RELATING WAVE GEOMETRY AND SURFACE DYNAMICS TO SUBSURFACE VELOCITIES

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INTRODUCTION

Quantifying subsurface velocity in the surf-zone beneath shoaling/breaking/broken waves is critical to accurately predict nearshore processes such as sediment transport [Hsu and Hanes, 2004]. The in-situ instruments designed to measure this velocity where waves break, such as velocimeters, routinely get buried, broken, or lost in the surf-zone. This limits our ability to collect field datasets of subsurface velocity in energetic wave conditions.

To address this, we propose to build on known relationships that link subsurface velocity behavior to more easily observable surface signatures. It is well documented that the topography of a coastal zone is an order one influence on nearshore hydrodynamics [Elgar et al., 2001]. The bathymetry influences the entire water column but can be most easily seen on the surface as differences in breaker type [Alagan Chella et al., 2015] and wave shape [Blenkinsopp and Chaplin, 2008]. The wave characteristics needed to distinguish breaker types (as defined by the Irribarren number [Camenen and Larson, 2007]) are discernible through optical and infrared surface measurements [Brodie et al., 2015]. And, for each breaker type, the subsurface velocity profiles are markedly different [Sakai and Iwagaki, 1978]. Additionally, wave height is of particular interest because it affects the subsurface velocity profile [Veeramony and Svendsen, 2000] and can be measured from an Unmanned Aircraft System (UAS).

Here, we collect the necessary surface and subsurface data to test the hypothesis that surf-zone surface measurements can predict subsurface velocity profiles extending to the bed. We use co-located remote and in-situ measurements to quantify the relationship between the surface characteristics of breaking waves and subsurface velocities. Once these relationships are established, it will be possible to collect subsurface velocity data solely with remote methods, negating the need for in-situ velocity measurements. This will expand the options for coastal data collection, aiming to make collecting new datasets in energetic regions less expensive, labor intensive, and thus more accessible.

METHODOLOGY

Before using video-based surface velocity measurements to predict subsurface velocity, we tested if video cameras and particle image velocimetry (PIV) techniques could reliably measure surface velocities without seeding. The camera-derived velocities agreed with the measurements of a co-located acoustic doppler velocimeter (ADV) within 12-16% error. From these experiments, we found that surface velocity needed to be combined with geometric measurements such as wave height from the long-shore oriented cameras to begin to predict the velocity profile below the breaking wave. To further investigate the surface-subsurface relationship, we conducted a series of deployments at the Field Research Facility (FRF) in Duck, North Carolina. Each deployment consisted of three sensors (Figure 1): 1) a light detecting and ranging (LiDAR) scanner-equipped UAS to measure the evolution of geometric wave properties such as wave height, length, vortex length and width, 2) a video camera-equipped UAS to record and measure surface velocities, and 3) a bottom mounted acoustic doppler current profiler (ADCP) to measure the subsurface velocity and pressure.

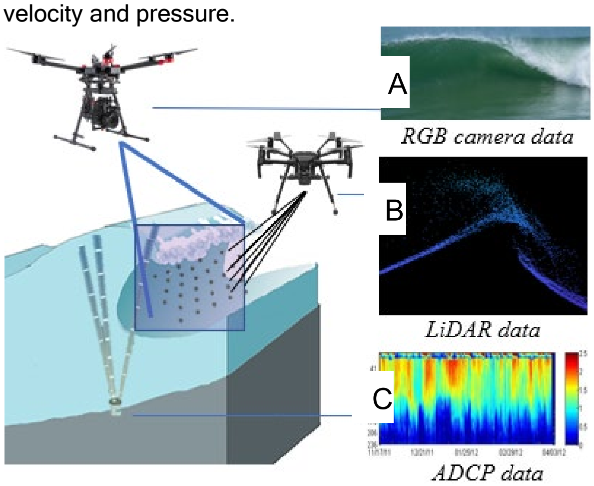

Figure 1: The instrument array used to measure wave shape and subsurface velocity consists of a drone equipped with an optical camera (top left) that records video of the nearshore surface (A); a drone-based LiDAR scanner (center) that collects three dimensional point clouds of the surface as waves break (B) [O'Dea, 2021]; and an upwards looking ADCP (bottom left) mounted on the bed near the break point in the surf zone for subsurface velocity measurements in the vertical (C) [FAU 2012] (Wave illustration adapted from [Romero 2021]).

The LiDAR UAS used was a Phoenix MiniRanger mounted on a FreeFly Alta X drone. This line scanning system collected two-dimensional cross-shore transects of the sea-surface elevation directly above the submerged ADCP (Figure 1).

The geometric measurements derived from the two-dimensional LiDAR dataset were dependent on the breaking regime of the wave as it passed over the ADCP. For shoaling, unbroken waves, we calculated surface elevation (relative to mean sea level), wave height, skewness, asymmetry, steepness, and area under the crest. For breaking waves, we calculated these shoaling measurements in addition to the Irribarren number. From broken waves, we measured bore height and the leading-edge angle.

The surface velocities were quantified using videos obtained with the camera-equipped UAS and Matlab based PIV program PIVLAB [Thielicke and Sonntag, 2021]. Bore speeds of broken waves were calculated by intensity thresholding a grayscale version of each frame to identify the bore centroid and tracking its displacement between frames.

The ADCP and video data were downsampled to match the sampling frequency of the LiDAR data, then all three were time synchronized. From these synchronous datasets, each measured parameter had a separate time series that was parsed into three groups: 1) ADCP: subsurface velocities measured in 20cm increments from the bed to the surface, 2) Camera UAS: surface velocity cross-shore and long-shore components, velocity magnitude, and surface vorticity and 3) LiDAR UAS: all the above-mentioned geometric parameters derived from the LiDAR data.

For each time step, the ADCP velocities were transformed into an equation that represents the profile using a best fit approach [Craig, 1996]. The data when no waves were passing the measurement area were discarded. Using the remaining data, a principal component analysis (PCA) of all the surface geometry and velocity metrics were used to identify which control the subsurface velocities. PCA assumes linear relationships, thus additional tests that are sensitive to nonlinear dependencies, such as a continuous analysis of variance test, were applied where appropriate based on the PCA results. Once the surface characteristics that were best able to predict subsurface velocity were identified, a dimensional analysis was used to attempt to quantify the surface-subsurface relationships.

RESULTS

Using the data set outlined above from underwater ADCP velocity measurements and co-located remote sensing techniques, we present a quantified empirical relationship between surface wave characteristics and subsurface velocity behavior in the surf-zone. For current-dominated, offshore flow between wave crests, the surface velocity measured by cameras has good skill in predicting the profile of the subsurface velocities. Preliminary results from observations of spilling-type breaking waves suggest that wave height and steepness are important parameters for predicting the subsurface velocity profile. Additionally, we found that the underwater velocity profile changes as the breaking process evolves, so identification of the stage in the breaking progression is crucial for predicting the subsurface velocity.

DISCUSSION

This initial study attempts to develop a relationship between surface characteristics and subsurface velocities in the surf-zone using synchronous data from collocated UAS mounted cameras and LiDAR scanners and a bottom mounted ADCP. This study is working to generate a set of relations that allow subsurface velocity information to be obtained without any in-situ velocity measurements and instead with shore-based or other remote methods.

The results show promise for a set of relationships that can be used to generate reliable synthetic subsurface velocity values in various wave conditions. Combining this with other data obtained remotely, such as beach morphology changes [Brodie et al., 2018], will allow us to more precisely quantify the hydrodynamic behavior responsible for morphological change. This quantitative understanding is imperative for being able to predict both short term and long-term changes to coastal environments.

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