CSDMS

COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

SEMI-ANNUAL REPORT

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CSDMS

COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

Preface

The Community Surface Dynamics Modeling System (CSDMS) develops, supports, and disseminates integrated software modules that predict the movement of fluids, and the flux of sediment and solutes in landscapes and their sedimentary basins. CSDMS involves the Earth surface — the dynamic interface between lithosphere, atmosphere, cryosphere, and hydrosphere. This Semi-Annual Report covers the period from January 2009 to June 2009, and provides an update since the last 2008 Annual Report to NSF.

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Year 2 Goal Updates

(4th Q of Y2 & 1st Q Y3: see 2009 Annual Report for earlier information)

Goal 1) ***Establish interface standards that define precisely the manner in which components can be connected.***

Numerical models can generally be subdivided into three phases: set up, execution, and teardown. The set up phase occurs before time stepping begins and initializes the model. The execution phase is the guts of a model and will be most everything within the main time loop of the model. The teardown phase occurs after time stepping and acts to clean up the model simulation. For models that are time-independent and do not have a time loop, the model calculations can be thought of as a time-stepping model with just one time step.

A **component interface** is a standardized set of functions that a component must provide in order to be usable in a plug-and-play framework. CSDMS has experimented with various interface standards for numerical models and for the most part has adopted the OpenMI version 2.0 standard, which is a significant improvement over OpenMI 1.4. The core of this and other interface standards for numerical models is what we refer to as an **IRF interface**. Here "IRF" refers to the minimal set of functions — *initialize*, *run*, and *finalize* — that are required to allow a calling application to control the model's execution. However, to allow meaningful communication with another model, it is also necessary for the calling application to retrieve or modify some of the other model's internal state variables. This can be done by including simple "*get_value*" and "*set_value*" functions as part of the interface, and like the IRF functions, these are easy to implement. These five functions, plus a few more that allow a calling application to query which variables it can get or set and to retrieve information about the grid that the model uses, comprise the CSDMS interface standard. CSDMS asks model contributors to provide this simple set of functions for the models they submit. An outline of the CSDMS model interface standard is posted on the CSDMS wiki at: http://csdms.colorado.edu/wiki/Help:IRF_Interface.

Goal 2) Link refactored code contributions from the community as CSDMS components within the CSDMS framework.

CHILD is a 2D landscape evolution model, "Channel-Hillslope Integrated Landscape Development" (http://csdms.colorado.edu/wiki/Model:CHILD). CSDMS software engineers worked with CHILD's developer (Greg Tucker) to write an Element interface for CHILD and allow for the ElementMapper tool in the OpenMI SDK to pass data from the CHILD mesh to the SedFlux mesh. The ElementMapper has now been wrapped from the OpenMI Java SDK as a CCA "MappingTool" component. Subroutines have been added to this MappingTool so that it can also create an OpenMI element set for any raster model (e.g. SedFlux), as required to use the ElementMapper. Bocca scripts were then written to build a CCA project with Driver, Marine (e.g. SedFlux), Terrestrial (e.g. CHILD) and MappingTool components and OpenMI/IRF and Mapper ports. This creates the "glue code" that is necessary for these four components to interoperate, despite being written in four different languages (C, C++, Java and Python).

Full OpenMI interfaces (i.e. ports) for CHILD and SedFlux are not yet possible due to a "circular reference" bug in Bocca. To work around this limitation, a "Driver" component in Python was written for linking a Marine and Terrestrial model via OpenMI/IRF ports. This driver utilizes the new MappingTool component to share data values (e.g. elevations) between the different computational meshes of the two models. The next step is to add new functions to both CHILD and SedFlux in order to allow their grid values to be accessed or changed (get or set) by another component. Authors of CHILD and SedFlux have been working together to implement the necessary changes.

As many of the models contributed to CSDMS are written in proprietary, high-level languages such as MatLab and IDL, CSDMS has looked into the problem of how best to incorporate them into its component-based, plug-and-play framework. In the case of IDL, most of this need has been met by extending an open-source application called I2PY that converts IDL code to Python. Based on how I2PY works, it would be possible to reuse much of it to create a similar program (M2PY?) for converting MatLab code to Python. However, it is also possible to save MatLab models in the form of C library files that could be utilized within the CSDMS plug-and-play component framework. While these library files are platform-specific, CSDMS could generate ones that can be used on its HPCC server running RedHat Linux.

Coupling between HydroTrend and SedFlux has been improved through developing a simple code that generates synthetic HydroTrend files based on simple discharge and sediment load scenarios. This methodology has been applied for stratigraphic simulations of fjord-rivers with variable sediment supply over a deglacial cycle

Goal 3) Implement a glacier erosion model (e.g. GC2D) with a distributed hydrologic model (e.g. TopoFlow) as an application built from CCA-compliant components.

Work has continued to make GC2D available as a CSDMS/CCA component that can be linked to other models such as TopoFlow. Bugs in the new Python version of GC2D were found and fixed and the code was streamlined. The ability to compute and export a glacier melt-rate was added to the code. The TopoFlow hydrologic model was converted to Python and packaged as a single component with a basic IRF interface. Components at the process level are much more useful than components at the model level as they allow for a greater range of plug-and-play options. Thus TopoFlow process modules are being repackaged as eight separate components (often containing multiple modeling methods), each with its own IRF interface:

1) Channel component (channels.py): Each with trapezoidal channel, Manning or Law of Wall methods for friction, but overbank flow not fully supported
    (a) Kinematic wave; (b) Diffusive wave; (c) Dynamic wave
2) Diversion component (diversions.py)
    (a) Sources, Sinks or Canals
3) Evaporation component (evaporation.py)
    (a) Priestley-Taylor; (b) Full energy balance
4) Groundwater component (groundwater.py)
    (a) Darcy's law, surface-parallel layers
5) Infiltration component (infiltration.py)
    (a) 100% infiltration until (h >= z); (b) Simple Green-Ampt, one storm event
    (c) Smith-Parlange 3-parameter, one storm event; (d) Richards' 1D equation, 6 layers
    (e) Beven exponential K, one storm event (incomplete)
6) Meteorology component (meteorology.py)
    (a) Shortwave and longwave radiation calculators, etc.
7) Precipitation component (precipitation.py)
    (a) Uniform in space, variable durations; (b) General space-time rainfall
8) Snowmelt component (snow.py): (a) Degree-day; (b) Full energy balance

Goal 4) Implement a landscape evolution model and a coastal evolution built as CCA compliant components.

The CSDMS IF has coupled the HydroTrend model with Brad Murray's Coastal Evolution Model (CEM). Both models now expose an IRF (initialize, run, and finalize) interface that will enable them to be more easily linked to other models. The models were coupled in a frameworkless environment

to demonstrate that a model with a simple interface makes it easier to couple it with other models (regardless of what framework the models are coupled within). The source code for the new version of HydroTrend is contained in the CSDMS Subversion repository at:
http://csdms.colorado.edu/svn/hydrotrend/branches/irf
The source code for the new version of CEM is contained in the CSDMS Subversion repository at:
http://csdms.colorado.edu/svn/deltas/trunk

Goal 5) Explore the coupling of a 3D hydrodynamic ocean model within CSDMS/CCA.

The CSDMS IF has not been able to obtain source code for Delft3D (http://csdms.colorado.edu/wiki/Model:Delft3D) due to contractual issues between State of Colorado and company Deltares. Delft is internally working towards a solution in 2010. CSDMS has intensified collaboration with Xbeach developers, which is an offspring of the Delft3D software, but is an open-source product. CSDMS endorsed an NSF proposal for enhanced development and will sponsor an XBeach community meeting in 2009.

Goal 7) Create two educational modules, conduct a training workshop and assist the CSDMS community in preparing code and model contributions that comply with the CSDMS standards and interfaces.

A 7 module (≈7 hr) short course in Earth Surface-dynamics Modeling and Model Coupling has been completed by Professor Syvitski and will soon be made available through the CSDMS Educational Repository. The course will be given in August, at the "Complexity and Coupling in Earth-surface Dynamics" or CCED Summer Institute at the NCED headquarters in Minneapolis MN. An expanded version (2 day) of the course will be given as a CSDMS sponsored short course as part of the "River, Coastal, Estuarine Morphodynamics" conference in Santa Fe, Argentina in September.

See also the EKT Working Group summary (page 14).

Goal 8) Develop the three CSDMS repositories (Data, Model, & Education), with community contributions. Target: A doubling of the number of data sets, contributed models and educational presentations hosted on the CSDMS site; track community interest and use of this material.

The CSDMS IF now uses Trac for web-based management of software projects. CSDMS members that house their projects within the CSDMS repository are able to create new Trac projects for their own project management. The goal of using Trac with CSDMS projects is to simplify effective tracking and handing of software issues, enhancements and overall progress as well as providing a location for end-user support. As an example, the SedFlux project now uses Trac and can be viewed at: http://csdms.colorado.edu/trac_projects/sedflux/

Model Repository Updates:

- Contacted 56 scientists to encourage them to fill out model questionnaire
- Subversion model repository is now migrated and accessible at river.colorado.edu
- The model repository has grown rapidly (doubled over the last six months) and now includes models associated with the new Focus Research Groups.

Repository statistics as of July 2009:

Model domain	**Listed models & subroutines**	**Questionnaires filled out**	**Source code available**
Terrestrial	102	75	46

Coastal	70	46	19
Carbonates	8	3	0
Hydrology	20	15	10
Marine	35	29	13

- The CSDMS Repository offers 52 downloadable models that have compiled. Over the last four months the following are the top ten most downloaded models

Model	**No. Times**	**Version**
flow,	*91*	flow-latest.tar.gz
topoflow,	*78*	topoflow-latest.tar.gz
child,	*75*	child-latest.tar.gz
midas,	*45*	midas-latest.tar.gz
bing,	*30*	bing-latest.tar.gz
2dflowvel,	*22*	2dflowvel-latest.tar.gz
topoflow,	*20*	topoflow-1.5.0.tar.gz
adi-2d,	*19*	adi-2d-latest.tar.gz
gc2d,	*18*	gc2d-latest.tar.gz
sedflux,	*17*	sedflux-latest.tar.gz

- CSDMS has started posting more elaborate descriptions of its Integration Facility models. These serve as an example for other modelers in the community to enhance model descriptions of their own code. As an example, SEDFLUX, HydroTrend, CHILD and PLUME model documentation is enhanced to now incorporate examples, description of visualization methodology, and references to both model papers and theoretical papers. Associated test files for test runs have been posted.

Datasets:

- Added Opentopography datasets to the repository
- We are now featuring links to projections of for example sea level and population, which may serve the community for running scenarios.
- ICE-5G Model Data (Global Grids of Ice Sheet Thickness and Paleotopography for 21,000 - present day), the ICE-5G (VM2) model mathematically analyses glacio-isostatic adjustment processes and provides model data on global ice sheet coverage, ice thickness and paleotopography at 10 min spatial resolution for 21ka and 0ka, and at 1degree spatial resolution for intervals in between these snapshots. These are NETCDF files.Sea Ice data (Global grids of daily/2-daily sea ice concentration 1979-2008). This data is actively generated by NSIDC/NASA from brightness temperature data derived from Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) and Defense Meteorological Satellite Program (DMSP) -F8, -F11 and -F13 Special Sensor Microwave/Imager (SSM/I) radiances at a grid cell size of 25 x 25 km. The data are in the polar stereographic projection.
- Developed new MATLAB scripts for processing sea ice and ice-5G data.
- HWSD Database (Harmonized World Soil Database).
- Sea Level Data: 1) PSMSL is the global data bank for longterm sea-level change information from tide gauges. The PSMSL collect data from several hundred gauges situated all over the globe. 2) Predictions of rates of relative sealevel rise for ICE-5G (VM2 L90) model version 1.2 for PSMSL tidegauge sites. This data set contains values of the rates of relative sealevel rise and of vertical motion of solid earth in mm/yr for times 100 years ago, present-day and 100 years into future.
- Human dimensions data 1) World Population Prospects United Nations Population Database, incorporating total pop, and pop density for all UN countries. The data covers 1950-2005 and projects to 2050 with 5 year intervals. 2) World Urbanization Prospects United Nations Population

(2007 revision) Database. This data shows total pop, rural pop and urban pop as well as annual growth rates for all UN countries. The data covers 1950-2005 and projects to 2050 w/5 yr intervals.

• Developing a strategy for Year 3 for dataset handling within CSDMS. Distinction between at least 3 data types as relevant for modeling: 1) boundary condition data, 2) model algorithm test data, 3) integrated test datasets for coupled model validation.

• Initiated a 'datatools' section that list open-source software for pre- or post-processing of data as well as simple scripts or codes for data extraction.

Data Repository statistics as of 06/15/09

Data	**Listed**	**Descriptions**	**Downloadable**
Topography	9	8	9
Bathymetry	3	-	3
Climate	6	-	6
Hydrography	5	-	5
River discharge	3	-	3
Cryosphere	2	-	2
Soils	1	-	1
Sealevel	2	-	2
Human Dimensions	2	-	2

Meta data and Matlab codes of developed models on Thaw lakes and Sea Ice and Fetch have been submitted to the CSDMS model repository.

Goal 9) Purchase and setup the CSDMS Experimental Supercomputer, test compilers with SedFlux, develop and open up to the CSDMS community for job sharing.

A series of test models have been successfully compiled and run on the new CSDMS HPCC 'beach'. These models include SedFlux, ROMS, and TopoFlow. The CSDMS IF has implemented the open-source programs Torque and Maui for batch scheduling of jobs. CSDMS members that wish to have an account on the CSDMS HPCC can apply for an account online at: http://csdms.colorado.edu/wiki/Help:HPCC_account_request

Goal 10) Further develop the CSDMS Wiki website in aid of community integration and participation.

1. **Migrated server:** The CSDMS wiki http://csdms.colorado.edu is migrated from mysticplum.colorado.edu to its own webserver: river.colorado.edu. This was necessary to increase performance and for ensuring less downtime.

2. **Security:** Migrated to Mediawiki 1.12.4, a required update for security reasons. Solved wiki security leak that made it possible to create a new page without logging in. Incorporated Captcha tool to prevent the creation of spam accounts by bots (you have to retype text from a figure to be able to 1) create an account, 2) make a link to a URL on any of the web pages)

3. **New functionality:** Incorporated a Dynamic Page list tool to the wiki, which makes it possible to visualize data on in page that is actually written on another page. All are model repositories are automatically updated. Added a "Page Trail" tool on request of some Working Group members. The Page Trail tool will highlight the last 7 pages you viewed on the wiki, provided in the main frame. Added automated model questionnaire counter. Each model domain repository has its own counter now for the number of questionnaires that are filled out. Incorporated a syntax highlight tool, to color syntaxes of code fragments posted on the CSDMS website. Added movie plugin to provide

the possibility to post movies on the website (for example simulation results: http://csdms.colorado.edu/wiki/Model:CHILD

4. **New pages:** Repository for Carbonate FRG: http://csdms.colorado.edu/wiki/Carbonate_Mo Repository for Hydrology FRG: (http://csdms.colorado.edu/wiki/Hydrology_Mo)

Goal 11) Organize and/or sponsor and/or host 3 workshops (Clinoform, Sedibud, CUAHSI Natl. Meeting), 5 working group meetings, 4 management meetings, 1 Open Town-hall meeting and 1 short course (coding camp).

Since the 2008 CSDMS Annual Report, the Integration Facility has sponsored, &/or hosted, &/or organized the following meetings:

- Three CSDMS Management meetings:
  - Steering Committee held 2/4/09 at CSDMS Integration Facility, Boulder, Colorado.
  - CSDMS Ribbon Cutting ceremony held 2/4/09 at CSDMS Integration Facility, Boulder, CO
  - Executive Committee held 3/2/09 at the University of California, Santa Barbara, CA.

- Five CSDMS Working Group (WG) and Focus Research Group (FRG) Meetings:
  - Hydrology FRG held Jan 2009 at CSDMS Integration Facility, Boulder, Colorado.
  - Carbonate FRG held Jan 2009 at CSDMS Integration Facility, Boulder, Colorado.
  - Terrestrial WG held Feb 2009 at CSDMS Integration Facility, Boulder, Colorado.
  - Coastal/Marine WG jointly held Feb 2009 at the University of Virginia, Charlottesville, VA.
  - Cyber-Num WG held March 2009 at the University of California, Santa Barbara, California
  - Chesapeake FRG held April 2009 at the Chesapeake Bay Program Office, Annapolis, MD

- CSDMS provided flashdrives containing information (model repositories, meeting details, member lists, handbook) for Marine & coastal WG meeting participants as a trial.

- Additional Presentations/Trainings:
  - CSDMS co-sponsored the 'Modeling of Turbidity Currents and Related Gravity Currents 2nd Workshop' held at the University of California, Santa Barbara, June 1-3, 2009.
  - CSDMS staff chaired the AAPG/SEPM session on 'Turbidity current modeling' in Denver, June 7-10, 2009.
  - CSDMS provided an invited keynote lecture on models and data at MARGINS S2S Conference, Gisborne, New Zealand, April 5-9, 2009.

Year 3 Goal Updates

<u>Year 3, Goal 1</u>: Work with the CSDMS Working Groups and Focus Research Groups to add additional models and subroutines as linkable components, using the procedures and interfaces developed during Year 2.

<u>Cyber-Num WG Meeting with follow-up discussion</u>:

- Continue to expand group by incorporating people with HPC knowledge to share their skills with CSDMS community.
- Working group plans to play a role analogous to other working groups in terms of vetting, prioritizing and advising on various HPC tools (as opposed to models like the other groups) including solvers, mesh generators, visualization, etc. A potential product will be a set of one-page "executive summaries" on the various packages and tools that are used within the HPC community including PETSc, HyPre, CVODES, SUNDIALS, VisIt, ParaView, Tecplot, MPI, OpenMP,

OnRamp, EUCALPYTUS, etc. This type of documentation (on our wiki) would help newcomers learn about the various resources and which ones are best suited to their particular needs and those of CSDMS. It could also be used to help decide what software should be installed on the CSDMS HPC system.

- Idea to embed an HPC expert at another lab (Ph.D. student, etc.) as way to mix knowledge around the community. Other ways may be to have longer workshops (like convention idea) plus focused meetings around certain areas (similar to Institute of Theoretical Physics).
- WG to maintain on the CSDMS wiki a list of HPC educational opportunities (workshops, seminars, tutorials, etc.). Several super-computing centers (e.g. ones in San Diego, Minneapolis, UAF, Illinois) offer training workshops on a variety of topics. Perhaps CSDMS could provide limited funds (maybe through a competition) to send a few grad students, postdocs or scientists per year to these sorts of training events. Perhaps require attendees to prepare educational materials for our wiki in exchange for financial assistance to attend a meeting. Courses can last from 2 days to 1 week in duration.
- At the next Cyber WG meeting the focus will be to gather collective wisdom and experience of WG members on these issues/models. We are not moving to an "uber' model paradigm (e.g. selecting one tool above other similar tools), but more wanting to retain a more community-based "stone soup" paradigm
- Next WG meeting would set aside time for HPC tool "review" activity that includes presentations of brief tool summaries. This could be done in advance of workshop to leave more time at meeting for discussion and prioritization.
- Potential to hold workshop jointly with another group. Thinks HPC people with other groups, maybe marine/coastal/terrestrial especially helpful as way to keep HPC folk connected with geophysical sciences

The Terrestrial WG Meeting with follow-up discussion:

- State of the art models were inventoried by classifying processes and models into 5 categories from "in the dark" (little knowledge, few or no models) to "enlightenment" (solved problem; universally accepted physical principles). Outcome indicated critical knowledge gaps, existing strong knowledge areas, and intermediate level of knowledge.
  - Critical knowledge gaps include: hillslope grain-size production and large-scale development of bedrock landscapes. Other important gaps include debris-flow erosion and routing; landscape-scale glacial erosion; long-term overland-flow erosion; deep-seated landsliding; chemical denudation; and long-term ice-sheet dynamics.
  - Areas where existing knowledge is strong and models available include: lithosphere flexure; meter-scale Darcy flow; catchment-scale groundwater flow (e.g., Modflow); free-surface and open-channel flow (Delft3D, MD-Swms)
  - Processes at an intermediate level of knowledge, with multiple working hypotheses based on observations and measurements, include: bedload sediment transport; bedrock river incision; structural development of orogens; soil production; small-scale (cm to m) glacial erosion; river meandering; hydraulic geometry; shallow landsliding; debris-flow motion dynamics (as opposed to erosion/entrainment); hillslope sediment transport; fluvial sorting and patch dynamics; delta formation; and delta formation.
  - The Terrestrial WG defined the following criteria for a proof-of-concept applications in coupled modeling: (1) the model should integrate at least two separate process domains (components) of the Earth surface system, (2) the model should address an issue of widespread interest within the CSDMS community and society as a whole, and (3) the problem should be well-posed from the standpoint of initial and boundary conditions, and should have a wide range of accessible data with which to verify model results. The first criterion applies specifically to coupled-system models. In addition to these, TWG recognize that model-data comparison studies of individual components (e.g., catchment evolution) are also needed. It is recommended that near-term proof-of-concept applications include at least one focusing on relatively short-

term (annual to decadal) interactions between process domains, and one focusing on landscape evolution over long (geologic) timescales and involving the coupling of a landform evolution model with a state-of-the-art atmospheric, lithospheric, or ecological model.

Proof-of-concept applications:

- Glacial-fluvial transition (mass balance of sediment over glacial-interglacial cycles, terrace generation etc).
- Hillslope-channel transition (post-fire erosion, alluvial fan aggradation via Plio-Q climate cycles)
- Valley-floor channel-groundwater aquifer transition (gaining and losing streams, groundwater sources, arroyo cutting in the SW)
- Inter-discipline coupling: Surface-atmosphere; Rock deformation-fluvial system coupling; Landscape processes and ecology
- Post-fire erosion (rich data along San Gabe front and Front Range 2002? fires). Components: hillslope-channel model that does rainfall-runoff-sediment flux. Interesting potential for long-term assessment (climate change/pine beetle/erosion/water quality etc.). These models will be highly parameterized because we do not fully understand how fire changes surface properties.
- Landscape-lithosphere: Terrestrial-to-marine coupling over geologic time scales (Eel River to shelf). e.g. CHILD to SEDFLUX. This sort of coupling can also be done currently with simpler 2D models as a "fall back".
- GCM to landscape evolution model (e.g. impact of future change in mean runoff and variation to erosion, flood potential, etc….) Long term: vegetation, hydro, and dust all feedback to climate. Short term: one-way input of GCM to landscape. Could include glacier advance/retreat. Data is a component, so the coupling of GCM model output to a landscape model is, in itself, a technical challenge.

Data-sets:

- Work close together with CZO and other data-rich consortia
- TWG recommends getting better about calibration and validation methods: "… The engagement of the terrestrial community in model inter-comparison projects provides a useful opportunity to advance the techniques we use for calibrating and validating process-based numerical models in geomorphology. Currently, model calibration and validation is, to a large extent, a process of trial and error that does not take into account uncertainty in the input data and, hence, does not quantify uncertainties in model outputs. Ideally, the proof-of-principle applications that the terrestrial working group of CSDMS focuses on will involve the testing of new techniques that have been developed in the Earth science modeling communities for improved model calibration, validation, and uncertainty estimate."

Prioritized list of computational infrastructure needs

- Get models into repository and make long-term reliability sure by:
    - Develop a strategy to guide the process from donation of a model to quality assured.
    - Use platforms like SourceForge to share code
    - Provide model status on CSDMS web with icons (IRF, Compl, etc)
    - Make it possible that users can provide comments
    - Have forums for each model
- CSDMS should make it as easy as possible for model developer to couple models by:
    - Keeping CCA complexity on the CSDMS site, only provide a Ccafeine GUI for end user
    - CCA toolchain only available for specific requests
- Provide IRF implementation path for contributor through:

  - Coding camps
  - Stick figures in manual
- Toolkits (either as libraries within components or as separate components):
  - E.g. terrain tools (slope, aspect, curvature)
  - HPC supported
  - Drainage area / watershed tools
  - Soil heterogeneity -> process tools / data tools
  - Process tools
  - Hydraulics tools
  - Basin tools
  - Support tools (IO, visual, sensitivity analysis)

Stimulate self-organizing collaborative teams

- TWG acknowledged that this is difficult to monitor, given the confidentiality issues that surround proposal generation, but anecdotally we have evidence that the CSDMS project is indeed stimulating development of new projects
- As far as Chair knows, 5 proposals are submitted that are fully terrestrial oriented or have a strong terrestrial component within them. As of today those proposals are still pending.
  - Fire erosion proposal
  - Ebro proposal, human impact
  - Front Range gully erosion and fire erosion

Define and prioritize educational needs / training for use CSDMS framework

- TWG is enthusiastic about training programs, such as coding camps, to bring people up to speed in CSDMS tools and infrastructure. It is recommended that training/demos be a component of future WG meetings.
- Although less time was available to discuss outreach and educational needs, a few sub group efforts were made to emphasis the importance of outreach. An EKT related proposal by J. Pelletier and W. Luo was submitted, proposing to make models more accessible by making them available through interactive web portals (like WilSim). The HydroHub proposal is another good outreach example for the TWG.

1. Terrestrial Working Group to submit a prioritized list of computational infrastructure needs
2. 2-3 proof of concept problems to illustrate the power of coupled models
   - Within earth surface processes
   - Between discipline couplings
3. Terrestrial proposals identified by Greg Tucker (Chair, Terrestrial WG):
   - Looking into joint proposal between Terrestrial WG & Hydrology FRG (in regarding to 6mnths funding of UC San Diego proposal).
   - Looking into joint proposal for fire erosion (Terr WG & Hydrology FRG)

A FULL DISCUSSION OF THE TERRESTRIAL WORKING GROUP IS AVAILABLE IN APPENDIX 1 (Page 24)

The Coastal WG Meeting with follow-up discussion:

Needs for Modeling Coastal Environments

- At a February 2009 meeting, the Coastal Working Group continued the discussion of the state of the art of coastal modeling, including key gaps in knowledge and modeling capabilities. (The full report is included as Appendix 2.)
- Building on the previous year's meeting (http://csdms.colorado.edu/mediawiki/images/MeetingRptCoastalWG.pdf), at the 2009 meeting the Working Group elaborated on gaps and modeling needs in three key sub-environments:.
  - Tidal Marshes and Lagoons

- Deltas
- Coastlines

Priority Projects

- At the 2009 meeting the Working Group also concentrated on identifying proof-of-concept projects to prioritize—projects that involve linking models of different environments (preferably spanning from Coastal to Marine and/or Terrestrial), which address compelling and relevant basic science questions.
- 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.
- We focused on five areas in which new model-linkage capability needs to be developed to address compelling questions:
  - Barrier-Island/Tidal Marshes (based on recent modeling in both environments: does a two-way coupling facilitate island survival, or disintegration, under different scenarios of rising sea-level and increasing storminess?)
  - Fluvial and Coastal Dynamics on Deltas (where wave-driven coastal sediment transport interacts with fluvial sediment delivery, how does the two-way coupling affect abrupt river-channel relocations and delta morphodynamics?)
  - Terrestrial Landscape Evolution and Delta Morphodynamics (how do land-use changes, which cause shifts in river sediment fluxes, affect estuary and delta evolution?)
  - Marine Shelf Processes and Coastline Evolution (how do different ways of modeling wave transformation, with different levels of realism and approximation, affect the results of coastline evolution models, in an environment of sea-level rise and likely changing storm patterns?)
  - Humans and Coastlines (what modes of behavior emerge in the new kind of landscape system in which shoreline stabilization efforts, and the sociological and economic dynamics behind them, have two-way couplings with coastline-evolution processes—especially as the sea-level, climate, and economic change?)
- At the end of the meeting, participants made plans to collaborate on, or spur collaboration by colleagues, on proposals to pursue each of these projects (with the exception of the second, which we are pursuing as an early proof-of-concept project using Integration Facility resources and expertise).

Follow Ups

- How to get more existing models into the CSDMS wiki? Brad Murray (Chair, Coastal WG) sent series of emails to the Coastal group re submitting their codes to CSDMS in order to build model toolbox on CSDMS wiki. Follow-up by CSDMS.
- Plans to move forward in linking the prioritized models (Coastal Evolution Model with Sedflux, introducing a brand new model and perhaps a terrestrial model)
  1) Goal is to have demonstration model of proof-of-concept for RCEM meeting in September. Question is whether we can link Delta plain model? Chair states there are a couple of proposals in the works for proof-of-concept.
  2) Coastal Working group is making progress on spurring proposals to address questions (listed above) that will require novel model coupling, and will provide linkable models to the CSDMS toolbox:
     a. Barrier Island-marsh-tidal being worked on by Laura Moore and Sergio Fagherazzi (for submission late 2009 or early 2010)
     b. Swan – shoreline model being worked on by Peter Adams and Dylan McNamara (submission summer 2009)

c. Ebro Delta project involving Andrew Ashton and Albert Kettner (re-submission planned)
d. Linking coastal economic and coastline evolution; an interdisciplinary project involving Marty Smith, Dylan McNamara, and Brad Murray is underway (submission summer 2009).

3) <u>The main goal of next meeting will be to</u>:
   - Proof-of-concept projects
   - Getting models available – submitting code (increase toolbox)
   - Help members with IRF while at CSDMS
   - Get larger group trained in broader process of collaboration
4) Re CSDMS HPC, some members have already gotten their HPC accounts with CSDMS

A FULL DISCUSSION OF THE COASTAL WORKING GROUP IS AVAILABLE IN APPENDIX 2 (Page 48)

<u>The Marine WG Meeting with follow-up discussion:</u>

1) How to get more existing models into the wiki? One challenge is to have MatLab compatible with CSDMS codes. Plan is for the group to first submit simple things to connect that do not require that extent of compatibility as proof-of-concept
2) How will CSDMS plan to classify codes – in terms of what? Group Chair sees a preference for identifying codes separately in the wiki according to whether they are 'repository' or 'module' oriented. Under discussion
3) Group identified needs to get the proof-of-concept:
   a. Have ROMS (etc.) brought into systems to get good bathymetry, gridded surface, etc.
   b. Have one source to generate a grid (base grid)
   c. Have way to get input – force data
   d. Have Matlab be compatible
4) <u>Plans for next Marine WG meeting (November 2009):</u> Hold in conjunction with Coastal WG – still receiving mutual benefit and many members are members of both. Carl Friedrichs (Member of MWG and new Chair of Chesapeake FRG) and Pat Wiberg (Chair of Marine WG) are working on a modeling proposal together that may be something that could be discussed – built upon for group.

<u>The Education & Knowledge Transfer WG Meeting with follow-up discussion:</u>

The EKT mission comprises several aspects: knowledge transfer to CSDMS modelers, to the new generation of earth scientists, to earth science educators and to federal agencies and industry partners. It will be key to develop among the community enough understanding of the CSDMS technology to allow efficient creation and use of CSDMS diverse codes.

Another key aspect of the CSDMS initiative is to develop fully functional and useful repositories for CSDMS models and numerical tools, CSDMS data, and models and model results for educational use**.** The Educational Repository must distribute CSDMS model simulations, educational presentations, reports, publications, short course materials, and CSDMS-hosted or sponsored workshops. In addition, it will feature teaching material to introduce earth science students into the use and development of numerical tools for earth science related problem solving and hypothesis testing.

We created our first educational modules both for modelers and for (under) graduate education. All products are served on the CSDMS wiki.
There are now examples of several educational products that we envision to expand on:

1) The CSDMS Handbook serves to educate modelers on preparation of their models to submit the as 'compliant' models to the CSDMS framework by restructuring their code so that it has an IRF (Initialize-Run-Finalize) structure.
2) CSDMS Integration Facility Staff has presented new CSDMS technology (f.e. wiki functionality, CCA tool kit, and IRF practices) at working group meetings. We also assisted interested modelers at the respective working group meetings with clean coding practices and hands-on model development.
3) Individual model pages are set up to include a lot of information for new model users. Examples are the SedFlux and CHILD pages, that have documentation on the model, literature references, information on installation, input files for test-runs, information on output processing. Contributions from the community are being solicited.
4) The BARSIM model is an example of a model offered to educators as a teaching resource. The model intents to provide insight in the response of beach and barrier coastal systems to changing sealevel. The model is offered as an executable-file that can straightforwardly be installed by the user. Accompanying notes offer a full-day classroom exercise.
5) CSDMS has developed an image and movie gallery. The gallery is intended to be used for download for illustration in basic earth sciences, and more advanced sediment transport and surface dynamics courses. The gallery is set up as a wiki system and contributions from the community are solicited.
6) Educational presentations are served in the Educational Repository.
7) All presentations of the working group and CSDMS related meetings are being offered for viewing and download on the CSDMS wiki (mostly under the 'Past Meetings' section).

The EKT Group met in Oct08. A chair was selected, Karen Campbell! The group has focused attention on models as educational tools, with a first priority to develop material for undergraduate education. A number of excellent examples of such educational models have been shown: examples are WILSIM, predator-prey model, Xbeach to name a few. The working group identified a number of lessons learned with these individual models and recommended that CSDMS educational models will be set up similarly.

- Models should be relatively simple (perhaps 5 free parameters).
- Ideally, models should be run over the web.
- Modules should be targeted at different levels of understanding and allow student to dig into detail if they wish.
- Models should have an associated system that allows quantification of the learning experience

The EKT group also brainstormed on long-term goals for the CSDMS EKT. The EKT group envisioned a series of well-documented model labs for different earth surface process dynamics. Our vision included presentation of these teaching materials in educational sessions of AGU and educational journals. Other big ideas are the development of animations for science museums and national parks.

In related matters, the CSDMS IF staff has helped Jon Pelletier and Rudy Slingerland with submission of their well-documented teaching models into the CSDMS model repository, one proposal has been submitted by two group members.

EKT Plans for Year 3:

- Include more simple, granular models to the CSDMS model repository that can be easily used for teaching. NCED postdoc Enrica Viparelli helps in 2009 with incorporating Gary Parkers teaching models into the CSDMS model repository.
- Put an EKT module on coupling models & examples on CSDMS web.
- Extend education repository with a movie gallery of real-world earth surface process and model simulations that can be used for educational purposes. All movies should include factsheets before

they are uploaded.

- Extend education repository with educational models that can be used for teaching earth surface dynamics. A really good example including different levels of process complexity, including of the shelf exercises and thorough documentation as well as evaluation metrics will set high standards for subsequent submission of teaching models by CSDMS community members.
- Offer RSS feeds to the CSDMS community so that they can subscribe to CSDMS RSS feeds to stay up to date with newly added educational material.
- Work with NCED and the Minnesota Science Museum to develop surface process dynamics simulations for science museum. A summer student at NCED will assist the EKT 2009 effort.

Hydrology Focus Research Group Meeting with follow-up discussion:

- We started with an update from Jay Famiglietti, Chair of Hydrology FRG, on the 2nd CHyMP scoping workshop. There seemed to be agreement that CHyMP should use the software and standards that CSDMS is developing for componentization and model coupling and that the CHyMP effort should focus on science, best numerical approaches and best modeling practices. Two more CHyMP community workshops are expected before a proposal submission in about 2 years.
- David Tarboton, group member, had agreed at the last FRG meeting to work on a proto-type coupling project using his snow model. Jay will follow up with David on this.
- Jay is working to drive interest in getting good codes on hydrology models into CSDMS. He is moving to having the group vet the models to decide which would go into CSDMS. Then, he understands that CSDMS would break them into components.
- Jay will email group to see what models interests them. Focus on members coming to next meeting with ideas on models to use for CSDMS.

Ideas for Next Meeting (November 2009):

- Target invites for the next FRG meeting are people who have experience in HPC: Mary Wheeler (HPC expert at Univ. Texas), people in Oak Ridge Natl. Lab and NCAR. Scott /CSDMS learned at ParFlow short course that Mary Wheeler was an advisor to Carol Woodward who is one of the applied mathematicians working at LLNL/CASC alongside the Babel/CCA developers. Carol is an expert on numerical methods and HPC who has worked on parts of ParFlow and may be a good person to involve in the FRG or Cyber groups.
- Hydrology FRG would likely meet for 1 day program, ideally next to Terrestrial WG.
- Focus on members coming to next meeting with ideas on models to use for CSDMS.

Carbonate Focus Research Group Meeting with follow-up discussion:

Although a Carbonate Workshop was held in January 2008, the Carbonate Focus Research Group (FRG) officially started in 2009 the 2nd year of CSDMS, so this is the first annual progress report for carbonates). The Carbonate FRG is tasked to make progress addressing the grand challenges for fundamental research on ancient and modern carbonate systems. To accomplish this, the main aim of the carbonate FRG for its first year was to submit a NSF Cyberinformatics Group proposal to fund a multidisciplinary, multi-institution research project to design and implement a next-generation carbonate modeling workbench. A 2-day workshop was held in Boulder CO, hosted by CSDMS (http://csdms.colorado.edu/wiki/Carbonate_FRG_2009) to plan the proposal and initiate writing. Chris Jenkins as proposal PI then lead completion and submission of the proposal for the July 8th, deadline. The proposed project will develop carbonate workbench components, including:

- Sediment production and availability
- Biological ecosystems and communities
- Bioengineering
- Dissolution, re-precipitation and cementation
- Diagenesis

- Objective, inversion, and analysis functions

The ultimate aim is for these model elements to combine to accurately predict modern and Holocene carbonate facies heterogeneity. The components will become part of the CSDMS model repository.

Work in process: Besides this group effort, the Chair of the Carbonate FRG, Peter Burgess, is in the process of submitting some of his older carbonate numerical models to the CSDMS model repository to serve as a starting point for some of the suggested components in the submitted proposal.

Long(er)-Term Goals (derived from meeting Jan. 2008 and Jan 2009)
a. Define a detailed coring program on one or more platforms to evaluate the platform depositional architecture, to provide information to test models.
b. Develop a rigorous understanding of the geochemical and physical constraints on carbonate production and its spatial heterogeneity and translate this into more process based numerical models. Workbench predictions will influence observatory systems like the Global Ocean Observatory.
c. Write a NSF proposal (deadline July 8th) to address CSDMS vision. Proposal will commit to develop the following components:
  - Diagenesis-compaction-infusion module (David Budd)
  - Carbonate Production (e.g. Chemical side) (Gene Rankey)
  - Biology module (Chris Jenkins & Rick Sarg)

Peter Burgess provided a list of models & developers that might want to share their models with the community (*Models are not linkable components most likely*). Assist needed in installing & running models on HPCC, including the installation of software (Matlab) on HPCC, and access to HPCC

Chesapeake Focus Research Group Meeting with follow-up discussion:

- Carl Friedrich chosen in April 2009 to be new Chair of the Chesapeake Focus Research Group.
- ROMS, and especially Ches-ROMS (ROMS with grids and input data set up for the Chesapeake Bay) were identified as models of key interest to this focus group at the last meeting in Annapolis. The main CCMP models are ROMS models. Member Harry Wang is a water quality and storm surge modeler (at VIMS) with a large research group who also uses Ches-ROMS. Member Courtney Harris is working with Carl on modeling the York River using ROMS.
- ROMS is already listed on our wiki and Scott thinks that it was recently installed on our server "beach". Discussion of whether Ches-ROMS should be listed separately on our wiki?
- Discussed whether it makes sense to have ROMS be 'linkable' or whether this would ever be required beyond the coupling to SWAN that Chris Sherwood's group is working on. However, SWAN is not of strong interest to this FRG.
- Members of this group tend to write simpler, MatLab (often 1D) models but are very interested in using bigger, well-established models like ROMS. They would like to see a simplified or "mini" version of ROMS for research and testing ideas.

Ideas for Next Meeting
- Next meeting Carl would move forward with ROMS and explore Ches-ROMS/CCMP – making implementation in CSDMS a priority. Also interested in routinely using Ches-ROMS at VIMS.
- Carl will call people one-on-one via phone to determine the focus of the next meeting. He looks forward to a monthly call from CSDMS.

***Year 3, Goal 2*: Explore the use of HPC-targeted component libraries such as PETSc and hypre, and existing CCA-compliant solver and mesh-generation components developed at DOE labs.**

The CSDMS IF has installed a set of tools on its new HPCC that are targeted to high performance computing. In particular, the PETSc and hypre libraries and optimized for the particular configuration of the CSDMS HPCC. Other installed HPC tools include various MPI implementations that include mpich2, mvapich2, and openmpi. These packages are customized to use both gigabit ethernet as well as the higher speed InfiniBand for inter-node communication. Alongside the set of GNU compilers, the CSDMS HPCC now contains the complete set of the fortran and c/c++ intel compilers, which are optimized for the Intel harpertown processors.

CSDMS members from the University of California at Santa Barbara (Mohamad Nasr-Azadani and Michael Zoellner) have begun testing of a turbidity current model, gvg3D. The model makes use of both PETSc and hypre and uses the mpich2 compiler.

***Year 3, Goal 3**: Adapt a client-based version of the Ccaffeine GUI, with a simple installation process, that CSDMS members can use on their own computers to link components into new applications that will run on the CSDMS supercomputer.*

Began work on a new CSDMS GUI for Ccaffeine that will allow CSDMS users to build applications from CSDMS components on their own PCs and then run them on our HPCC server called "beach". Messages and files are passed between the user's PC and our HPCC server via SSH tunneling, while data generated by model runs resides on our server. The GUI is now operational and work to add each of the following new features is complete:

- "Bulletproof", client-side Java application that can be easily installed by CSDMS members on their desktop or laptop computers. Tested on several major operating systems including: Windows, Mac OS X and Linux versions. Fixed bugs that caused it to intermittently freeze up or "hang".
- Added a login dialog (and Login button) that allows users to choose between working with a CCA project on their own computer or connecting to a remote computer that is running Ccaffeine, such as beach.
- Added ability to select from a droplist of CSDMS "component palettes" that are available on beach.
- Added ability to save a CCA component "wiring diagram" that a user has created and to then "import" or "open" a previously saved diagram as the starting point for additional model runs. This can also be used to display a pre-wired model to help new users get started.
- Added a console or "output log" window to display messages generated by simulations running on a remote computer (e.g. beach).
- Improved appearance of the GUI, with "branding" such as a Help menu with information on how to use the GUI, links to CSDMS and CCA websites, and new menus, buttons and colors.

Work is ongoing to incorporate visualization tools into the new GUI, starting from those that are available as open-source code in VisIt. VisIt was designed for terrascale, multi-processor rendering for HPC models in a client-server configuration. It also supports a wide variety of data formats including netCDF, VTK, many image formats such as PNG and TIFF, all of the GIS formats in the well-known GDAL package (e.g. shapefiles) and the SILO format (e.g. used by ParFlow). Like Ccaffeine and its GUI, VisIt is similarly split into client-side and server-side components. It can now be launched from the CSDMS GUI to generate graphics from model output files that reside on our server and display them on the user's PC.

It is important for the new CSDMS version of the Ccaffeine GUI to be "bullet-proof". It is intended to serve as the main means for CSDMS users to perform model runs on our supercomputer. The "Ccaffeine GUI" program is a portable Java application that allows users to graphically connect CCA components to create new applications. The program's job is to create a Ccaffeine script that can either be run on the same computer or sent to a remote computer (such as the CSDMS supercomputer, "beach") to be run by the Ccaffeine program. Ccaffeine is a CCA-compliant framework that supports parallel computation. While Ccaffeine is a large and complex program (without native support for Windows) and may be difficult for a user to install on their personal computer, the Ccaffeine GUI is a small, easy-to-install Java application, which can be used on any computer that supports Java.

***Year 3, Goal 4*: Assist CSDMS members who have HPC experience with installing and running their models on our new supercomputer, and encourage them to share their knowledge with other CSDMS members via our wiki, workshops and recommended reading. Prepare educational materials related to high-performance computing (HPC) (e.g. how to use MPI and OpenMP) and add this material to the CSDMS wiki.**

The CSDMS website has added instructional pages to assist CSDMS members with HPC issues. Under the "Help" tab is a section that deals with high performance computing and how to use some of the resources on the CSDMS high-performance computing cluster. Information on how to submit jobs to run on the CSDMS HPCC can be found at the following URL: http://csdms.colorado.edu/wiki/Help:HPCC_Torque . This describes the use of the batch job scheduling software, Torque as it is used on the CSDMS HPCC. Also included are sample submission scripts for both serial and parallel programs as well as examples that use the MPI implementations installed on the CSDMS HPCC.

The CSDMS Service Desk has helped members upload, compile, and run their models on the HPCC so that they are able to run successfully in a parallel environment. In particular,

- Greg Tucker and Nate Bradley (University of Colorado) have installed the Child landscape evolution model and conducted a Monte Carlo simulation that consisted of hundreds of simulations, each run on a separate processor.
- Mohamad Nasr-Azadani and Michael Zoellner (University of California at Santa Barbara) have installed the turbidity current model gvg3D and begun test runs. This model is parallelized using MPI and compiled with mpich2.
- Scott Bachman (University of Colorado) installed and ran the flow routing model TopoFlow on large data sets (on the order of one million cells) for more than 700,000 time steps.
- Aaron Bever (Virginia Institute of Marine Science) has installed and began to run ROMS, a parallel ocean circulation model.

***Year 3, Goal 5*: Work with the Community Sediment Transport Modeling System (CSTMS) group to determine feasibility of getting the ROMS based sediment model to be compliant with the CSDMS CCA OpenMI framework and interface standards.**

No progress to date.

***Year 3, Goal 6*: Define the needs of datasets and put them in the repository. Milestones: Describe all new and listed datasets. Organize the 3 model domains (Terrestrial, Coastal, Marine) into sub categories.**

Data repository

Downloaded and provided link to ASTER Global Digital Elevation Model (GDEM v001) data which covers the Earth's land surface between 83N and 83S latitudes. Distribution contains ~22,895 tiles of 1º x 1º.

<u>Year 3, Goal 7</u>: Put an EKT module on coupling models & examples on CSDMS web. Milestone: Extend education repository with a movie gallery of model simulations that can be used for educational purposes. Numerical movies should include some description before they are uploaded.

Attended a short, hands-on course at the Colorado School of Mines on the ParFlow hydrologic HPC model. ParFlow will soon be installed on beach and generates output in the SILO format that can be rendered with VisIt

Provided guidance and feedback to Gary Parker's group regarding conversion of his ebook code from Visual Basic to C.

<u>Year 3, Goal 8</u>: Offer RSS (Really Simple Syndication) feeds to the CSDMS community so that they can subscribe to CSDMS RSS feeds to stay up to date with newly added material.

CSDMS RSS feeds on Wiki: *Email notification of pages that are marked as 'watch'*

- Incorporated tool to monitor any changes on pages that are of interested to a certain user. Also incorporated feeds.
- Incorporated help pages on how to change settings to receive email notification of watchlist: http://csdms.colorado.edu/wiki/Help:Watchlist

CSDMS news feed activated

- CSDMS news feed (RSS) is installed and activated for the wiki. Everybody can subscribe to the feed to keep informed about:
    - All changes made on the CSDMS wiki (subscription to site).
    - Changes made on any page of interest (subscription per page).
- Incorporated help pages on how to subscribe to the CSDMS news feed: http://csdms.colorado.edu/wiki/Help:NewsFeeds

<u>Year 3, Goal 9</u>: Develop an automated web structure such that the content of certain CSDMS web forms are automatically incorporated in CSDMS web pages. Develop a web structure that's able to, for example, automatically incorporate newly produced statistical data of model information into the CSDMS wiki. Automate website database backups to ensure that data won't get lost. Offer possibility for CSDMS community members to list their model papers.

- Upgraded the mediawiki software for the CSMDS wiki to version 1.14.0, such that new software capability can be applied to the web site. Upgraded version 1.14.0 with mediawiki version 1.14.1 for some security holes that were found by the mediawiki community. Installed Semantic Forms (SF) wiki software. With SF it is possible to integrate a database within the wiki-database through a form. For example, the model questionnaire form will be converted into SF format such that the input fields are stored in a database that then can be questioned like: how many models are written in fortran or are working on Mac OSX platform.
- Created 8 mailing lists, one for each of the CSDMS Working or Focus Research Groups, so the Executive Assistant or each of the chairs can send out email to all the WG/FRG members. Information on how to subscribe or unsubscribe is put in place on the web site.

CSDMS automated web pages added:

- SLOC page (Source Lines of Code): http://csdms.colorado.edu/wiki/Model_SLOC_Page. This page will be automatically updated every day and SLOC data is directly injected into the Wiki database such that information can be parsed into other wiki pages if needed.
- Nr. of successful model downloads (from ftp): http://csdms.colorado.edu/wiki/Model_download_Page. Page is automatically updated every day. Number of successful model downloads from CSDMS ftp site are displayed in a few ways.

Information is directly injected into Wiki database so information can be parsed into other wiki pages.

Automated security:

- Email notification when new users subscribe (create login) to the wiki. This makes it possible to detect early on 'Spam accounts', and can be directly (manually) deleted.
- Email authentication is now required before people can edit wikipages. On first login users need to provide their email address. An automated email is send to new users on which they have to respond within a certain time to activate their account. Migrated to Mediawiki 1.12.4. A required mediawiki update for security reasons.
- The information people have to provide (e.g. SSN & date of birth) to require a HPCC account is handled now over a secured web connection (HTTPS). Once information is submitted it will be submitted to CU-ITS by email. The campus IT Security Office, which makes rules on what can and can not be passed via e-mail, allows the last 4 digits of SSNs to go through e-mail.

MediaWiki API (Application Programming Interface) installation:

Python mediawiki toolkit is installed to provide direct, high-level access to the data contained in the CSDMS wiki databases (Only accessible for the webmaster). This provides the possibility to automate wiki maintenance (backups, broken external links, parse data to wikidb, etc).

Other Updates:

CSDMS Personnel: New to the CSDMS staff, or those taking on new responsibilities include:

Jisamma Kallumadikal has accepted the CSDMS Computer Scientist position (Industrial Consortium). Jisamma received her Bachelors in Computer Science & Engineering, Cochin U. of Science & Technology, India and her Masters in Computer Engineering, U. Duisburg – Essen, Germany. Her previous work experience includes: 1) systems engineer for T Systems Enterprise Services, Bonn, Germany, 2) computer scientist with Fraunhofer SCAI, Sankt Augustin, Germany, 3) software developer with Nokia Networks, Research and Development, Düsseldorf, Germany, 4) software developer with Teles Computer Systems India Pvt Ltd, Bangalore, India, and 5) software developer with BNS Solutions, Trivandrum, India. Her technical skills include: Eclipse, Netbeans, WebLogic 8.1, CVS, Power Designer, Innovator, Apache Tomcat, ANT, TOAD; Java, J2EE (Underwent training by SUN), JSP, XML, Python, Oracle 10g PL/ SQL; Visual Basic 6.0, Java Swing, Netbeans Matisse; MS Windows 98/2000/XP, Linux.

Beichuan Yan has accepted a CSDMS software engineer position. Beichuan received his B.E. and M.S. in Civil Engineering from Tsinghua U., Beijing, China and his Ph.D. in Civil Eng from U. Colorado – Boulder. His research experience includes work on stress-strain and consolidation simulation (FEM) and discrete element modeling of granular materials and coupling with FEM. His technical skills include C, C++, Fortran, Matlab, OS and shell/Perl programming, data structures, and object-oriented programming and design.

Irina Overeem has accepted the CSDMS Education and Knowledge Transfer position. Irina was already in charge of the CSDMS Industrial Consortium. Irina received her BSc. Soil, Water and Atmosphere, Wageningen University and her MSc. Summa cum Laude, Engineering Degree in Soil Science and Geology, both from Wageningen U., The Netherlands. Her PhD was in Civil Engineering and Applied Earth Sciences, Delft U. Technology. Irina previously worked as an Assistant Professor, Dept. Geotechnology, Delft U., from 2005-2007, and is a RSII at INSTAAR, U. Colorado – Boulder. Through her career, Dr. Overeem has worked as both an outstanding educator, and with a long history of interaction with industrial (energy and environmental) companies. Her research has principally involved the development of CSDMS-related numerical models and their real-world application.

Carl Friedrichs has accepted the position as Chair of the Chesapeake Focus Research Group. Carl received his B.A from Amherst College, and then his Ph.D. from Massachusetts Institute of Technology/Woods Hole Oceanographic Institution. Carl is presently a Professor of Marine Sciences at the Virginia Institute for Marine Sciences. Carl's long-term research goals are to better understand the fundamental aspects of coastal and estuarine physics, which control sediment and other material fluxes at time-and length-scales important to geology, biogeochemistry, and ecology. His technical approach involves fieldwork, analytical theory, numerical modeling and the intersection of all three in the utilization of coastal observation and prediction systems.

Integration Facility Reports & Publications:

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2. Hutton, E.W.H., J.P.M. Syvitski & S.D. Peckham, in press, Producing CSDMS-compliant Morphodynamic Code to Share with the RCEM Community. River, Coastal and Estuarine Morphodynamics, Balkema Press
3. Kettner, A.J., and Syvitski, J.P.M., 2009. Fluvial responses to perturbations in the Northern Mediterranean since the Last Glacial Maximum. Quaternary Science Reviews, doi:10.1016/j.quascirev.2009.05.003
4. Kettner, A.J., Gomez, B., Hutton, E.W.H., and Syvitski, J.P.M., 2009. Late Holocene dispersal and accumulation of terrigenous sediment on Poverty Shelf, New Zealand. Basin Research, 21, doi:10.1111/j.1365-2117.2008.00376.x
5. Kettner, A.J., Restrepo, J.D., Syvitski, J.P.M., in review, Spatial Simulation of Fluvial Sediment Fluxes within an Andean Drainage Basin, the Magdalena River, Colombia. *J Geology*
6. Overeem, I. & Syvitski, J.P.M. (editors) (submitted 2009). Dynamics and Vulnerability of Delta Systems. LOICZ – Land-Ocean Interactions in the Coastal Zone Special Publication 35. 60 pp.
7. Overeem, I. & Syvitski, J.P.M. (submitted 2009). Experimental Exploration of Fjord Stratigraphy, chapter in book on Fjord Depositional Environments and Processes. Geological Society Special Publication.
8. Overeem, I., Syvitski, J.P.M., in press, Experimental Exploration of Fjord Stratigraphy, In: Fjords: Depositional Systems and Archives, J. Howe (Editor), Geological Society, London
9. Overeem, I., Syvitski, J.P.M., in review, Shifting Discharge Peaks in Arctic Rivers, 1977-2007, *Geografiska Annaler*
10. Pyles, DR, Syvitski, JPM, Slatt, R., 2009, Applying the Concept of Grade to Basin-scale Stacking Patterns and Reservoir Architecture: An Outcrop Perspective. SEPM Workshop on Stratigraphic Evolution on Deep-Water Architecture, Mariarmen Alicon, Chile, Feb 22-29, 2009.
11. Syvitski, J.P.M. and Slingerland, R.L., 2009, CSDMS and What it Means in the MARGINS context. MARGINS Newsletter No. 22, pg. 16-17.
12. Syvitski, J.P.M., AJ. Kettner, MT. Hannon, EW.H. Hutton, I Overeem, G. R Brakenridge, J Day, C Vörösmarty, Y Saito, L Giosan, R J. Nicholls in press, Sinking Deltas, *Nature Geoscience*
13. Syvitski, J.P.M., DeLuca, C., David, O., Peckham, S., Hutton, E.W.H., Gooding, J., in preparation. Cyber-infrastructure. *In: Handbook of Environmental Fluid Dynamics*
14. Syvitski, J.P.M., in preparation (invited), Modeling the sediment dispersal from land to the coastal ocean. *Annual Review of Marine Science.*
15. Syvitski, J.P.M., Nittrouer, C.N., in preparation, Lessons learned from Source to Sink investigations on the Eel, New Jersey, Adriatic and Gulf of Lions continental margins, *Marine Geology.*
16. Syvitski, J.P.M., R.L. Slingerland, P. Burgess, E. Meiburg, A. B. Murray, P. Wiberg, G. Tucker, A.A.

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Scientists Visiting the CSDMS Integration Facility

- **Yunzhen Chen, Post-doctoral student - Nanjing University School of Geographic and Oceanographic Sciences** Research project: (09/01/08-08/31/09)
  "Application of numerical models to understand the development of stratigraphy within the Bohai and Yellow Seas from sediment delivered by the Yellow River (Huanghe)".

- **Juan Restrepo, Ph.D., Professor of Geological Sciences, EAFIT University, Colombia, Argentina** Research project: (01/01/09 – 04/30/09)
  Developed a cooperative agreement between INSTAAR, CU and the EAFIT University in order to promote collaboration and scientific-academic exchange. Analyzed water discharge and suspended sediment load data of the Magdalena River in order to develop a joint publication. Established a database of deltaic regions of South America; in particular the Columbian systems that have evolved over extreme climatic, geological and oceanographic conditions, to ensure that this region is also fully covered in the global delta database.

- **Ilja de Winter, Ph.D. student, Delft University of Technology, The Netherlands** Research project: (June 11-20, 2009)
  Worked with CSDMS staff on coupling glaciological and sediment production and transport models, June 11th-20th 2009.

- **CSDMS Industrial Consortium:**
  - Provided ExxonMobil with database (DVD) of model repository & CCA software
  - Provided StatoilHydro with the database (DVD) of our model repository & CCA software.

- **HydroTrend:**
  - Coded up HydroTrend in IRF (Initialize, Run Finalize) format
  - Provided HydroTrend support to Phaedra Upton, Kerry McCarney and Jon Pelletier.

- **ArcGIS:**
  ESRI license manager version 8.x & 9.x are migrated to river.colorado.edu.

- **Graduate and undergraduate modeling projects completed under (co-) supervision of CSDMS Facility Staff:**
  - Nora Matell, University of Colorado, Boulder. "Shoreline erosion and thermal impact of thaw lakes in a warming landscape, Arctic Coastal Plain, Alaska". Msc thesis.
  - Dan McGrath, University of Colorado, Boulder. April 2009. "Sediment Plumes in Sondre Stromfjord, Greenland as a proxy for runoff from the Greenland Ice Sheet". Msc thesis.
  - Cordelia Holmes, University of Colorado, Boulder. March 2009. "Focused Temporal and Spatial Study on Sea Ice Location in the Beaufort Sea, Alaska, and its Role in Coastal Erosion". Honors Bsc thesis.

Appendix 1: Recommendations for Modeling Land-Surface Processes: A Report of the Community Surface Dynamics Modeling System (CSDMS) Terrestrial Working Group Winter 2009 Meeting

Report prepared on behalf of the Terrestrial Working Group[1] by … (list of contributing authors)

July 2009

1. Introduction

Developing integrated models of earth-surface dynamics across a wide range of scales represents an exciting challenge and opportunity for the research community. This document summarizes the deliberations and recommendations of the second annual meeting of the CSDMS Terrestrial Working Group (TWG). The meeting was held in Boulder, Colorado, in February 2009, and was attended by about two dozen participants. One of the main goals of the meeting was to develop a set of guidelines and recommendations in three areas:

- Reviewing current state of the art with respect modeling terrestrial environments, and highlighting knowledge gaps and research needs. This includes compiling an inventory of basic knowledge, existing computer models, and knowledge/model gaps, as well as identifying essential components of a first-generation model.
- Developing criteria for proof-of-concept applications, identifying specific applications that are of high priority to the community, and analyzing key requirements for model-data comparison.
- Identifying issues, needs, risks, and opportunities pertaining to technical aspects of modeling and the development of a comprehensive model-component repository.

This report is accordingly divided into three sections that cover each of the above items. A summary of recommendations can be found in the final section of this report.

2. Knowledge Gaps and Research Needs

2.1 The Challenge

Solving major problems in Earth surface processes requires understanding coupled systems. This section begins to address the question of the state of the discipline: how close are we to realizing this goal? The fact that CSDMS has been envisaged not as a single "super-model" but rather as a framework means that there is flexibility in how we represent different processes, and at different scales. However, it also requires the community to make decisions about how to prioritize efforts and to identify key knowledge gaps.

2.2 A framework for identifying necessary processes and evaluating our ability to model them ("scoping")

An Earth system can be thought of as consisting of a set of "boxes" that represent different subsystems (such as climate, ecosystems, and tectonics), with fluxes of quantities such as mass and energy between them (Figure 1). Other geoscience fields have "exploded" their boxes, assessing and organizing the community's knowledge of constituent processes. Examples include the Computational Infrastructure for Geodynamics (CIG) and the Community Climate System Model (CCSM). The surface-process community (geomorphology, sedimentology, and related sub-disciplines) is now in the process of "exploding the box" and examining the state of the contents. Some key elements in the domain of CSDMS Terrestrial Working Group include:

- Pathways of mass (solid or solute) from source, via transport, to sink.
- Continental focus.
- Source = bedrock weathering and erosion.

[1] A list of members of the Terrestrial Working Group can be found on the CSDMS web site.

- Sink = delivery to a reservoir where storage occurs for a time long with respect to the timescale for system evolution, such as: continental shelf/ocean, sedimentary basins, and continental water bodies.
- Transport = any intermediate process that causes mass flux
- Note that sign of net transport (i.e., flux divergence) can create local source or sink.

Thus, the “domain” of terrestrial processes includes all major processes responsible for mass transport across the earth’s land surface.

The source-to-sink path that one draws, and the list of processes that must be included, depends on the question being posed. As an example, consider the transport path that would apply to one of the CSDMS Grand Challenges: “tracking surface dynamics through glacial cycles.” A more specific science question within this theme is: How does a fluvial system respond to changes in sediment supply, sea level, and other factors during rapid glacial terminations like those that occurred in the Pleistocene? A schematic illustration of the system (Figure 1) helps to identify the necessary components of such a model. The diagram illustrates, in one dimension, a transport pathway for sediments and solutes from generation in uplands (upper left) to a coastline (lower right). Processes include weathering (in the sense of both chemical reactions and rock disintegration by mechanical and chemical processes), hillslope and fluvial transport, grain-size distribution and evolution, hydrologic forcing and feedbacks, tectonic forcing, and biological influences.

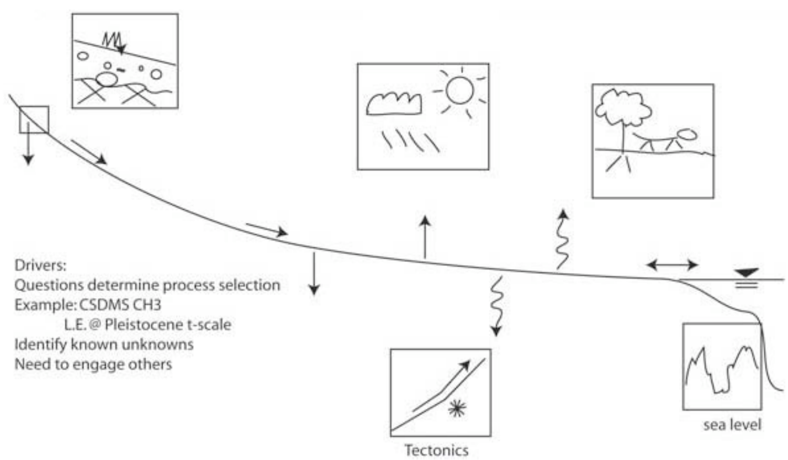


Figure 1: Schematic illustration of processes that must be considered in a model of surface dynamics across glacial-interglacial cycles.

These represent the only classes of mechanisms we need to worry about in this particular “box.” Limiting the problem to a subset of processes is not an attempt to trivialize or oversimplify the problem, but rather represents the top layer of a top-down approach. There have of course been many quantitative efforts to understand the details of some of the arrows and sub-arrows in Figure 1. This exercise is a critical part of solving the problem: which terms can we neglect, which can we parameterize? Sample dilemmas include: How deeply do we need to understand weathering? Do we need to model microbial metabolism, or is a soil production rate constant sufficient? Are chemical mass fluxes sufficiently small that they can be neglected? Addressing these questions also helps us identify the gaps in our knowledge: terms that cannot be crossed out, but for which we lack well-developed theory or methods.

To fully evaluate the state of the art for a given process or set of processes, one would “explode an arrow” (or a box), and address the following:

- List the processes that fall within this category

- Evaluate “readiness” of each process component, or at least a subset that spans the full range of our level of understanding
    - Theory
    - Field or experimental validation
- Determine whether there are established methods for modeling the process
- Inventory available codes

Table 1 provides a preliminary identification and ranking of a set of important geomorphic erosion/transport processes. The table is organized around several criteria for each process or phenomenon: the degree to which a quantitative framework has been discovered, the extent of calibration or validation efforts, the human effort being devoted to it, and the degree to which the process has been expressed numerically via computer code. For each of these attributes, processes may be classified on a five-point scale, ranging from “in the dark” to “enlightenment” (Table 1). Examples of processes or phenomena for which the state of knowledge is “in the dark” or “faint flame” include the dynamics of bedrock-dominated landscapes, controls on grain-size production and evolution, incision and land sculpture by debris flows, ice erosion, deep-seated landsliding, and chemical denudation. By contrast, processes and phenomena in the “sunshine” to “enlightenment” categories include catchment-scale groundwater flow, small-scale Darcy flow, free-surface and open-channel flow, suspended-sediment transport (when the bed texture is known), annual to decadal ice dynamics, and lithosphere flexure. In all of these cases, one can find existing codes that solve a generally agreed-upon set of equations. A great many processes, however, lie between these extremes. There may be, for example, multiple competing erosion/transport laws (as in the case of bedrock river erosion), limited but growing data sets, and a significant ongoing research effort.

Table 1 illustrates the tremendous breadth of terrestrial processes, as well as some of the significant challenges ahead. In order to meet these challenges, it is essential that members of the community share their expertise and contribute their understanding and models.

	In the dark	**Faint flame**	**Lighthouse**	**Sunshine**	**Enlightenment**
Quantitative framework	None	A few straw-man expressions based on intuition	Multiple competing hypotheses based on observations and measurements	Widely accepted, mechanistic theory has emerged	Solved problem. Universally accepted physical principles
Calibration/validation efforts	None	Initial efforts to calibrate expressions are underway, but no real tests have been performed.	Several calibration exercises have been performed. Initial efforts to test predictions against field or laboratory data are underway.	Parameters have been calibrated for many scenarios. Predictions have been tested against multiple laboratory and field measurements by independent groups.	Moot, except for efforts to measure parameter values for specific sites
Human effort	We know it’s important, but almost nobody is working on it	A handful of groups are working on it	Every other group is working on it	A few groups are working to refine the details	No need to work on it. Everyone uses it.
Existing code	None	A few in-house efforts	Many different in-house versions, a few longer-term development efforts, some distributed packages	Community models, widely available commercial packages	Shipped with textbooks
Examples [and names of existing codes/developers, if applicable]	> hillslope grain size production & comminution > large-scale development of bedrock landscapes	> debris flow incision and routing > landscape-scale glacial erosion > long-term overland flow erosion > deep-seated landsliding > chemical denudation	> bedload sediment transport [Parker, Wilcock, Cui] > bedrock river incision > structural development of orogens > soil production > local (cm to m-scale) glacial erosion > river meandering [Tucker,	> Catchment-scale groundwater flow [MODFLOW] > free-surface/open-channel flow [Delft3D, MD-SWMS] > suspended sediment transport	> Lithospheric flexure > small-scale (meters) Darcy flow

		> long-term ice sheet dynamics	Lancaster, others] > hydraulic geometry: fluvial channel width and depth > shallow landsliding [SHALSTAB] > debris flow dynamics > hillslope sediment transport > fluvial sorting and patch dynamics > delta formation	> short-term (years) ice dynamics	

3. Applications of Terrestrial CSDMS models

The processes and feedbacks acting on Earth's surface are richly varied and depend on complex initial conditions and forcing mechanisms. A key goal of CSDMS is to facilitate the development of coupled models that allow previously uncoupled process domains to be linked so that the complex, nonlinear behavior of the Earth surface system can be better understood and predicted. The goal of this section is two-fold: to develop criteria for proof-of-concept problems that illustrate the power of coupled model development and to identify specific proof-of-concept applications that are of high priority to the terrestrial geomorphic community. Our focus is primarily on what scientific questions can be tackled in the short term, which we consider to be a 6-12 month timeframe, that will both advance our understanding of a portion of the earth surface system, demonstrate that CSDMS can produce results, and provide a template for future development of the CSDMS effort.

Any plan must include a strategy for engaging as large a portion of the terrestrial geomorphic community as possible. To this end, we believe it is important to identify problems that draw from a range of existing component models rather than choosing one or two particular component models. Model intercomparison can be a useful means of engaging the broader geomorphic modeling community in these proof-of-concept application efforts. The primary goal of model intercomparison is not necessarily to provide a definitive answer to a scientific question, but, rather, to focus many developers on a focused scientific problem or set of problems in order to explore what techniques work best, solve the inevitable technical challenges that will arise when coupling component models, and facilitate collaboration, especially among scientists who focus on different process domains. Model intercomparison is also essential for validating individual component models.

The proof-of-concept problems and associated coupled models developed by the terrestrial working group within CSDMS should, at a minimum, meet the following criteria:

- The model should integrate at least two separate process domains (components) of the Earth surface system.
- The model should address an issue of widespread interest within the CSDMS community and society as a whole.
- The problem should be well-posed from the standpoint of initial and boundary conditions, and should have a wide range of accessible data with which to verify model results.

In addition, the ideal problems will possess natural lines of future inquiry, some of which may not be feasible at present, but that hold significant promise for new insight with additional data and/or model development. Problems of this sort generally fall into one of two categories – those problems that represent a process-domain transition within the Earth surface community (e.g., hillslope-channel coupling) and those that reach across traditional disciplinary boundaries with other communities. Examples of each are given below, but, in general, the working group discussions highlighted the fact that many of the exciting problems in our discipline lay at the interface between Earth's surface and atmospheric dynamics, lithospheric deformation, and ecosystem behavior. We suggest that the CDSMS Terrestrial working group should focus on two proof-of-concept efforts over the next 6 to 12 months. One of these would ideally focus on relatively short-term (annual to decadal) interactions between process domains, while the other should focus on landscape evolution over long (geologic) timescales and involve the coupling of a landform evolution model with a state-of-the-art atmospheric, lithospheric, or ecological model.

3.1 Short-time-scale problem

The landscape response to intense wildfires poses a societally important, data-rich proof-of-concept problem for a CSDMS model. Post-fire erosion involves complex changes to the hydrological and erosional properties of hillslopes. The hillslope response often delivers a pulse of sediment to downstream reaches that leads to a fill-and-cut cycle and which has strong negative impact on riparian ecosystems and human infrastructure. Modeling this landscape response would require linkage of modules that include:

- Climatic forcing from actual or synthetic data sets
- Runoff/infiltration modeling reflecting the evolving state of regolith and vegetation.
- Regolith detachment by runoff reflecting the evolving state of regolith and vegetation – amount and grain size distribution.
- A model of vegetation recovery (perhaps empirical, but likely highly parameterized).
- Coupling of erosion and vegetation history to regolith state, including armoring, bioturbation, changes in critical shear stress, etc., as appropriate.
- Modules for extreme events, mass movements like landslides and debris flows.
- Routing of sediment through the channel system, including multiple grain sizes, fan and terrace development and incision, and timeline of delivery of sediment to reservoirs (e.g. Gabet, 2003).

The strong perturbation, rapid evolution, and highly coupled nature of the hillslope-channel system offer both opportunity and challenge to model development. Initial models would not necessarily involve full coupling of models of vegetation growth and recovery with physical process models, but the opportunity is there for future development of this sort. An important aspect of such a model will be to explore the sensitivity of the response time of the system as a whole to the disturbance imposed by such an event, and how this depends upon the response times of each of its components. At some level (to be determined by the time and length scale of the model) this model requires that the geomorphic modeling community reach out to the ecological modeling community.

We suggest that data from fires and their aftermath in Southern California over the last 50 years may be employed. This includes sedimentation rate in manmade sediment basins, debris flow generation, etc. (e.g. Lave and Burbank, 2004). Large fires in forested or chaparral landscapes result in significant short-term hazards from increased sediment yield, more frequent and larger discharges from a given precipitation event, and hillslope instability as landslides/debris flows. In some settings, such events may comprise the majority of sediment input to the fluvial system and dominate the landscape morphology. Large-scale, post-event data collections efforts in places such as the San Gabriel Mountains in California and after the 1996 and 2002 forest fires in the Colorado Front Range form reference databases for model development and validation. Data may include:

- Vegetation changes through time
- Documentation of hillslope channeling and soil loss
- Analysis of regolith properties in affected and unaffected comparative sites
- Movement of the sediment wave through the fluvial system, including volumes and grain size distribution
- Deposition in reservoirs, including grain size distribution
- High-resolution topography from aerial photography, LiDAR, or TLS, preferably as a time-lapse.
- Timelines of sediment yield, vegetation recovery, routing of the sediment pulse
- Precipitation history from local or nearby weather stations

3.2 Long-time-scale problem

Some of the most exciting problems in geomorphology involve the history of large-scale landscapes over millions to tens of millions of years. Tectonic geomorphology is informing our understanding of the tectonic history of mountain belts, and there is a growing appreciation that mountain belts can incite complex feedbacks between uplift, erosion, and climate change at a wide range of spatial and temporal scales. To better understand these feedbacks, it is essential to develop models that include the geophysical and atmospheric processes involved in the evolution of landscapes. At the scale of a mountain range, it is individual faults whose slip generates a rock-uplift pattern on which the geomorphic processes act. Faults redistribute mass in the upper crust and therefore incite flexural deformation of the lithosphere. In addition, on long time scales the growth of significant topography affects the flow of the atmosphere and the resulting distribution and phase of precipitation. Such models therefore require linkage of modules that include:

- Elastic dislocation along prescribed faults
- Flexural accommodation of changing load
- Viscous deformation of the substrate that sets a time scale for flexural-isostatic adjustment
- Orographic precipitation
- Hydrology
- Hillslope processes
- Fluvial bedrock incision

The development of coupled landscape-lithosphere and/or landscape-atmosphere models encourages a connection to ongoing efforts to develop such models outside of CSDMS, including the Computational Infrastructure for Geodynamics (CIG) efforts. Specific field areas where these models could be focused include the Sierra Nevada and areas of the Basin and Range or the Himalayas. In these areas, a wealth of data currently exists to calibrate and validate models including:

- Topography
- Seismically constrained stratigraphy
- Thermochronology, radioisotope and cosmogenic isotope dating
- Viscous times scale from deformation of Bonneville shorelines (e.g. Bills et al., 1994)
- Closed basin in the Great Basin allows closure of sediment budget
- Knowledge of the range of climates in the Quaternary (from Last Glacial Maximum versus present water budgets in pluvial lakes, glaciers)

3.3 Model Calibration, Validation, and Uncertainty Estimation

The engagement of the terrestrial community in model intercomparison projects provides a useful opportunity to advance the techniques we use for calibrating and validating process-based numerical models in geomorphology. Currently, model calibration and validation is, to a large extent, a process of trial and error that does not take into account uncertainty in the input data and, hence, does not quantify uncertainties in model outputs. Ideally, the proof-of-principle applications that the terrestrial working group of CSDMS focuses on will involve the testing of new techniques that have been developed in the Earth science modeling communities for improved model calibration, validation, and uncertainty estimate. To take one example of these new techniques, Markov Chain Monte Carlo (MCMC) algorithms for parameter optimization and uncertainty estimation are "adaptive search" algorithms that mimic the processes of biological evolution (random mutations and fitness selection) in order to determine optimal parameter sets for complex, nonlinear systems with multiple types of output (e.g. discrete and continuous, point-based and spatially-distributed) (e.g. Vrugt et al., 2003). The uncertainties of "known" parameters are propagated through these algorithms to provide quantitative estimates of the uncertainty in the "unknown" or inferred parameters. The hydrology community has been successful in using of MCMC algorithms for inferring spatially and temporally distributed input data (e.g. hydrologic conductivity, rainfall intensity) given a hydrological model and observational data (e.g. station hydrographs). Now is an ideal time to improve the model inference protocols currently used by the geomorphic community and CSDMS is ideally suited to lead that effort. The newly acquired supercomputer at the CSDMS Integration Facility will be essential to this effort.

3.4 Linkage with Educational and Knowledge Transfer Working Group

It is important that the proof-of-principle projects developed in CSDMS be quickly disseminated in the form of animations, interactive Java-based simulations, and curriculum materials. The EKT working group has expertise in the development of these educational and outreach activities. Wei Luo, for example, has developed a Java-based landform evolution model, WILSIM, that teaches students about river incision and drainage basin self-organization. Wei's model, and the materials that support it, have reached hundreds of thousands of students worldwide. Proposals are currently in review to expand these activities, and the results of prototype CSDMS models should be distilled into animations, interactive inquiry-based learning modules, and curricular materials for use by undergraduate educators.

3.5 Longer-term Research Topics

Our recommendation for criteria for proof-of-concept problems and associated coupled models can be carried over to longer-term goals (i.e. not prioritized for the next 6-12 months, but for 2010-2012). The first criterion that models should integrate at least two separate process components of the Earth surface system, provides a number of key coupling problems that would yield new insights:

- glacial-fluvial transition (example: melt on the Greenland Ice Sheet propagated into the fluvial systems or retreating glaciers over a glacial cycle and its impact on the local valley morphology).
- ecology – land surface processes (for example, the role of vegetation interacting with weathering and erosion processes during landform evolution in temperate and humid landscapes)
- terrestrial-coastal transition (for example, the role of sea level changes on landform evolution in coastal regions)
- morphological transitions: can we combine meandering river models and braided river models to dynamically transition when controlling conditions change.

The second criterion is that the model should address an issue with widespread interest within the CSDMS community and society as a whole. A number of key challenges were posed:

1) predictions of changes in earth surface dynamics looking forward to 2050 and 2100 by coupling to CCM efforts
2) coupling of terrestrial-hydrological earth surface models to policy tools (e.g. floodplain risk mapping)

4. Computational Challenges and Needs

4.1 Mitigating Risk

One way to support the success of a complex effort like CSDMS is to envisage potential "failure modes": risks to the project that can be avoided if proper steps are taken. The Terrestrial Working Group identified a set of twelve potential risks, and highlighted ways to avoid them.

Risk 1: Poor Quality Control – Currently, the CSDMS model repository has a low threshold for participation: a developer only needs to request that his or her model be listed. CSDMS is not currently evaluating the quality of contributed models. This runs the risk that users may be disappointed in not finding the information they require about model suitability, past performance, etc. At one stage in the development, a quality-control "pyramid" had been envisioned, from donated, caveat-emptor software at the base to fully tested/validated code at the top. The implication at the time was that working groups would play an evaluative role, but at the meeting the practical limitations of such an approach were noted.

Several measures were recommended to address quality-control issues. Providing information on the frequency or number of downloads would give some indication of popularity to prospective users; while popularity does not necessarily correlate with quality, it does provide an indication that a particular code is in active use. Model contributors should also be encouraged to provide analytical test cases and/or unit tests (which are also useful for checking compiler dependency). These do not test the applicability of the code to any particular natural phenomenon or target problem, but they do demonstrate robustness of the numerical algorithms with regard to the underlying equation set. In addition, it is recommended that the web site include standard flags/symbols/icons that would indicate the degree to which a particular code is CSDMS-compliant, provides standard test cases, or provides actual field data for testing. It is also recommended that developers/contributors be encouraged to provide references to literature in which the model is applied, described, or tested. Finally, a user discussion forum for models is recommended, as this would promote sharing of information about a model as well as problems encountered, frequently asked questions, etc.

Risk 2: Poor Documentation – Any model can be used badly. The probably that a particular model, tool, or component will be used inappropriately is greatest when the documentation supporting it is weak or nonexistent. Currently, the standard model-submission form does ask for documentation. In addition, the OpenMI interface provides methods for exchanging meta-data among components, so to some extent this problem will be addressed by developers who implement OpenMI interfaces. Aside from these steps, the Working Group recommended adopting a "wait and see" approach to this risk.

Risk 3: The Complexity of CCA will Discourage Users and Developers – The Working Group acknowledged that the CCA tool-chain is indeed rather complex – challenging for computationally oriented geoscientists, and possibly daunting for others. The recommended solution is to shield users from the full CCA system by allowing most users to rely on a suitably modified version of the Ccaffeine graphical user interface, which is much simpler to work with than the complete CCA system. The full CCA tool-chain would still be available, but would only be necessary for certain high-level operations.

Risk 4: It will be difficult to transition from simply listing models to hosting/encouraging simulations – At present the CSDMS Models web site is primarily a listing service. The supercomputer is seen as something that will attract users. In addition, the possibility of a "build server" for download configurations is suggested.

Risk 5: CSDMS may make it difficult to do "offline" modeling work – To the extent that the key tools and models are centralized on computers hosted by the CSDMS Integration Facility, it may become more difficult for users to work "offline" on their own platforms. However, even if this were to prove true, it was not seen as necessarily a bad thing. Climate modeling has, for example, brought about a slight change in the mode in which climate scientists operate.

Risk 6: CSDMS models and tools will be mis-applied – This is particularly a risk when a "modeling environment" like Ccaffeine makes it possible for naïve users to connect incompatible models, leading to "garbage in, garbage out." In fact, this is a risk in science in general. The Working Group noted that there is little that can be done about this risk, apart from offering training and ensuring that documentation and bibliographies are readily available (as noted above).

Risk 7: CSDMS will become dependent on the success of outside initiatives and organizations – CSDMS is already adopting products and methods from projects such as OpenMI, CCA, and even Java, and in some cases this has slowed development (for example, waiting for critical bug fixes in CCA). This represents a tradeoff between risk and efficiency: the risk could be avoided by creating a new set of model interaction protocols and tools, but that in turn would bring its own risk in the form of increased development time. The recommended solution is to choose to rely only on projects that are well established and have solid support (like CCA and OpenMI) and to try as far as possible to become engaged with their personnel.

Risk 8: Coupling models and components will lead to problems in conservation of mass, momentum, and/or energy, especially with dissimilar grids – Interpolation methods can lead to information loss, particularly when interpolation is repeated. Several complementary solutions are recommended: (1) work on good re-mapping tools (or incorporate existing ones), (2) encourage use of models with similar grid structures, (3) incorporate parallel remapping tools (e.g., ESMF, MCT).

Risk 9: Overwhelming data volumes – There is potential for increased volumes of computer-generated data. There are a number of potential issues that can arise. When grids become very large, performance of some numerical algorithms can become very poor. In addition, large data sets involve increasingly large volumes of memory that must be addressed and accessed, and may involve reduced performance even beyond the limitations of a numerical algorithm simply due to frequent I/O operations. There are several potential solutions. Recent work in the GIS and computer science communities has led to I/O-efficient GIS algorithms, and similar approaches could be applied to common numerical algorithms. Partnering with these groups is recommended. In addition, the Working Group noted that there are special funding opportunities for petascale computing.

Risk 10: The community may be reluctant to transition to HPC – High-performance computing requires expertise that many geoscientists do not possess, and there is a risk that few in the community will feel motivated to make the necessary investment. Potential solutions include coding camps, demonstrations of "success stories," and strong technical support.

Risk 11: Traditional supercomputer-based HPC will be superceded by new technologies like cloud and GPU-computing – It is possible that a significant investment in traditional HPC will strike a dead end as scientific computing shifts toward cloud-based (e.g., Amazon, EC2, Eucalyptus) and graphical-processor-based computing. The Working Group noted that it is notoriously difficult to predict the direction that technological innovations will take. At present, supercomputer and cluster-based computing have a solid foundation in the sciences. The best way to mitigate this risk therefore is simply to keep an eye on developments and be prepared to adapt.

Risk 12: The CSDMS/CCA communication layer is a black box that will be difficult for users to manage – Some commercial attempts at common, modular development environments have failed (e.g., Mozilla's object model; ESRI). Recommendations to avoid problems arising from a complicated "black box" include: requesting different degrees of diagnostic output (for debugging/development), encouraging use of transparent code (e.g., option to write netCDF output), working top-down (e.g., initially wrapping an entire model and only later breaking into components), and inter-model comparison testing. It was noted that the target audience is reasonably sophisticated in terms of scientific model development. One recommendation is to provide support in the form of a support@csdms.edu email hotline.

4.2 General Recommendations on Modeling and Software Development Issues

Several additional ideas and recommendations emerged from the Working Group's deliberations on the topic of modeling and software development:

3) A pragmatic approach is to work top-down: begin by wrapping ("RTF'ing") whole models, and split as/when needed.
4) Be on the lookout for code duplication
5) Encourage swapping of modules as cross-checks of models (a form of inter-model comparison)
6) Provide "support@csdms.edu"
7) In prioritizing models, begin with an overview of main processes; give modules usable names like "1d flow," "turbulence closure," etc.
8) Provide coding camps
9) Include "stick figure" cartoons in manuals/guides

4.3 Recommended Components and Toolkits

The Working Group noted that, in addition to process codes, there are many types of utility software that will be critical for some aspects of CSDMS. These include terrain-modeling tools that are common in GIS packages, for performing operations such as computation of slope, aspect, curvature, and calculation of watershed and drainage pathways. They also include a wide range of hydrologic and hydrodynamic modeling codes (for example, 2D shallow-water equation solvers). Ultimately such components should be HPC compatible. **Figure 2** illustrates some fundamental components.

CSDMS should transition over the next few years from being primarily focused on coupling models to providing a framework supporting model construction from the ground up, with basic pre-existing software components to handle common tasks such as terrain representation and stratigraphy.

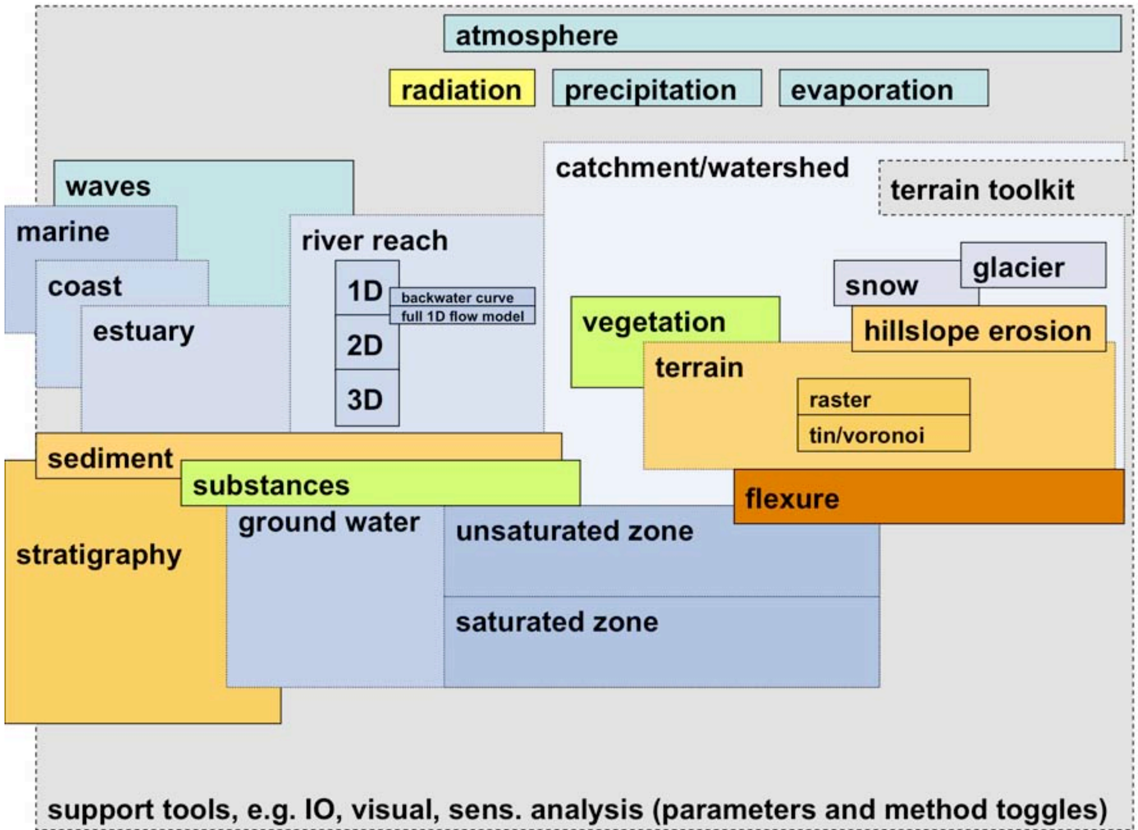


Figure 2: Schematic illustration of some common components.

4.4 Categories of Modules

Modeling Needs

The plug & play components that ultimately will make up the CSDMS library will be a mix of complete models, tools and individual algorithms. There are many ways to categorize this hierarchal and overlapping mix of components, but the system advocated here reflects the typical categories anticipated for terrestrial modeling needs. In order to highlight model development needs, a break-out group from the Terrestrial Working Group February 2009 Meeting highlighted that a more thorough inventory of what available open-source components already exist is needed. To effectively build that inventory, it was suggested that a more comprehensive list of open-source tools could be established. One of the key oversights of the existing ‘model lists’ are that the meta-data necessary to determine OpenMI , CCA and CSDMS compliance (or potential for compliance) is not explicitly collected. **From this inventory, the sub-group hopes to be able to identify where effort should be invested over the next year to build a basic core library of components for building terrestrial models.**

List of Categories for Modules

There is a list of basic attributes for all modules that should establish basic meta-data for the code and ultimately be used to determine compatibility and interoperability. Many of these attributes are already well defined through the CSDMS 'Model Questionnaire': http://csdms.colorado.edu/wiki/Models_questionnaire The attribute categories include: 1) Personal Information on Modeler, 2) Model Identity, 3) Technical Information, 4) Input/ Output Description, 5) Process Description, 6) Model Testing, 7) User Groups, 8) Documentation, 9) Additional Comments. This questionnaire is currently targeted at just the authors of the code. Despite the richness of information solicited, the lists are currently only queried by a single field (model domain). **Here we would like to extend that attribute list to (a) serve as a more comprehensive survey and inventory of what is available and exists (not necessarily just entered by the developer); and (b) allow users and CSDMS integration personnel to be able to perform more sophisticated queries of a more comprehensive list to aid in model integration and helping highlight most pressing community needs.** The questionnaire can easily be modified to include these additional attributes in the module database (goal a). However, the Wiki may not be the best web-tool available for allowing users to query the database.

As a matter of semantics, the existing questionnaire allows users to 'contribute their model, tools or algorithms', but solicits these contributions under the banner of 'model'. It might be clearer and more accurate to call this the module or component questionnaire, wherein a complete model, tool or algorithm can still be contributed. Also, there are many tools and libraries potentially available that may be appropriate for use in CSDMS terrestrial models, but that are not authored by members of the CSDMS community. As such, the questionnaire needs to allow members of the CSDMS community to upload components to the database that are authored by someone else (provided they are open-source). So that the process of filling out the questionnaire is educational, we strongly suggest hyperlinking any possible terms or names in the survey (with pop-up windows) to a website with more information on that term (e.g. clicking on "CCA" could provide a link to the Common Component Architecture website).

As the attribute categories already defined in the 'Model Questionnaire' are already a logical starting point, this document and suggested changes and additions are organized around the nine existing categories. The subsections that follow make specific recommendations for the modification and expansion of these categories. It is intended that this will provide a clear workflow for modifying the form, database and how that information is accessed via the CSDMS website. For each category, a screen shot of the existing 'Model Questionnaire' is provided as a starting point. The key recommendations are bolded in each section.

Section 1 is very logical for components being submitted by the code author or member of the development team. However, for those components not actually submitted by the author, the form makes no provision. **We suggest adding field(s) to list the name and contact details of the actual individual submitting the information.** For user friendliness, a check box can be provided, which 'Use Same Information as Primary Model Contact' to allow author contributors to avoid entering information twice (when checked it grays out the 'Submitted by' fields. Sub-headings should clearly distinguish between the information solicited that describes the personal information of those involved in the module itself, from someone simply recommending a module. Given these changes, it might make sense to change the section heading from 'Personal Information Modeler' to simply 'Contact Details'.

The model identity is where we propose the most comprehensive additions. These additions are primarily specific to the Terrestrial and Hydrology model domains, but may serve as a template for similar changes by the other working groups. First, the **following changes are suggested to the existing fields**:

- Change 'Model Identity' section title to 'Module Identity'
- Change 'Model Name' to 'Module Name'
- Change 'Type' options from a) model, b) tool, c) single, and d) modular (not clear what these all are) to: a) Model (stand-alone), b) Pre-Processing Software, c) Post-Processing Software, d) Project

Management tools, d) Visualization Software, e) Analysis & Generic Algorithm Tools, f) Process Subroutine/Function, g) other.

- Include some notes as to what the types are defined by
- Change 'model description' to 'module description'.

Personal Information on Model

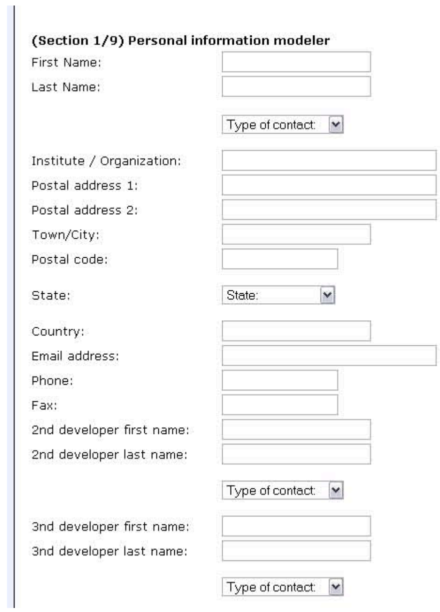
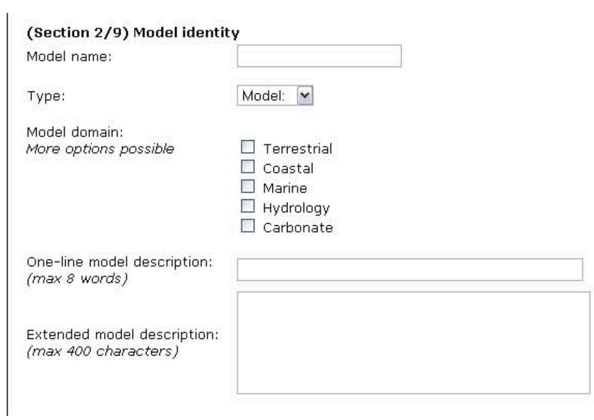

(Section 1/9) Personal information modeler
First Name:
Last Name:
Type of contact:
Institute / Organization:
Postal address 1:
Postal address 2:
Town/City:
Postal code:
State: State:
Country:
Email address:
Phone:
Fax:
2nd developer first name:
2nd developer last name:
Type of contact:
3nd developer first name:
3nd developer last name:
Type of contact:

Figure 1 – Existing Section 1 Fields

Model Identity


(Section 2/9) Model identity
Model name:
Type: Model:
Model domain:
More options possible
- ☐ Terrestrial
- ☐ Coastal
- ☐ Marine
- ☐ Hydrology
- ☐ Carbonate

One-line model description:
(max 8 words)
Extended model description:
(max 400 characters)

Figure 2 – Existing Section 2 Fields

Based on the user selections for module domain and type, a different set of metadata categories should be provided.

Generic Fields to Be Added

A variety of generic fields could be added to this section to help distinguish between module contributions of any type. These include spatial scale, spatial dimensions and temporal scale. These are described in the following sub-sections.

Spatial Scale & dimensions

Under spatial scale, spatial extent, resolution and dimensions need to be defined.

For a check-box field 'Spatial Extent' of module, the following options might apply (admittedly fluvio-centric) (note: multiple categories allowed):

- Global
- Continental (order 1,000 km)
- Regional-Scale (order 100 km)
- Landscape-Scale (order 10 km)
- Watershed-Scale (order 1 km)
- Reach-Scale (order 100m)
- Patch-Scale (order 1-10m)
- Grain-Scale (order 0.00001 to 1m)
- Point-Based

Check box field of 'spatial dimensions' of module:

- 1D (e.g. profiles)
- 1.5D (e.g. 2D projections extracted from 1D profiles)
- 2D (e.g. a DEM grid with one value of z for every x-y location)
- 3D (e.g. multiple z values possible for every x-y location)

Check box field of 'spatial resolution' of module, or fill-in text box with "typical computational element size."

Temporal Scale

The following temporal fields need to be defined:

€ A checkbox filed for 'Temporally Dynamic Model?', with options a) Steady-State, b) Dynamic, c) Time evolving

€ If 'Temporal Dynamic Model' is true,

  - a text field for 'Temporal Resolution (i.e. range of possible timesteps)
  - a radio button for 'Time Step type' – Fixed, or Variable
  - a text field for Temporal Extent (i.e. range of possible simulated model durations)

Fields to be added based on module domain

Based on whether the user filling out the questionnaire selects terrestrial, coastal, marine, hydrology or carbonate, a different selection of 'process algorithms' may be appropriate to display. For this document, we only address those that might be appropriate to Terrestrial or Hydrology (there is likely to be some overlap). The other working groups may wish to undertake a similar exercise.

Fields to be added based on module type

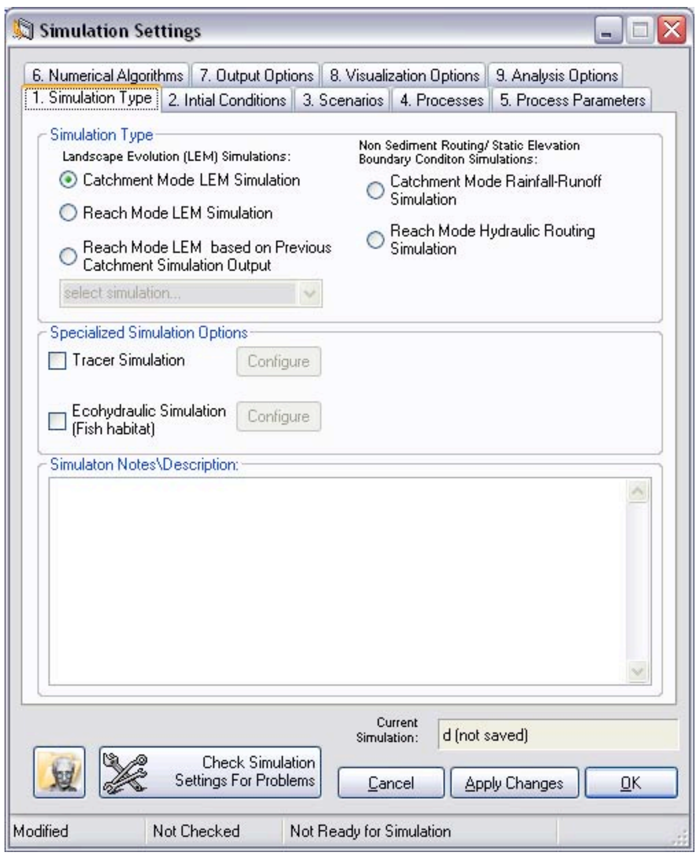
This is one of the most critical fields collected for determining the utility of the submitted module. The next eight subsections, describe fields that should be added to discriminate common attributes of those specific tools.

Model (stand-alone)

From a terrestrial perspective, a model types field should be added with a check-box selection provided from the following primary fields:

- Landscape Evolution Model
- River channel morphology model
- Morphodynamic Model
- Soil-erosion Model
- Eolian Model
- Hillslope process model
- Hydrologic Model
- Hydraulic Model
- Groundwater Model
- Other _________

It should be a checkbox selection, as some models (e.g. below) are capable of running in multiple modes.

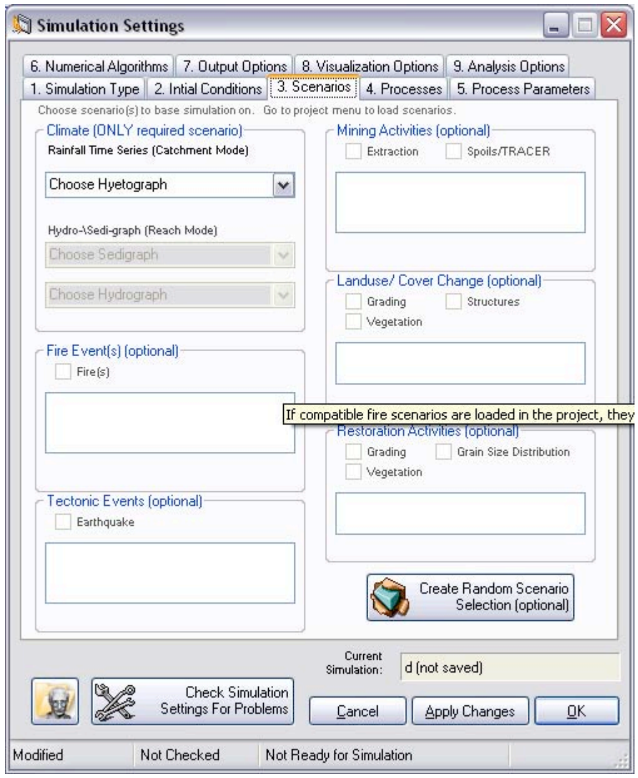


There might be an additional checkbox field called 'model style' with choices of:

- Spatially-Distributed (Raster-Based)
- Spatially-Distributed (TIN-Based)
- Spatially-Distributed (Unstructured Grid)
- Spatially-Distributed (Agent-Based)
- Lumped
- Schematic

Pre-Processing Software

Most dynamic terrestrial models have some sort of scenario drivers. For hydrologic models, this is a hyetograph, for hydraulic models, a hydrograph. Some of these scenarios may be based on continuous time-series data (e.g. rainfall and streamflow), whereas others may be based on discrete events (e.g. earthquakes, fires, etc.). For post-diction modeling simulations these may be based off actual data, but for many post-diction and prediction simulations these may be entirely synthetically produced scenarios (e.g. IPCC climate change scenarios). There are generic tools for preparing such scenarios, which may be usefully submitted as modules in CSDMS. A screen shot from ooCAESAR below illustrates these concepts.



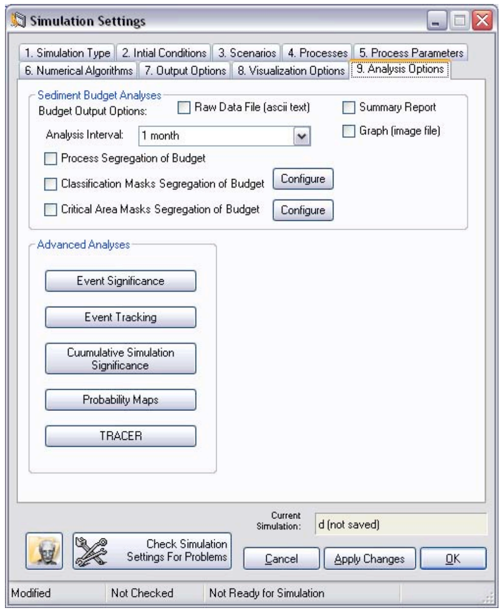
It may make sense to define the following fields for Pre-Processing Software for scenarios (allowing "both" as a possibility):

Scenario-Type: a) discrete (events), b) continuous

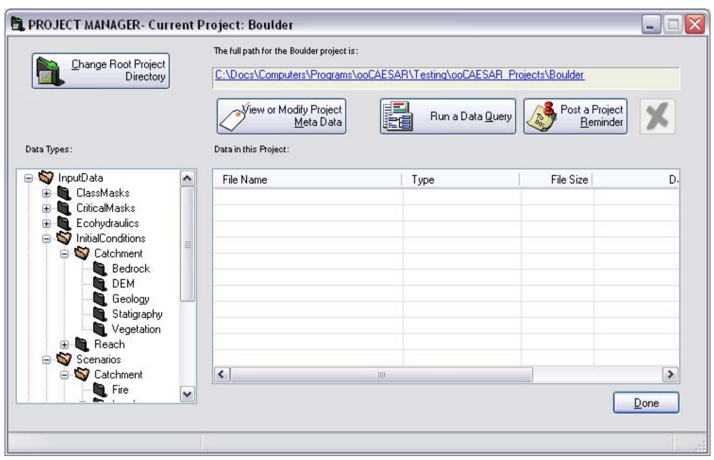
Other Pre-Processing Software fields might include:

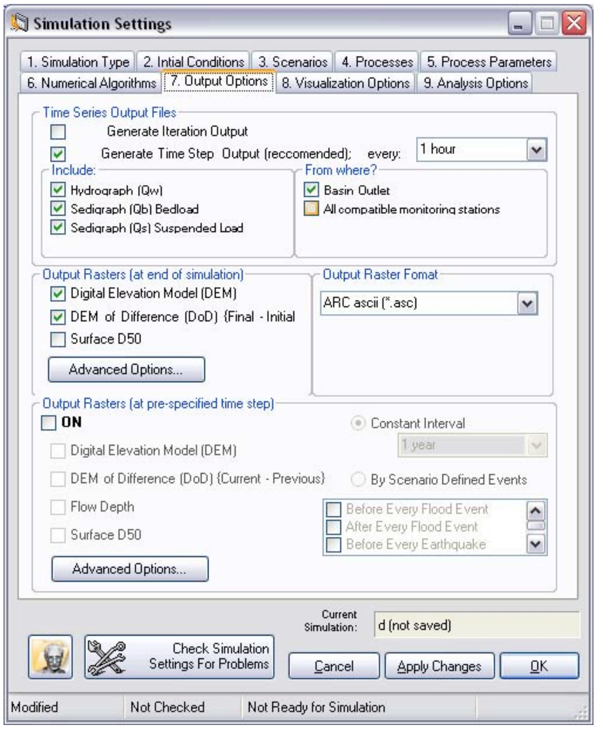
- Pre-Processor Type: a) Scenario Preparation, b) Data Conversion, c) Parameter estimation, d) Grid Construction, e) Boundary Condition

Post-Processing Software

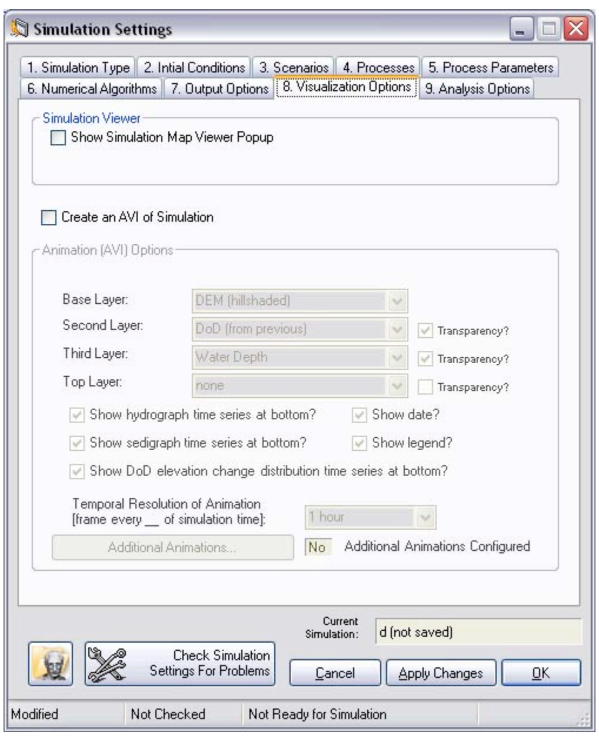


Project Management tools





Visualization Software



Analysis & Generic Algorithm Tools

Raster Based Analyses

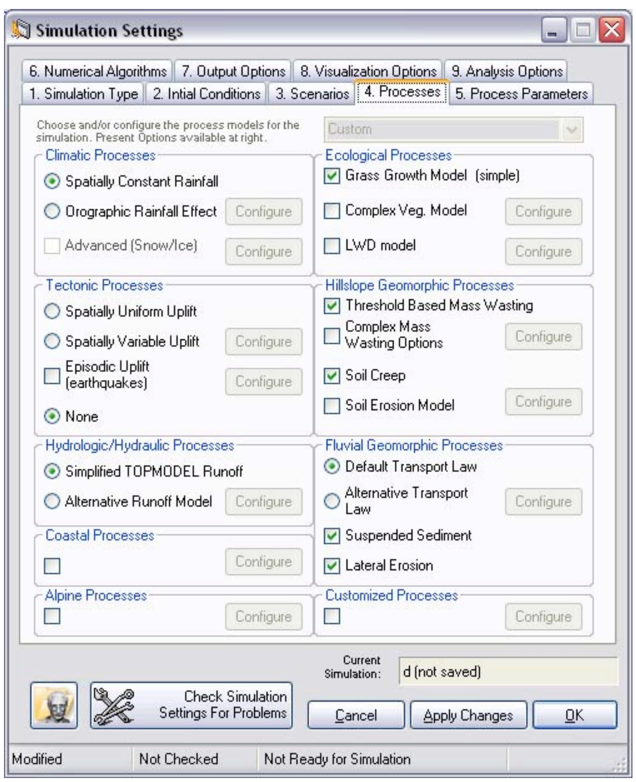
Vector Based Analyses

Numerical Solvers

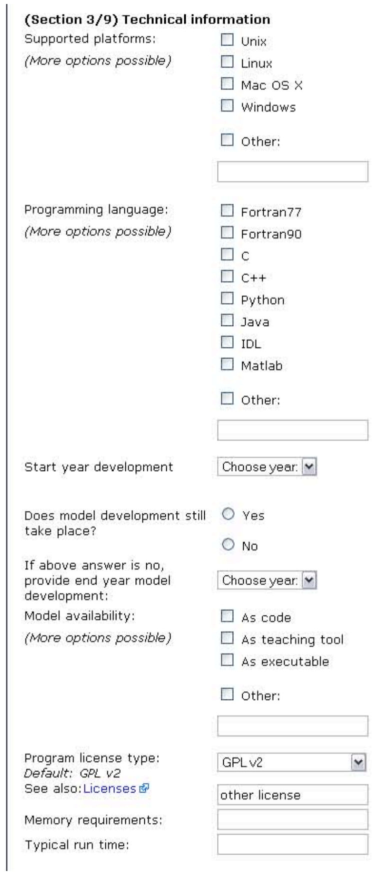
Process Representation

A field for Process Representation Type(s):

- Aeolian
- Hillslope
- Hydrologic
- Rainfall
- Runoff
- Fluvial
- Landsliding
- Soil creep
- Other hillslope processes
- Tectonics
- Ecological
- Climatic
- Glacial
- Soil production / rock weathering
- Geochemistry / solute flux
- Dissolution / karst



Technical Information



(Section 3/9) Technical information

Supported platforms: *(More options possible)*
- ☐ Unix
- ☐ Linux
- ☐ Mac OS X
- ☐ Windows
- ☐ Other: [ ]

Programming language: *(More options possible)*
- ☐ Fortran77
- ☐ Fortran90
- ☐ C
- ☐ C++
- ☐ Python
- ☐ Java
- ☐ IDL
- ☐ Matlab
- ☐ Other: [ ]

Start year development: [Choose year]

Does model development still take place?
- ○ Yes
- ○ No

If above answer is no, provide end year model development: [Choose year]

Model availability: *(More options possible)*
- ☐ As code
- ☐ As teaching tool
- ☐ As executable
- ☐ Other: [ ]

Program license type: *Default: GPL v2* See also: Licenses [GPL v2] [other license]

Memory requirements: [ ]

Typical run time: [ ]

Figure 3 – Existing Section 3 Fields

This section is generally applicable to all modules. We suggest:

- Adding a checkbox field for 'Compiled Code is Distributed as': a) GUI, b) Web-Application, c) Command-Prompt Application, d) Library (e.g. DLL), e) script, f) other ________
- Adding Checkbox field for: 'Code optimized for:' a) Single Processor, b) Parallel Computing, c) High-throughput computing, d) High-Performance Computing
- Adding radio button field and text field (for notes) for 'OpenMI compliant' with options: a) Yes, b) No, but Planned, c) No, but possible, d) No, not possible
- Adding radio button field and text field (for notes) for 'CCA compliant' with options: a) Yes, b) No, but Planned, c) No, but possible, d) No, not possible
- Adding radio button field and text field (for notes) for 'Fully CSDMS compliant' with options: a) Yes, b) No, but Planned, c) No, but possible, d) No, not possible (somewhere the web site should explain what "Fully CSDMS compliant" entails)
- Adding radio button field and text field (for notes) for 'Is code already in "IRF" interface?' with options: a) Yes, b) No, but Planned, c) No, but possible, d) No, not possible
- Modifying the 'Typical Run Time' tool to include another fields for 'On what type of system' and 'For what type of tasks'.

Input/ Output Description

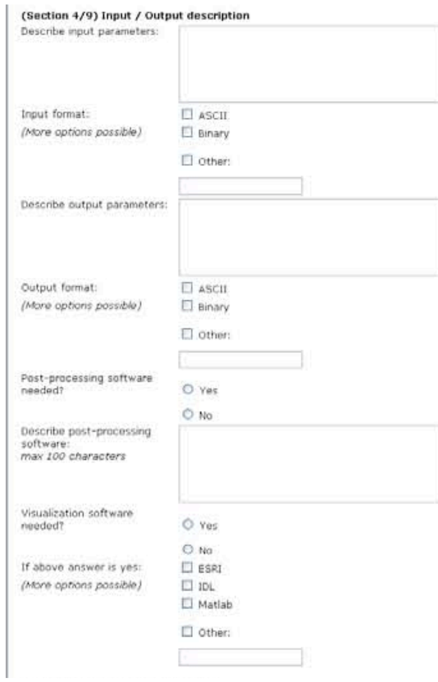
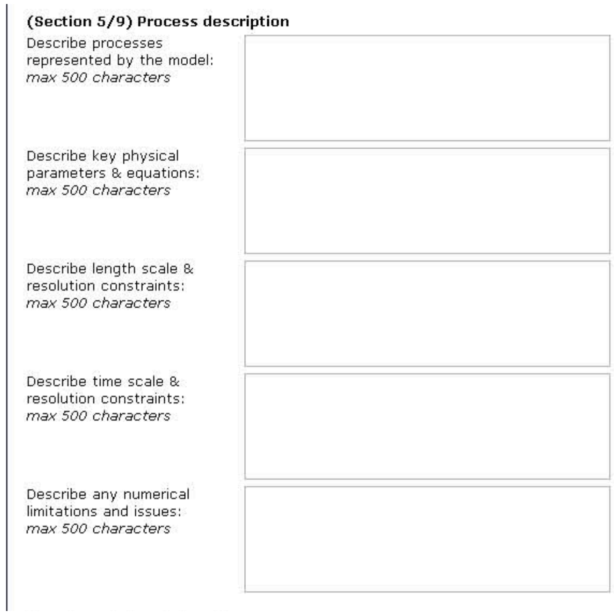

(Section 4/9) Input / Output description
Describe input parameters:
Input format: *(More options possible)* ☐ ASCII ☐ Binary ☐ Other:
Describe output parameters:
Output format: *(More options possible)* ☐ ASCII ☐ Binary ☐ Other:
Post-processing software needed? ○ Yes ○ No
Describe post-processing software: *max 100 characters*
Visualization software needed? ○ Yes ○ No
If above answer is yes: *(More options possible)* ☐ ESRI ☐ IDL ☐ Matlab ☐ Other:

Figure 4 – Existing Section 4 Fields

This section is sufficiently generic to still apply to all 'modules'. We suggest:

- Graying out options based on user selections (i.e. if 'no' chosen, don't make available the 'if yes, questions').
- Duplicate post-processing software section with a 'pre-processing software' selection.
- Consider how this section might be extended to include other data-type standards (e.g. XML, CUAHSI-HIS, etc.)
- Adding check-box field to post-processing that enables a drop-down list of all modules of type 'Post Processing Software' already submitted to CSDMS. Repeat for pre-processing and visualization software.

Process Description


(Section 5/9) Process description

Describe processes represented by the model: *max 500 characters*

Describe key physical parameters & equations: *max 500 characters*

Describe length scale & resolution constraints: *max 500 characters*

Describe time scale & resolution constraints: *max 500 characters*

Describe any numerical limitations and issues: *max 500 characters*

Figure 5 – Existing Section 5 Fields

Under the suggestions recommended in this document, these descriptions are only applicable to those individuals submitting a module of 'type' Model or Process Representation Algorithm. Moreover, the spatial temporal fields we feel are better placed under the 'model identity' section as they are fundamental to the module's identity and eventual compatibility and interoperability.

We suggest:

€ Only allowing users to fill in this section if they've selected a module type of model or process representation algorithm.

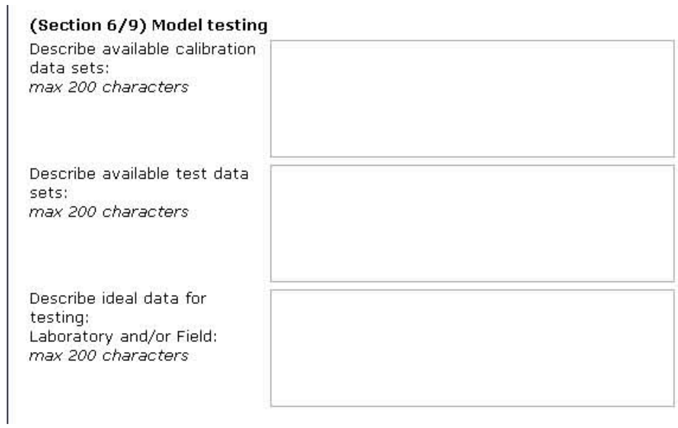
€ Changing Title to 'Process Representation'

€ Deleting spatio-temporal fields

€ Moving the last field 'numerical limitations and issues' to 'Model Testing'

€ Add a text and file field to allow the upload of an image of a flow-chart or diagram of a conceptual model the process representation is based on and a text field for its description.

Model Testing



(Section 6/9) Model testing

Describe available calibration data sets:
max 200 characters

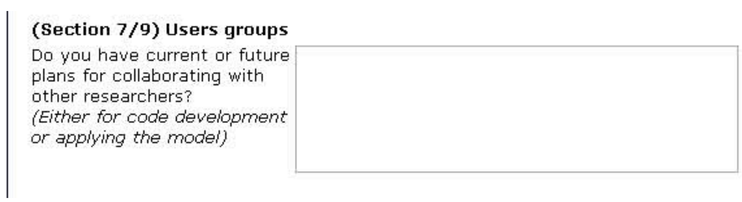
Describe available test data sets:
max 200 characters

Describe ideal data for testing:
Laboratory and/or Field:
max 200 characters

Figure 6 – Existing Section 6 Fields

Provide additional fields to provide a title and URL of places to acquire the 'available calibration data sets' described and 'test data sets'. Change name from 'Model testing' to 'Module Testing'.

User Groups



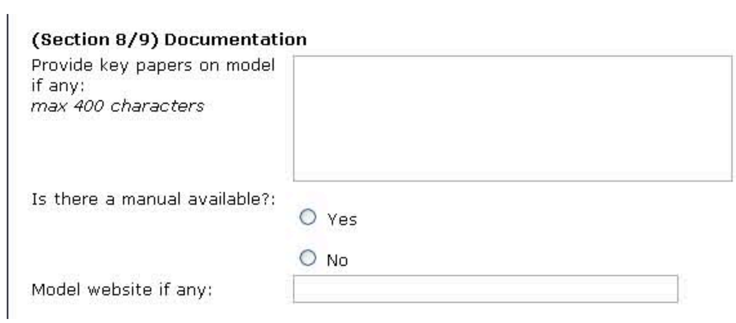
(Section 7/9) Users groups

Do you have current or future plans for collaborating with other researchers?
(Either for code development or applying the model)

Figure 7 – Existing Section 7 Fields

This is a good start. Provide a field for adding multiple names and corresponding website URLs (if applicable) of other collaborative research groups, working groups, organizations, projects, etc.

Documentation



(Section 8/9) Documentation

Provide key papers on model if any:
max 400 characters

Is there a manual available?:
Yes
No

Model website if any:

Figure 8 – Existing Section 8 Fields

For documentation, three additions are recommended.

- **Under the key papers on model field, add a button should be added to 'Add Documentation', which triggers a pop-up dialog form for entering the 'key papers' into consistent bibliographic fields.** The first prompt should be for paper type (e.g. Journal Article, Book Section, Report, etc.), which then determines which fields the user is prompted to enter. All journal entries should ask for a DOI or URL where the publication is available. This information can then be used not just to produce a consistently formatted bibliography within section 8 of the module page, but can also be used to add to complete bibliography lists which may be useful elsewhere in the CSDMS website (these could be avialble for website visitors to download as EndNote or BibTex libraries for example).

- **A button should be added under the 'manual' section to 'Add Manual' in a similar manner to the 'key papers' field above.** Again this should have the URL where this can be downloaded or a facility to upload the manual directly to CSDMS.

- **An additional field should be added for the URL to a 'Model Forum or Discussion Board (if applicable)'.**

Additional Comments

Figure 9 – Existing Section 9 Fields

It is always good to have a slop category for things that do not fit neatly into the eight other categories. No change is necessary here.

Summary

The way to implement the above suggestions is simple. First the 'Model Questionnaire' web form should be modified and the additional fields should be built into the database. Secondly, this break-out group will take an initial stab at populating the database based on our own knowledge of existing components. Third, we will solicit contributions from the rest of the terrestrial community and review those to make recommendations regarding model development priorities. Finally, a dynamic web-page (to be hosted on the CSDMS website) should be constructed which provides users the means to query the database in a variety of fashions needs to be built. There can still be several default lists (e.g. now there is one for each working group). The list will never be complete, but the web-form and dynamic web-page allow the list to grow indefinitely. No doubt, as the CSDMS effort matures and grows, new metadata categories may be deemed appropriate to add. As contributors to the list can always edit their entries, updating past entries will be feasible.

Secondarily, it is hoped that the above meta-data fields may become a basis for a generic CSDMS object-oriented class-structure for organizing these types of module component contributions into different libraries.

References Cited

Bills, B.G., D.R. Currey and G.A. Marshall, 1994, Viscosity estimates for the crust and upper mantle from patterns of lacustrine shoreline deformation in the Eastern Great Basin, *Journal of Geophysical Research*, *99*(B11), 22,059–22,086.

Gabet, E.J., 2003, Post-fire thin debris flows: Sediment transport and numerical. modeling, *Earth Surface Processes and Landforms*, vol. 28: 1341-1348

Lave, J., and Burbank, D., 2004, Denudation processes and rates in the Transverse Ranges, southern California: Erosional response of a transitional landscape to external and anthropogenic forcing: *Journal of Geophysical Research*, v. 109, F01006, doi: 10. 1029/2003JF000023.

Vrugt, J.A., H.V. Gupta, L.A. Bastidas, W. Bouten, and S. Sorooshian, 2003, Effective and efficient algorithm for multi-objective optimization of hydrologic models, *Water Resources Research*, 39 (8), art. no. 1214, doi:10.1029/2002WR001746.

Appendix 2: State of the Art of Modeling Coastal Processes: Report of the Community Surface Dynamics Modeling System (CSDMS) Coastal Working Group Winter 2009 Meeting

Note: This report builds on the material in the report from the Working Group's 2008 meeting (http://csdms.colorado.edu/mediawiki/images/MeetingRptCoastalWG.pdf).

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 that 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 that 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.

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Appendix 3: Morphodynamic Models: An Overview

Morphodynamic Models: An Overview

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ABSTRACT: Morphodynamic modeling involves fluid dynamics, geodynamics and ecodynamics with and without human interaction. Scales are immense, whether the dimensions are time or space. Morphodynamic models are ever increasing in the processes they incorporate, and in their dimensionality. Challenges facing the morphodynamic modeling community include: upscaling, process coupling, model coupling, data systems, high-performance computing, and model testing.

1 INTRODUCTION

The science of morphodynamics involves the response of bathymetry to fluid dynamical processes, and the interaction that each has on the other (Wright & Thom 1977). Since this early definition, the morphology portion of the term has correctly expanded to include topography or any earth-surface elevation change; the dynamics portion has expanded beyond fluid interactions to include ecodynamics and geodynamics, and even human dimensions. Morphodynamics in other scientific realms has other meanings; for example developmental morphodynamics involves the physical and geometrical principles that underlie biological processes during development. This article presents an overview of earth-surface morphodynamics from a modeler's perspective, with contributions from the scientific chairs of the Community Surface Dynamic Modeling System (csdms.colorado.edu/wiki/). The article is not a review of the literature, which is vast (Syvitski et al. 2007). Rather the paper focuses on general trends and areas for future developments. We begin with modeling aspects concerning the terrestrial environment, then move into coastal and estuarine environments, the open marine environment including carbonate morphodynamics, and end with a limited discussion on high performance computing in relationship to turbidity currents.

2 TERRESTRIAL MORPHODYNAMIC MODELS

2.1 *Introduction*

Morphodynamic processes and phenomena on land range vastly in scale, from eolian ripples to mountain chains. Terrestrial morphodynamic models have been developed to address a correspondingly wide range of research problems, from the shape of a sand dune to potential feedbacks between climate and tectonics in a continent-continent plate collision.

Terrestrial morphodynamic models share the common elements of describing evolving forms as a function of physical and/or chemical transport processes. Thus a critical challenge has been the formulation, testing, and refinement of mathematical functions that describe the rate of mass transport by a particular process, either from point-to-point in space (as in sand transport by a river) or from one form into another (as in the conversion of rock into sediment and solutes by erosion and weathering processes). The development of transport laws has been accompanied by the creation of time-evolving numerical models of landform evolution, which combine one or more transport laws with a continuity of mass framework to describe the morphodynamics that emerge from various combinations of processes, materials, and driving forces. Models of this type cover a broad range of time and space scales, but in nearly all cases the data necessary to test these models have lagged behind the models themselves. This is particularly true for longer-term models.

2.2 *Geomorphic Transport Laws*

Dietrich et al. (2003) define a geomorphic transport law as "a mathematical expression of mass flux or erosion caused by one or more processes acting over geomorphically significant spatial and temporal scales." Geomorphic transport laws include expressions for physical transport of mass from place to place, and expressions for transformation of mass between one form and another (such as the conversion of rock to soil or vice versa). A hallmark of geomorphic transport laws is that they describe time-integrated mass fluxes, rather than transport during a particular event such as an individual landslide or debris flow. When geomorphic transport laws are combined with a continuity of mass equation, the result is a mathematical expression of morphodynamic evolution (e.g. Kirkby 1971).

Geomorphic transport laws can be grouped into those that deal with (1) physical alteration of rock by weathering to form soils or regolith, produce solutes, and generate solutional landforms, (2) transport of sediment mass by primarily gravitational processes, (3) erosion and transport by moving liquid water, (4) transport and erosion by flowing ice, and (5) transport and erosion by wind. Since the 1960s, many geomorphic transport laws have been proposed for hillslope sediment transport processes (e.g. Carson & Kirkby 1972), and to a lesser extent for transport in streams and other environments. However, relatively few of these transport laws have been properly tested, as the time scales involved make testing difficult.

Dietrich et al. (2003) provide a perspective on the current status of geomorphic transport laws for hillslope and channel processes. Recent work has provided empirical support, for example, for the hypothesis that the rate of bedrock transformation into regolith tends to decline with increasing soil-mantle thickness (e.g. Heimsath et al. 1997, Small et al. 1999), with evidence for a maximum production rate under a finite cover thickness in some environments (Anderson 2002). However, at present the rate coefficients must be calibrated in the field, and their dependence on factors such as climate, materials, and biota is poorly known. Hillslope soil creep has received considerable attention, leading to linear and nonlinear slope-dependent transport laws that are supported by observational and experimental data (e.g. Roering 2008). However, much work remains to be done to develop well-tested transport laws for other forms of gravitational mass movement, such as slump-style mass wasting and debris flows (e.g. Stock & Dietrich 2006). Transport laws for sediment movement by rivers are well developed, in the sense that there are many formulas for bed-load and suspended-load sediment transport. Development of models for river incision into bedrock has been an area of particularly active research recently. Several different models have been proposed (e.g. Whipple 2004), and there has been a significant ongoing effort to compile data sets to test current models and distinguish between alternative formulations (e.g. Stock & Montgomery 1999, Snyder et al. 2003, Tomkin et al. 2003, van der Beek & Bishop 2003, Whittaker et al. 2007). Progress is also ongoing for transport and erosion by ice (e.g. Hallet 1996, MacGregor et al. 2000) and wind (e.g. Werner 1995).

2.3 *Coupled Modeling of Landform Evolution*

Numerical models of landform evolution combine one or more geomorphic transport laws with a continuity of mass equation in order to simulate the time evolution of landforms. Models of three-dimensional hillslope and drainage basin evolution were introduced in the 1970s (Ahnert 1976, Armstrong 1976). The number and sophistication of models have since increased tremendously. Figure 1 shows an example of a landscape evolution model in a configuration that combines an eroding source terrain on a rising fault block with a depocenter on a subsiding block. This type of model typically represents terrain using either a regular grid or an unstructured polygonal mesh (Braun & Sambridge 1997, Tucker et al. 2001), and routes water across the surface using either a cellular algorithm or a numerical solution to an approximate form of the shallow-water equations. Water fluxes drive erosion and transport, and cell elevations evolve through time in response to the resulting mass flux.

Among current landscape evolution models, some have targeted small-catchment scales and relatively short time periods, ranging from the late Quaternary to the Anthropocene (e.g. Willgoose et al. 1991, Coulthard et al. 1998). Others address regional to sub-continental scales associated with problems such as orogenesis and flexural isostasy (e.g. Beaumont et al. 1992, Tucker & Slingerland 1996, van der Beek & Braun 1999). Commonly the models address fundamental theoretical issues such as the initiation and growth of channels (Smith et al. 1995), the regular spacing of drainage basins (Perron et al. 2008), and location-specific applications.

The majority of landscape evolution models have focused on terrain formed around hillslopes and channel networks. The most basic form of such models combines a diffusion equation for hillslope transport with either an erosion law or a sediment transport formula that is a function of local slope and drainage area (as a surrogate for water discharge) (Willgoose et al. 1991, Moglen & Bras, 1995, Simpson & Schlunegger 2003). Many models have since grown to include additional phenomena and capabilities. For example, some models have addressed transport of multiple grain-size fractions in river networks (Coulthard et al. 1998, Gasparini et al. 1999, 2004, Clevis et al. 2003, 2006, Sharmeen & Willgoose 2006). Although many models have been developed to explore the genesis of erosional topography, there has been increasing attention to coupled erosional and depositional systems (e.g. Johnson & Beaumont 1995, Clevis et al. 2003, Shennan et al. 2003, Fagherazzi et al. 2004).

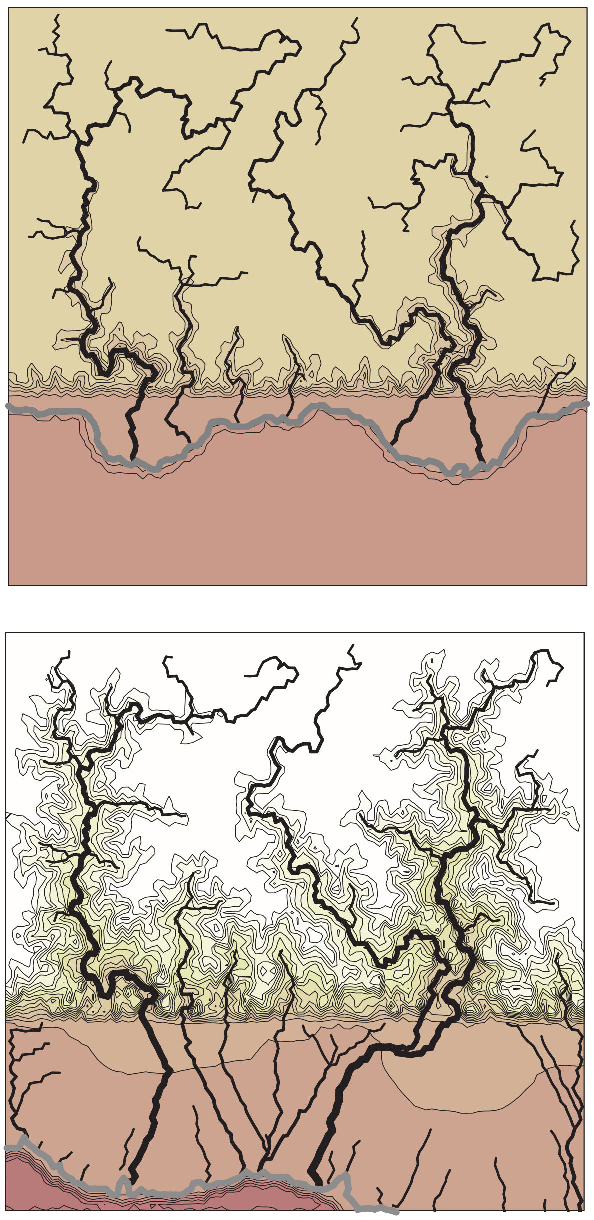

Figure 1. Example simulation using the CHILD landscape evolution model (Tucker et al. 2001), showing erosion of a rising source terrain and growth of fan delta complexes on a subsiding fault block. Domain size is 10 x 10 km.

Stratigraphically oriented applications range from the orogen scale (Johnson & Beaumont 1995) to the scale of individual alluvial fans and river valleys (Coulthard & Macklin 2003, Clevis et al. 2006, Nicholas & Quine 2007). In this example from Clevis et al. (2006), the model domain is a segment of a meandering river valley (Fig. 2). A river meandering sub-model (Lancaster & Bras 2001) is used to compute the evolution of the channel planform through time, while overbank deposition rate in response to a stochastic sequence of floods depends on local flood depth and distance from the main channel. Such simulations enable one to visualize the relationships between depositional processes and the resulting stratigraphic patterns.

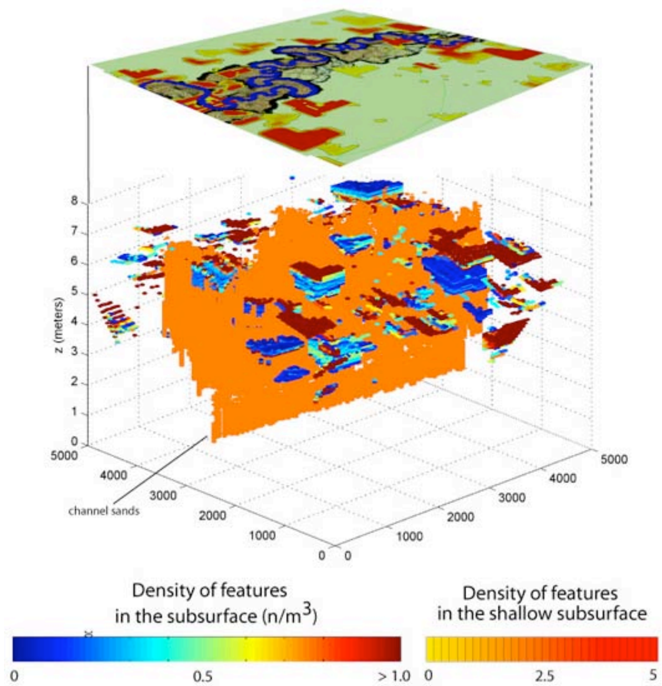

Figure 2. Cut away image from a high-resolution CHILD simulation of stratigraphy beneath a meandering-river valley, showing distribution of channel sands (orange) and density of associated archaeological features. Meandering channel is shown in blue on surface image. From Clevis et al. (2006).

The past ten years have seen a rapid proliferation of applications and capabilities of landscape evolution models. Although a comprehensive review is beyond the scope of this paper, there have been several excellent papers in recent years that review various aspects of models and their application (Beaumont et al. 2000, Coulthard 2001, Wilcock & Iverson 2003, Martin & Church 2004, Willgoose 2005, Codilean et al. 2006, Bishop 2007, Coulthard & Van de Weil 2007).

2.4 *Testing Landscape Evolution Models*

The development of data sets for testing landscape evolution models has tended to lag behind the development of the models themselves. For obvious reasons, this is particularly true for longer-term applications. To date, quantitative tests of models have focused on the use of terrain statistics. G. Willgoose and G. Hancock of U. Newcastle in Australia have, together with colleagues, contributed significantly to developing methods for testing of landscape evolution models using terrain statistics such as the slope-area relationship, as well as experimental data (Willgoose 1994, Willgoose et al. 2003, Hancock & Willgoose 2001, Hancock et al. 2002).

For fluvial process laws, it has been recognized that cases of transient response are generally more diagnostic than steady cases (Whipple & Tucker 2002). This has motivated the search for natural experiments in transient landscape evolution, such as the case of accelerated fault motion studied by Whittaker et al. (2007) and Attal et al. (2008). In general, there remains a pressing need to identify and develop natural experiments in that provide strong constraints on terrain evolution, whether through preserved sediment volumes, cosmogenic isotope data, thermochronology, preserved remnants of past land surfaces, or (ideally) a combination of several of these sources.

2.5 *Outlook*

A large and growing number of models have been developed to compute the morphodynamic evolution of land surfaces. These span a range of process combinations, scales, and levels of detail. In many cases, the geomorphic transport laws in these models remain relatively poorly tested, and one of the most pressing needs is to identify data sets that can provide meaningful tests of terrestrial morphodynamic models at the proper time and space scales. As with many types of environmental model, scaling presents a challenge, and thus an additional research imperative is analysis of how the rules governing surface mass fluxes change at different levels in the scale hierarchy.

3 COASTAL MODELS

Gaps in knowledge and modeling capabilities that apply across the coastal environments include:

- Different models are required to address different questions at different scales, yet the processes at different scales interact. Thus we need to better ‘up-scale’ or parameterize the effects that smaller- and faster-scale processes collectively have on larger-scale processes. For example, ripples and small-scale bedforms affect—and are in turn affected by—currents and sediment transport patterns on scales much larger than those of the small bedforms.
- Limited techniques for including the processes involved in cohesive and mixed sediments.
- Interactions between coastal landscape change, land use, and direct human manipulation (such as beach stabilization) needs to be more widely addressed. Two-way couplings likely play a first-order role in steering the evolution of many coastal landscapes, but our ability to model these couplings, and the resulting feedbacks, remains in its infancy
- Coupling of models of different subenvironments, e.g. beaches, marshes, estuaries and rivers, represents a ubiquitous challenge — one of the central challenges of CSDMS.

3.1 *Tidal Marshes and Lagoons*

A number of new models explore interactions between sediment transport and vegetation growth in tidal environments (e.g. Fagherazzi et al. 2006, D’Alpaos et al. 2007, Kirwan & 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 models consider the effect of vegetation on channel flow, wave erosion, and sediment settling, resulting in potentially complex interactions and multiple stable equilibria. 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. 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 & Murray 2007, Marani et al. 2007).

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 & Murray 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.

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.

3.2 *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; Edmonds & Slingerland 2007, 2008). Geomorphologic models using simplified hydrodynamics and sediment transport simulate landscape-scale delta evolution over millenia, capturing planform shoreline and distributary-network dynamics, including avulsion (Sun et al. 2002) and alongshore transport (Ashton & 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. CSDMS provides the opportunity to address these issues 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 milenial-scale changes resulting from anthropogenic forcing (e.g. Ebro, Mississippi) can serve as a useful testing ground for these new coupled delta models.

3.3 *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 a 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 (2006) coastline model, 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, Stopler et al. 2005).

Large-scale coastal modeling efforts have not yet incorporated some of the processes that are important in the evolution of many sandy coastlines. The role of biology and geochemistry remains an open question, and the role of heterogeneous underlying lithology is only recently being incorporated in numerical models. The role of humans in altering coastlines has only recently been investigated (e.g. McNamara & 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 high-stands, 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 & 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 years, 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?

4 INTEGRATED ESTUARINE MODELING: CHESAPEAKE BAY CASE

The Chesapeake Bay is the largest estuary in the United States and one of the largest estuaries in the World. The Bay has enjoyed a long history of attention and funding for research, monitoring, and modeling. It is special because it has been under increasing pressure from the growing population on the watershed and the associated economic infrastructure that has been developing. Among other large estuaries, it is probably the most populated and impacted. It also has a remarkably large watershed to waterbody area ratio or about 15, which only adds to the loading that the Bay receives from the land.

4.1 *The CBP models*

Chesapeake Bay modeling has historically evolved around water quality issues. The Chesapeake Bay Program (CBP) was charged to develop the tools needed to support decision making for the Bay, to help establish the Total Daily Maximum Loads (TMDL) and identify the quotas for loading from the five states in the watershed. The CBP modeling suite consists of:

1. The Community Multi-Scale Air Quality modeling system (CMAQ) that produces atmospheric deposition data for nutrients and other constituents;
2. The watershed model (HSPF) that produces loadings that come from the land into the estuaries;
3. The Water Quality and Sediment Transport Model (WQSTM), a 3D model of the tidal Bay, that incorporates a full sediment transport simulation that supports PCB and other toxic modeling efforts. Living resource models of filter feeders and underwater grasses are embedded within the WQSTM.

The modeling system has developed over the past 25 years. The models are linked only loosely. Output from one model is sent as input into the other model as a data file (Fig. 3). Decisions are mostly based on the predictions for the future state of the Chesapeake Bay in terms of such indicators as the area of hypoxia, or suitability of habitat for oysters, while most of the decisions are made for the watershed, where the nutrient load is generated. The estuary model is very much dependent upon the loadings that it receives from the watershed model. Whenever the watershed model gets updated, it produces different output. As a result, every time the watershed model is changed, the estuary model needs to be re-calibrated.

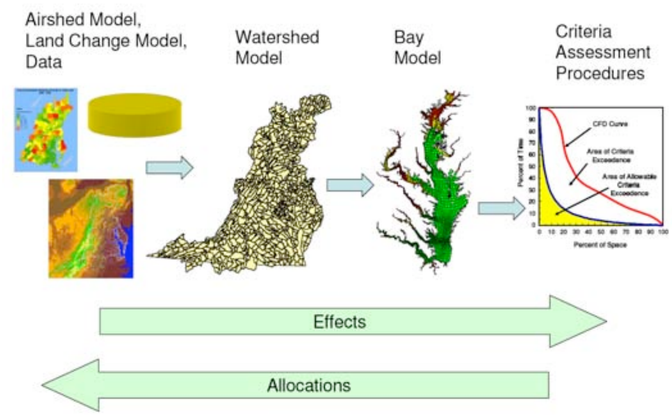

Figure 3. The CBP suite of models. The Airshed model generates nutrient deposition for the watershed model that then calculates the loads that go into the Estuary model.

By linking the models together, the overall modeling effort is simplified. However the overall complexity increases every time a new component is linked, making calibration more difficult, and reducing one's ability to understand the whole model suite. While the CBP modeling suite has been criticized on several occasions for lacking flexibility, being over-parameterized, and lacking uncertainty analysis, it remains the main decision support tool used for the Bay.

4.2 *Chesapeake Bay Forecast System*

The Chesapeake Bay Forecast System (CBFS, http://www.climateneeds.umd.edu/chesapeake/index.html) consists of regional atmosphere, ocean, biogeochemical and land dynamical models that are coupled together to provide comprehensive forecasts of the environmental behavior of the Chesapeake Bay region (Fig. 4). CBFS dynamically downscales global climate forecasts at time scales from subdaily to interannual and decadal. The CBFS provides

16-day forecasts for the state of the Bay ecosystem. The Weather Research and Forecast (WRF) model, coupled to the NOAH land-surface model at 7.5 km resolution, provides the atmospheric component of CBFS. At present the NOAA/NCEP Global Forecast System model provides lateral boundary forcing for WRF 16-day forecasts. In the future, the Global ENsemble System (GENS) will produce the 16-day WRF forecasts for the Chesapeake Bay and its watershed.

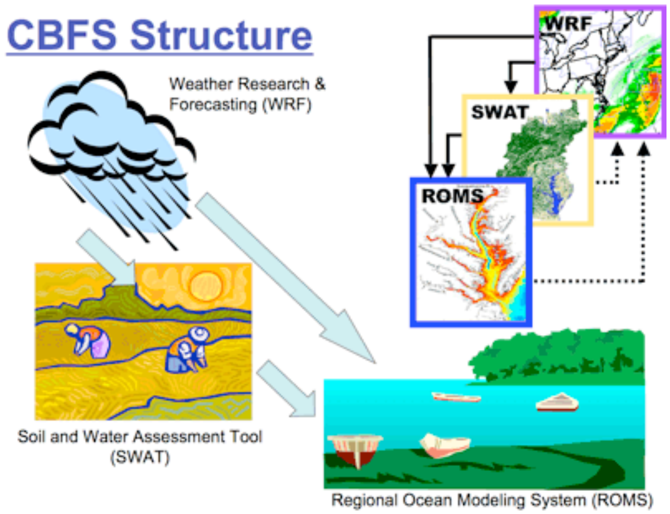

Figure 4. The Chesapeake Bay Forecasting System (CDFS) is made of components models.

The watershed component of the CBFS is the Soil and Water Assessment Tool (SWAT), which is integrated with NOAH and coupled to the WRF atmosphere. When fully implemented, SWAT will be run for each tributary of the Chesapeake watershed. The land use types, crop types for agricultural lands, point and distributed sources of pollution and nutrients, management data, and other details have been gathered for the Chesapeake watershed starting from 1995 with some future scenario projections of land use.

The Regional Ocean Modeling System (ChesROMS) is used for the marine component of Chesapeake Bay, employing a marine ecosystem model and an Ensemble Kalman filter assimilation system. Freshwater forcing in forecast mode from all the tributaries is prescribed in the demonstration phase from regression relations between historical runoff data and the NARR precipitation over the catchment area. Atmospheric flux forcing for the ROMS is obtained from WRF model forecasts. In the current demonstration phase, the atmospheric component of the CBFS provides forecasts of 16-day long hourly time series of temperature, moisture and winds at the surface and a number of levels in the free atmosphere, as well as precipitation, evaporation and radiation budget components at the surface on a regular grid with a spacing of 7.5 km for the entire Chesapeake Bay watershed region.

SWAT predicts quantities related to surface runoff, including stream flow, sediment load and concentrations, nitrogen load, phosphorus load, algal biomass, carbonaceous biochemical demand, dissolved oxygen, soluble and absorbed pesticide output, bacteria, and metal transported out of the tributaries. The ocean component of the CBFS provides forecasts of currents, temperatures and salinities at a number of levels in the vertical on a regular grid with a spacing of about 3 km. Coupled biogeochemical models provide forecasts of dissolved oxygen, chlorophyll, nitrate, and tidal and non-tidal water levels. Digital elevation models are used in conjunction with water level forecasts to provide predictions of inundation and storm surge at street-level resolution. The goal of the CBFS is to transition to seasonal to inter-annual forecasts, which will be issued once the NCEP Climate Forecast System forecasts for the longer lead-times are available routinely and operationally.

4.3 *Chesapeake Inundation Prediction System*

The initial prototype uses advanced modeling and visualization techniques to depict expected inundation at a spatial resolution of less than a city block (≈ 50 m, Fig. 5) and a vertical resolution of ≈30 cm in a time-step display of one hour or less (Stamey et al. 2007). The system is driven by the coupled WRF - regional atmospheric modeling system, coupled with LIDAR data and the ROMS hydrodynamic models. NOAA's Middle Atlantic River Forecast Center will provide river discharge forecasts from the Advanced Hydrologic Prediction Service.

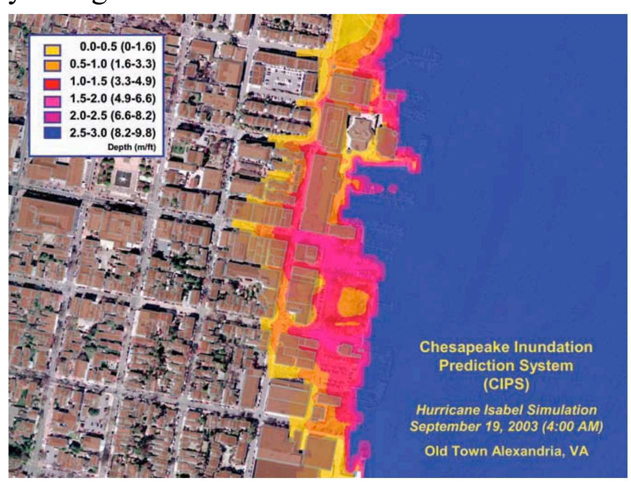

Figure 5. The visualization that the CIPS framework is going to provide to Emergency Managers

4.4 *Chesapeake Community Modeling Program*

The CCMP (ches.communitymodeling.org/index.php) is developing an open-source shared modeling effort driven primarily by researchers from Universities collaborating within the Chesapeake Research Consortium (CRC). The CCMP is soliciting various open source components that can be then rearranged depending upon the needs of particular applications and projects. CCMP, and its CSDMS partner, takes advantage of the wealth of data accumulated over the many years of monitoring and measurements throughout the Bay, providing a unique test bed for models, and effort supported by the Chesapeake Bay Environmental Observatory (CBEO, cbeo.communitymodeling.org/testbed_data.php) team, which seeks innovative ways to explore, present, analyze and disseminate data related to the Chesapeake Bay (CBEO 2008). As more CCMP research is merged with the CSDMS development, outreach to stakeholder is likely to emerge as the major focus of the program.

5 MARINE MORPHODYNAMIC MODELING

Over the last 30 years or so, the development and application of numerical models for marine environments has produced significant advances in our understanding of and ability to predict short-term sediment processes on shelves and slopes and long-term stratigraphic evolutions of continental margins (Syvitski et al. 2007); ongoing and future modeling efforts on these problems will continue to be important. Advances in model capabilities, concomitant with our growing understanding of marine surface dynamics, have poised the marine modeling community to move in several new directions. These include models that integrate hydrodynamics, sediment dynamics, morphological response and, in some cases, biological and biogeochemical processes to better represent the complex coupled dynamics and feedbacks present in marine systems; models that bridge the coastal divide and couple terrestrial and marine environments (“source-to-sink”); and models that more directly relate short-term processes to long-term morphological and stratigraphic response. This section will briefly describe an example or two from each of these 3 directions in marine modeling.

5.1 *Models that integrate processes within the marine environment*

Surface dynamics in the marine environment is critically tied to ocean hydrodynamics. Recent advances in computer hardware and software have paved the way for a number of efforts to develop the next generation of hydrodynamic models for the ocean, including ROMS (the Regional Ocean Modeling System; www.myroms.org), FVCOM (The Unstructured Grid Finite Volume Coastal Ocean Model; fvcom.smast.umassd.edu/FVCOM) and Delft3D (delftsoftware.wldelft.nl). In addition to resolving 3D flow fields, modules for calculating sediment transport, water quality, sea ice, and biogeochemical and biological processes are available or are being developed for these models, making them valuable tools for exploring complex surface dynamics and transport problems in the marine environment.

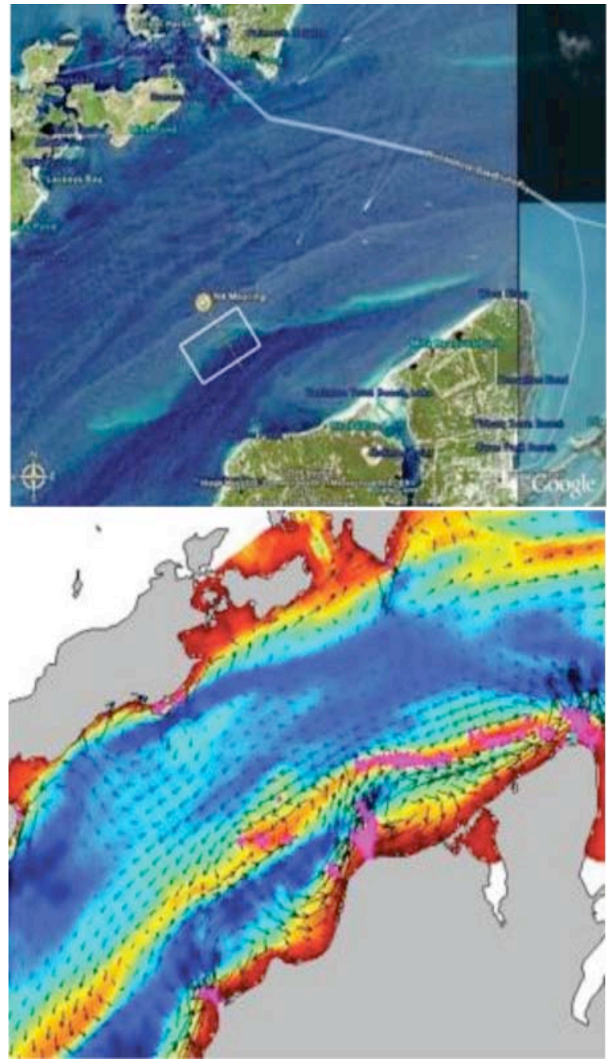

Figure 6. Example application of the CSTMS to shoal formation at Middle Ground, Vineyard Sound, MA. Middle Ground is apparent in the air photo (left panel; Google Earth with IKONOS imagery). The tidal-residual circulation (arrows, right panel) in the CSTM simulations generates sediment transport consistent with observed bedform migration patterns. Modeled long-term deposition (magenta symbols) occurs on the crest of the shoal (bathymetry is shown in color) (Courtesy of R.P. Signell; www.cstms.org).

The NOPP Coastal Sediment Transport Modeling System (CSTMS; www.cstms.org; Warner et al., 2008) project is building on ROMS, adding additional hydrodynamic, sediment transport and morphodynamic algorithms to enable realistic and useful simulations of processes that influence sediment transport in the coastal ocean (e.g. Fig. 6), including estuaries, nearshore regions, and the continental shelf over regional length scales (10’s of meters to 100’s of kilometers) and time scales ranging from transport events to decades. Sediment process modules being added to ROMS through CSTMS include ones for fluid mud, sediment gravity flows and flocculation, each of which has the potential to affect the hydrodynamics, creating feedbacks that the coupled model will be able to capture.

5.2 *Models that couple source to sink*

The problem of linking terrestrial processes to coastal and marine processes has begun to receive considerable attention during the last 15 years. Programs including the ONR STRATAFORM (Nittrouer et al. 2007) and EuroSTRATAFORM (Milligan & Cattaneo, 2007; Wiberg et al., 2008) programs, the NSF MARGINS Source-to-Sink program and now the CSDMS program are contributing critical observations and models to address these linkages. A recent example of the use of models and observations to study the phasing and dispersal of river sediment delivery to the coastal ocean comes from a MARGINS study by Bever *et al.* (2009) in the Waipaoa Sedimentary System (WSS), New Zealand, part of a larger effort to study transport pathways and sediment dynamics within a system that spans source areas in the headlands to marine depositional sinks.

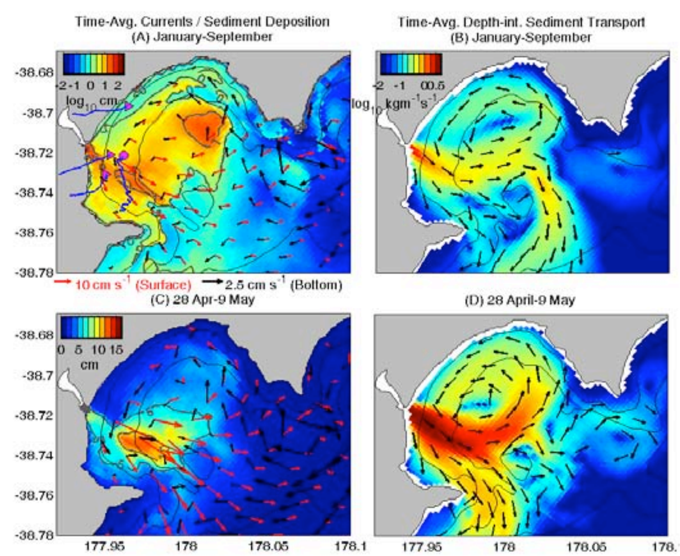

Figure 7. (A, C) Time-averaged currents (arrows) and sediment deposition (colors) over the time frame in the titles. (C, D) Depth-integrated and time-averaged sediment transport direction (arrows) and magnitude (colors), showing the estimated direction and magnitude of sediment transport from the Waipaoa River mouth during 2006. April – 9 May encompasses a moderate storm (from Bever *et al.*, 2009).

Poverty Bay, the shallow marine portion of the WSS, has displayed shoreline progradation over the past 7 ky, but currently seems to deliver most of its fluvial load to the continental shelf, offshore. Bever *et al.* (2009) used ROMS to estimate hydrodynamics and sediment transport during a winter storm and flood season that overlaps observed water column currents, turbidity, and wave properties and seafloor mapping. Tides, waves, winds and freshwater input were accounted for in the hydrodynamic modeling. An estuarine-like pattern of circulation emerged from the ROMS model, where surface waters were directed seaward and nearshore flows were landward, likely in response to baroclinic pressure gradients combined with offshore directed winds. Depositional patterns reflected counterclockwise circulation, with sediment deposited in the middle and towards the southern side of the bay (Fig. 7A). Sediment deposition during storms occurred offshore of the river mouth (Fig. 7C), but this material was subsequently resuspended and transported out of the bay towards the shelf (Fig. 7B). Model results indicated that sediment dispersal from the bay during floods might take a different pathway than material that is resuspended after a period of ephemeral deposition.

5.3 *Models that relate short-term processes to longer-term evolution of morphology*

The problem of upscaling from event time scales (storms, floods, slope failures) to morphologically or stratigraphically relevant time scales (usually 1000's of years or more), is one of the most challenging problems in surface dynamics modeling. Several approaches are possible, including the use of simplified models that attempt to capture the dominant short-term process responsible for long-term change and the use of more detailed models to parameterize relationships that can be applied over longer time scales. An example of each is provided here.

Friedrichs & Scully (2007) developed The Wave and Current Supported Sediment Gravity Flow Analytical Model (WSGFAM), a 2-D discretization of depth-integrated analytical equations for the gravity-driven transport of fine sediment, to simulate annual cycles of flood-induced sedimentation on several riverine shelves around the globe (Fig. 8). The governing equations of WSGFAM are (i) a Chezy-type balance between the sediment-induced down-slope pressure gradient and bed friction, (ii) a bulk Richardson-number criteria which limits to total suspended load, and (iii) the Exner equation for bed change in response to flux convergence or divergence. External forcings/boundary conditions include initial shelf bathymetry, wave height and period and a line-source of riverine sediment input along the coastline. Results for predicted deposition patterns are most sensitive to (in order of decreasing importance) (i) shelf bathymetry (both depth and slope), (ii) strength and time-history of ambient waves and currents, (iii) sediment supply along the coast, and (iv) model coefficients.

Slingerland *et al.* (2008a; 2008b) have been investigating the structure and evolution of clinoforms on the inner shelf of the Gulf of Papua (GoP) off the Fly River to determine how clinoform morphology and internal geometry vary as a function of relative sea level fluctuations, changes in sediment flux to the shelf, and oceanographic processes dispersing sediment across the shelf as part of the MARGINS Source-to-Sink program. To derive causal relationships between oceanographic processes and clinoform characteristics, they hindcast a year of tidal, oceanic, and wind- and thermohaline-driven currents in the Gulf of Papua using NCOM, the US Navy Coastal Ocean Model embedded inside EAS16NFS, an experimental real-time 1/16th degree ocean nowcast/forecast System developed by the U. S. Navy for the East Asian Seas (Barron *et al*. 2004).

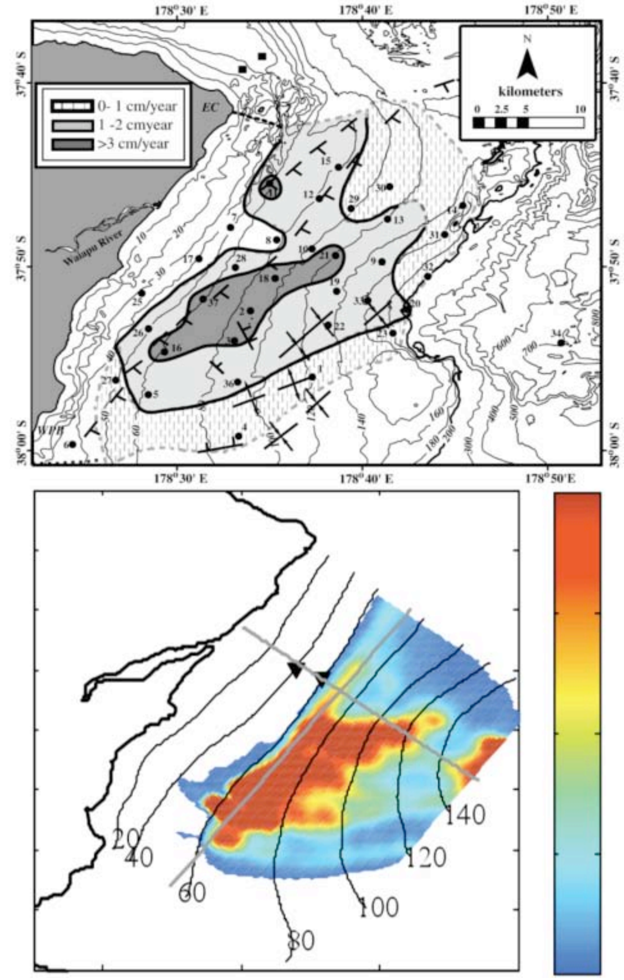

Figure 8. Comparison of observed shelf mud deposits with those predicted by the WSFAM model for the Waiapu shelf, northeastern New Zealand, for (a) observed 210-Pb sediment accumulation rate (Kniskern *et al.*, in press) and (b) modeled deposit thickness from winter 2004 floods (from Y. Ma & C.T. Friedrichs).

The upper 100 m of the Gulf of Papua Shelf comprises two stacked clinothems—an older deeply eroded clinothem forming the middle and outer shelf, and a superjacent younger clinothem extending from the coast offshore, forming the inner shelf. Computed annual circulation of the GoP in response to trade wind and monsoon conditions shows that the flow fields are significantly more complex than previously understood (Fig. 9). During trade winds sediment particle paths on the clinoform top are obliquely offshore to the east. A zone of convergence lies near the 25-m isobath along the clinoform face, where offshore-directed waters on the shelf meet onshore-directed bottom waters climbing the clinoform face, possibly localizing sediment deposition there. This could be a mechanism for clinoform formation and explain the dearth of modern sediment offshore. During monsoon conditions, average bottom flow is landward on the modern clinoform top and minimal over much of the slipface, suggesting that variations in sediment type at the bed level may be circulation related and seasonal. The overall potential transport pathways presumably indicate that the majority of sediment will be deposited on the inner shelf between the Fly and Kikori Rivers, although the disparity between fluvial sediment input and total post-LGM sediment volume within the modern clinoform, on the other hand, suggests a major escape, perhaps to the west.

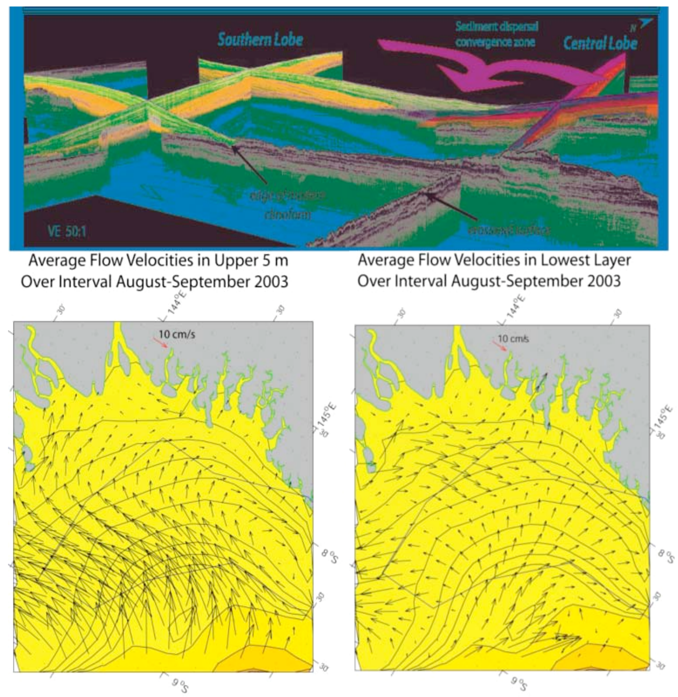

Figure 9. A) Chirp fence diagrams of the GoP clinothems showing a southern lobe downlapping the central lobe. The downlapping stratal geometry of the southern lobe onto the central lobe suggests an abrupt shift in the loci of deposition away from the central lobe. Sediment rerouting due to oceanographic changes accounts for this dramatic shift in the depositional lobes (from Johnstone et al. unpub.). B) Surface and C) bottom currents predicted by the EAS16NFS during the 2003 trade wind period in the Gulf of Papua (Courtesy of R.L. Slingerland).

6 CARBONATE MORPHODYNAMIC MODELS

A key difference between siliciclastic and carbonate morphodynamic forward models is inclusion of chemo-biological elements in the later to calculate in-situ production of carbonate sediment. In carbonate systems, unlike in siliciclastic systems, much material that accumulates and is preserved as strata was produced in-situ by living organisms that precipitated calcium carbonate from solution in seawater to form their skeletal elements. These skeletal elements are then disarticulated and broken down to create carbonate sediment. Sediment transport is also a key process in carbonate systems, but before any sediment can be transported, it must be produced. Carbonate sediment production is typically modeled as a water-depth dependent process using a depth production profile, either based on measured levels of light in the water column (Bosscher & Schalger 1992) or inferred from modern or ancient carbonate accumulations (Pomar 2001).

6.1 *Modeling large-scale platform architecture*

Many carbonate morphodynamic models focus either on replicating one of the types of carbonate platform system (e.g. flat-top attached platforms), or on replicating a sub-system within a particular platform type (platform interior strata). Production-depth profiles play a key role in determining carbonate platform architectures. Some of the earliest carbonate forward models successfully reproduced basic progradation geometries in two-dimensions (e.g. Bice 1988). Bosence & Waltham (1990) followed with an illustration from a 2D model of how relative sea-level oscillations could control platform geometry.

More recent morphodynamic modeling to recreate basic platform geometries has demonstrated, for platforms generally (Warrlich et al. 2002), the Oligocene to Recent of the Bahamas (Eberli et al. 1994), the Miocene and Pliocene in Mallroca (Bosence et al. 1994, Huessner et al. 2001) and the Triassic of the northern margin of Tethys (Emmerich et al. 2003), details of their depositional history and the factors that might control their development, including early diagenesis (Whitaker et al 1997; Whitaker et al 1999). Carbonate ramp platforms remain relatively poorly understood in terms of their formative processes, and modeling helps illustrate how sea level control (Read et al. 1991) and interactions of sediment production and transport (Aurell et al. 1998, Warrlich et al. 2008) may contribute to their formation. This work illustrates the power of morphodynamic models to generate concepts and hypotheses that can then be tested with outcrop and subsurface data, but care must be taken not to over-interpret the model results, particularly when geometries are dominated by the initial model conditions (e.g. Schlager & Warrlich, in press).

6.2 *Modeling platform interior stacking patterns*

Cyclicity in carbonate strata, particularly platform interior strata, has been a fruitful topic for morphodynamic modeling since the earliest models were developed to investigate it (Read et al. 1986, Spencer & Demicco 1989). Goldhammer et al. (1990) used a 1D model to investigate the influence of composite eustasy, and found, perhaps unsurprisingly in the absence of many other processes, that simple, hierarchical oscillations in relative sea-level produced ordered, hierarchical allocyclic strata, though they noted that accumulation is modulated by varying subsidence regime. Barnett et al. (2002) used two different models, one 2D allocyclic model and one autocyclic 3D model to conclude that Visean strata were most likely controlled by combined third and forth order eustatic oscillations, and Paterson et al. (2006) reached a similar conclusion about ice house platforms generally using a 3D model, but also made some interesting observations about unfilled accommodation and bucket-morphologies on ice-house platform tops.

Morphodynamic modeling has investigated the influence of autocyclic processes on stacking and facies partitioning in platform interiors. Ginsburg (1971) first proposed a simple and elegant process of autocycle generation based on observations from modern carbonate shorelines, and led to the development of an autocycle model based on migrating islands on a platform top (Pratt & James, 1986). A 2D model reproduced the Ginsburg model, generating unforced cyclicity via shoreline and tidal flat progradation (Demicco 1998), and subsequence 3D modeling studies explored the Ginsburg process more fully showing how it could be an important contribution to cyclicity in platform-top strata (Burgess et al. 2001, Burgess & Emery 2005, Burgess 2006). Burgess (2001) showed how parasequence thicknesses and stacking patterns commonly attributed to forcing by relative sea-level changes could also be attributed to autocycles influenced by variations in production and transport rates, perhaps related to climatic fluctuations. Burgess & Wright (2003) used a hybrid deterministic and stochastic 3D model to show how autocyclic platform interior strata may be highly discontinuous, with low stratigraphic completeness. Results from these morphodynamic models suggests that development of platform interior strata may be considerably more complicated than previous generations of numerical model suggested, and more complicated than most sequence stratigraphic models currently used to interpret outcrop data.

6.3 *What next?*

Despite significant effort in formulating, testing and inverting forward morphometric models, significant issues remain with applications aiming to reproduce and predict specific stratal geometries from outcrop or subsurface data because of issues like sensitive dependence that place severe limits on deterministic predictive power (Burgess & Emery 2004, Tetzlaff 2004). Warrlich et al. (2008) claimed progress in this area with a 3D carbonate model, but typically best-fit modeling approaches have tended to suffer from issues of an overly-simple objective function and potentially circular reasoning whereby parameters derived from interpretations of data were input into the model, which then rather unsurprisingly reproduced the same interpreted geometries; it remains unclear what this actually demonstrates, or what predictive power a single best-bit model of this type actually has.

More experimental approaches constructing models to formulate hypotheses of the form "what strata geometries would result if a carbonate system worked as follows" represent a possibly more useful application of carbonate morphometric modeling. Recent examples include Drummond and Dugan (1999) who used cellular automata to reproduce negative exponential thickness-frequency relationships observed in outcrop successions. Given our still incomplete understanding of the origins of these basic thickness-frequency relationships (Burgess, 2008) this seems like a very fruitful avenue of investigation for the next-generation of carbonate morphodynamic models.

7 HIGH-PERFORMANCE COMPUTING: TURBIDITY CURRENTS

Turbidity currents can be maintained for hours or even days, transport many km^3 of sediment each, and they can propagate along the ocean floor over distances up to 1,000 km. The sediment deposits generated by these currents, known as turbidites, extend over tens or even hundreds of kilometers along the bottom of the ocean. They frequently are hundreds of meters deep and exhibit pronounced, self-organizing topographical features such as channels and gullies, levees and sediment waves. These individual features, with horizontal length scales ranging from O(100m) to several kilometers, and depths from a few to hundreds of meters, may subsequently become charged with oil and/or gas. Hence they play an important role in determining the spatial extent and geometry of individual oil and gas reservoirs (Syvitski et al. 1996).

Physics-based computational modeling of the sediment transport and deposition by turbidity currents has the potential of playing an important role in producing reliable reservoir models of turbidite deposits. To date, efforts in this regard have been based almost exclusively on simplified sets of equations such as depth-averaged models (see Huppert 2000, Syvitski et al. 2007). While this approach requires only moderate computational resources, it invokes drastic, physically questionable simplifications and requires a number of empirical assumptions that make it unsuitable for predictive purposes. In contrast, the capability to perform high-resolution simulations based on physically realistic models allows for the detailed reproduction of the processes leading to the formation of sediment deposits in the form of levees, channels and sediment waves, including the spatial distributions of grain sizes, porosity and permeability. Over the last decade, high-fidelity computer simulation models for these complex processes of sediment transport and deposition by turbidity currents have been developed (e.g. Necker et al. 2002, Blanchette et al. 2005, Necker et al. 2005). These models are based upon the fundamental physics of the flows, utilizing direct numerical simulations (DNS) to solve the Navier-Stokes equations; they are not dependent upon empirical or arbitrary rule sets to generate geologically plausible results. The simulations are fully three-dimensional, incorporate erosion as well as deposition, respond dynamically to pre-existing and evolving bed topography, account for high-density effects in the flows, and explicitly describe the thickness and grain-size distribution of the resulting deposits.

7.1 *Progress to Date and Future Challenges*

Figure 10 shows a snapshot of one of the largest simulations carried out to date (from Gonzalez-Juez, pers. comm.). These simulations employ $O(10^8)$ computational grid points, and they typically run for several weeks on O(100) processors of midsize or larger clusters. The CPU effort required for such simulations is largely a function of the Reynolds number of the flow. Today, we can carry out direct numerical simulations (DNS) for Reynolds numbers of $O(10^3\text{-}10^4)$ and large eddy simulations for $O(10^4\text{-}10^5)$, which corresponds to typical laboratory size flows. In contrast, large scale turbidity currents in the ocean are characterized by Reynolds numbers of $O(10^9\text{-}10^{10})$. From basic scaling considerations for turbulent flows (Tennekes & Lumley 1972), we know that the ratio of the largest to the smallest scales in the flow increases as $Re^{3/4}$. For three-dimensional simulations this implies that the number of required grid points scales as $Re^{9/4}$. Since the number of required time steps typically increases as $Re^{3/4}$ as well, the overall computational effort can be estimated to scale as Re^3. Note that this estimate is based on the (optimistic) assumption that the computational effort scales linearly with the number of grid points. Based on the above scaling argument, the overall computational effort required for a DNS simulation of a geophysical turbidity current with $Re=10^{10}$ is $O(10^{18})$ larger than for the case shown in Figure 8, so that DNS simulations of geophysical turbidity currents will be out of reach in the foreseeable future even on the largest computing facilities. Some progress can be accomplished with advanced turbulence modeling approaches. However, for complex, variable density two-phase flows such as turbidity currents, with the additional complication of a bottom topography evolving as a result of sedimentation and erosion, this approach is fraught with its own uncertainties, so that other advances should be exploited to the maximum extent possible, in order to perform simulations of the highest possible fidelity.

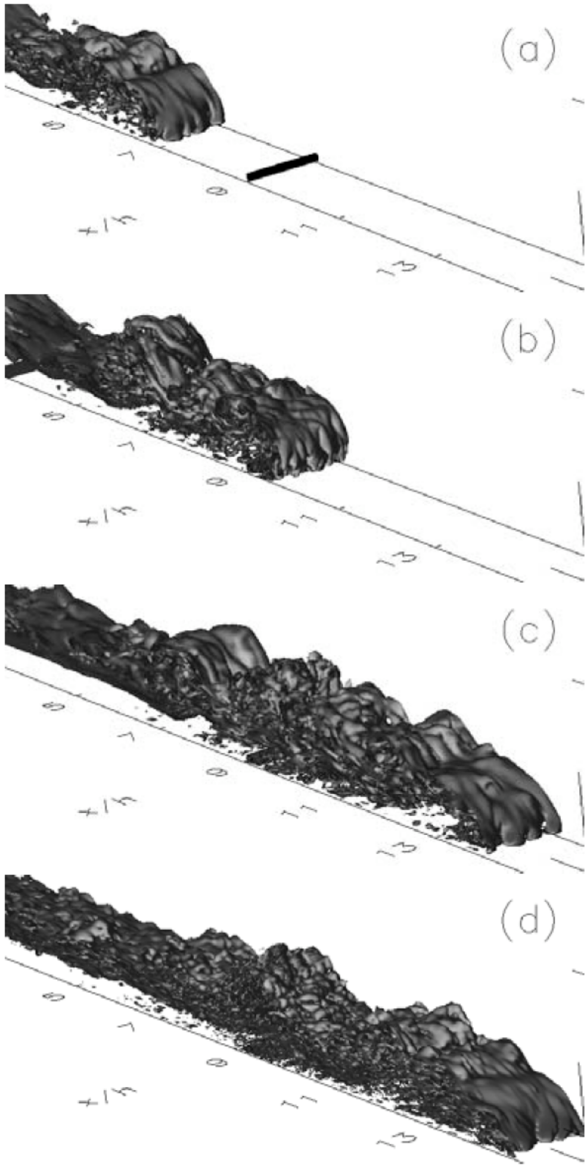

Figure 10: Temporal evolution of a gravity current flow over a cylindrical obstacle such as a submarine pipeline (from Gonzalez-Juez et al. 2009).

Advanced adaptive meshing approaches offer some promise in this regard. As can be seen in figure 8, turbidity currents are characterized by steep velocity and concentration gradients (fronts) that are limited to a small portion of the overall flow field. In addition, the accurate representation of the current's thin bottom boundary layer is crucially important, since it governs the dynamics of sedimentation and erosion. On the other hand, much of the flow outside the turbidity current remains relatively unperturbed, and hence does not give rise to small-scale motion. This indicates that large savings can be realized by employing a variable mesh size. One needs to keep in mind, however, that the turbidity current front is continuously moving through the flow field in an unsteady fashion, so that a static mesh will be inadequate. Instead, adaptive meshes are needed that will automatically refine the resolution where required. Novel concepts for the accurate solution of the Navier-Stokes equations on adaptive meshes, are based on recursive data structures of the quadtree and octree type (Samet 1989, Samet 1990). Recently, new approaches have been developed that allow for second order accuracy on such meshes, e.g. (Losasso et al. 2006). Their efficient implementation on massively parallel computer architectures with O(10^4-10^6) processors, however, represents a challenging task. Here it is important to keep the discretization local, in order to minimize the need for communication among the processors (Gibou et al. 2006).

The chief bottleneck that determines how far Navier-Stokes simulations can be scaled on massively parallel computers lies in the size of the Poisson system that can be solved. For problems of even modest size, the Poisson solver dominates computational time. The fraction devoted to the Poisson solver grows with problem size (Aggarwal 2008). For very large-scale simulations, the Poisson solver will account for nearly all of the computational work. It also represents the most communication-intensive part of the computation due to global data dependencies. Nevertheless, promising developments are currently taking place in this field.

In order to develop efficient simulation codes for future facilities with O(10^6) processors as envisioned by the National Science Foundation and other organizations, there is a need for a scalable development environment. This will allow for the implementation and testing of the various components of the simulation code on virtual facilities. Towards this end, novel approaches such as the open-source cloud computing infrastructure 'Eucalyptus' (cf. eucalyptus.cs.ucsb.edu/) offer new opportunities, as they enable the simulation of systems that are larger in scale than the underlying hardware on which they run.

Many of the above mentioned developments are in a state of flux, and subject to revision, due to the fact that high-performance computer architectures in general are rapidly evolving as a result of such developments as many core chips, heterogeneous processors such as GPUs, massively multithreaded architectures and high-speed interconnect technology. Hence the development of simulation tools for future machines whose specifications are presently unknown has to involve components of modeling, validation, and simulation.

8 CONCLUSIONS

This overview of earth-surface morphodynamic models summarizes some of the challenges facing the community: upscaling, coupling, data systems, computing, and testing. The community is presently self-organizing and rallying behind efforts such as CSDMS, to rapidly advance the field of morphodynamic modeling. The challenging problems facing

CSDMS scientists relate to: self-organization, localization, thresholds, strong linkages, scale invariance, and interwoven biology and geochemistry. These lead to the following fundamental scientific questions that form the foundation and motivation for the CSDMS effort:

1. What are the fluxes, reservoirs, and flow paths associated with the physical, biological, and chemical transport processes across and through the earth's surface? How do these depend on substrate properties like morphology, geology, and ecology, and on human activities?
2. What processes lead to self-organization and pattern formation in surface systems? How do self-organized patterns mediate surface fluxes and evolution?
3. How do material fluxes and surface evolution vary across time and space scales?
4. How are physical and biological processes coupled in surface systems?
5. How is the history of surface evolution recorded in surface morphology and physical, chemical, and biological stratigraphic records?
6. How do linked surface environments communicate with each other across their dynamic boundaries? How do changes in one part of the global surface system affect other parts?
7. How does the Critical Zone couple to the tectosphere, atmosphere, hydrosphere, cryosphere, and biosphere and serve as the dynamic interface among them?

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Appendix 4: Producing CSDMS-compliant Morphodynamic Code to Share with the RCEM Community

Producing CSDMS-compliant Morphodynamic Code to Share with the RCEM Community

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ABSTRACT: The Community Surface Dynamics Modeling System (CSDMS) provides cyber-infrastructure in aid of development, distribution, archiving, and integration of the suite of models that define Earth's surface. This paper concentrates on the integration of models and guidelines to help modelers within the RCEM community create models to share within their community and within the broader Earth-surface modeling community. We describe how models integrate with each other within the Common Component Architecture (CCA) component-modeling framework and requirements for them. For models to be integrated within a component framework, they should expose an Initialize, Run, and Finalize interface, and be properly annotated to give metadata necessary for integration with other models. By refactoring existing models, and creating new models that follow this pattern, the community gains access to a large suite of standardized models. This allows the community to integrate models within new applications, compare and test models, and identify model overlap and gaps in knowledge.

1 INTRODUCTION

The Community Surface Dynamics Modeling System (CSDMS) develops, supports, and disseminates integrated software modules that predict the movement of fluids, and the flux (production, erosion, transport, and deposition) of sediment and solutes in landscapes and their sedimentary basins. CSDMS uses the software architecture CCA to allow components to be combined and integrated for enhanced functionality on high-performance computing (HPC) systems. CCA defines the standards necessary for the interoperation of components developed in the context of a "framework" — a software environment or infrastructure in which components can be linked to create applications (Bernholdt et al., 2006). The CCA/CSDMS framework, *Ccaffeine*, provides a set of services for use in parallel computing that all components can access directly.

Bocca is a CCA development environment tool used as a comprehensive build environment for creating and managing applications composed of CCA components (Elwasif et al., 2007). *Bocca* operates in a language-agnostic way by automatically invoking the Babel tool. Babel is a language interoperability compiler that automatically generates the glue code that is necessary for components written in different computer languages to communicate. It currently supports the following open-source languages: C, C++, Fortran (all years), Java and Python. Babel enables passing of variables with data types (e.g. objects, complex numbers) that may not normally be supported by the target language. *Babel* uses *SIDL* — Scientific Interface Definition Language whose sole purpose is to describe the interfaces (as opposed to implementations) of scientific model components. *SIDL* has a complete set of fundamental data types, from Booleans to double precision complex numbers. It also supports more sophisticated types such as enumerations, strings, objects, and dynamic multi-dimensional arrays.

CSDMS uses *OpenMI* (Open Modeling Interface) as its model interface standard — a standardized set of rules and supporting infrastructure for how a component must be written or refactored in order for it to more easily exchange data with other components that adhere to the same standard (Moore and Tindall 2005, Gregersen et al 2007). Such a standard promotes interoperability between components developed by different teams across different institutions. Model components that comply with this standard can, without any programming, be configured to exchange data during computation (at run-time). The *OpenMI* standard supports two-way links where the involved models mutually depend on calculation results from each other. Linked models may run asynchronously with respect to time steps, and data represented on different geometries (grids) can be exchanged using built-in tools for interpolating in space and time.

As a community effort, CSDMS: 1) ensures continuity and project robustness in face of uncertain funding and institutional support; 2) cuts redundancy since with open modeling and open source code new models can be built upon already existing concepts, algorithms and code; 3) allows scientists to work with software engineers, helping to bridge the cultural and, often, institutional gap between these teams; and 4) offers transparency that promotes user participation, better testing, more robust models and more acceptance of the results. The RCEM community is encouraged to join and promote the CSDMS effort; to provide CSDMS with their code, documentation and test cases; to employ good software development practices that favor transparency, portability, and reusability; and to include procedures for version control, bug tracking, regression testing, and release maintenance.

2 THE CCA TOOL CHAIN

The Common Component Architecture (CCA) is a set of tools dedicated to bringing a plug-and-play style of programming to high performance scientific computing. CSDMS supports its application in the terrestrial, coastal, and marine modeling communities. Although the CCA tools are extensive, this section gives a brief introduction to three of the main tools of the CCA tool chain: *babel*, *bocca*, and the *ccafe* GUI.

2.1 *Babel*

Our modeling communities have generated a large number of useful standalone models. However, for the most part, model developers did not intend for these models to communicate with one another. Not surprisingly then, existing models were written in a range of programming languages. This language interoperability is a basic problem in trying to have a model communicate with another within a programming environment.

Babel is an open-source, language interoperability compiler that automatically generates glue code necessary to allow components written in different computer languages to communicate. It currently supports C, C++, Fortran (77, 90, 95 and 2003), Java and Python. *Babel* is more than a least common denominator solution; it enables passing of variables with data types that may not normally be supported by the target language (e.g. objects, complex numbers). *Babel* was designed to support scientific, high-performance computing and is one of the key tools in the CCA tool chain.

In order to create the glue code needed for two components written in different programming languages to communicate (or pass data between them), Babel needs only to be aware of the interfaces of the two components. It does not need to know anything about how the components have been implemented. *Babel* was designed to ingest a description of an interface in either of two fairly language neutral forms, *XML* (eXtensible Markup Language) or *SIDL* (Scientific Interface Definition Language). The *SIDL* language was developed for the *Babel* project. Its sole purpose is to provide a concise description of a scientific software component interface. This interface description includes complete information about a component's interface, such as the data types of all arguments and return values for each of the component's methods. *SIDL* has a complete set of fundamental data types to support scientific computing, from booleans to double precision complex numbers. It also supports more sophisticated data types such as enumerations, strings, objects, and dynamic multi-dimensional arrays.

2.2 *Bocca*

Bocca is a tool in the CCA tool chain designed to help create, edit and manage a set of CCA components and ports that are associated with a particular project. A model developer uses *Bocca* to prepare a set of CCA-compliant components and ports that can then be loaded into a CCA-compliant framework. *Babel* then compiles the linked components to create applications or composite models.

Bocca can be viewed as a development environment tool that allows application developers to perform rapid component prototyping while maintaining robust software- engineering practices suitable to HPC environments. *Bocca* provides project management and a comprehensive build environment for creating and managing applications composed of CCA components. *Bocca* operates in a language-agnostic way by automatically invoking the lower-level Babel tool. *Bocca* frees users from mundane, low-level tasks so they may focus on the scientific aspects of their applications. *Bocca* can be used interactively at a Unix command prompt or within shell scripts.

2.3 *Ccafe-gui*

Ccaffeine is one of many CCA-compliant frameworks for linking components, but it is the one used most often. There are at least three ways to use *Ccaffeine*, (1) with a graphical user interface, (2) at an interactive command prompt or (3) with a *Ccaffeine* script. The GUI (*Ccafe*-gui) is especially helpful for new users and for demonstrations and simple prototyping, while scripting is often faster for programmers and provides them with greater flexibility.

Ccafe-gui is easy to use. It consists of a palette of available components that are available for the user to make use of. The components may be stored locally or in a repository on a remote server. The user pulls components from the palette into an arena to be connected with one another. Once in the arena, an instance of the component is created and is ready to be connected with other compatible components.

Component boxes contain one or more ports that are labeled as a particular type of port. It is through these ports that models communicate and use the functionality of other components. Any two components that have the same port can be connected by clicking first on the port of one and then the same-named port of the other. A link connects these ports to indicate that the components are connected. In this way, a wiring diagram is constructed that describes the composite model. The user then clicks the start button of the base component to run the new model.

3 MODEL INTERFACE STANDARDS

A model should have two levels of interfaces: a user interface, and a programming interface. A user interface could be a graphical user interface (GUI), where a model user is able to control the model simulation through one or more graphical windows. A user interface could also be a command line interface (CLI) and is more common for models in our community. Oftentimes the user will create a set of input files and then run the program from the command line with a set of flags that controls the model execution.

Unlike the above interfaces, a programming interface is not seen by model users, but rather by model developers. A model's application programming interface (API) gives a programmer an interface to the functionality of that model, and at the same time obscures the details of the model's implementation. A good model API is essential in linking existing models within a new application.

3.1 *Initialize, Run, Finalize (IRF)*

Many of the models that exist in our community do not have an extensive programming interface. This is most likely because their authors did not write them with the intent of having their model linked with other models. Typical surface dynamics models have a common structure, and so lend themselves well to a standard interface. In its basic form, this interface provides entry points into a model's initialize, run, and finalize steps.

Most surface dynamics models advance values forward in time on a grid or mesh and have a similar internal structure. This structure consists of some lines of code before the beginning of a time loop (the initialize step), some lines of code inside the time loop (the run step) and finish with some additional lines after the end of the time loop (the finalize step). Virtually all component-based modeling efforts have recognized the utility of moving these lines of code into three separate functions, with names such as Initialize, Run and Finalize. This simple refactoring is an important first step towards allowing a model or process module to be used either as a component within a larger application or as a stand-alone model. It provides a calling program with fine-grained access to the model's capabilities and the ability to control the overall time stepping of the model.

4 USES AND PROVIDES PORTS

Within a general component framework, a component will have two types of connections with other models. These connections are made through ports that come in two varieties. Within the CCA framework, these ports are called, *provides*-ports, and *uses*-ports. The first provides an interface to the component's own functionality. The second specifies a set of capabilities that the component will need to use from another component.

A provides-port presents to other components an interface that describes its functionality. That is, the functionality that it can provide to another component that lacks (but requires) that functionality. For instance, if a provides-port was to expose an IRF interface of the previous section, it would allow another component to gain access to its initialize, run, and finalize steps. Any interface can be exposed through a port, but it can only be connected to another port with a similar interface.

The uses-port of a component presents functionality that it lacks itself and therefore requires from another component. Any component that provides the required functionality is able to connect to it. Thus, the component is not able to function until it is connected to a component that has the required functionality. This allows a model developer to create a new model that uses the functionality of another component without having to know the details of that component or to even have that component exist at all.

This style of plug and play component programming benefits both model programmers and users. Within this framework model developers are able to create models within their areas own of expertise and rely on experts outside their field to fill in the gaps. Models that provide the same functionality can easily be compared to one another simply by unplugging one model and plugging in another, similar model. In this way users can easily conduct model comparisons and more simply build larger models from a series of components to solve new problems.

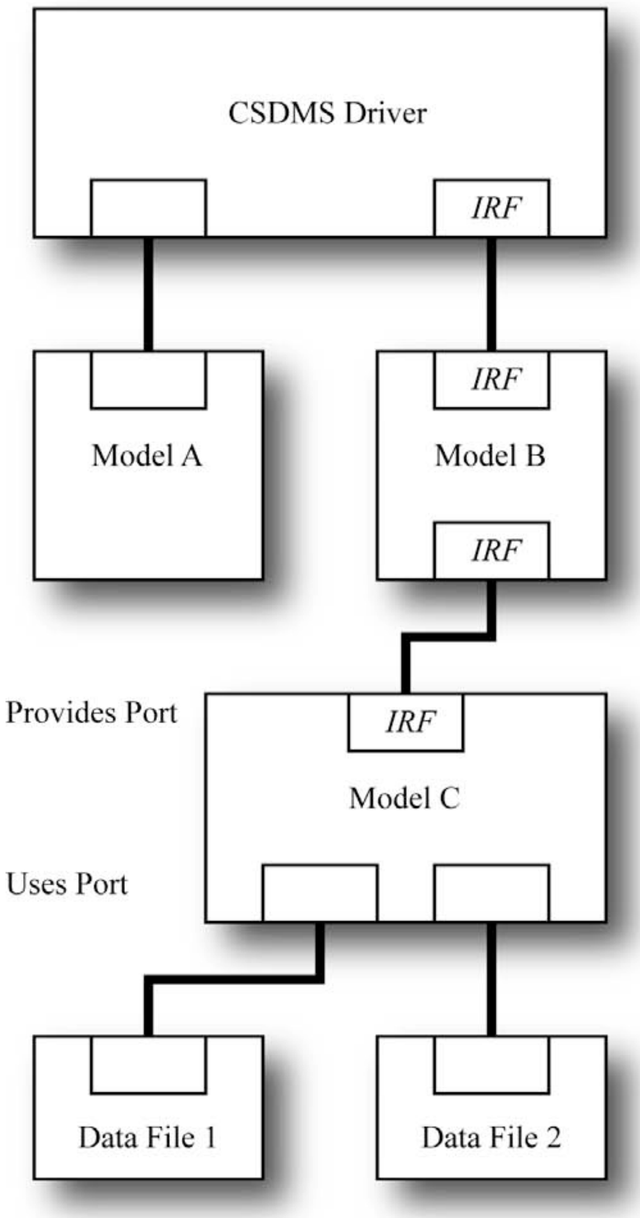

Figure 1. Wiring diagram of a set of CCA components that have been combined to form a new model. Uses-ports are to the bottom, and provides-ports to the top.

5 ANNOTATIONS FOR MODEL DEVELOPERS

Once a model has been written so that it provides entry points to its functionality (whether it be an IRF interface, or otherwise) it can be wrapped as a component to be used within a modeling framework (such as the CCA framework described above). The precise steps needed to do this depend on the framework. However, if the model contains sufficiently descriptive metadata, it can be easily imported into any modeling framework.

Because modeling frameworks may change over time, it is important to provide this type of metadata within a model so that it does not tie itself to any one framework. If a framework injects too much of itself into a model, the model becomes reliant on that framework. It should be that the framework relies on its set of models, not the other way around. To help with this problem, a key step when refactoring one's model is to annotate the model source code so that the required metadata stays with the model.

Using special keywords within comment blocks, a programmer is able to provide basic metadata for a model and its variables that is closely tied to the model but doesn't affect how the model itself is written. For example, metadata for a variable could follow its declaration in a comment that describes its units, valid range of values and whether it is used for input or output. Another annotation could identify a particular function as being the model's initialize, run, or finalize step. This type of annotation makes it possible to write utilities that parse the source code, extract the metadata and then automatically generate whatever component interface is required for compatibility with other models. In fact, this metadata could be automatically extracted and used for a wide range of purposes such as generating documentation, or providing an overview of the state of a community's models.

6 REQUIREMENTS FOR CODE CONTRIBUTORS

Although this paper has focused primarily on the linking of models as components, this is only one goal of CSDMS. Of equal importance to CSDMS is to organize its community's models. To this end, CSDMS seeks models of all types, and has few requirements for code contributors. We ask only two things: models are licensed under an open-source license (http://csdms.colorado.edu/License), and that a form be filled out that gives basic metadata for the model (http://csdms.colorado.edu/Questionnaire).

7 SUMMARY

CSDMS looks to its community for support and supports the community in return. Through a model repository CSDMS organizes models so that they have a home that is independent of the funding that built the model. The repository clearly presents the state of a community's models and identifies areas of duplication as well as gaps in model coverage. The open-source nature of the repository gives transparency to what used to be black-box models. This allows better model testing and verification, faster development, and model acceptance.

The CSDMS modeling framework will provide the community with a set of model components with standard interfaces that can be linked with one another. This allows model developers to concentrate on writing models that they know best. Thus, the model user is certain that they are using that community's best model, even though they may not be part of that community of experts.

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