STRATAFORM Plume Study: Analysis and Modeling

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LONG-TERM GOAL

The long-term goals of this program are to understand the mechanics of river-plume transport of sediment and its influence on the trapping and dispersion of sediment on the continental shelf. This effort will also contribute to the development of predictive models of sediment dispersal and sedimentary strata formation.

OBJECTIVES

In collaboration with Courtney Harris and Peter Traykovski, I am using models and field observations to investigate the influence of river plume dynamics on the delivery of sediment to continental margins. The objectives of this analysis and modeling study are 1) to quantify the delivery of sediment by the plume to different regions of the shelf under varying forcing conditions; 2) to investigate the influence of particle aggregation on the sediment transport; and 3) to investigate the influence of wave resuspension and wave-boundary layer processes (including the formation of fluid mud) on the fate of the sediment.

APPROACH

The main thrust of the Year 2000 activity has been to investigate the influence of wave-induced resuspension on the transport of sediment. Three papers addressing the Rapid Response studies were revised and accepted for publication during 2000.

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 Year 2000 modeling activity focuses on realistic domain simulations, using the actual bathymetry of the Eel shelf and realistic forcing by winds, river flow and waves. The major innovation is the incorporation of bottom boundary layer processes in the model, particularly the contributions of surface gravity waves. This effort is being conducted in collaboration with Courtney Harris at the US Geological Survey in Woods Hole.

The goal of these simulations is to determine the influence of transport processes and forcing variables on suspended sediment distribution and on the formation of flood deposits. The observed suspended sediment distributions from the Rapid Response helicopter observations and the moored sensors provide a test of the model's simulation of the time-varying suspended sediment. The observed spatial structure of flood deposits obtained by Wheatcroft and colleagues provides a specific benchmark against which to evaluate the end-point of the simulated sediment delivery. The timing predicted for depositional events has been evaluated using data obtained by Traykovski using downward looking acoustical instruments. These comparisons are critical for determining whether the model contains all of the necessary physics to quantify the along-shelf and cross-shelf sediment transport processes.

The Year 2000 modeling studies document the role of conventional sediment transport processes on the Eel shelf and motivate future investigations of the roles of flocculation and gravity-driven flow. Neither process has been fully accounted for by our efforts to date, but appear to explain the discrepancy between model predictions and field observations (Figure 1). The incorporation of these physics into the 3-D model has been proposed for Year 2001, and will build on simpler 1- and 2-dimensional models that Traykovski and Friedrichs have developed to address gravity-driven motions of fluid muds within the wave boundary layer.

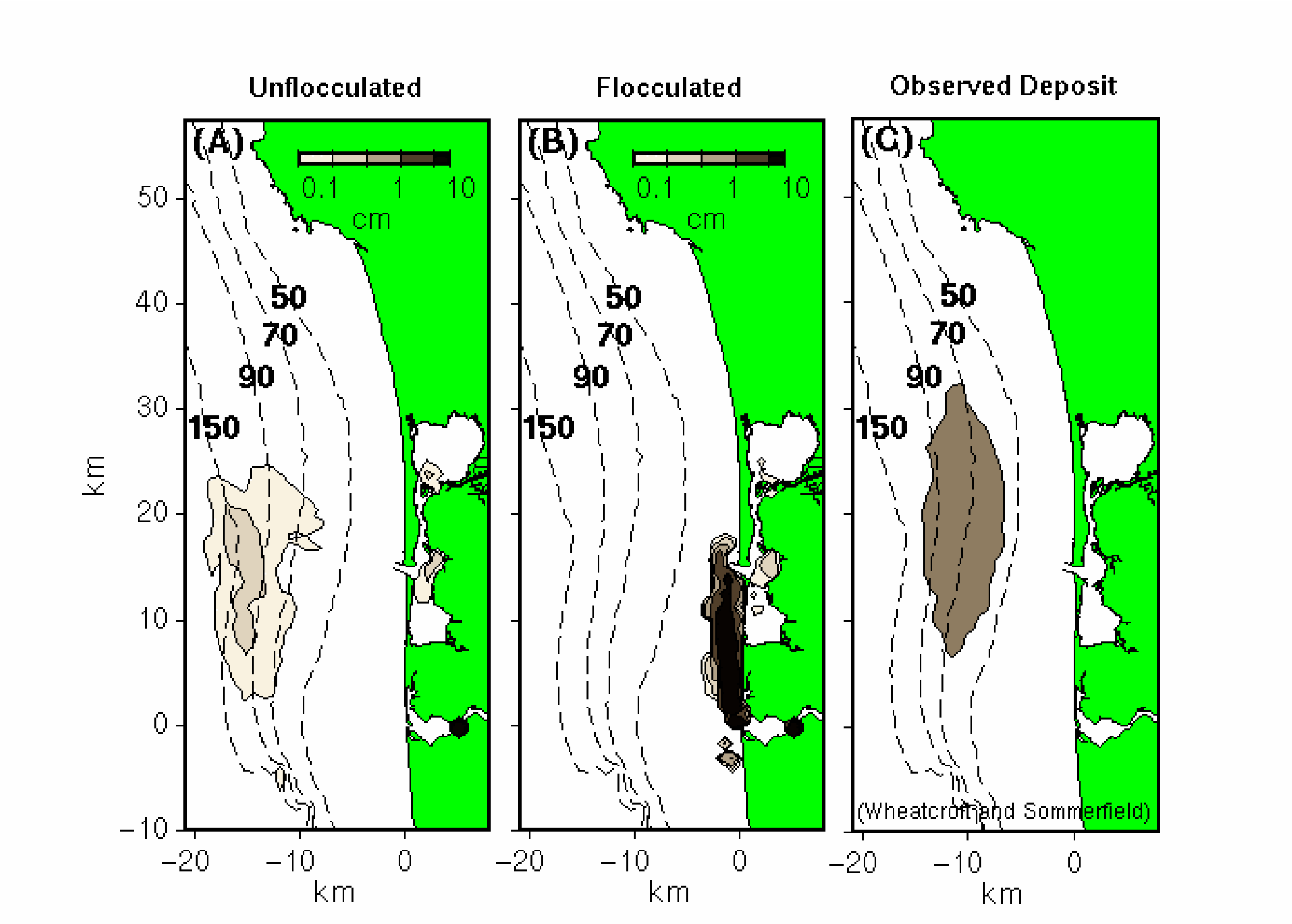

Figure 1. Sediment deposition predicted (A—B) four days after the 1997 flood event, compared with the observed flood deposit (C). Panel (A) indicates the distribution of unflocculated sediment (w_s=0.1 mm/s), and (B) predicts the deposition of flocculated sediment (w_s=1.0 mm/s). The observed deposit (C) has a maximum thickness of approximately 8 cm. These model results indicate that an additional process must contribute to the cross-shelf transport of flocculated sediment.

I am also working with Joint-Program student Dan McDonald on the plume "lift-off" problem, the dynamics of the river plume as it first separates from the bottom. Because the mouth of the Eel is logistically infeasible for a shipboard study of plume lift-off, we have chosen the Fraser River, in British Columbia, which provides a system of similar scale to the Eel but with more manageable sea conditions during flood events. We have analyzed data from 1999 flood conditions and have completed measurements during the 2000 freshet. These observations provide critical information about the dynamics and sediment transport at the river mouth, where sand and coarse silt rapidly separate from the buoyant plume (Figure 2).

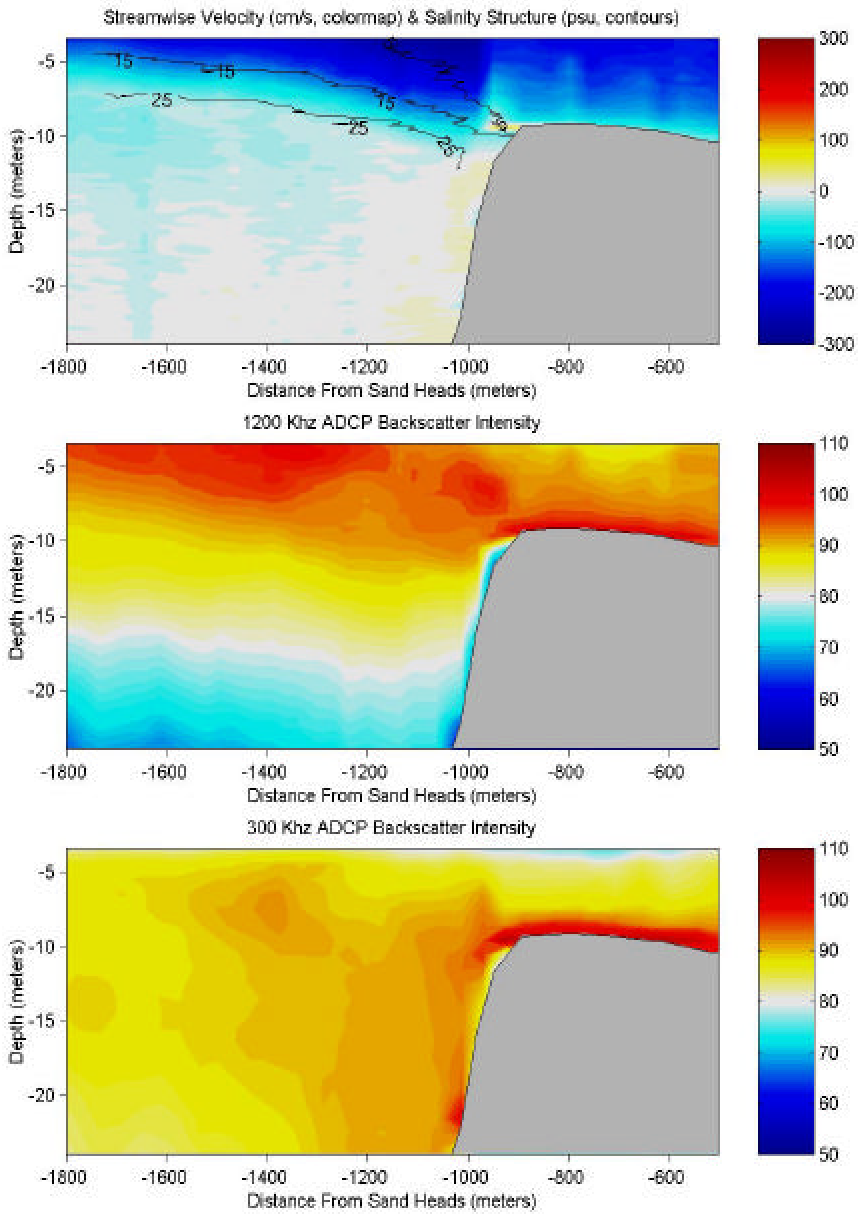

Figure 2. Cross-section of the "lift-off" zone of the Fraser River during high flow. The top panel shows the salinity (contour lines) and velocity, with currents of 200 cm/s at the mouth. The 2nd and 3rd panels indicate backscatter at 1200 kHz and 300 kHz. The 1200 kHz signal is more sensitive to fine particles that are carried seaward by the plume, whereas the 300 kHz signal is more sensitive to the coarse material, which drops out of the plume within several hundred meters of the mouth. (In panels 2 and 3, red indicates high concentrations; blue indicates background concentrations).

WORK COMPLETED

The early part of 2000 was spent finalizing three papers that will be published in the “Flood Volume” of Continental Shelf Research. The paper by Geyer, Hill and Milligan presents the results of the Rapid Response plume studies, focussing on the plume structure and its influence on sediment transport. The Hill, Milligan and Geyer paper describes the particle dynamics within the plume and their influence on the fate of the sediment. The Traykovski, Geyer, Irish and Lynch paper reveals the newly discovered mechanism of gravity flow within the wave boundary layer based on tripod observations during the plume study.

Courtney Harris presented the early results of our 3-dimensional simulations at the Ocean Sciences meeting in San Antonio in January, 2000. McDonald presented preliminary results of the Fraser River plume lift-off study at the same meeting.

RESULTS

The Year 2000 modeling work provides a quantitative assessment of the impact of boundary layer processes on the transport of plume-derived sediment. Our results verify that most of the sediment falls directly from the plume onto the inner shelf, as indicated by the plume observations. The wave-resuspension processes on the inner shelf keep much of the sediment in suspension, and ambient shelf currents result in offshore transport of the unflocculated portion of the sediment (Figure 1A). The model indicates, however, that the distribution of suspended sediment and sediment deposits depend sensitively on the settling velocity. Disaggregated sediment (settling velocity 0.1 mm/s) is broadly distributed as suspended sediment across the shelf and forms a thin deposit in the vicinity of the observed flood deposit (Figure 1A). Flocculated sediment (settling velocity 1 mm/s) is predominantly trapped beneath the plume, and ambient currents cannot carry it away as quickly as it is supplied from above. Using the ratio of flocculated to unflocculated sediment of 60/40 (Hill, et al.), the model produces a large accumulation of sediment on the inner shelf. This distribution is inconsistent with the observed pattern of deposition on the mid-shelf, indicating that processes that are not included in the predictions must contribute to the off-shelf advection of suspended sediment.

The missing process is believed to be gravitationally driven motion of dense suspensions within the wave boundary layer. During 2000, Traykovski has developed simple models for the vertical and across-shelf structure of these thin turbidity currents. I have provided comments and suggestions on Peter’s work, and we are making plans to incorporate these processes into the 3-D model in 2001.

The analysis of the plume “lift-off” problem has yielded some important results. The turbulent dissipation rates within the lift-off zone are higher than observed in almost any oceanographic environment. The irregular traces of the salinity contours (Fig. 2) indicate overturns, which are symptoms of this intense turbulence. This high dissipation may briefly inhibit particle aggregation at the fresh-salt interface due to floc break-up. The multi-frequency observations of sediment shown in Figure 2 show how the different size classes are segregated at the front. These observations will be valuable for testing the model in its representation of the sediment transport processes near the river mouth.

IMPACT/APPLICATION

This combination of measurements and modeling is leading to a quantitative understanding of the impact of river plumes on the coastal environment. The 3-dimensional modeling approach we have adopted is clearly the most direct path toward prediction of oceanographic and seabed conditions in regions of riverine influence. The model is already capable of providing realistic predictions of the near-surface turbidity plume. With the continued development of the wave-boundary-layer sub-model and a seabed-evolution model, this approach will ultimately lead to predictive capability for the formation and evolution of sedimentary strata.

TRANSITIONS

I am working with Harris, Signell and Sherwood at USGS to develop a "Community Sediment Transport Model." Although this model is still in the conceptual stage, it would have much in common with the 3-D model we are presently using for the Eel River simulations. This Community Modeling approach would significantly improve the transitioning of the research results to other academic researchers and the military. I am also embarking on a community model-testing program with support from ONR (see below), which has the express purpose of increasing communication about model development and improving transitions to implementation.

RELATED PROJECTS

I am involved with a study of plume dynamics as it relates to harmful algal blooms in the Gulf of Maine, in collaboration with Don Anderson (WHOI) with funding from NOAA and NSF as part of the ECOHAB project. I will be supported in 2001 by ONR to develop robust tests for advanced numerical models. I am working on studies of sediment and contaminant transport in the Hudson River estuary with funding by the ONR Harbor Processes Program and the Hudson River Foundation. There are similarities in the characteristics of sediment trapping and transport processes in the two systems. Similar modeling techniques are being used in the Hudson estuary projects as in the STRATAFORM study.

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