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SHOREWARD PROPAGATING ACCRETIONARY WAVES (SPAWs): OBSERVATIONS FROM A MULTIPLE SANDBAR SYSTEM

Timothy Price[1], Niels van Kuik[1], Liza de Wit[1], Sara António[1] and Gerben Ruessink[1]

Abstract

Recent observations have shown that the shallow parts of subtidal crescentic bars may separate from the bar and migrate onshore as spatially coherent features, termed *Shoreward Propagating Accretionary Waves* (SPAWs). It is thought that this onshore migration of SPAWs plays a role in the sand exchange within the bar-beach-dune system. In this contribution, we explore the wave conditions related to the emergence and onshore migration of SPAWs, and to estimate the volume of sand contained within a SPAW. Based on a 14-year data set of video images, we show that SPAWs emerge from crescentic bars during more energetic conditions with obliquely incident waves. Under low energetic conditions SPAWs may migrate onshore, but they disappear under larger wave heights and angles of wave incidence. Using model-data assimilation, we estimated the volume of sand contained within a SPAW to be 14700 m^3.

Key words: nearshore morphodynamics, cross-shore migration, subtidal bars, alongshore variability, sediment transport, video monitoring

1. Introduction

At straight sandy coasts, wave- and wind-induced processes often lead to intriguing, yet unexplained alongshore-variable morphology on spatial scales from tens of meters to a few kilometers. During severe storms, wave-induced processes can dramatically erode the beach-dune system with a striking alongshore variability in the amount of sand eroded and deposited seaward in the subtidal zone (Thornton et al., 2007; Castelle et al., 2015). The subsequent recovery of the beach-dune system is a much slower process, taking months to years. Here, wave-driven sand transport returns the eroded sand landward onto the intertidal beach, where it is picked up by the wind and returned into the dune system, again often with intriguing alongshore variability. Recent observations suggest that alongshore variations in subtidal morphology are key to this alongshore variability in dune recovery (Keijsers et al., 2014; Castelle et al., 2017).

The morphological patterns emerging in nearshore bars have been widely observed and studied, and often exhibit landward-protruding shallower areas at regular intervals alongshore, known as horns (e.g. Van Enckevort et al., 2004; Price and Ruessink, 2011). The alongshore depth variation in these so-called crescentic bars is thought to affect the morphodynamics of the more landward beach-dune system by acting as an alongshore-variable filter for the wave field, both during erosional storm events (Thornton et al., 2007; Castelle et al., 2015) and the accretionary recovery periods in between storms (Castelle et al., 2010; Price et al., 2014). Moreover, recent observations have shown that the horns of crescentic bars may separate from the bar and subsequently migrate onshore towards the beach as a spatially coherent structure, termed *Shoreward Propagating Accretionary Wave*, or SPAW (Wijnberg and Holman, 2007). These SPAWs may eventually merge with the intertidal beach, resulting in alongshore variations in sand supply for wind-induced transport towards the dunes (e.g., Houser, 2009; De Vries et al., 2014). It remains unknown, however, what role this onshore migration of SPAWs plays in the sand exchange within the bar-beach-dune system, and the development of alongshore-variable morphology.

Although it has been observed that SPAWs emerge from the horns of crescentic sandbars (Wijnberg and Holman, 2007; Almar et al., 2010), the concomitant wave conditions remain unclear, as well as the volume of sand reaching the beach as the SPAW welds to the shoreline. In this contribution, we aim to explore the

[1]Department of Physical Geography, Faculty of Geosciences, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands. t.d.price@uu.nl, b.g.ruessink@uu.nl

offshore wave conditions related to the emergence and onshore migration of SPAWs, and to estimate the volume of sand contained within a SPAW, based on video images from Egmond aan Zee, the Netherlands. First, in Section 2, we introduce the field site and methodology. Then, in Section 3, we describe the morphological evolution and wave conditions during observations of SPAW emergence and onshore migration. Finally, we discuss the implications of our findings and future work in Section 4, and present the main conclusions in Section 5.

2. Field site, data and methodology

2.1 *Egmond aan Zee*

Our observations are from the beach approximately 3 km south of the coastal town of Egmond aan Zee, the Netherlands (Figure 1). This wave-dominated, microtidal (1.7 m tidal range) straight stretch of beach contains three subtidal sandbars and an approximately 50-m wide beach backed by a dune system. The sandbars exhibit a net offshore migration (Ruessink and Kroon, 1994) with a period of approximately 15 years (Wijnberg, 2002). During this net offshore migration, alongshore-averaged distances between the inner bar and the shoreline increase from 100 to 200 m, whereas the distance between the middle and inner bars typically increases from 150 to 300 m. Temporal variations in alongshore bar variability decrease seaward from the inner bar to the outer bar, with typical wavelengths of 30 – 100 m in the inner bar and 1000 – 3000 m in the middle and outer bars. The mean offshore significant wave height is about 1-1.5 m (with periods of 4-5 s), reaching over 5 m during north-westerly autumn and winter storms. The dominant wave directions are from the northwest and southwest.

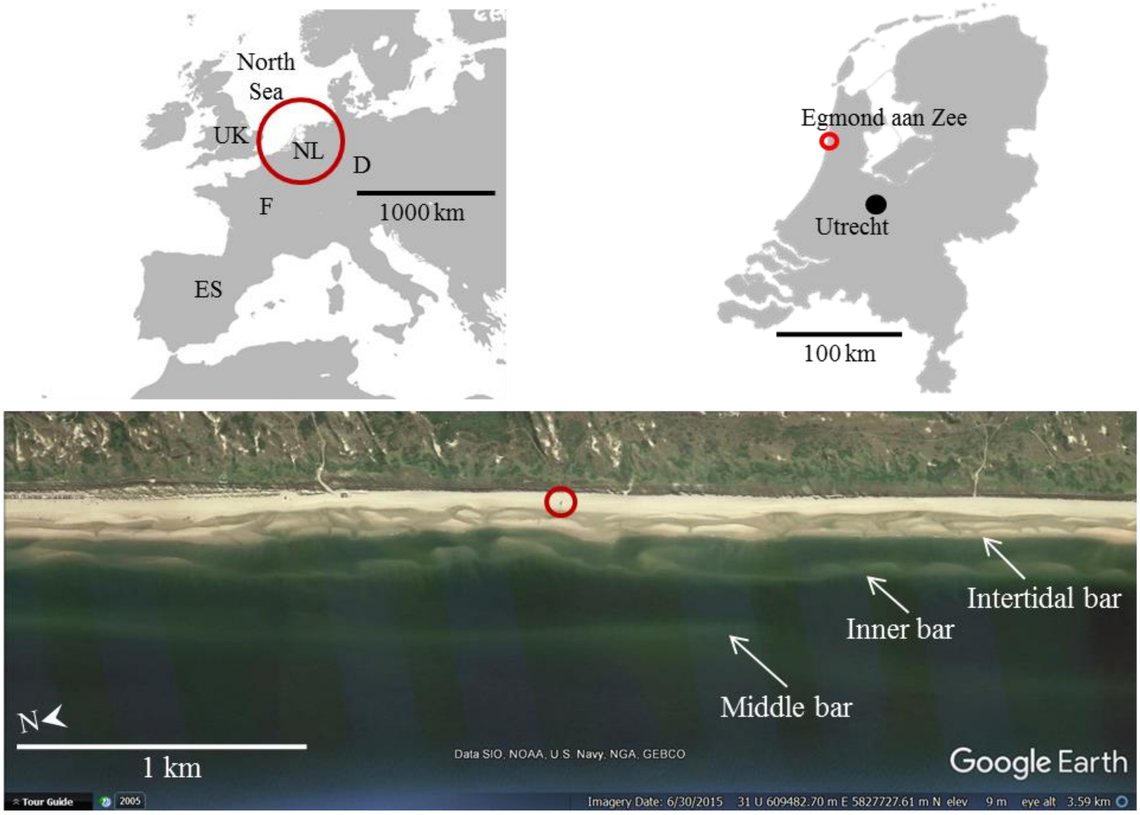

Figure 1. Location of the field site at Egmond aan Zee, The Netherlands. The red circle in the lower panel indicates the location of the Argus video system.

2.2 ***Video observations and wave data***

Our observations consist of a 14-year data set of daily video images, collected by an Argus video station (Holman and Stanley, 2007), mounted atop a 48 m high tower located on the beach (Figure 1). The system comprised five cameras, which provide a 180° view of the Egmond coast. We used 10-minute averaged planview time-exposure images, recorded at low tide, which reveal the high-intensity areas of wave breaking that serve as proxies for sandbar, shoreline and SPAW positions (Figure 2). Due to its depth of approximately 5 m, the outer, degenerating, bar is not often seen in the images due to the lack of wave breaking over the bar. SPAWs are visible as isolated patches of foam between the middle and inner bars, or between the inner bar and the shoreline (Figure 2). We manually determined SPAW presence in the images, using the criteria for the SPAW duration as defined by Wijnberg and Holman (2007): from the moment the patch of foam is fully detached from its parental bar up to the moment of welding with the inner bar or shoreline. We also observed SPAWs to disappear during their onshore migration (further discussed in Section 3), which provided an additional criterion for the end date of a SPAW. Furthermore, we determined cross-shore and alongshore SPAW dimensions by measuring the extent of the foam patches. The offshore wave conditions (root mean square wave height H_{rms}, peak period T_{peak} and angle of incidence, relative to shore normal θ) were collected hourly by a directional wave buoy 20 km offshore in 21 m depth. Using these measured wave parameters, we computed the wave power P and the alongshore component of the wave power P_y, which represents the portion of wave power available for alongshore sediment transport (see Komar, 1998).

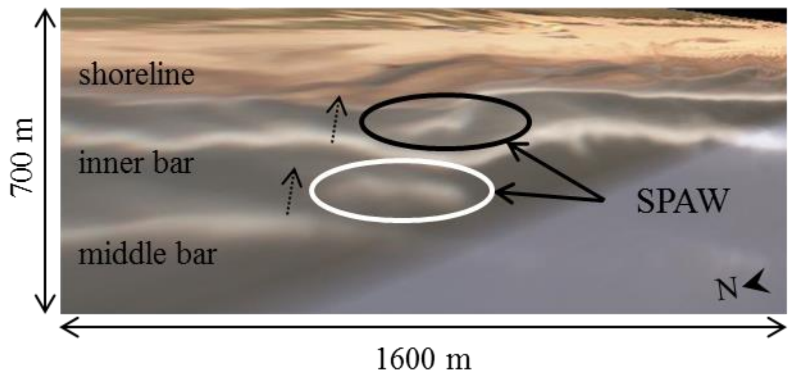

Figure 2. Example of a planview time-exposure image, taken on 30 August 2012, showing SPAWs migrating (arrows with dotted lines) from the middle bar to the inner bar (white oval) and from the inner bar to the shoreline (black oval).

2.3 ***Model-image assimilation***

Although the images allow for an estimation of the cross-shore and alongshore extent of a SPAW, they do not provide information on SPAW height and, thus, volume. Existing bathymetric data were collected at insufficient spatial density (in alongshore direction) and too infrequently (yearly) to be of use to our study and we therefore estimated SPAW depths from time series of time exposure images. Image intensity can be seen as a proxy for the roller dissipation D_r (Aarninkhof et al.., 2005), allowing the underlying bathymetry to be estimated through model data assimilation. We applied the assimilation model XBeachWizard (Van Dongeren et al., 2008), which uses a least squares estimator approach to estimate the bathymetric evolution from a series of time exposure images in combination with the process-based numerical model XBeach (Roelvink et al., 2009). Following the method outlined in Price and Ruessink (2013), we applied XBeachWizard to explore the morphological evolution of a SPAW during its onshore migration from the middle to the inner bar between June and September 2001. We extended the image preprocessing to account for a dissipation peak in the cross-shore profile related to the presence of a SPAW in the images, besides the dissipation peaks over the bars (Alexander and Holman, 2004). Of the 962 planview images available, 628 images (65%) provided suitable input for XBeachWizard after preprocessing.

3 Results

3.1 *General observations*

Over the 14-year period, we observed a total of 93 SPAWs of which 41 emerged from the middle bar and 52 from the inner bar (Figure 3). The average lifetime of a SPAW was approximately 40 days, with average (alongshore) lengths and (cross-shore) widths of approximately 200 m and 30 m, respectively. Over the study period, the SPAWs increasingly emerged from the inner bar and to a lesser extent from the middle bar (Figure 3), relating to the inter-annual net offshore migration of the nearshore bars. No SPAWs emerged from the outer, degenerating, bar. On a seasonal scale, SPAWs mostly emerged during the autumn and winter, during which storms are generally more frequent. Approximately half of the observed SPAWs merged with the inner bar or beach, whereas the other half vanished whilst migrating across the trough. In the next subsections, we focus on two periods where SPAWs emerged from the middle bar, migrated onshore and either merged with the inner bar (Section 3.2) or disappeared before reaching the inner bar (Section 3.3).

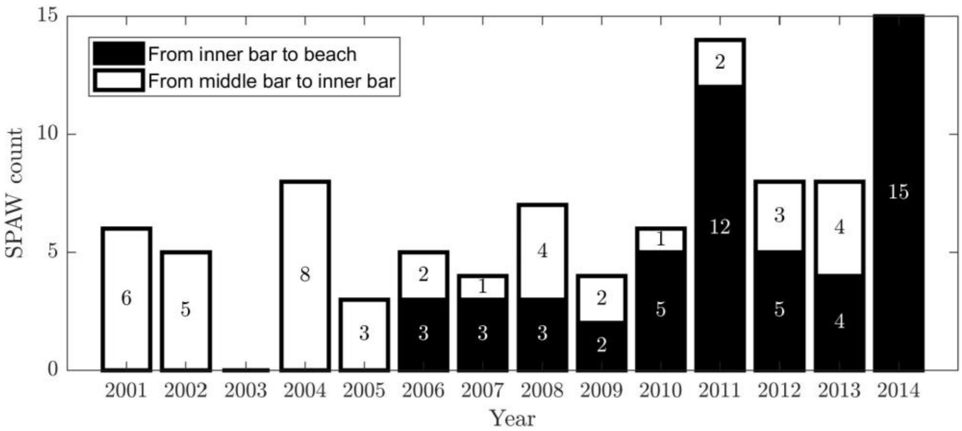

Figure 3. Observations of annual SPAW occurrence over the 14-year study period. White (black) rectangles indicate the number of SPAWs migrating from the middle (inner) bar to the inner bar (beach).

3.2 *SPAW emergence and onshore merging*

To explore the wave conditions associated with the emergence and onshore merging of SPAWs, we first focus on a period from May to October 2012, during which SPAWs emerged both from the middle and the inner bars (also shown in Figure 2). Figure 4 shows eight planview images, together with timeseries of H_{rms}, θ, P and P_y during this period. In Figure 4a, on 12 May, a horn in the middle bar is clearly visible as a landward protruding section of the bar, and the inner bar exhibits high alongshore variability with attachments to the low-tide shoreline. Shortly after, on 15 and 16 May (Figure 4b), waves with heights over 1.5 m and from the northwest (Figure 4i-k; positive θ and P_y values) led to the partial separation of a SPAW from the middle bar horn, visible in the planview of 17 May (indicated by the arrow in Figure 4c). A month later, when waves broke over the entire middle bar as well as the SPAW, the middle bar had straightened and the SPAW was now clearly visible as an isolated foam patch (Figure 4d). Here, wave heights again exceeded 1.5 m, but now came from southwesterly direction. Over the low-energetic summer months the SPAW continued to migrate onshore (Figures 4e-f). The first northwesterly autumn storm on 31 August, with wave heights exceeding 2 m, caused a jump in the onshore migration rate together with an alongshore migration of the SPAW (compare the SPAW positions in Figures 4f and g). Similarly, the SPAW continued to migrate towards the inner bar during September (Figure 4g), accelerated by more energetic wave conditions, and eventually merged with the inner bar on 2 October (Figure 4h).

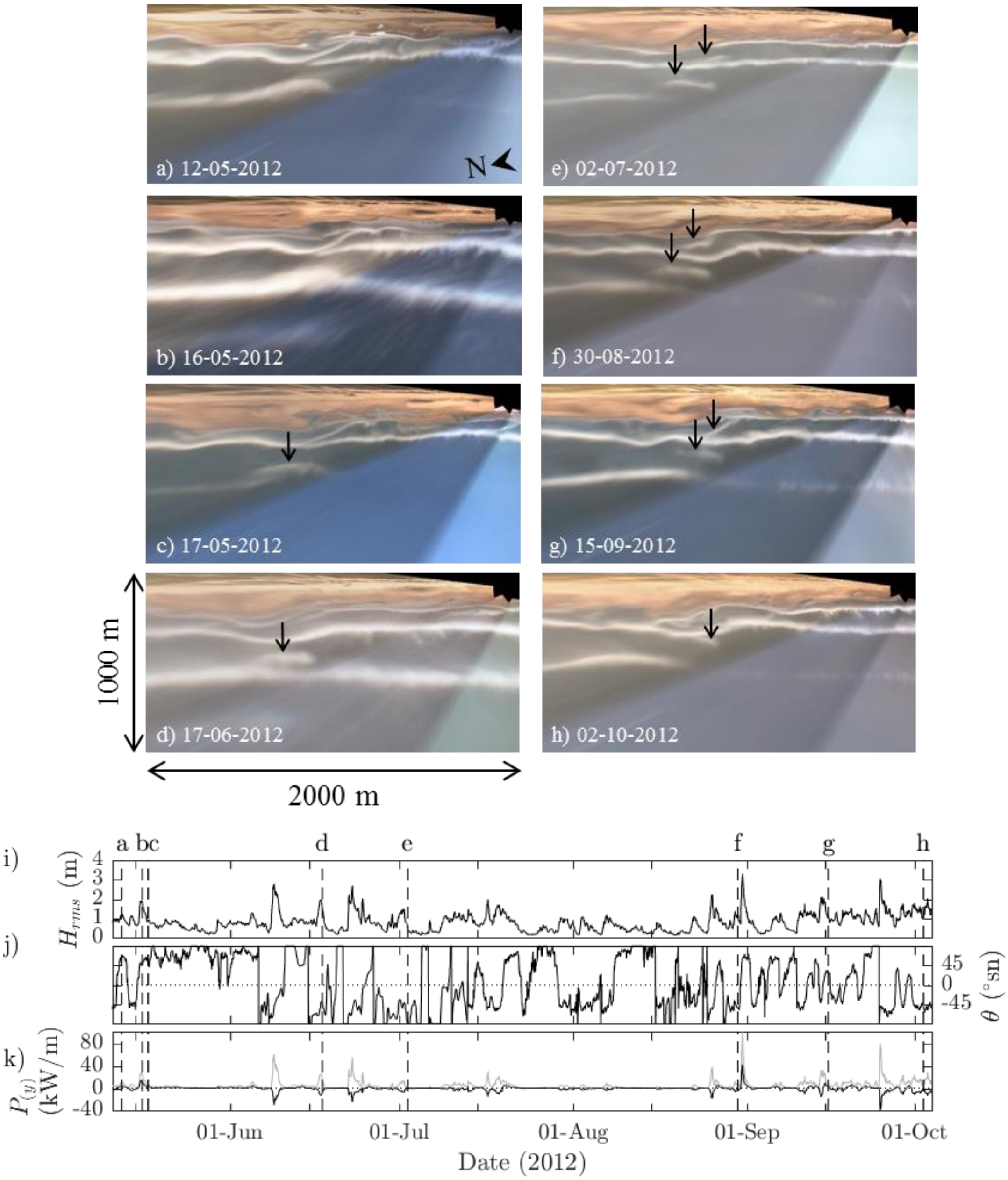

Figure 4. Observations of SPAW morphodynamics in May-October 2012, showing (a-h) planview time-exposure images and timeseries of (i) H_{rms}, (j) θ, (k) P (gray line) and P_y (black line). Black arrows in (a-h) indicate (emerging) SPAWs, the vertical dashed lines in (i-k) indicate the time the planview images were taken. See text for further details.

Landward of the middle bar horn, the inner bar exhibited a bifurcation that connected to the shoreline (Figures 4a-c). This bifurcation disappeared during the more energetic southwesterly waves on 16 June (Figure 4d), but another bifurcation started to form at the same alongshore position after two weeks of increased wave heights from the southwest (indicated by the more landward black arrow in Figure 4e). During the low energetic summer conditions the bifurcation, or spit-like feature, extended southward in the direction of the shoreline and remained connected to the inner bar at its northern side. Increased wave heights from the southwest on 25-26 August coincided with a separation of the spit-like feature from the inner-bar together with the offshore migration of the inner bar, leading to the emergence of a SPAW (Figure 4f). In the weeks thereafter, the SPAW reconnected to the inner bar and the shoreline and eventually disappeared under higher, obliquely incident waves in the last week of September (Figure 4h).

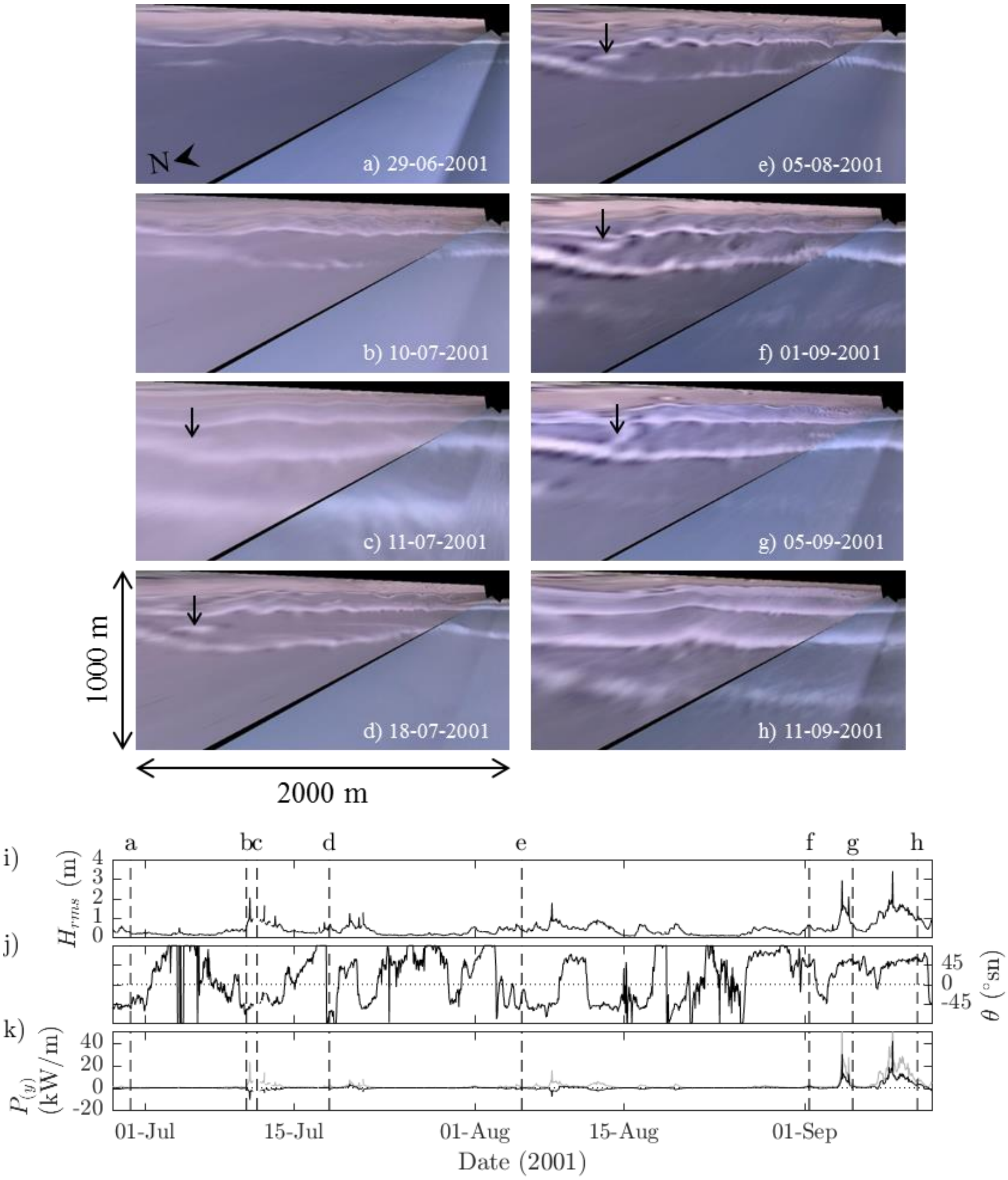

Figure 5. Observations of SPAW morphodynamics in July-September 2001, showing (a-h) planview time-exposure images and timeseries of (i) H_{rms}, (j) θ, (k) P (gray line) and P_y (black line). Black arrows in (a-h) indicate SPAWs, the vertical dashed lines in (i-k) indicate the time the planview images were taken. See text for further details.

3.3 *SPAW emergence and disappearance*

Figure 5 shows the planview images (Figures 5a-h) and associated timeseries of wave characteristics (Figure 5i-k) of an observation period from July-September 2001. Here, as in the previous observation period, a horn in the middle bar is clearly visible as a shallow (Figure 5a), landward protruding area of the middle bar (Figure 5b). Under southwesterly waves with heights exceeding 2 m on 11 July, the horn started to separate from the middle bar (Figure 5c), and eventually led to the emergence of a SPAW (Figure 5d). In the following weeks, the SPAW slowly migrated onshore under the low-energetic summer wave conditions (Figure 5e-f). As it neared the inner bar, a short period of northwesterly waves on 5 September with heights of approximately 1.5 m coincided with the alongshore diffusion of the SPAW in southerly direction (Figure

5g). Similar conditions on 10 September continued the alongshore diffusion of the SPAW, leading to its disappearance by 11 September (Figure 5h).

3.4 *SPAW volume estimation*

As explained in Section 2.3 we applied XBeachWizard to the period June - September 2001, of which the observations were discussed in Section 3.3. The assimilation resulted in 628 bathymetric maps, corresponding to the number of planview images used for the assimilation. Figure 6 shows the assimilated bathymetry from 29 July 2001, in which the SPAW can clearly be distinguished as an isolated feature in the trough between the middle (here indicated as outer bar) and inner bars. The assimilation resulted in a mean SPAW height of 0.7 m, and a mean (alongshore) length and (cross-shore) width of 300 m and 70 m, respectively. Together, this results in a mean SPAW volume of 14700 m^3.

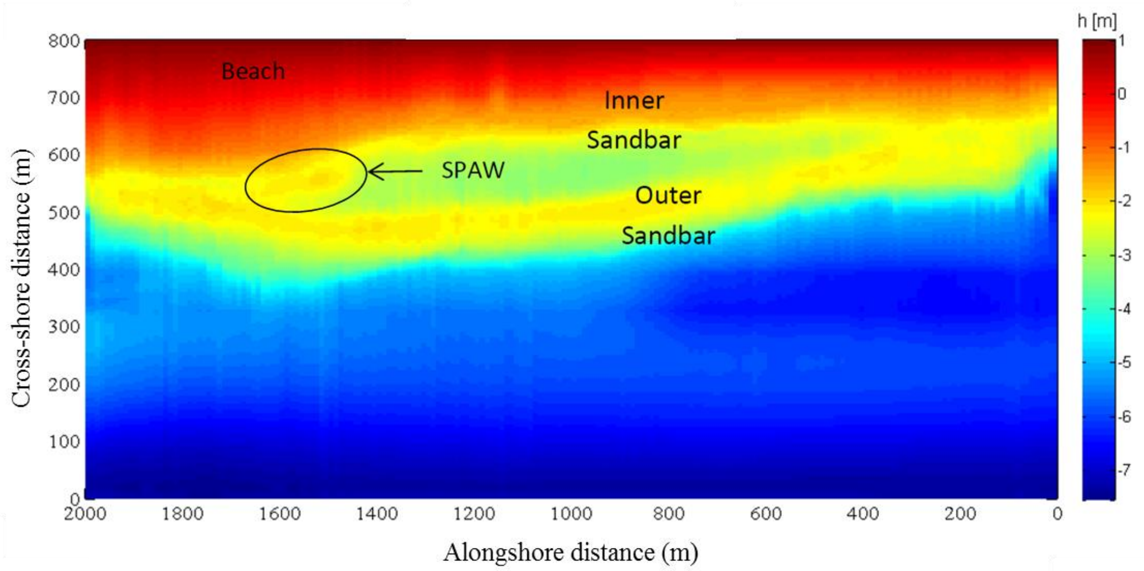

Figure 6. Estimated bathymetry on 29 July 2001, using XBeachWizard. The SPAW can be seen as an isolated morphological feature in the trough between the middle (here indicated as outer bar) and the inner bars. The color scale indicates waterdepth *h*.

4 Discussion

Our observations show that SPAWs either emerged from the horns of crescentic bars or resulted from bar bifurcations. Wijnberg and Holman (2007) and Almar et al. (2010) both report SPAWs emerging from the horns of crescentic bars. Based on observations from a multi-bar coast with net offshore bar migration, Shand (2007) observed bifurcations that detached, moved landward and in some cases welded to the foreshore, similar to the observations presented herein. Although the field sites studied by Wijnberg and Holman (2007) and Almar et al. (2010) did not exhibit (gradual) net offshore migration, it remains unknown whether detached bifurcations are found in such systems.

Our observations also show that SPAWs may disappear before merging with the inner bar or shoreline, similar to the findings of Konicki and Holman (2000), who found that, under some conditions, well-developed bar horns may detach and either dissipate in the trough or migrate landward. Our observations show that the disappearance of the onshore migrating SPAW coincided with more energetic, obliquely incident waves, the same conditions that seem to spark SPAW emergence. At our site, more energetic waves are commonly obliquely incident (either from the northwest or from the southwest). Although other SPAW observations suggest that the emergence of SPAWs coincide with high energetic events (Shand, 2007; Wijnberg and Holman, 2007; Almar et al.,2010), the role of the angle of wave incidence remains unclear. As all observations of SPAW emergence involve well-developed crescentic bars, wave height and angle of incidence may be important for the straightening and offshore migration of the bar (Price and Ruessink, 2011), necessary for the separation of the bar horn.

SPAWs provide a mechanism for bringing sand from the subtidal zone to the intertidal zone and the beach. Our SPAW volume estimate of ~15000 m^3 falls within the range of ~7000 m^3 to 30000 m^3 found by Wijnberg and Holman (2007) and Almar et al. (2010), respectively. To determine how this sand input varies, it will be necessary to obtain bathymetric measurements of SPAWs as they migrate onshore. In short, further study of SPAW morphodynamics, including field measurements, is required to give us more insight into the role of SPAWs in nearshore morphodynamics.

5 Conclusions

Using a 14-year data set of daily low-tide time-exposure video images from Egmond aan Zee, the Netherlands, together with offshore wave data, we aimed to explore the wave conditions related to the emergence and onshore migration of SPAWs, and to estimate the volume of sand contained within a SPAW. In total, we observed a total of 93 SPAWs of which 41 emerged from the middle bar and 52 from the inner bar. SPAWs either resulted from the detachment of the horns of crescentic bars, or from bar bifurcations that detached. In both cases, more energetic (H_{rms} of 1.5-2 m), obliquely incident waves coincided with SPAW emergence. Approximately half of the observed SPAWs merged with the inner bar or beach, whereas the other half vanished whilst migrating across the trough. Onshore migration was found during the summer months, when wave heights were lower, whereas SPAWs were diffused and eventually disappeared whilst in the trough if wave heights and angles of wave incidence increased. Over the study period, SPAWs increasingly emerged from the inner bar and to a lesser extent from the middle bar, relating to the inter-annual net offshore migration of the nearshore bars. Using model-data assimilation, we estimated the volume of sand contained within a SPAW to be 14700 m^3.

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References

Aarninkhof S.G.J., Ruessink B.G., Roelvink J.A., 2005. Nearshore subtidal bathymetry from time-exposure video images. *Journal of Geophysical Research* 110: C06011.

Alexander P.S., Holman R.A.. 2004. Quantification of nearshore morphology based on video imaging. *Marine Geology* 208: 101–111.

Almar, R., Castelle, B., Ruessink, B.G., Sénéchal, N., Bonneton, P. and Marieu, V., 2010. Two-and three-dimensional double-sandbar system behaviour under intense wave forcing and a meso–macro tidal range. *Continental Shelf Research*, 30(7) : 781-792.

Castelle, B., Ruessink, B.G., Bonneton, P., Marieu, V., Bruneau, N., and Price, T. D., 2010. Coupling mechanisms in double sandbar systems. Part 1: Patterns and physical explanation. *Earth Surface Processes and Landforms*, 35(4): 476-486.

Castelle, B., Marieu, V., Bujan, S., Splinter, K.D., Robinet, A., Sénéchal, N. and Ferreira, S., 2015. Impact of the winter 2013–2014 series of severe Western Europe storms on a double-barred sandy coast: Beach and dune erosion and megacusp embayments. *Geomorphology*, 238: 135-148.

Castelle, B., Bujan, S., Ferreira, S. and Dodet, G., 2017. Foredune morphological changes and beach recovery from the extreme 2013/2014 winter at a high-energy sandy coast. *Marine Geology*, 385: 41-55.

De Vries, S., Arens, S.M., de Schipper, M.A. and Ranasinghe, R., 2014. Aeolian sediment transport on a beach with a varying sediment supply. *Aeolian Research*, 15: 235-244.

Houser, C., 2009. Synchronization of transport and supply in beach-dune interaction. *Progress in Physical Geography*, 33(6): 733-746.

Keijsers, J.G., Poortinga, A., Riksen, M.J. and Maroulis, J., 2014. Spatio-temporal variability in accretion and erosion of coastal foredunes in The Netherlands: Regional climate and local topography. *PloS one*, 9(3): e91115.

Komar, P.D., 1998. *Beach processes and sedimentation*, Second edition, Prentice Hall, New Jersey.

Konicki, K.M. and Holman, R.A., 2000. The statistics and kinematics of transverse bars on an open coast. *Marine Geology*, 169: 69–101.

Price, T.D. and Ruessink, B.G., 2011. State dynamics of a double sandbar system. *Continental Shelf Research*, 31(6): 659-674.

Price, T.D. and Ruessink, B.G., 2013. Observations and conceptual modelling of morphological coupling in a double sandbar system. *Earth Surface Processes and Landforms*, 38(5): 477-489.

Price, T.D., Ruessink, B.G. and Castelle, B., 2014. Morphological coupling in multiple sandbar systems-a review. *Earth Surface Dynamics*, 2(1): 309.

Roelvink, D., Reniers, A., Van Dongeren, A.P., de Vries, J.V.T., McCall, R. and Lescinski, J., 2009. Modelling storm impacts on beaches, dunes and barrier islands. *Coastal Engineering*, 56(11): 1133-1152.

Ruessink, B.G. and Kroon, A., 1994. The behaviour of a multiple bar system in the nearshore zone of Terschelling, the Netherlands: 1965–1993. *Marine Geology*, 121(3): 187-197.

Shand, R.D., 2007. Bar splitting: system attributes and sediment budget implications for a net offshore migrating bar system. *Journal of Coastal Research*, (50): 721.

Thornton, E.B., MacMahan, J. and Sallenger, A.H., 2007. Rip currents, mega-cusps, and eroding dunes. *Marine Geology*, 240(1): 151-167.

Van Dongeren A., Plant N., Cohen A., Roelvink J.A., Haller M.C., Catalán P., 2008. Beach wizard: nearshore bathymetry estimation through assimilation of model computations and remote observations. *Coastal Engineering*, 55: 1016–1027.

Van Enckevort, I.M.J., Ruessink, B.G., Coco, G., Suzuki, K., Turner, I.L., Plant, N.G. and Holman, R.A., 2004. Observations of nearshore crescentic sandbars. *Journal of Geophysical Research: Oceans*, 109(C6).

Wijnberg, K.M., 2002. Environmental controls on decadal morphologic behaviour of the Holland coast. *Marine Geology*, 189(3): 227-247.

Wijnberg, K.M. and Holman, R.A., 2007. Video-observations of shoreward propagating accretionary waves. *Proceedings of the RCEM 2007*: 737-743.