Meeting Report:

Coastal Working Group, Feb. 25-26, Charlottesville, VA

At the February meeting of the Coastal Working Group (Charlottesville, VA, in conjunction with the Marine WG), working group members expanded on the discussion begun at the previous meeting (http://csdms.colorado.edu/wiki/index.php/Coastal_Reports) concerning the present state of knowledge and modeling capabilities, as well as gaps in knowledge and modeling capabilities, in several coastal sub environments. Summaries for select sub environments constitute section 1 of this report. (Bob Demicco summarized the efforts of the Carbonate Focus Group, not included here.)

The bulk of our discussions focused on potential Proof-of-Concept projects. At the previous meeting (http://csdms.colorado.edu/wiki/index.php/Coastal_Reports) we enunciated the desirable criteria for such projects, and here we brainstormed with the goal of defining a number of scientific questions requiring novel model linking that groups of coastal scientists could address on a relatively short timescale (a few years or less). Highlights of this discussion constitute section 2.

1. State of Knowledge and Modeling in Select Sub Environments

Tidal Marshes and Lagoons

A number of new models have been developed recently to explore interactions between sediment transport and vegetation growth in tidal environments (e.g. Fagherazzi et al., 2006; D'Alpaos et al., 2007; Kirwan and Murray, 2007; Marani et al., 2007; Temmerman et al., 2007). These models find that feedbacks between vegetation growth and the depth of water inundating an intertidal surface strongly influence the morphology of these environments and their resilience to changes in rates of sea level rise and sediment delivery. Many of these models consider the effect of vegetation on channel flow, wave erosion, and sediment settling, resulting in potentially complex interactions and multiple stable equilibria. For example, an increase in inundation associated with increased rates of sea level rise has been shown to increase the stability of salt marsh ecosystems by increasing vegetation productivity, sediment trapping efficiency, and contributions of organic matter. At the same time, increases in inundation on the marsh tend to increase the efficacy of wave erosion, the volume of water contributed to the channel network (leading to channel erosion), and in some cases the reduction of vegetation biomass. Interactions between these components lead to the common model observation that vegetated intertidal surfaces and unvegetated subtidal mudflats can occur as alternative stable equilibrium states for a single combination of sea level rise rate and sediment supply (Kirwan and Murray, 2007; Marani et al., 2007).

At this point, several knowledge gaps require these types of models to be primarily used for exploring interactions between biotic and abiotic components, rather than for predictive purposes. In particular, vegetation treatments are in their infancy. Vegetation biomass typically increases with inundation duration in these models (Morris et al., 2002; Kirwan and Murray et al., 2007), though some (D'Alpaos et al., 2007; Marani et al., 2007) also consider the opposite scenario. It remains unclear whether these types of relationships are generally applicable to a variety of regions and vegetation types, or if they should be determined locally and for each type of vegetation. While research has focused to date on tidal surfaces covered by salt marsh vegetation, similar modeling approaches may provide useful insight into the morphology and evolution of surfaces covered by mangroves, freshwater marshes, sea grasses, and macrophytobenthos.

Deltas

State of the art models for deltaic systems are highly scale dependent. Engineering models such as Delft3D (Lessera et al., 2004) couple detailed hydrodynamics with morphologic change, and can simulate evolution of a single delta lobe over tens of km and decades, capturing fine-scale plume and bar dynamics within one or a few channels (Storms et al., 2007). Geomorphologic models using simplified hydrodynamics and sediment transport simulate landscape-scale delta evolution over millennia, capturing planform shoreline and distributary-network dynamics, including avulsion (Sun et al., 2002) and alongshore transport (Ashton and Murray, 2005). As in landscape evolution, most geomorphic delta models treat channels using a sub-grid approach, but the recent model by Seybold et al. (2007) resolve channels and levees.

Deltas house large populations and valuable biological and economic resources which are threatened by coastal and riverine flooding, exacerbated by subsidence and sea level rise (Ericson et al., 2006). While current delta models are able to capture self-organized dynamics under a constant forcing regime, effective management of deltaic environments will require understanding of response to changing natural and anthropogenic forcings.

Coastlines

The majority of existing large-scale coastline models address sandy coastline evolution. The spatial scales addressed in these models range from meters to kilometers while temporal scales range from hours to millennia. The smaller space and time scale models typically employ explicitly reductionist methodologies where conservation of momentum forms the explicit means for evolving the system. Often these models are used to simulate specific locations or response from individual event scale forcing. As an example, XBEACH (Roelvink et al., 2007) uses conservation of momentum and advection diffusion equations for sediment transport to simulate the response of the coast and dune to individual storm events. Larger scale models use of range of approaches to evolve system characteristics. In some cases, model dynamics represent abstractions of fine scale processes. An example of this methodology is the Ashton/Murray coastline model (Ashton and Murray, 2006), in which the dynamics are based on abstracted parameterizations that represent the collective effects of smaller-scale details of sediment transport and on a series of rules for wave shadowing around complex coastlines. In other large-scale models, morphological evolution occurs in response to changes in geometric relationships. An example of this approach is the morphological-behavior model, GEOMBEST (Moore et al., 2007; Stolper et al., 2005).

To date, large-scale coastal modeling efforts have not yet incorporated some of the processes that are important in the evolution of many sandy coastlines. For example, the role of biology and geochemistry is an open question, and the role of heterogeneous underlying lithology is only recently being incorporated in numerical models. In addition, the role of humans in altering coastlines has only recently been investigated (e.g. McNamara and Werner, 2008), and considerable effort remains to augment and explore the impact of coupling humans in varying coastal systems. There is also currently a lack of modeling efforts addressing the evolution of other coastal environments including arctic coastlines and rocky coastlines.

An array of processes contributes to long-term evolution of rocky coasts. During sea level highstands, sea cliffs retreat in response to an incoming wave field through the processes of abrasion, block failure, and microcracking by cyclical wave loading (Adams et al., 2005). Sea cliff retreat rate is also strongly influenced by lithology. Long-term (several kyr) generation and degradation of marine terraces has been simulated by Anderson et al. (1999). Most recently, numerical models of sea cliff evolution have been developed to investigate the response of cliffed coasts to climate change over the 21st century (Dickson et al., 2007; Hall et al., 2006; Walkden and Hall, 2005). Links should be developed between a sea cliff retreat model and models simulating other geomorphic systems in the coastal environment. How does wave transformation over a continental shelf influence the alongshore transport and redistribution of sediment, a.k.a. exposure of the sea cliff toe? Over timescales of thousands to millions of year, and spatial scales of 10's to 100's of km, how does an evolving plan-view pattern of sea cliff retreat and alongshore transport pathways evolve and interact with a growing shelf and nearshore-connected submarine canyons that serve as sediment sinks?

2. Select Outlines for Possible Proof of Concept Projects

In all of our discussions about linking models of different environments, we emphasized the desirability of using multiple models for each environment, to see how the results might or might not depend on the way processes are represented in different models, and on the level of detail in different models. Proof-of-concept projects are likely to link only one model from each environment initially, to maintain a tractable scope for proposals to fund these efforts, but multiple models should be the ultimate goal.

Tidal Marshes/ Lagoon Linkages

Because intertidal environments occur at the interface of marine and terrestrial environments, they provide an exceptional opportunity to explore interactions between terrestrial, coastal, and marine systems. For example, terrestrial land use change can lead to dramatic changes in the morphology and stability of salt marshes by altering sediment delivery rates to the estuary.

Characteristics of the adjoining coastal and marine systems are also important. Direct wave erosion may exceed rates of marsh loss due to sea level rise, and tidal amplitude is widely considered an important variable controlling the ability of marshes to maintain elevation relative to rising sea level.

Barrier islands and marshland may represent a system that evolves co-dependently, and whose survival depends directly on interactions between its components. Characteristics of barrier islands (e.g. morphology, rate of retreat) depend directly on the topography of the surface over which they retreat, and the elevation of marshes depends on barrier characteristics (e.g. sediment deposition due to overwash events, exposure to wave erosion, tidal amplitude). In areas with depleted sediment sources and high sea level rise rates, survival of marshland may depend on overwash events, and the survival of barrier islands may depend on the presence of high elevation marsh to retreat over.

Delta Linkages

CSDMS provides the opportunity to address delta responses to changing natural and anthropogenic forcings by coupling delta dynamics to upstream sediment and water supply, downstream waves and sea level, and coastal plain subsidence, using models for each of these components. Deltas with documented millenial-scale changes resulting from anthropogenic forcing (e.g. Ebro, Mississippi) can serve as a useful testing ground for these new coupled delta models.

For landscape-scale applications, SEDFLUX3D is available through CSDMS, as is the Ashton-Murray (2006) model (Coastline Evolution Model, CEM). However CSDMS currently lacks models which treat self-organized channel network evolution (e.g. avulsions), which would be needed to explore feedbacks between planform channel patterns and waves or subsidence. Several published and unpublished models which would be suitable for this purpose exist, but are not currently available through CSDMS. In particular, the fan-delta models of Sun et al. (2002), and Wolinsky (unpublished), as well as the birdfoot delta model of Seybold et al. (2007). In addition, unpublished alluvial fan models by Alan Howard and by Jon Pelletier, and an avulsion model by Jerolmack and Paola (2007) should be easily adaptable to fan-delta simulation.

Proof of concept problems discussed for deltas focused on millennial-scale evolution driven by changes in forcing. Particular problems suggested were 1) affects of land-use change on wave-influenced deltas, in particular the Ebro or Nile, and 2) interaction of delta growth with subsidence due to fluid withdrawal and compaction, applied to the Niger or Mississippi. For 1) the Ashton and Murray (2005) wave-influenced delta model would be coupled to a terrestrial-oriented delta model, possibly SedFlux3D, with the incorporation of one of the self-organized avulsion models discussed above. The upstream and downstream boundary conditions could be implemented simply, using HYDROTREND and the Ashton-Murray wave climate scheme, or using full models such as CHILD and SWAN. For 2) the SedFlux subsidence modules could be coupled to any of the delta models available in CSDMS. Connections of deltas to other coastal proof-of-concept problems were also discussed tangentially, in particular the role of delta switching in determining the “geological framework” of barrier island retreat (e.g. for the Chandaleurs), but this would likely be a one-way coupling.

Coastline Linkages

Nearshore wave fields drive alongshore currents that are responsible for the redistribution (erosion/accretion) of coastal sediment. We need to know how nearshore wave conditions develop from deep-water conditions to evaluate coastal vulnerability and driving forces responsible for coastal geomorphic change. More specifically, is the procedure of simple wave ray tracing an adequate substitute for more sophisticated (spectral/diffraction) techniques of computing wave transformation from deep-water to the nearshore zone? To answer this question, we should pursue a quantitative evaluation of the differences between the two techniques of calculating wave transformation along both idealized and measured coastal bathymetries. Having distinguished the differences, we can explore implications for the instability in coastline shape arising from gradients in alongshore sediment flux (Ashton et al., 2001), by linking the various wave transformation models to the Coastline Evolution Model of Ashton and Murray (2006).

Because human manipulations of the coastline—stabilizing the location of the shoreline in front of developed areas—can affect sandy coastline evolution as much as natural forces do, and because coastline evolution drives human manipulations, where coasts are developed the human and coastline components are coupled into a single system. Human decisions concerning coastline stabilization are affected by influences including shoreline change rates, economics, and sociology. Models of human dynamics (analytic or agent based) and models of coastline change need to be coupled to address the behaviors of the new coupled system and how it responds to changing forcings.

References:

Adams, P.N., Storlazzi, C.D., and Anderson, R.S., 2005, Nearshore wave-induced cyclical flexing of sea cliffs: Journal of Geophysical Research-Earth Surface, v. 110.

Anderson, R.S., Densmore, A.L., and Ellis, M.A., 1999, The generation and degradation of marine terraces: Basin Research, v. 11, p. 7-19.

Ashton, A., et al. (2001), Formation of coastline features by large-scale instabilities induces by high-angle waves, *Nature/*, /414/, 296-300.

Ashton, A., and A.B. Murray (2005) Delta Simulations Using a One-Line Model Coupled with Overwash. Coastal Dynamics 2005. doi:10.1061/40855(214)13.

Ashton, A, and Murray, A.B., 2006, High-angle wave instability and emergent shoreline shapes: 1. Modeling of capes, flying spits and sandwaves, Journal of Geophysical Research, 111, F04011, doi:10.1029/2005JF000422.

D'Alpaos, A., Lanzoni, S., Marani, M., Rinaldo, A., 2007b. Landscape evolution in tidal embayments: modeling the interplay of erosion, sedimentation, and vegetation dynamics. Journal of Geophysical Research 112, F01008, doi: 10.1029/2006JF000550.

Dickson, M.E., Walkden, M.J.A., and Hall, J.W., 2007, Systemic impacts of climate change on an eroding coastal region over the twenty-first century: Climatic Change, v. 84, p. 141-166.
Ericson, J.P., C.J. Vörösmarty, L.S. Dingman, L.G. Ward, and M. Meybeck (2006) Effective sea-level rise and deltas: Causes of change and human dimension implications. Global and Planetary Change, doi:10.1016/j.gloplacha.2005.07.004.
Fagherazzi, S., Carniello, L., D'Alapos, L., Defina, A. (2006). Critical bifurcation of shallow microtidal landforms in tidal flats and salt marshes. *Proceeding of the National Academy of Sciences* v. 103 (22), p. 8337-8341.
Hall, J.W., Sayers, P.B., Walkden, M.J.A., and Panzeri, I., 2006, Impacts of climate change on coastal flood risk in England and Wales: 2030-2100, p. 1027-1049.
Jerolmack, D.J., and Paola, C., 2007, Complexity in a cellular model of river avulsion, Geomorphology, 91, 250-270.
Kirwan, M.L., and Murray, A.B. (2007), A coupled geomorphic and ecological model of tidal marsh evolution, *Proc. Natl. Acad. Sci., 104*, 6118-6122.
Lessera, G.R., J.A. Roelvink, J.A.T.M. van Kester, and G.S. Stelling (2004) Development and validation of a 3D morphological model. Coastal Engineering, doi:10.1016/j.coastaleng.2004.07.014
Marani, M, D'Alpaos, A, Lanzoni, S., Carniello, L., Rinaldo, A., 2007. Biologically-controlled multiple equilibria of tidal landforms and the fate of the Venice lagoon. Geophysical Research Letters 34, L11402, doi:10.1029/2007GL030178.
McNamara, D. E., and B. T. Werner (2008), Coupled barrier-island-resort model: 1. Emergent instabilities induced by strong human-landscape interactions, *Journal of Geophysical Research, Earth Surface*, 113, F01016, doi:10.10292007JF000840.
Morris, J.T., Sundareshwar, P.V., Nietch, C.T., Kjerfve, B., and Cahoon, D.R. (2002), Responses of coastal wetlands to rising sea level, *Ecology, 83,* 2869-2877.
Moore, L.J., et. al., (2007), Modeling barrier island response to sea-level rise. in Coastal Sediments '07, edited by N. Kraus and J. Rosati, pp. 1153- 1164, American Society of Civil Engineers.
Roelvink, D., Reniers, A., Van Dongeren, A., van Thiel de Vries, J., Lescinski, J., Dirk-Jan Walstra, D-J., 2007, XBeach Annual Report and Mode Description. Modeling of Hurricane Impacts, Pentagon Annual Report A560364.
Seybold, H., J.S. Andrade, and H.J. Herrmann (2007) Modeling river delta formation. Proceedings of the National Academy of Sciences, doi:10.1073/pnas.0705265104.
Stolper, D., et al. (2005), Simulating the evolution of coastal morphology and stratigraphy with a new morphological-behavior model (GEOMBEST), *Marine Geology*, 218, 17-36.
Storms, J.E.A., M.J.F. Stive, D.A. Roelvink, and D.J. Walstra (2007) Initial morphologic and stratigraphic delta evolution related to buoyant river plumes. Coastal Sediments '07, doi:10.1061/40926(239)56.
Sun, T., C. Paola, G. Parker, and P. Meakin (2002) Fluvial fan deltas: Linking channel processes with large-scale morphodynamics. Water Resources Research, doi:10.1029/2001WR000284.
Syvitski, J.P.M., and Saito, Y. (2007) Morphodynamics of deltas under the influence of humans. Global and Planetary Change, doi:10.1016/j.gloplacha.2006.12.001.

Temmerman S., Bouma, T.J., van de Koppel J., van der Wal D., de Vries M.B., Herman P.M.J., 2007. Vegetation causes channel erosion in a tidal landscape. Geology 35: 631-634.
Walkden, M.J.A., and Hall, J.W., 2005, A predictive Mesoscale model of the erosion and profile development of soft rock shores: Coastal Engineering, v. 52, p. 535-563.
Young, A.P., and Ashford, S.A., 2008, Instability investigation of cantilevered seacliffs: Earth Surface Processes and Landforms, v. 33, p. 1661-1677.

Written by:

A. Brad Murray, Nicholas School of the Environment, Center for Nonlinear and Complex Systems, Duke Univ.

Peter N. Adams, Dept. of Geological Sciences, University of Florida

Matt Kirwan, USGS, Dept. of Environmental Sciences, Univ. of Virginia

Dylan McNamara, Univ. of North Carolina, Wilmington

Laura Moore, Dept. of Environmental Sciences, Univ. of Virginia

Matt Wolinsky, Shell International Exploration and Production

With contributions from other participants:

Bob Demicco, SUNY Binghamton

Alan Howard Dept. of Environmental Sciences, Univ. of Virginia

Chris Kendall, Dept. of Geological Sciences, Univ. of South Carolina