows considerable variations between monsoon years in the strength of the northeast and southwest monsoons. Mean frequency of off-shore winds varied from 103 to 142 days and of on-shore winds from 127 to 154 days. Mean Beaufort force of these respective winds varied from 2.4 to 4.2 and 2.7 to 4.7. Also, it has been noted that both the northeast and southwest monsoons on the west coast of Thailand blows in cycles with periods of strong winds followed by periods of calm.

The analysis of wind stress and sea temperature changes during the 1979/1980 monsoon year suggest a direct influence of the former on the latter. The following is a generalization of the probable sequence of events. Winds generally begin to blow with high frequency from the E, NE and SE during December. These off-shore winds push the warm, surface water away from the coast allowing the intrusion of cold, deep water onto the shelf. The off-shore winds persist with high frequency through February. The cumulative effect of sustained transport of surface water is that the outer and mid continental shelf is completely inundated with cold water from the deep. Consequently, water on the shelf is strongly stratified with temperature difference from surface to bottom of 8° C at 100 m. Winds are more variable during March—April, and do not influence appreciably the thermal stratification of the shelf water.

Winds begin to blow in May more frequently from the W, NW, SW and by June are blowing constantly from these directions. These winds persist with high frequency through September. These on-shore winds push warm oceanic water onto the shelf. Oceanic water "piles-up" and eventually occupies the entire continental shelf after prolonged periods of transport onto the shelf. Water over the shelf during the latter half of the southwest monsoon is essentially homogeneous with temperature differences between the surface and bottom less than 3° C at 100 m. Winds are more variable in October which they do not alter the homogeneity of the shelf water.

Upwelling off the west coast of Thailand and the dominant currents in the Andaman Sea are generated by the monsoon system. Pilot charts published by the Hydrographic Office of the U.S. Secretary of the Navy shows the dominant currents in this sea to be northwesterly in January and southeasterly in July. The northwesterly current of the northeast monsoon is probably the stronger current.

Annual variations in the strength of the northeast monsoon can be expected to generate corresponding differences in the intensity of upwelling off the west coast of Thailand. Fukuoka (1965) noted the upwelling off the Venezuelan coast to be more pronounced in spring 1964 than it had been during the previous spring, and presented evidence that this difference was caused by the respective wind strengths during these 2 years. He concludes "it is possible that with better wind observations and more oceanographic data we can develop empirical equation, whereby, based upon the wind speeds,

rates of upwelling can be predicted". This conclusion is equally valid for the west coast of Thailand where there is a direct correlation of wind stress and sea temperature changes.

The west coast of Thailand is similarly situated with respect to the ocean as the west coast of India. The monsoon system extends from West Africa through Southeast Asia so that the west coasts of Thailand and India are influenced by winds from the same general direction during the same periods. Upwelling occurs off the west coast of India (Banse, 1959). However, upwelling off this coast differs from that off the west coast of Thailand in many respects. Upwelling occurs during the southwest monsoon, essentially from July to September. The prevailing winds during this monsoon are northwesterly and westerly whereas the prevailing current is southeasterly. Upwelling extends over a larger area from 15° N, and perhaps from 18° N to 8° N latitude and is stronger to effect a noticeable lowering of surface sea temperatures between Quilon to Cape Comorin. The strong southeasterly current is attributed to be the principal force in generating upwelling off the west coast of India. This upwelling system, therefore, is similar to the major upwelling systems along the eastern boundary currents with prevailing current and winds parallel to the coast (Cushing, 1959).

The markedly different thermal structure of the shelf water between monsoons may be a factor affecting the distribution of large pelagic fish. Schools of large pelagic fish were counted at rates of 1.1 sighting/h during the 1979 southwest monsoon and 1.5 sighting/h during the 1979/1980 northeast monsoon. Most of these sightings were schools of longtail tuna *(Thunnus tonggol)*. This tuna is a coastal species of the Indo-Pacific tropical province so that the thermal habitat of young adults can be inferred to be a narrow range in the upper limits of sea temperatures. Shelf water during the northeast monsoon is strongly stratified with a thin veneer of high temperatures and rapidly declining temperatures with depth. The higher sighting rate obtained during this monsoon may have resulted from the increased probability of sighting of confinement of fish in the upper, high temperature layer of the water column.

6. SUMMARY

1. Mean monthly air temperatures at the Phuket International Airport ranged from 26.9° to 29.2° C during 2 monsoon years. Precipitation totalled 198.3 cm during 1978/1979 and 253.4 cm during 1979/1980. Ninety percent and 85% of these respective totals occurred during the southwest monsoon.

2. On the west coast of Thailand, the prevailing winds during the northeast monsoon is easterly and during the southwest monsoon is westerly. There is considerable differences in direction and force of winds from one year to another. The 1977/1978 northeast and 1978 southwest monsoons were appreciably stronger than those of the 2 more recent years.

3. Mean sea surface temperatures around south Phuket Island was lowest (28.6° C) at the start of northeast monsoon and highest (30.2° C) at the start of the southwest monsoon.

4. Water over the shelf was strongly stratified with 8° C difference in temperature from surface to bottom at 100 m during the northeast monsoon. A progressive decrease in bottom temperatures occurred through this monsoon season. Water over the shelf was essentially homogeneous during the southwest monsoon with temperature difference from surface to bottom of less than 3° C at 100 m. An increase in bottom temperatures was noted during the early part of this monsoon season.

Upwelling off the west coast of Thailand is generated principally by wind. This upwelling system differs from the system off the west coast of India.

7. ACKNOWLEDGEMENTS

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