Three-Dimensional Modeling of Sediment Trapping and Dispersal on River-Influenced Continental Shelves

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LONG-TERM GOALS

The long-term goals of this program are to understand the mechanics of sediment delivery, transport and accumulation on the continental shelf, and to develop predictive models of sediment dispersal and sedimentary strata formation.

OBJECTIVES

The focus of this final year of support under the STRATAFORM Program is the three-dimensional modeling of the shelf processes during floods, including river plume dynamics, bottom boundary layer processes, and gravity-driven transport of fluid mud within the wave boundary layer. The inclusion of turbidity currents within the wave boundary layer is an important addition to the modeling approach that provides more realistic simulations of the cross-shelf sediment transport processes. This model development is an important step toward integrated, 3-dimensional models of sedimentary strata formation.

APPROACH

In a collaborative effort with Courtney Harris of Virginia Institute of Marine Science, a 3-dimensional numerical model (the Princeton Ocean Model) was used to simulate the plume structure and to determine the influence of different forcing variables on the trajectory of suspended sediment. The effort up to the first half of Year 2001 included a "conventional" representation of suspended sediment transport, without an explicit representation of the wave boundary layer. The influence of waves on resuspension was included insofar as it affects the bottom stress and rate of sediment resuspension, but for the "conventional" simulations, the bottommost grid cell was not small enough to resolve the wave boundary layer. A set of sensitivity studies was performed with the conventional model to determine the extent to which the model could reproduce the observed sediment transport on the Eel River shelf during the events observed in the winters of 1997 and 1998.

A one-dimensional numerical model was developed to test parameterizations of wave boundary layer processes which were included in the three dimensional model. This simplified one-dimensional model was tested against data taken at the K-60 site on the Eel Shelf and against a high resolution Mellor & Yamada turbulence closure model developed by Strataform Investigator Chris Reed and subsequently modified by us to include gravitational forcing. Both model parameterize resuspension for the seafloor

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14. ABSTRACT
The long-term goals of this program are to understand the mechanics of sediment delivery, transport and accumulation on the continental shelf, and to develop predictive models of sediment dispersal and sedimentary strata formation.

15. SUBJECT TERMS

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in terms of a reference concentration and parameterize deposition by a settling velocity. The primary difference is that the simplified scheme uses a prescribed eddy viscosity turbulence closure with a simple density stratification correction scheme based on the Richardson number at the top of the wave boundary layer while the high-resolution model uses the Mellor & Yamada turbulence closure scheme.

The results of the one-dimensional modeling of the wave boundary layer were used to develop a set of subroutines in the three-dimensional model that represents the transport processes in the wave boundary layer. The wave boundary layer is represented as a separate layer, beneath the conventional model grid, in which the equations for momentum and sediment conservation are solved during each time-step. The thickness of the wave boundary layer is determined dynamically, based on the wave-forcing, currents and depth. Typical wave-boundary-layer thickness for the Eel River shelf simulations is 10 cm—this compares with a typical thickness of the bottom grid cell in the conventional model of 1-m. Resolving the suspended sediment distribution and velocity in the wave boundary layer is essential for quantifying the influence of gravity-driven transport, which is now believed to be the dominant mechanism for cross-shelf transport on the Eel River shelf (Traykovski et al., 2000) and potentially in many coastal environments (Geyer et al., in prep.).

WORK COMPLETED

The sensitivity studies of the “conventional” model simulations have been completed and presented at the Chapman Conference in Puerto Rico in June (Geyer and Harris, 2001). The one-dimensional wave boundary-layer modeling studies have been completed. Portions of this work were also presented in Puerto Rico. The implementation of the wave-boundary-layer model within the 3-D model is underway, with preliminary results discussed below.

RESULTS

The sensitivity confirm that there is no viable mechanism for significant cross-shelf sediment transport when only conventional sediment transport processes are included. Performing realistic simulations of the 1997 Eel River flood with a generous range of model parameters, e.g., settling velocity, wave amplitude, resuspension rate, there were no combination of parameters that would lead to significant deposition on the middle shelf. Some of the runs (e.g., high waves or low settling velocities) produced significant offshore transport and dispersion, but these did not produce a mid-shelf flood deposit as observed. Higher settling velocities and lower wave energy would produce flood deposits, but they were confined to the inner shelf (less than 40-m water depth), whereas the observed flood deposit extends from 55 to 90-m water depth.

The one-dimensional model studies indicate that the simplified scheme is able to capture the essential features of the offshore gravitational flow in the wave boundary layer (Figure 1). Both the high resolution model and the simplified scheme show concentrations of ~200 g/l in the wave boundary layer with associated offshore gravitationally forced velocities of 15 to 20 cm/s. The slight difference in the velocity and sediment profiles due to the different turbulence closure schemes employed should not be significant in the 3-dimensional model.

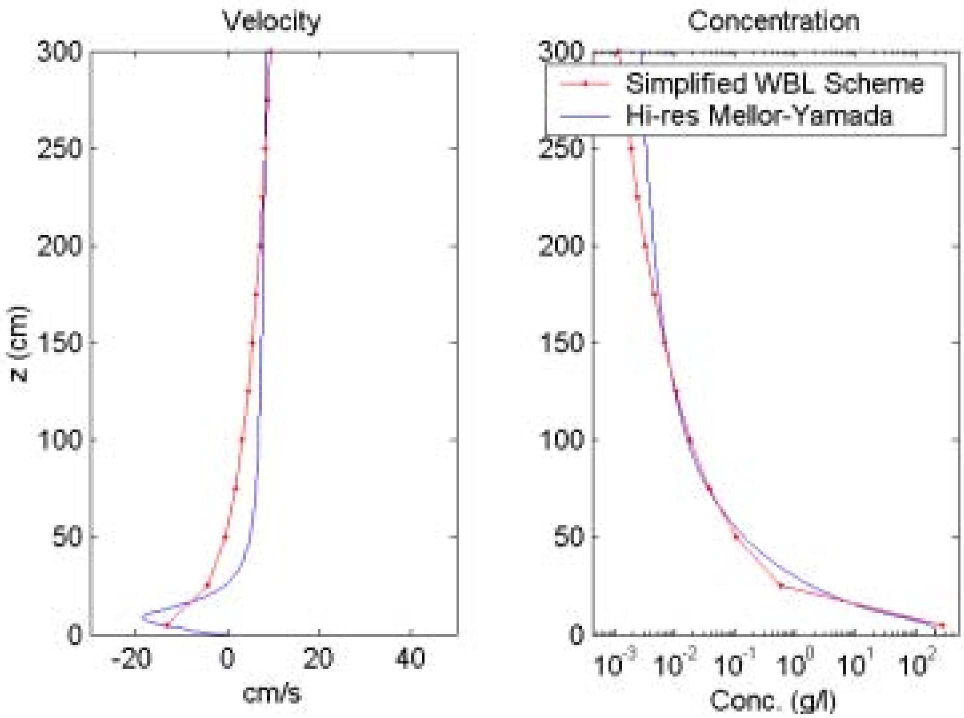

Figure 1. Velocity (left) and Concentration (right) profiles from the simplified 1-d gravitational forcing scheme developed for use with the 3-d model and a high vertical resolution Mellor & Yamada turbulence closure scheme.

The three-dimensional simulations with the wave-boundary-layer are still preliminary; they represent tests of the model implementation rather than predictions or hind-casts of actual sediment transport events. However, these tests have progressed far enough to reveal a significant role of the wave-boundary-layer in cross-shelf sediment transport. The concentrations in the model wave-boundary layer are found to reach fluid mud concentrations (more than 300 g/l), and the gravity-induced, offshore velocity reaches 20 cm/s in the wave-boundary layer. The associated sediment flux is the dominant fraction of the offshore transport in these simulations, apparently large enough to account for the mid-shelf flood deposit.

IMPACT/IMPLICATIONS

The inclusion of the wave-boundary layer in the 3-d model is a major step in the development of realistic models of continental shelf sediment transport. The observations of the Eel River sediment transport and deposition patterns clearly implicated wave-boundary-layer processes as potentially dominant in the offshore transport of sediment. This model implementation provides a tool that can be applied in the detailed investigations of that mechanism and in the prediction of strata formation. It is likely that wave-boundary-layer sediment transport processes are relevant in a large number of continental shelf environments, thus this type of model formulation will likely become a standard and essential part of future sediment-transport models. This type of formulation is necessary for a broad suite of Navy-relevant issues, including the prediction of the near-bottom turbidity, seabed characteristics, sediment deposition and erosion, and the time evolution of seabed morphology.

TRANSITIONS

The results of the sensitivity studies and the one-dimensional modeling studies were presented at the Chapman Conference on the Formation of Sedimentary Strata on Continental Margins in Puerto Rico in June, 2001 (Geyer and Harris, 2001). These presentations allowed us to communicate these methodologies to many of the leading researchers in the observations and modeling of shelf sediment transport processes. The recent developments and results of the three-dimensional wave-boundary-layer modeling will be communicated at the STRATAFORM Modeling Coordination Meeting in October, 2001. These results will also be incorporated into the STRATAFORM Master Volume and in two research papers, one concentrating on the three-dimensional modeling and the other addressing the one-dimensional, wave-boundary-layer model studies.

RELATED PROJECTS

Geyer was lead author and PI on an ONR-funded review of buoyancy-driven sediment transport processes, which has resulted in a review paper that will be submitted for publication in 2001. Geyer is also co-PI on an ONR-funded project to develop rigorous tests of three-dimensional numerical models of river plumes, representing one aspect of the development of community models for coastal oceanographic processes. Geyer is also funded by the by the ONR Harbor Processes Program and the Hudson River Foundation for studies of sediment and contaminant transport in the Hudson River estuary.

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