ACTA UNIVERSITATIS LODZIENSIS
FOLIA GEOGRAPHICA PHYSICA 3, 1998

Ahmad Shaharuddin

COOLING EFFECTS OF A RIVER AND SEA BREEZE ON THE THERMAL ENVIRONMENT: A CASE OF KUALA TERENGGANU, TERENGGANU, MALAYSIA

OCHŁADZAJĄCY WPŁYW RZEKI I BRYZY MORSKIEJ NA WARUNKI TERMICZNE NA PRZYKŁADZIE KUALA TERENGGANU, TERENGGANU, MALEZJA

A series of sea breeze observations have been carried out along the Terengganu river in the state of Terengganu on the east coast of the Peninsular of Malaysia. These observations were carried out during the north-east monsoon months of November and December, 1993. Wind and temperature data were measured at the height of about 1.5 m above the ground along the three traverses on both sides of the river which is approximately 10 km long that perpendicular to the coast and then the results were presented in a horizontal cross-section. Generally, the formation of sea breeze of the speed of $\geqslant 4.1$ ms^{-1} was observed capable in reducing the ambient air temperature of about 2.0° to 4.0°C. Although the effect of sea breeze can be traced further inland along the river, its cooling effects, however, were well marked at the estuary of the Terengganu river than at the 7th km interior area of Kuala Terengganu. The difference in the temperature decrease was observed in the order of 1.7° and 2.4°C from the inland to the coastal areas, respectively. During the sea breeze episode, most of the coastal field stations indicated a slower temperature increase than the field stations located in the interior area. Furthermore, the effect of sea breeze in reducing ambient air temperature was well marked above the river (stations on bridges) than stations on both sides of the river. Simultaneously, an overall time-lag increase in relative humidity was observed during the fall of ambient air temperature, owing to the effect of sea breeze. In general, the establishment of sea breeze cooling effect was significantly felt about 3 to 6 hours period i.e., between 14.00 and 20.00 (Malaysian Local Time) which was varied between stations; longer period was experienced by stations located at or near the coastal area than stations further inland.

INTRODUCTION

Sea breeze is an air "parcel" moving toward land from the open sea in response to differential heating across the coastline during the day. The riverse direction established at night when the air moving toward open sea from inland due to the same reason (land breeze). The presence of sea breeze has been proven as one of a very important cooling effect factors to seaside cities in the world (Frizzola et al. 1963; Fergusson 1971; Banfield 1991; Shaharuddin 1993). Besides, the shoreline has always been a favourite holiday area. In addition, several studies such as Cole (1977); Spillane (1978); Evans et al. (1982) have shown an important role played by sea breeze in pollution dispersal. Sea breeze phenomena being regarded as part of coastline meteorology, therefore, is of practical importance to study.

This paper attempts to study the inland penetration of sea breeze at three different traverses that run approximately 7 km long parallel to the Terengganu river which is perpendicular to the coastline. The establishment of sea breeze along the traverses was then statistically analysed to find significant of its cooling effect on thermal urban environment.

STUDY AREA DESCRIPTION

Map 1 shows the location of Kuala Terengganu as a study area. Kuala Terengganu ($\varphi = 5°07'–5°27'N$, $\lambda = 103°00'–103°11'E$) with a population of approximately quarter a million in 1991 is one of several big and important towns in the east coast of Peninsular of Malaysia. Because of its location at the coastal area, therefore it is easily exposed to the influence of prevailing wind blowing from an open South China Sea throughout the year. The Terengganu river flows in the south-west-north-east direction which split the town into two growth centre areas i.e., one on the north and the other on the south banks. The width of the river mouth is wide enough to be considered as an open area and therefore can exert quite a significant influence on the temperature distribution within the town area. Being a state capital of Terengganu, understandably most of the urban development has been carried out in and around the Kuala Terengganu municipality area.

Table 1 shows some of the important climatic parameters observed at the Kuala Terengganu Airport for the 16-year period (1980–1995). Kuala Terengganu experiences a hot and wet equatorial climate throughout the year. The annual mean temperature is about 23.5°C with monthly mean varies between 23.1°C (in December) and 24.1°C (in May), giving the monthly temperature range of about 1.0°C. Maximum and minimum temperatures established around April–June and November–December, respectively. The mean monthly total of rainfall for the 16-year period was calculated at about 2633 mm with the mean monthly maximum and minimum observed toward the end and beginning of the year, respectively. With regard to the relative humidity, it is clearly shown that Kuala Terengganu experiences a reasonably wet atmospheric condition throughout the year. None of the months has ever recorded the relative humidity of less than 80.0 percent.

Table 1

Maximum, minimum and mean temperature, rainfall and relative humidity at Kuala Terengganu Airport for the 16-year period (1980–1995)

Temperatura maksymalna, minimalna i średnia, opad i wilgotność względna na lotnisku Kuala Terengganu dla okresu 16-letniego (1980–1995)

Month	Max temp. (°C)	Min. temp. (°C)	Mean (°C)	Rainfall (mm)	Relative humidity
January	29.3	26.0	23.3	98.9	82.8
February	30.0	26.4	23.3	28.0	82.1
March	31.6	27.0	23.2	85.4	81.9
April	32.3	27.7	23.9	96.6	83.0
May	32.8	28.0	24.1	73.4	83.2
June	32.9	27.7	24.0	156.6	83.0
July	31.9	26.8	23.4	200.9	84.9
August	31.7	26.6	23.2	263.9	85.4
September	31.4	26.6	23.5	155.1	85.8
October	31.3	26.7	23.6	290.8	86.0
November	29.2	25.4	23.2	412.5	88.1
December	28.6	25.5	23.1	770.9	86.4
Mean	31.1	26.7	23.5	2633.0	84.4

Kuala Terengganu has experienced the two most significant prevailing winds all year round i.e., the strongest north-east during the months of November–March and less stronger of south-west during the months of April–June. Kuala Terengganu has the average of 6.8 hours of sunshine per day with the average sunshine hours during the strongest north-east monsoon is approximately 4.5 hours while the average of about 8.0 hours is normally recorded during the south-west monsoon. With such pattern of sunshine hours, therefore the highest and lowest evaporation are observed during the middle and at the end of the year, respectively.

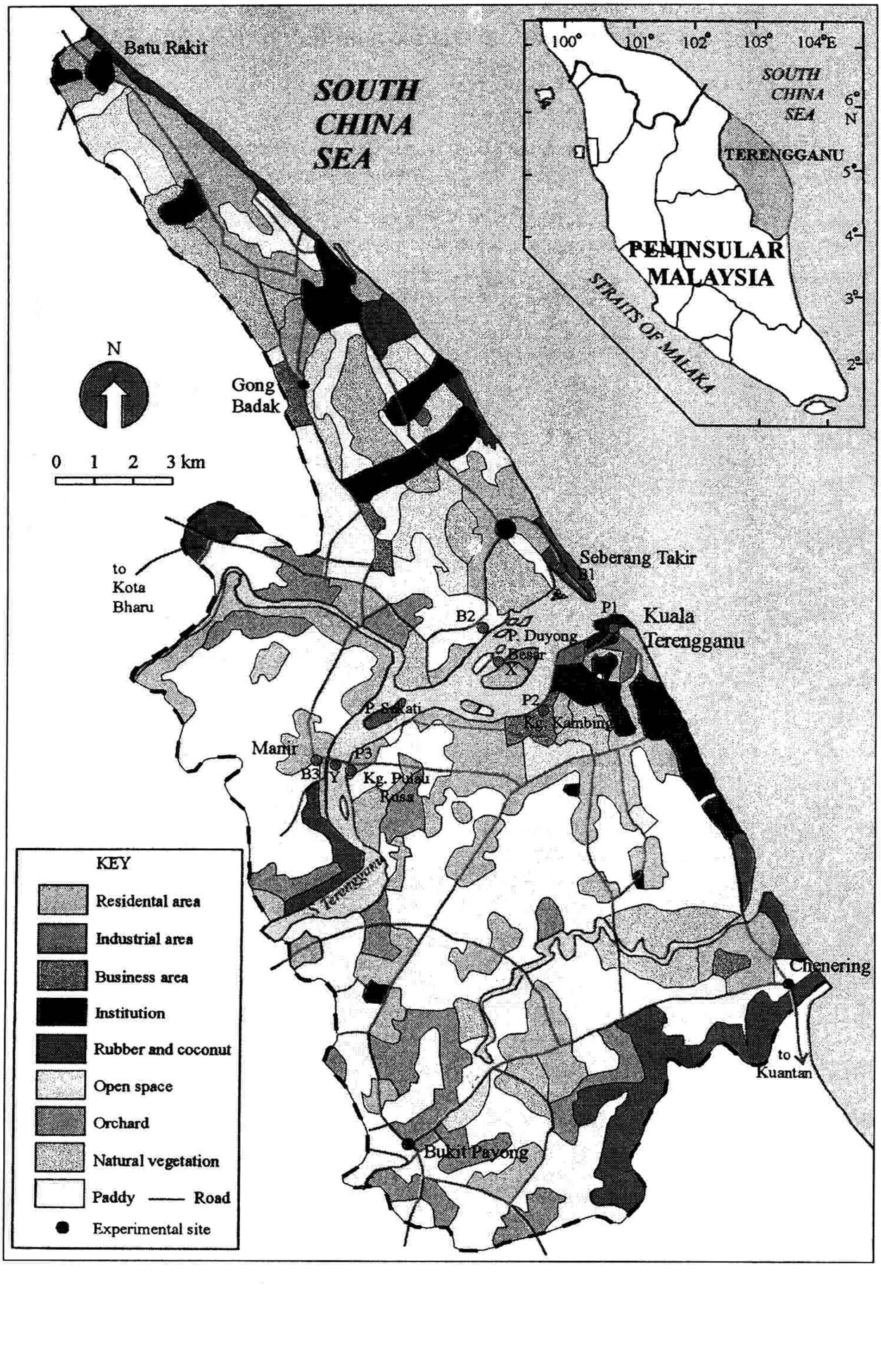
FIELD OBSERVATIONS

The data used in the study were gathered from the field observations which was carried out during the month of November and December, 1993 at eight different field stations in the Kuala Terengganu area (see Map 1).

Map 1

Kuala Terengganu and the location of field stations

Kuala Terengganu i lokalizacja stacji



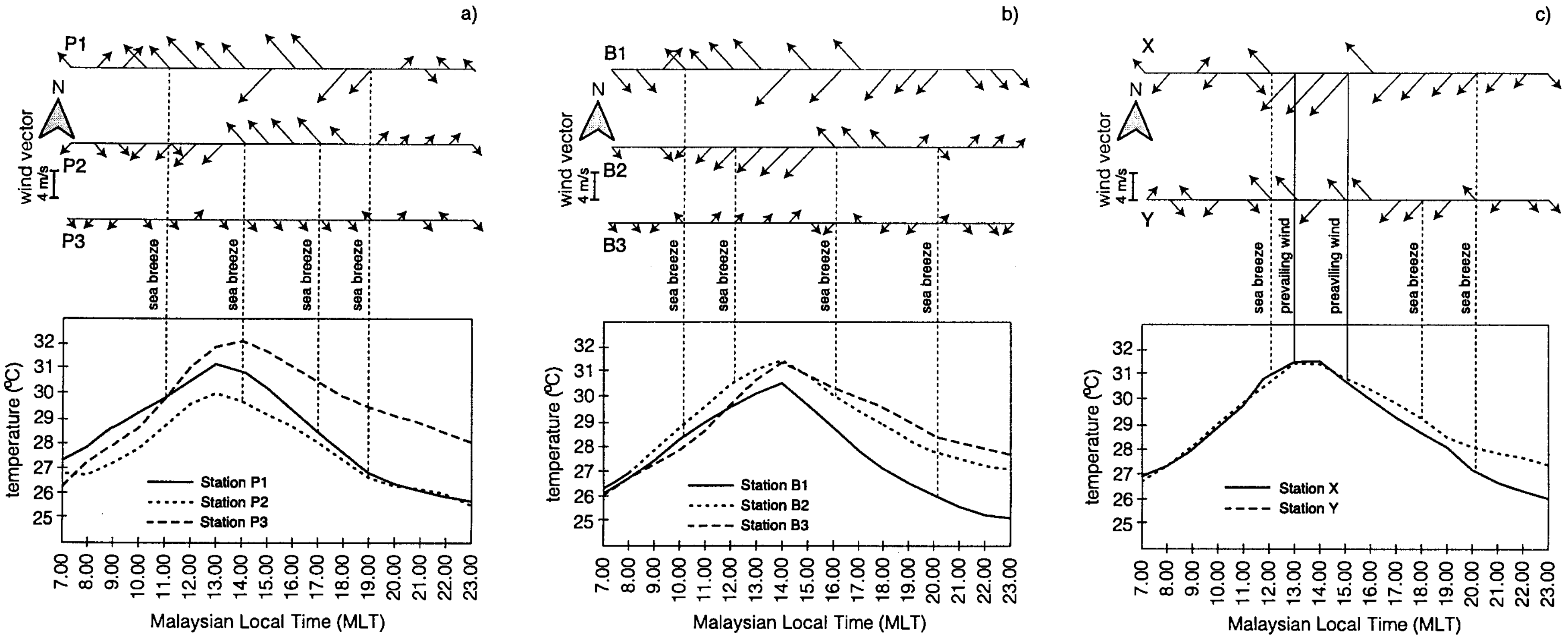


Fig. 1 Diurnal fluctuation of wind speed and air temperature at three traverses in Kuala Terengganu on 26–29 November and 2–3 December 1993; (a) at P1, P2 and P3, (b) at B1, B2 and B3, (c) at X and Y

Rys. 1. Dobowe fluktuacje prędkości wiatru i temperatury powietrza na trzech przekrojach w Kuala Terengganu w dniach 26–29 listopada i 2–3 grudnia 1993 r.; (a) P1, P2 i P3, (b) B1, B2 i B3, (c) X i Y

Three 7 km long traverses that run perpendicular to the coastline toward inland were used in order to value how far the sea breeze can penetrate to the interior part of Kuala Terengganu. Three sites of measurements were used at each traverse except for the middle traverse along the middle of Terengganu river. The first traverse was on the lower bank of the Terengganu river (P1 to P3); the second on two bridges across the Terengganu river (X and Y), and the third on the upper bank of the river (B1 to B3). The distance between the first and the second and between the second and the third stations was approximately 2.5 and 4.5 km, respectively. The distance from one traverse to the other is about one to two km apart.

Dry and wet temperatures were measured by Casella whirling hygrometer at about 1.5 meter about the ground. The instrument accuracy is $\pm 2\%$ relative humidity dependent upon temperature and wet bulb depression. The average of at least three temperature readings were taken at each stations. The average dry and wet temperature readings were then converted to relative humidity (RH) by using the RH slide ruler. The battery operated Digitar weather data model 7103 was used for measuring the wind speed and direction. The instrument was placed at about 1.5 meter above the ground on its stand. The sensor of the instrument was set to the north-south direction before it can be used. The wind direction is set either at 2° or 10° increment. In either case, the accuracy of the data is $\pm 10°$. With the help of research assistants these data were measured simultaneously for every hour starting from 7.00 until 24.00 (Malaysian Local Time) at all filed stations.

RESULTS AND DISCUSSION

INLAND PENETRATION OF SEA BREEZE

Figure 1a, b and c show the hourly advancement and inland penetration of sea breeze of the speed of $\geqslant 4.1$ ms^{-1} at the three traverses during the six days of observation i.e., 26 to 29 November and 2 and 3 December 1993. In general, the formation and cessation of sea breeze were observed occur at different time of the day at P1 and P2. Earlier time of formation was observed at P1 i.e., around 1100 hr (MLT) while at P2 it was traced at around 14.00 (MLT). Sea breeze lasted for about eight and three hours at P1 and P2, respectively. However, the penetration of sea breeze was untraceable at P3, the most inland field station (Fig. 1a).

The more stronger sea breeze was observed at B1, site at the spit of Kampong Seberang Takir (Map 1 and Fig. 1b). It was also observed that longer sea breeze duration established at B1 i.e., about 10 hours period (from 10.00 until 20.00). Comparatively, it was only about four hours duration of sea breeze episode established at B2 and none of the wind speed of the sea breeze characteristic was observed at B3. With the assumption that an open area is more exposed to the wind effect, therefore two filed sites were established on two different bridges across the Terengganu river i.e, one nearest to the sea on Sultan Mahmud bridge and the other site further inland on Manir bridge. As expected, the formation of sea breeze at both sites was matched with the occurrence of sea breeze at B1, implying that an open area is easily exposed to wind effect from the sea (Map 1 and Fig. 1c). Both field stations had recorded more than six hours of sea breeze episode during the observation period.

Table 2

Relationship between sea breeze and temperature changes: (a) slowing down the temperatures increament, (b) increasing the temperatures drop

Związki między bryzą morską a zmianami temperatury: (a) spowolnienie przyrostu temperatury, (b) przyspieszenie spadku temperatury

	Stations	Pearson correlation, r
(a)	B1	-0.55 (99%)
	P1	-0.61 (95%)
	X	-0.74 (99%)
	Y	-0.82 (99%)
(b)	B1	+0.68 (99%)
	B2	+0.59 (99%)
	P1	+0.39 (99%)
	P2	+0.57 (99%)
	X	+0.79 (99%)
	Y	+0.56 (95%)

The formation of sea breeze and its association with the advancement of hourly temperatures was also observed at all field stations. In general, the advancement of sea breeze was observed having a significant effect in slowing down the increament of late morning temperatures. On the other hand, the late afternoon temperatures decreased significantly during the sea breeze episodes. These situations were particularly observed between the first and the second stations on each traverse (see Fig. 1a, b, c). The strength of sea breeze in both slowing down the increament of morning temperatures and increasing the sudden drop in the late afternoon temperatures were not quite significant established at the interior field stations for the P1–P3 and B1–B3 traverses.

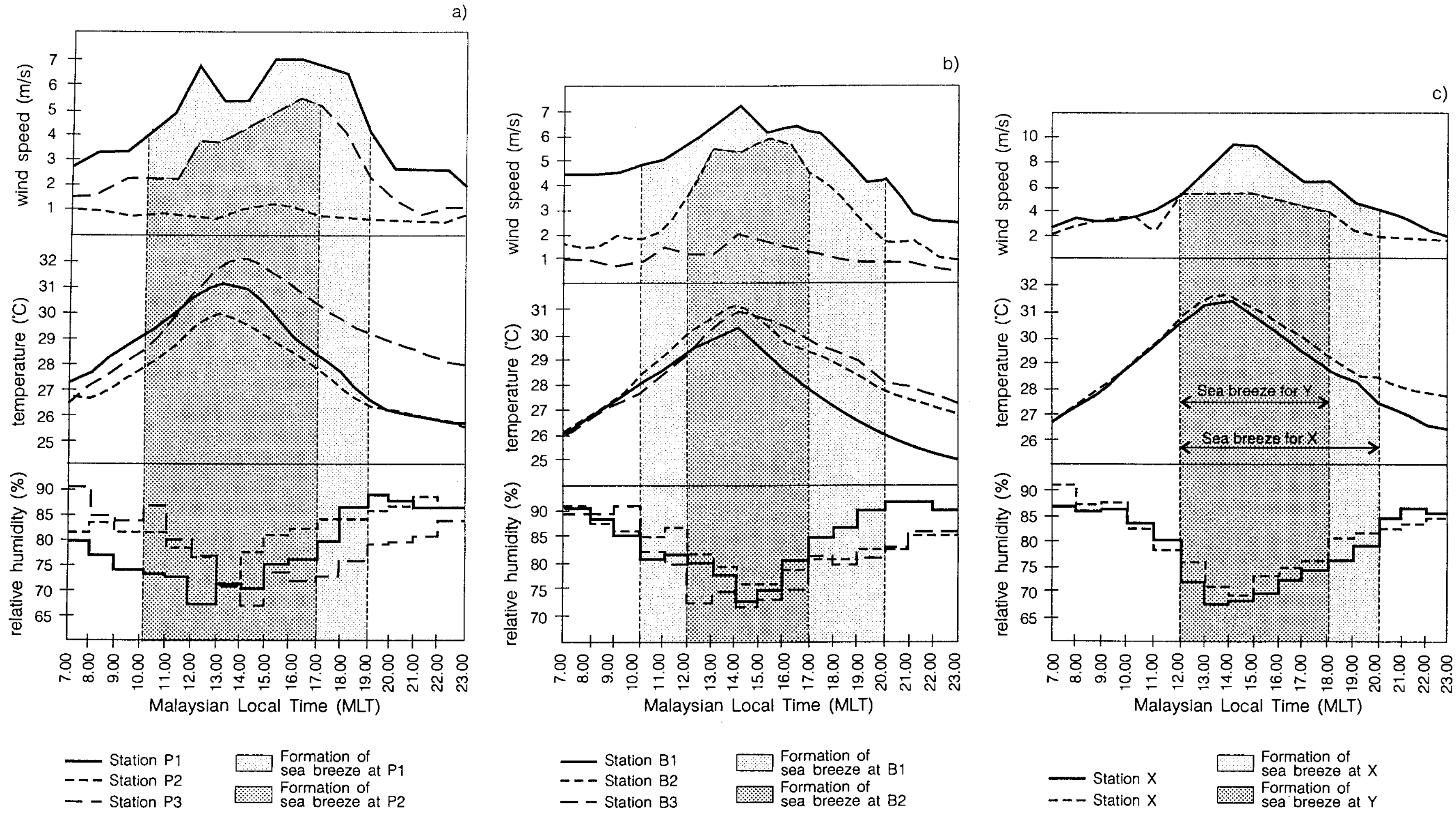


Fig. 2. Diurnal variation of sea breeze formation measured at three traverses in Kuala Terengganu on 26–29 November and 2–3 December 1993: (a) at P1, P2 and P3, (b) at B1, B2 and B3, (c) at X and Y

Rys. 2. Dobowe zmiany w tworzeniu bryzy morskiej mierzone w trzech przekrojach w Kuala Terengganu w dniach 26–29 listopada i 2–3 grudnia 1993 r.: (a) P1, P2 i P3, (b) B1, B2 i B3, (c) X i Y

Pearson correlation technique was then used to find any significant correlation between the strength of sea breeze and temperature changes with time at stations near to coastline for the three traverses (Tab. 2a, b). Obviously, the relationships were significant at the level of between 95 and 99 percent at all stations.

These phenomena can be attributed to two possible reasons; one due to the topographic and morphologic factors at and surrounding the interior filed stations. Generally, those statios are located at the lee side of a small hill. Moreover, the sites are secured by the establishment of the secondary forest on the seaward area. The other reason is contributed to the dominant wind factor. During the study it was observed that more than 60.0 percent of the wind came from inland at most of the interior stations whereas at the stations near to coastline, 60.0 to 70.0 percent of the wind came from an open South China Sea. At station X on the Sultan Mahmud bridge, the maximum wind speed was observed at about 7.5 ms^{-1} around 16.00 (MLT). This station was not only recorded the highest wind speed throughout the study but also seemed to show the longest duration of sea breeze episode in a day as compared to the P1 and B1 stations (stations near to coastline).

THE EFFECT OF SEA BREEZE ON THERMAL ENVIRONMENT

Figure 2a, b and c show the formation of sea breeze along the three traverses up to about 2.5 km inland of Kuala Terengganu. The cooling effect of sea breeze on the thermal environment especially after 14.00 (MLT) was quite significant at all stations and it can be distinguished from the earth radiation cooling effect in the evening. This cooling effect can be traced one to two hours after the formation of sea breeze (B a n f i e l d 1991).

The formation of sea breeze at about 14.00 (MLT) which was observed specially at station P1 contributed to the decrease of air temperature of about 4.2°C i.e., from 31.0°C at around noon to about 26.0°C at 19.00 (MLT) (Fig. 2a). The effect can be traced further inland i.e., at station P2 where sea breeze contributed to the decrease in air temperature of about 1.8°C even though its formation was lasting for about 3 hours long i.e., from approximately 14.00 to 17.00 (MLT) (Fig. 2a). However, the effect of sea breeze on air temperature was not traceable at station P3, the most inland field site. Similar results were observed at station B1 and B2; the most temperature dropped was at station B1 i.e., 4.4°C where as at station B2 it was only about 2.0°C (Fig. 2b).

Because of the location of stations X and Y on the two bridges which is practically exposed to open sea, therefore the effect of sea breeze on air temperature at both stations had shown a quite similar pattern. Generally, it showed that the values of temperature dropped was only about 2 to 3°C at both stations between 15.00 to 20.00 (MLT) (Fig. 2c).

The effect of sea breeze on hourly changes of relative humidity was also observed at all field stations on the three traverses (Fig. 2a,b,c). Slightly increase in relative humidity was observed at about one or two hours after the decrease in air temperature especially at stations on the coastline areas such as stations P1, B2 and X. For instance, an increase of about 19 percent of relative humidity was observed at P1 between 14.00 and 19.00 (MLT) whereas at P2, the value was only about 7 percent. Similar situation was established at stations B1 and B2 where the increase in relative humidity was about 20 and 9 percent, respectively. Peculiar pattern was observed at stations X and Y where it showed no different in value of increase in relative humidity; both stations had recorded increase in relative humidity of about 11 percent.

It is clearly demonstrated that horizontally the significant effect of sea breeze on the thermal environment of Kuala Terengganu has limited to about 10 km toward inland. This is due to several factors such as the topographic effect that prevented sea breeze penetrate further toward inland of Kuala Terengganu significantly. The inland penetration of sea breeze could also be limited due to small temperature differences between land and sea, thus reduce the strength of wind speed to certain velocity. This could be happened because this study was carried out during the north-east monsoon months where in general the mean monthly temperature is only about 23 to 24°C (Tab. 1). Another possible reason is the morphologic features along the three traverses such as tall buildings and trees that possibly blocking the incoming sea breeze. Because of local and strong influences of these various obstacles, therefore the wind direction became more irregular and inconsistency in speed (K a t a y a m a et al. 1990/91). Hence, the lack of sea breeze influences on the thermal environment toward inland areas was obviously prevailed at stations such as P3, and B3.

CONCLUSIONS

The study has shown some important findings with regard to the effects of sea breeze and river on the thermal environment. Such results could be of significant findings to the town planners in their affords to plan for a future urban structure such as urban centre for Kuala Terengganu. This is simply true as far as sea breeze is concerned because it can be used in minimizing any unfavourable phenomena in urban areas such as "urban heat island" and uncomfortable condition. Moreover, it also can be very useful in urban air pollution dispersal process (Evans et al. 1982). Knowing that sea and river breezes have a good potential in slowing down the morning air temperature and increasing the temperature drop in the evening, thus it is useful for the seaside goers in planning their appropriate time of the day to visit coastal recreational sites.

With the combination of satellite pictures (to detect sea breeze front) and the horizontal movement of sea breeze, it is possible to identify unstable and turbulent conditions of atmosphere. Normally, sea breeze front is often reconizable as the dividing zone between the area of fair weather cumulus clouds and an area of clear skies behind the sea breeze front. Probably such knowledge is very useful as far as weather foecasting is concerned because it will help in tracing and predicting the movement of water vapour with time until the time when the cloud has reach its saturation level.

REFERENCES

Banfield C. E., 1991, *The Frequency and Surface Characteristics of Sea Breeze at St. John's Newfoundland*, Clim. Bull. - Canad. Meteor. a. Ocean. Soc., 25, p. 1–20

Cole R. J., 1977, *Climate and Building Design*, Weather, 32, p. 400–406

Evans L. F., Eccleston A. J., Weeks I. A., 1982, *The Sources Areas and Impact Areas of Photochemical Smog in Melbourne*, Clean Air, August, p. 45–54

Fergusson P., 1971, *A Sea Breeze at Harrogate*, Weather, 26, p. 125–127

Frizzola J. A., Fisher E. L., 1963, *A Series of Sea Breeze Observations in the New York City Area*, J. Appl. Meteor., 2, p. 722–739

Katayama T. et al., 1990/91, *Cooling Effects of a River and Sea Breeze on the Thermal Environment in a Built-up Area*, Energy and Buildings, No 15–16, p. 973–978

Shaharuddin Ahmad, 1993, *An Observation Study of Sea Breeze in Kota Kinabalu, Sabag, Malaysia*, [in:] *Paper Presented at the sixth National Meteorological Congress II Iberoamerican Congress of Atmospheric Environment. Mexico City, Mexico. October, 27–29*, 11 pp.

Spillane K. T., 1978, *Atmospheric Characteristics on High Oxidant Days in Melbourne*, Clean Air, November, p. 50–56

Department of Geography
University Kebangsaan, Malaysia

STRESZCZENIE

Serię obserwacji bryzy morskiej wykonano wzdłuż rzeki Terengganu w stanie Terengganu na wschodnim wybrzeżu Półwyspu Malajskiego. Obserwacje te prowadzono w listopadzie i w grudniu 1993 r. w czasie trwania północno-wschodniego monsunu. Pomiary temperatury i wiatru wykonywano na wysokości 1,5 m n.p.g. wzdłuż trzech tras o długości około 10 km wyznaczonych po obu stronach rzeki prostopadle do wybrzeża. Wyniki zaprezentowano na

poziomym przekroju. Ogólnie, obserwowano kształtowanie się bryzy morskiej o prędkości $\geqslant$4,1 m/s zdolnej do redukcji temperatury powietrza o około 2–4°C. Chociaż efekt bryzy morskiej może być obserwowany również w głębi lądu wzdłuż rzeki, jednak jej ochładzający wpływ jest lepiej widoczny u ujścia rzeki Terengganu. Obserwowano spadek różnic temperatury od 1,7°C wewnątrz lądu do 2,4°C na obszarach nadbrzeżnych. W czasie epizodu bryzy morskiej większość stacji nadbrzeżnych wykazuje wolniejszy wzrost temperatury niż stacje zlokalizowane wewnątrz lądu. Ponadto wpływ bryzy morskiej na redukcję temperatury powietrza jest lepiej widoczny ponad rzeką (stacje na mostach) niż na stacjach po obu jej stronach. Równocześnie podczas spadku temperatury powietrza obserwowano opóźniony w czasie wzrost wilgotności względnej spowodowany efektem bryzy morskiej. Zazwyczaj ochładzający efekt bryzy morskiej jest znacząco odczuwalny w okresie około 3–6 godz., tj. pomiędzy godz. 14.00–20.00 czasu lokalnego w zależności od położenia stacji. Dłuższy okres był notowany przez stacje na wybrzeżu lub w najbliższym jego sąsiedztwie, krótszy na stacjach wewnątrz lądu.