

Video-observations of shoreward propagating accretionary waves

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ABSTRACT: A 10 year database of daily time-exposure images of the nearshore zone, collected by an Argus video system installed at Duck, NC, revealed a new phenomenon in the evolution of nearshore topography. Under some conditions, a nearshore sand bar can shed a small bar-like feature from its shoreward facing side. This pinched off daughter bar subsequently transits the trough as an intact feature and merges with the beach. The average onshore propagation rate of the feature is about 3 m/day and, with an average size of about 130 m by 30 m and a height comparable to that of the inner bar, it represents a locally significant onshore sediment flux.

1 INTRODUCTION

Currently we are only partly aware of the range of morphologic behavior that can occur in the nearshore zone. Waves and currents have ample capacity to move sediment around in the nearshore zone. The nonlinearities in both the sediment transport processes and the surf zone hydrodynamics carry with them a large potential for generating unexpected gradients in sediment transport across the nearshore topography, hence producing unexpected bathymetric change. Documenting the natural range of morphologic behavior in the nearshore zone is therefore indispensable to focus our thinking about nearshore morphodynamics.

The present perception of breaker bar evolution is that bars generally reshape into linear forms in association with storm events. Under subsequent lower energy conditions, these bars are usually observed to move shoreward and to develop three-dimensionality that may be rhythmic or irregular and complex (Lippmann & Holman 1990). It has been commonly assumed that the response of a bar to changing wave conditions occurs as an intact, albeit evolving, sand bar form.

A large database of routinely collected time-exposure video images of the nearshore zone near Duck (North Carolina, USA) revealed that this is not always the case. Under some conditions, a sand bar can shed a small bar-like feature from its shoreward facing side. This pinched off daughter bar subsequently transits the trough as an intact feature and merges with the beach (Fig. 1). Tentatively, we have named this phenomenon a Shoreward Propagating Accretionary Wave or, abbreviated, a SPAW. The

term 'wave' was chosen to reflect the similarities between the observed phenomenon and a solitary wave in fluid dynamics. That is, both phenomena are single, isolated perturbations that maintain their shape as they propagate. In both cases, the latter involves a net displacement of material in the direction of propagation.

In this paper we will present a first documentation of this newly observed phenomenon and discuss its relevance for understanding the nearshore morphodynamic system.

2 DUCK FIELD SITE AND DATA BASE

The Duck study area is near the CERC Field Research Facility (FRF), which is located at about the middle of Currituck Spit, a 100 km long unbroken stretch of shoreline facing the Atlantic Ocean. The beach is generally fronted by one or two nearshore bars, with variable planforms through time (Lippmann & Holman 1989). The sediment is in the medium sand range with a mixture of coarser material on the beach (Larson & Kraus 1992). The mean annual wave height and period are about 1 meter and 8 second; the spring tide range is about 1.5 meter (Leffler et al. 1992).

The video camera that collected the images from the beach is mounted on a 43 m-high tower at the dune crest near the FRF-pier. The area of interest in the field of view of the camera extends about 800 m alongshore. In the cross-shore direction the study area extended from the inner nearshore bar to the shoreline. The analyzed period spans from October 7, 1986 until December 1996. During this period one

major data gap exists in the image time series, which extends from August 10, 1992, to January 28, 1993.

3 METHODOLOGY

SPAW events are identified by scanning long time series of time-exposure images by eye. The presence of an isolated, but coherent patch of foam in between a nearshore bar and the shoreline indicates the presence of a submerged mound of sand, the SPAW.

Having recognized a SPAW feature, the dates of starting and ending of the event are determined to obtain statistics on the duration of a SPAW event.

The starting date of a SPAW is defined as the first day on which separation of the SPAW from the parent bar becomes apparent. The exact starting date may be obscured because of high wave conditions, which usually occur in conjunction with SPAW initiation. The residual foam that is generally present during those conditions may merge with the foam due to bathymetry-related wave breaking such that

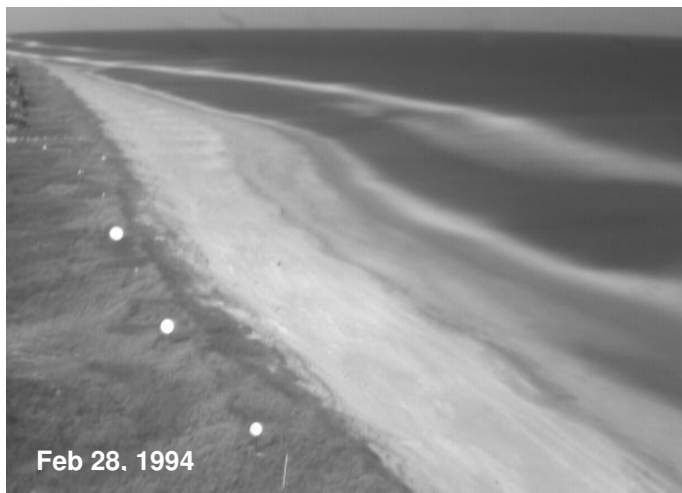
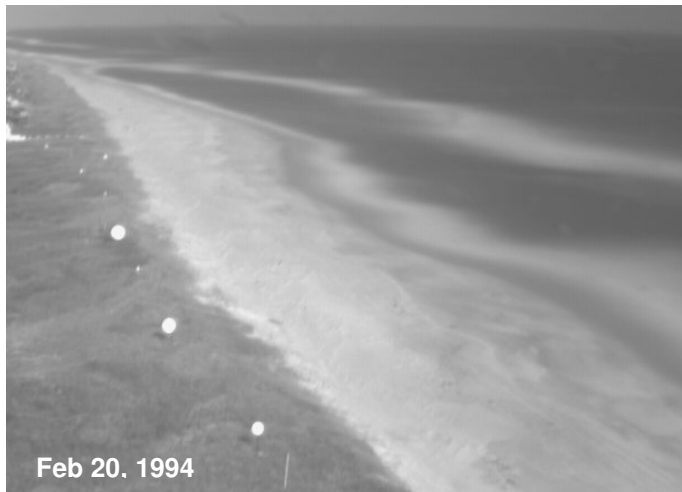


Figure 1: Sequence of time exposure images near Duck illustrating a SPAW event

the bathymetric separation of the SPAW from the parent bar may not be visible from the earliest moment.

The ending date of a SPAW event is defined as the date on which no noticeable traces are left of its occurrence. Because the disappearance of the shoreline protrusion is generally gradual in nature, some arbitrariness exists in the choice of the ending date.

To account for the potential arbitrariness in the quantification of SPAW duration, three operators independently viewed the same time series of images to detect SPAWs and identify their starting and ending dates. Subsequently, the image time series was re-examined to reconcile the differences in interpretation of the individual operators. Dubious cases were omitted for the final statistics. Inter-operator variability will be presented in the results section.

In addition to assessing the frequency of occurrence and the duration of a SPAW event, we obtained several morphometric measures. These are: (1) the cross-shore position of the SPAW at initiation (which, divided by SPAW duration, provides an estimate of the propagation speed) and (2) the size of the SPAW as defined by the width and length of the foam patch, which is actually a proxy measure for the actual size of the submerged mound)

The surf zone time-exposure images discussed in this paper are obtained by land-based cameras. The oblique images of the beach produced by these cameras can be transformed into plan view images by standard photogrammetric relationships (Holland et al., 1997). These rectified images can be used to take undistorted measurements of the above indicated morphometric properties.

The cross-shore position (D) of the SPAW is measured from the time-exposure image by determining the distance between the crest of maximum intensity on the SPAW, as a proxy for the SPAW crest position, and the maximum intensity at the shoreline (Fig. 2). The length (L) and width (W) of a SPAW just after its initiation are determined from a

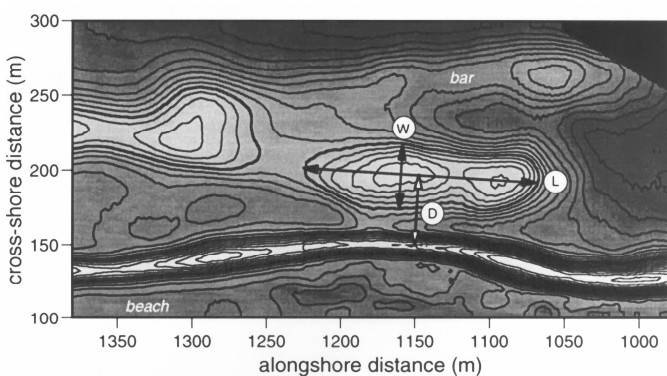


Figure 2: Definition sketch of morphometric measurements based on contoured time-exposure image (contours based on pixel intensity). W=SPAW width, L = SPAW length, D=SPAW initiation distance

contour plot of the intensities on the time-exposure image (Fig. 2). After densely contouring the time-exposure image a single contour is picked to represent the SPAW. Either the outermost closed contour around the SPAW feature is picked or, in case of a less strongly developed separation from the parent bar, the outermost contour showing contractions around the SPAW feature is picked. The area where the contour contracts indicates the location where the daughter bar is separating from the parent bar.

It should be noted that the SPAW length scales as determined from the time exposure images are proxy measures, because only the shallower part of the SPAW where wave breaking occurs is visible on the image. In addition, image intensity of itself is not an exact measure for depth, so the equal intensity contour used to represent the circumference of a SPAW does not necessarily relate to a single depth contour around the SPAW. Nevertheless, using the same type of measure for all SPAWs gives us some handle on the average size of the phenomenon as well as its variability.

4 RESULTS

4.1 Frequency and duration of SPAW events

Near Duck, one can observe on average about two SPAW occurrences per year (19 events in 9.75 years covered by video-imagery, along 800 m of beach). However, the inter-annual variability is large (Fig. 3). The same holds for the duration of a SPAW event; on average it takes 17 days for a SPAW to transit the trough, merge with the beach, and be re-distributed alongshore such that no noticeable traces are left of its occurrence. Some SPAWs, however, only need just over a week to complete this sequence, whereas one needed up to 7 weeks (Fig. 4); the standard deviation in SPAW duration was found to be 9 days.

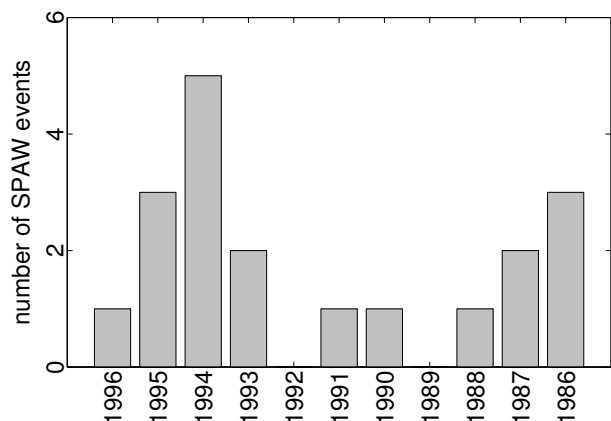


Figure 3: Number of SPAW events per year, as observed along 800m of beach. Note that the value for 1986 is based on only 3 months of observations, and 1992 on only 7 months.

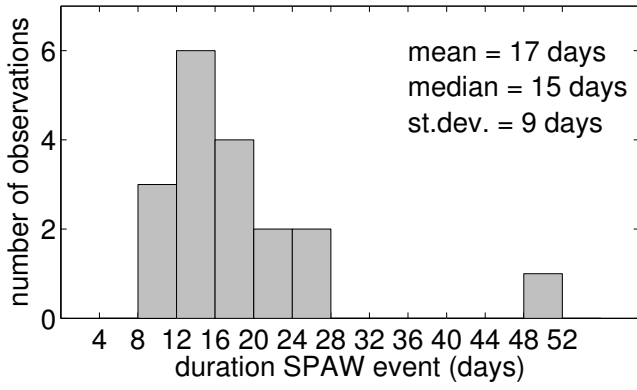


Figure 4: Histogram of observed durations of SPAW events (note $N_{total}=18$, because for one SPAW event a 20 day data gap prevented observation of its evolution.)

Table 1: Inter-operator variability in SPAW identification.

Number of operators n identifying the same SPAW event	Number of SPAW events identified by n operators	
	Original data set	Final, reconciled data set
1	14	5
2	4	3
3	11	11
≥ 1	29	19

The inter-operator variability in the identification of the SPAW events is presented in Table 1. Of the original 29 cases, 10 were omitted because we were not sufficiently confident that the features welding to the beach did truly separate from the parent bar. Of these 10 cases, 9 were identified by only one operator.

The estimates of the duration of individual SPAW events varied among the different operators. The magnitude of the inter-operator differences appeared to be proportional to the duration of the event. So, in terms of the number of days, the individual duration estimates for longer duration events tended to be wider apart than for shorter duration events. On average, the operator deviations from the final data set equaled 20% of the magnitude of the values used in that final, reconciled data set. Some of the larger deviations originated from differences in the interpretations of the start of an event. In three cases a bifurcation developed but it did not separate from the main bar for some time (1 to 2 weeks). Some interpreted the moment of initial bifurcation while others identified the day of separation as the start of the SPAW (the latter was used for the final data set). Further, on three occasions SPAW events occurring closely in time were interpreted as one single event by some of the operators. These interpretations were based on the oblique image time series. Rectified images of these cases helped to solve this ambiguity.

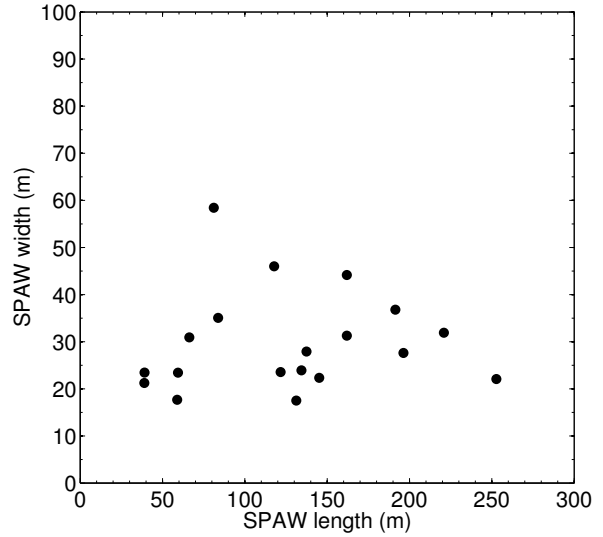


Figure 5: Plan shape geometry of SPAWs.

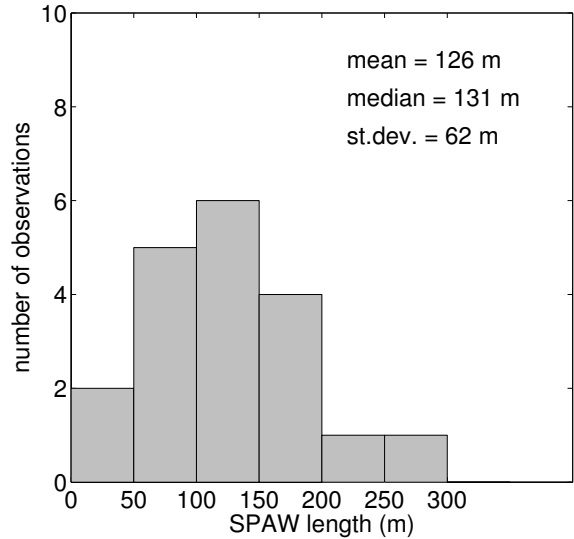


Figure 6: Histogram of observed SPAW lengths.

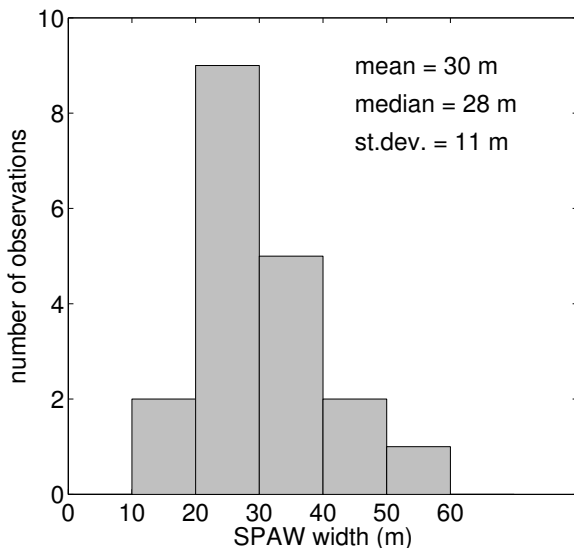


Figure 7: Histogram of observed SPAW widths.

4.2 SPAW size and shape

Generally, SPAWs are elongated features (Fig. 5). The length of the SPAWs, as determined from the white patches that disclose the subaqueous presence of SPAWs, varied between about 40 m and 255 m. The average length scale for SPAWs was found to be 126 m with a standard deviation of 60 m (Fig. 6). The width of these same patches varied between 18 m and 58 m, having an average of 30 m with a standard deviation of 10 m (Fig. 7). A measure for the vertical scale of a SPAW, such as the elevation difference between the crest of the SPAW and the trough landward of it, is hard to obtain from the video time-exposures. However, just after its initiation a SPAW will probably have a vertical scale comparable to that of the parent bar. The SPAW pinches off from the parent bar, so the trough level with which to compare the crest elevation is comparable for the SPAW and the parent bar. In addition, the crest elevation of the SPAW will be close to that of the parent bar, otherwise no waves would be seen breaking over the SPAW.

A bathymetric survey conducted during the Duck'94 experiment fortuitously captured a SPAW (Figs. 8, 9), which indeed shows that the vertical scale of the SPAW and parent bar are similar (Fig. 10). Figure 8 further shows that in the background of the surveyed SPAW a second SPAW event is occurring simultaneously (but was not covered by the bathymetric survey). In the considered case, the SPAW crest-trough elevation difference is about 0.7 m. No bathymetric data were available to determine the amplitude evolution of the SPAW feature as it propagated onshore.

4.3 SPAW propagation and beach accretion

Estimates of average onshore propagation speeds can be determined by taking the ratio of the distance to the shoreline at initiation and the duration of each individual SPAW event. On average, SPAWs are initiated at 50 m from the shoreline, but distances half and twice as large have been observed too (Fig. 11). Propagation speeds appeared to vary between 1.7 m/day and 4.8 m/day (Fig. 12). Averaged over all SPAW events, a mean onshore propagation speed of 3.1 m/day was found with a standard deviation of 0.8 m/day.

The onshore sediment flux related to the SPAW propagation can be estimated from the above numbers to amount to about 1 to 2 m³/m/day (assuming an approximate SPAW height of 0.5 m). This amount is a significant contribution to the daily cross-shore sediment flux in the inner nearshore zone. For comparison, net daily sediment fluxes to the beach, determined from densely sampled DGPS surveys of the beach elevation, are of the same order of magnitude (Fig. 13). The fluxes shown in Figure

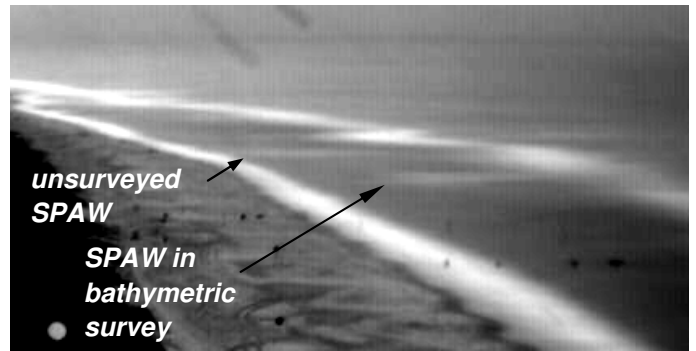


Figure 8: Time exposure image of Duck beach, 6 Sep. 1994, showing the SPAW captured in the bathymetric survey shown in Figure 9.

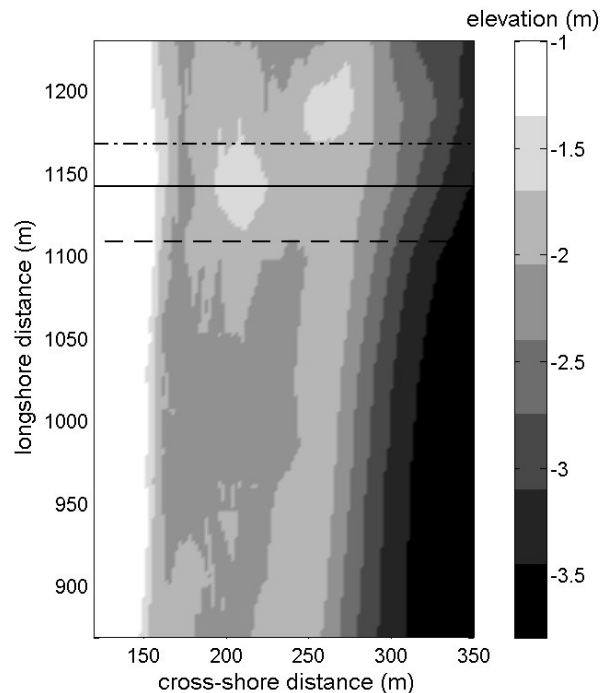


Figure 9: Bathymetric survey, Duck, 7 Sep. 1994, capturing a SPAW. The three lines (dash-dotted, solid, dashed) indicate the location of transects shown in Figure 10

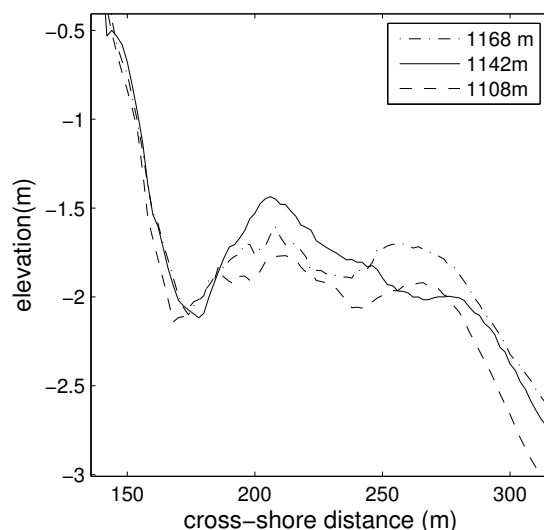


Figure 10: Bathymetric transects crossing a SPAW near Duck (survey 7 Sep. 1994, see Figure 9 for plan view).

13 represent the net cross-shore flux that occurred in the slice of beach between the 0.5 m and 2 m elevation contour, averaged over a 100 m longshore section of the beach (under the assumption that volume change in this reference box occurred due to cross-shore exchange with the nearshore).

5 DISCUSSION

Various models exist to simulate nearshore morphodynamics, but so far none of them has explicitly brought up the possibility of shedding isolated features like SPAWs. Many of these model are template models in which patterns in the nearshore flow field enforce similar patterns in the underlying sand bed (e.g. Dyhr-Nielsen & Sorensen 1970, Bowen & Inman 1971, Holman & Bowen 1982, Sallenger & Howd 1989, Howd et al. 1991). However, nearshore topographical change may also be explained by feedback models that, in contrast to template models, lack the requirement of pre-existing patterns in the flow field (cf. ripple formation under steady currents). Such types of models for the nearshore were already proposed three decades ago (Hino 1974) but also received attention more recently (e.g. Deigaard et al. 1999, Ribas et al. 2003)

The creation of an isolated mound of sediment in the trough of a sand bar that maintains its integrity as it transits the trough seems inconsistent with the concept of feature generation as a direct response to a fluid forcing template. Instead, we think that the creation and stability of SPAWs point out the probable importance of feedback between topographic features and their perturbations to overlying fluid motions.

6 CONCLUSIONS

A large database of video time-exposure images of the surf zone near Duck (NC, USA) revealed that a nearshore bar can occasionally become unstable and shed a small bar from its landward facing side. This daughter bar subsequently transits the trough as an intact feature and merges with the beach. These generally elongated features were found to have a length of 126 ± 60 m and a width of 30 ± 10 m. A typical duration of the event is 17 ± 9 days, and the average onshore propagation speed of a SPAW is 3.1 ± 0.8 m/day. The related onshore sediment flux was estimated to be about 1-2 $\text{m}^3/\text{m}/\text{day}$, which is a locally significant contribution to the beach accretion rate that is normally observed along the studied beach.

None of the existing nearshore morphodynamic models has explicitly brought up the possibility of shedding isolated features like SPAWs so far. This may indicate a 'missing process' in the current models. Therefore, further study of SPAWs can contrib-

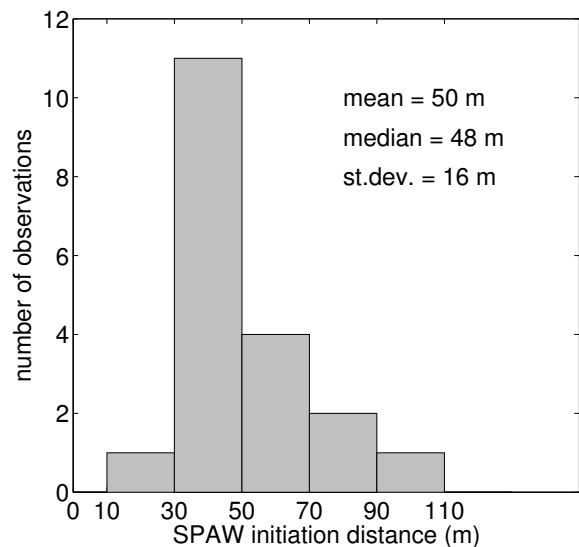


Figure 11: Histogram of observed SPAW initiation distances.

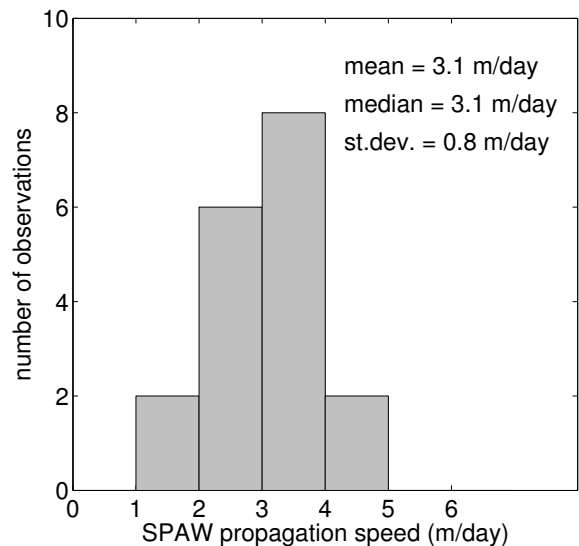


Figure 12: Histogram of observed SPAW propagation speeds.

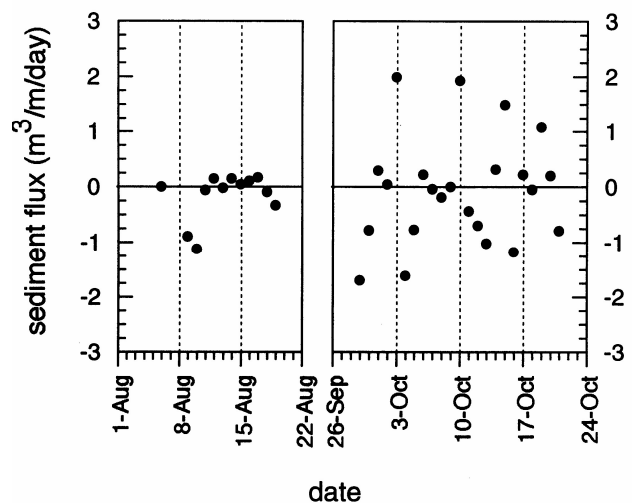


Figure 13: Daily mean sediment fluxes to the beach near Duck, based on beach surveys collected during Duck'94 experiment (courtesy: N.G. Plant).

ute useful information to our general understanding of the nearshore processes, even though SPAWs have a relatively low frequency of occurrence and have only a local impact on the beach. For example, understanding the mechanism that allows the SPAW to maintain its integrity throughout its onshore propagation across the trough may help us better understand the cross-shore transport processes in the nearshore environment.

7 ACKNOWLEDGEMENTS

We would like to acknowledge Amanda Barstow and Eric Gilbert for their conscientious efforts in viewing all the images for the occurrences of SPAWs which allowed us to establish the operator dependence of SPAW identification. Thanks also go to Nathaniel Plant for kindly providing the data on daily sediment fluxes to the beach of Duck. In addition we thank the CERC Field Research Facility for providing the bathymetric data. We gratefully acknowledge support from the Office of Naval Research, Coastal Geosciences program for helping make possible long-term Argus collections.

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