# THE SPATIAL VARIABILITY OF LARGE SCALE SAND BARS

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Abstract

In this work we describe preliminary results from a newly developed aerial video system which can be used to rapidly (2-4 hours) and accurately (5 m resolution) sample the horizontal scales of sand bar morphology over several hundred km's of coastline. Observations from, for example, the North Carolina coastline on the central eastern seaboard of the U. S., indicate marked changes in the alongshore morphological patterns, which can be cyclic with lengths scales of 5-10 km's along one stretch of coast but adjacently the bars can be absent altogether. Other observations from the lower sloping west coast beaches of the U. S. Pacific Northwest show highly complex sand bar morphology which also exhibit marked alongshore variability. Along this coast the beach systems are not continuous and are separated by large headlands, and the morphology at any particular beach behaves independently from the bar morphology in adjacent compartments.

## Introduction

Nearshore morphology exhibits spatial variability spanning over 5 decades of scale. Morphologies ranging from wave- and mega-ripples (10-100's of centimeters) to large scale sand bars and shoreline features spanning 10-100's of kilometers reflect a variety of fluid-sediment interactions spanning comparable scales. The temporal response of these features is similarly broad (from 10's of seconds to years). This wide range of scales presents difficult sampling problems. Commonly used nearshore

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surveying techniques are limited in spatial and especially temporal resolution, require a large resource of manpower, and are generally only feasible in moderate wave conditions. Yet, for many applications it is of interest to sample the sometimes rapid, large changes in beach morphology that occur during single storm events, or over a series of several to many storm cycles.

One remote sensing technique which has successfully resolved rapid changes in large scale sand bar morphology is based on sub-aerial video of surf zone wave breaking (Lippmann and Holman, 1989; 1990). Time-averaged video images detect the horizontal scales of the average wave breaking patterns, and because waves preferentially break over shallow regions, the large scale morphologic features associated with bars are revealed. The video techniques are not limited by adverse wave conditions, and have thus proven useful in sampling long time series (up to 5 years and continuing today) of nearshore morphologic variability (Lippmann and Holman, 1990; Lippmann, *et al.*, 1993).

The most severe limitation of the video techniques is that the resolution of the images degrades rapidly as the distance from the camera increases, particularly for the highly oblique views typically used to study nearshore processes (*i.e.*, Holman, *et al.*, 1993). The useful spatial coverage of the land-based video techniques is determined by the pixel resolution of the image, which depends strongly on camera elevation above mean sea level and the distance to the target (Holland, *et al.*, 1997). For the Duck, NC, camera location, the useful ground coverage imaged in Lippmann and Holman (1990) and Lippmann, *et al.* (1993) spanned alongshore distances of about 400 m alongshore. Since the bar position was averaged over the entire view for the time-exposure data used in Lippmann, *et al.* (1993), any alongshore variability that may have been present at wavelengths greater than 400 m could not be addressed, nor the potential for alongshore migrating large-scale bar features which could also produce the transition sequence observed by either Lippmann, *et al.* (1993) or Birkemeier (1984).

Sand bars with large alongshore length scales of O(10 km) have been observed to migrate along the Dutch coast using 40 years of annual profile measurements spanning 350 km alongshore (Wijnberg, 1995). These large scale features dominate the variability over the 40 year time series, and show variability in time and length scales that is presently not understood. The Dutch JARKUS profile data is unique in

its breadth of temporal and spatial sampling. It is, however, a very difficult task to produce a single survey of 350 km of coast, often taking 6 months to complete one survey.

Aerial Video System

Recent advances in aerial videography have shown that rapid acquisition of the spatial patterns of large scale sand bar morphology is possible (Worley, *et al.*, 1997). The development of an aerial system was motivated by the need to measure larger length scale sand bars accurately and in a timely manner. The modular, low-cost system was configured so that it could be quickly deployed in easily accessible, inexpensive Cessna 172 or 182 aircraft at locations where forecasted weather predictions indicated the development of large storm systems, and thus the potentially large scale changes of the beach system to could also be quantified. The system utilizes a gyro-stabilized compass and inclinometer to maintain the camera in a vertically down-ward orientation within a walk-circle of 1 degree diameter. The azimuthal angle of the camera view and altitude (measured with a pressure sensor) is recorded on a lap-top PC and is synchronized with the video using timing obtained from a hand-held GPS receiver. The horizontal real-word UTM coordinates and vertical elevation of the aircraft are also measured using differential GPS systems with reliable positioning and high accuracy of order 0.05-0.5 m, depending on distance to the base station.

The precision and accuracy of the components of the aerial video system and image resolution and averaging times are summarized in Worley, *et al.* (1997). Assuming precise positioning, and for a typical deployment using a 2/3 inch format video camera with wide angle lens, the expected image resolution ranges between 1.1-5.9 (1.6-8.8) meters in the cross-shore (longshore) directions, depending on flight altitude ranging 457-2438 m (1500-8000 ft). With a typical aircraft ground speed of 80-100 knots (~50 m/sec) we expect sampling periods and averaging times in one flyby to be about 17-89 seconds for flight altitudes. The averaging time can be increased linearly by making several flyby's of the same ground area.

Field Data

We have conducted over-flights periodically for the past 13 months at several regions of the U. S. (Figure 1). Approximately bi-monthly flights have been

conducted from the Mexican border to Santa Barbara, spanning the entire Southern California Bight. Flights have been conducted also along the Central California coast from Monterey to Tomales Bay at the north end of Pt. Reyes, and along the northern Oregon-southwest Washington coast from Waldport, OR, to Pt. Grenville, WA. Finally, several flights have been conducted along the North Carolina coast from Cape Hatteras to the Virginia border, and span the period of the 1997 SandyDuck experiment.

Sand bar morphology is inferred from the location of average breaking patterns in time-exposure images created over the approximately 30-40 second duration (for aircraft altitude of 3000 ft) that ground features remain within the camera field of view, similar to the land-based methods (Lippmann and Holman, 1989; 1990). In the aerial techniques, the image transformation must be done on a frame-by-frame basis, and is accomplished by synchronous integration of the measured azimuthal orientation of the camera view and position of the aircraft with the VITC time-stamp on each video frame. Individual frames are rectified into the UTM ground coordinate system and digitally added in sequence using image processing, video, and computer hardware in our laboratory. Time-exposure images span the length of the flight-track which ranges about 75 km for some of the shorter southern California flights to about 300 km in the Pacific Northwest.

The data have shown remarkable alongshore variability in sand bar morphology, and have revealed, for example, alongshore regular patterns in sand bars along the North Carolina coastline with length scales of the order of 5-10 km that dominates the alongshore variability in bar position. An example 35 second aerial time-exposure spanning about 10 km alongshore, obtained about 20 km north of Duck, NC, on 27 September 1997, is shown in Figure 2. The resolution for this image is 5 m horizontally, and shows well defined sand bars emanating obliquely away from the shoreline, eventually fading away seaward behind adjacent, more shoreward bars further down the coast. Interestingly, several similar obliquely oriented bars were observed at approximately regular spacing along 36 km of the same stretch of coast (Figure 3), yet just to the south, the aerial time-exposure indicates the presence of only a single bar very close to shore (Figure 4).

The possible migration of the large scale bar features can be addressed from time series of aerial time-exposures. The behavior of the coast to changing wave

conditions in relation to the alongshore configuration of the bar system, and is the subject of ongoing research.

The morphologic variability can also be quite high at other beaches with different characteristics than North Carolina, where low-relief barrier islands span the length of coastline and the beaches are relatively steep. Along the U.S. Pacific Northwest coast, most beaches are backed by cliffs or high dunes and bounded laterally by many headlands, are generally more gently sloping, and are subjected to the more energetic Pacific swell for much of the year. Figure 5 shows an 11 km section of coast near Siletz Spit (shown in the center of the image) in the central Oregon coast obtained on 2 June 1998. The wave heights were over 2 m for this day and the surf zone spans about 400 m across-shore. The alongshore variability is quite complicated, without any particular regularity apparent. In contrast, about 90 km or so to the north the bar forms appear more regular in morphology, with sinuous bars extending alongshore continuously for several kilometers and sometimes attach to the shoreline (Figure 6).

## Summary

Results from deployment of a recently developed aerial video system for measuring large scale sand bar morphology are briefly discussed. The system, based on inferring sand bar shapes and location from time-averaged breaking patterns, was deployed on both the west and east coasts of the U.S. Observations of sand bars, for example, offshore of North Carolina coast along the central eastern seaboard and along the Pacific Northwest coast, reveal substantial alongshore variability in sand bar patterns. Series of large scale oblique bars, emanating from the shoreline and diminishing down the coast behind other similar bars, were observed over 30-40 km of part of the North Carolina coast, yet observations of the 30-40 km just to the south revealed only a single bar located close to shore. In the Pacific Northwest, highly complex bar patterns were observed with no apparent connection between adjacent beach systems separated by headlands. The evolution of these large scale bar forms, from both the steeper east coast beaches and the more gently sloping, energetic west coast beach systems, are the subject of ongoing investigations utilizing data obtained from the aerial video system.

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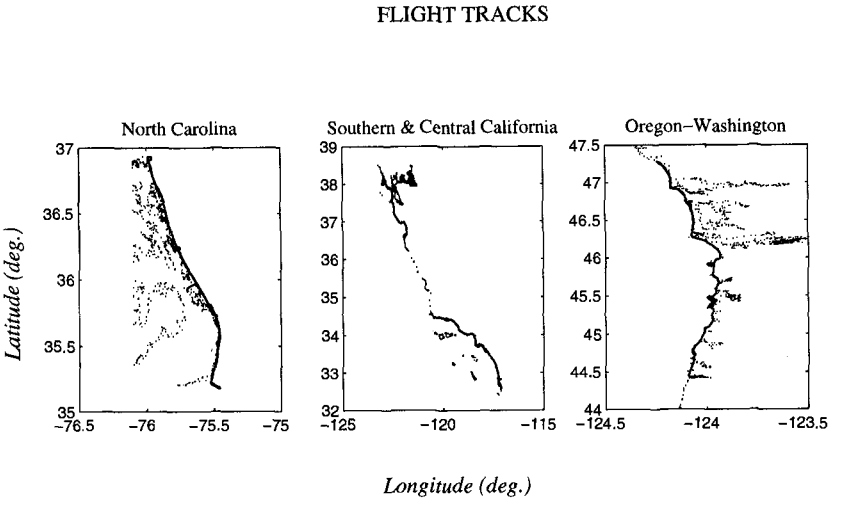


**Figure 1.** Maps of the coastline (dotted lines) and the flight tracks (solid lines) for the geographical regions studied with the aerial video system. The flight track in North Carolina (left panel) extends from Cape Hatteras to the Virginia border, in California (center panel) from the Mexican border to Santa Barbara and from Monterey to Pt. Reyes, and in northern Oregon and southwest Washington from Waldport, OR, to Pt. Grenville, WA.

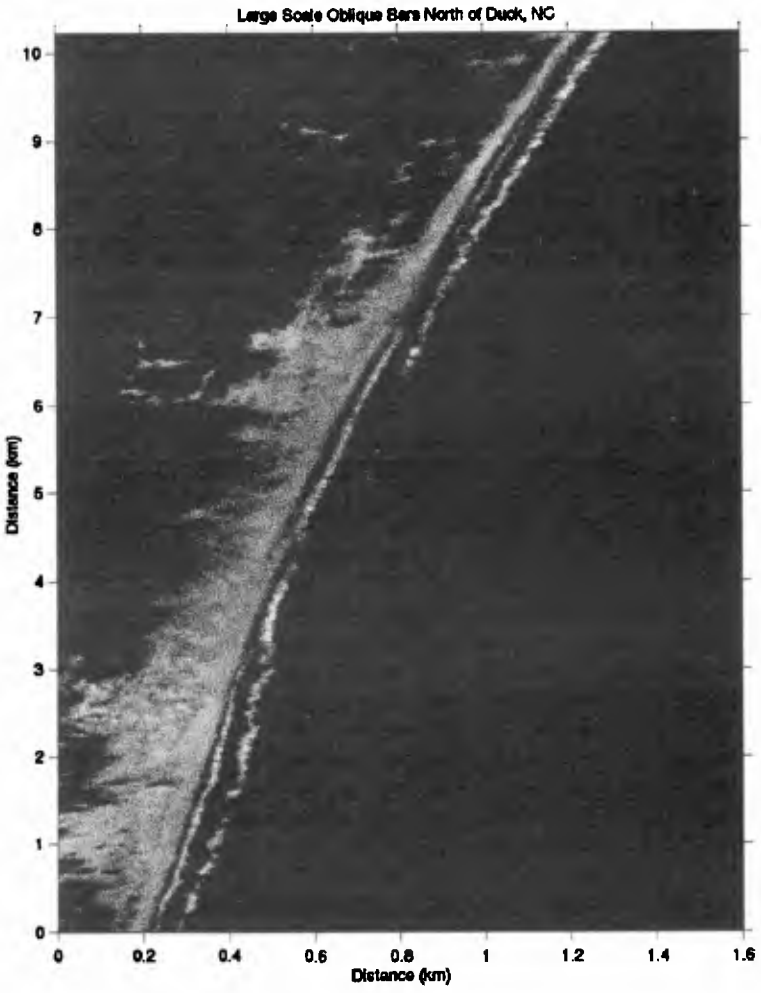


**Figure 2**. Example 35 second aerial time-exposure along 11 km of the North Carolina coast just north of Duck. The coordinate system (in km) has arbitrary origin with north towards the top and ocean (east) to the right in the image. The image resolution is 5 m in both the cross- and along-image axes. The location of large scale oblique sand bars are indicated by the white bands located 25-200 m offshore.

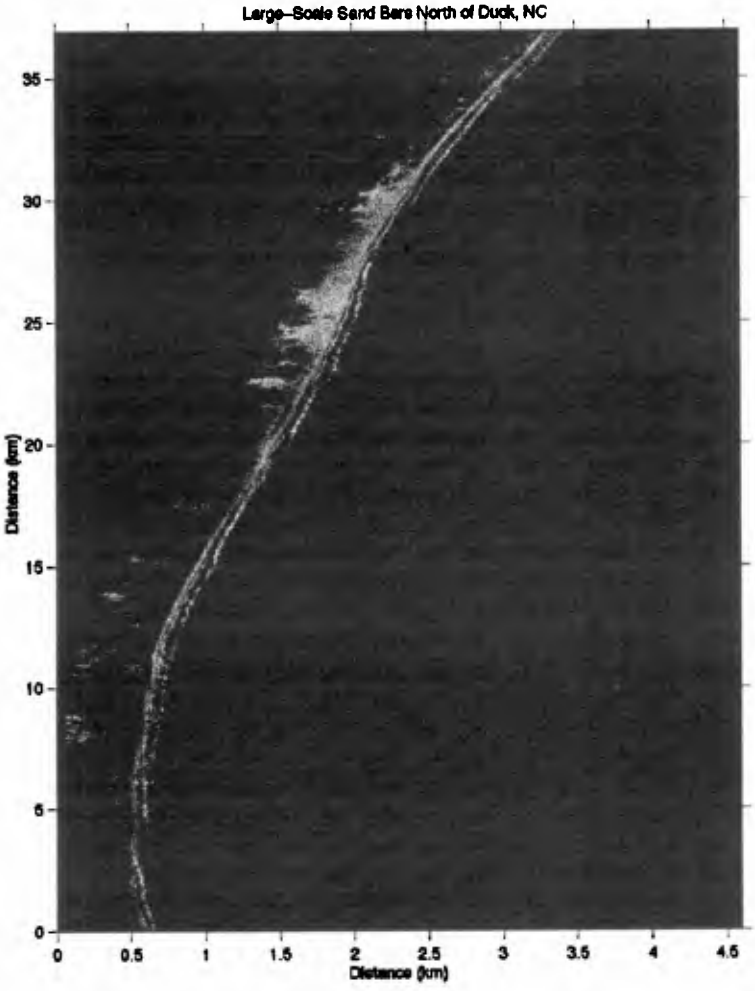


**Figure 3.** Example 35 second aerial time-exposure along 36 km of the North Carolina coast just north of Duck. The coordinate system (in km) has arbitrary origin with north towards the top and ocean (east) to the right in the image. The image resolution is 5 m in both the cross- and along-image axes. Several oblique sand bars emanating away from the coast are visible in the image as the white bands with 25-200 m of the shoreline.

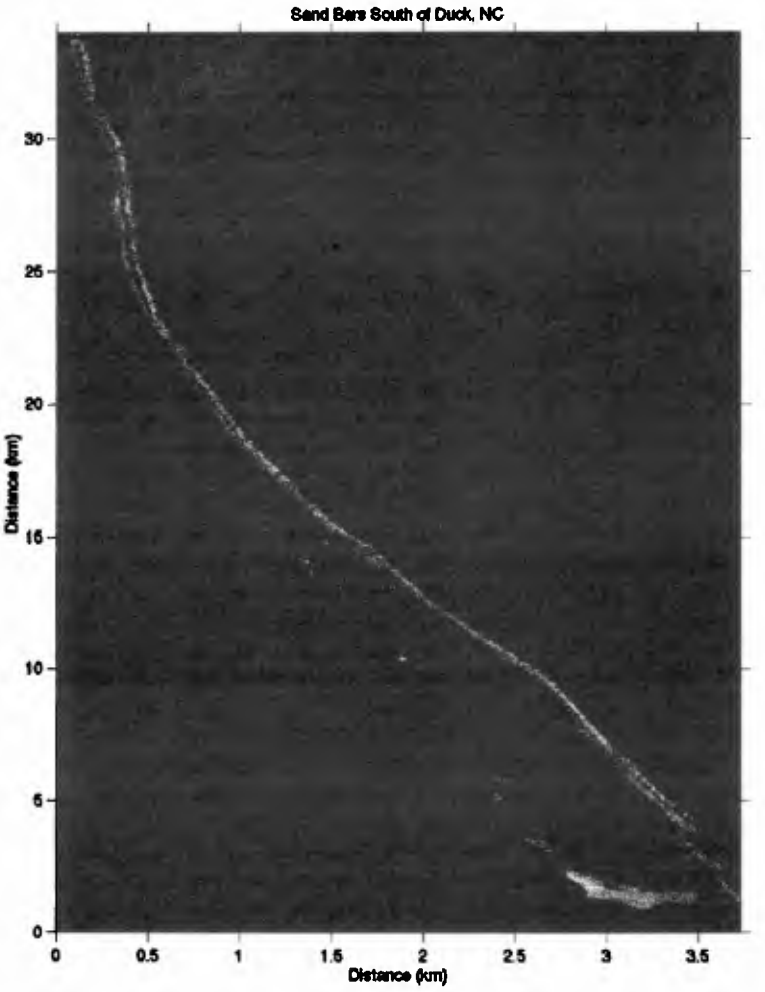


**Figure 4**. Example 35 second aerial time-exposure along 33 km of the North Carolina coast just south of Duck. The coordinate system (in km) has arbitrary origin with north towards the top and ocean (east) to the right in the image. The image resolution is 5 m in both the cross- and along-image axes. The sand bar is located very close to shore, with no discernible offshore breaking apparent seaward of about 80 m from the shoreline.

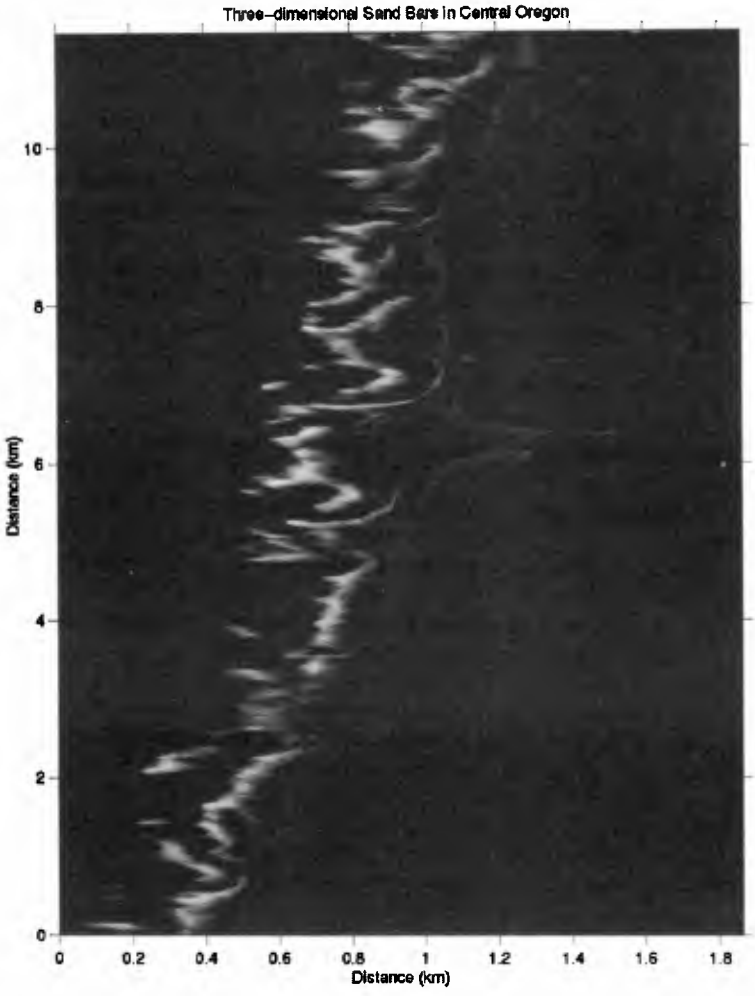


**Figure 5.** Example 35 second aerial time-exposure along 11 km of the central Oregon coast near Siletz Spit. The coordinate system (in km) has arbitrary origin with north towards the top and ocean (west) to the left in the image. The image resolution is 5 m in both the cross- and along-image axes. The large scale nearshore morphology is highly variable alongshore with no regularity apparent.

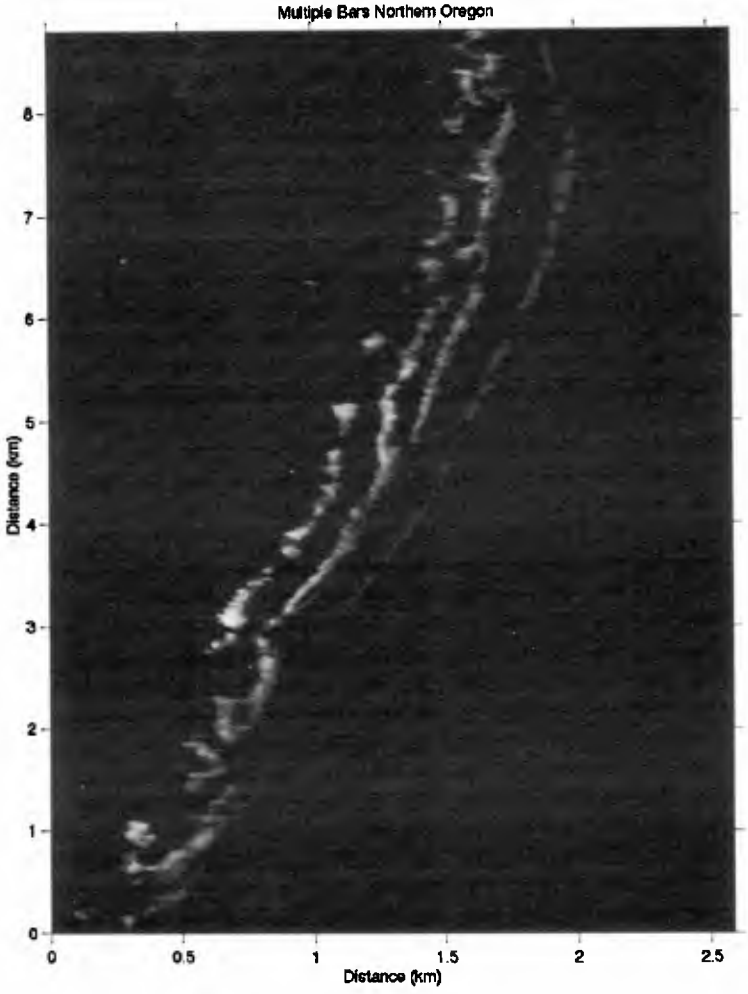


**Figure 6.** Example 35 second aerial time-exposure along 9 km of the northern Oregon coast near Tillamook Bay. The coordinate system (in km) has arbitrary origin with north towards the top and ocean (west) to the left in the image. The image resolution is 5 m in both the cross- and along-image axes. The large scale nearshore morphology shows long, sinuous bar features which sometimes attach to the shoreline.