CHAPTER 325

Sea breeze Effects on Nearshore Coastal Processes

Charitha Pattiaratchi[1] and Gerhard Masselink[2]

Abstract

The sea breeze, created by the diurnal solar heating and cooling cycle, is a well known meteorological phenomenon and occurs globally on a regular basis with varying intensity. The impact of the sea breeze system on nearshore coastal processes and sediment budget has received very little attention. In this paper, field data collected from two micro-tidal coastal regions: south-western Australia and Sri Lanka, are presented to illustrate the importance of the sea breeze system in these regions. It is shown that the rapidly changing wave climate, generated by the sea breeze, increases the cross-shore and longshore currents and sediment suspension on the beach. This results in an increase of the longshore sediment flux by up to a factor of 100. The effects of the sea breeze may be present up to 10 hours after the cessation of the sea breeze. The sea breeze system plays a major role in the coastal sediment budget in these regions.

---

[1] Senior Lecturer, Department of Environmental Engineering, Centre for Water Research, The University of Western Australia, Nedlands 6907, Australia.
[2] Research Fellow, Department of Environmental Engineering, Centre for Water Research, The University of Western Australia, Nedlands 6907, Australia.

Introduction

On micro-tidal wave dominated beaches, morphological change is primarily induced by variations in the incident wave climate. These variations are usually ascribed to the passage of storms. A neglected source of change to the wave field is the diurnal sea breeze, generated by the differential solar heating of the land and ocean, which could be obscured by the presence of high-wave energy levels or tidal effects. The sea breeze is a dominant feature along tropical and sub-tropical coastlines and occur along two thirds of the earth's coastlines (Abbs and Physick, 1992; Simpson, 1994). In these areas wind waves generated by the local sea breeze can contribute significantly to the temporal variation in the incident wave climate. In this paper, field studies undertaken in south-western Australia and Sri Lanka are presented to demonstrate the importance of the sea breeze system on the nearshore region and, in particular, the coastal sediment budget.

Data presented in this paper were collected during three field experiments. Two of these experiments were undertaken at City Beach, Western Australia (Figure 1) on 23 January 1992 and 3-9 March 1994. The third experiment was conducted in Ambakandawila, located to the south of Chilaw along the west coast of Sri Lanka (Figure 2). Both sites are located on a relatively straight, north-south oriented shoreline far from any engineering structures and are micro-tidal (tidal range < 0.7 m at spring tides). However, in Western Australia, the tide is diurnal whilst in Sri Lanka the tide is semi-diurnal. The swell waves approach the beach from the south-west at both sites but the direction of the wind (sea breeze) waves differ due to the different direction of the sea breeze. In Western Australia, the sea breeze blows parallel to coastline from the south (an explanation for this effect is given in Pattiaratchi et al., 1997) and thus the sea breeze generated waves approach the beach with a crest of angle 70° (from south-south-west). In Sri Lanka, the sea breeze (in January) blows from north-west and the sea breeze generated waves also approach from the same quadrant. The occurrence of sea breezes in both of these regions is well known to local residents and fisherman in these regions. In Western Australia, the sea breeze is called the 'Fremantle Doctor' due to cooling effect of the breeze during the summer. In Sri Lanka (in the Chilaw region), the sea breeze is termed Kode by the fisherman.

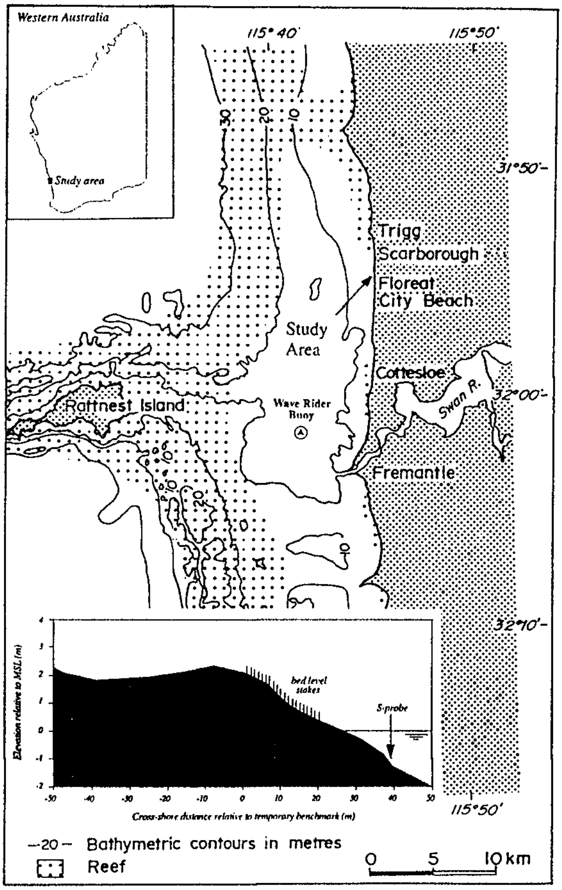

Figure 1 - Location of City Beach, Western Australia

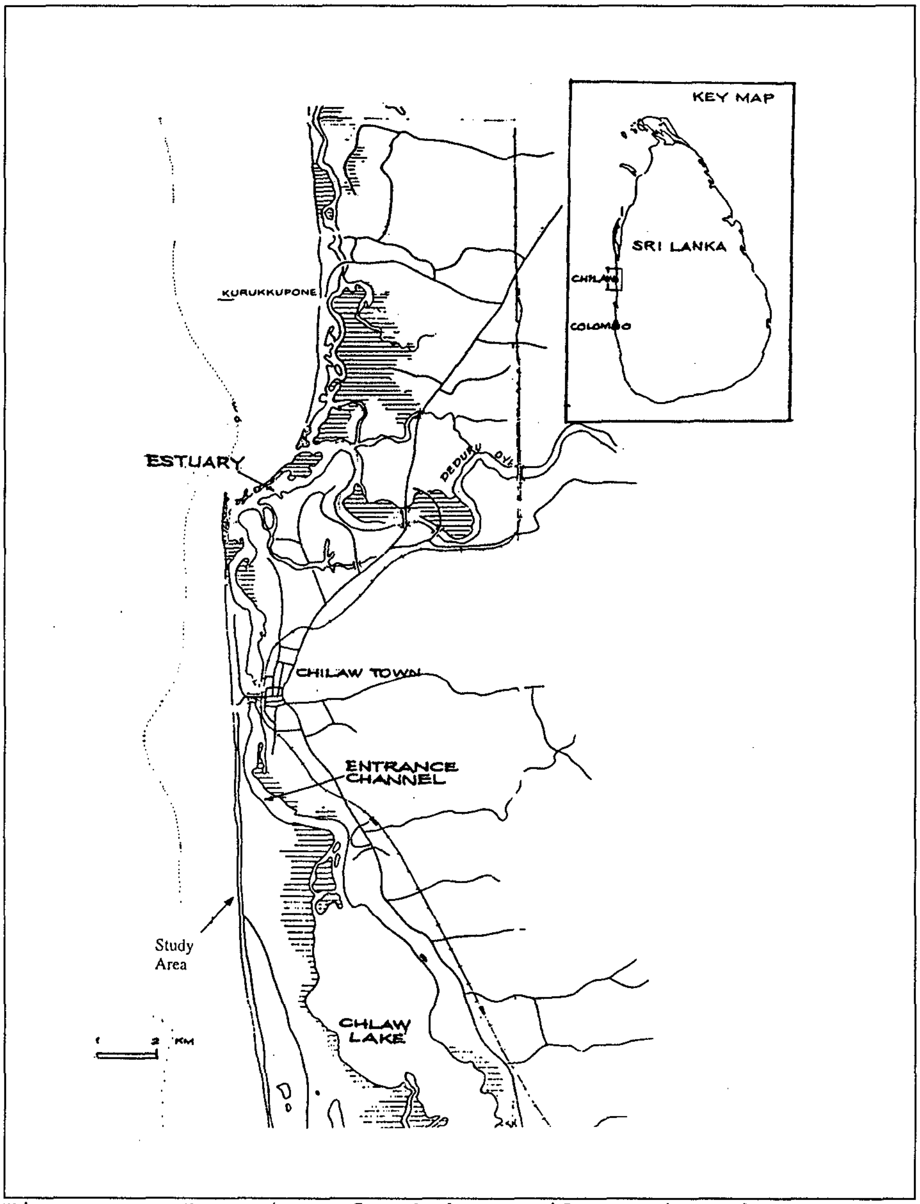

Figure 2 - Location of Ambakandawila, Sri Lanka

Although the sea breeze is a global phenomenon, it's intensity, which depends primarily on the land-ocean temperature gradients, varies geographically. The field data presented in this paper were collected under sea breeze speeds between 7 and 12 ms^{-1}. To allow comparison with other regions, the following maximum speeds, recorded during the sea breeze, have been reported: 14 ms^{-1} in Barcelona, Spain (Redano et al., 1991); 10 ms^{-1} in Greek waters (Prezerakos, 1986; Balopoulos et al., 1986); 9 ms^{-1} near Kingston, Jamaica (Huntley et al., 1988); 8 ms^{-1} in Tokyo (Yoshikado and Kondo, 1989); 7 ms^{-1} in Monterey, California (Banta, 1995);.and, 5 ms^{-1} in Santa Rosa Island, Florida (Sonu et al., 1973).

Methodology

The data presented in this paper were all collected using the 'S-probe', an instrument package, developed at the Centre for Water Research, University of Western Australia. It consists of a Digiquartz pressure sensor, a Neil Brown ACM2 acoustic current meter and three optical backscatterance sensors. The pressure sensor was mounted 0.35 m from the sea bed, whereas the two-dimensional, horizontal current velocity was recorded 0.2 m above the bed. The optical backscatterance (OBS) sensors measured the suspended sediment concentration (SSC) at 0.025 m, 0.125 m and 0.275 m from the bed. The data were transferred via a cable connected to a shore-based computer and logged at a sampling rate of either 5 Hz (exp. 1) or 2 Hz (expts. 2 and 3). The S-probe was deployed in the surf zone at each of the study sites. Calibration of the OBS sensors was conducted with sand samples collected at the survey site, using the methods and apparatus similar to that described by Ludwig and Hanes (1990). Analysis of the water surface elevation, current velocity and suspended sediment concentration records were carried out on time series of 2048 points (approximately 7 or 17 minutes). Although additional data (e.g. offshore wave climate, beach ground water levels, instantaneous shoreline, beach morphology changes etc), have been collected at each of these sites only data collected by the S-probe is presented here. More comprehensive account of the data sets from City Beach may be found in Pattiaratchi et al. (1997), Masselink and Pattiaratchi, (1997), Masselink et al., (1997).

Data obtained from City Beach on 23 January 1992 (expt 1) is limited to four hours after the onset of the sea breeze. After this time, the S-probe could no longer be maintained in an upright position due to the extremely energetic surf zone conditions. However, continuous data over 3 sea breeze cycles are available from the subsequent survey from City Beach, 3-9 March 1995 (expt 2) and over two days from Ambakandawila, Sri Lanka, 18-20 January 1996 (expt 3).

Results

Experiment 1: City Beach, WA - 23 January 1992

Time series of wind speed and direction obtained on this day indicate a typical sea breeze cycle characterized by weak offshore winds in the morning and early afternoon, and a strong sea breeze starting at 1445 hours which continued into the evening (Figure 3). Wind speeds associated with the sea breeze exceeded 10 ms^{-1} and occur frequently in the summer months in this region. The direction of the sea breeze was consistently from the south and hence the sea breeze was blowing parallel to the shoreline, a feature of the sea breeze system in this region (Pattiaratchi et al., 1997).

Changes in wind speed and direction are reflected in the incident wave field, nearshore currents and suspended sediment concentrations (Figure 3). Prior to the sea breeze, small-amplitude swell (H_S=0.4 m) with zero-upcrossing periods (T_Z) of 7-8 s were present. Mean cross-shore (offshore) and longshore (northerly) currents were less than 0.05 ms^{-1} and 0.1 ms^{-1}, respectively whilst the mean SCC at a distance of 0.275 m above the bed was about 1 gl^{-1}. Sediment was only re-suspended during the passage of large waves in wave groups. The onset of the sea breeze induced an almost instantaneous change in the nearshore hydrodynamics. The wave height increased (H_S=0.7 m), the wave period decreased and assumed a constant value (T_Z=4 s) within one hour of the start of the sea breeze. Offshore-directed cross-shore currents in the surf zone rapidly increased in strength to a maximum of 0.16 ms^{-1} and the northerly longshore current progressively increased and exceeded 1 ms^{-1}. Sand was continuously re-suspended by the waves and the amount of SSC in the water column (at 0.275 m) increased seven-fold to 7 gl^{-1}. The surf zone averaged northward longshore suspended sediment transport rate increased from approximately 1 kg s^{-1} before the start of the sea breeze to 100-200 kg s^{-1} during the sea breeze, an increase by a factor of 100 (Figure 3).

Experiment 2: City Beach, WA - 4-6 March 1995

The results from this experiment are essentially the same as that for experiment 1. However, due to weaker sea breezes (max 7 ms^{-1}), the hydrodynamic changes induced by the sea breeze were less extreme. Continuous measurements of three successive sea breeze cycles were made and these enabled the investigation of the recovery period of the wave conditions after the cessation of the sea breeze. Prior to the sea breezes, offshore winds prevailed with speeds of 2-3 ms^{-1}. All three sea breezes persisted for approximately 7 hours and a relatively constant wind speed of 5-7 ms^{-1} was maintained. After the onset of the sea breeze, immediate changes occurred to the incoming wave field with a decrease in T_Z from 10 to 5 s and an increase in the longshore current velocity to 0.15-0.2 ms^{-1}. Around 2045 hrs each day, the sea breezes stopped. The wind direction gradually shifted back to the east and the wind speed decreased to < 4 ms^{-1}. T_Z increased and the longshore current velocity decreased immediately after the sea breeze had subsided. Around 0600 hrs on the following day, nine hours after the end of the sea breeze, the wave period and the longshore current velocity had reached pre-breeze levels.

Energy spectra of the cross-shore current were computed to construct a three-dimensional time-frequency plot to illustrate the change in spectral signature over the second sea breeze cycle (Figure 4). The cross-shore current data were used, rather than the

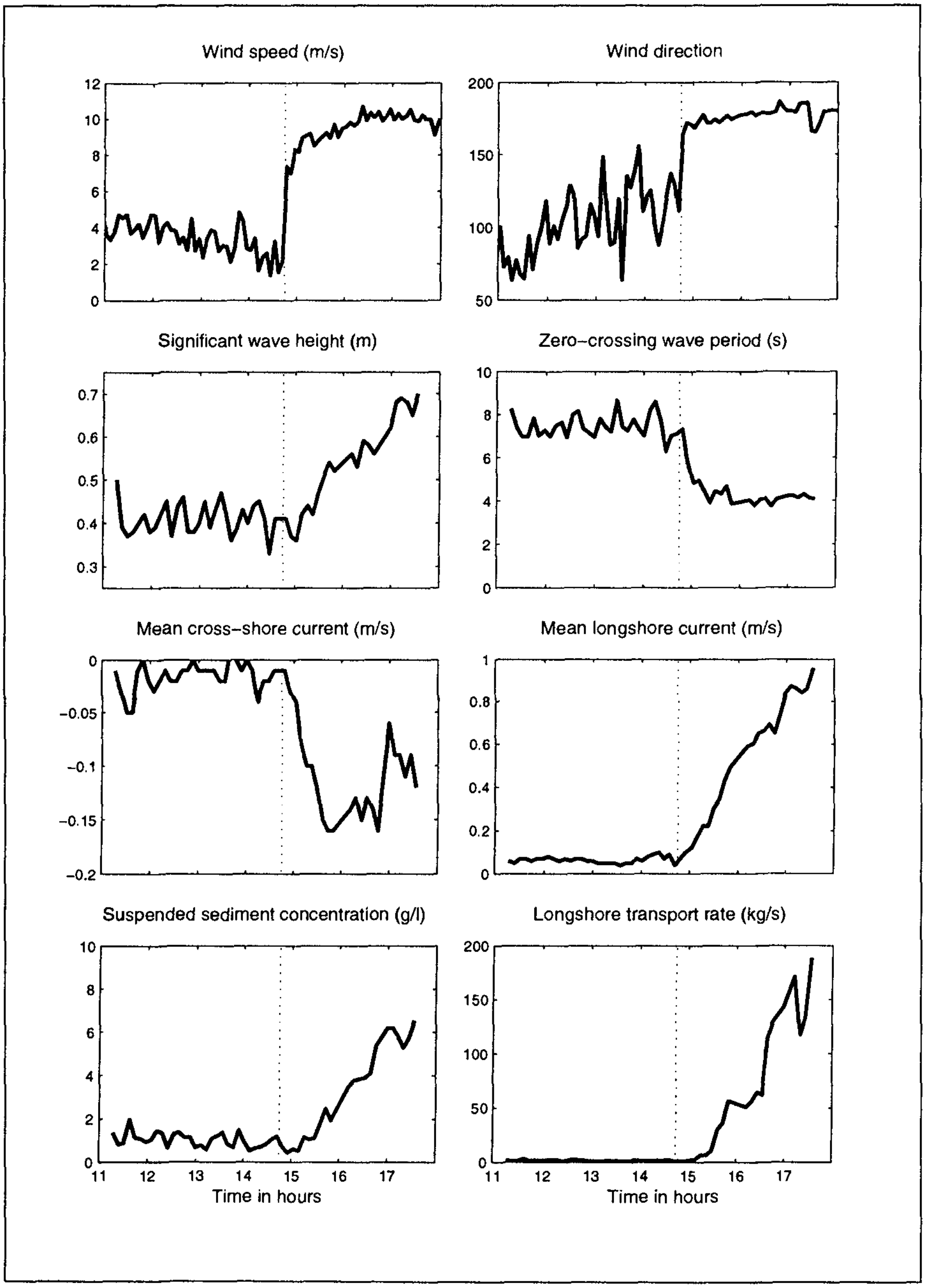

Figure 3 - Time series results for Experiment 1. The vertical dashed line indicates the start of sea breeze.

water surface elevation because they show more clearly the short-period wave energy caused by the sea breeze (frequency > 0.15 Hz). The long-period background swell is present in the time-frequency plot in the form of a linear ridge at frequency 0.07-0.1 Hz. The peak period associated with the swell energy was 12 s and remained relatively constant. After the onset of the sea breeze, wind wave energy begins to emerge at the high-frequency end of the spectra, indicating peak wave periods of 2.5 s. During the sea breeze, the frequency associated with the wind waves decreased progressively, forming a curved ridge in the frequency-time plot. At the end of the sea breeze (2100 hrs), the wind wave energy was concentrated around a frequency of 0.25 Hz, indicating a peak period of 4 s. After the sea breeze had subsided, the wind wave energy gradually decreased, but remained significant. The frequency associated with the wind wave energy decreased to 0.15 Hz, merging with the swell energy. Fifteen hours after the cessation of the sea breeze (1200 hrs 08/03/93), there was still some wave energy present which was generated by the sea breeze in the nearshore zone. This implies that the effect of the sea breeze on the nearshore hydrodynamics may be felt continuously during the sea breeze season (summer).

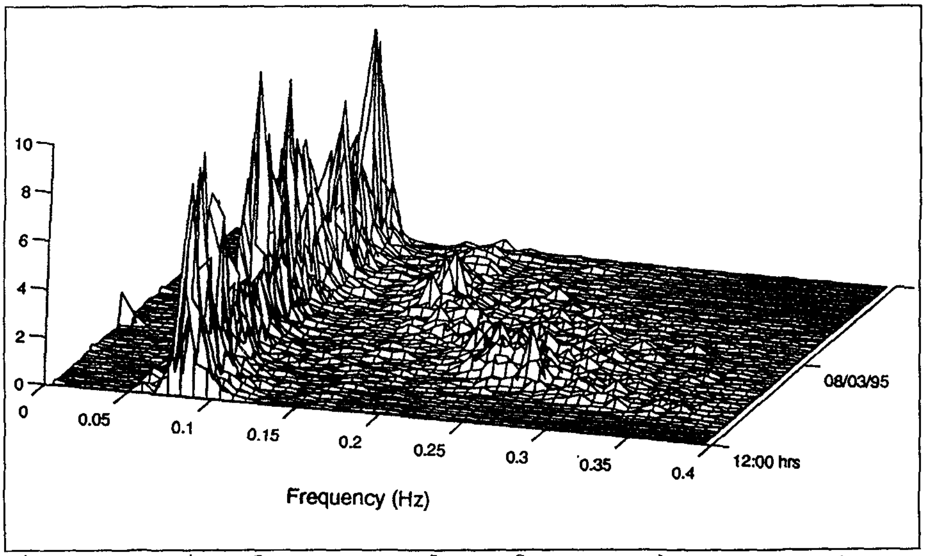

Figure 4- Time frequency plot of cross-shore currents

Experiment 3: Ambakandawila, Sri Lanka - 18-20 January 1996

Data collected from this experiment has not been thoroughly analysed and only a preliminary description is given here. On 18th January 1996, the sea breeze started at 1415 hours and 30 minutes later reached a maximum speed of 10-12 ms^{-1}. Continuous wind data is unavailable at present and the wind speeds quoted here were obtained using a hand-held anemometer on the beach. Coincident with the increase in wind speed, the longshore current increased from 0.05 to 0.75 ms^{-1} and then decreased just before midnight (Figure 5). The cross-shore currents (max = 0.23 ms^{-1}) and SSC (max = 3.8 gl^{-1}) indicated a similar trend (Figure 5). Pre-sea breeze values were reached prior to midnight. The exact time of the sea breeze cessation is unknown at present.

On the following day (19th) the sea breeze started earlier, at 1215 and continued blowing at 6-7 ms^{-1} throughout the afternoon. Here, although the sea breeze was weaker than the previous day, the recorded maximum values are higher (Figure 5): the longshore current max. is 0.80 ms^{-1}; max cross shore current 0.35 ms^{-1}; and, max. SSC 4 gl^{-1}. As per previous day, all values had returned to pre-sea breeze levels before midnight. On both days, the longshore suspended sediment flux (southward) increased by a factor of 60 during the sea breeze.

Discussion

This paper summarizes the results of three field experiments aimed at investigating the impact of sea breeze activity on nearshore processes. The findings are similar to those of Sonu et al. (1973), to date the only other study into sea breeze effects. In summary, the sea breeze results in: (1) an increase of the wave height; (2) a decrease in the wave period; (3) an intensification of the nearshore currents; and, (4) an increase in suspended sediment levels and suspended sediment transport. In Western Australia, due to the predominantly longshore component of the sea breeze,

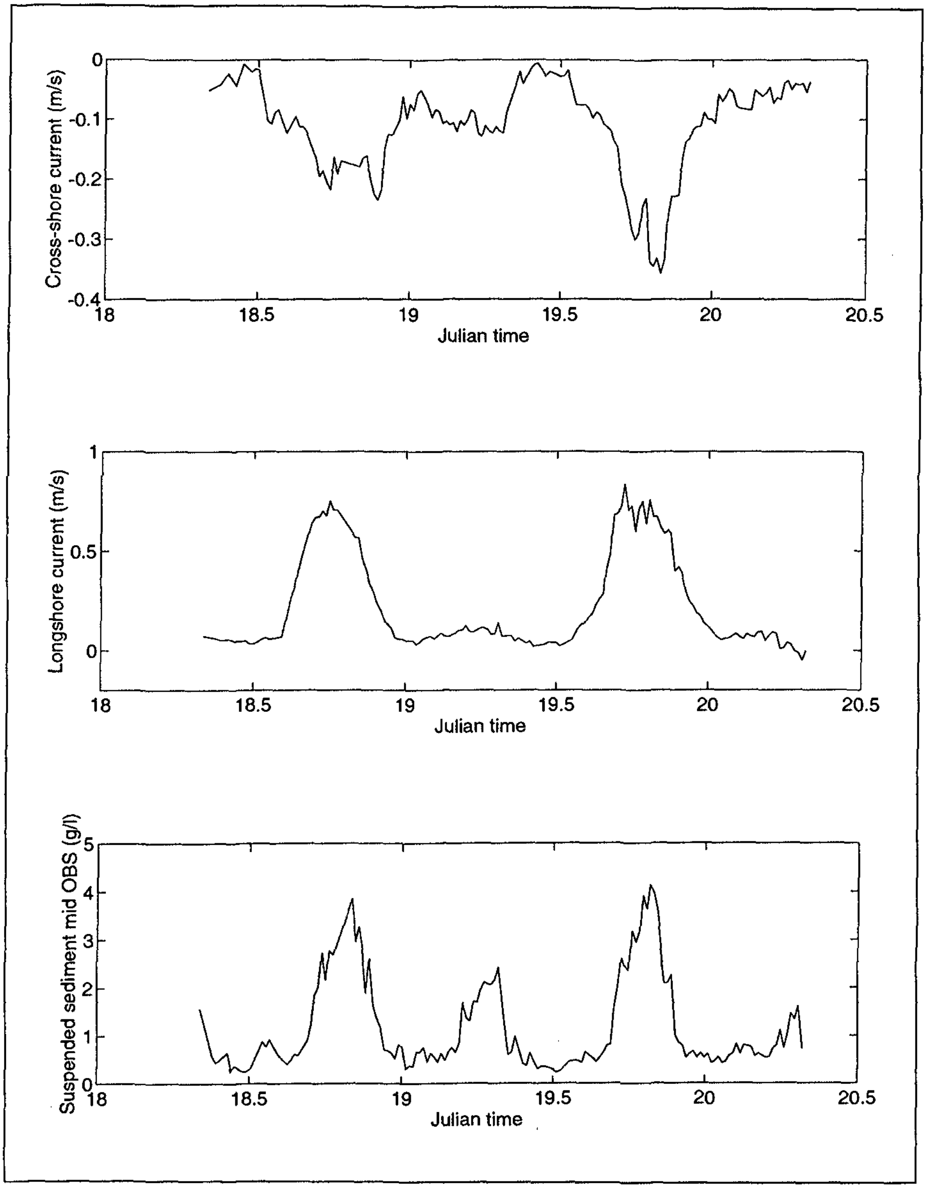

Figure 5 - Time series of cross-shore and longshore currents and SSC from Ambakandawila, Sri Lanka.

the nearshore hydrodynamics are affected long after the sea breeze has ceased to blow. Sonu et al. (1973)

refer to this as the "afterglow effect". Preliminary data from Sri Lanka, shown here, indicate that the impact of the sea breeze did not persist after midnight although visual observations of wave direction on the following morning indicated waves approaching from the direction of the sea breeze. Both the strength and consistency of the sea breeze, and the afterglow effect contribute to the important role that the sea breeze plays on the nearshore processes in both regions.

The sea breeze induces a diurnal cycle of beach change by causing erosion of the upper part of beach and/or planation of beach cusp morphology (Masselink et al., 1997). These changes are reversible in that the beach is usually restored to its pre-breeze state after the cessation of the sea breeze Pattiaratchi et al. (1997). On the larger temporal and spatial scale, the dramatic increase in the longshore sediment transport caused by the sea breeze is important. Masselink and Pattiaratchi (1997) and Pattiaratchi et al. (1997) estimate that along the stable Perth Metropolitan coastline, the annual longshore transport driven by the sea breeze is approximately 100,000 m^3. This estimate of longshore transport due to the sea breeze compared favourably with estimates of sediment accumulation at the southern side of Trigg Island (Perth) at the end of the summer. During the winter, the predominant north-westerly storms transport this sand southwards thus completing the seasonal sediment budget. Hence, it is clear that the sea breeze plays a dominant role in the sediment budget of the coastline around Perth.

Similarly, the sea breeze plays an important role in the annual longshore sediment budget along the west coast of Sri Lanka. During the south-west monsoon (May to September), the longshore sediment transport is predominantly northward. The occurrence of the sea breezes during the north-east monsoon period (October to February) would transport some of this sediment southward as shown by the results obtained from this study. Hence, also in this region, the sea breeze plays a dominant role in the annual sediment budget.

Conclusions

Field data presented from two different micro-tidal areas have shown the importance of the sea breeze system on nearshore processes. The sea breeze system induces a diurnal change in the incident wind wave climate (wave height and period) resulting in large increases to longshore and cross velocities and suspended sediment concentrations. The longshore suspended sediment flux can increase by a factor of 100 or more during the sea breeze which is very important in terms of annual sediment budgets.

Acknowledgments

A large number of individuals assisted in the data collection at the West Australian (WA) site and we would particularly like thank Dr Bruce Hegge for his efforts. Funding for the WA experiments was provided by an Individual Research grant awarded by the Division of Engineering and Computer Science at the University of Western Australia (UWA) to CP. Funding for the development of the S-probe was provided by UWA and the Centre for Environmental Fluid Dynamics. The Perth City Council is acknowledged for granting access to the field site. Funding for the field experiments at Ambakandawila (Sri Lanka) was provided by the Ministry of Fisheries and Aquatic Resources (Sri Lanka) as part of the ADB Chilaw Anchorage project to Lanka Hydraulic Institute and the Centre for Water Research. This paper has Centre for Water Research reference ED1243 CP.

References

Abbs D.J. and Physick W.L. 1992. Sea breeze observations and modelling: a review. Australian Meteorological Magazine, 41, 7-19.

Balopoulos E.Th., Collins M.B. and James A.E. 1986. Satellite images and their use in the numerical modelling of coastal processes. International J. Rem. Sens., 7, 905-919.

Banta R. 1995. Sea breezes shallow and deep on the California coast. Monthly Weather Rev., 123, 3614-3622.

Huntley D.A., Hendry M.D., Haines J. and Greenidge B. 1988. Waves and rip currents on a Caribbean pocket beach, Jamaica. J. Coast. Res., 4, 69-79.

Ludwig K. and Hanes D. 1990. A laboratory evaluation of optical backscatterance suspended sediment solid sensors exposed to sand-mud mixtures. Marine Geology, 94, 173-179.

Masselink G. and Pattiaratchi C.B. 1997. Morphodynamic impact of sea breeze activity on a beach with beach cusp morphology. J. of Coastal Research, (in press).

Masselink G., Hegge B. and Pattiaratchi C.B. 1997. Beach Cusp Morphodynamics. Earth surface processes and landforms, (in press).

Pattiaratchi C., Hegge B., Gould J and Eliot I. 1997. Impact of sea breeze activity on nearshore and foreshore coastal processes in southwestern Australia. Continental Shelf Res. (in press).

Prezerakos N.G. 1986. Characteristics of the sea breeze in Attica, Greece. Boundary Layer Meteorology, 36, 245-266.

Redano A., Cruz J. and Lorente J. 1991. Main features of the sea breeze in Barcelona. Meteorology and Atmospheric Physics, 46, 175-179.

Simpson J. E. 1994. Sea Breeze and Local Wind. Cambridge University Press, 234 pp.

Sonu C. J., Murray S. P., Hsu S. A., Suhayda J. N. and Waddell E. 1973. Sea breeze and coastal processes. EOS, Transactions American Geophysical Union 54:820-833.

Yoshikado H. and Kondo H. 1989. Inland penetration of the sea breeze over the suburban area of Tokyo. Boundary Layer Meteorology, 48, 389-407.