Predicting the Distribution and Properties of Buried Submarine Topography on Continental Shelves

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LONG-TERM GOALS

Compile geological data and develop methods to predict the distribution and properties of features hypothesized to be responsible for sonar geoclutter. Geological structures just beneath the seafloor, such as steep-walled channels, may have high-angle reflecting surfaces that can return false sonar alarms to ships operating in the littoral zone. The major goal is to contribute to the reduction or mitigation of geologic clutter observed on fleet sonar systems.

Two issues define the problem.

- Landscape forming issue: In area 'x', can the Navy expect geoclutter features and if so what are their sonar characteristics, i.e. channel orientation.
- Landscape burial issue: If geoclutter features are expected in area 'x', will the features be exposed or buried. Areas of low interest to the Navy include locations where Holocene deposits are thick. Areas of high interest to the Navy include locations where Holocene deposits are thin thereby allowing for the shallow burial of Pleistocene topography.

OBJECTIVES

- Define the character of different kinds of buried channels (size, shape, properties).
- Define the spatial distribution of these buried channels (river, tidal, hyperpycnal).
- Develop a global atlas of candidate geoclutter features and their characteristics.
- Develop and merge global databases of pertinent geological and oceanographic data.
- Develop predictive models and apply to margins of interest. Test predictive models in a known geoclutter rich area.
- Share and merge these databases, models and results with those in the Geoclutter Research Group working on tracking algorithms.

APPROACH

1) Compile a global database of pertinent geological and oceanographic data, for use as initial inputs and constraints for sediment flux models (*HydroTrend* and *SedFlux*).

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2) Measure and analyze terrain attributes. Perform a comprehensive analysis of real and simulated elevation grids using RiverTools® and other GIS software. Calculate the geometric and statistical characteristics of landforms and how these characteristics vary from one geologic setting to another.

3) Classify terrain from geologic information. Classify "terrain types" in terms of the initial and boundary conditions (e.g. geology, erosion rates, excess rain rates) that produced the terrain types, using physics-based landform models.

4) Determine the burial depth potential of low-sea level produced topography. Develop simple scaling relationships for deposition rate as a function of sediment input rates from rivers, wave and current conditions, and shelf geometry. Refine these bulk estimates with more detailed consideration of the nature of sediment delivery to the shelf (e.g., episodic storm-driven flooding vs. seasonal snowmelt flooding; the role of estuaries) and sediment redistribution, bypassing and deposition on the shelf (e.g., the long-term manifestation of short-term, episodic, storm-driven transport on the shelf).

5) Model the flux of sediment to and across continental shelves. Use process-based models (*HydroTrend*) to obtain a detailed consideration of the nature of sediment delivery to the shelf and sediment redistribution, bypassing and deposition on the shelf.

WORK COMPLETED

1. Parameter estimation for fluvial landscape evolution models

1A. Estimating the geomorphic effective rain rate: Fluvial landscape evolution models that give rise to mature, channelized land surfaces are always driven with a "geomorphic effective rain rate", R. This rain rate plays a major role in setting both the drainage density of the embedded river network, and other characteristic length scales such as for gully features. Our recent work also suggests that it also acts as a vertical scale factor. A precise definition of this rain rate, say in terms of bank-full discharge or a magnitude-frequency relationship has remained elusive. During this last year, a topographically derived estimator for this effective rain rate was determined, allowing landscapes to be evaluated in terms of their characteristic fingerprint.

1B. Estimating exponents in slope-area-discharge relationships: Fluvial landscape evolution models utilize semi-empirical sediment transport laws in which the transport rate is expressed in terms of slope and basin area raised to powers. We have developed simple formulas that allow these exponents to be estimated from best power-law curve fits to longitudinal profiles.

1C. Estimating basin-averaged temperature: Basin-averaged temperature is needed for the estimation of sediment discharge to the coast for use by algorithms that bury channels offshore. We have developed a method for estimating mean annual temperature as a function of latitude, longitude and elevation (including the impacts of ocean warming and continent cooling effects via lat/long rules). Another recursive computer program was rewritten to average a quantity such as temperature over the pixels in a river basin.

2. East Coast Pixel Database to Global Database

2A. Completed routines to extract coastal pixels and to compute basin areas, basin relief, basin-averaged temperature, hydraulic geometry, channel slopes, and other geomorphic variables. Also investigated the Rosgen stream classification method, which is based on four dimensionless numbers: slope, width-to-depth ratio, channel sinuosity and the entrenchment ratio, as a method for connected basin-scale geometric measurements such as basin area to channel-scale measurements need by the Geoclutter project.

2B. The global monthly climate statistics (temperature, precipitation and there standard deviations) of the Last Glacial Maximum, 21kyBP, were retrieved from the NCAR Community Climate Model1 (CCM1) in such a way that they easily can be used as an input for HydroTrend for any river in the world. See animations: http://instaar.colorado.edu/deltaforce/projects/geo_clutter_animations.html.

3. Landscape evolution modeling - Simulations

3A. Ran UVA (Alan Howard) landscape evolution model MARSSIM for a variety of parameter settings and identified bugs in the model that hindered progress. These bugs were recently resolved but new simulations have not yet been performed.

3B. Developed a fluvial landscape evolution model that is somewhat simpler than MARSSIM and derived a Courant condition for stability, which depends on the exponents in the slope-area-discharge formulas. This stability criteria has not yet been implemented or tested.

3C. Worked out a sophisticated Ritz-Galerkin, finite-element numerical method for solving the steady-state fluvial landscape equation, but encountered stability problems during implementation that have not yet been fully resolved.

4. Landscape evolution modeling – Theoretical results

4A. Showed that all solutions to a steady-state fluvial landscape model based on conservation laws are hydrologically sound, or free of pits. Also demonstrated with examples that local landscape features such as saddles, monkey saddles, peaks, forks, channels, and hillsopes are all realizable as solutions to the model. Found a general solution method for the "local equation" and showed that this equation is essentially a local restatement of mass balance combined with a slope-discharge relationship.

4B. Discovered and proved that if $f(x,y)$ is a solution to the steady-state fluvial landscape equation for $R=0$, then $g(x,y) = -(1/R) * \ln(f(x,y))$ is a solution to the equation for $R > 0$. This result is very important as it results in a tremendous simplification of the problem with regard to find both analytic and numerical solutions. The simple form of this transformation also makes it relatively easy to impose boundary conditions.

4C. Showed how the exponent in the power-law form of longitudinal profiles is related to the exponent(s) in slope-area-discharge formulas.

5. Seascape burial modeling

5A. The model HydroTrend is made available for all GeoClutter project members through the web: http://instaar.colorado.edu/deltaforce/models/hydrotrend.html.

5B. Predicted the monthly sediment discharge for US east coast rivers (Fig. 1.) See also: http://instaar.colorado.edu/deltaforce/projects/mine_burial_final_report.html#Animations.

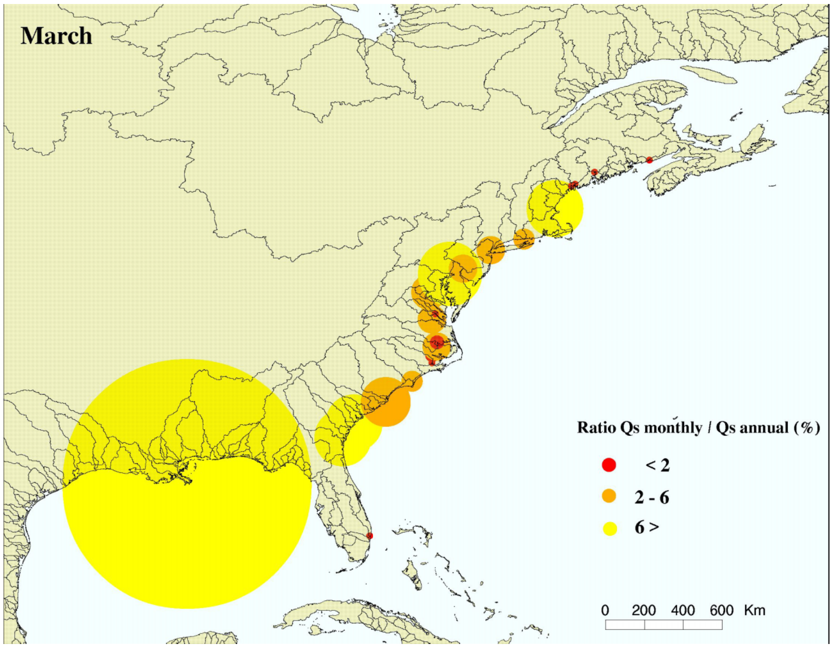

Figure 1. Sediment discharge of US east coast rivers where the color and diameter of the circles shows the magnitude and ratio of the monthly Qs:Qs annual.

5C. Modeled the time-varying bathymetry for the East coast of the U.S. across the last 21,000 years using isostatic (dynamic) adjustments of ice sheet load along with eustatic (static) changes in sea level due to fluctuations in ice volume (Fig. 2). Applied the HYDRO1K DEM data to analyze the sea level change for the North America east coast for 21kBP till now. Provided these results to the landscape evolution modelers (S. Fagerazzi, A. Howard).

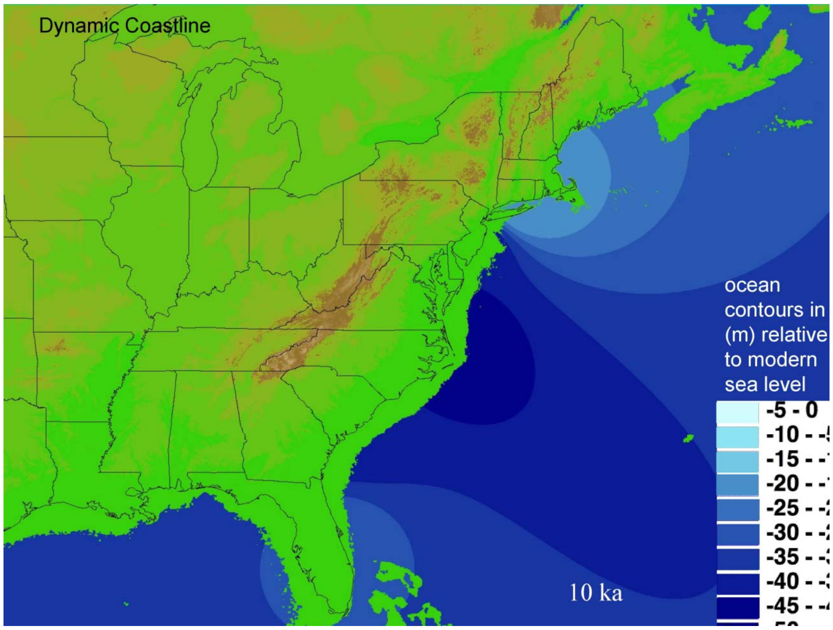

Figure 2. Coastline of the eastern US at 10KyrBP compared to modern position of the coastline. Ocean colors show the impact of isostatic and eustatic impacts on sea level.

5D. Developed an interpolation scheme using the GRIP ice-core (δO18 variation) to determine time continuous temperature and precipitation values between 21 kBP and present-day. Sea level changes and Laurentide Ice Sheet melting influence the drainage basin characteristics and are used to model the flux of sediment to the coastline. *HydroTrend* predictions of discharge and sediment load for the LGM to present are handed over to other GeoClutter project members (Sergio Fagherazzi) for channel-forming simulation.

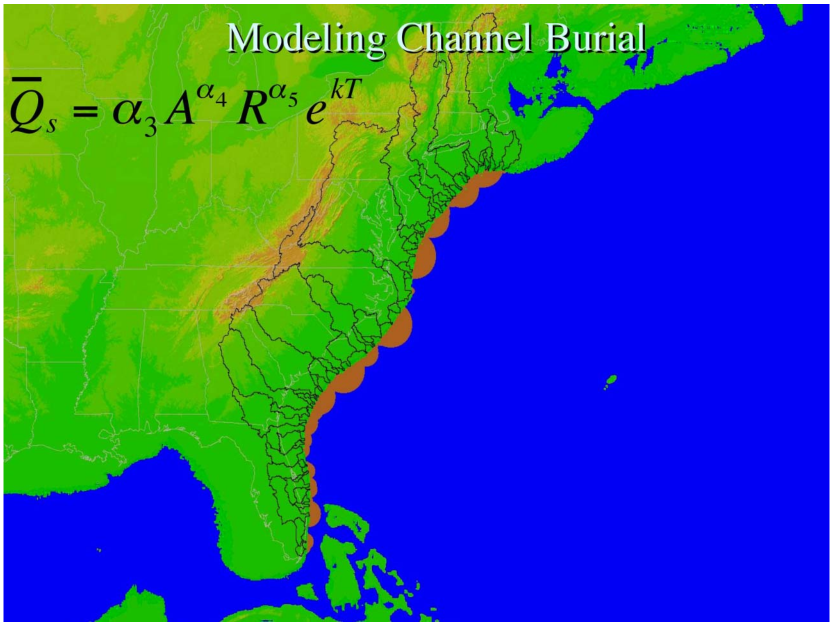

Figure 3. Coastline of the eastern US at 21KyrBP showing the relative magnitude of sediment flux and the predicted geographic spread of that flux given the configuration of rivers at that time.

RESULTS

A simple calculation based on elevations in the immediate vicinity of an area of interest provides an estimate of R, the rain rate that controls the morphology of river channels. What is exciting about this result in the context of Geoclutter is that if part of the once-subaerial paleo-topography can be observed, either because it is exposed on the seafloor (i.e. not buried beneath a mud layer) or because it can be imaged with limited acoustic surveys, then it may be possible to estimate the geomorphic effective rain rate that was in effect when the paleo-topography was formed. This estimate of R can then be used to drive simulations. Some studies suggest that fluvial landscapes tend to evolve toward land surfaces that exhibit a spatially uniform distribution of unit stream power. Our proposed method may make it possible to estimate regional exponents in slope-area-discharge formulas, with much less information than a longitudinal river profile. Longitudinal profiles for nearby subaerial regions can also be used as surrogates. We have developed a method for predicting the flux of sediment to the coastal ocean for an entire coastline, and this provides a means to estimate the likelihood of channel burial at any given offshore region along a continental margin. This accomplishes a major goal of the project.

IMPACT/APPLICATIONS

New numerical tools allow for predicting the burial of channels carved into the seafloor during times when the sea level was as much as 120 m lower than observed today. Because these tools are driven by environmental data they offer the promise to provide seafloor acoustical information of continental margins at the global level.

RELATED PROJECTS

NSF MARGINS: Experimental and Theoretical Study of Linked Sedimentary Systems:
http://instaar.colorado.edu/deltaforce/projects/margins.html
NSF CSDMS: Community Sedimentary Model Science Plan:
http://instaar.colorado.edu/deltaforce/workshop/csdms.html
ONR Seabed Uncertainty: http://instaar.colorado.edu/deltaforce/projects/dri.html
ONR EuroSTRATAFORM: http://instaar.colorado.edu/deltaforce/projects/euro_strataform.html

PUBLICATIONS

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