Coastal Morphodynamics at Skallingen, SW Denmark: Low and Moderate Energy Conditions

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This paper describes some preliminary results from a field experiment on suspended sediment transport and cross-shore profile evolution in an environment subjected to storm surges. The experiment was conducted during the fall of 1994 at the barrier beach of Skallingen, SW Denmark. Data were collected over several tidal cycles comprising low through moderately-high offshore energy conditions. During the experimental period, a swash bar developed on the foreshore and migrated onshore, accreting significantly in the process. Surf zone sediment transport was heavily influenced by a rip current crossing the second bar. Topographic changes in the nearshore consisted of a progressive lowering of vertical bar relief, as a result of a balance between offshore directed sediment transport due to the rip during moderate/high energy conditions, and onshore wave-induced transport during low energy conditions when the waves were not breaking over the second bar.

Keywords: *Sediment transport, cross-shore profile, rip currents, swash bars, sediment traps.*

One of the most challenging aspects of coastal research is to describe and quantify cross-shore sediment transport across the nearshore and adjacent subaerial beach regions. First, these environments are very difficult to monitor. Second, a large number of physical processes occur and the interactions between these processes are complex. Finally, an understanding of the transport processes will have important implications for our perception and management of the coastal environment.

Until recently, sediment transport in the surf zone has been measured indirectly using tracers (e.g. Ingle, 1966; Komar & Inman, 1970; White & Inman, 1989) or simple profile differencing techniques. These studies focussed mainly on longshore sediment transport and argued that bedload was the main sediment transport mechanism. However, a reinterpretation of the Komar & Inman (1970) data set (Hanes, 1988) showed that their results could equally well be explained by intermittent suspension. Suspended sediment concentrations have been recorded using traps (e.g. Kraus, 1987) or suction samplers (e.g. Nielsen, 1984; Bosman et al., 1987) again focussing mainly on longshore sediment transport and/or suspended sediment motion.

Within the past decade, the advent of fast-response optical and acoustic sensors for suspended sediment concentration (Downing et al., 1981; Vincent & Green, 1990; Hay & Sheng, 1992) has increased significantly our ability to investigate the processes of sediment resuspension and cross-shore sediment transport in natural environments (e.g. Huntley & Hanes, 1987; Osborne & Greenwood, 1992; Aagaard & Greenwood, 1994a). Moreover, it has become possible to investigate the relative importance of various hydrodynamic processes (e.g. wind waves, long waves, mean currents; Aagaard & Greenwood, 1994b), and to relate sediment transport rates and directions to a specific set of environmental conditions. These studies have also indicated that in the nearshore environment, suspended load is generally more important than bedload (e.g. Sternberg et al., 1989).

This recent research, however, has only very rarely addressed the relationships between sediment flux and morphological change. Osborne & Greenwood (1992) recorded onshore sediment transport accomplished by oscillatory wave motions across a longshore bar during moderate energy conditions. The morphological result was a landward migration of the bar. The sediment transport effects of an intense storm leading to a seaward bar migration on the order of 25 m were reported by Aagaard & Greenwood (1994b, 1995). The offshore transport of sediment was due mainly to seaward directed mean currents (undertow) while the movement of the bar form was a result of large spatial sediment transport gradients induced by standing infragravity waves. However, no studies have addressed quantitatively the sediment transport rates and directions within the nearshore zone and the beach face (swash zone) under conditions which lead to beach erosion and/or accretion; furthermore, the effects of storm wave activity occurring in connection with a locally raised mean water level, i.e. under conditions of a storm surge, when the nearshore profile is significantly out of equilibrium, have not been investigated so far.

It is anticipated that global sea level will increase significantly in the future due to global warming caused by greenhouse gases. Expected consequences are accelerating beach erosion, disintegration of coastal dune systems and an increasing overwash activity on barrier islands. In order to evaluate which countermeasures might be taken to mitigate such problems, it is of importance to understand the environmental conditions (wind, waves, water level) under which beach/dune erosion and subsequent accretion occur, and which specific physical processes are responsible.

In this paper, some preliminary results from the Skallingen-94 field experiment are described. The objective of the experiment was to measure suspended sediment transport rates across the surf and swash zones in order to gain an understanding of the processes responsible for sediment exchanges between the nearshore and beach face/dune, and thus to understand the cross-shore profile changes which occur during high- and low-energy conditions. A further experimental goal was to quantify threshold velocities for sediment entrainment in the swash zone in terms of near-bottom current and wave conditions.

Skallingen-94 was the first of a 3-year series of field experiments termed MOSS (Morphodynamics of Storm-surge Shorelines) which aim to document the morphodynamic behaviour of beaches subjected to storm surge activity. The study is funded by the Danish Natural Sciences Research Council and future experiments are scheduled for 1995 and 1996.

Field Site and Instrumentation

This research is being conducted at Skallingen, a barrier spit in the Danish Wadden Sea (Figure 1). The area is frequently subjected to storm surges associated with onshore gale force winds and storms which may raise the water level to the toe of the dunes (or higher), causing beach face/dune erosion or, alternatively, overwash of the barrier spit. During low-energy conditions the water level returns to normal and a portion of the eroded sediment is transferred back to the beach face and to the storage depot in the dunes. However, as Skallingen is presently experiencing net erosion, with a rate of shoreline retreat on the order of 3 m/a (Nielsen, 1991), the beach/nearshore clearly suffers from a net sediment deficit.

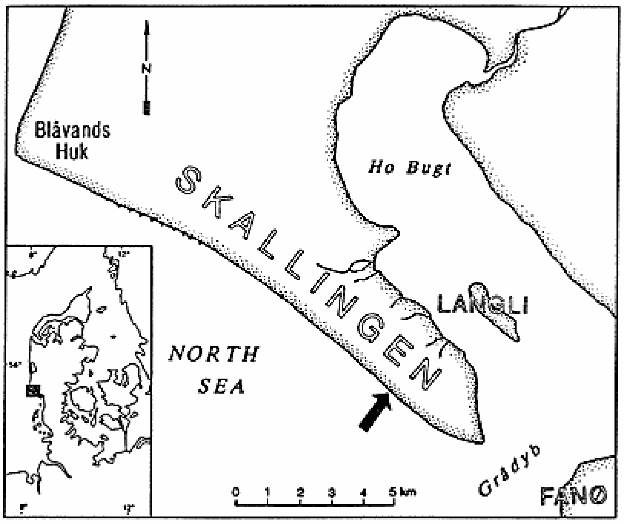

Figure 1: Map of Skallingen. The experiment site is indicated with an arrow.

Field work spanned the period September 25-October 27, 1994 (Julian Days 268-300). Figure 2 illustrates the cross-shore profile of Line 6420 along which the instruments were deployed. Line 6420 is part of the coastal survey grid established by the Danish Coastal Authority. The beach face and nearshore on this part of Skallingen is composed of sand having mean grain sizes in the range of 160-230 μm with an admixture of pebbles on the beach, often occurring as distinct layers resembling lag deposits. The beach face is backed by a narrow foredune reaching an elevation of about +7.5 m DNN (Danish Ordnance Datum); the slope of the nearshore is $\beta \approx 0.008$. As a result of this low gradient, the surf zone becomes very dissipative even under moderate wave energy conditions. The slope of the beach face is $\beta \approx 0.02$.

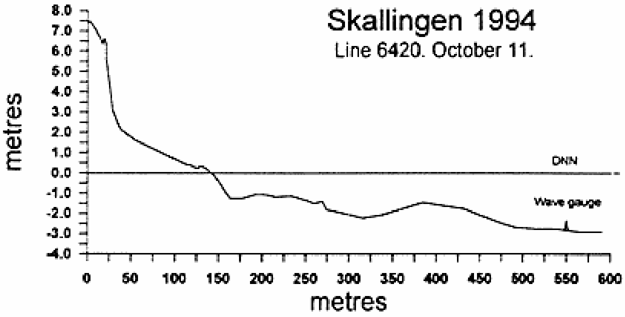

Figure 2: The cross-shore profile at Skallingen, surveyed on October 16, 1994. The location of the offshore wave recorder is indicated.

The upper shoreface contains three bars. The innermost bar resembles an ephemeral swash bar (Figure 2) which functions as a berm during low-tide conditions and as a nearshore bar during high tide and storm surges. As a rule, the second bar is linear, but broken by rip channels commonly with a spacing of 300-500 m. Prior to the '94 experiment, the instrument transect crossed the second bar between two rip channels where the bar had a significant vertical relief. However, a gale occurring during instrument deployment on September 26-27 remoulded the second bar and a rip channel developed more or less along the transect. This rip, which was part of a series having spacings of ≈ 900 m, remained throughout the experiment and significantly influenced the velocity field and sediment transport patterns measured in the surf zone.

Six instrument stations were deployed in a cross-shore array across the two inner bars (see Figure 3) in order to measure local suspended sediment transport rates. These stations were each equipped with a Marsh-McBirney OEM512 electromagnetic current meter and 3 optical backscatter sensors (D&A Associates, OBS-1P) for measuring sediment concentration. Current meter elevations were initially set at 0.3 m above the bed, whereas the backscatter sensors were mounted at $z = 0.05$, 0.10 and 0.20 m, respectively. The latter were adjusted frequently to compensate for erosion/accretion of the bed. Before and after the experiment the optical sensors were calibrated in the Sediment Recirculating Facility at the University of Toronto, using sand from the field deployment locations. Net suspended sediment transport rates were then computed as

$$<q_s> = 1/T\ \Sigma uc$$

where <> denotes the time-average, T is record length whereas u and c represent instantaneous velocity and sediment concentration, respectively.

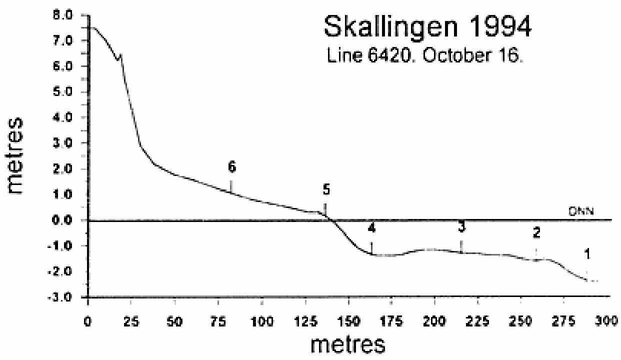

Figure 3: Cross-shore profile of the transect surveyed on October 16, 1994. Locations of instrument stations S-1 through S-6 are shown.

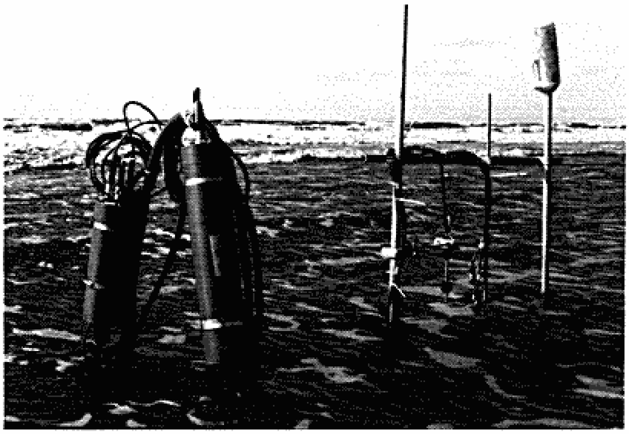

Figure 4: Photo of station S-6 equipped with an electromagnetic current meter and three optical backscatter sensors.

Stations S-1 and S-5 were also equipped with a Hales & Rogers WHM2 pressure sensor to monitor waves and mean water level. Figure 4 illustrates one of these instrument stations. The sensors were all cable-linked to a shore-based Hewlett-Packard Data Acquisition System and sampled at 4 Hz for 34 minute intervals every hour during periods of interest. A total of 142 runs comprising about 300 Mb of data were collected from these sensors.

Approximately 10 m south of the instrument transect on the seaward side of the swash bar, a 150 kHz Dantec laser-doppler was mounted 0.08m above the bottom (+0.10 m DNN) in order to measure both horizontal and vertical velocity components to determine sediment transport initiation. However, this part of the project is still in its initial phase and only 26 runs were recorded. Record lengths were 5 minutes. The tripod system (Lund-Hansen et al., 1995) also consisted of a 1.75 m high stack of 5 cylindrical sediment traps with an aspect ratio (Gardner, 1980) of 6. The traps were separated by a vertical distance of 0.35 m, the lowest trap deployed at 0.35 m above the bottom. The traps were emptied at each low tide, and the contents of each trap was weighed. In this way, a sample was collected for each tidal cycle.

Seaward of the third bar, at x ≈ 550 m (see Figure 2), a Pacer Model 10688 WTG wave recorder was deployed to measure incident wave characteristics prior to breaking, as well as mean water level data for comparison with the gauge permanently deployed by the Esbjerg Harbour Authority at the Grådyb ebb tidal delta.

Morphological changes were documented using a cross-shore array of 17 depth-of-disturbance rods (DOD-rods; Greenwood & Hale, 1980) which were jetted into the beach at 5 m intervals across the swash bar. These rods were fitted with a washer to provide information on net erosion/deposition as well as the maximum depth of scour. The rods were generally surveyed at each low tide throughout the experimental period. Finally, 5 survey transects spaced at 50 m intervals (ranging 100 m on each side of the instrument transect) were surveyed at frequent intervals from the top of the dunes to the limit of wading. These transects were occasionally extended several hundred meters offshore using an echo-sounder.

Results

Environmental Conditions

A plot of significant wave height and mean water level at the offshore wave recorder is shown in Figures 5 a&b. The period of measurement spans the 47 tidal cycles between October 2-26 (Julian Days 275-299), comprising a wide range of offshore wind and wave conditions. The interval was dominated by three moderately-high energy events occurring on October 2-3 (JD 275-276; no sediment transport data were collected during this event as recording did not commence until noon of October 3) and on October 6-8 (JD 279-281) which coincided with a large spring tide, the tidal range reaching 1.9 m (Figure 5b). During this latter event, the winds were southwesterly, reaching velocities up to 11 m/s, and maximum significant wave heights at the offshore wave recorder reached 1.15 m with peak spectral periods of ≈ 7.5 s. The final event occurred on October 22-24 (JD 295-296) during southerly winds blowing up to 13 m/s producing offshore waves peaking at 1.25 m with periods of ≈ 8 s.

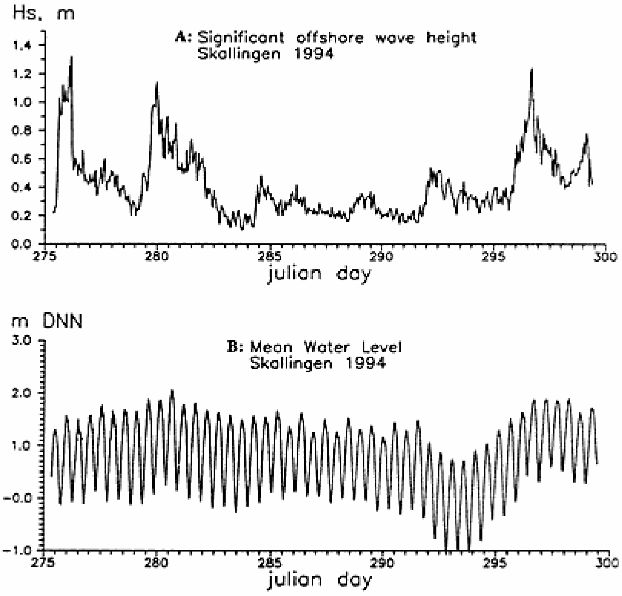

Figure 5a&b: Plots of (a) significant wave height, and (b) water level recorded by the wave gauge immediately seaward of the outer bar. Julian Day 275 corresponds to October 2. 47 tidal cycles are represented.

Sediment transport rates and morphological changes were also measured during periods of moderate wave activity on JD 276-277 (northwesterly winds) and on JD 291-293 (southeasterly winds). Finally, low energy conditions are represented by measurements taken on JD 285-286.

Breaker patterns were clearly tidally modulated, although during high energy events, waves typically spilled across the third bar and reformed in the trough, while the surf zone was almost saturated from the second bar to the shoreline. However, increased breaking intensity occurred at the step (around S-5), where the waves usually steepened significantly, followed by violent plunging. A result of this intense plunging was that sediment samples from the traps located at the shorebreak often contained significant numbers of pebbles (2-2.5 cm diameter), even to elevations of 0.70 m above the bed.

Sediment Transport in a Rip Channel

Immediately prior to the beginning of the measurement programme, a ≈ 100 m wide rip channel developed across the second bar along the instrument transect, with the main channel axis located approximately 20-30 m to the south (Figure 6).

North and south of the rip channel, the second bar was straight and two-dimensional with a 0.6-0.7 m high, relatively steep landward slope. In contrast, along the instrument transect the bar was low with a steep seaward face between S-1 and S-2 (see Figure 3). The subdued bar morphology along the transect was surprisingly stable throughout the experiment. The bar became progressively flattened by onshore as well as offshore sediment transport (Figure 7) and the trough landward of the second bar was infilled as sediment was transported onshore by incident waves and/or longshore by the currents associated with the rip cell circulation. This created an almost delta-like feature (see Figure 6)

The sand surface in the incipient rip channel was frequently covered by megaripples (Figure 8). On account of the orientation of the megaripple crests which were lunate to sinuous but roughly perpendicular to the beach, they were almost certainly maintained by mean currents.

During the high-energy events, both the velocity and sediment transport patterns in the surf zone were dominated by the rip current circulation. Figure 9a illustrates the vectors of the mean current velocity and the suspended sediment transport rates recorded on October 23 (JD296), 1600 h at high tide during the peak of the final high-energy event. Winds were from the SSW and the waves were oblique ly incident to the beach with an angle of $\approx 17^0$. Offshore, the significant wave height was 1.21 m and the tidal elevation was +1.88 m DNN. The waves were breaking mostly between instrument stations S-1 and S-2. Within the surf zone (S-3 through S-6), the mean currents were consistently directed against the direction of wave approach as the rip channel axis was located slightly south of the instruments. There was no evidence of any wind- or wave-induced longshore current. The mean current reached a maximum at S-3 with velocities of 0.34 m/s. During the subsequent falling tide, the rip circulation intensified due to the increased breaking intensity and/or drainage of the troughs as water depth over the bar decreased. The mean currents at S-3 reached a maximum of 0.56 m/s at 1930 h when the significant offshore wave height was 0.73 m and the tidal elevation +0.95 m DNN.

Sediment transport in the surf zone was also directed against the waves, i.e. offshore and to the south. Moreover, the net sediment transport vectors were more or less aligned with the mean current vectors, illustrating the dominance of the rip current in the net sediment transport pattern. Oscillatory sediment transport (due to wave motion) was of very limited importance in the surf zone at this time. The OBS's at S-6 seem to have been malfunctioning for at least part of this event and the records from these sensors were thus not used in the present paper. Seaward of the average breakpoint of the waves (i.e. at S-1), the cross-shore sediment transport was directed onshore (Figure 9a). Net sediment transport thus converged between S-1 and S-2, conceivably leading to sediment accumulation and bed accretion here. Further data analysis is required to ascertain whether this transport convergence was a common occurrence during the high-energy events;

Figure 6: *The rip channel at very low tide on JD 293, seen from the top of the tower holding the laser-doppler. Instrument stations and sensor cables are in the right-hand side of the picture; S-4 is at the extreme right while S-3 is discernible at the crest of the second bar. The main rip channel is at the extreme left (south), and a smaller marginal channel is located slightly north of the instruments.*

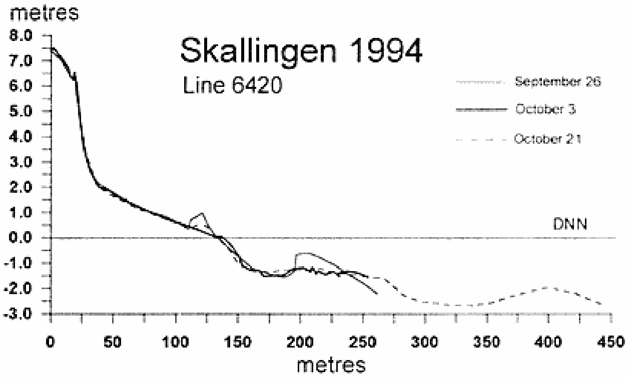

Figure 7: *Cross-shore profiles of Line 6420, surveyed on September 26 (prior to the experiment), October 3 and October 21, 1994.*

Figure 8: *Megaripples in the rip channel.*

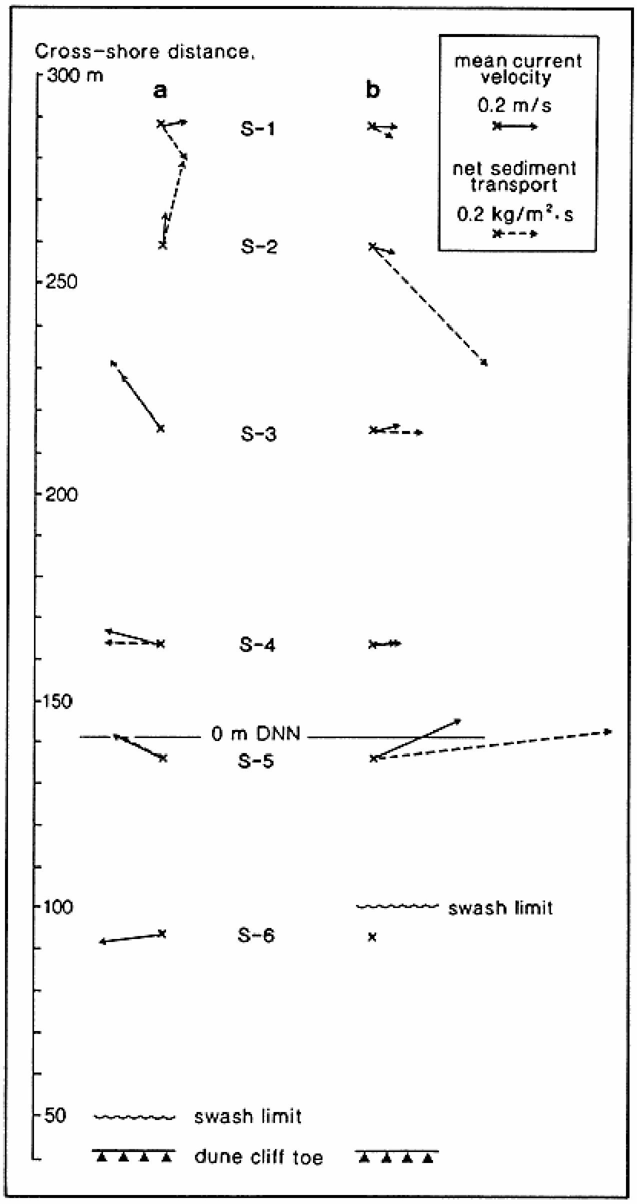

Figure 9: Plan view of mean current velocity and net sediment transport vectors at the six instrument stations. (a) October 23, 1600 h, (b) October 22, 1700 h, 1994.

if so, this would explain the steep seaward face of the second bar.

Figure 10(a&b) illustrates variance density spectra of velocity and concentration at this station, as well as the cospectrum of cross-shore velocity and sediment concentration at the level of the lowermost OBS (z = 0.05 m). The spectrum of cross-shore velocity indicates that the peak

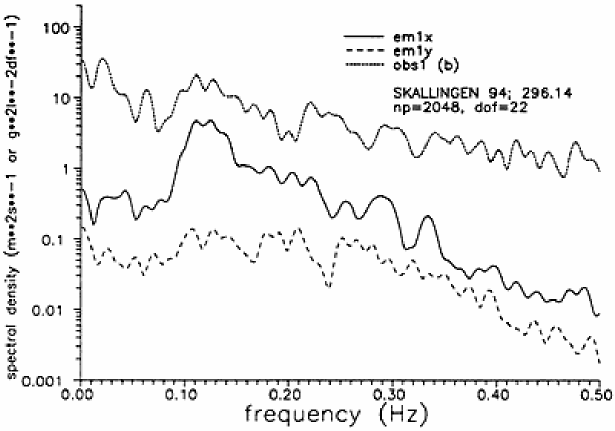

Figure 10a: Energy spectra of cross-shore (em1x) and longshore (em1y) oscillatory currents, as well as sediment concentration at nominally z=0.05 m (obs1(b)), recorded October 23, 1600 h.

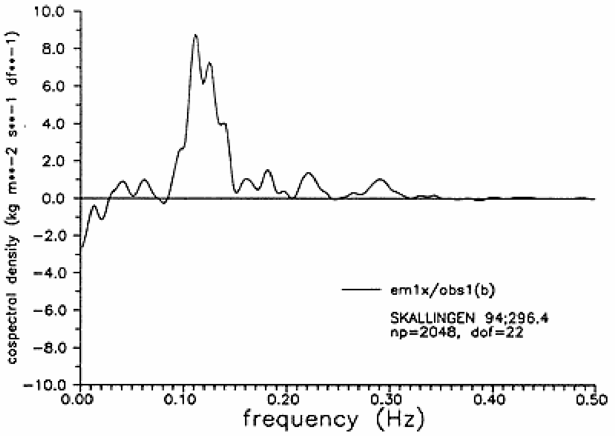

Figure 10b: Cospectrum of cross-shore velocity and sediment concentration at z=0.05 m recorded at S-1, October 23, 1600 h, 1994.

period of the incident waves was 0.12 Hz (8.3 s) and the cospectrum shows that these waves transported the sediment shoreward, whereas a small seaward directed sediment flux occurred at low frequencies. The net cross-shore oscillatory flux at S-1 was thus computed at +0.19 $kgm^{-2}s^{-1}$ (onshore), while the mean flux due to the rip circulation was -0.03 $kgm^{-2}s^{-1}$ (offshore) yielding a total net flux of +0.16 $kgm^{-2}s^{-1}$. The onshore directed sediment transport at S-1 was therefore due to the incident waves.

Figure 9b illustrates mean currents and net sediment transport rates during a time when waves were not breaking over the second bar (October 22, 1700; H_s = 0.28 m; tidal elevation = +1.27 m DNN). At this time, the rip current was essentially inactive and the net cross-shore sediment transport over the second bar was dominated by wave motions at stations S1-S3. This is also indicated by the large angular deviations between the mean currents and the net sediment transport vectors. The net transport across the second bar was directed onshore, being induced by the incident waves. The mean currents were directed towards the north and were probably caused by wind stress as the winds were southeasterly, blowing parallel to shore. At this time, the net sediment transport apparently converged around S-3 on the inner margin of the second bar. The large transport rates at S-5 were due to the fact that the main plunge point of the waves was located at this station. Sediment concentrations were in this case a factor three larger than the example shown in Figure 9a.

The stability of the bar was probably accomplished through a balance between the offshore (rip-induced) transport at times of relatively high wave energy, and onshore directed transport due to the incident waves during periods of low wave energy. This would also explain the consistently low relief of the bar. During a southwesterly gale on November 1 (after the site had been evacuated), with water levels reaching +2.75 m DNN off the Skallingen shoreline, the rip channel infilled and the second bar again became two-dimensional.

Swash Bar Dynamics

The most significant morphological changes during the study period other than the initial excavation of the rip channel were observed on the inshore swash bar. The bed elevation changes which occurred at this bar are plotted in Figure 11 illustrating the evolution of the bar through time. Initially, over the spring tide occurring on October 4-8 (JD277-281; tidal cycles 4-12), cycles of alternating erosion and accretion occurred. Comparing these cycles with significant offshore wave heights and tidal elevations (Figure 5) reveals that the morphological changes are to some extent associated with the diurnal inequality of the tide; during this period, the high tides occurring during the day were higher than nightly high tides. Periods of erosion were generally associated with high high tides and/or increasing energy, while periods of swash bar accretion generally occurred in connection with low high tides and/or decreasing wave energy. However, these relationships are

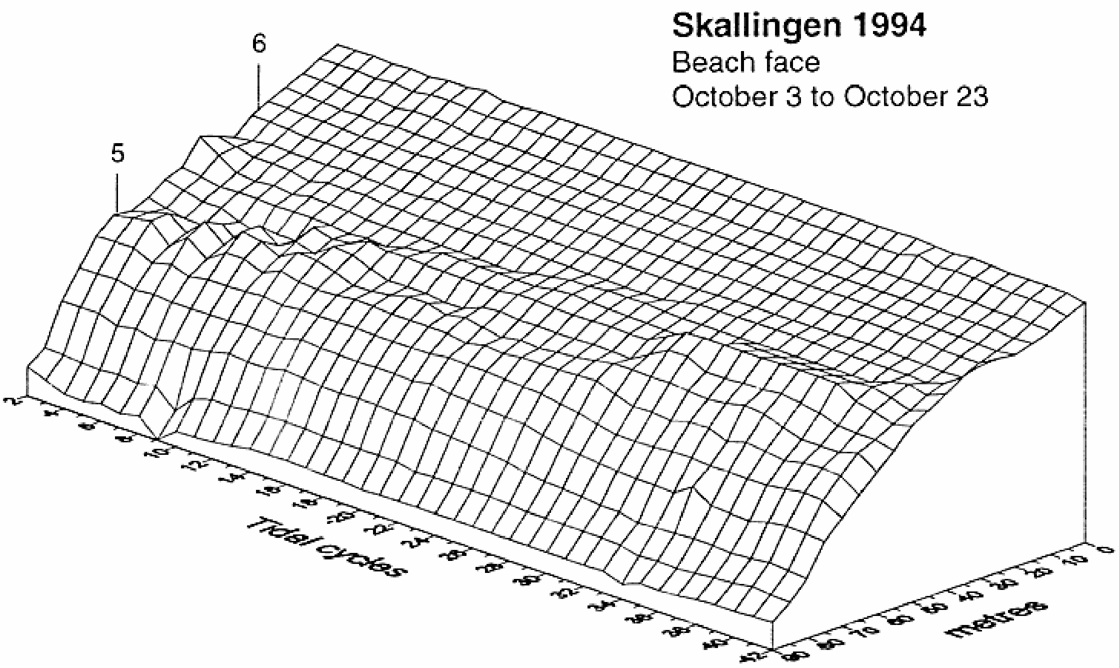

Figure 11: The evolution of the swash bar through time, as recorded by the DOD-rods. The x-axis is cross-shore distance measured from the innermost rod, the y-axis represents the number of the tidal cycle. Cycle no.2 is the morning tide on October 3 (JD276) while cycle no.42 is the evening tide of October 23 (JD296). Locations of instrument stations S-6 and S-5 are also given.

not straightforward and further analyses are needed to investigate the physical processes involved.

The swash bar accreted steadily on October 8-9 (JD281-282; tidal cycles 12-15, see Figure 11) and a double crest evolved. During the following neap tides with low wave energy, the bar was comparatively inactive. The inner bar crest did, however, migrate slightly onshore, particularly on October 12-13 (JD285-286; tidal cycles 20-22). At the same time, the diurnal inequality of the tide was significant with above-normal high tides during the night (Figure 5b). Water levels reached +1.67 m DNN on the morning of October 12; also at this time offshore wave heights increased somewhat (Figure 5). Following a period of slightly increased wave heights on October 16 (JD289; tidal cycles 27-28), the outer crest migrated significantly onshore while the inner crest disappeared; the profile then remained stable until the final high-energy event, when the bar again migrated landward, particularly during the waning of this event on the evening of October 23 (JD296; tidal cycle 42).

Figure 12 illustrates the results from the sediment traps over the period October 3-6 (JD 276-279). Because of the changing water level due to the tide, the results are given as trapping-rate per hour of submergence for each of the traps. There are generally two vertical profile shapes in Figure 12. Samples 1-3 trap more sediment at all elevations than samples 4 and 5. These differences partly reflect incident wave conditions. Significant offshore wave height was 0.4-0.6 m during samples 1-3, decreasing to 0.3-0.4 m during sample no.4, and further to 0.2-0.3 m during sample no.5. However, the profile patterns also reflect morphological changes since the lowermost trap collected increasing amounts during periods of swash bar accretion, and decreasing amounts during swash bar erosion.

Samples 4-5 show a near-exponential increase in the amount of trapped sediment from the 1.05 m level downwards. This may indicate that resuspension takes place up to this level above the beach face during low energy conditions. From the 1.05 m level and upwards the traps collect approximately the same amount, which may reflect the background suspended matter concentration. In contrast, during higher energy conditions (samples 1-3) the profile shapes are near-exponential all the way from the upper trap and down to the second lowermost trap. Under such conditions the two lowermost traps collect approximately the same amount of sediment. One possible explanation is that trap efficiency for the lowermost traps drops significantly, when the traps become nearly filled with sediment during higher energy conditions. In support of such an explanation is the fact that an extrapolation of the near-logarithmic trend in figure 12 down to the level of the lowermost trap yields hourly averaged trapping rates corresponding to suspended sediment concentrations of 2-2.5 g/l for this level. Such concentrations are very similar to concentration measurements from the nearby station S-5, which showed that at z=0.20 m, the mean concentrations varied between 2-4 g/l.

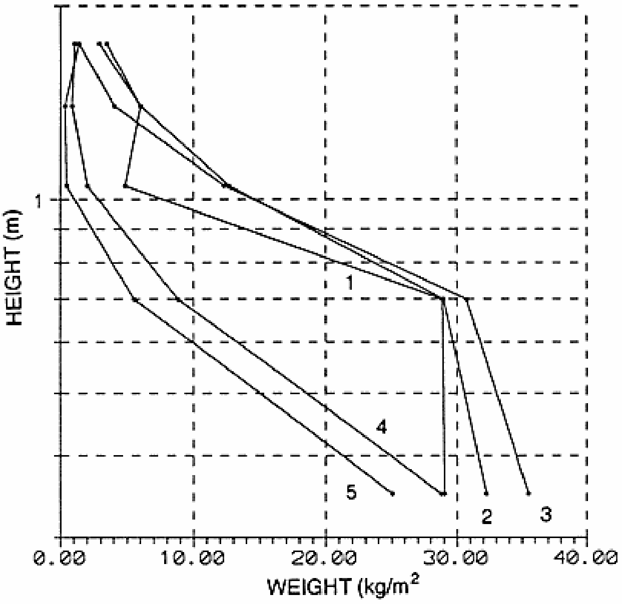

Figure 12: Hourly average trapping rates as a function of logarithmic elevation above the bed. Numbers correspond to sample number. Referring to Figures 5b and 11, the samples were taken over the period JD 276-279 with sample nos. 1-4 corresponding to tidal cycle nos. 4-7 on the graph while sample no.5 corresponds to cycle no.9.

As the trapped sediment was coarse grained with average settling velocities of 0.03-0.07 m/s, the majority of the sediment must have been derived from local resuspension. The lower traps often contained up to 0.25 m of sediment, which approximately corresponds to the net amount of vertical accretion of the beach face at times when this was building upwards (Figure 11). Additionally, the traps 0.70 m above the bottom collected as much as 225-240 kg/m^2 during individual tidal cycles. Such observations suggest a dominance of suspended load in this high energy environment.

The laser doppler system was not in operation during these first 5 trap system recordings. Results from October

19 (JD292) with similar wave conditions (Figure 5a) gave swash transport velocities up to 0.75 m/s for individual grains and backwash velocities up to 0.45 m/s. Using the ratio between individual grain RMS velocity and mean velocity over 5 minute intervals as a measure of turbulence it could be shown that turbulence was 107-986% higher than the mean velocity. Such observations indicate that sediment activity is high in this high energy zone. They may also indicate a larger suspended sediment transport rate in the swash than in the backwash which is in accordance with observations reported by Horn & Mason (1994).

The net effect of the wave and tidal conditions during the experiment was a consistent accretion of the beach face/ foreshore. No periods of significant erosion occurred, whereas this was the case immediately prior to and after the experiment. The experimental results suggest that there is a lower threshold of incident wave activity and/or tidal elevation necessary for swash bar accretion. The thresholds for sustained swash bar erosion, however, were not encountered during the 1994 field experiment. There were also indications that when the swash bar reached a higher elevation on the beach, it was less prone to erosion.

The high-energy events occurring on October 6-7 and 22-23 were virtually identical in terms of incident wave energy. During the former event, the swash bar was subjected to cycles of erosion and accretion, whereas the latter event resulted in significant accretion (Figure 11). However, during the latter event the bar was located at a higher elevation and high tide elevations were lower (Figure 5b). The bar was thus located in the swash zone for longer periods of time. During the former event, the swash bar occupied a position in the surf zone and was thus being subjected to the effects of the offshore directed mean currents for longer periods of time.

Discussion and Conclusions

The environmental conditions encountered in the course of this experiment were somewhat untypical. First, no major storms occurred and secondly a rip current channel developed along the instrument transect. A rip current significantly complicates the interpretation of sediment transport patterns. On the other hand, offshore sediment transport in rips is undoubtedly of considerable importance to the overall sediment budget of the nearshore, particularly at Skallingen where they appear frequently. To the authors' knowledge, quantitative measurements of sediment transport in rip currents have not yet been reported in the literature. This is probably due to the fact that rips are often ephemeral features, occupying the same position for only relatively short periods of time. Their width is small relative to the total length of a given stretch of shoreline (in this case, the rip was ≈ 100 m wide and the spacing between rips was approximately 900 m). Finally, active rips are not easy to instrument. The present data set thus has considerable potential value for our understanding of the role of rips in sediment exchanges in the nearshore zone.

The morphological response to the conditions occurring during the experimental period was an accretion of the foreshore. This evolution was related to an erosional event occurring on September 27 immediately prior to instrument deployment, when the second bar as well as the swash bar, which was very prominent at this time, were eroded and the sediment transported offshore. Wave and tidal conditions occurring over the experimental period partly restored the swash bar through surf and swash/backwash processes, i.e. onshore sediment transport accomplished by the run-up due to incident waves. The results from the sediment traps suggest that the majority of the sediment transport occurred in suspension. There was no evidence of a new swash bar forming in the inner surf zone once the old bar had welded to the beach.

In the nearshore, only relatively small topographic changes occurred. The trough between the second bar and the beach was infilled and the seaward slope of this bar accreted somewhat. Surprisingly, the bar crest neither scoured as a result of continuing rip current activity, nor accreted as a result of wave-induced landward transport. This was probably a result of a near-balance between offshore sediment transport due to the rip current during high-energy conditions and onshore transport due to incident waves during low-moderate energy conditions and/or diverging transport directions over a tidal cycle. However, the relief between the bar crest and the trough was progressively lowered as the trough became infilled, probably from longshore sources as a result of the rip cell circulation.

Discussion of the obtained results in a global context would be premature at this stage of data analysis. However, Greenwood & Davidson-Arnott (1979) and Greenwood (1986) also reported cases with virtually no net longshore bar movement, under conditions with significant cross-shore sediment transport. Using box-cores from a rip-channel setting, Greenwood & Davidson-Arnott (1979)

found seaward-dipping units of megaripple cross-stratification indicating offshore sediment transport by rip currents, interbedded with landward dipping cross-stratification due to onshore directed incident wave transport.

The field campaign scheduled for 1995 will occupy the same site. The field season will, however, be extended in time as long as necessary in order to record a significant erosional event. The 1996-experiment will occupy a site further north at Skallingen, where an overwash fan has developed. The purpose of this final experiment will be to document the processes responsible for onshore sediment transport during overwash at this site (Nielsen, 1991; Aagaard et al., in prep.). This is required in order to investigate the mechanics of onshore barrier migration. A further goal of these experiments will be to study aeolian sediment transport leading to sediment storage at the landward boundary of the active profile through dune accretion.

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