

Scaling and Integration of Process-Response Stratigraphic Models

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LONG-TERM GOALS

Formulate predictive and diagnostic models on how sedimentary processes create strata, and contribute to the stratigraphic record. Of special concern are capturing the important rare events affecting strata formation (e.g., slides, floods) that are often difficult to observe but can control the stratigraphic development of a margin. The cumulative impact of these rare events can be predicted through numerical experiments, within the context of other relevant marine processes (e.g., earthquakes, tsunamis, climate, storms, river discharge).

OBJECTIVES

1A) Set up a computational facility at INSTAAR, offering remote log-on access by the STRATAFORM modeling community.

1B) Implement the ONR-MG plan entitled the Integrated Modeling System for Simulating the Evolution of Continental Margin Stratigraphy, i.e.

- Refine the *SedFlux* model to include 3 shelf-sediment transport (SST) modules.
- Test SST upgrades to *SedFlux* against known environmental conditions (Eel Margin).
- Couple the latest acoustic module from Duke U. to *SedFlux*.
- Ensure the *Sequence* model is completed and tested against a known environment.

2A) Construct a numerical model to simulate delta-lobe switching that will include autocyclic processes and allow for the influences of allocyclic forces. Add the module to *SedFlux*. The 3D-version of the model should numerically handle complex shorelines (boundary shapes).

2B) Develop upscaling routines for *SedFlux-2D* to allow for application of the model to simulate long period geological periods.

2C) Determine how large sediment waves form on continental margins as a result of river floods. Determine optimal conditions for sediment wave formation, including bed slope, macro-roughness wavelength, sediment size, sediment concentration.

APPROACH

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14. ABSTRACT Formulate predictive and diagnostic models on how sedimentary processes create strata, and contribute to the stratigraphic record. Of special concern are capturing the important rare events affecting strata formation (e.g., slides, floods) that are often difficult to observe but can control the stratigraphic development of a margin. The cumulative impact of these rare events can be predicted through numerical experiments, within the context of other relevant marine processes (e.g., earthquakes, tsunamis, climate, storms, river discharge).					
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1A) Set up the ONR Environmental Computation and Imaging Facility by installing the Sun Enterprise 5500 and 6500 servers, 25 work stations, UPS, and RAID tape system. Make facility available to ONR MG users. Install ONR MG models.

1B) Ensure STRATAFORM shelf modelers are aware of *SedFlux* architectural needs, boundary conditions, and operating environment. Imbed stand-alone shelf Bottom Boundary Layer models into *SedFlux*, including: a) a vertically-averaged advection-dispersion formulation (Wiberg, UVA); b) an analytical gravity-driven model (Friedrichs and Scully, VIMS); and c) a 2-D model (vertical and cross-shelf) climate-driven transport model (Reed and Niedoroda, URS). Change the output of 2D-*SedFlux* to provide more realistic geotechnical parameters at the local level. Compile the Biot acoustic model developed by Lincoln Pratson (Duke U.) on the ECI servers and link the output of the improved 2D-*SedFlux* to the Biot acoustic model.

1C) Coordinate a mid-course modeling assessment meeting at ONR-HQ.

2A) Using Brownian motion theory, implement a delta-lobe switching model in *SedFlux* and test model results against the switching frequencies of well-studied deltas (Po, Yellow, Mississippi) and data from the U. Minneapolis laboratory experiments.

2B) Employ probabilistic density functions in *SedFlux* to run river discharge and plume sedimentation modules.

2C) Employ an event-based layer-averaged formulation (*Inflo*) to determine optimal conditions for sediment wave formation.

WORK COMPLETED

1A) The Environmental Computation and Imaging (ECI) Facility is now operational at CU, and employed by ONR participants and others at INSTAAR. ONR STRATAFORM software is installed, tested and in some cases multithreaded to take advantage of the multiple processors available.

1B) Three shelf boundary layer models (VIMS, UVA, URS) are compiled on the INSTAAR ECI Facility. The VIMS and UVA models were completely rewritten in ANSI C and imbedded in 2D-*SedFlux*. The schema to provide newly required input files on wave conditions and shelf currents across thousands of years, including seafloor currents, remains to be addressed by the *SedFlux* community. Work with Patricia Wiberg continues on this subject. 2D-*SedFlux* has moved from a Global domain model to a Local domain model wherein the geotechnical properties of the simulated deposits have become more realistic. Duke U. new acoustic model is compiled on the INSTAAR supercomputer, and coupled with the improved 2D-*SedFlux*.

1C) A mid course workshop for STRATAFORM modelers was held in Arlington, Oct. 16, 2001. The workshop focused on milestones and deliverables in four areas: a) contributions to *SedFlux*; b) contributions to *Sequence*; c) progress in *3D plume-shelf transport*; and d) progress in linking transport models to acoustic models. A further workshop was held in Boulder to consider a larger effort in model coordination to examine the development of a Community Sediment Model. A draft of an integration chapter on STRATAFORM modeling was completed

2A) A numerical lobe-switching model is operational and implemented in both 2D and 3D-*SedFlux*. The 2D version has been successfully tested against a U. Minneapolis tank experiment (Paola et al., 2001).

2B) 2D-*SedFlux* now employs probabilistic density functions of river discharge and plume sedimentation. This updated version has been used to simulate stratigraphic development of the N.J. margin.

2C) Numerical experiments have demonstrated the self-amplification of sediment waves (Lee et al., in press).

RESULTS

The INSTAAR ECI Facility now offers 32 multiprocessors to aid in the running of complex numerical models. The *SedFlux* model now uses multithreading in its compaction and river plume routines. The sediment failure routine has been speed up by 100 times older versions of the model.

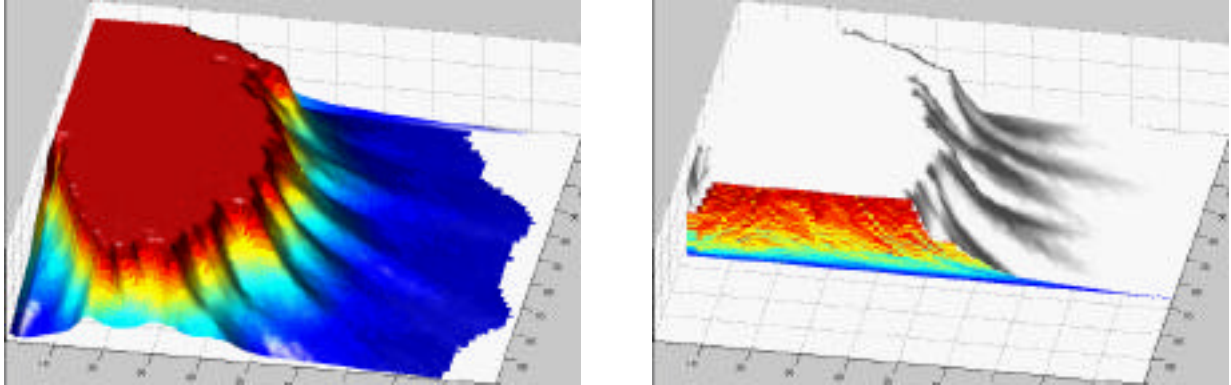
Three approaches modeling shelf sediment transport were implemented in *SedFlux*. The INSTAAR shelf diffusivity method employs a daily *pdf* of regional ocean energy (Airy wave theory) to estimate the local bottom boundary layer (BBL) energy. If the energy exceeds the resuspension criteria for a given grain size then that grain size is mobilized and advected into deeper water. Bed armoring is an integral part of the method. The method is simple and robust, and compatible with landscape evolution models. The VIMS gravity-driven slope-equilibrium method employs the local Richardson number (Ri) (ratio of density stratification to velocity shear). If excess sediment enters the BBL and the Ri increases beyond some critical value (0.25), then turbulence is dampened, sediment settles out and stratification reduced. If excess sediment settles out, or bottom stress increases and the Ri decreases beyond some critical value, then turbulence intensifies, sediment re-enters base of boundary layer, and stratification increases. The UVA event-based sediment redistribution method employs a vertically averaged advection-dispersion formulation in which suspended sediment concentrations and flux at each node are computed in the vertical dimension. Net deposition/erosion and changes in bed texture are determined for given wave and current conditions.

The *SedFlux* model was modified to more realistically simulate the distributions of seafloor geotechnical parameters on a seismically active continental margin. New methods were implemented for the prediction of the coefficient of consolidation, remolded shear strength, internal friction angle, sediment cohesion, dynamic viscosity and excess pore pressure. The model predicts that more sediment failures are likely to occur during periods of falling or low sea level conditions, and be confined to the upper continental slope (500±250 m water depth). Shallower failures appear to be more characteristic of the period represented by the last two episodes of low sea level (i.e. during the Late Pleistocene), affected by the magnitude of the sea level fluctuation. Most predicted failures have thickness < 10m. Larger failures occur during periods of rising or high sea level stand.

The realization of a Community Sediment Model (CSM) was brought one step closer when 60 researchers developed a working blueprint, drawing upon a history of modeling experience, while addressing unique challenges of the sedimentary system's multiple processes and scales (<http://instaar.colorado.edu/deltaforce/workshop/csm.html>). The CSM is to be community-built and freely available, and designed as integrated, ever-improving software modules able to predict the

transport and accumulation of sediment in landscapes and sedimentary basins over a broad range of time and space scales.

A draft of a chapter on STRATAFORM modeling has been completed that includes descriptions of modeling philosophy, component modules (rivers, plumes, shelf transport, sediment failures, compaction, sediment gravity flows), integrated stratigraphic models, and coupled sediment-acoustic modeling. The coupling of SedFlux with the Duke U. Biot model has allowed geophysicists to examine for the first time the divergence of acoustic reflectors and timelines. In addition this coupled modeling approach provides direct realizations to the acoustic community engaged in naval operations.



The figure to the left shows the distribution of grain size (red is coarse sand, blue is fine mud) from a 3D-SedFlux run, while the figure to the right shows a section through the same deposit and the layering architecture.

A river avulsion module is implemented in both 2D- and 3D-SedFlux models. The delta channel-switching (or avulsion routine) module simulates the seafloor deposits from multiple distributary channels and plumes, as shown in the above simulation of an ideal river (after the Yellow River). In addition 3D-SedFlux now simulates longshore transport from breaking waves, and shelf sediment transport (preliminary module).

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.

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 EuroSTRATAFORM: Modeling the Effect of Climatic and Human Impacts on Margin Sedimentation

NSF MARGINS: Experimental and Theoretical Study of Linked Sedimentary Systems

NSF MARGINS: Community Sedimentary Model Science Plan for Sedimentology and Stratigraphy.

PUBLICATIONS

Hutton, E.W.H. and Syvitski, J.P.M. in review. Advances in the numerical modeling of sediment failure during the development of a continental margin. *Marine Geology*

Lee, H.J., Syvitski, J.P.M., Parker, G. Orange, D., Locat, J., Hutton, E.W.H. and Imran, J., in press. Turbidity-current generated sediment waves: modeling and field examples. *Marine Geology*.

Morehead, M., Syvitski, J.P., and Hutton, E.W.H., 2001. The link between abrupt climate change and basin stratigraphy: A numerical approach. *Global and Planetary Science*, v. 28: 115-135.

O'Grady, D.B., and Syvitski, J.P.M., in press, Large-scale morphology of Arctic continental slopes; influence of sediment delivery on slope form. *Geological Society*.

O'Grady, D.B., and Syvitski, J.P.M., 2001. Predicting profile geometry of continental slopes with a multiprocess sedimentation model. In: D.F. Merriam and J.C. Davis (eds.) *Geological Modeling and Simulation: Sedimentary Systems*. Kluwer Academic/Plenum Publishers, New York, p. 99-117.

Paola, C., J. Mullin, C. Ellis, D. C. Mohrig, J. B. Swenson, G. Parker, T. Hickson, P. L. Heller, L. Pratson, J.P.M. Syvitski, B. Sheets, N. Strong, 2001. Experimental Stratigraphy, *GSA Today*, July, p. 4-9.

Pratson, L., Imran, J., Hutton, E., Parker, G., Syvitski, J.P., 2001. BANG1D: A one-dimensional, Lagrangian model of turbidity current mechanics. *Computers and Geosciences*, 27(6): 701-716.

Syvitski, J.P., and Hutton, E.H., 2001. 2D SEDFLUX 1.0C: An advanced process-response numerical model for the fill of marine sedimentary basins. *Computers and Geoscience* 27(6); 731-754.

Syvitski, J.P.M. and Hutton, E.W.H., in press. Failure of marine deposits and their redistribution by sediment gravity flows. *Pure and Applied Geophysics*.

Syvitski, J.P.M., and Bahr, D.B., 2001. Numerical Models of Marine Sediment Transport and Deposition. *Computers and Geosciences*, 27(6): 617-753.

Syvitski, J.P.M., Hutton, E.W.H., Friedrichs, C., Wiberg, P., Reed, C. 2002. Coupled Land-Sea Numerical Sediment-Transport Models And The Formation Of Shelf Stratigraphy. IAS/SEPM Environmental Sedimentology Workshop on Continental Shelves: Processes, record, utilization and management - Hong Kong 7-10 January 2002, p. 48-49.

Syvitski, J.P.M., Paola, C. and Slingerland, R., 2002. Workshop on development of a Community Sediment Model, *MARGINS Newsletter* 8, p. 8-9.