Sains Malaysiana 36(2)(2007): 165-173

Current Circulation Pattern in Waters Around Pulau Tinggi, Johor

(Corak Peredaran Arus di Perairan Pulau Tinggi, Johor)

FREDOLIN T. TANGANG, MOHD SYAMIL MOHD YUSSOF & LIEW JUNENG

ABSTRACT

The current circulation pattern in waters around Pulau Tinggi, Johor was deduced based on the results of the Acoustic Doppler Current Profiler (ADCP) measurements during a period of 16 – 19 August 2004. It appears that the currents, regardless of tidal cycle, were predominantly southerly or southeasterly with average speeds of between 30 – 50 cm s^{-1}. There appears to be current speed horizontal gradient toward the island as the current became weaker as it gets closer to the island. In the upper 10-15 m the currents were slowed by the prevailing winds which were predominantly southeasterly during the period. In the lower layer, about 10 m from seabed, the current speed reduced drastically due to bottom friction. The circulation pattern proves to be a typical pattern of a flow around an island where an evident of an eddy was captured in the observation data in a station located south of the island. Estimated shallow water Reynolds number indicates that the flow may produce a pair vortex of opposite direction and a central return flow at the southern end of the island.

Keywords: Pulau Tinggi; current circulation pattern; tides; island wake

ABSTRAK

Corak peredaran arus di perairan Pulau Tinggi Johor telah disimpulkan berdasarkan hasil pengukuran arus menggunakan Acoustic Doppler Current Profiler (ADCP) bagi tempoh dari 16 hingga 19 Ogos 2004. Didapati corak arus, tanpa mengira fasa pasang-surut, adalah mengarah ke selatan atau tenggara dengan purata kelajuan antara 30 – 50 cm s^{-1}. Terdapat kecerunan mendatar kelajuan arus ke arah pulau di mana arus menjadi semakin lemah apabila menghampiri pulau. Di lapisan atas iaitu pada kedalaman 10-15 m, arus diperlahankan oleh tiupan angin yang dominan ke arah tenggara pada tempoh tersebut. Di lapisan bawah, lebih kurang 10 m dari dasar kelajuan arus menurun secara mendadak akibat geseran dasar. Corak peredaran yang diperolehi adalah corak yang biasa bagi aliran mengelilingi pulau dengan cerapan menunjukkan terdapat pusaran di stesen bahagian selatan pulau. Anggaran nombor Reynolds menunjukkan aliran mungkin menghasilkan satu pasangan vorteks yang bertentangan arah dan satu aliran kembali di hujung bahagian selatan pulau ini.

Kata kunci: Pulau Tinggi; corak peredaran arus; pasang surut; keracak pulau

INTRODUCTION

Pulau Tinggi lies approximately 32 km southeast of Mersing, Johor. The island is about 6 km long and 4 km wide with its land elevation peaks to the highest point of about 625 m above sea level. The island, which has been gazetted as a marine park in 1994, is rich with marine flora and fauna. As in other marine ecosystems, the island's rich and diverse marine ecosystem is very much influenced and probably constrained by various physical conditions of its surrounding waters including the current circulation around the island. Current patterns can be important in various biological and chemical processes such as larval dispersal and pollutant transport (Tsanis & Wu 1995; Cowen et al. 2003). The existence of coral and sea grasses around the island is probably influenced by the water circulation around the island.

The water circulation forms an integral part of the dynamic processes in waters around an island and the tidal cycle could very much be part of this circulation. In coastal sea, tidal current is likely to reverse its direction during opposite phases of tidal cycles. Another interesting phenomenon with regard to water circulation around an island is the island wake. Depending on several dynamical factors, a circulation flow around an island may produce a wake (Wolanski et al. 1984; Tomczak 1988a). Since Pulau Tinggi is located in the southwestern corner of the South China Sea, its circulation may also be part of the large-scale circulation of the sea. There have been only a few reports of current and circulation patterns in the South China Sea including those of Dale (1956), Wyrtki (1961), Brown (1973) and Liew et al. (1987). Generally, the circulation in the South China Sea is very much influenced by the monsoon system. During the northeast monsoon period, the current in waters off the east coast of Peninsular Malaysia is mostly southerly while during the southwest monsoon period the direction is northerly. However, the circulation pattern may also vary inter-annual (Wu et al.

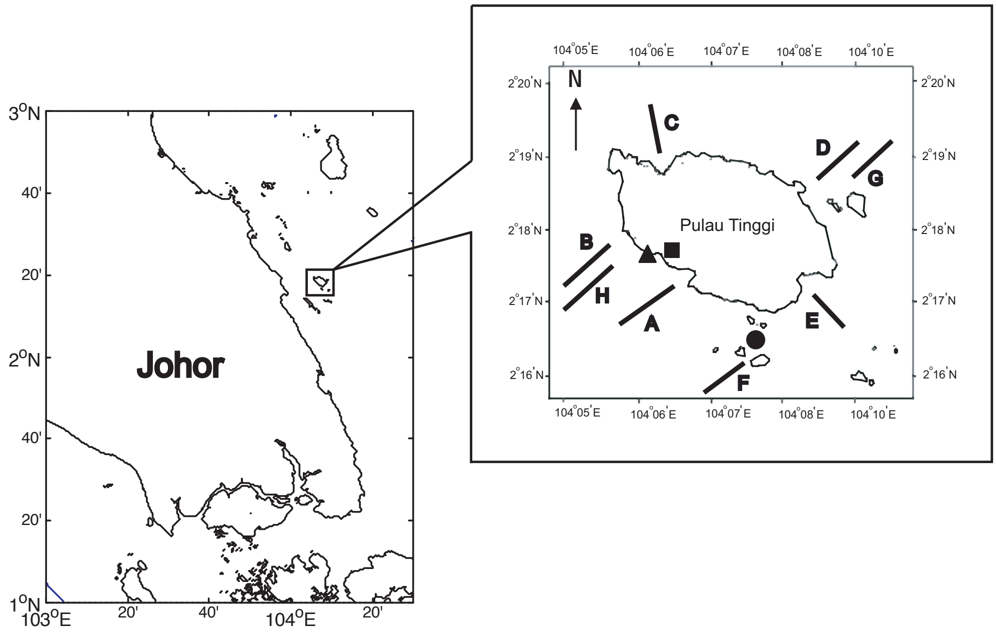

FIGURE 1. The approximate location of sampling transects around the island

1998). There appears to be no earlier work of direct current measurement in waters around this island.

MATERIAL AND METHOD

The sampling was conducted during a period of 16 to 19 August 2004 in waters around Pulau Tinggi, Johor. The current measurements were carried out using a Nortek Acoustic Doppler Current Profiler (ADCP). This instrument has a frequency range of 1 MHz with a maximum profiling range of 25 m. It can be deployed upward looking on the seabed or tied downward looking to the side of a ship. In this study, the ADCP was fixed downward looking to the side of a ship. To prevent the ship from drifting, the ship was anchored during the sampling period. The ADCP was programmed to profile 25 layers of each 1 m depth (i.e. for a maximum depth of 25 m). The ADCP profiled the current in each layers for every three minutes with 60 seconds averaging time for each observation. A total of eight transect lines extending outward, each with three stations, was established in waters around the island (Figure 1). The dot indicates a sampling station between Pulau Nanga Kecil and Pulau Apil. The triangle and square indicate the locations of the Minitroll pressure sensor and the Automatic Weather Station, respectively. The first station (e.g. A1) represents the inner station (i.e. shallow and close to the island) while the third station (e.g. A3) represents the outer one. The distance between stations in each transect was about 500 – 1000 m. An additional station in the channel between Pulau Nanga Kecil and Pulau Apil was also established. The ADCP measurements at each station were conducted for about 30 minutes. A pressure gauge (i.e. Minitroll pressure sensor) was also deployed in the jetty of Kampong Pasir Panjang to monitor sea level fluctuation due to tide during the measurement period. An Aandera Automatic Weather Station (AWS) was also set up at Kampong Pasir Panjang. Wind speed and wind direction were recorded by the AWS for a period from 16 to 19 August 2004 at an interval of 5 minutes. Depth at a particular station was measured with a portable depth sounder. The position of a station was determined using a handheld global positioning system (GPS).

RESULTS

Figure 2 shows the sea level fluctuation (in terms of pressure) due to tides from 22:04:30 15 August 2004 to 06:29:00 19 August 2004. However, the Minitroll pressure sensor failed after the period. As shown in Figure 2, the tide in Pulau Tinggi was a mixed type with predominantly semi-diurnal category. Figure 2 also show the sampling period of each transect line with respect to the tidal cycles. The letter indicates the sampling transect as indicated in Figure 2. Both G and H are not shown as the sampling periods for these two transects were conducted after the pressure sensor stopped recording. Transect A, C and E were sampled in the morning when the tidal condition was approaching a higher high water (HHW). Transect B, D and F were sampled in the afternoon when the tide was receding to a higher low water (HLW). The sampling in the channel was conducted from 10:10 to 10:52 19 August 2004. Similar to the sampling period of transects A, C and E, the sampling in Transect G was conducted from 11:23 to 13:28 19 August 2004 when the condition was approximately approaching a HHW. The sampling in Transect H was done at night i.e. from 20:55 to 23:50 19 August 2004 when the tidal condition was approximately approaching a lower high water (LHW). Figure 3 shows the wind stick plot for each of the four sampling days. Except during early morning of 16 August 2004, the prevailing winds during

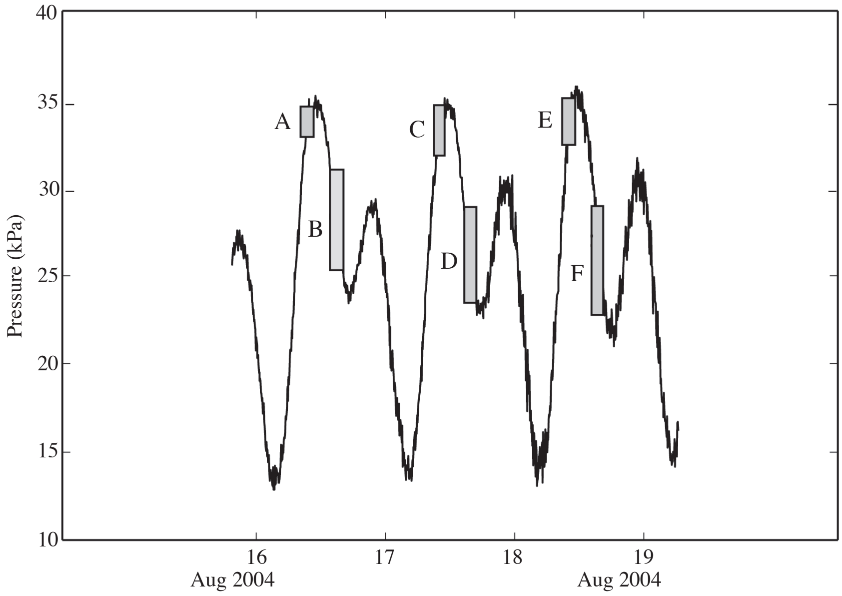

FIGURE 2. The sea level fluctuation time series due to tide from 22:04:30 15 August 2004 to 06:29:00 19 August 2004

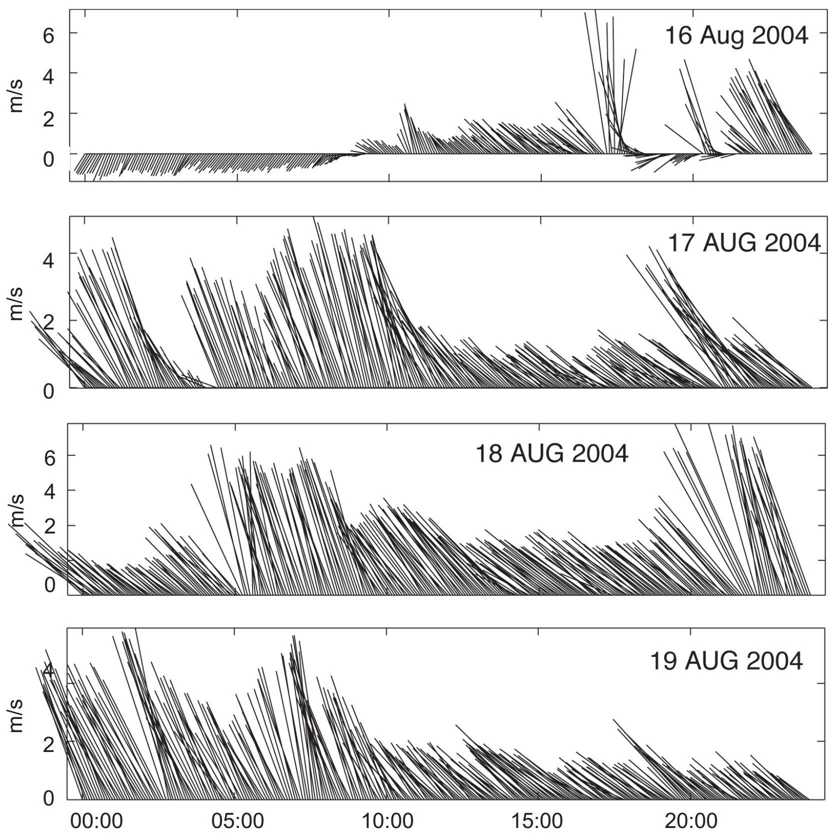

FIGURE 3. The wind stick plot from 00:00 to 23:55 for 16, 17, 18 and 19 August 2004. A stick pointing upward (perpendicular to time axis) indicate a southerly wind

the sampling periods were predominantly southeasterly with speeds ranging from 2 to 6 ms^{-1}. These wind patterns are consistent with the winds during the southwest monsoon season.

A total of 24 ACDP measurements were carried out during the four days sampling period. The current stick diagram and current speed depth profile were plotted for all the 24 measurements. The currents at inner stations of depth < 10 m appeared to be very weak and with no particular direction. This may represent the frictional boundary around the island. However, the current speed increased steadily as well as the current direction became apparent in middle and outer stations of more than 15 m depth. Figure 4 shows the current stick plot at various depths for station C3. The direction of the current was southerly i.e. towards the island, with a maximum speed

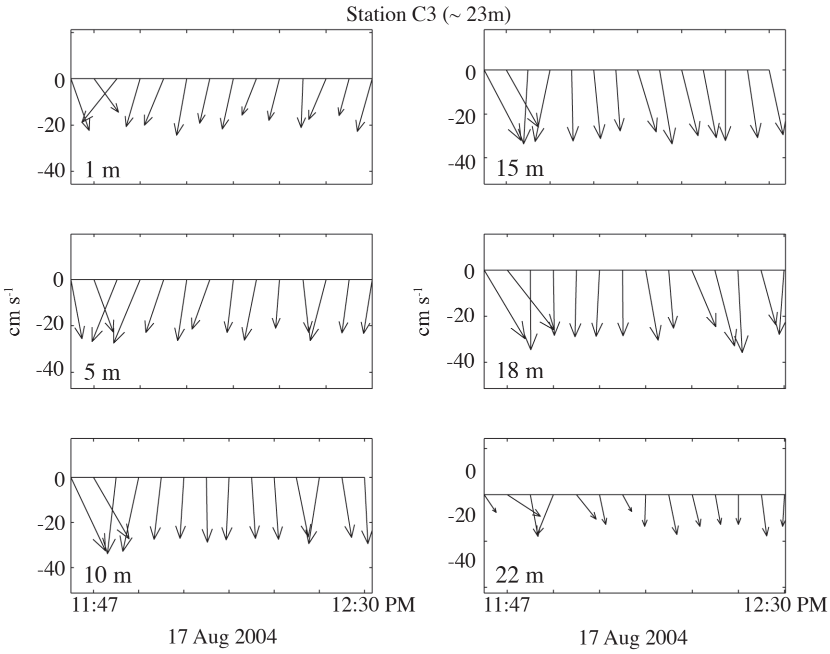

FIGURE 4: The current stick plot showing the current vectors at various depths in Station C3. A stick pointing downward (perpendicular to time axis) indicates a southerly current. The number in the parenthesis indicates water depth at the station

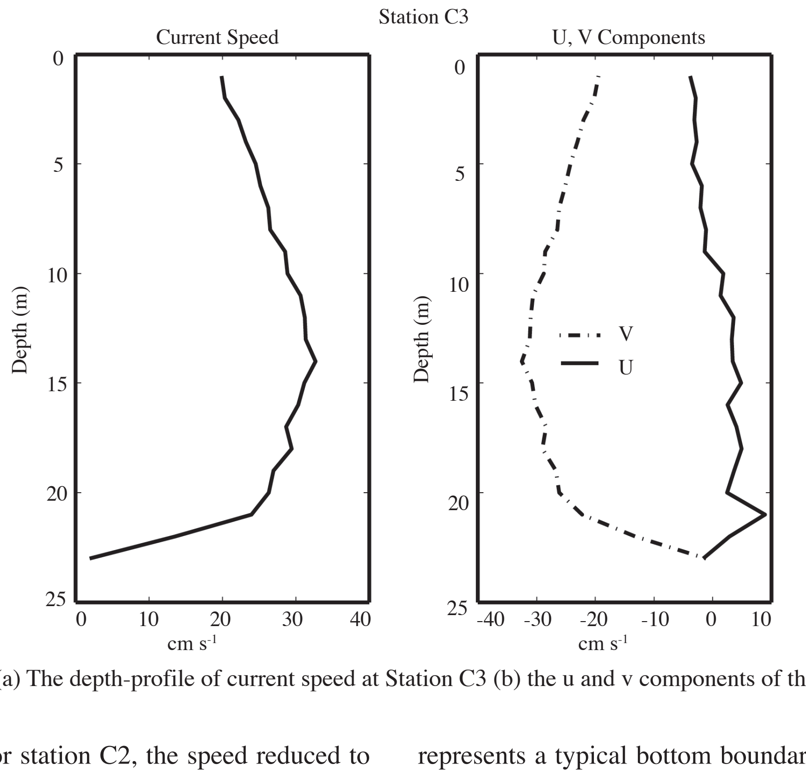

FIGURE 5. (a) The depth-profile of current speed at Station C3 (b) the u and v components of the velocity

of about 30 cm s^{-1}. For station C2, the speed reduced to about 20 cm s^{-1} with predominantly southerly direction. In station C1, the southerly flow appeared to be interrupted by the island. Figure 5 shows the current speed depth-profile as well as the u and v velocity components of Station C3. The current speed increased with ~ 20 cms^{-1} at the surface to ~ 30 cms^{-1} at a depth of about 15 m. Below 15 m the current speed decreased gradually but below 20 m the speed reduced rapidly to nearly zero at 22 m. The current speed profile from the seabed to a depth of about 15 m represents a typical bottom boundary layer in which the speed is very much influenced by the bottom friction. However, the speed reduction in the upper layer is obviously due to wind influence. The sampling period in Station C3 was between 11.47 am to 12.30 pm on 17 Aug 2004. As indicated in Figure 3, the prevailing winds during this period were predominantly southeasterly, nearly opposite to the direction of the current. The opposite winds slowed down the current speed by ~ 10 cm s^{-1} at the surface. Interestingly, the wind influence reached to a depth of about 14 m.

Figure 6 indicates the current stick plot for station B3. Similar patterns were observed in station B2 (not shown). The direction of the current was southerly – southeasterly with an average speed of 40 cm s^{-1}. The current patterns in station B1 were irregular due bottom and lateral frictions. The current speed depth-profile in station B3 and B2 were similar to that of A3. Figure 7 shows the current stick plot for station A3. As in station A2, the current directions were predominately southeasterly with an average speed of 45 – 50 cm s^{-1}. As in B1, the currents in A1 were also irregular. The current patterns in station F2 and F3 were similar to those in A2 and A3 with average speeds of 30 – 40 cm s^{-1}. Figure 8 indicates the current stick plot of station D2. The current patterns in stations D1, D3, G1, G2 and G3 were similar to those in D2 with southeasterly (with very strong easterly components) direction. The average speed of currents in these stations was between 25 – 30 cm s^{-1}. Figure 9 shows the current patterns in station E3. The current directions were predominantly southerly with a period of ~ 15 minutes of very irregular and rotating strong current

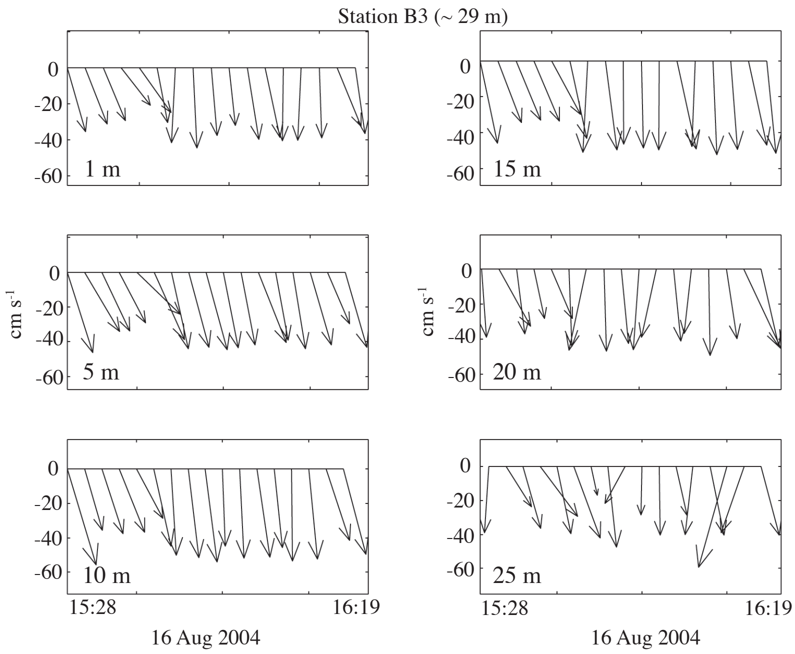

FIGURE 6. As in Figure 4 except for Station B3

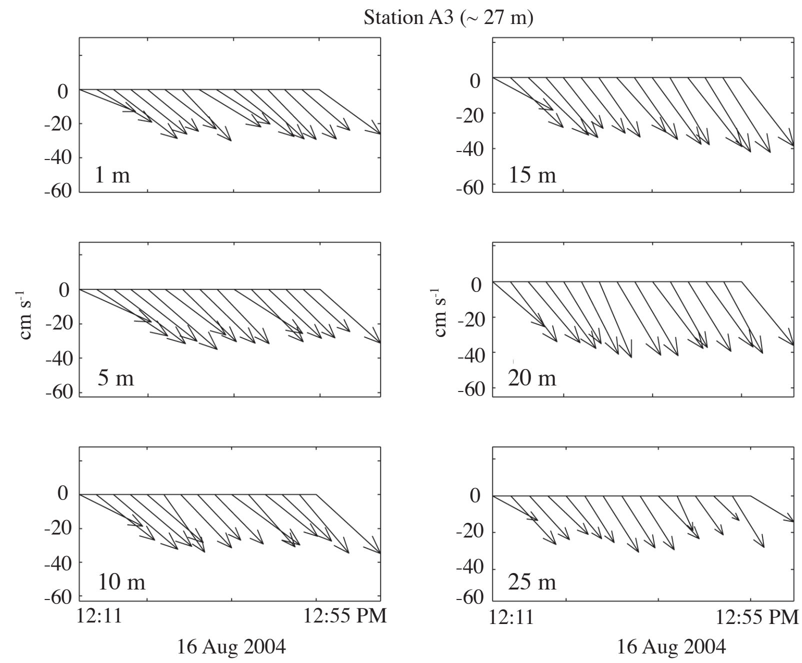

FIGURE 7. As in Figure 4 except for Station A3

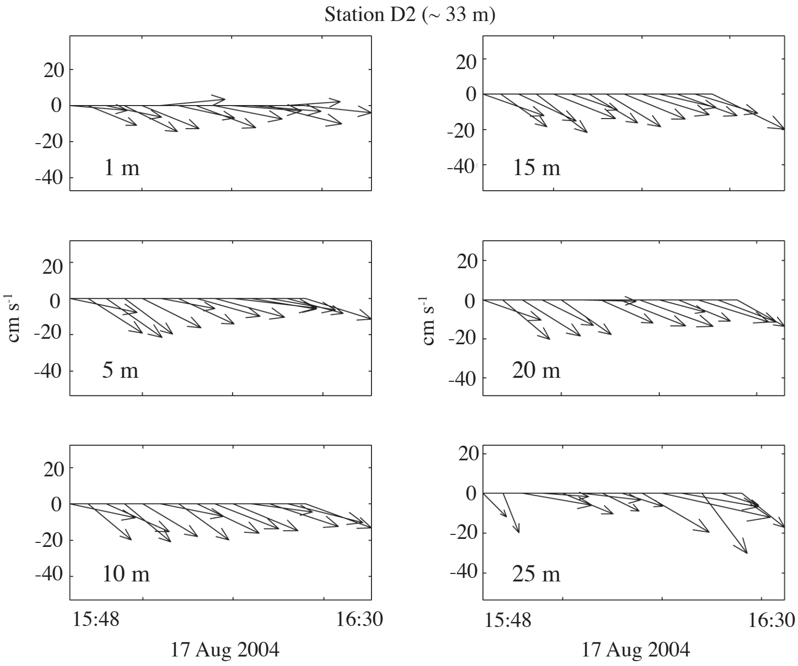

FIGURE 8. As in Figure 4 except for Station D2

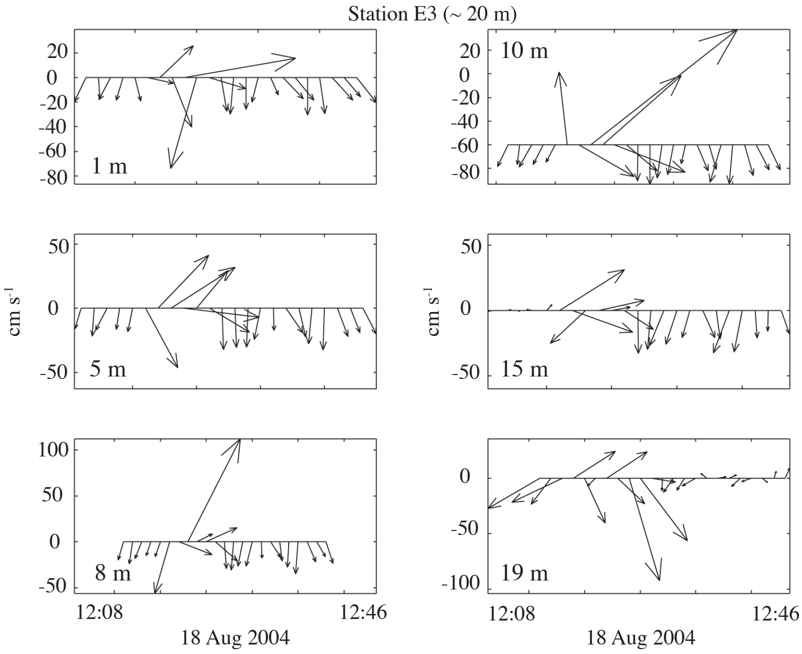

FIGURE 9. As in Figure 4 except for Station E3

(see discussion). The current patterns in E2 and E1 were also predominantly southerly with average speed of about 15 – 20 cm s^{-1}. The currents in the channel between Pulau Nanga Kecil and Pulau Apil were very weak (zero in V component and between 2 – 5 cm s^{-1} in U component [Figure 10]). Visual observation showed that the areas in the vicinity of the stations were covered with sea grasses. Figure 11 shows the current patterns in station H2. Interestingly for the upper layer of about 10 – 15 m, the flows were predominantly northerly i.e. opposite to the current patterns in station B2 and B3.

Discussion and Conclusion

The current stick plots for stations in transect C, B, A, F, D, G, and E indicate southerly – southeasterly current encountering the island. From a theoretical point of view, this is a typical flow around an island that may or may not produce island wakes (Tomczak 1988a). If the wakes were formed, the wakes would be located in the southern parts of the island, in the vicinity of transect E. Indeed, the rotating current captured by the ADCP in station E3 (Figure 9) represents an eddy that passed by during the sampling in station E3. Interestingly, the maximum speed of the eddy

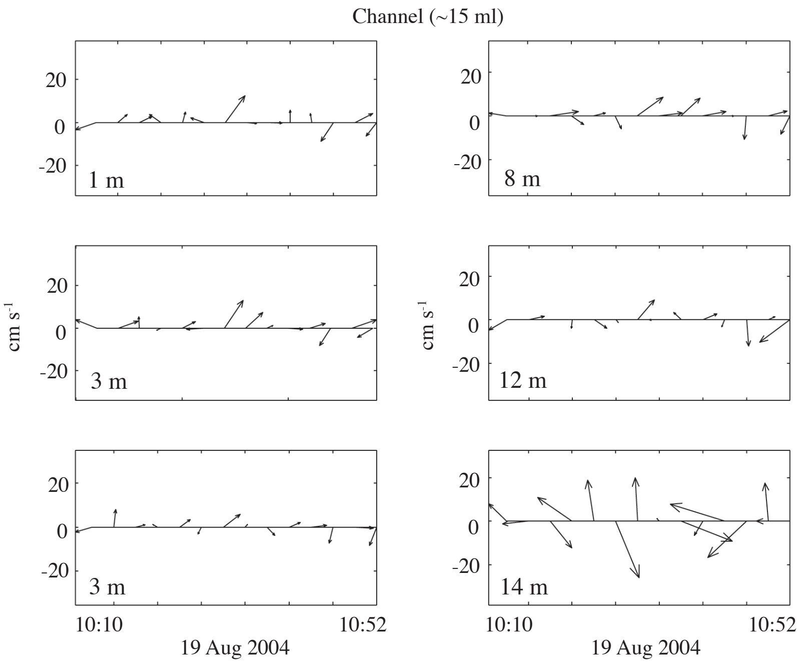

FIGURE 10. As in Figure 4 except for the station in the channel in between Pulau Nanga Kecil and Pulau Apil

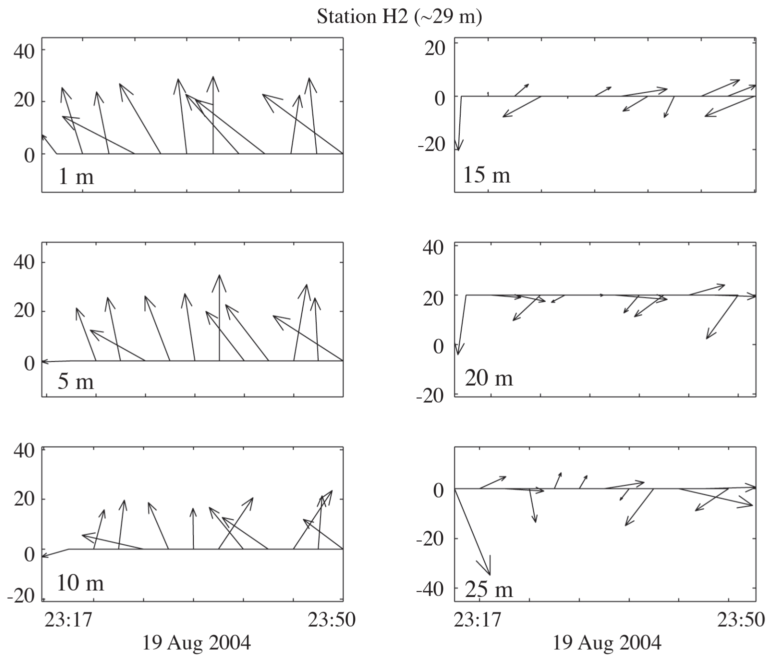

FIGURE 11. As in Figure 4 except for Station H2

reached 100 cm s^{-1}, about five times faster than background velocity. From a theoretical point of view, the effect of an island on the flow field depends on the relative importance of the inertial and frictional forces (Tomczak 1998a). If the frictional dominates, the particles will be dragged along the island's coast. If the inertial force dominates the particles will be thrown off from their paths and the flow will separate from the island. The ratio between inertial force and frictional force is given by a dimensionless number known as Reynold number and for shallow water it is given as (Tomczak 1998a):

$$Re^s = \frac{uH^2}{A_v L}$$

where u is the background velocity, L is the width of the island, H is the water depth and A_v is the vertical eddy viscosity. Table 1 presents the plausible values for Re^s for u=30 cm s^{-1}, L=4000 m and H=20 m. Values for A_v are variable, between 10^{-5} to 10^{-1} m^2s^{-1} (Pond & Pickard 1995). For smaller A_v value of 10^{-5} m^2s^{-1}, the Reynolds number is quite large, around 300. With this large Reynolds number,

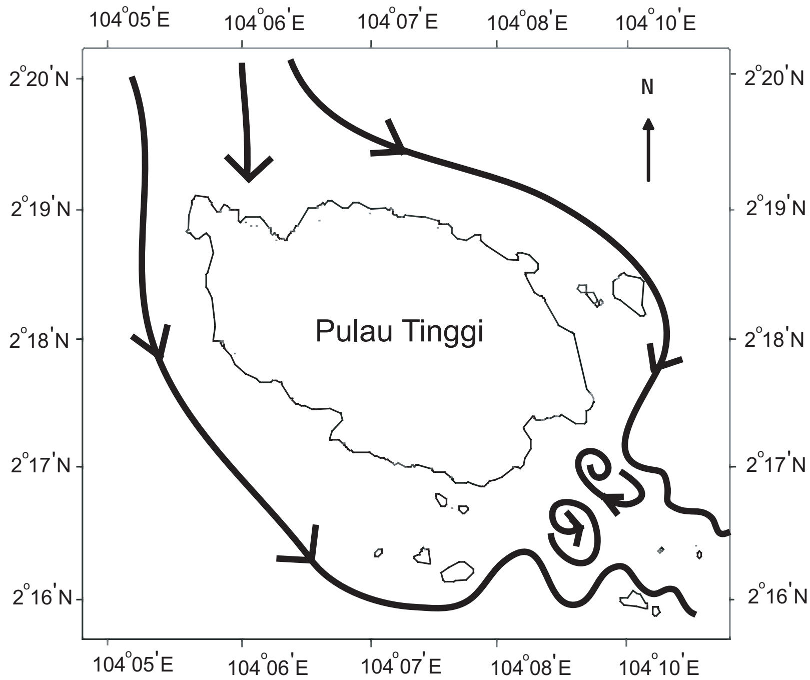

FIGURE 12. The schematic representation of the circulation around the island based on the current pattern measured in various transects. The occurrence of eddies in the southern part of the island indicate the island wake phenomenon

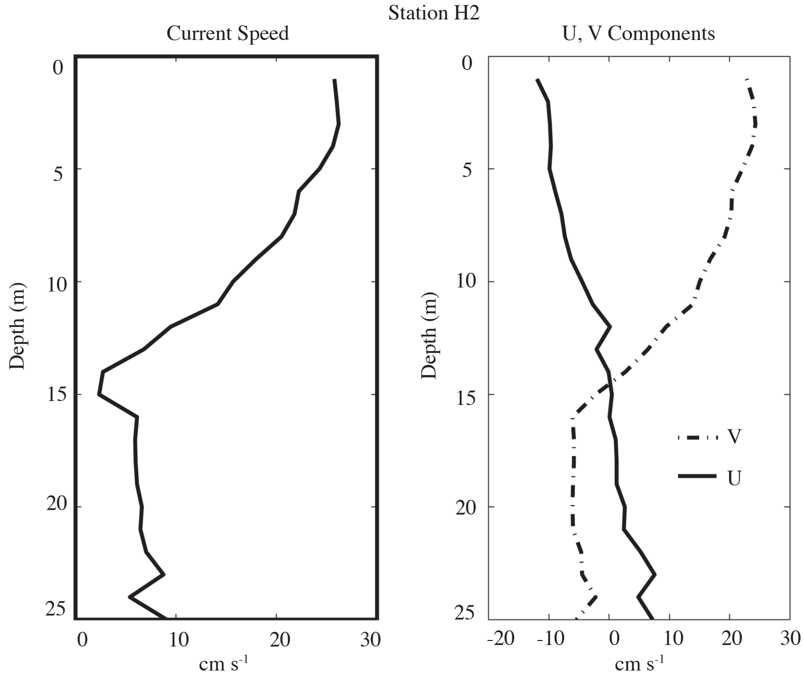

FIGURE 13. As in Figure 5 except for Station H2

the flow would be producing wake with wave disturbances and von Karman street. However, Tomczak (1998b) indicated that Re^s is a scaled-down Reynolds number and hence the highly turbulent regimes of wakes with wave disturbances or von Karman vortex street are rarely produced in the coastal sea. The second and third scenarios might be possible. With these values of Reynolds number, the boundary layer separates behind the southern end of the island creating a vortex pair with opposite direction and a central return flow at the southern end of the island. The 'rotating' current captured by the ADCP in station E3 is related to this condition (Figure 9). The fourth and fifth scenarios with very small Reynolds numbers, 0.3 and 0.03 are very unlikely as these conditions lead to laminar and no separation flow. The condition here can be further investigated by having more transects lines in the southern parts of the island, using aerial and satellite images or numerical simulations.

TABLE 1. Plausible values for shallow water Reynolds number for various values of vertical eddy viscosity

	Plausible values for Reynolds number				
Vertical Eddy Viscosity (A_v, m^2s^{-1})	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}
Reynolds number for shallow water	300	30	3	0.3	0.03

Generally, incorporating the current patterns in all transects and arguments of wake formation, the flow pattern around the island can be best presented schematically as in Figure 12. The agreement between the current patterns in transects A, C, E, and G (i.e. when the tide was rising and getting to a HHW) and transects B, D and F (i.e. when the tide was receding and getting to HLW) seems to suggest the circulation pattern in Figure 12 does not change or reverse during period of opposite tidal phases. However, the current patterns of the top 10-15 m in transect H (i.e. during the rising of the second tide to LHW) seems to suggest otherwise (Figure 11). Could this be due to wind stress in the northerly direction during the sampling period in transect H? Figure 13 indicates the current speed depth-profile in station H2. The extent of that northerly current to ~ 10 m depth seems to point the influence of wind stress. The wind patterns during the sampling at this transect were predominantly southeasterly with comparable speed to those during the sampling at station C3 (Figure 3).

However, if the general circulation around this island is as depicted in Figure 12, it was certainly opposite to the general circulation in the South China Sea during the southwest monsoon season. Based on surface current report compiled by Wyrtki (1961), the upper circulation during the month of August (i.e. during the southwest monsoon) is northerly. Could the circulation in the island during the period be an intermittent feature of the large-scale circulation in the South China Sea or could it be part of a coastal counter current in the area? These questions require further investigation. There is also a possibility that the current reverses direction when the tidal condition recedes to lower low water (LLW). To ascertain this, a continuous measurement of the current for several tidal cycles is needed. This can be achieved by deploying the ADCP upward looking at the sea bed. However, with many sampling stations and water depths of 20-30 meters, an ADCP deployment can be a risky exercise.

ACKNOWLEDGMENT

The authors acknowledge the staff of Jabatan Taman Laut and Taman Negara Johor for their assistance. The authors thank all Marine Science Program UKM second year students of 2004-2005 & Mr. Fauzi and Mr. Mark Mariba for helping with the ADCP and CTD measurements.

REFERENCES

Brown, R.J. 1973. Results of a current survey off the East Coast of West Malaysia. Unpublished Report No. 3131-1, prepared by R.J. Brown and Associates for ESSO Exploration Malaysia Inc.

Cowen, R.K., S. Sponaugle, C. B. Paris, K.M.M. Lwiza, J.L. Fortuna & S. Dorsey. 2003. Impact of North Brazil current rings on local circulation and coral reef fish recruitment to Barbados, West Indies. In *Interhemispheric water exchange in the Atlantic Ocean*, G.J. Goni and P.M. Rizzoli, eds. Amsterdam: Elsevier.

Dale, W.L. 1956. Wind and drift currents in the South China Sea. *Malay. J. Trop. Geogr*. 8: 1-31.

Liew, H.C., Samo K. & Matsumitsu S. 1987. Subsurface currrents off the South-western portion of the South China Sea. In: Mohsin, A.K.M., Ambak, M.A. & Ridzwan, A.R. (Eds.) *Expedisi Matahari '86*. Occasional Publication no. 4. Faculty of Fisheries and Marine Science: 17-22. U.P.M. Serdang Selangor, Malaysia.

Pond, S. & Pickard, G.L. 1995. *Introductory dynamical oceanography*. 2nd edition. London: Butterworth-Heinemann.

Tomczak, M. 1988a. Island wakes in deep and shallow water. *Journal of Geophysical Research* 93: 5153 - 5154.

Tomczak, M. 1988b. Shelf and Coastal Oceanography (http://www.es.flinders.edu.au/~mattom/ShelfCoast/, accessed on 19 October 2005).

Tsanis, I.K. & Wu, J. 1995. A nested-grid hydrodynamic/pollutant transport model for nearshore areas in Hamilton Harbour. *Water Pollution Research Journal of Canada* 302: 205-229.

Wolanski, E., Imberger, J. & Heron, M.L. 1984. Island wakes in shallow coastal waters. *Journal of Geophysical Research*. 89(C6): 10553-10569.

Wyrtki, K. 1961. Physical oceanography of the Southeast Asian waters. NAGA report vol. 2, Scientific Results of Marine Investigation of the South China Sea and the Gulf of Thailand, Scripps Institution of Oceanography, La Jolla, California, 195 pp.

Wu, C.R., Shaw, P.T. & Chao, S.Y. 1998. Seasonal and inter-annual variation in the velocity field of the South China Sea. *J. Oceanography* 54: 361-372.

Marine Science Program
School of Environmental and Natural Resource Sciences
Faculty of Science and Technology
Universiti Kebangsaan Malaysia
43600 UKM Bangi, Selangor D.E.
Malaysia

Received: 15 October 2005
Accepted: 17 April 2007