Marine Geology 193 (2003) 171–176

MARINE GEOLOGY
INTERNATIONAL JOURNAL OF MARINE GEOLOGY, GEOCHEMISTRY AND GEOPHYSICS

www.elsevier.com/locate/margeo

Letter section

A note on megaripples in the surf zone: evidence for their relation to steady flow dunes

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Received 26 July 2002; accepted 22 November 2002

Abstract

Megaripples in the combined flow environment of the nearshore are proposed to behave like dunes or large ripples in rivers, tidal estuaries, and deserts. Their profile basically is symmetric and thus significantly different from the traditional asymmetric triangular features observed in steady flows. Similarly their planform often exhibits little directionality, unlike crescentic or lunate steady flow dunes that point in the downstream direction. These characteristics are the result of complex combined flows in the nearshore, including oscillatory flows, wave skewness, and steady currents (undertow, rips and alongshore flows). Recent observations of megaripples in the nearshore suggest that they occur frequently. However, they are rarely considered in studies of flow resistance or sediment transport. In addition, megaripples are thought to be the source of hummocky cross-stratification in sedimentary sequences and are generally attributed to storm waves on inner continental shelves. However, observations show that they also exist inside the surf zone and under lower-energy conditions. A better understanding of their dynamics and thus their occurrence and characteristics would improve the understanding of nearshore wave and circulation dynamics, sediment transport, large-scale morphodynamics, and the resulting sedimentary sequences. It is hypothesized that megaripples in the nearshore are dynamically similar to steady flow features, which are observed in rivers, estuaries and deserts and have been studied in much more detail.

Keywords: megaripples; nearshore; bedforms; surf zone; combined flow; dunes

1. Introduction

Megaripples in the nearshore are bedforms with wavelengths of 1–5 m and heights of about 10–50 cm. They are often short-crested (short in the direction parallel to the crest, 0.5–2 m), irregular, and often look like oval-shaped holes (Swift et al., 1983). They are sometimes observed to be slightly lunate in shape (Hay and Wilson, 1994; Clifton et al., 1971). Megaripples are known to exist in the nearshore, but little is known about how they are formed. Hummocky cross-stratification is usually attributed to megaripples on the continental shelf formed during storm wave events. Swift et al. (1983) observed both megaripples and hummocky cross-stratification in continental shelf sediments. They concluded that the oscillatory current was

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0025-3227/02/$ – see front matter
doi:10.1016/S0025-3227(02)00662-X

subordinate to mean flow in megaripple formation. Greenwood and Sherman (1986) found hummocky cross-stratification in a storm wave-dominated surf zone where the oscillatory currents dominated the steady flows. Allen (1985) and Nottvedt and Kreisa (1987) argued that both steady currents and waves are important for megaripple formation on the continental shelf. This is in agreement with the observations of Gallagher et al. (1998), who found that the instantaneous combined flow determined the migration direction of the megaripples in the surf zone. It was found that bedforms migrated in the direction of the gross transport normal to the bedform crest, following the theory of Rubin and Hunter (1987), which was developed for subaerial dunes. These studies suggested that all components of a flow field contribute to bedform dynamics. In this paper, observations of morphology of megaripples in the nearshore are used to relate them to dunes in steady flow environments and it is hypothesized that they are basically similar features. However, it is illustrated that the complex flow environment in the nearshore alters their morphology.

2. Observations

During the SandyDuck nearshore field experiment an array of downward looking sonar altimeters (Gallagher et al., 1996) was mounted on the CRAB (the Army Corps of Engineers' amphibious surveying vehicle, see http://www.frf.usace.army.mil). The wheels of the CRAB are approximately 8 m apart and thus the vehicle cannot resolve megaripples. However, by placing an array of sonars on the vehicle (and compensating for the motion of the vehicle with pitch, roll and yaw measurements) smaller-scale bedforms were measured. Approximately daily surveys of the bed from the shoreline to 5 m water depth (spanning the surf zone and the wave-shoaling region) were done for about 4 weeks in September–October 1997 (Gallagher et al., 2003). A profile across a field of megaripples in 4 m water depth is shown in Fig. 1a.

During the Duck94 nearshore field experiment, a small (1.5×1.5 m) array of similar sonars was mounted on a stationary frame in about 2 m water depth, inside the surf zone. This array was used to measure the migration of megaripples for 3 months (Gallagher et al., 1998). A time series of bedforms migrating beneath the array is shown in Fig. 1c. The locations of the observations in Fig. 1a,c on the large-scale, cross-shore profile are shown in Fig. 1b,d, respectively.

During both experiments, the waves and currents were measured using cross-shore arrays of stationary bi-directional electromagnetic current meters and pressure sensors. The measurements of bedforms from the CRAB during SandyDuck were generally about 15 m away from the frame-mounted flow sensors. The Duck94 measurements of bedforms using stationary sonars were within

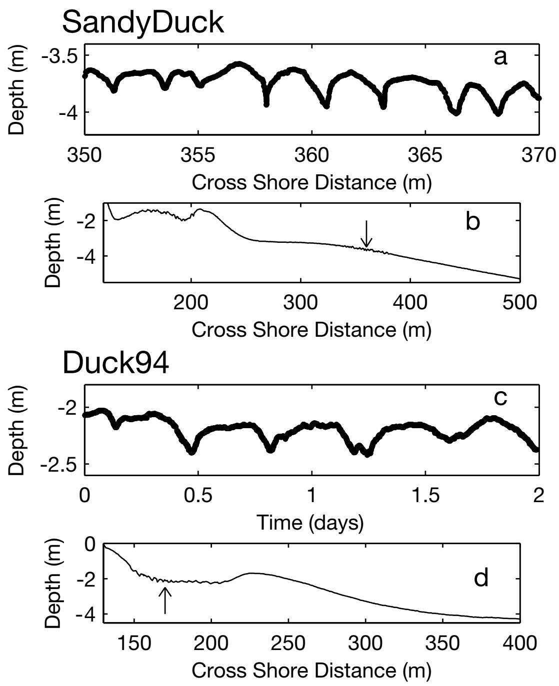

Fig. 1. (a) Profile across a field of megaripples from one of the sonar altimeters mounted on the CRAB during the SandyDuck nearshore field experiment. (b) Beach profile from the shoreline (at $x = 120$ m) to 5 m water depth. The arrow shows the location of the megaripples in panel a. (c) Time series of megaripples migrating beneath a stationary sonar altimeter during the Duck94 nearshore field experiment. (d) Beach profile from the shoreline (at $x = 120$ m) to 4 m water depth. The arrow shows the location of the stationary array and the megaripples in panel c.

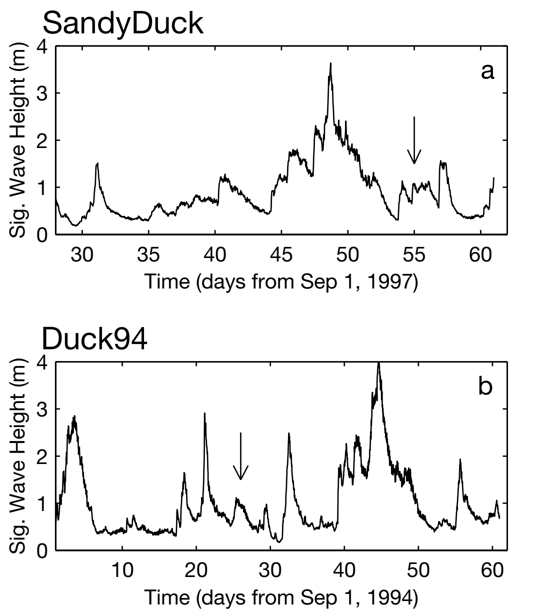

Fig. 2. Significant wave height versus time measured in 8 m water depth during the (a) SandyDuck and (b) Duck94 nearshore field experiments. The arrows show the times when the observations in Fig. 1 were made.

1 m of the flow measurements (instruments were mounted on the same frames). The offshore wave conditions for the two experiments are shown in Fig. 2 and the arrows indicate when the observations shown in Fig. 1a,c were made. During both experiments wave heights ranged from less than 0.5 m to 3–4 m and wave-dominated and combined flow conditions were experienced.

Figs. 1a (the spatial profile) and c (the time series) show similarly shaped features, with broad flat crests and narrow steep troughs. The bedforms shown in Fig. 1a have wavelengths (distance from one trough to the next) of about 2 m. The typical migration rate of the bedforms during Duck94 was found to be about 30 cm/h (with some speeds up to 150 cm/h, Gallagher et al., 1998), thus giving wavelengths of about 2–5 m for the features shown in Fig. 1c. The height of the ripples in both examples is about 20–30 cm.

The crest lengths (distance along a given crest) or spans of megaripples are observed to be quite short. Using cross-correlation between closely spaced sensors for both the spatial and temporal measurements, the correlation coefficient usually drops below 0.4 for lags between 0.5 and 2 m (not shown). Examples of the spatial (CRAB) measurements were interpolated and mapped, illustrating the plan view morphology and the crest lengths (Fig. 3). The area from which the profile in Fig. 1a is taken (4 m water depth and offshore of the outer bar, Fig. 1b) is shown in Fig. 3a and these bedforms are relatively long-crested. For example, in Fig. 3a at $x = 365$ m, a bedform spans the figure and is at least 4 m long. Features that are shorter-crested, with spans of about 1–1.5 m, are shown in Fig. 3b, for example at $x = 182$ m, $y = 1281$ m. The features in Fig. 3b are from the cross-shore transect shown in Fig. 1b, but they are in shallower water, about 2 m water depth, inside the surf zone ($x = 175$–195 m in Fig. 1b). Frequent diver observations confirm that, in plan view, megaripples inside the surf zone often look like oval-shaped holes with steep slopes, close to the angle of repose, which are separated by long, flat expanses, O(1–5 m). Sometimes the oval holes are crescentic (Hay and Wilson, 1994; Clifton et al., 1971). These examples illustrate some of the different large bedform plan views that were observed with the CRAB altimeter array.

3. Comparison with steady flow observations

In steady flows, dunes or large asymmetric ripples have a triangular cross-section (Fig. 4a), where the upstream face is long, with a low slope, and the downstream face is short and steep (Allen, 1968). Sediment is transported as bedload along the upstream face until it reaches the crest, where it tumbles down the slip face. In addition, there is usually flow separation over the crest causing turbulent eddies in the lee of the bedform, suspension of sediment and complex flow patterns in the trough. With slow steady transport of sediment up and over the crest of the bedform, migration in the downstream direction takes place (Engelund and Fredsoe, 1982; Middleton and Southard, 1984).

It is hypothesized that megaripples in the surf zone have a similar dynamic to dunes or the lunate large-scale ripples observed by Allen (1968)

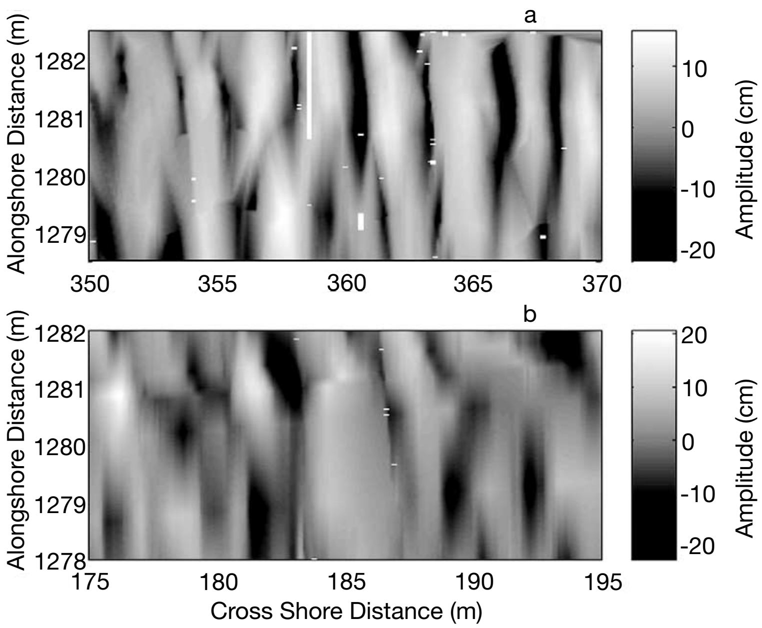

Fig. 3. Plan view of megaripples measured with an array of sonar altimeters mounted on the CRAB during the SandyDuck nearshore field experiment. Shading represents amplitude of bedforms in cm relative to local (within 20 m) mean bed elevation. (a) Example of relatively long-crested megaripples in ∼4 m water depth (at arrow in Fig. 1b). (b) Example of short-crested megaripples in ∼2 m water depth (at $x = 175$–195 m in Fig. 1b), measured about 3.5 min after the megaripples shown in panel a.

in steady flow or quasi-steady flow environments, like rivers, deserts and tidally driven estuaries. However, because the flows in the nearshore include oscillatory flows owing to waves as well as different types of steady flows (often not aligned with the waves), the morphology described for steady flow is altered. In addition, the wave-driven oscillatory velocities are not symmetric. Waves in shallow water are skewed resulting in stronger velocities in the onshore direction and weaker velocities in the offshore direction (e.g. Elgar et al., 1988). Skewed wave velocities and steady currents are both responsible for net sediment transport in the nearshore, thus migrating large-scale bedforms are generated. However, their shapes are altered from that of their steady-flow counterparts by the combined wave and current conditions. Fig. 4b illustrates this altered profile for the bedforms observed in the nearshore (Fig. 1).

During the onshore surge of a wave, sediment is moved along the broad flat crest until it comes to the slip face and tumbles down into the trough. There is flow separation at the bedform crest, which suspends sediment and generates turbulence. Moments later, during the offshore surge of the wave, sediment is transported in the opposite direction. Because, over the course of the wave cycle, sediment is moved in both directions, a steep slip face evolves on both ends of the bedform. When the waves are skewed or there is a

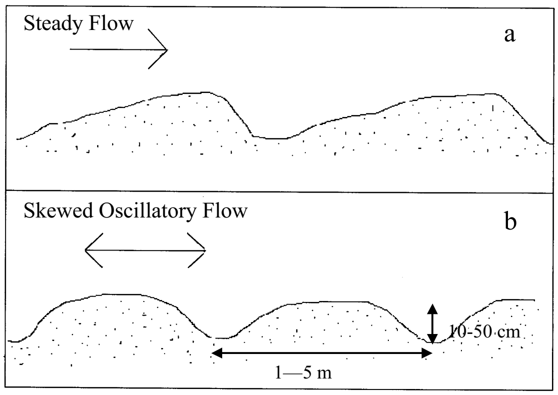

Fig. 4. Illustration of large-scale ripple profile in (a) steady flow and (b) oscillatory flow.

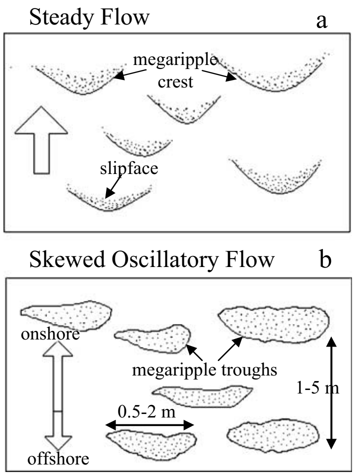

Fig. 5. Illustration of plan view of large-scale lunate bedforms in (a) steady flow and (b) skewed oscillatory flow.

superimposed steady flow, the magnitude of the transport in one direction will be dominant, and the bedform will migrate in that direction. However, the flow in the subordinate direction is sufficient to alter the shape of the features. Thus the megaripples in the nearshore have a broad flat crest, which is the equivalent of the gentle upstream slope of a steady flow dune and they have steep slopes on both ends of the feature, the equivalent of the lee slip face, which is smoothed and rounded.

In planform, the lunate shape observed in steady flow is also altered by the oscillatory flows in the nearshore. Instead of a curved shape that points in the downstream direction (Fig. 5a), the back and forth motion of the wave-driven flow smoothes out the pointed lunate shape and leaves an oval-shaped trough (Figs. 5b and 3b). If the steady flow or wave asymmetry is large compared with the oscillatory flow the oval-shaped hole can have a slight curve with ends pointing in the direction of dominant transport (Hay and Wilson, 1994; Clifton et al., 1971). However, the definitive lunate shape (e.g. Allen, 1968, Fig. 5a) seen in steady flows often is not seen in the nearshore.

4. Conclusion

Megaripples in the nearshore are hypothesized to be similar to dunes or large ripples in steady flow environments. Their profile and planform are significantly different from the traditional morphologies observed in open channels and in deserts. This is owing to the complex combined flows (including skewed waves and steady currents) in the surf zone, which alter the asymmetric, steady flow features and make them smoother and more symmetric in both plan view and in profile. Observations have been made of megaripples in the nearshore, which suggest that they occur frequently. However, they are rarely considered in studies of flow resistance or sediment transport. A better understanding of their dynamics and therefore their occurrence and their characteristics would improve the understanding of circulation dynamics, sediment transport, and large-scale morphodynamics. These features are recognized as hummocky cross-stratification in sedimentary deposits and generally attributed to storm waves on continental shelves. Observations suggest that they also are common under lower-energy conditions inside the surf zone where skewed wave and steady currents both contribute to the generation of these migrating features.

Acknowledgements

This research was funded by the Office of Naval Research Coastal Dynamics program (Award N00014-00WR20257) and the National Science Foundation Marine Geology and Geophysics program (Award OCE-9811207). These observations would not have been possible without the expertise and dedication of the staff at the Center for Coastal Studies Scripps Institution of Oceanography, the staff at the Army Corps of Engineers Field Research Facility, and the staff at the Naval Postgraduate School.

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