Modeling the Effect of Climatic and Human Impacts on Margin Sedimentation

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LONG-TERM GOALS

Coordinate the EuroSTRATAFORM modeling effort. Model the hydrological routing of water and sediment into the Northern Adriatic and the Gulf of Lions. Determine if there is a connection between point source or line-source sediment supply and sea level, and whether this connection controls canyon morphology, failure frequency, and gravity flows.

OBJECTIVES

1A) Coordinate the EuroSTRATAFORM modeling efforts designed to formulate predictive and diagnostic models on how sedimentary processes create strata, and contribute to the stratigraphic record.

1B) House and test the EuroSTRATAFORM models at INSTAAR's Environmental Computation and Imaging Facility. Make these models available to the larger EuroSTRATAFORM community.

2A) Determine the long-term and short-term climate changes, and the perturbations from human impacts, on the hydrological routing of water and sediment (e.g., floods, droughts) including the Po, selected rivers along the Apennines, and the Rhone River.

2B) Determine any connections between point-source and line-source sediment supply and sea level, and whether these connections control canyon morphology, failure frequency, and gravity flow dynamics. Determine if the formation and intensity of hyperpycnal flows generated at river mouths directly affects the position and formation of submarine canyons.

2C) Support the effort to understand how the dynamics of delta lobe switching frequency imparts a recognizable signature on margin architecture (e.g., through plume sedimentation).

2D) Support the effort to understand the dynamic response of a continental margin to large-amplitude sea-level changes, beginning with those of the last glacial cycle.

2E) Support the effort to develop coherent techniques for upscaling individual processes/events into long-term stratigraphic-architecture and seascape-evolution models.

APPROACH

1A) Through regular meetings and electronic communication, develop a US-European community of modelers who together develop a suite of numerical tools to model events affecting strata formation that are otherwise difficult to observe. The cumulative impact of these high-energy events can be predicted through numerical experiments, within the context of other relevant marine processes (e.g., earthquakes, tsunamis, storms, seasonal discharge). Have the EuroSTRATAFORM numerical and laboratory group will work closely with scientists collecting field observation, for insight and validation.

1B) Combine single-component models into a larger numerical framework, including the conversion of 2D-*SedFlux* into 3D-*SedFlux*. Encourage code sharing among participants of EuroSTRATAFORM.

2A) Locate and analyze the discharge records for key rivers in our Mediterranean study areas. Collect appropriate climate and geomorphic data for input to *HydroTrend*, and generate synthetic discharge data and sediment loads, across historical and geological periods. Make *HydroTrend* results (water and sediment discharge) available to other EuroSTRATAFORM participants. Predict flood probability distributions, and simulate conditions favorable to the development of hyperpycnal flows.

2B) Determine if the Apennines rivers are able to generate hyperpycnal flows. Apply state-of-the-art 3-D hydrodynamic models of hyperpycnal plumes to investigate the line source vs. point source question. Use hyperpycnal and hypopycnal plume models to investigate the effect of sea-level change and shelf width on density-driven flows in submarine canyons. Model the interaction between long-shore currents and an evolving hyperpycnal or hypopycnal plume.

2C) Construct a numerical model to handle both autocyclic and allocyclic processes. Test the model against the switching frequencies of well-studied deltas (Po, Rhone, Yellow, and Mississippi). Add the delta-switching model to the *3D-SedFlux* model and model the offshore sedimentation patterns given *HydroTrend* synthetic discharge data. Compare model results with field data from the Gulf of Lions and the Adriatic.

2D) Support those who will apply *SedFlux* to the simulation of seafloor deposits on the Italian margin and the Gulf of Lions.

2E) Investigate the employment of two scaling techniques: (i) coherency-modified probabilistic frequency distributions (*e.g.* for river discharge), and (ii) application of statistical properties of Laplace-generated deposits within a compute-and-drift scheme. Scale between laboratory experiments and continental margin observations, employing *SedFlux* [this activity will extend beyond FY-03].

WORK COMPLETED

1A) Convened a well-attended workshop entitled *PREMISE*: *PRE*dictive *M*odeling *I*n *S*upport of *E*uroSTRATAFORM on Oct. 17/2001 in Arlington. The workshop set the ONR-EuroSTRATAFORM course to (i) integrate models across time and space, (ii) coordinate laboratory modeling efforts with numerical modeling efforts, (iii) coordinate proposed modeling and field efforts, with particular emphasis on providing testable predictions to be studied by the field programs, and (iv) link efforts with European projects: EURODELTA, PROMESS, and EU-EuroSTRATAFORM. Supported the efforts of European scientist to acquire EC funds for these EU projects. Coordinated US efforts with

EURODELTA scientists (Jan. 21-23, 2002, Bologna) and EuroSTRATAFORM scientists (April 9, Sitges). Supported the organization of the kickoff meeting of EU and US EuroSTRATAFORM efforts in Winchester (Sept 8-12, 2002).

1B) Begun conversion of 2D-*SedFlux* into 3D-*SedFlux* with the following modules complete: avulsion of a delta's distributary channels, multiple plumes, longshore transport from breaking waves, and shelf diffusion. Provided one 8-hr and two 16-hr courses to the Europeans on the development of numerical models for purposes of predicting the evolution of the sedimentary deposits found along world continental margins. 122 scientists attended the courses from 22 cities (Netherlands, Italy, Spain, France, UK).

2A) Adapted relational and spatial methods (i.e. *RiverTools®*, *HYDRO1k*, *ArcInfo®)* to facilitate the process of data acquisition used by the sediment discharge model *HydroTrend*. As a climate-driven hydrological model, *HydroTrend* incorporates drainage basin properties (river networks, hypsometry, relief, lakes) through high-resolution digital elevation models, along with other biophysical parameters (basin-wide temperature, precipitation, evapo-transpiration, canopy, soil depth, hydraulic conductivity, ice fields). Using modern climate conditions, *HydroTrend* generated synthetic discharges of the following Italian rivers: Po, Metauro, Chienti, Tronto, Pescara, Sangro, Musone, and Potenza.

2B) Adapted a 3-D hydrodynamic model (*FLUENT*) to study the plunging of a river to the ocean bed. Many of the modeled Apennine rivers appear able to generate hyperpycnal flows on a every few year basis.

2C) Completed the first stage of a numerical model to handle autocyclic and allocyclic river mouth channel switching and incorporated code into *3D-SedFlux*. Work is ongoing to add AquaTellus, a Delft University model, to *3D-SedFlux* model. This addition will allow the modeling of deltaic channels and their floodplain sedimentation through the process of overbanking.

2D) Shared code and operational procedures for 2D-*SedFlux* with Southampton Oceanographic Center (Dr. Carl Amos) and the University of Brest (Dr. Marina Rabineau). These scientists will use and adapt 2D-*SedFlux* to simulate the seafloor deposits off of the Po and Rhone, respectively. We have worked with CNR-IGM scientists (under Dr. Fabio Trincardi) to produce the paleo data required by *SedFlux* as input.

2E) Implemented a pathway in *SedFlux* that analyzes the results of *HydroTrend* and produces a cumulative distribution function of sediment discharge. The top (i.e. use-defined number of days per year) discharge events are modeled separated by inter-event mean values, thereby reducing the number of modeled days by 70 to 90%. We have increased the run time of the sediment failure module in *SedFlux* by two orders of magnitude.

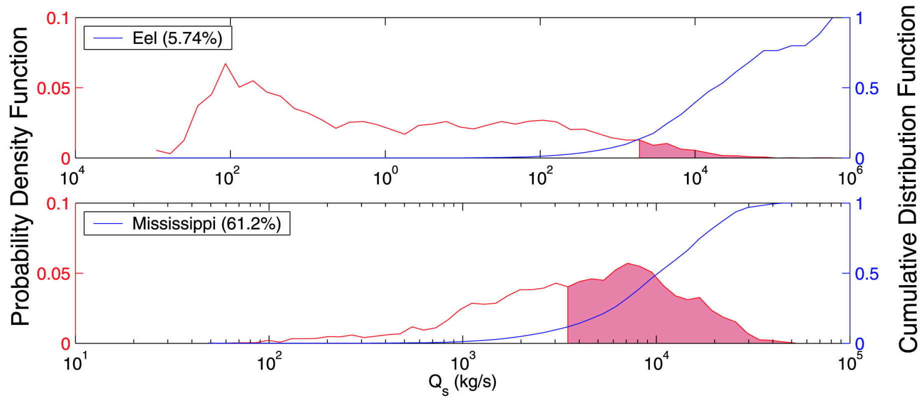

Figure shows the probability density function of the sediment load for the Eel River, California, and the Mississippi River, along with their cumulative distribution function. In the Eel case, 5.74% of the days moves 90% of the sediment. In the Mississippi case, 61.2% of the days are needed to move 90% of its annual sediment load.

RESULTS

Many of the Apennine rivers are predicted to be capable of generating hyperpycnal flows every few years. Most hyperpycnal flows do not last much longer than one day. For example the Chienti River is expected to go hyperpycnal, on average, twice a year lasting for 1.5 days.

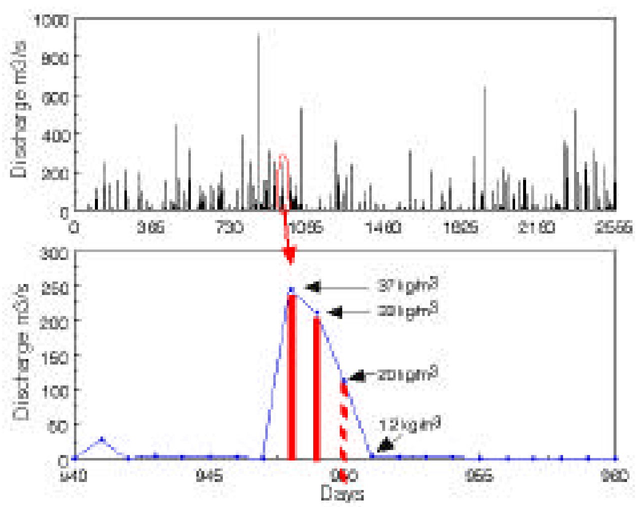

Figure shows the first 7-yr of a 1000-yr daily discharge (HydroTrend) simulation of the Chienti River, Italy. The annual discharge is ≈10 m^3/s. Seasonal floods that last for 1 to 3 d can exceed 500 m^3/s. The lower panel shows a 3-d flood event with discharges in the 100 - 250 m^3/s range and sediment concentrations in the 20 - 37 kg/m^3 range. The river would likely go hyperpycnal for the first two days of the flood.

The *FLUENT* model allows determination of the exact location of the plunge point when a river has the potential to generate hyperpycnal flow. The model provides accurate upstream boundary conditions for a 2.5-D (depth-averaged) model to be extensively used in this research. The model solves the depth-averaged equations of the conservation of fluid mass, momentum, suspended sediment concentration of multiple grain size, and turbulent kinetic energy in conjunction with the Exner equation of bed sediment continuity in a downslope and lateral coordinate system. The incorporation of the turbulent kinetic energy in the model allows for more accurate prediction of seabed scour/deposition in response to a hyperpycnal flow event. The code is written using the visual basic programming language and has a user-friendly interface for model input. The model is currently being rigorously tested and verified.

The first stage of a river avulsion module is implemented in *SedFlux*. The delta channel-switching (or avulsion routine) module simulates the seafloor deposits from distributary channels and plumes.

IMPACT/APPLICATIONS

New numerical tools that predict the general nature of seafloor morphology and the developing sediment stratigraphy, allow for realistic simulations in the littoral zone. The tools are being coupled to acoustic models and used to assess acoustic reverberation and propagation. Because these tools ingest environmental data they offer the promise to provide seafloor acoustical information of continental margins at the global level.

TRANSITIONS

ExxonMobil is using versions of *SedFlux* to characterize offshore reservoirs. The geotechnical community is using *SedFlux* to investigate the role of marine slope failures in generating tsunamis. SACLANT, Applied Physics Lab (Washington) and Applied Research Lab (Penn State) are using realizations of *SedFlux* in their studies of transmission loss and tactical environmental uncertainty. The *SedFlux* model is being used to investigate sonar geoclutter. *HydroTrend* is being used to characterize the sediment delivery to potential mine burial sites.

RELATED PROJECTS

ONR Geoclutter: Predicting the Distribution and Properties of Buried Submarine Topography on Continental Shelves
ONR Mine Burial: Sediment Flux to the Coastal Zone: Predictions for the Navy
ONR Uncertainty: Seabed Variability and its Influence on Acoustic Prediction Uncertainty
ONR STRATAFORM: Scaling and Integration of Process-Response Stratigraphic Models
NSF MARGINS: Experimental and Theoretical Study of Linked Sedimentary Systems
NSF MARGINS: Community Sedimentary Model Science Plan for Sedimentology and Stratigraphy.

PUBLICATIONS

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