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The Influence of Coastal Morphology on Shoreface Sediment Transport under Storm-Combined Flows, Canadian Beaufort Sea

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ABSTRACT

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Wind, wave and current measurements were carried in the nearshore zone of the Canadian Beaufort Sea at two coastal sites having distinct morphologies. The first site is a sandy beach backed by a low bluff, while the second site consists of low-lying barriers. Computation of potential sediment transport using a numerical model for combined flow conditions (Li and Amos, 1993) suggests that coastal morphology may play a significant role on circulation and sediment transport on the shoreface during storm events. Downwelling near-bottom currents and offshore sediment transport were observed at all sites during storm surges, but with some variations in the shoreface current patterns and sediment transport. According to the numerical model used in this study, offshore sediment transport is more significant where the beach is backed by a bluff acting as a natural barrier. Such condition appears to be favorable to the development of strong seaward-directed horizontal pressure gradients that drive offshore bottom currents. Along low barriers that are easily submerged and overwashed, sediment transport is mainly directed obliquely offshore due to more limited set-up of sea level at the coast during storm surges. These results suggest that coastal morphology may be responsible for variable offshore sediment dispersal on the shoreface during storms. Our results show that sediment may be transported offshore to depths from which fairweather waves may not be capable of returning the material onshore. Consequently, a loss of material to the offshore may be greater where overwashing is restricted due to the presence of a coastal feature that acts as a boundary for onshore-driven surface waters.

ADDITIONAL INDEX WORDS: *Shoreface sediment transport, combined flows, storm surges, Beaufort Sea, Canada.*

INTRODUCTION

A better understanding of sediment transport processes in the nearshore zone is necessary for improving physical and theoretical models of beach morphological changes. Numerous models of beach/nearshore profile changes are based on the concept of an equilibrium profile that responds to wave-energy dissipation by adjusting to an equilibrium slope for given wave conditions and sediment grain-size (Dean, 1977; Bailard and Inman, 1981; Kriebel *et al.,* 1991). Although wave-driven processes undeniably play a major role in coastal sediment transport and beach profile adjustments, the nearshore zone is not solely affected by surface gravity waves, but also by other forcing mechanisms that may significantly influence fluid motions and substrate response. Several lines of evidence from modern environments (*cf.* Pilkey *et al.,* 1993 for review) and the geological record (Duke, 1990; Beukes, 1996) show that mean non-oscillatory currents that commonly interact with wave orbital motions in the nearshore zone may play an important role in cross-shore sediment movement. In addition to tidal currents, wind-induced upwelling flows and density currents, strong seaward-directed downwelling flows may develop during storms and may be responsible for significant offshore sediment transport. Offshore-directed storm currents have been identified in various modern nearshore environments (Morton, 1981; Swift *et al.,* 1985, 1986; Wright *et al.,* 1986, 1991; Snedden *et al.,* 1988; Hequette and Hill, 1993; Xu and Wright, 1998), and inferred from ancient sandy shallow marine deposits (Duke, 1990; Walker and Plint, 1992; Wignall *et al.,* 1996).

This paper is not concerned with sediment transport processes in the surf zone (*i.e.,* inshore of the breaker line) which is dominated by the action of longshore currents driven by the energy of breaking waves, but rather by the hydrodynamics and sediment transport on the shoreface, seaward of the surf zone, where surface wind stress, internal pressure gradients, and tides are major factors forcing mean currents. Although these forces are significant factors controlling nearshore circulation, oscillatory flows associated with wave orbital motions remain the most important source of bottom

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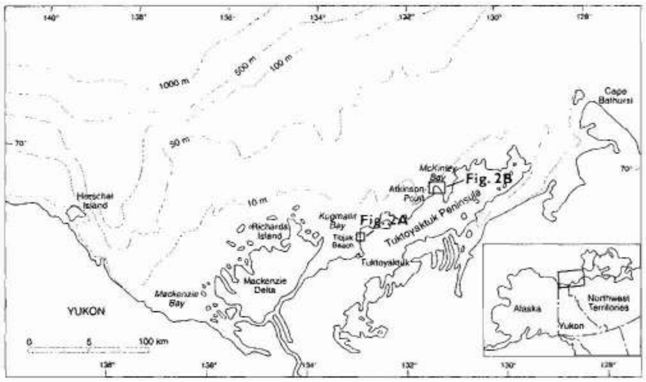

Figure 1. Location map of the study sites on the coast of the Canadian Beaufort Sea.

sediment remobilization in this zone of shoaling but non-breaking waves (NIEDORODA *et al.,* 1984; SWIFT *et al.,* 1985; WRIGHT *et al.,* 1986). As a consequence, sediment transport on the shoreface is the result of combined flows, the incident waves being of primary importance in bed agitation, and the unidirectional currents strongly controlling the transport direction (WRIGHT *et al.*, 1991; HEQUETTE and HILL, 1995).

The shoreface also represents a transition zone between the beach/surf zone system and the continental shelf, and is the site of on-offshore sediment transport between these two environments (SWIFT *et al.,* 1986; WRIGHT *et al.,* 1991; KEEN *et al.,* 1993; STONE and STAPOR, 1996). Several studies have shown that the exchange of sand between the inshore and offshore environments plays a major role in coastal evolution and shoreline stability (SWIFT, 1976; NRC, 1990; BIRKEMEIER *et al.,* 1991; PILKEY *et al.,* 1993; JAFFE *et al.,* 1997). Very few studies, however, have examined the role of coastal morphology on nearshore circulation and resulting sediment flux across the shoreface. The aim of this paper is to present the results of wave and current measurements carried out at two coastal sites of the Canadian Beaufort Sea (Figure 1), showing the influence of coastal morphology on the circulation and sediment transport on the shoreface during storm events.

STUDY SITES

Both study sites are located on the Tuktoyaktuk Peninsula, in the southeastern Canadian Beaufort (Figure 1). The coast of the Tuktoyaktuk Peninsula consists of low bluffs (<10 m) of unconsolidated Quaternary sediments and of beaches, spits and barrier islands undergoing rapid retreat (FORBES and FROBEL, 1985; HEQUETTE and RUZ, 1991). Wave generation is inhibited by the presence of sea ice during winter, but even during summer the presence of the pack-ice offshore limits wave energy by restricting the fetch. During the open water season, most of the high energy waves originate from the west and northwest in response to storm winds. The Canadian Beaufort Sea is a microtidal environment, the mean tide ranging from 0.3 to 0.5 m. In addition to tide-induced water level fluctuations, storm surges may raise coastal water levels in excess of 2 m above mean sea level along the Tuktoyaktuk Peninsula (HARPER *et al.,* 1988).

The first study site is the nearshore zone of Tibjak Beach (Fig. 2A), located near the mouth of Kugmallit Bay, a wide and shallow embayment of less than 10 m water depth (Figure 1). Tibjak Beach is a 2.5 km long beach of medium-grained sands, characterized by a steep foreshore backed by a low bluff (Figure 3). Seaward, the shoreface profile is very gentle, with an average slope of about 1:200 from 0 to 5 m water depths. Bottom sediment on the shoreface consists of well-sorted sand having a mean diameter of 0.25 mm. The second study site is the nearshore zone seaward of Atkinson Point, a small sandy promontory from which developed two spits of fine to medium sand continuing to the southwest as a barrier island (Figure 2B). These coastal accumulation landforms are low-lying features that are extensively overwashed during storm surges (CLOUTIER and HEQUETTE,

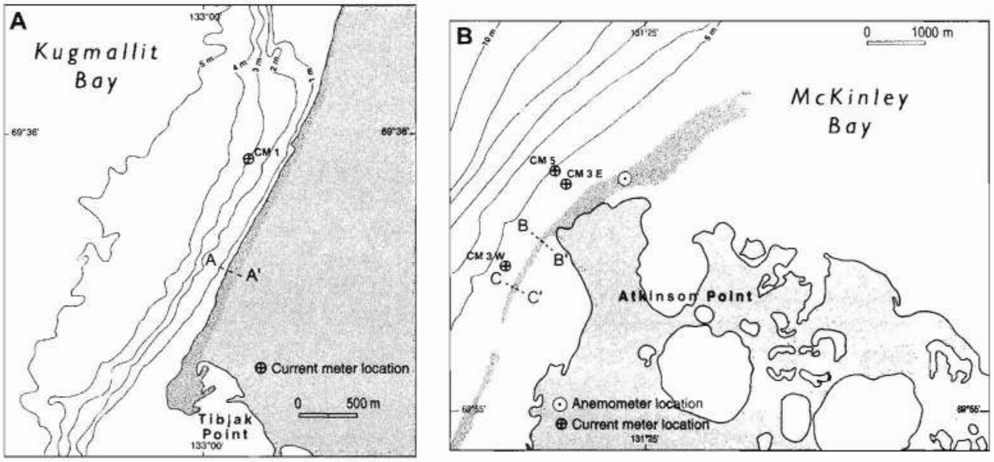

Figure 2. Location of current meters, anemometer, and beach profiles at the (A) Tibjak Beach study site (1987), and at the (B) Atkinson Point study site, 1992 and 1993.

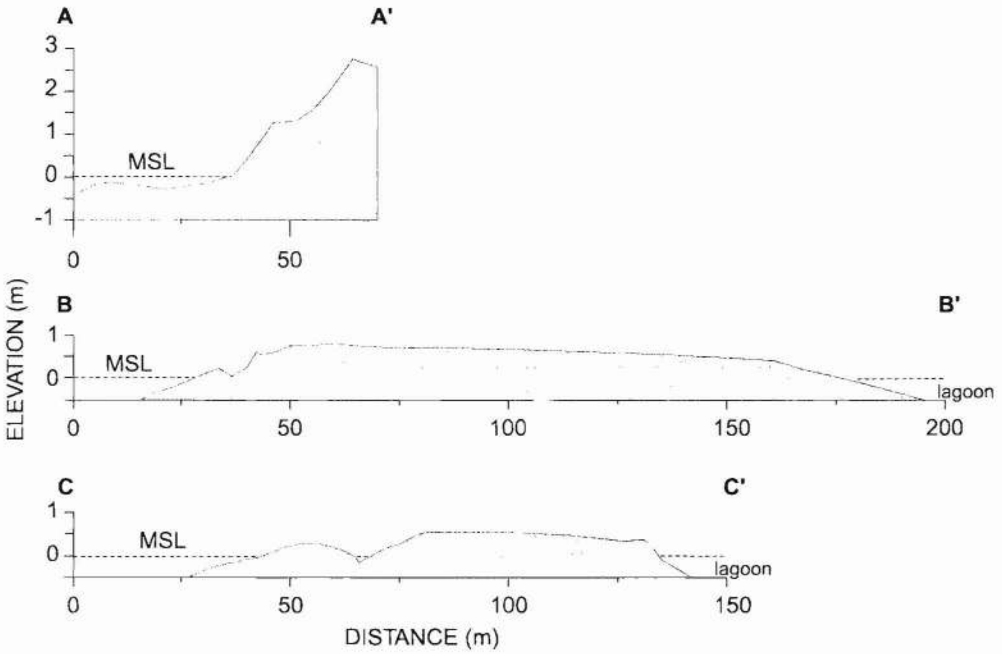

Figure 3. Beach morphology at Tibjak Beach (profile A-A') in 1987,and at Atkinson Point (profiles B-B' and C-C') in 1992. MSL is mean sea level. See Fig. 2 for location.

1998). The spits generally do not exceed 0.7 m above mean sea level (Figure 3) while the height of the barrier island barely reaches 0.6 m. The shoreface has a slope of about 1: 130, down to 5 m water depth, with a mean grain-size of 0.20 mm. Both study sites face the northwest which corresponds to the dominant storm wave approach (HARPER and PENLAND, 1982), but the Atkinson Point site is more exposed to high energy waves compared to the Tibjak Beach site which is partly protected from westerlies by a headland.

METHODS

Beach morphology was surveyed using a theodolite. Bottom sediments were sampled with a Van Veen grab sampler from an inflatable boat. Grain-size analyses were carried out with a settling tube developed according to the specifications of SYVITSKI *et al.* (1991). For the Tibjak Beach site, hourly wind velocity and direction were obtained from the Tuktoyaktuk weather station (Figure 1), located 15 km south of the study site. Wind data for the Atkinson Point site were recorded using a Lambrecht anemometer (model 1482) deployed on the eastern spit (Figure 2B) at 3 m above ground.

Directional wave and current data were obtained at Tibjak Beach in August and September 1987, using a Sea Data model 621 wave and current meter deployed in 3.4 m water depth (Figure 2A), relative to mean sea level (0.45 m above Chart Datum). At Atkinson Point, wave and current measurements were carried in 1992 and 1993, using InterOcean S4 current meters. Two current meters were deployed in approximately 3.5 m water depth in July and August 1992, while one current meter was moored in 5.0 m water depth in August 1993 (Figure 2B). The current meter deployed at Tibjak Beach was programmed to record velocity components and pressure at a frequency of 1 Hz for 1024 consecutive seconds (17.07 minutes burst record duration), every 3 hours. The instruments at Atkinson Point were programmed to record samples at a frequency of 2 Hz for 8 minutes, every 3 hours.

Spectral analyses of the raw data yielded values of wave direction, significant wave height, and peak period. Mean sea-surface elevation above the bottom and mean current velocity and direction were also obtained for every burst. All these instruments were located in the lower part of the water column, at heights of 0.8 to 1.1 m above the seabed, so the mean current components correspond to the time-averaged residual near-bottom flows.

In nearshore environments, sediment transport results from the combined action of unidirectional steady currents and oscillatory flows in the bottom boundary layer. Sediment transport on the shoreface was calculated using a one-dimensional numerical model for combined-flow conditions (SEDTRANS92) developed by LI and AMOS (1993). This model provides solutions for the combined flow shear velocity (u_{*cw}) based on the GRANT and MADSEN (1986) combined flow boundary layer theory. This requires the calculation of a combined flow friction factor, f_{cw}, calculated from:

$$1/(4f_{cw}^{0.5}) + \log[1/(4f_{cw}^{0.5})] = \log(C_r u_b/\omega z_0) + 0.14(4f_{cw}^{0.5}) - 1.65 \qquad (1)$$

where u_b is the maximum near bed wave orbital velocity, ω is the radian wave frequency ($2/T$, where T is the wave period), z_0 is the bottom roughness related to the bottom roughness height, k_b, by $z_0 = k_b/30$ and C_r is the wave to current strength ratio calculated from the vector addition of the enhanced current and wave shear stress components separated by an angle, ϕ:

$$u_{*cw} = u_{*wm}[1 + 2(u_{*c}/u_{*wm})^2 \cos \phi + (u_{*c}/u_{*wm})^4]^{1/4}$$
$$= u_{*wm} C_r^{0.5} \qquad (2)$$

where u_{*wm} is the maximum wave shear velocity and u_{*c} is the current shear velocity. SEDTRANS92 makes an initial estimate of f_{cw} using equation (1) and an arbitrary value for C_r, then estimates u_{*wm} from:

$$u_{*wm} = (C_r f_{cw} u_b^2/2)^{0.5} \qquad (3)$$

Using equation (2), initial values of u_{*cw} and u_{*c} are then computed and these values are used to recalculate C_r. The program iterates through the entire process until convergence on stable values for the combined flow friction factor and combined wave and current shear stress. SEDTRANS92 predicts sediment transport rates using different algorithms depending on the nature of the seabed and dominance of currents or waves. In this study, the rate of sediment transport per unit width of bed (q_s) was calculated using a modified ENGELUND and HANSEN (1967) total load equation for a non-cohesive bed with mean grain sizes larger than 0.15 mm:

$$q_s = 0.05 D u_{100}^2 \rho^2 u_{*cw}^3 / D[(\rho_s - \rho)g]^2 \qquad (4)$$

where D is the grain diameter of the sediment, u_{100} is the mean current velocity at 1 m above seabed, g is the acceleration of gravity, ρ and ρ_s are the fluid and sediment density respectively. In order to achieve reasonable transport predictions, the model includes a critical shear velocity (u_{*cr}) as a threshold criterion below which no transport is assumed. When current velocity was measured at a height z other than 1 m above the bottom, u_{100} was obtained from a logarithmic profile:

$$u_{100} = u_z \log(30/k_b)/\log(30z/k_b) \qquad (5)$$

where u_z is the mean velocity at height z above the bottom. A more detailed description of the theory and procedures for computing the different parameters included in the model is given in LI and AMOS (1993).

RESULTS

Nearshore sediment transport at Tibjak Beach

Five intense wind events occurred during the period of the field experiment during which winds were predominantly from the northwest. These storms resulted in significant wave heights of more than 0.9 m in 3.4 m water depth, reaching a maximum of 1.3 m on August 28 (Figure 4). Sea ice had retreated to a distance of 400 to 500 km from the coastline during that period, allowing the generation of high amplitude waves. High water levels were observed at Tibjak Beach during these storms due to wind-induced set-up of the sea surface against the shore. Several positive surges in excess of 0.7 m above mean sea level were measured at the study site, with a maximum storm surge of 0.96 m above mean sea level recorded on August 31 (Figure 4).

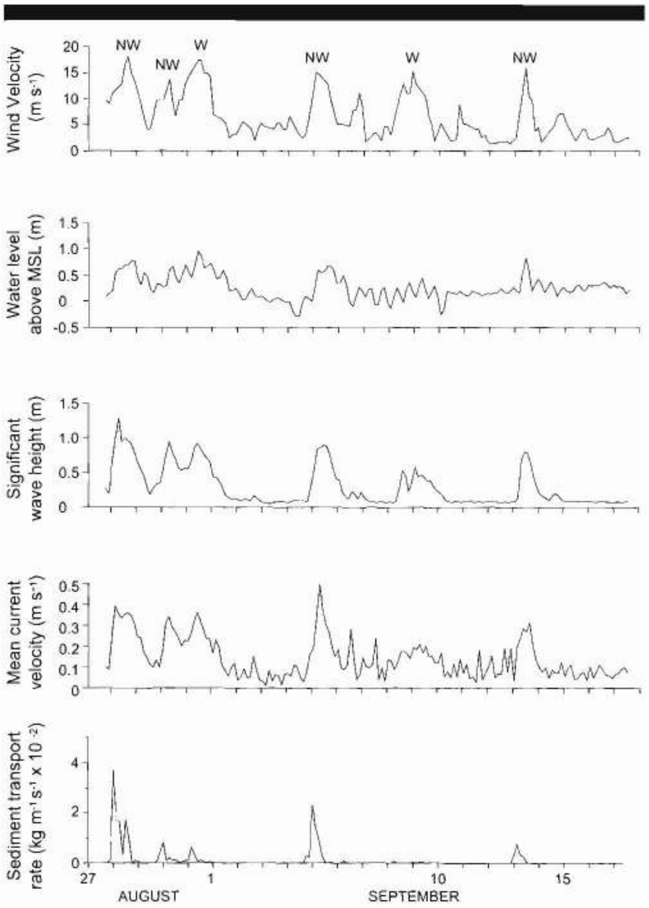

Figure 4. Time series of A) wind velocity at Tukyoyakyuk, B) water-level fluctuations relative to mean sea level, C) significant wave height (H_s), D) near-bottom mean current velocity recorded in 3.4 m water depth (relative to mean sea level), seaward of Tibjak Beach (see Fig. 2 for current meter location), and E) sediment transport rate according to LI and AMOS (1993) numerical model. Chart Datum is approximately 0.45 m below mean sea level.

The directional distribution of mean near-bottom currents showed that alongshore flows dominated during fairweather conditions, setting either to the north-northeast or south-southwest (HEQUETTE and HILL, 1993). During storms, however, the distribution of mean near-bottom currents was significantly different and high-velocity offshore-directed currents (NNW to NW) were recorded during northwesterly storms. Mean offshore current speeds of 0.25 to 0.35 m s^{-1} were recorded during those events, but a maximum of 0.5 m s^{-1} was recorded during the September 5 storm (Figure 4). The seaward-directed currents varied in duration from one event to another, but were generally persistent during each storm once they began to develop. During most of the storms, near-bottom currents were directed offshore for periods of at least 6 to 9 consecutive hours, and on 13 September, seaward currents occurred continuously for more than 18 hours.

These storm-generated currents were strongly controlled by wind forcing and by the pressure field associated with the set-up of the mean sea surface against the coast. Onshore-blowing winds induced a landward water transport at the

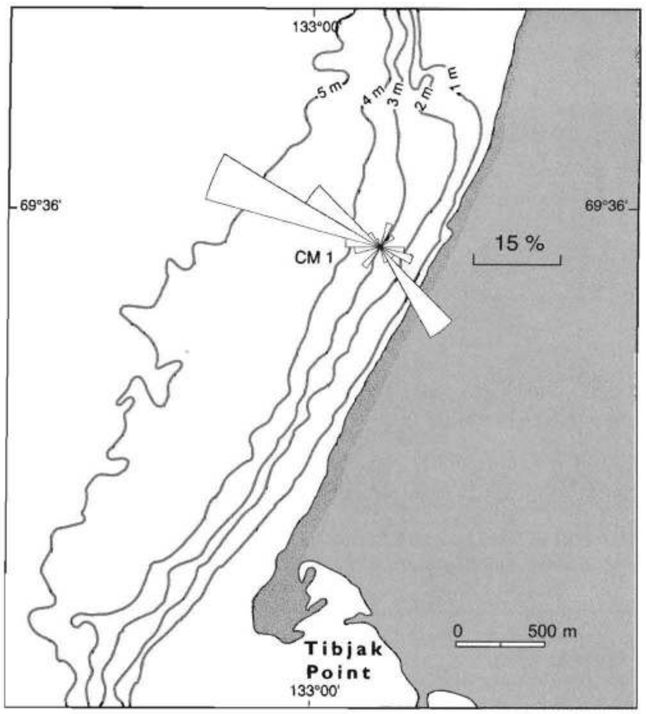

Figure 5. Direction of sediment transport at Tibjak Beach (computations based on the numerical model of LI and AMOS, 1993).

surface which was compensated by coastal downwelling and offshore bottom flow (Figure 4). During storm surges, small but important slopes of the sea surface develop in the nearshore zone, extending down from the coast. Such sea level slopes cause seaward-directed horizontal pressure gradients that drive offshore-directed mean bottom currents (SWIFT *et al.*, 1985).

High wave-orbital velocities (>1.0 m s^{-1}) were recorded during the storms (HEQUETTE and HILL, 1995) which, according to the numerical model used in this study, contributed to significant sediment remobilization. The model suggests that up to 3.7×10^{-2} kg m^{-1} s^{-1} were transported during these events (Figure 4) and that most of the sediment load was directed offshore (Figure 5) in response to combined wave oscillatory currents and mean flows. Some onshore transport occurred during the initial phase of the storms and was followed by offshore transport when downwelling circulation was established.

Once waves have supplied power to remobilize sediment, the direction and rate of the resulting sediment transport is strongly affected by the steady flow component over the seafloor, so the sediment load was directed offshore because of the downwelling circulation that was taking place during northwesterly storms. Mean current measurements in 5.0 m water depth revealed that bottom flow velocity may exceed 30 cm s^{-1} during downwelling events (HEQUETTE and HILL, 1993), showing that sediment may be transported offshore to depths from which fairweather waves may not be capable of returning the material onshore.

Nearshore sediment transport at Atkinson Point

Fairweather circulation in the nearshore zone of Atkinson Point is dominated by low-velocity currents setting alongshore to the northeast. Measurements of mean near-bottom currents down to 11 m water depth revealed that during conditions of low wind velocity (<3 m s^{-1}) mean flow speed is generally less than 10 cm s^{-1} (DESROSIERS, 1998). Bottom currents tend to respond quickly to wind forcing, however, flow velocity rapidly increasing with wind speed and current directions becoming more variable, especially during storms. During the periods of wave and current measurements in the summers of 1992 and 1993, northwesterly winds occurred at Atkinson Point, also resulting in surges in the coastal zone in response to onshore surficial water transport (Figure 6). The nearshore circulation at Atkinson Point during these storm surges showed some differences with the circulation observed at Tibjak Beach.

Several wind events occurred during the 3 week period of the 1992 field experiment but they were characterized by highly variable directions (Figure 6). Wind velocity was rather moderate, rarely exceeding 12 m s^{-1}. Fetch length during the summer of 1992 was extremely reduced due to proximity of sea ice. The edge of the pack-ice had advanced to less than 100 km north of Atkinson Point, and at about 200 km to the northwest by mid-August (DESROSIERS, 1998). Therefore, wave heights recorded during that period were limited, the maximum height reaching only 0.87 m on August 9 in response to northwesterly winds (Figure 6). Another wave event took place on August 13 also due to winds from the northwest. Virtually no wave activity was recorded during the rest of the study period in 1992 because wind velocity was either too low or because the wind was blowing from a direction that would not result in significant wave generation (offshore-blowing winds or limited fetch length).

Wind activity nevertheless induced some water level variations during summer 1992. During the first part of the experiment, wind direction was too variable to cause significant water level changes, but on August 6 offshore-directed winds exceeding 10 m s^{-1} caused a significant set-down of the water level at the coast (Figure 6). Circulation was upwelling, with near-bottom currents predominantly directed southward. Conversely, northwesterly wind events resulted in sea level set-up, causing the submergence of the Atkinson barriers on August 13 (Figure 6). Higher water levels were reached during that event because of higher wind velocities and more persistent onshore winds. Mean current velocities increased during both northwesterly wind events, reaching 0.33 and 0.43 m s^{-1} on August 9 and 13 respectively (Figure 6). Near-bottom currents were downwelling, setting obliquely offshore to the north and northeast. Current velocity peaked at 0.45 m s^{-1} on July 30 while the wind was blowing from the southwest. These high velocity flows were possibly wind-forced currents driving an alongshore coastal jet.

According to our numerical modeling, the threshold of sediment motion was only exceeded on three occasions (Figure 6). On July 30, sediment transport occurred on the shoreface in response to high velocity unidirectional near-bottom flows. The absence of significant wave oscillatory currents, however,

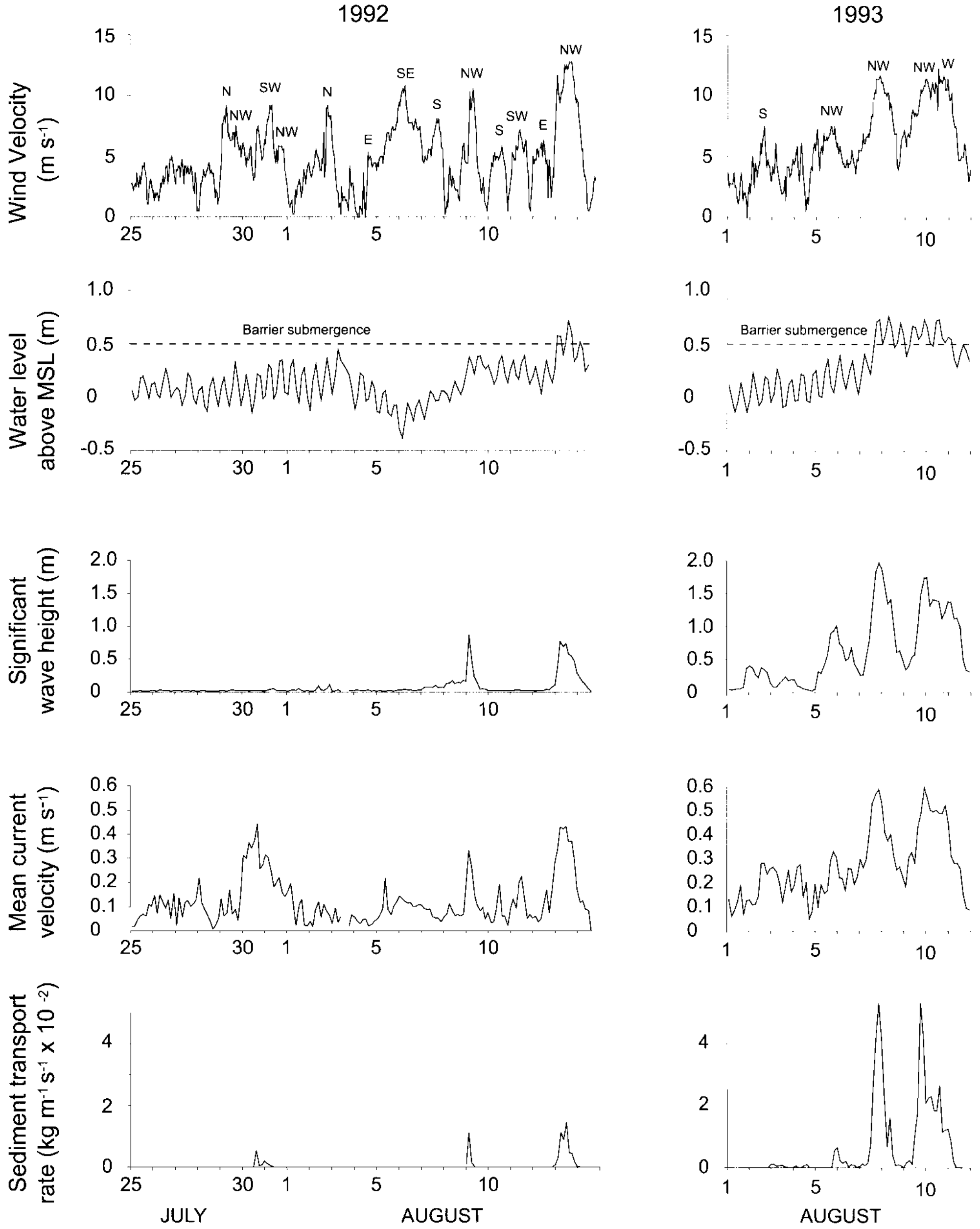

Figure 6. Time series of A) wind velocity, B) water-level fluctuations relative to mean sea level, C) significant wave height (H_s), D) near-bottom mean current velocity recorded at Atkinson Point in July and August 1992 (CM 3E), and in August 1993 (CM 5), and E) sediment transport rate according to LI and AMOS (1993) numerical model. The CM 3E and CM 5 were deployed in 3.5 m and 5.0 m water depths respectively, relative to mean sea level (see Fig. 2 for location). Chart Datum is approximately 0.45 m below mean sea level.

resulted in low sediment transport rates during this event. More sediment transport occurred during the moderate northwesterly storms of August 9 and 13, but the transport rate was limited to less than 1.5×10^{-2} kg m^{-1} s^{-1} because of restricted wave activity. Sediment transport was mainly directed alongshore or obliquely offshore during these storms (Figure 7).

Wind and ice conditions were more favorable to wave generation during summer 1993 as the fetch was already of more than 400 km to the northwest in mid-July. Wind measurements during the first two weeks of August showed that this period was dominated by two northwesterly storms on August 7–8 and 9–10 which induced a significant surge that reached about 0.7 m above mean sea level on several occasions (Figure 6), causing extensive overwashing and submergence of the barriers. Surface currents were directed onshore at the surface and downwelling near-bottom currents developed on the shoreface, setting to the north during the first storm and to the

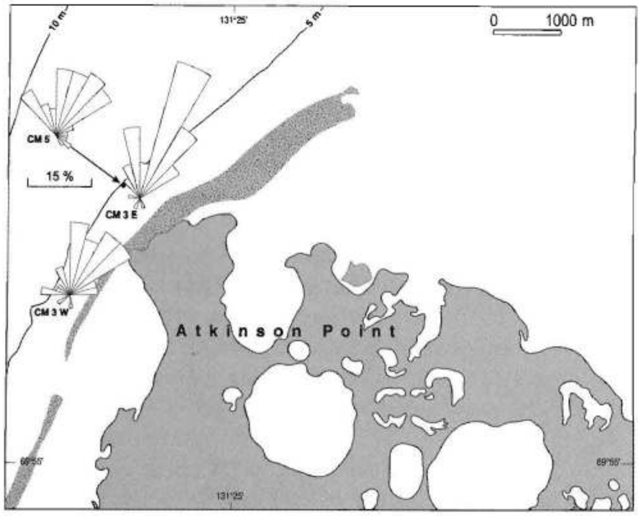

Figure 7. Direction of sediment transport at Atkinson Point in 1992 (CM 3E and CM 3W), and in August 1993 (CM 5) (computations based on the numerical model of LI and AMOS, 1993).

north-northeast during the second storm. Mean current velocities were particularly high during these storms, reaching 0.58 m s^{-1} on August 7 and 0.6 m s^{-1} on August 9. High amplitude waves were recorded during these events, with significant heights up to almost 2 m on August 7 and of 1.75 m on August 9 in 5.0 m water depth (Figure 6). According to the numerical model, these large waves combined with strong near-bottom flows resulted in significant sediment transport on the shoreface, with transport rates exceeding 5.0×10^{-2} kg m^{-1} s^{-1} during both storms. Again the direction of sediment transport was alongshore to offshore (Figure 7).

DISCUSSION

According to the numerical model used in this study, the potential sediment transport due to combined flows on the shoreface during northwesterly and westerly storms is characterized by a more pronounced offshore component at Tibjak Beach than at Atkinson Point. Although small differences in wind direction may result in variations in sea level set-up at the coast which may affect nearshore circulation (HEQUETTE and HILL, 1993), both sites experienced storms with similar characteristics in terms of wind direction and speed. The results of our experiments, nevertheless, show significant differences in shoreface current patterns and sediment transport in response to storms between the two experimental sites. The variability between the two sites is therefore believed to be mainly due to differences in shoreline configuration and in coastal morphology rather than variations in wind and wave characteristics during the observed storm events.

In addition to meteorological forcing, the magnitude of sea level set-up at the coast may also depend on coastal morphology which can limit or conversely facilitate submergence and overwash processes. Based on a volume conservation and water budget approach, set-up is a function of radiation stress inducing wave set-up superimposed on wind-induced storm surge driving water inshore, while bottom mass return flow is a response to a pressure gradient induced by water accumulation a the coast. A high coastal barrier or the presence of a bluff in the backshore may therefore favor coastal set-up by restricting surbmergence, acting as a boundary for onshore-driven surface waters. This would result in a significant horizontal pressure field driving offshore-directed near-bottom barotropic currents, responsible for shore-perpendicular sediment transport (Figure 8a). These conditions occur at the Tibjak site where the beach is backed by a low bluff for several kilometers. Moreover, Tibjak Beach is affected by more significant storm surges than the surrounding areas, due to its location at the mouth of Kugmallit Bay, because wind set-up of the sea surface is increased in coastal embayments (HARPER *et al.*, 1988).

Conversely, the submergence and overwashing of low barriers result in water mass transfer over the top of the barrier to the lagoon, this mechanism being responsible for removing a portion of excess water in the nearshore zone. Such conditions may decrease the nearshore water level and offshore pressure gradient. The set-up of coastal waters would therefore be more limited at Atkinson Point, mainly because of the low elevation of the coastal accumulation landforms which are extensively overwashed and easily submerged, even during moderate storms. As a consequence, conditions are less favorable to the formation of a seaward sloping sea surface, thus limiting seaward-directed horizontal pressure gradients that may induce offshore bottom flows. Downwelling flows were observed on the Atkinson Point shoreface during northwesterly storms, but numerical modeling showed that sediment was transported alongshore to obliquely offshore rather than directly offshore during these events (Figure 8b).

Although storm surges are mainly caused by onshore-directed wind stress, wave set-up contributes to raising the water surface on the beach and in the surf-zone. According to theoretical and experimental studies (BATTJES and STIVE, 1985; GOURLAY, 1990), wave set-up is strongly controlled by the nearshore bathymetry, the set-up increasing with decreasing bathymetry. It is therefore possible that a proportion of the observed variations in set-up between both experimental sites may also be due to some differences in nearshore bathymetry and slope. This factor is thought to have a limited effect, however, because our results mainly concern the shoreface where changes in sea surface elevations are mostly wind-forced rather than wave-induced.

The role of coastline orientation relative to the wind field and the influence of coastal geometry on nearshore currents and associated sediment transport during storms has been mentioned in several studies (SWIFT *et al.*, 1985; HEQUETTE and HILL, 1993; KEEN *et al.*, 1993; JAFFE *et al.*, 1997). Numerical modeling of coastal circulation and sedimentation in the western Gulf of Mexico and in the Middle Atlantic Bight during storm surges by KEEN *et al.* (1993) suggests that the large-scale variability of the coastline is a primary factor controlling the alongshore variations in near-bottom flows and sediment paths on the shoreface. Analyses of historical bathymetric and shoreline surveys along the Louisiana coast also suggest that changes in shoreline orientation partly ex-

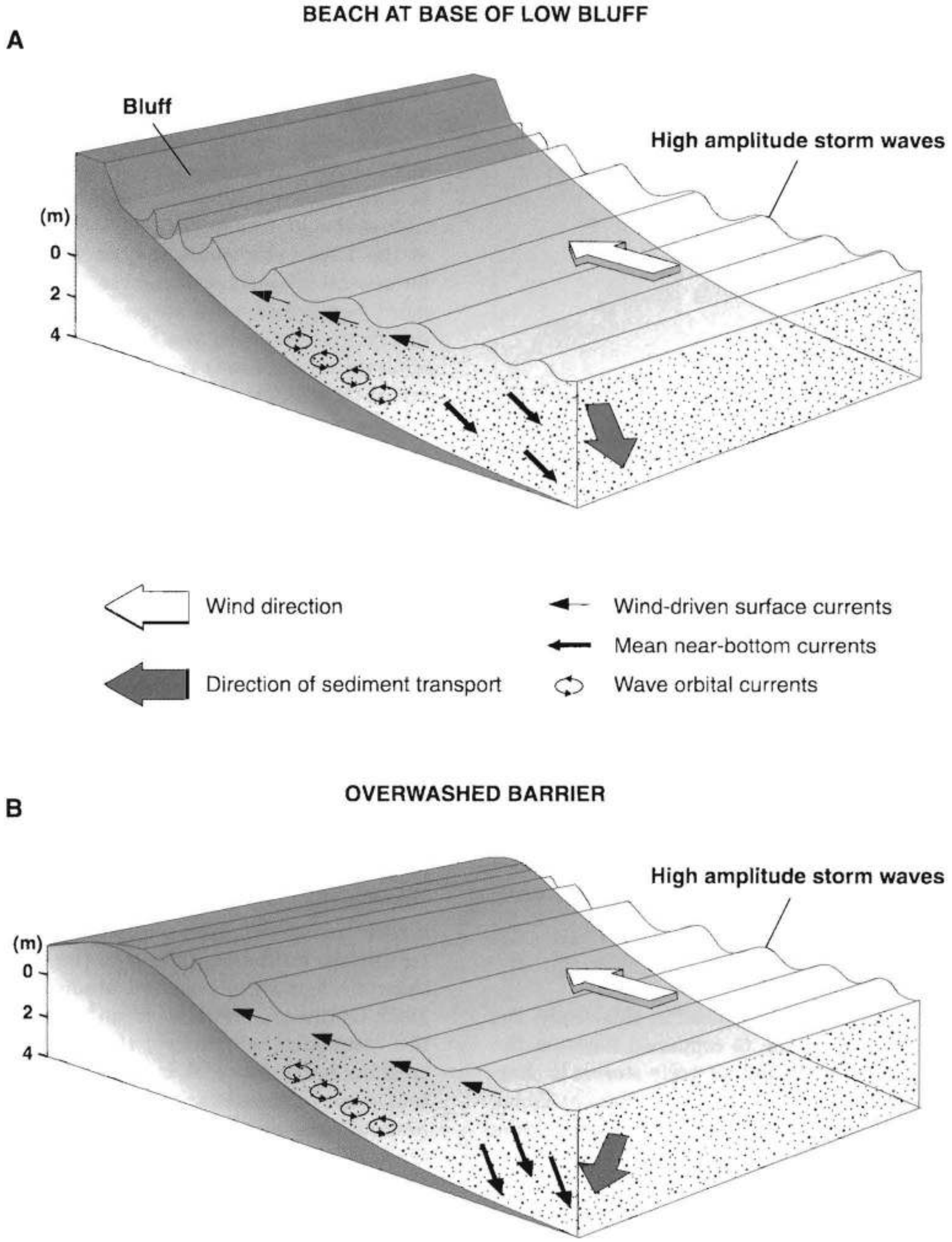

Figure 8. Conceptual model of nearshore sediment transport during storm surges seaward of (A) a beach backed by a low bluff, and (B) a low-lying spit or barrier beach.

plain the variations in sand deposition on the shoreface induced by wind-driven storm currents (JAFFE *et al.*, 1997). The possible influence of coastal morphology on storm flows and sedimentary processes on the shoreface, however, has received little attention, yet our results suggest it may be important. A consideration of coastal morphology may lead to alternate explanations of the mechanisms responsible for beach erosion and offshore sediment transport during storm surges.

In a study of the response of the Chandeleur barrier islands to storms, southeast of the Mississippi delta, for example, KAHN and ROBERTS (1982) showed that the large variability observed in storm impact greatly depends on shoreline orientation and barrier morphology. When a tropical storm or a hurricane strikes this coastline, the flat and low barriers of the southern part of the barrier island may be almost totally overwashed. This results in landward sediment transport to the lagoon, while strong currents entrain nearshore sand alongshore. The central and northern parts of the islands arc consist of semi-continuous barriers with well-developed, 2 to 4 m high, foredunes. Storm impacts on this coastline are severe beach erosion, foredune scarping, localized overwashing at low spots in the foredune line, and sand transport to the nearshore. Based on morphological evidence, KAHN and ROBERTS (1982) suggest that this offshore transport is caused by storm-surge ebb flow concentrated through overwash channels. Although storm-surge return flows due to the relaxation of water trapped in coastal embayments and lagoons may lead to offshore sand transport, such flows may not represent the only mechanism contributing beach sand to the shoreface. It is also possible that the morphology of the backshore, with foredunes preventing submergence and acting as a natural boundary, was responsible for more pronounced offshore near-bottom currents.

The results of our study may have implications for coastal defense strategies. Beach loss in front of seawalls is a well known problem (PILKEY and WRIGHT, 1988; GRIGGS *et al.*, 1994). Reflection of incident waves on seawalls has been suggested as a primary cause of beach lowering and offshore sand transport. Although wave/seawall interactions probably affect cross-shore sediment transport and beach volume, the results of our study suggest that the loss of sand to the offshore may be also due to downwelling flows that are locally enhanced by the seawall acting as an artificial barrier for the surface waters transported shoreward by onshore winds. More research is needed however to investigate these hypotheses.

CONCLUSION

This study suggests that sediment transport due to the combined action of waves and currents may vary significantly from one nearshore site to another during episodic storm events, leading to variable offshore sediment dispersal along the shoreface. Shoreline evolution may thus be very different along the coast as increased offshore sediment transport at certain locations may lead to a loss of material for the coastal zone and contribute to coastal erosion problems. These results have implications for coastal managers and decision-makers who have to plan future development in the coastal zone, as it shows that potential loss of material to the offshore zone may be increased during storm surges in coastal areas backed by an artificial or a natural barrier such as a bluff.

This study is also another example showing that the concept of equilibrium shoreface profile based solely on wave-energy dissipation is not totally satisfactory (WRIGHT *et al.*, 1991; PILKEY *et al.*, 1993) since other mechanisms such as wind-driven storm currents may play a major role on nearshore sediment transport. According to our numerical modeling, sediment transport rates and directions on the shoreface greatly depend on the magnitude and direction of unidirectional currents, especially when storm-generated downwelling flows occur. Since the exchange of sand between the beach and inner shelf is strongly controlled by these forcing mechanisms, shoreface profile variations can not be explained solely by wave-induced bottom stress.

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