Sediment Redistribution and Seabed Modification in the Western Adriatic

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LONG-TERM GOALS

This project develops our ability to quantify sediment transport and modifications to the seabed in coastal environments by enhancing numerical representations of sediment transport to account for complex coastal circulation, sediment properties, and realistic wave fields. Calculations made over timescales of months to years can be compared to observations, and the validated model can then used to extrapolate to larger temporal and spatial scales.

OBJECTIVES

By quantifying sediment delivery, flux, resuspension, and deposition within a three-dimensional hydrodynamic model, this project links sediment transport in the western Adriatic Sea to seabed texture and sedimentation patterns. Depositional patterns resulting from point and line sources of sediment will be compared by contrasting delivery of sediment by the Po River and several smaller rivers that drain the Apennine Mountains from north of Ancona to the Gargano Peninsula (see figure 1). Subsequent reworking of sediment is predicted and textural and sedimentation patterns will be tested against field observations made by EuroSTRATAFORM colleagues. Additionally, the circulation and sediment transport calculations completed will be useful to field scientists in planning deployments and interpreting point measurements.

APPROACH

A numerical model of suspended sediment transport and bed reworking has been built within the framework of the Navy Coastal Ocean Model (NCOM, see Martin 2000), a primitive equation circulation model. The hybrid sigma / z coordinate system used by NCOM is useful in the Adriatic because the bottom-following sigma grid is needed within shallow shelf waters, but a z-grid is preferred in deep ocean basins. Pullen et al. (2002) have used NCOM to predict water column structure and circulation to the Adriatic, and found that the calculations are sensitive to the spatial and temporal resolution of the forcing wind field. To specify wind forcing of circulation, we use hourly wind stress predictions from the Naval Research Laboratories COAMPS™ model (Coupled Ocean Atmospheric Mesoscale Prediction System; see Hodur, 1997; Hodur, *et al.,* 2001), calculated at a 4 km spatial resolution, as recommended by Pullen et al. (2002). NCOM has been parallelized and has full nesting capabilities, which facilitates predictions with sub-kilometer resolution, and for timescales spanning allied field deployments.

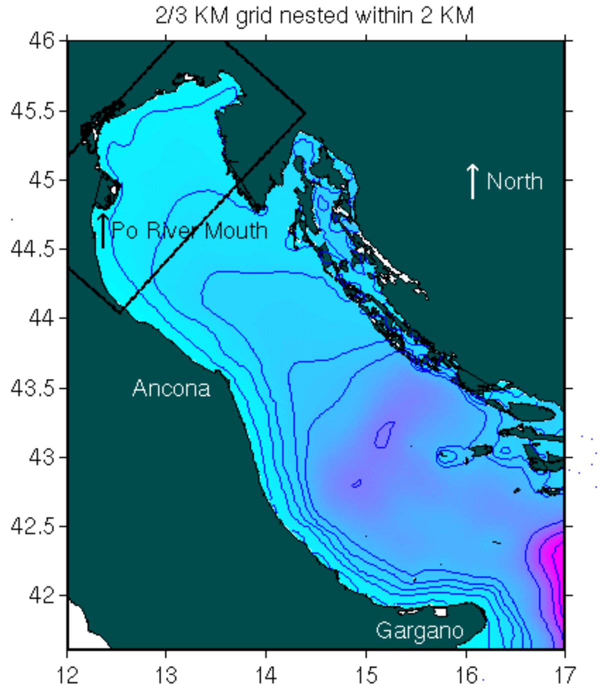

Figure 1: Northwestern Adriatic Sea, showing location of Po River mouth; bathymetry indicted by color and contour lines (every 20m). The location of the high-resolution nested model grid (2/3 km grid) outlined by the box in the northwestern Adriatic.

The fully three-dimensional sediment transport routines developed for NCOM allow sediment input from fluvial sources and exchange between suspended and sea-floor sediment. Sediment is transported by advection due to settling, oceanographic currents, and turbulent diffusion. The bottom boundary condition of the transport model is the net difference of settling from the bottom-most grid cell, and an entrainment from the bed that depends on the excess shear stress of the flow, following Harris and Wiberg (2001). Erosion of each class of sediment during any timestep is limited by the amount of that sediment type in the active layer of the bed. Multiple grain types are used to track changes to seabed texture, bed armoring, and differential transport of material. The sediment bed model uses a three-dimensional grid underneath the hydrodynamic grid. Sediment within each class is exchanged between the bed model and the overlying water column through erosion and deposition, with the bed model tracking changes to seabed composition. The bed model can incorporate effects such as bed consolidation and biodiffusion, pending guidance from field observations. The multiple sediment types included in the calculations provide a platform for including potentially important aggregation and disaggregation processes for fine grained sediment.

For this application, NCOM must be enhanced to include surface gravity waves, a key component for sediment transport and coastal oceanography. Waves increase bed shear stress and apparent roughness in coastal areas, and often dominate transport there (see, e.g. Grant and Madsen, 1979; Smith, 1977, and Drake and Cacchione, 1985). Including waves within NCOM requires generation of a realistic wave field, input routines for wave characteristics, and inclusion of wave/current interaction in hydrodynamic and sediment transport calculations. We plan to add wave/current interaction to NCOM following either Grant and Madsen (1979), Styles and Glenn (2000), or Wiberg et al. (1994). The wave field to be input will likely be waves computed using the SWAN (Simulating WAves Nearshore) model (see Booij, *et al.,* 1999). Rich Signell (SACLANT-CEN) plans to complete a series of SWAN computations for the Adriatic as part of the Adriatic Current Experiment (ACE), and has agreed to supply the calculations of near-bed orbital velocity and wave period required as input into the wave/current interaction module (see figure 2 for an example of Signell's SWAN calculations).

Detailed forcing is needed to predict dispersal in an area with complex circulation and wave fields, as the Adriatic appears to be (see figure 2). Using the COAMPS™ winds and the SWAN wave field as input, this sediment transport model promises a more realistic platform for quantifying sediment transport in the coastal ocean than has been possible with previous efforts.

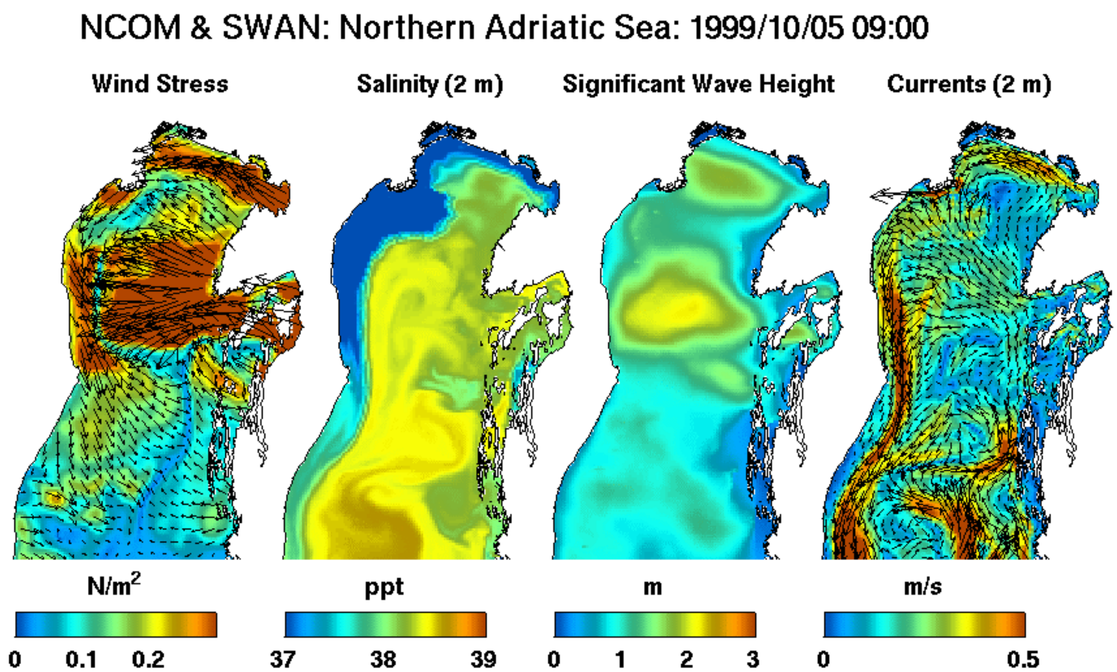

Figure 2: Snapshot of circulation and wave calculations for realistic simulation of October, 1999 showing (a) wind stress magnitude and direction from COAMPS™, (b) salinity, (c) SWAN-predicted wave height, (d) near-surface current magnitude and direction. Figure illustrates the complex nature of wind, wave, and currents in the Northern Adriatic; provided courtesy of Rich Signell, SACLANT-CEN.

WORK COMPLETED

We developed a numerical model of sediment deposition and dispersal of Po River sediment, and evaluated the sensitivity of sedimentation patterns to wind and wave forcing. This included writing a sediment-transport routine and building a model of the seabed, as well as more mundane efforts such as developing model visualization capabilities, and modifying input/output routines. A 2 km resolution model has been run, and a higher resolution nest (2/3 km) of the northern Adriatic has been developed for the circulation calculation (see figure 1), though the sediment bed model has not yet been fully nested.

Model forcing has been generated using idealized runs and by nesting within lower resolution models. The computations are driven using either an idealized wind field, or realistic winds from COAMPS™ model runs provided by Julie Pullen (Naval Research Laboratory at Monterey). Initial conditions and boundary conditions at Otranto Straight have also been provided by Julie Pullen from calculations made using a lower resolution (4 km) NCOM model grid. Discharge of the Po River is specified using daily averaged values available from Pontelagascuro. Figure 2 provides a snapshot of circulation calculations completed for a realistic simulation of October, 1999 by Julie Pullen. I completed similar circulation calculations for January, 2001 that included sediment transport, as described below. At present, a simple wave component has been included in NCOM to evaluate the sensitivity of resuspension calculations to wave shear stress. A full wave/current interaction program is forthcoming.

RESULTS

Results from a realistic simulation completed using river and wind forcing from January, 2001 imply that dispersal of fluvially delivered sediment depends to the first order on sediment settling characteristics, and secondarily to wave energy and circulation patterns. Two classes of sediment were input at a constant concentration of 50 mg/L each. One sediment class was modeled as flocculated material (w_s = 1.0 mm/s); and the second as unflocculated material (w_s = 0.1 mm/s). Sediment that is packaged as flocculated material is predicted to settle out of the flood plume of the Po River rapidly, within 10 km of the river mouth (figure 3). Sediment is more widely dispersed if it is delivered as

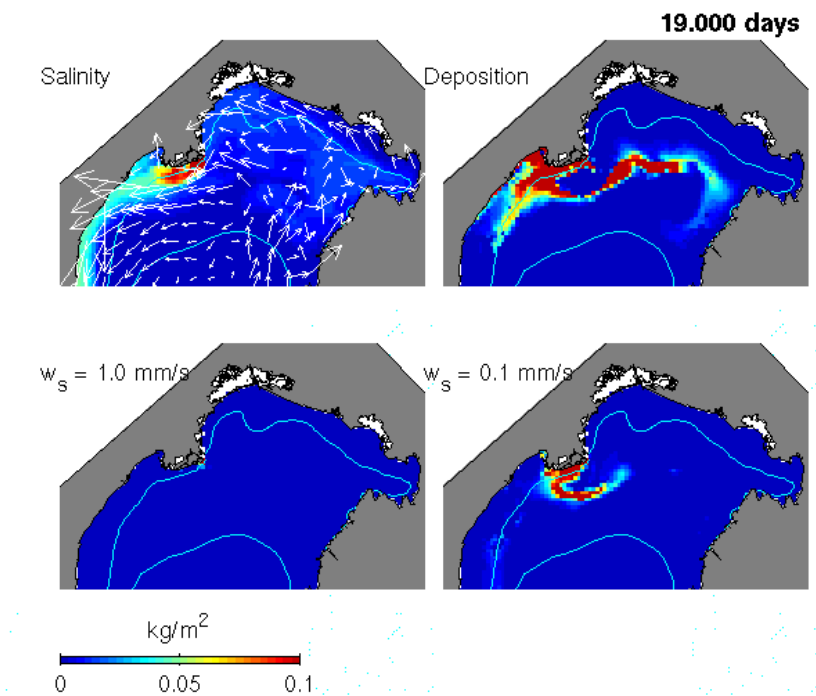

Figure 3: Estimates of (a) surface circulation and salinity; (b) sediment deposition; and depth-integrated amount in suspension for sediment modeled as (c) flocculated; w_s=1.0 mm/s; and (d) unflocculated, w_s=0.1 mm/s. Calculations made on 2 km grid at day 19 of the January, 2001 simulation using COAMPS™ wind field and concurrent record of daily Po River discharge from Pontelagascuro; but neglecting waves.

slowly settling, unflocculated particles, or if flocculated material becomes disaggregated in the coastal ocean. Sediment modeled as unflocculated material was transported by the southward flowing coastal current, and in this simulation, by a north-eastward arm of the buoyant plume predicted during energetic Bora wind forcing (figure 3). Comparison of the calculations made using realistic wind forcing to those made using a steady, uniform wind field imply that temporal variance in circulation may lead to intermittent periods of erosion and deposition near the mouth of the Po River. The addition of a depth-varying shear stress from energetic waves (H_{sig}=2m) significantly increased dispersal of both unflocculated and flocculated material, with the flocculated material being confined to the shallowest sites near the coastline. Full animations of both figures 2 and 3 available; www.vims.edu/~ckharris/Eurostrataform.html.

IMPACT/APPLICATIONS

The development of wave / current interaction and sediment transport routines increases the ability of NCOM to predict circulation, sediment transport, and light attenuation in the coastal ocean. Addition of a wave-current interaction module in particular will improve the validity of NCOM in shallow areas, where waves increase shear stress and bottom roughness.

TRANSITIONS

The circulation and sediment transport model for the Adriatic provides useful predictions and materials to scientists involved in EuroSTRATAFORM and related projects. The bathymetry and coastline used by the model have been provided to colleagues through an anonymous ftp site and the ADRIA23 web-site (https://gsvaresa07.er.usgs.gov/QuickPlace/adria23/Main.nsf) for use in planning field operations and presenting work. Calculations of water column properties and circulation will also be made available to EuroSTRATAFORM scientists (Geyer, Kineke, Ogston, etc.) to aid in the final planning of field operations for the fall, 2002 – spring, 2003. These calculations will be completed in a manner similar to those described above, but with the addition of freshwater and sediment discharge from important Apennine rivers, and using wind and boundary conditions appropriate for fall as well as winter.

Three dimensional calculations of sediment reworking and resuspension will be compared to one-dimensional calculations completed using a more highly resolved vertical grid by Patricia Wiberg (University of Virginia). Through this exercise, we plan to evaluate the utility of one-dimensional resuspension calculations in a complex coastal environment such as the Adriatic, and also to improve the representation of resuspension within a necessarily more coarsely gridded three-dimensional model. By completing several months' worth of calculations, we also gain insight for scaling transport processes to longer timescales.

RELATED PROJECTS

My effort links EuroSTRATAFORM and other experiments underway in the Adriatic including the ACE (primarily NRL and SACLANT-CEN), DOLCE VITA (Dynamics Of Localized Currents and Eddy Variability In The Adriatic; see http://thayer.dartmouth.edu/other/adriatic). The large number of field programs underway in the Adriatic Sea within the timeframe of our funding cycle promises to provide ample data for testing model predictions of water column structure, sediment concentrations, and seabed modifications. Collaboration with scientists outside of the EuroSTRATAFORM community is facilitated by the ADRIA23 web-site (URL provided previously), and by participation in meetings such as the one held at SACLANT-CEN in the spring of 2002, and the joint EGS/AGU meeting to be held in Nice, France in April, 2003.

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