USGS Capabilities for Studying Sediment Transport in the Ocean

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Introduction

The transport and fate of sediment particles is important to the basic understanding of issues involving the coastal ocean, such as habitats, erosion and the movement of contaminants. Fundamental science issues concerning the physics of the bottom boundary layer and particle behavior remain to be resolved in order to develop a predictive capability for particle transport in the coastal ocean. This paper is an introduction to USGS Coastal and Marine Geology Program (CMGP) and provides a summary of the Program's overall mission, how sediment monitoring is important to the mission, an overview of the state of the technology in the CMGP, an example of some of the technological issues we are working on, and finally some examples of recent field programs which use this technology. The people and web pages mentioned here will point to information for follow up during and after this workshop.

The Coastal and Marine Geology Program (CMGP) is "designed to describe marine and coastal geologic systems, to understand the fundamental processes that create, modify and maintain them, and to develop predictive models that provide understanding of natural systems, the effects of man's activities on them, and to provide a capability to predict future change. The program addresses issues of national importance in the areas of environmental quality and preservation, natural hazards and public safety, and natural resources, providing information and comprehensive understanding of marine and coastal geology for public benefit. The program will provide information and products to guide the preservation and sustainable development of the Nation's marine and coastal environment of both the oceanic and Great Lakes coastal domains" (CMGP National Plan, 1997).[1] While written in 1997, these basic principles continue to drive future research and technology. Our information allows the public and resource managers to evaluate the consequences of management actions in the coastal environment. Examples of some everyday issues for which the public demands USGS quality data are: whether or not to nourish a beach, the impact of coastal development, where to dredge, where to locate a sewage outfall pipe, or where the best sand and gravel may be found. The recent National Academy of Sciences' National Research Council review recommended an increased USGS involvement in predictive capabilities. Developing a Community Sediment Transport Model is now a major focus of the CMGP.

The CMGP's strength is its ability to map, measure and model ocean processes on a regional basis using state of the art technology. Our field studies address the following basic questions: where is the sediment now, what kind is it, under what circumstances will it move, and once re-suspended, where will it go. The problems are four dimensional and sometimes unbounded on many sides, offering a special challenge to modeling.

Field Capabilities

It is a priority in the CMGP to maintain cutting edge technology in sea-floor mapping and sediment transport. We prefer to buy commercially available instruments, but often the technology we need does not exist on the commercial market. We work closely with other institutions to help fund new technological advances and to identify the best new technologies. This has resulted in a suite of reliable, productive, and efficient instrumentation that produces high-quality data specific to CMGP's scientific objectives. Our technology includes in situ instrumentation for long term deployment, side scan sonars and sub-bottom profilers for mapping, real time video of the sea bed, and sediment samplers. Instruments are either towed behind or mounted on vessels for real time surveys, or deployed in situ for periods of one month to a year on moorings and bottom platforms. The ships we use range from our own vehicle towed survey boats to 200 foot research vessels that are contracted or part of the University National Oceanographic Laboratory System (UNOLS) or the U.S. Coast Guard. Personnel and equipment are distributed among three Field Centers located in Menlo Park, CA, Woods Hole, MA and St. Petersburg, FL, each with its own scientific, technical and regional specialization. The Centers cooperate to share resources and knowledge.

Figure 1: A short subsurface mooring consisting of a float, Honjo trap and anchor being deployed off Scituate, MA from the USCG Marcus Hanna.

Moorings for Time Series Observations

Oceanographic moorings and bottom platforms are used by the CMGP to deploy instrumentation in situ for periods of one month to a year. An oceanographic mooring consists of floatation (steel, glass or foam) which suspends instruments on chain and wire and is anchored to the bottom by a large weight (Fig 1). Moorings can be as long as 2000 m. The floatation may or may not be a buoy on the surface. Data can be telemetered to shore by acoustic and radio modem links, or via satellite, but most often it is recovered when the instruments are recovered at the end of the deployment. Bottom platforms are almost always a

tripod design for stability, and can range from 1-5 m high depending on the instrumentation being deployed (Fig 2). The moorings and tripods are built to withstand the rigors of coastal storms such as hurricanes and nor'easters as well as entanglement with fishing gear. In many locations large surface "guard" buoys are deployed to mark the site to prevent entanglement by fishing activity.

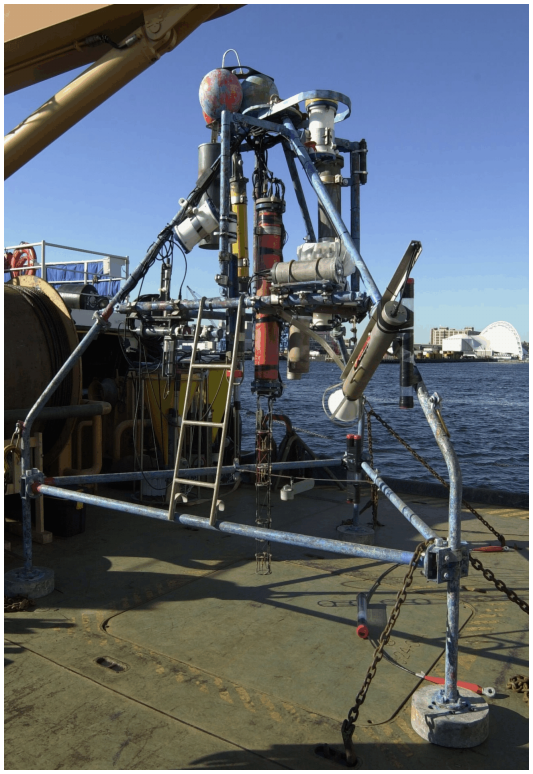

Figure 2: Large tripod aboard the USCG Marcus Hanna awaiting deployment in Massachusetts Bay.

Sea Floor Mapping and Imaging

High resolution acoustic mapping and imaging systems are employed to map and characterize the sea floor. Sea floor mapping presents regional overviews of what sediments are in place, both at the seabed and below.

- Figure 3 is one of the seismic reflection "fish" towed behind a ship to map below the sea floor. A typical product is a mosaic map compiled of the individual lines run by the ship, or a sub-bottom profile of the sediment below. The maps are ground-truthed using samples, bottom photographs and video to gain detailed information about what kind of sediment had been mapped by the acoustics or seen moving by in situ sensors.
- The Coastal Profiling System uses personal water craft (jet skis) fitted with and acoustic echo sounder and a Differential Global Positioning System (DGPS) to perform sub-aqueous bathymetric surveys in shallow water (0-10 m).
- The SWASH (Surveying Wide-Area Shorelines) is a vehicle-based system for measuring shoreline position which utilizes an array of DGPS sensors to measure elevation and tilt which are extrapolated to a shoreline datum (Fig 4). SWASH has mapped pre and post storm changes in beach profiles on Cape Cod, MA and the banks of North Carolina.
- Sector scanning sonar is used to image sand ripples on the sea bed. Using images taken over several months, movies are created from these images,

Figure 3: The new seismic reflection system with the "cataraft" sled designed at the Menlo Park Center so data can be collected in water <10 m deep.

showing the creation, progression and destruction of sand ripples in response to bottom processes.

Figure 4: SWASH. Note the multiple GPS receivers on the top of the buggy.

Sediment Sampling and Imaging

Mechanical samplers such as settling traps, gravity cores and van-veen grabs are used to collect sediment samples from the sea floor or within the water column. These have been particularly valuable techniques for associating transport of heavy metals with specific storm events. Sediment analysis is performed by a network of laboratories located at all three Centers, and work continues on databases such as the contaminated sediments database and aggregates database. A few of the more advanced mechanical sampling systems in use by CMGP are the slow corer, the SEABOSS, and time-series settling traps:

- The slow corer is an hydraulically damped corer can take up to 50-60 cm sediment cores without disturbing the sediment-water interface at the sea bed. Video cameras allow scientists to examine the sea floor in real time and choose where to take a sample.
- The SEABOSS is able to obtain real time video of the bottom, take 35 mm still images, and acquire a grab sample. SEABOSS is typically suspended above the bottom as the ship is allowed to drift over sites of interest. Both the winch operator and scientist can simultaneously monitor the video.
- The Honjo trap is a long-term, in situ time series settling trap consisting of a large diameter collecting cone attached to a rotating carousel of collection bottles (Fig. 1). Bottle rotation is controlled by a computer programmed with a pre-selected schedule.
- The super-sucker is a water transfer system[2] which collects sediment by pumping a fixed volume of in situ water past a pre-weighed filter, which traps the sediment. Also computer controlled, this instrument selects sampling time based on real time analysis of in situ conditions. Bottle and filter contents from these samplers are analyzed for chemical and geological properties depending on the particular study.

Near Bed Currents and Suspended Sediment Concentration

One of the most difficult problems has been to model, in three dimensions, the types of sediment that are resuspended and transported under various conditions. This is key to achieving a predictive capability. Attenuation sensors, backscatter sensors, profiling and single point current velocity sensors are deployed in situ for one month to a year to acquire time series sediment resuspension caused by different processes (storms, internal waves, tidal flow, etc.). These data are used to develop and test three dimensional hydrodynamic and sediment transport models. The challenges in making these measurements can be divided into two areas: obtaining

high resolution data near the sea bed in the presence of resuspension events (such as storms), and calibrating instrumentation to determine sediment concentration.

Acoustic profiling instruments are routine working instruments for water column profiling over ranges of 5 to 500 m. This technique is presently limited when brought close to a boundary such as the sea bed. The challenge is to obtain water column profiles of flow and sediment concentration at high resolution without disturbing the flow, for example, to profile 1 m above the sea bed at 1 Hz, with 10 cm resolution and better than 5 cm/s accuracy, over a period of four months. There are rapid sampling, highly accurate single-point acoustic sensors, but the challenge remains to profile accurately at such rates. New "pulse-to-pulse coherent" Doppler profiling techniques are beginning to attack this problem. Over the past year, the CMGP has been using state of the art instruments available commercially in routine experiments and in testing during special deployments. These instruments perform very well when presented with slower, steady state, two dimensional flows, but this is not the reality of the coastal ocean, especially during storms. We are presently evaluating the errors induced in these instruments by waves and highly turbulent flows so that future data analyses will be more accurate, and so that we can establish, program-wide, a single, accepted technique for these kinds of measurements.

Acoustic and optical sensing techniques exist to detect resuspension of sediment. It is difficult to gain information about the size, concentration and settling velocity of the particles that are in motion, especially over long periods of time. Estimates of mass sediment transport are needed to test and refine models. Sediment samplers which trap particles provide information about the particles they capture, but they are limited by the volume of sediment they can store and the mechanical problem of dividing the samples in time so that one knows when the particles arrived on site. They are often biased collectors of particles. Remote sensing techniques which do not disturb the environment they sample are preferred for long term, in situ measurements. Sensors which detect backscatter, either of light or sound, have been very productive, however they are sensitive to different sizes and mixes of particles. The transmissometer is a favorite sensing technique for lower concentrations of sediment.

Backscatter sensors must be calibrated to convert the signal to useful measures of sediment concentration. These calibrations, be they acoustic or optical (including the transmissometer), are particle size and concentration dependent. Flocculation of particles under different stress conditions further complicates the calibration problem. CMGP and Woods Hole Oceanographic Institution scientists are working together to calibrate optical and acoustic backscatter sensors in the laboratory using in situ sediment samples taken from experiment sites. The challenge remains to build a calibration facility that uses volumes of sediment samples that are practical to transport from the experiment site, and that can maintain the volume of sediment in suspension long enough for a stable calibration. Each new experiment at a new location with different sedimentary features requires a new calibration. Even then, the assumption is that the degree of flocculation is dependent on the way the sediment is handled and may or may not represent flocculation at the actual experiment site. Finally, the calibration is dependent on the mixture of particle sizes and types, which may not represent the concentrations found at the bed.

Backscatter intensity recorded over a range of acoustic frequencies may be able to separate sediment into ranges of size or concentration. Single frequency information is widely available as a level of acoustic backscatter; it is a standard diagnostic parameter that is stored by all acoustic current velocity sensors that utilize Doppler shift to make measurements. Transmissometers and optical backscatter instruments are also de-facto single channel sensors, as they simply respond to the gross change in sediment resuspended in the water. One advance has been the commercial availability of multi-frequency acoustic backscatter systems that can remotely sense and record profiles of backscatter intensity above the bed. These allow classification of resuspended matter into bands of concentration, and once calibration techniques are improved, may possibly give information about concentrations of particles of various sizes. Another technique which shows great promise can classify particles by size based on laser scattering, however the instrument must be present in the flow field (and therefore cause a disturbance) to do so, and it cannot profile at present.

Photographic imaging shows promise for determining grain size. The CMGP has developed its own photographic system to obtain images of the surface sediment. Named the "Poking-Eyeball", it recently underwent its first full field trial. The Poking Eyeball is brought against the sea bed to image sediment in situ at sufficient magnification to determine grain size. Such images (Fig. 5) provide a time history of the type of particles on the sea bed. This technique offers an advantage over settling traps in that many more images can be taken over the course of a deployment.

Figure 5: Magnification of the sea floor, in situ, captured by the Poking Eyeball. Visible are shells and sediment grains.

Processing and Archival of Data

Data archive and the recording of appropriate metadata in the face of ever growing amounts of data is an ongoing challenge for the CMGP. Twenty years ago, a single instrument would produce 2 MB of data in an experiment, and seismic mosaics were pieced together from paper printouts. Today we deploy arrays of instruments which each generate 40 MB to 2 GB of data, and we map and generate digital mosaics in real time with resolution of a few meters or less. We are striving to standardize techniques used by our Centers to handle data from our instrumentation so that these data are more accessible to researchers both immediately after the experiment and into the future. A single point of contact and a standardized data processing system provide a useable archive of data back to 1975. Standardization provides a "best basic version" of data to scientists for analysis. Sometimes we can rely on manufacturers software, but such software is often designed for a very generic user, and is dependent on the

manufacturer's long term support. We often find ourselves looking to more open source methods for long term archival and data manipulation.[3] GIS and database techniques, MATLAB and open format standards such as netCDF are some of the tools we use. Standardization this way has made collaboration with other institutions, and among our own sister offices, much more productive.

Examples of Current Projects

There are several CMGP field projects that are collecting data relevant to sediment resuspension studies:

- Long Term Oceanographic Observations in Massachusetts Bay is an ongoing long term field program to understand the long-term fate of sediments and associated contaminants.[4,5] It has provided one of the longest continuous time series of currents and sediment observations (1989 to present). Figure 6 shows how sediment samples are used with oceanographic observations for analysis. The long-term observations document seasonal and inter-annual changes in currents, hydrography, and suspended-matter concentration in western Massachusetts Bay, and the importance of infrequent catastrophic events such as major storms or hurricanes in sediment resuspension and transport.
- Off Washington State, the U.S. Geological Survey and the Washington State Department of Ecology initiated a multi-disciplinary cooperative study to gather information on the entire coastal system to address the causes of the recent change to increased erosion of the coast.[6]
- During the winter of 2002-2003, CMGP participated in the Eurostrataform program[7] which brought together scientists from the U.S., Italy, Spain and elsewhere to use selected areas of the European continental margin to explore the fate of sediment particles from their

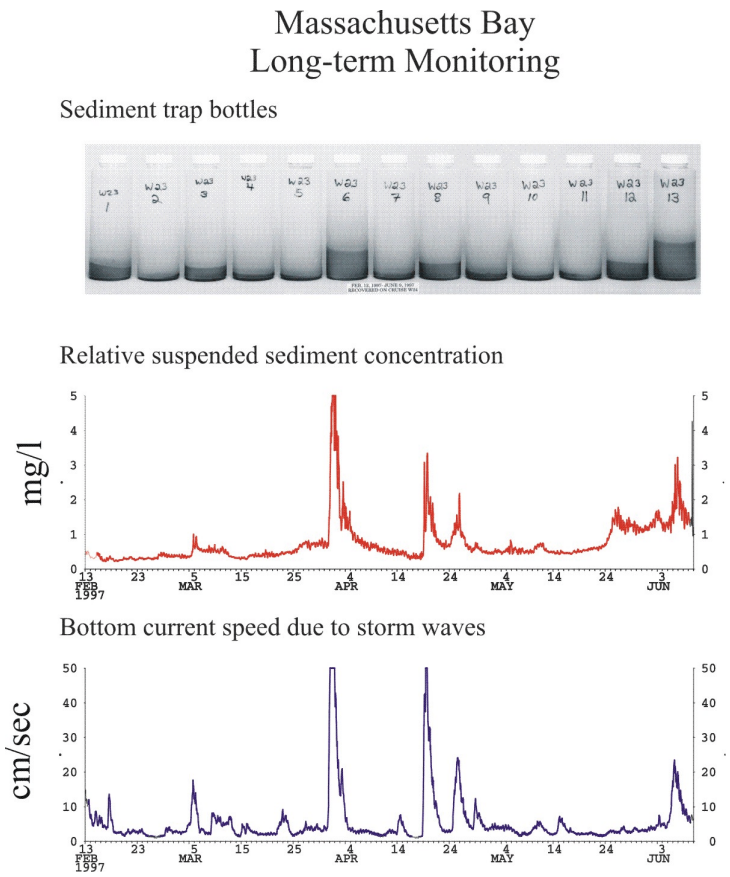

Figure 6: Collection bottles from a time series settling trap show how amounts of sediment can vary with resuspension events.

source in rivers to their deposition on shallow deltas, on the continental shelf, and in deep-sea basins.

- Another unique field program is designed to investigate sediment turbidity current events in Monterey Canyon.[8] Three long moorings with numerous settling traps, transmissometers and current meters have been deployed in the canyon axis at depths of 1800-800 meters since December, 2002 to document an event. We hope to see how much sediment is transported, how far, and how high from the sea floor.
- This summer we performed a short instrumentation test off Martha's Vinyard, MA, in cooperation with the Woods Hole Oceanographic Institution, to test two commercial instruments which can perform high resolution profiling of currents and sediment resuspended above the sea bed.

All of these projects provide observations for testing numerical models of circulation for the Community Coastal Sediment Transport Model.[9] This project works to improve prediction of the transport, transformation, and fate of sediment and particle-bound nutrients and contaminants. Goals are to produce advanced numerical models and model infrastructure for coastal sediment transport that are scientifically sound, expertly coded, well tested, and suitable for use in both research and practical applications.

Summary

Two technological challenges that are a top priority for study in the CMGP are: high resolution profiling within 1-2 m above the sea bed, and calibration of sensors that can detect and measure sediment resuspension events. We want to be able to measure the properties of sediment while not disturbing the flow environment and without disturbing too much sediment at the experiment site. This will require a suite of sensors to be deployed together. Some will be on platforms designed not to interfere with flow, and some will be bulkier systems to provide information needed for calibrations.

The long term objective of the CMGP is to improve our ability to predict the transport, transformation and fate of sediment in the ocean. The wide array of instruments provides the field data to develop, test and improve coupled hydrodynamic and sediment transport models.

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9. Community Model for Coastal Sediment Transport, http://woodshole.er.usgs.gov/project-pages/sediment-transport/

Coastal & Marine Program Technologist Contacts and Web sites

acoustic Doppler profilers	Marinna Martini, Jessie Lacy
analytical labs	Ellen Mecray http://woodshole.er.usgs.gov/operations/sedimentlab/index.html
coastal profiling system	(near shore mapping) Guy Gelfenbaum, Peter Ruggiero
current measurement	Marinna Martini, Brad Butman
high resolution profiling	(water column) Joanne Ferreira, Jessie Lacy, Chris Sherwood
moorings & tripods	Jonathan Borden
poking eyeball	Dave Rubin, Hank Chezar
scanning sonar	Marinna Martini, Chris Sherwood, Phil Thompson
SEABOSS	Dann Blackwood, Page Valentine http://woodshole.er.usgs.gov/operations/seaboss/seaboss.html
seafloor mapping	Bill Danforth, Jane Denny, Larry Kooker http://woodshole.er.usgs.gov/operations/sfmapping/default.htm, http://walrus.wr.usgs.gov/pacmaps/
sediment databases	Larry Poppe, Jeff Williams http://instaar.colorado.edu/~jenkinsc/dbseabed/dbseabed.html
settling traps, slow corer	Rick Rendigs, Mike Bothner
SWASH	Amy Farris, Jeff List http://woodshole.er.usgs.gov/operations/swash/index.html

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