Advancing Predictive Models of Marine Sediment Transport Over Intermediate to Long Time Scales

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LONG-TERM GOAL

My long-term goal within the STRATAFORM program has been to increase our understanding of the processes controlling the formation, reworking and preservation of event-scale stratigraphy on the continental shelf. My primary goal in the last phase of STRATAFORM was to extend our capability for modeling shelf sediment transport to time scales appropriate for models of the geologic evolution of continental margins (e.g., SEDFLUX and SEQUENCE).

OBJECTIVES

The objectives of this project for FY02 have been to investigate approaches for scaling up representations of sediment transport on the continental shelf to longer time scales and to complete our modeling study of the importance of flocculation and consolidation on shelf sediment transport at short and long time scales.

APPROACH

My approach combines model development and application with data analysis to better understand shelf sediment transport processes, facilitate data analysis, and improve our predictive capabilities. This approach yields insights into transport and bed processes at time scales of events to decades (period of record is up to 100 years), and geological time scales (1000's years or more).

WORK COMPLETED

During FY02, I 1) continued working on approaches to scaling up to longer time scales, with a particular effort to develop a cross-shelf shelf sediment transport model with a daily time, which is better suited to SEDFLUX than several other approaches I have considered; 2) reformulated the entrainment function in the coupled resuspension/flocculation/consolidation model we developed last year and explored the implications of the model for shelf sediment transport and deposits; and 3) made significant contributions to three chapters of the STRATAFORM Master Volume.

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14. ABSTRACT
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RESULTS

Up-scaling shelf sediment transport calculations

Models of the geologic evolution of continental margins (e.g., SEDFLUX and SEQUENCE) require some characterization of shelf sediment transport, but on time-scales much longer than those for which sediment transport models are normally constructed. One of the challenges of STRATAFORM has been to use our experimental and theoretical understanding of site-specific, event-scale shelf sediment transport (from, e.g., STRESS and STRATAFORM) to represent the effects of shelf seediment transport over times scales associated with climate change and morphologic avolution of the shelf. Last year (FY01), I used my one-dimensional shelf model, run over a set of points (representing, e.g., a cross-shelf transect), to estimate vertically averaged net sediment flux at each point following a transport event. The cross-shelf divergence of the flux, calculated for each grain size in the bed, was then used to calculate net erosion (or deposition) and a new grain size distribution at each point. This event-based model was incorporated into SEDFLUX, but has presented several problems. One is specification of forcing and the other is the somewhat indeterminate time scale associated with events. A long-term model cannot use direct records of forcing (because the data don't exist). Instead they must rely on estimated long-term average values of forcing (such as wind speed or wave height), or randomly select values from a distribution of forcing conditions that ideally is developed from available data from a particular site. It is not clear whether an "average event" is a useful idea given the range of magnitudes and frequencies of events, and our records of events are limited enough that it is difficult to develop a general distribution of events. As an alternative that is more straightforward to formulate, implement and test, I modified the model during FY02 to operate on daily time steps rather than events.

The 1D steady, shelf sediment transport model I developed and tested during STRESS and STRATAFORM can be run with any time step (it calculates equilibrium solutions for each specified combination of waves and currents). At hourly time steps, input hourly averaged wave condtions and current velocities yield suspended sediment concentration profiles in good agreement with hourly-averaged measured values. When daily time steps are used, however, daily-averaged wave and current input yields suspended sediment concentrations and fluxes that are too small (Figure 1a). This is because daily averaged currents average out important tidal variations that contribute to shelf sediment transport and daily averaged wave height does not capture the peaks in wave height that generate the highest bed shear stresse. To include effects of shorter-term variation, I calculated shear stresses (at bed and in water column) using the daily mean plus the standard deviation of current velocity and daily significant wave height, while daily mean currents were used to specify velocity in the flux calculations. With this approach, suspended sediment fluxes across the Eel shelf calculated with daily time-step model are in good agreement with values calculated with the hourly time-step model (Figure 1b). I am currently developing distributions of daily forcing based on data from the Eel shelf to use as input to the model. For other sites and longer time scales I am using the Cookman and Fleming (2001) simple shelf circulation model to relate wind records (available globally for last 50 years) to daily current means and standard deviations and using NOAA wave data to characterize daily averaged waves conditions.

Resuspension-flocculation-consolidation model for fine-grained shelves

During the last two years (FY00-01), Joel Carr (graduate student) and I developed a 1D (vertical), coupled, time-dependent model that includes wave-current interactions, resuspension, flocculation and consolidation. Application of the model showed that consolidation limits entrainment rates while flocculation increases particle settling rates. We contined to work on the model this year, with a focus on 1) improving our representation of bed sediment entrainment, with the goal of adopting a formulation that can be directly parameterized using results from erosion chamber measurements such as those I am making in EuroSTRATAFORM; 2) understanding the relationship between water column dynamics and bed properties, particularly with respect to the bed sediment size distribution of deposits formed from a flocculated suspension; and 3) preparing a manuscript describing the model and its application to the Eel shelf (J..A. Carr and P.L. Wiberg, A coupled resuspension and flocculation model for the continental shelf. Draft available upon request.)

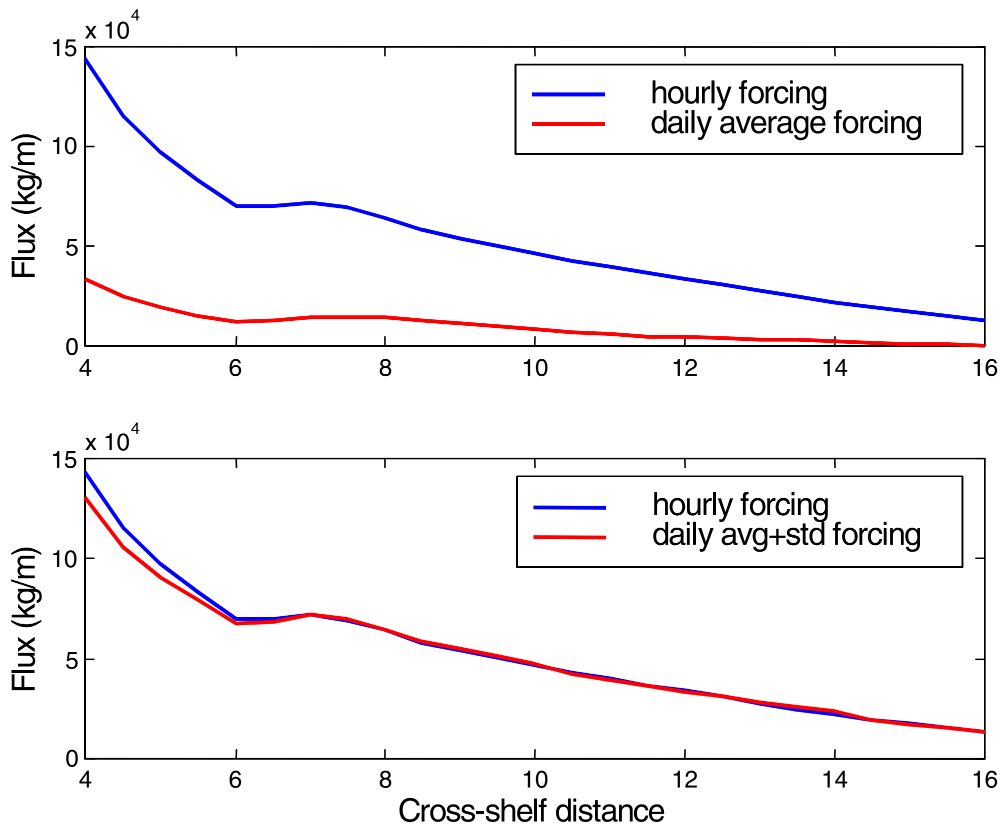

Figure 1. Suspended sediment flux as a function of cross-shelf distance along the S–line on the Eel shelf during the fall of 1995. The blue curve was calculated using a 1D shelf sediment transport model with hourly time steps; this model has been shown to be in good agreement with measurements at 60 m on the S-line. The red curves were calculated with a daily time-step model. In the top panel, daily averaged currents and waves were used in the daily model; fluxes are greatly underestimated. In the bottom panel, the mean plus standard deviation of currents and the daily significant wave height were used to calculate suspended sediment concentrations in the daily model; in this case, the results agree well with the hourly model.

In our initial model development, we implemented a bed-sediment entrainment condition based on the expected steady-state reference concentration. This year, we replaced this formulation, which was originally developed for non-cohesive sediment, with one that is better suited to cohesive beds (Sanford and Maa, 2001). The Sanford and Maa (2001) entrainment function was developed for beds in which the critical shear stress for entrainment increases with depth and explicitly accounts for bed properties such as porosity that are important in consolidated beds of fine-grained sediment. The Sanford and Maa entrainment function requires specification of critical shear stress and porosity as a function of depth (which can be determined from a coupled model of bed consolidation or measurements) and a site-specific entrainment parameter. The entrainment parameter can be measured using erosion chambers or in situ flumes. As part of EuroSTRATAFORM, I will be making erosion chamber measurements in the Adriatic and Gulf of Lions, using the results to determine the entrainment parameter, and then testing the resulting calculations of sediment transport against near-bed measurements collected in field experiments at both sites. For our Eel shelf calculations, we used one of the tripod data sets (fall, 1995) from the long-term tripod at S-60 to determine the entrainment parameter.

During FY02, we used the model to calculate suspended sediment concentrations, suspended floc percentages and bed grain size for all of the S-60 deployments (except the one used to calibrate the entrainment function) as well as for a set of steady-state conditions. We found that with the disaggregation parameter set at a value consistent with results obtained in field measurement by Hill et al. (2001; disaggregation at water column shear stresses of ~0.1Pa for large flocs), almost all sediment was disaggregated before deposition in the Eel shelf model runs, irrespective of the percentage of sediment incorporated into flocs in the water column. As a result, it was not evident from the calculated bed size distributions that the sediment had been flocculated. In fact, if the critical shear stress for resuspension is 0.1 Pa (the value for surficial mud on the Eel shelf), then the stress in the wave boundar layer is always high enough to disaggregate flocs when sediment is being resuspended from the bed. Furthermore, only if the wave conditions die down to a level such that the bed stresses are < 0.1 Pa while significant suspended sediment concentrations remain in the water column, can flocculated sediment be deposited without disaggregation. Relatively large wave conditions are required to put sufficient sediment into suspension to produce a large population of flocs. Because of the rapid settling rate of flocs (~1 mm/s), wave conditions would have to drop rapidly to allow flocs in suspension to deposit without dusaggregating. These conditions are most likely to be met if flocs are advected into a region of lower energy (e.g., deeper depths) or if turbulence is suppressed, e.g. in fluid mud. This suggests that beds with grain size distributions consistent with floc deposition (Hill and Milligan studies) may be diagnostic of specific types of conditions favorable to floc deposition rather than just the presence of flocs in suspension.

Analysis of decadal and longer time-scale variations in forcing

This element of my STRATAFORM plans for FY02 was largely put on hold as we (Michael Mann, the climatologist working on this project with me) and I) recruited a graduate student to work on this problem. We found an excellent student who began in August, 2002. I am planning to request a no-cost extension of a year on this project to allow this student complete and extend the analysis we began in FY01. During FY02 we did acquire the data we need for this study from the 50-year NCEP climate reanalysis.

STRATAFORM Master Volume

During FY02 I made contributions to three chapters of the STRATAFORM Master Volume: Syvitski et al.'s chapter on modeling; Pratson et al.'s chapter on seascape evolution; and Wheatcroft et al.'s chapter on post-depositional alteration and preservation of strata.

IMPACT/APPLICATION

Upscaling of shelf sediment transport relationships (or products) is essential if the continental shelf is to be reasonably represented in longer-term margin stratigraphic or morphologic models. One of the main limitations for calculating sediment redistribution on shelves is characterizing entrainment rates of fine-grained sediment. The resuspension/flocculation/consolidation model we developed in STRATAFORM provides a means of testing erosion formulations against field measurements and direct measurements of erosion. Doing this is a goal of EuroSTRATAFORM

TRANSITIONS

The daily time-step cross-shelf sediment transport model will being incorporated into SEDFLUX. The resuspension/flocculation/consolidation model will be tested at two shelf sites that contrast with the Eel shelf during EuroSTRATAFORM.

RELATED PROJECTS

Representing shelf processes in long-term stratigraphic models is related to efforts in the Geoclutter program to model the evolution of continental shelf morphology, particularly the formation and filling of channels, under conditions of varying sea level. My EuroSTRATAFORM erosion chamber measurements will be used to parameterize entrainment rates in the resuspension/flocculation/ consolidation model.

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