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Building a Community Sediment Transport Model

Introduction

Predictions of the transport and long-term fate of particles in the coastal ocean are needed to address issues related to commerce, defense, public health, and the quality of the marine environment. For example, models can be used to investigate waste disposal and the transport and fate of contaminated materials; burial rates for naval mines or archaeological artifacts; water-column optical properties; transport and fate of biological particles; prediction of coastal flooding and coastal erosion; impacts of sea-level or wave-climate changes and coastal development; construction and maintenance of navigable waterways; habitat for commercial fisheries; impacts of natural or anthropogenic changes in coastal conditions on recreational activities; and design of intakes and outfalls for sewage treatment, cooling systems, and desalination plants.

Community Approach to Model Development

The U.S. Geological Survey (USGS) is leading a collaborative effort to develop and test a coupled hydrodynamics and sediment transport model to address coastal issues and has implemented and tested algorithms for calculating erosion, transport, and deposition of multiple sediment classes and evolution of sediment stratigraphy and benthic habitats in coastal environments. The emerging model has been used to simulate grain-size changes caused by wave- and current-induced sediment transport and sorting to evaluate model performance and to obtain solutions to real-world problems such as fate of contaminated sediments on the Palos Verdes shelf (fig. 1) and pollution in Massachusetts Bay (fig. 2).

The computer code for the Community Sediment Transport Model (CSTM) is freely available and publicly accessible. Researchers can modify the code to address specific needs. Improved versions of the model are collated and released by a “keeper of the code” (http://marine.rutgers.edu/po/index.php?model=roms).

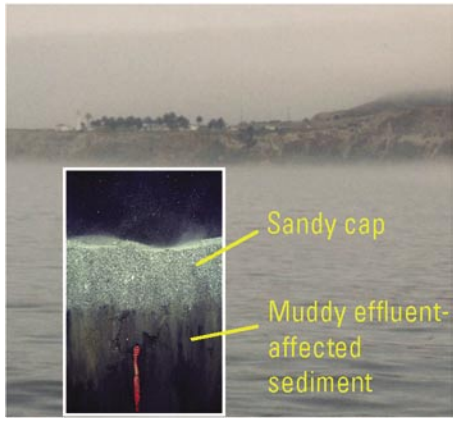

Figure 1. A pilot study toevalueate capping of contaminated sediments was performed off the Palos Verdes Peninsula (pictured above) by the U.S. Army Corps of Engineers. The inset is a side view of the sediment profile showing the sand cap overlying fine effluent-affected sediment with benthic infauna. Models are helping to evaluate cap effectiveness and predict fate of contaminates. (REMOTS© photo courtesy SAIC.)

There are many advantages to open-source, community-based software development. Experts can improve parts of the model so that other users can benefit. When alternative parameterizations of the same physical or geological process are included, they can be compared and evaluated in identical frameworks. Users (including scientists from other disciplines, students, resource managers, engineers, and operational personnel) may draw from well-tested, state-of-the-art algorithms. Collaborative work on a community model helps synthesize understanding of sediment transport, identify key research and modeling issues, and efficiently focus research efforts, minimizing duplication and preventing critical components from being overlooked. Wide use and broad participation in model development, along with extensive testing and peer review, help identify bugs and produce a robust model that can serve as a scientific and legal standard.

Coastal Ocean Modeling with ROMS

The community sediment transport model is part of the Regional Ocean Modeling System (ROMS). ROMS has been developed by a group of academic, industry, and federal researchers supported with funds from the National Oceanographic Partnership Program. The model code, as well as documentation and supplemental programs to prepare input and evaluate results, is maintained by Rutgers University. The USGS has contributed routines to calculate vertical mixing, erosion, transport, and deposition of sediments, as well as evolution of small-scale stratigraphy in the seabed (fig. 3).

Winds, waves, tides, rivers, heating and cooling, and offshore motions all influence the coastal currents responsible for sediment movement. Decades of effort have gone into developing numerical models for these processes, and ROMS incorporates some of the most advanced modeling technology. The physical oceanographic model is based on the Reynolds-averaged Navier-Stokes equations, written for a finite-difference grid. The horizontal grid is curvilinear, and the vertical grid

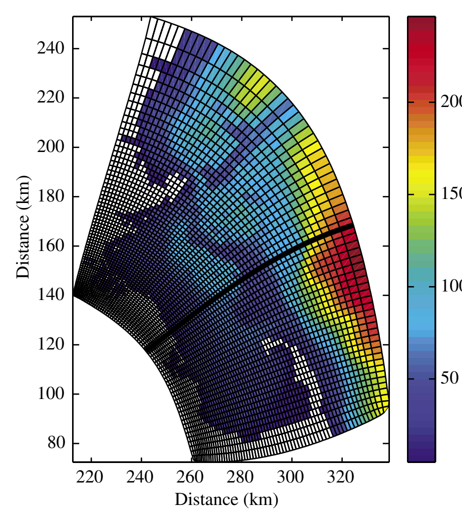

Figure 2. Model grid for Massachusetts Bay simulation showing horizontal grid with bathymetry in meters.

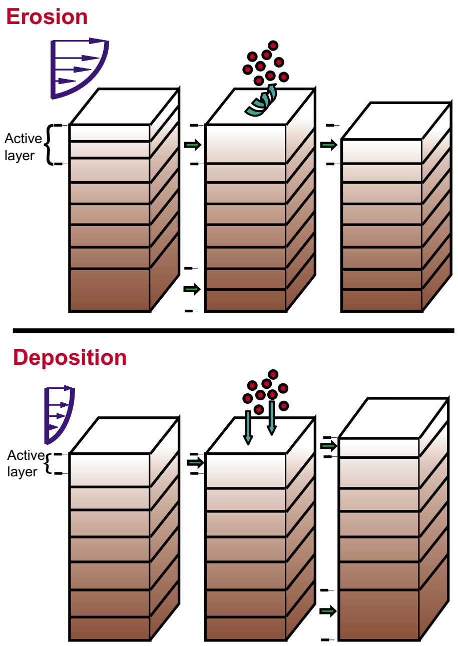

Figure 3. Schematic illustration of bed evolution during erosion (top panel) and deposition (bottom panel) in community sediment transport model.

is terrain following. Currents are driven by winds, water-level gradients, and density gradients under the influence of friction and the Coriolis effect. Sub-grid-scale mixing is represented with one of several turbulence models with one or two equations that describe transport of turbulence quantities. Highly accurate third- and fourth-order advection schemes are used to calculate movement of water, salt, heat, sediment, and biologically important quantities. The effect of waves on near-surface and near-bottom mixing and shear stress is included, and ROMS can be coupled with wave-evolution models, including the public domain model SWAN. Heating and cooling across the air-sea interface can make use of data from detailed atmospheric models. Tides can be imposed at the boundaries, and rivers or other sources can provide inputs of water and sediment. The model is written in modern FORTRAN90 and can take advantage of multiple processors using either shared-memory or distributed-memory computer architectures. It runs in most computing environments from laptops to supercomputers.

Sediment Dynamics

Coastal sediment ranges in size from cobbles to fine mud. Finer materials can remain in suspension for long periods and be transported great distances by currents. Coarser, faster settling sediment moves only intermittently, often in response to wave motions, and is transported more slowly. Small-scale seabed stratigraphy and biological mixing of bottom materials are important in determining what type of sediment is available for transport. Near-bottom currents critical to sediment transport are affected by small-scale bottom topography, like ripples. Various components of the sediment transport model have been developed to address these and other processes. Parameterization of these processes is a topic of active research, and the modeling community will incorporate improvements as they develop. The model maintains a record of how much of each kind of sediment is in each layer of the bottom and updates the stratigraphy when erosion, deposition, or sediment mixing occurs. These procedures allow the model to represent natural processes like winnowing of fine material and development of graded beds under waning transport conditions. Both bedload and suspended sediment transport are included. To date, wave-driven circulation has not been simulated, but the physics of nearshore processes will be improved in the future.

Regional Applications

The CSTM is being applied to several coastal systems. In Massachusetts Bay, the model has been used to study changes in bottom-sediment distribution caused by winter storms. Under storm conditions, large waves and currents generated by winds and tides combine to winnow fine sediment from shallow regions and deposit it in relatively quiet deeper regions. When the simulations are started with an idealized uniform blanket of mixed sediments, the bottom sediment distribution evolves toward one that resembles actual sediment-distribution maps (fig. 4). This confirmation of patterns of erosion and deposition suggests that the model is capable of accurately modeling transport pathways for fine sediment and associated contaminants.

CSTM results from the Hudson River Estuary are being compared with field data obtained by scientists from Woods Hole Oceanographic Institution. These comparisons allow evaluations of the vertical mixing algorithms in the model that are critical to estuarine circulation.

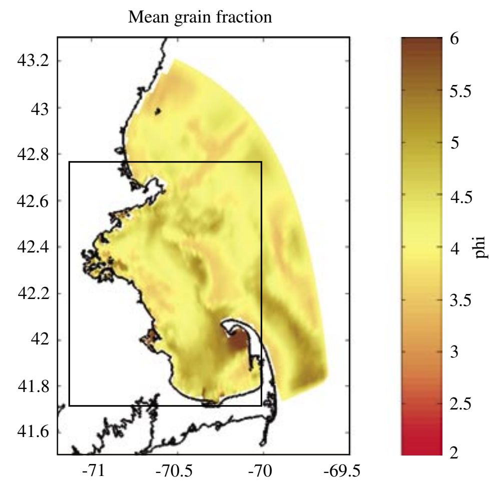

Figure 4. Sediment-size distribution in Massachusetts Bay obtained by simulating waves, currents, and sediment transport during winter storms.

An extensive data set has been collected from the Adriatic Sea, located in Europe between Italy and Croatia. The Adriatic presents an excellent test case because it is a largely enclosed sea, forced mostly by local weather and river input. A large, multi-institution research effort during the winter of 2002-2003 has produced an outstanding data set that has been used to quantify water transport in the coastal current. The comparison demonstrates that the model has predictive skill over long times (several months) and great distances (hundreds of kilometers).

For additional information, please contact:

Christopher R. Sherwood
Richard P. Signell
John C. Warner
U. S. Geological Survey
384 Woods Hole Road
Woods Hole, MA 02543-1598
(508) 548-8700

E-mail: csherwood@usgs.gov
rsignell@usgs.gov
jcwarner@usgs.gov