NEARSHORE WAVE AND CURRENT DYNAMICS

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LONG-TERM GOAL

The long-term goal of this research is to increase our understanding of nearshore (shoreline to nominally 15 m depth) dynamics and to enhance our predictive modeling of waves, currents, and bathymetry in that region.

SCIENTIFIC OBJECTIVES

Present scientific objectives of this program are to increase our understanding and modeling of:

- Mean current dynamics over alongshore-varying topography,
- Shear instabilities of the alongshore current (50 to 1000 s periods),
- Infragravity wave (20 to 200 s periods) dynamics,
- Short-wave (sea and swell, 3 to 20 s periods) dynamics across the nearshore,
- Nearshore bathymetry.

APPROACH

As field observations have become more detailed and have covered a broader sample of natural surf zones, the weaknesses of some of our simpler models have become evident (e.g., present model prediction of alongshore currents on a barred beach). As a result, new models are evolving. However, these next-generation models are more complex and therefore more susceptible to developing on a path incompatible with field studies and prediction.

We believe that such a pitfall can be avoided if there is active cooperation between field observationalists and modelers. Such a cooperation will result in the development of models that can accept input parameters provided by field observations and provide as outputs parameters that can be compared with field data. Also, such a collaboration is also useful for the effective design of field experiments.

The two P.I.s on this project are a nearshore wave and current dynamics observationalist/data analyst (Joan Oltman-Shay) and theoretical/numerical modeller (Uday Putrevu). Our approach is to investigate nearshore fluid dynamics using theoretical, numerical modeling, and field observation

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methods. Our motivation is the development of new models, or adaptations and extensions of existing models, that can be driven by and compared with field measurements

WORK COMPLETED

We have successfully completed the following:

- > An evaluation of the limitations of using a simple model to evaluate the effects of alongshore variations of topography for longshore currents (Putrevu *et al.,* 1995; Sancho *et al.*, 1997),
- > An extension of the dispersive mixing of momentum (Putrevu and Svendsen, 1997)
- > An evaluation of how nonplanar topography influences edge waves (Putrevu and Oltman-Shay, 1997), and
- > An evaluation of the effects of forcing on shear waves in the nearshore (Haller *et al*., 1997)

RESULTS

Sancho, Svendsen, and Putrevu, 1997 (Modeling of longshore currents over longshore nonuniform topographies: Effects of second-order terms, in preparation, *J. Geophys Res*). As discussed below, Putrevu *et al*. (1995) found that alongshore inhomogenieties of the bottom topography induce alongshore pressure gradients which can significantly influence the longshore currents. For the case in which the alongshore variations of the bottom topography are weak, Putrevu *et al.* suggested that the alongshore pressure gradient can be calculated in a simple way. This work was designed to evaluate the limitations of the simple model proposed by Putrevu *et al.* The results show that the Putrevu *et al.* model works in cases in which the alongshore variations in the bottom topography vary over lengths that are long in comparison with the surf zone width. For cases in which the alongshore variation of the topography occurs over relatively short distances (like, *e.g.*, in a rip-channel) the simple model of Putrevu *et al.* does not work even if the absolute magnitude of the changes is relatively small.

Haller, Putrevu, Oltman-Shay, and Dalrymple, 1997 (Wave group forcing of low frequency surf zone motion, in preparation, *J. Geophys. Res*.). In this work, we investigated the effects that wave group forcing has on shear instabilities in the nearshore region. This work was motivated by the results of Dodd *et al.* (1992) and Shrira *et al.* (1997). Dodd *et al.* found that Bowen and Holman's (1989) instability theory fails to explain the observations of shear waves on planar beaches. (The theory predicts that the instabilities will be damped out due to friction for realistic values of the bottom friction.) Shrira *et al.* showed that shear waves that are expected to be damped out by friction in the Bowen and Holman theory could grow to significant amplitudes due to triad interactions provided their initial amplitudes excceded a certain critical value. However, how such initial (small amplitude) shear waves are generated remains unexplained in the work by Shrira *et al*. In this work we showed that the direct forcing by wave groups sets up oscillations that are remarkably similar in all respects to shear waves. We further showed that the forced response is extremely strong and could easily provide the initial amplitudes required by the Shrira *et al.* model. We then analyzed field data from the NSTS and SUPERDUCK experiments and showed that there is significant evidence that the forcing required to set up these initial oscillations existed during these experiments.

Putrevu and Svendsen, 1997 (Shear dispersion in the nearshore, in revision, *J. Fluid Mech*.). In this work, we extended the results of Svendsen and Putrevu (1994) to the general case in which the assumptions of alongshore uniformity and steady state are abandoned. This work showed that it is possible to account for the dispersive-mixing effects of the vertical nonuniformity of the short-wave-averaged velocity field over an abitrary bottom topography without resorting to a fully three-dimensional calculation. The results, however, are far more complicated than the results for the simple situation considered by Svendsen and Putrevu (1994). In particular, this work shows that the results obtained by Svendsen and Putrevu represent only the leading term of the complete result. The importance of these additional terms is at present unknown.

Putrevu and Oltman-Shay, 1997 (Influence functions for edge wave propagation over a nonplanar bathymetry, *Phys. Fluids*, in press). In this work we investigated how nonplanar features influence the propagation of edge waves. To do this, we assumed that the bottom topography over which the infragravity waves propagate was broken down into a base profile (*e.g.*, a planar profile) and a deviation from the base profile. The edge-wave quantities (*i.e.*, surface elevation and wavenumber) were similarly expanded. We found that when these expansions are substituted into the edge-wave equations, the lowest order edge-wave problem reduces to the problem of edge waves propagating over the base profile (whose solution is known by assumption), and the next order problem gives us the corrections to this base solution. We found that the correction to the dispersion relationship is proportional to the (cross-shore) integral of the product of the bottom perturbation and an "influence function". This influence function has its maximum at the shoreline and decays away from the shore. Also, the magnitude of the influence function increases with edge-wave mode. These results show that the dispersion relationship is more sensitive to the features at the shoreline and quite insensitive to features at moderate distances from the shore, thus explaining the differences between Holman and Bowen's (1979) and Kirby *et al*.'s (1981) results. Our results also lead us to conclude that the higher modes are more sensitive to shoreline features than the lower modes. The effect of deviations from planar topography for the spatial structure similarly can be expressed in terms of influence functions, but are slightly more complicated.

Putrevu, Oltman-Shay and Svendsen, 1995 (Effect of alongshore nonuniformities on longshore current predictions, *J. Geophys Res. 100*, 16119-16130). This work demonstrates that the often neglected alongshore bathymetric inhomogeneities in the surf zone induce alongshore pressure gradients that can contribute at first order to the forcing of longshore currents. This point is demonstrated via both an ordering argument, and by examination of analytical solutions of the depth-integrated, wave-averaged equations of mass, momentum, and energy. The work differs from previous efforts in considering the effect of bathymetric inhomogeneities within the surf zone, in isolation of the bathymetric inhomogeneities outside the surf zone that lead to alongshore variations in breaker height. In addition, this analytical study provides the tools to assess the importance of alongshore pressure gradients for varying wave and beach conditions.

Oltman-Shay, Putrevu, Kirby, and Wei, 1995 (Radiation stresses in the Boussinesq approximation: Part 1 -- Intermediate depth and Part 2: Moderately nonlinear waves, AGU 1995 Fall Meeting presentations). In this work, we calculated the radiation stresses of moderately nonlinear waves propagating over a horizontal bottom using the Wei *et al*. (1995) Boussinesq model and compared the results with those obtained from linear wave theory. The comparisons showed that, in this regime, the difference between the radiation stresses derived from full, nonlinear wave theory and from linear wave theory depends on the Ursell number [the ratio of nonlinearity parameter (wave height/water depth) and the square of the frequency dispersion parameter (wavenumber multiplied by the water depth)]. Specifically, the results showed that for Ursell numbers greater than 1, the Boussinesq-derived radiation stresses are increasingly less than the linear-theory-derived radiation stresses. For example, for an Ursell number of 4, the radiation stress calculated from the Boussinesq model is only about 70% of that estimated from linear theory. This means that using linear theory to calculate the forcing for short-wave-averaged motions leads to a significant over-estimation of the forcing even for moderately nonlinear waves.

In addition to the above basic research (ONR Contract N0001496C0075), Oltman-Shay and Putrevu are working on an applied project (ONR Contract N0001495C0217) to design and test a “Beach

Probing System (BPS).” The BPS measures the offshore (of the breakers) wind and infragravity wave field to estimate the inshore bathymetry and the wave and current conditions. This application is a direct result of basic research on nearshore infragravity waves conducted by the nearshore community of scientists under ONR Coastal Dynamics sponsorhip. Oltman-Shay and Putrevu continue to do basic research on infragravity dyanmics, in part guided by their BPS work. The Physics of Fluids paper (“Influence functions for edge wave propagation over a nonplanar bathymetry”), discussed above, was motivated by the BPS effort.

A detailed presentation of the objectives and approach of the BPS project can be found in the technical proposal (Oltman-Shay, 1996). The work completed, the results, and the next steps of this five-year project are discussed in the semi-annual reports (Oltman-Shay *et al*., 1996, 1997).

IMPACT/APPLICATION

Scientific results that will influence the modeling of nearshore waves and currents include the following:

It is important to account for alongshore nonuniformities of the bottom topography. For instance, the alongshore current could deviate by up to 30% from the mean for a 10% deviation of the bottom topography, and the location of maximum current variability is inshore of the location of maximum topography variability. Existing models of alongshore currents (which typically assume alongshore uniformity) easily can be extended to include minor alongshore variations as long as these variations occur over lengths that are much larger than the surf zone width.

It is possible to account for the dispersive mixing effects of the vertical nonuniformity of the short-wave-averaged velocity field over an abitrary bottom topography without resorting to a fully three-dimensional calculation.

Although it has been shown previously that edge wave propagation is strongly influenced by shoreline bathymetric features (Oltman-Shay and Guza, 1987; Oltman-Shay and Howd, 1993), it is now apparent that higher mode edge waves are more influenced to shoreline features than are lower mode edge waves, even though these higher modes are propagating over a larger region of the nearshore than the lower modes. In addition, it is now understood that the relative significance of the myriad of shoreline features on the edge wave solutions is different for the dispersion relation solution and the cross-shore variance solutions.

The use of linear theory to calculate the forcing for short-wave-averaged motions leads to a significant over-estimation of the forcing even for moderately nonlinear waves.

RELATED PROJECTS

Our basic research efforts are closely tied to the modeling efforts of Drs. Ib Svendsen, James Kirby, and Tony Dalrymple, and the modeling and field work of Dr. Ed Thornton. We are working with Dr. Kirby on this ONR project, and we are collaborating with Drs. Svendsen, Dalrymple, and Thornton on our ONR Waves BAA project, Nearshore Circulation on Variable Bathymetry.

Oltman-Shay is a member of the planning and reporting committee for the February 1997 Tactical Oceanography Symposium on Naval Special Operations, sponsored by the Chief of Naval Operations, Chief of Naval Research, and organized by the National Research Council of the National Academy of Sciences.

Oltman-Shay participated (Sept 1995) in the "Symposium for Meterology and Oceanography for Ship Shelf Defense and Strike Warfare" sponsored by the Chief of Naval Operations, Chief of Naval Research, and organized by the National Research Council of the National Academy of Sciences.

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