Characterization of Environmental Parameters Affecting Bed Stability

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LONG-TERM GOAL

The goal of the project is to support the Mine Burial Prediction (MBP) modeling efforts by providing characterizations of environmental parameters affecting bed stability (especially waves, currents and tides) at the MBP study sites and other sites of interest.

OBJECTIVES

The objectives of this study are to: 1) provide information about the spatial and temporal distribution of bed shear stress due to waves, tides and currents to MBP investigators working on bedform migration and scour processes; 2) evaluate models that provide hindcasts and/or forecasts of environmental forcing (waves, currents) against available data; and 3) investigate the data requirements (quality and quantity) for meaningful estimates of bed shear stress distributions.

APPROACH

My approach during the current phase of the MBP program has been to use available measurements (e.g., wave buoy data) and models (e.g. the Wave Watch III wave model) of environmental parameters to characterize the potential for mobilizing the seabed. Measured and modeled wave conditions were compared to evaluate the skill of model hindcasts and forecasts at the sites of the upcoming field experiments at Martha's Vineyard and Indian Rocks Beach. As measurements of waves, currents and resuspension become available from these sites, these will be added to the characterization and used to test the models.

WORK COMPLETED

During FY02, we compared buoy measurements of wave characteristics to hindcasts and forecasts from the WAVEWATCH III (WW3) global wave model. The model and measurements were then used to characterize wave and bed shear stress conditions at selected sites. We focused on three sites: the area southeast of Cape Cod (NDBC Buoy 44008), the northeast Gulf of Mexico (Buoy 42036), and the Eel River shelf, California (Buoy 46022). The first two of these are sites of the MBP intensive field studies of mine burial by scour and bedform migration. The Eel shelf was the site of another intensive sediment transport study (in STRATAFORM), for which in situ data are available. Comparisons included wave height and period statistics, daily average wave conditions, and bottom wave orbital velocity for the period from 1997-2001. WW3 predictions of wave conditions during spring 2002 were also compared to measured conditions. The results indicate that the WW3 model

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14. ABSTRACT
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15. SUBJECT TERMS

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performs well at the selected sites. The model was then used to examine the potential for sediment mobilization at a range of depths at each site.

RESULTS

Comparison of wave statistics

Distributions of significant wave height and dominant period were calculated for the 3 focus sites. Wave heights and periods from the WW3 global wave model included all 3-hourly calculated values from Feb 1997 through 2001. Buoy-measured wave heights and periods included all recorded values from 1997 - 2001. Measured and modeled wave height distributions agreed well for the east-coast sites, although the percentage of values near the modal wave height was overestimated at Buoy 42036 (W. Tampa). The distribution of calculated wave heights for the northern California site (46022) under-represented small wave heights and the modal percentage compared to the measured values. In part, these levels of agreement reflect the greater effort within the WW3 program on modeling the western north Atlantic. Distributions of calculated peak wave frequency ($1/T_p$) appeared systematically higher (peak periods systematically lower) than values determined from measured wave spectra. Near-bed orbital velocity and bottom shear stress depend on both wave height and period, but are generally more sensitive to wave height.

Comparison of daily averaged wave conditions

To determine the accuracy of the WW3 wave conditions, time series of daily-averaged calculated significant wave height and peak period were compared with time series of daily-averaged measured values for the 3 study sites. Time series for Buoy 46022 (Eel shelf) during 2001 are used to illustrate the level of agreement. Scatter plots of measured (NDBC) vs. calculated (WW3) heights and periods (Figure 1) include data from all 3 stations from 1997-2001 (dot colors differ by year). Daily-averaged measured and calculated daily-averaged wave heights peak are well correlated, with an average r^2 for the 5 years of 0.86-0.90. Calculated peak periods tend to underestimate measured values by an average of 1.3 s (44008) to 0.4 s (42036); average r^2 for the 5 years is 0.4-0.6.

Orbital velocity and bed shear stress

On most continental shelves, sediment transport depends strongly on high wave-generated bed shear stresses. These shear stresses, in turn, depend on near-bed wave orbital velocity, which can be determined from high frequency (>1 Hz) measurements of near-bed current or calculated from surface wave-height spectra. These two methods of determining orbital velocity have been shown to be in good agreement at sites in water depths of 50 m and greater on the California shelf. Near-bed wave orbital velocities calculated directly from hindcast significant wave height and peak period alone overestimated the values calculated from the measured wave spectrum by almost a factor of 2. . However, using a JONSWAP spectrum to estimate the full spectrum given significant wave height and peak period (iterating until significant wave height inferred from the spectrum was equal to the specified H_s) yielded estimates of orbital velocity in excellent agreement with those determined from the measured spectra (Wiberg and Haney, 2002).

Bed shear stresses were calculated from orbital velocity using a wave friction factor. There was good agreement between cumulative distributions of orbital velocity and bed shear stress at depths of 30, 60, and 90 m on the Eel shelf (Buoy 46022) calculated from WW3 hindcasts and from NDBC buoy data. Distributions of bed shear stress vary with wave conditions and depth. The distributions calculated for a depth of 30 m based on WW3 hindcasts from 1997-2001 indicate large differences in shear stress among the 3 selected sites (Figure 2). These differences in bed stress will be reflected in differences in sediment transport. For example, taking a nominal threshold of motion of 1 dy/cm^2, the Eel shelf experiences sediment transport at a depth of 30 m >90% of the time compared to <10% on the Florida shelf near Tampa (Figure 2). These analyses can be readily extended to larger coastal regions using the WW3 model hindcasts.

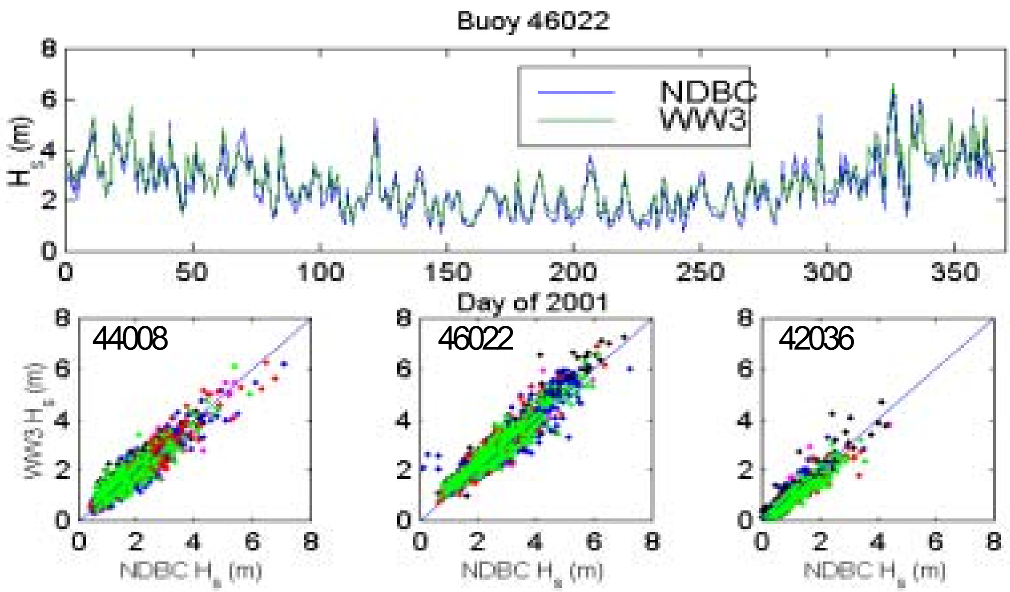

Figure 1. Comparison of wave heights measured by NOAA surface wave buoys and predicted by the WW3 wave model for 3 sites: Buoys 44008 (Nantucket, MA), 46022 (Eel shelf, CA) and 42036 (W. Tampa, FL). The year-long time series (for Buoy 46022) and the scatter plots showing 5 years of data (1997-2001) indicate good agreement between measured and modeled wave height.

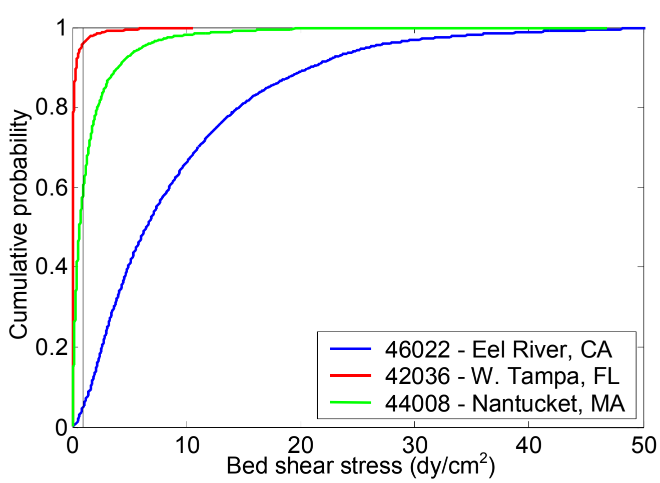

Figure 2. Cumulative probability of wave-generated bed shear stress exceeding values from 0 – 50 dy/cm^2 at a depth of 30 m for three sites. The Eel shelf is the most energetic of the three, with bed shear stress exceeding 7 dy/cm^2 50% of the time. In contrast, more than half the time the wave-generated bed stress at the Nantucket and W. Tampa sites is less than 1 dy/cm^2.

WW3 provides 5-day wave forecasts based on NOAA/NCEP 5-day wind forecasts. These forecasts were compared weekly with measured wave conditions at NDBC buoys 44008 and 42036 during March-April, 2002 (Figure 3). Predicted wave heights were generally close to measured values (Figure 3). Near the Martha's Vineyard (MV) site (Buoy 44008), the r^2 of measured vs. predicted wave heights was 0.58 for the 5-day forecasts and 0.71 for the first 1.5 days of the forecast (the length of the COMPS current forecasts); corresponding values near the Indian Rocks Beach (IR) site (Buoy 42036) were 0.67 and 0.82. The correlation was not as good for peak period. The r^2 of measured vs. predicted period was 0.19 (5-day) and 0.40 (1.5-day) at MV and 0.13 (5-day) and 0.21 (1.5-day) at IR. Near-bed wave orbital velocity and wave-generated bed shear stress are more sensitive to wave height than period, so the errors in predicted wave period are not likely to have a large effect on the resulting orbital velocities. The level of agreement suggests that we may be able to make useful sediment transport forecasts in regions of the shelf where waves dominate bed shear stress using the WW3 forecasts to calculated bottom stresses as shown above for the hindcasts.

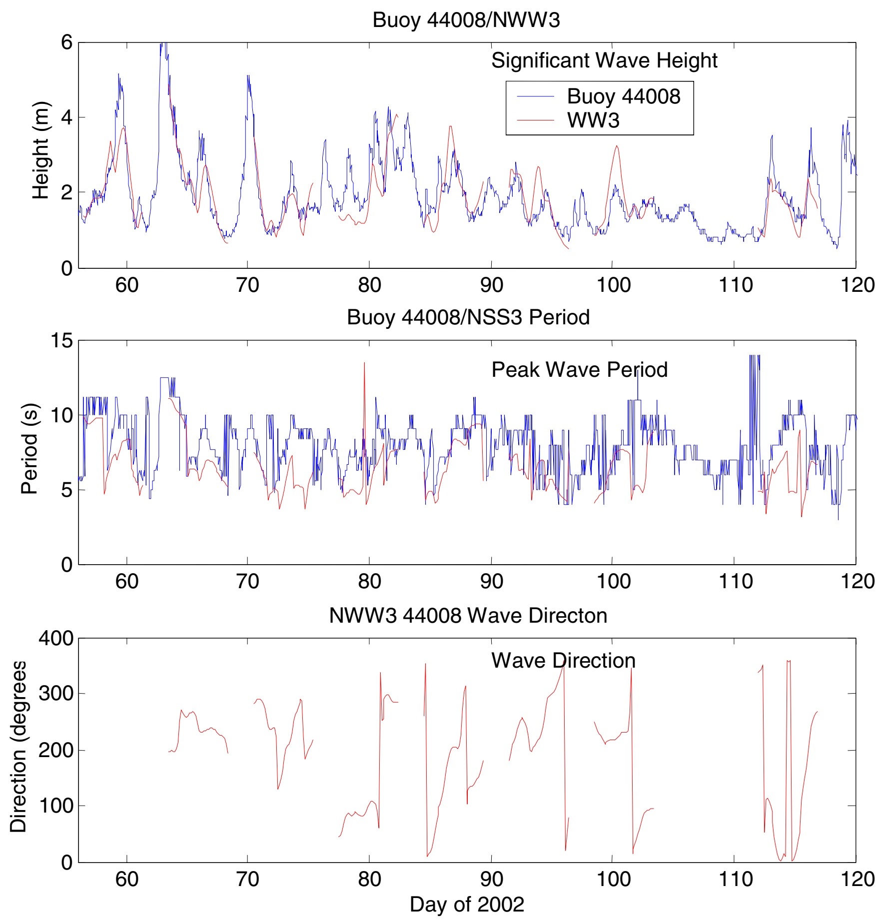

Figure 3. Comparison of predicted (using weekly 5-day predictions; red line) and measured (blue line) wave conditions at Buoy 44008 (Nantucket), The agreement between predicted and measured wave height is good, particularly during the fiest 1-2 days of the 5-day prediction (top panel). Peak wave period tends to be underestimated by ~1s (middle panel). The predictions also provide wave direction, which is not available from the buoy data.

IMPACT/APPLICATIONS

Reliable predictions of wave height and period and wave-generated bed shear stress for several days into the future could be valuable in planning research and operations at sites on the continental shelf. These predictions also make is possible for mine burial models that depend on wave conditions to be run in forecast mode as a test of model skill.

TRANSITIONS

In the next phase of the Mine Burial Prediction program, Carl Friedrichs and I have proposed to provide running 5-day forecasts of environmental variables (waves, winds, currents) and related sediment transport quantities (bed shear stress, suspended sediment concentration, bedload transport rates) at the MBP field sites to the MBP community during the intensive field experiments. The predictions will be made available through a web page at the Virginia Institute of Marine Science and will be linked to the MBP web page.

RELATED PROJECTS

Reliable hindcasts and forecasts of wave conditions and wave-generated bed shear stress at shelf sites around the world would be useful for a variety of sediment transport modeling efforts, including, e.g., the Community Coastal Sediment Transport Model currently being spearheaded by the USGS with initial funding from NOPP.

PUBLICATIONS

Wiberg, P.L. and M.C. Haney, Comparison of wave height and bottom shear stress on the shelf calculated from spectral wave-buoy data and global wave hindcasts and forecasts, AGU Ocean Sciences Meeting, Honolulu, HI, February, 2002.