Meeting Report: The Coastal Working Group and Carbonate Focused Research Group at the 2010 CSDMS All Hands Meeting

The Coastal Working Group and the Carbonate Focused Research Group held a joint meeting within the CSDMS all-hands meeting in October, 2010. We discussed opportunities for synergistic combinations of the knowledge based and modeling capabilities represented by the two communities, and developed initial plans for possible scientific collaborations, as outlined below. We also reviewed progress and priorities for the two groups.

1 New Collaborations Between Coastal and Carbonate Groups

1.1 Feedbacks between carbonate production and coastline progradation (large-scale)

Carbonate sediment produced on or near the crest of a reef will be swept to the adjacent shoreline by waves. That sediment source will tend to make the shoreline prograde, which could in turn inhibit carbonate production when the progradation causes depths at the reef to decrease. Investigating the dynamics resulting from this interaction requires a model of long-term, large-scale coastline change. The Coastal WG model repository includes such a model, the Coastline Evolution Model (CEM), which has been componentized—it is ready to be coupled to other models, with minimal additional work. The Carbonate group has a model of carbonate-sediment production, which can be relatively easily coupled to CEM to address questions about how carbonate coastlines evolve, under varying wave climates and coastline geometries, which both affect the rate and pattern of shoreline progradation. This model coupling could yield interesting scientific results on a relatively short time scale.

Because the medium-term priorities for the Coastal WG include coupling CEM to the stratigraphy-producing components of SedFlux (as part of a program of delta research described below), coupling a carbonate-production model to CEM will also facilitate investigating the stratigraphic patterns produced by prograding carbonate coastlines.

1.2 Biomorphodynamics of carbonate reefs

On scales of approximately 10 m, the interactions between the growth rate of coral and sediment transport processes can lead to ‘spur and groove’ morphology. We can hypothesize that as corals grow in some locations and focus fluid motions into adjacent areas, the burial and abrasion by the sediment that collects there will tend to inhibit coral growth locally. This feedback could lead to the self-organization of the corral-free corridors aligned parallel with the direction of wave-orbital motions. This hypothesis could be tested by combining a hydrodynamic and sediment-transport model such as Delft-3D (soon to become part of the

CSDMS model repository) with a model for coral growth as a function of sediment coverage/abrasion (which would need to be developed/refined).

2 Coastal Working Group Progress and Priorities

We reviewed previous and ongoing Working Group activities, including: 1) Assessing the state of knowledge and modeling capabilities concerning key coastal environments, and soliciting the key models from the community (http://csdms.colorado.edu/mediawiki/images/MeetingRptCoastalWG.pdf); and 2) catalyzing new collaborations involving coupling of models of multiple environments or processes to address new scientific questions (http://csdms.colorado.edu/mediawiki/images/MeetingReportCvill2009.pdf; http://csdms.colorado.edu/mediawiki/images/CTWG_meeting_report_oct09v2.pdf). Such collaborations both serve as proof-of-concept projects for CSDMS and represent a strategy for accumulating model components that have been 'componentized,' so that they can be coupled with each other via CSDMS software. Collaborations that have resulted from the previous Working Group meetings are in various stages of development, ranging from grant proposals in the planning stages to pending and funded proposals, and these collaborations include terrestrial and marine components as well as coastal environments and processes.

2.1 Showcase proof-of-concept projects

The most mature of these projects involve delta morphodynamics—two related investigations, both involving interactions between terrestrial (fluvial) and coastal processes.

One addresses the striking changes in the morphology and size of the Ebro Delta (Spain) related to the millennia of land-use changes in the drainage basin. In this project, Albert Kettner (CSDMS Integration Facility) and Andrew Ashton (Coastal Working Group member) have coupled two models: one that relates terrestrial land use to the sediment load delivered by the river to the coast, and one that relates wave-driven and fluvial sediment fluxes to changes in delta shape. A grant funding this work has recently been awarded, and the two models (Hydrotrend and CEM) have been coupled, and are part of the repository of componentized (couple-able) models available through CSDMS.

The other of these in-progress projects addresses two-way couplings between coastal and fluvial processes. Fluvial bifurcations and avulsions on or near deltas both depend on the distance to the shoreline. The shape of a deltaic shoreline, which determines the distance to the shoreline from any point on or above a delta depends on an interplay between fluvial sediment flux at the river mouth and wave-driven processes that redistribute the bedload portion of that flux. Thus, coastal processes must affect fluvial behaviors, as well as the reverse. Eric Hutton (CSDMS Integration Facility) and Andrew Ashton have developed a model of channel bifurcation, and coupled it to a model framework for delta growth and CEM (both available as CSDMS components). Initial experiments examining the behaviors of the coupled coastal/fluvial system are underway (presented in a keynote talk at the CSDMS All Hands meeting by Andrew Ashton), as is refinement of the bifurcation model.

2.2 Grand-challenge: Deltas and Humans

As illustrated by the Ebro Delta proof-of-concept project, human terrestrial land-use changes, and the associated changes in fluvial sediment delivery, can overwhelm natural factors in determining how deltas grow or shrink, and change shape. Given the dense human habitation on deltas around the world, and the associated pervasive manipulations to the fluvial and coastal systems, human activities on deltas themselves also likely steer large-scale delta evolution, and therefore affect the continued habitability and sustainability of delta environments. Based on discussions in break-out sessions at the 2009 joint Terrestrial and Coastal Working Group session (http://csdms.colorado.edu/mediawiki/images/CTWG_meeting_report_oct09v2.pdf), and at the 2010 all-hands CSDMS meeting (Appendix below), the Coastal Working Group has identified human/delta morphodynamics as a central priority. We plan a phased series of model couplings and related model experiments spanning the next five years and beyond, to address questions including:

- *What are the fundamental controls on delta size, shape, and elevation?*
- *How might deltas change as dams are removed and sediment flux is restored to a pre-dam level?*
- *How do human manipulations of fluvial processes on deltas alter delta evolution?*
- *What determines the extent of wetlands, under various scenarios of human manipulations, relative sea-level rise (including subsidence) and upstream land-use changes?*
- *How do storm surge and flooding threats vary among different scenarios?*

In the **short-term (1 – 2 years)**, we will build on the existing and underway model development and coupling described in section 2.1 above, adding components for delta subsidence (already componentized in the CSDMS repository), and aggradation of tidal marsh and fluvial floodplain environments. Initially, models for floodplain/wetland aggradation will involve simple dependencies on relative sea-level rise rate and distance from fluvial channels. Subsequently, a model of tidal marsh and channel-network eco-morphodynamics, which can address the potential loss of marsh environments to lateral erosion, as well as 'drowning,' will be added. As the central priority of the Coastal Working Group, these tasks can be accomplished with CSDMS Integration Facility help, without waiting for the timescale of grant-proposal funding.

In the **medium-term (2 – 4 years)**, the additions of subsidence and aggradation models outlined above will allow an examination of how fluvial avulsion processes affect the surrounding marshes (through the delivery of muddy sediment) as well as how they are affected by changes in the relative elevations of river channels and floodplains—and how human alterations of these processes (e.g. restricting the course of a river within boundaries defined by constructed levees) change delta size, shape and elevation. Coupled-model experiments will address these questions, along with the affects of changes fluvial sediment deliver to the delta (related to upstream land-use changes, not explicitly modeled in the initial stages).

To complement and support this phased model development, other, more detailed models addressing hydrodynamics and morphodynamics on smaller time scales and should also be utilized, both to address shorter-timescale phenomena such as storm surge and fluvial flooding, and to inform and refine the parameterizations in the longer-timescale models. The development of simpler, more synthetic models should also parallel these efforts.

Model components and their coupled behaviors will be tested against existing data sets documenting delta evolution in recent centuries, in both heavily developed environments and those less affected by human activities.

Accomplishing these medium-term tasks, as well as the long-term plans, will require working group members to gather external funding. Andrew Ashton, Doug Evans, and Eric Hutton have volunteered to develop a grant proposal to support some of this work. Other proposals will need to follow—including potentially a large proposal as funding opportunities and solicitations arise.

In the **long-term (4 years +)**, other model components can be added, including a component for delta progradation and the resulting stratigraphy (already componentized in the CSDMS repository), and explicit simulations of upstream drainage basin land-use changes, including dam pervasive dam removal (using existing model components).

Model experiments can explore delta evolution under various scenarios for human policies and manipulations of the terrestrial and delta environments, as well as scenarios for climate change and relative sea-level rise. In each scenario, the size and elevation of deltas, and the extent of valuable tidal wetland environments, can be evaluated. Coupling a storm-surge model and a hydrodynamic model to determine the extent and depth of fluvial flooding will allow an evaluation of impacts to human infrastructure and communities of different delta-management policies.

Ultimately, to explore the emergent dynamics of the coupled human/landscape system, the dynamics of the human component of delta systems can be represented via agent-based modeling, more classical economic modeling, or some hybrid.

APPENDIX:

CSDMS Breakout session on Delta Morphodynamics

10/14/10

NOTES:

SHORT TO MEDIUM TERM GOAL: develop a delta modeling system that incorporates different couplings. What are the basic portions of the delta system? What are the necessary components?

1. Upland River
   a. Controls delivery of sediment, which is influenced by floodplain storage/exchange, and water
   b. Could be parameterized by a single boundary condition rather than resolving it
2. Deltaic portion of the river
   a. Morphodynamic feedbacks, couplings between fluvial, wetlands, and coastal environments
   b. floodplains
3. Coastal/ocean basin
   a. Eustatic sea level rise
   b. Subsidence, relative sea level (local and regional)

What is the time scale of interest? Years to centuries (e.g. human interventions) or millennia and longer (e.g. building of continental shelf; geologic).

One of the things we want to understand is what straight jacketing levees will do and how that might change delta morphodynamics.

We need a suite of models that bridges the gap between the 10^1 yr and 10^4 yr time and 10^1 km^2 and 10^3 km^2 spatial scales.

This could be done with different grid scales (a la ROMS). The hierarchy could bridge the scales. And could be done with a number of model widgets that can be combined into a suite of models that can simulate long term delta behavior. Some widgets need to have the same time step as what it is feeding into.

MEDIUM TERM GOAL: What kind of observational data is needed to verify the results? Provide verification data so users can see what different scenarios the model has been verified for. There is a lot of data on network topology that can be used and there are series of serial imagery documenting delta evolution that can be used as a comparison. We should also take advantage of reservoirs with deltas.

There is a ~100 yr time scale that we can exploit to see how deltas evolve and use that to verify simulations. We need to verify these delta simulations at large and small scales. What delta morphology metrics are sensitive indicators that can be used to verify models?

LONG TERM GOAL: Putting the human dynamics and the processes/decision making that affect these things in our model. What scale of human decision making do we include? Chemical, water quality, flooding risk, wetland restoration? This can be done with a user changing boundary conditions (e.g. resolving climate change by simply changing Q) or with a decision making model that dynamically changes boundary conditions based on the growth of the delta. Small to medium dams are filling with sediment and are creating hazard. This raises an important question: *For instance, what will happen to delta shape, size, and elevations under different scenarios of sea level rise and human manipulations as dams are removed and sediment flux is restored to a pre-dam level?*

We need to incorporate the mud into the delta simulations. WLD is storing ~30% of the mud that is coming in whereas the LaFourche lobe is storing ~50% of the mud.

What types of models are needed to recognize these goals?

Hierarchical scale that includes multiple time scales. Certain models fit into certain time/spatial scales and decision making can be added. Model components need to be able to adapt to these different time/spatial scales.

We need to couple between different processes, e.g. nearshore sediment transport model coupled with delta evolution coupled with upstream floodplain evolution. Modeling fluvial channel evolution as a diffusional process, coupled with a floodplain model (determines relative agg. rates and avulsions), coupled with a nearshore coastal model. In this context, coupling doesn't actually mean the simultaneous solution of all the equations. Really we mean feedbacks, not coupling in the computer science sense.

CSDMS Breakout session II on Delta Morphodynamics

10/15/10

We need a list of steps that will lead to the different goals both over the short and long term. This group will most effectively build a large model(s) with multiple components. We need to make a statement about what model(s) are needed in the next five years.

One approach is to develop a series of models that start from broad brush, big picture simulations that predict macro features and move to more detailed simulations with different models that predict finer scale features (i.e. from delta scale to channel scale).

To make CSDMS work, plans and proposals need to be submitted that utilize multiple models in the spirit of CMT. These models may exist or may need to be built.

One potential avenue for investigation is using Delft3D as a platform. Is this the right platform? What else exists? Competitors?

We may not want to limit ourselves to one platform, because, for instance, if one is interested in lobe switching scale a platform other than D3D would be needed.

Perhaps we need two modeling approaches: more detailed and more synthetic. One model/platform may not suit all of our needs.

<u>What models do we need??</u>

MODELS FOR UPSTREAM BOUNDARY CONDITIONS (primarily supply Qs): HYDROTREND, CHILD (long time scale), HSPF, AGNSP.

MODELS FOR DELTAIC DYNAMICS: Delft3D, 1D long profile diffusion of fluvial channels, avulsion rules (Mohrig superelevation, SEDFLUX), EFDC , cellular delta models (Man Liang/paola/voller, Seybold).

MODELS FOR COASTLINE PROCESSES: CEM, Delft3D, ROMS, ADCIRC (lots of physics), SLOSH (fast storm surge model), models for subaqueous profiles, models for hyper/hypo flows, Coastal modeling system (CMS), XBEACH, GEOMBEST

MODELS FOR PRODELTA: Winterweerp, Deflt3D, Swenson

MODELS FOR WETLAND EVOLUTION: Jim Morris model, Matt Kirwan model of marsh accretion, Sergio Fagherazzi

MODELS FOR FLOODPLAIN EVOLUTION/DEPOSITION: Washload as floodplain material load (Viparelli Model), Exponential rule of floodplain deposition, MODELS FOR RELATIVE SEA LEVEL CHANGE: both dynamic and static, SUBSIDE, compaction, eustatic sea level rise

GAPS:

1. models for large scale delta evolution at a time and spatial scale larger/longer than network development. Perhaps combine Kim model with avulsion rules?
2. The study of lakes and their formation within deltas and floodplains is poorly understood. How do they fill in and change with time? Do we have a model for their formation?
3. Megacities and the related subsidence
4. Models for human manipulation (long term goal) that can be dynamic or scenario based
    a. They protect levees
    b. Alter hydrographs, sediment supply, discharge
    c. Construct canals
    d. Construct diversion
    e. Land use upstream (damn dams)
    f. Subsidence (anthropogenic) : extraction, infrastructure
    g. Coastal protection
5. Freshwater marsh evolution, swamps (part of the floodplain)
6. Model integration tools (CMT)
7. What is model uncertainty? What observation sets can we use to compare and test model runs?
8. Any model should include a widget for grain size tracking through deltaic systems. Need capabilities for both the surface and subsurface. What to do with mud?
9. Vegetation and sedimentation, ecomorphdynamics

<u>What are the scientific objectives/questions for the CSDMS five year plan?</u>

1. *What are the fundamental controls on delta size, shape, and elevations?*
    a. *What controls the extent of wetland development in deltaic settings?*
2. *How are those controls modified under different scenarios of sea level rise and human manipulations (e.g. as dams are removed and sediment flux is restored to a pre-dam level)?*
3. *How do coastal sediment redistribution properties interact with fluvial properties (e.g. avulsion)?*
4. *What effects do extreme climate events have on delta geomorphology?*
5. *What are the characteristic time scales of delta location adjustment to external forcings?*
6. *How does the transition between deltas and estuaries occur?*

<u>What are our short, medium, and long-term plans?</u>

SHORT TO MEDIUM TERM: sedflux components, with diffusional river and avulsion rules, coupled to CEM, and then to subsidence and wetland/floodplain aggradation components.

MEDIUM TO LONG TERM: complementary efforts with other models and approaches. More detailed models that can be used on short time and spatial scales, as well as more synthesized, simpler models. Alternative models componentized. Observational datasets.