

Spectral Wave Decay due to Bottom Friction on the Inner Shelf

Timothy P. Stanton

Oceanography Department

Naval Postgraduate School

Monterey, CA 93943-5000

phone: (831) 656 3144 fax: (831) 656 2712 email: stanton@oc.nps.navy.mil

Edward B. Thornton

phone: (831) 656 2847 fax: (831) 656 2712 email: thornton@oc.nps.navy.mil

Award#: N0001402WR20017

<http://www.oc.nps.navy.mil/~stanton/showex/>

LONG TERM GOALS

Long term goals are to observe and model wave and current boundary layer processes above mobile beds to determine wave dissipation and wave-bed interactions in coastal and nearshore regions using novel instrumentation techniques.

OBJECTIVES

The primary scientific objective of this project is to measure the bottom dissipation of surface gravity waves as they shoal across the continental shelf as a component of the Shoaling Waves Experiment, SHOWEX. Detailed observations of the bottom boundary layer (BBL), resolving the thin oscillatory wave boundary layer over a rippled sandy bed, have been made at two sites with differing wave forcing, mean currents and sediment bed types. Analyses from these datasets are being used to develop a spectral wave dissipation model for the continental shelf. At each site, continuous maps of the small-scale morphology have been made in an area surrounding the detailed bottom boundary layer measurements to study changes in the bed in response to wave forcing, and to relate the effects of these morphology changes on turbulence in the BBL. A spectral dissipation model is being developed to include effects of a wave-forced mobile bed, and parameterizations for low frequency currents including strong baroclinic tidal and wind-driven currents.

APPROACH

Two long term inner shelf observation sites were established to measure wave and current forcing and detailed measurements of BBL - bed responses. The Monterey Inner Shelf Observatory (MISO, Stanton 1999) has a shore-cabled instrument frame at 12m depth in the southern end of Monterey Bay at a site with .15mm mean diameter sandy bed and moderate, primarily narrow band, long period swell forcing conditions. A second site was established in 11m of water offshore from the Duck pier between 28 September and 10 December 1999 during the main SHOWEX observation program. The Duck site has significantly finer sediment and forcing is generally shorter period, with frequent energetic wave forcing, and strong, low frequency, alongshore currents in comparison with the Monterey site. A

nearly continuous two year wave forcing and bed map timeseries at the Monterey Bay site has been completed, providing a unique data set to test ripple formation models over a wide range of seasonal wave forcing conditions.

At each field site, dissipation rates in the bottom boundary layer have been estimated from $O(1\text{cm})$ resolution, three component velocity profiles measured by a Bistatic Coherent Doppler Velocity Profiler (BCDVP) instrument (Stanton 1996, 2001, 2002). These instruments measure vertical profiles of velocity and sediment concentration over a 60 cm range above the bed at a 40Hz rate. These small-scale measurements of the bottom boundary layer are extended through the water column with high speed Broad Band Acoustic Doppler Profilers. Wave dissipation rates in the mean current and wave-forced bottom boundary layer are being estimated by decomposing mean, wave, and turbulent components of the three component velocity vector profiles to estimate the wave work term that dissipates wave energy in the WBBL. The co-located measurements of the velocity vector profiles and sediment concentration also allow the sediment buoyancy terms in the TKE balance in the bottom boundary to be estimated when sediment suspension is occurring.

As the local sediment morphology can greatly influence the characteristics of the bottom boundary layer, a two axis scanning sonar altimeter was developed and deployed to quantitatively measure finescale morphology over a 2 by 2 m area spanning an area below the BCDV profile measurements, with 2cm horizontal and 0.25 cm vertical resolutions and 15 - 25 minute sampling. These local morphology maps were extended at the Duck site by qualitative 2D side-scan morphology images out to a 10m radius around the instrument frame to identify larger scale morphological features. In addition, cross-shelf side-scan swaths of larger scale bed features were measured with a multibeam survey sonar from the R/V Creed in collaboration with Fred Dobson to estimate mobile bed changes to strong forcing events.

Four modeling efforts are in progress to test morphology evolution and wave dissipation parameterizations. A new version of Don Slinn's DNS model of turbulent flow over a sampled bed-form is being run at NPS. The resulting velocity fields have been resampled in time and space with a modeled BCDVP response to assess the robustness of the stress, shear and shear production method used estimate wave dissipation rates in the oscillatory boundary layer. The DUNE2D boundary layer model for small-scale morphology, (Andersen, 1999), has been used by a graduate student, LCDR Steve Martin, to model bedform evolution at the Duck site. This 2D model is significantly less expensive than the DNS to run on ocean-scale 2D domains, and is being used to test simple morphology formation models using forcing and mapped morphology from the Duck site. A further model / data comparison has been made in collaboration with a doctoral student, Emily Zedler and her dissertation supervisor Bob Street at Stanford. Emily's LES model has successfully simulated a morphology / forcing case sampled from a storm during SHOWEX.

The objectives in our modeling efforts are to test and improve on existing ripple formation models based on spectral wave forcing and prescribed mean currents, and to compare predicted wave stress and wave work rates with the SHOWEX observation timeseries. The BBL dissipation formulations will be tested against *in situ* cross shelf directional wave buoy observations being made by Herbers and O'Rielly at the SHOWEX site, and incorporated into a shelf wave model being developed by Phd student Fabrice Arduin and Tom Herbers (Arduin et al, 2000).

WORK COMPLETED

Analysis of data from prototype versions of the BCDV and scanning altimeter used during SandyDuck and the SHOWEX observations have allowed techniques to be developed for estimating Reynolds stresses and dissipation rate profiles across the thin oscillatory boundary layer above a sloping and rippled bed. Part of this work has been accomplished with theoretical contributions from NICOP collaborators Paolo Blondeux and Geovana Vittori. (Blondeaux et al 1999 and 2000).

Results from Direct Numerical Simulations of a randomly forced oscillatory bottom boundary layer developed by SHOWEX collaborator Donn Slinn are being used to explore how the finite sample volume, vertical profiles of velocity made by the BCDV can be optimally used to measure the wave dissipation rates. High resolution model output from both a flat bottom run and a sinusoidal rippled bed have been “sampled” using the acoustic response of the BCDV to investigate what part of the stress and strain and shear field is resolved by the instrument, and importantly, what turbulence terms contributing to dissipation are not resolved. These detailed simulations suggest that the limited resolution oscillatory boundary layer measurements made with the BCDV adequately resolve the dominant wave-induced shear production terms across the oscillatory boundary layer for bed morphologies observed both at Duck and Monterey Bay, although final comparisons are awaiting the completion of runs from modified codes. Favorable comparisons of flow fields and sediment transport were achieved with a large domain LES model with a bed morphology adapted from SHOWEX observations, forced with the observed free-stream wave velocity (Zedler 2002).

A processing technique has been developed to analyze the long time series of bed morphology maps made by the X/Y altimeter. The processing extracts dominant ripple direction, crest lengths, ripple height and wavelength statistics from each map. A MS thesis project was completed (Blodgett 2002) performed a statistical analysis of these bed response timeseries to selected wave and current forcing parameters for the Monterey Bay MISO timeseries. A similar analysis has been completed for the Duck SHOWEX site, and a manuscript describing the bed response and comparison with existing laboratory-based models is in progress.

RESULTS

Analysis of the 0.6cm resolution vertical profiles of three component velocity measured by the BCDV have allowed the near-bed vertical Reynold's stress profiles to be estimated while minimizing the contributions of the strong wave-induced oscillatory flow to the cross-shore $\langle v'w' \rangle$ correlations. Under moderate to strong wave conditions, the stress profile is resolved across the 4 to 10cm thick oscillatory boundary layer allowing a τ_{0w} wave bed stress to be estimated. The resulting wave work rate compares favorably to the integrated wave shear production term estimated across the oscillatory boundary layer. Stanton 2002a describes the BCDV instrument and it's application to measuring turbulent stresses and dissipation in the wave bottom boundary layer. DNS modeling of a forcing / bedform case selected from the Monterey Bay MISO data set are currently being re-run following model changes. These model data will be compared with the more coarsely sampled BCDV velocity measurements to determine unresolved turbulent terms. Techniques developed to measure and characterize small scale bed morphology during SHOWEX are described in Stanton 2002b. These analysis techniques have allowed the role of forcing factors including mean currents, orbital displacement, wave directional spread, wave groupiness and swell wave asymmetry on the bed formations to be statistically inferred for the SHOWEX duck and MISO sites. A paper including Bill

Blodgett's wave / current forcing analysis from his MS thesis results is being prepared. These morphology changes are being compared with selected timeseries of BBL turbulence to assess morphology contribution to a net friction factor which can be applied to a fine scale regional model.

IMPACT / APPLICATIONS

Observations of cross-shelf wave shoaling and energy loss under low wind conditions across the continental shelf (for example Herbers et al, 2000) suggest that bottom dissipation is a zero'th order term in the cross-shelf wave evolution. Modeling of bottom dissipation in coastal regions will directly improve shelf wave models, which have wide ranging navy and civilian applications.

TRANSITIONS

Improved field measurements of the wave and current forced BBL are being used to improve high resolution wave models over the continental shelf.

RELATED PROJECTS

This research has benefited from and contributed to the ONR-sponsored SandyDuck program in the development and deployment of the scanning X/Y altimeter and the prototype BCDV, which address overlapping issues in both programs, and to the upcoming NCEX field program.

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