CSDMS

COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

ANNUAL REPORT

JULY 2016

NSF COOPERATIVE AGREEMENT 0621695

CSDMS
COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

Executive Summary

The Community Surface Dynamics Modeling System (CSDMS) is a NSF-supported, international and community-driven program that seeks to transform the science and practice of earth-surface dynamics modeling. CSDMS, now in its 9th year, integrates a diverse community of 1414 members representing 186 U.S. institutions (132 academic, 29 private, 25 federal) and 334 non-U.S. institutions (223 academic, 32 private, 79 government) from 67 countries. CSDMS distributes 264 Open Source models and modeling tools, provides access to high performance computing clusters in support of developing and running models, and offers a suite of products for education and knowledge transfer. The CSDMS architecture employs frameworks and services that convert stand-alone models into flexible "plug-and-play" components to be assembled into larger applications. CSDMS activities are supported through multiple NSF funding units: GEO/OCE Marine Geology and Geophysics, GEO/EAR Geoinformatics, GEO/EAR Geomorphology and Land-use Dynamics, GEO/EAR Sedimentary Geology and Paleontology, GEO/EAR Education and Human Resources, GEO/EAR Hydrological Sciences, BIO/DEB Macrosystems Biology, BIO/DEB Ecosystem Studies, and NSF's Advanced Computational Infrastructure. This report highlights web portal developments, model uncertainty support services, software stack distribution system, and the CSDMS Web Modeling Tool (WMT), the web-based successor to the desktop Component Modeling Tool that allows users to build and run coupled Earth system models on a high-performance computing cluster (HPCC) from a web browser. Reports from each of the six CSDMS Working Groups and seven Focus Research Groups are also provided. We outline past achievements and their plans to implement the CSDMS Strategic Plan. This Annual Report covers the period from August 2015 to July 2016.

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CSDMS 2.0 2016 Annual Report

1.0 CSDMS Mission

The Community Surface Dynamics Modeling System (CSDMS) catalyzes new paradigms and practices in developing and employing software to understand the earth's surface — the ever-changing dynamic interface between lithosphere, hydrosphere, cryosphere, and atmosphere. CSDMS focuses on the movement of fluids and the sediment and solutes they transport through landscapes, seascapes and sedimentary basins. CSDMS models also include those that include ecosystem and human dimension interactions. CSDMS supports the development, integration, dissemination and archiving of community open-source software that reflects and predicts earth-surface processes over a broad range of temporal and spatial scales.

2.0 CSDMS Management and Oversight

2.1 The CSDMS Executive Committee (ExCom) is comprised of organizational chairpersons:

- **James Syvitski**, Chair ExCom, CSDMS Executive Director, INSTAAR, U Colorado – Boulder
- **Greg Tucker** (November 2015—), CSDMS Deputy Director, CIRES, U Colorado – Boulder
- **Patricia Wiberg** (Apr. 2012—), Chair, CSDMS Steering Committee, Univ. of Virginia, VA
- **Christopher Sherwood** (Sept. 2014—), Chair, CSDMS Interagency WG, USGS, Woods Hole, MA
- **Nicole Gasparini** (Apr. 2016—), Chair, Terrestrial WG, Tulane University, New Orleans, LA
- **Brad Murray** (April 2007—), Chair, Coastal WG & Coastal Vulnerability Initiative, Duke Univ., NC
    - *Chris Thomas (May 2014 —), Vice Chair, Coastal WG, British Geological Society, Edinburgh, UK*
    - *Hans-Peter Plag (May 2014—), Vice Chair, Coastal Vulnerability Initiative, Old Dominion U Norfolk VA*
- **Courtney Harris** (Apr. 2012—), Chair, Marine WG & Continental Margin Initiative, VIMS, VA
- **Tom Hsu** (Sept. 2015—), Chair, Cyberinformatics & Numerics WG, U. Delaware, Newark, DE
    - *Scott Peckham (Dec. 2013—) Vice Chair, Cyberinformatics & Numerics WG, U. Colorado – Boulder*
- **Wei Luo** (Sept. 2015—), Chair, Education & Knowledge Transfer WG, N Illinois U Dekalb, IL
- **Brian Fath** (Nov. 2014—), Chair, Ecosystem Dynamics FRG, Towson University, Towson, MD & International Institute for Applied Systems Analysis, Laxenburg, Austria
- **Peter Burgess** (Sept. 2008—), Co-Chair, Carbonate FRG, Royal Holloway, U. London, UK
- **Chris Jenkins** (Nov. 2015—), Co-Chair, Carbonate FRG, U Colorado – Boulder
- **Venkat Lakshmi** (Sept. —), Chair, Hydrology FRG, University of South Carolina, Columbia, SC
- **Raleigh Hood** (Jul. 2014—), Chair, Chesapeake FRG, U. of Maryland, Cambridge, MD
- **Chris Duffy** (Mar. 2013—), Co-Chair, Critical Zone FRG, Penn State U., PA
- **Alejandro Flores** (Oct. 2014—), Co-Chair, Critical Zone FRG, Boise State U., ID
- **Mark Rounsevell** (Nov. 2014 —), Co-Chair, Human Dimensions FRG, U of Edinburgh, UK
- **Kathleen Galvin** (Jan. 2013—), Co-Chair, Human Dimensions FRG, Colorado State, Ft Collins CO
- **Phaedra Upton** (Mar. 2013—), Co-Chair, Geodynamics FRG, GNS, Lower Hutt, New Zealand
- **Mark Behn** (Mar. 2013—), Co-Chair, Geodynamics Focus Research Group, WHOI, MA

The Executive Committee is the primary decision-making body of CSDMS, and ensures that the NSF Cooperative Agreement is met, oversees the Bylaws & Operational Procedures, and sets up the annual science plan. The ExCom approves the business reports, management plan, budget, partner memberships, and other issues that arise in the running of CSDMS.

2.2 The CSDMS Steering Committee (SC) includes representatives of U.S. Federal Agencies, Industry, and Academia:

- **Patricia Wiberg** (Sept. 2012—), Chair, CSDMS Steering Committee, Univ. of Virginia, VA
- **Tom Drake** (April 2007—), U.S. Office of Naval Research, Arlington, VA
- **Bert Jagers** (April 2007—), Deltares, Delft, The Netherlands
- **Marcelo Garcia** (Dec. 2012—), Univ. Illinois at Urbana-Champaign, IL
- **Chris Paola** (Sept. 2009—), NCED, U. Minnesota, Minneapolis, MN
- **Cecilia DeLuca** (Sept. 2009—), ESMF, NOAA/CIRES, Boulder, CO
- **Boyana Norris** (Sept. 2009—), University of Oregon, Eugene, OR
- **Guillermo Auad** (Jan. 2013—), Bureau of Ocean and Energy Management, Herndon, VA
- **Efi Foufoula-Georgiou** (March 2016—), NCED, University of Minnesota, Minneapolis, MN
- **David Mohrig** (March 2016—), University of Texas, Austin, TX
- **James Syvitski** (*ex-officio*), CSDMS Executive Director, INSTAAR, CU-B, Boulder, CO
- **Rudy Slingerland** (*ex-officio*), Past Chair, Penn State University, University Park, PA
- **Paul Cutler** (*ex-officio),* National Science Foundation

The CSDMS SC assesses the competing objectives and needs of CSDMS, assesses progress in terms of science, outreach and education, advises on revisions to the evolving 5-year strategic plan, and approves the Bylaws and its revisions.

2.3 CSDMS Working and Focus Research Groups

There are currently 1414 members representing 186 U.S. institutions (132 academic, 29 private, 25 federal) and 334 non-U.S. institutions (223 academic, 32 private, 79 government) from 67 countries. Members are organized within 6 working groups (Terrestrial, Coastal, Marine, Education and Knowledge Transfer, Cyberinformatics and Numerics, and Interagency) and 7 focus research groups (Human Dimensions, Carbonate, Hydrology, Critical Zone, Geodynamics, Chesapeake, and Ecosystem Dynamics).

Terrestrial	672	Geodynamics	124
Coastal	533	Carbonate	97
Hydrology	528	Critical Zone	70
Marine	343	Chesapeake	69
EKT	212	Human Dimensions	66
Cyber	201	Ecosystem Dynamics	51

2.4 The CSDMS Integration Facility (IF)

The CSDMS Integration Facility (IF) maintains the CSDMS repositories and facilitates community communication and coordination, public relations, and product penetration. The IF develops the CSDMS cyber-infrastructure, provides software guidance to the CSDMS community, maintains the CSDMS vision, and supports cooperation between observational and modeling communities. As of July 2016, CSDMS IF staff includes:

- Executive Director, Prof. James Syvitski (April, 2007—) - CSDMS & CU support
- Executive Assistant, Lynn McCready (Dec. 2015 —) - CSDMS support
- Senior Software Engineer, Dr. Eric Hutton (April 2007—) - CSDMS support
- Software Engineer, Dr. Mark Piper (Oct. 2013—) - CSDMS & other NSF support
- Cyber Scientist, Dr. Albert Kettner (July 2007—) - CSDMS & other NSF & NASA support
- EKT Scientist, Dr. Irina Overeem (Sept. 2007—) - CSDMS & other NSF & NASA support

• Research Scientist, Dr. Kimberly Rogers (March 2012—) - Other NSF support
• Postdoctoral Researcher, Dr. Stephanie Higgins (Sept. 2010—)- NASA & Belmont Forum support
• Research Associate, Dr. Mariela Perignon (June 2015 —) -Other NASA & NSF support
• Research Associate, Dr. Elchin Jafarov (June 2015 —) -Other NSF support
• Systems Administrator, Chad Stoffel (April 2007—) - Multiple grant support
• Accounting Technician, Chrystal Pochay (July 2013 —) - Multiple grant support
• Director, Flood Observatory, Dr. G Robert Brakenridge (Jan. 2010—) – NASA, World Bank support
• Senior Research Scientist, Dr. Christopher Jenkins (Jan. 2009—) – NSF, BOEM & other support

Departures
Executive Assistant, Lauren Borkowski, (Jan. 2014 – Oct. 2015) – CSDMS support

2.5 CSDMS Industrial Partners

Industry partners (csdms.colorado.edu/wiki/Industry_partners) play an important role in contributing to the success of CSDMS through their financial or in-kind contributions. Sponsorship supports the CSDMS effort and thus the next generation of researchers working to develop innovative approaches towards modeling complex earth-surface systems. CSDMS consortium members: 1) demonstrate corporate responsibility and community relations; 2) contribute to the direction of CSDMS research and products; 3) access the latest CSDMS products and information; and 4) join an association of diverse scientists, universities, agencies, and industries. Approximately 12% of CSDMS member institutions are with the private sector.

3.0 JUST THE FACTS

3.1 CSDMS Model Repository

The CSDMS Model Repository hosts open-source models, modeling tools, and plug-and-play components, including: i) Cryospheric (e.g. glaciers, permafrost, icebergs), ii) Hydrologic, from reach to global scale, iii) Marine (e.g. ocean circulation), iv) River, coastal and estuarine morphodynamics, v) Landscape or seascape evolution, vi) Stratigraphic, and vii) Affiliated domains (e.g. weather & climate models). About 70% of the models are distributed through a central repository hosted at GitHub (https://github.com/csdms-contrib); others are distributed through linkages to existing community efforts. The centralized model repository at GitHub makes source code version control, contributions, sharing, down loading and managing individual code repositories easier with more control for the code developer. The many different ways to share source code through GitHub make it difficult to present download statistics. We hope to present such information in future annual reports. The table below represents the total number of source code projects (264) per domain where one model project could be in multiple domains.

Models, Tools and WMT components by Environmental Domain
http://csdms.colorado.edu/wiki/Main_Page

Domain	Models	Tools	WMT Components
Terrestrial	76	72	3
Coastal	58	5	4
Marine	48	6	2
Hydrology	58	43	17
Carbonate	3	3	-
Climate	11	2	-
Geodynamic	12	-	-

Over last year the following new models were either submitted to the Model repository or source code was made available through external sites (http://csdms.colorado.edu/wiki/Models_all#All_models):

Model	Description	Developer
CLUMondo	The CLUMondo model is a spatially explicit and dynamics land system change model	Peter Verburg
Underworld2	Underworld2 is an open-source, particle-in-cell finite element code tuned for large-scale geodynamics simulations.	Louis Moresi
LaMEM	LaMEM - Lithosphere and Mantle Evolution Model	Anton Popov
DynEarthSol3D	DynEarthSol3D is a finite element solver that models the momentum balance and the heat transfer of elasto-visco-plastic material in the Lagrangian form.	Eh Tan
SiStER	An easy-to-use MATLAB code to simulate long-term lithosphere and mantle deformation.	Jean-Arthur Olive

AnugaSed	Add-on package to ANUGA with modules for sediment transport and vegetation drag	Mariela Perignon
1DBreachingTurbidityCurrent	1D Breaching Turbidity current model for generating continuous turbidity currents	Esther Eke
Cross Shore Sediment Flux	Cross-Shore Sediment Flux Equations	Alejandra Ortiz
RAFEM	River Avulsion and Floodplain Evolution Module	Katherine Ratliff
DeltaRCM	River delta formation and evolution model with channel dynamics	Man Liang
GLUDM	Global future agricultural land use dynamics model	Sagy Cohen
Badlands	Basin and landscape dynamics	Tristan Salles
Reservoir	Reservoir: Tools for Analysis, Design, and Operation of Water Supply Storages	Sean Turner
WOFOST	WOFOST (WOrld FOod STudies) is a simulation model for the quantitative analysis of the growth and production of annual field crops.	Hendrik Boogaard
Ecopath with Ecosim	Ecopath with Ecosim (EwE) is an ecological modeling software suite for personal computers	Villy Christensen
Auto marsh	Cellula automata model for salt marsh evolution with variable soil resistance under wind waves attack	Nicoletta Leonardi

New tools either submitted to the repository or source code made available through external sites include (http://csdms.colorado.edu/wiki/Models_all#All_tools):

Tool	**Description**	**Developer**
OptimalCycleID	A numerical method to analyse a vertical succession of strata and identify the most cyclical arrangement of constituent facies	Peter Burgess
KnickPointPicker	Matlab-based script to extract topometrics for catchments and river knickpoints.	Bodo Bookhagen

22 source code projects that were previously marked as 'models' were moved to our 'tool repository and are not listed above.

CSDMS provides the option (and encourages its members) to track papers, books, chapters, or reports that describe or apply single or multiple models that are currently listed in the CSDMS model repository. So far CSDMS is managing references to 733 papers. Last year alone 147 references were added to the model reference database.

3.2 CSDMS Data Repository csdms.colorado.edu/wiki/Data_download

Data Repository as of July 2016

Data Type	Databases
Topography/bathy	19
Climate	6
Hydrography	7
River discharge	9
Cryosphere	5
Surface Properties	6
Land cover	6
Substrates	4
Human Dimensions	2
Sea level	1
Oceanography	12
GIS Tools	12

3.3 CSDMS Education & Knowledge Transfer (EKT) Repository

CSDMS maintains and develops an online repository with educational resources. Online material is all provided open source, and is organized in several tiers: 1) basic educational resources such as movies, animations and imagery, 2) Science on a Sphere datasets, 3) CSDMS course lectures, 4) teaching labs using models and the CSDMS HPCC including model development teaching labs.

Movie repository

CSDMS has expanded the number of earth surface processes real-world movies and model animation to approximately 140 movies during 2015-2016. The 2016 CSDMS Annual Meeting was jointly organized between CSDMS and the Sediment Experimentalist Network (SEN). This collaboration made it evident that many movies in the SEN Research Coordination Network could be incorporated into the CSDMS movie repository, with the potential to expand the accessibility for teaching faculty and teaching assistants. We have initiated the documentation of 10 key experiments, which would be useful for teaching purposes, for the CSDMS repository.

Data Set Title	Web link	Contributor
Carbonate Precipitation in Meandering Rivers	http://sedexp.net/catalog/meandering-rivers-experiments-carbonate-precipitation-process	Wonsuck Kim
Ice Delta	http://sedexp.net/catalog/ice-delta-experiments	YeJin Lim
Delta and vegetation development	http://sedexp.net/catalog/delta-veg	Anastasia Piliouras
Sorting in Flash Floods		Kealie Goodwin
Bedform dynamics	http://sedexp.net/catalog/bedform-dynamics-and-strata-experiments	Robert Mahon
Delta building with backwater effect	http://sedexp.net/catalog/time-lapse-images-sen-csdms-rigid-lid-experiment	Wonsuck Kim
Bedrock Incision with Suspended Sediment	http://joelscheingross.com/research/	Joel Scheingross
Bedrock Incision with Bedload	http://joelscheingross.com/research/	Joel Scheingross

Table 3.3.1. Joint CSDMS-SEN 2016 Annual Meeting results in new contributions to the EKT movie catalogue as connected to the EarthCube SEN RCN Knowledgebase.

Basic Modeling Labs and Spreadsheet Exercises for High School and Undergraduate Students

These exercises are aimed to be easy-to-use and teach basic concepts in surface processes. These labs consist partly of spreadsheet labs and web-based models developed at the CSDMS Integration Facility, and in addition include many contributions from the wider CSDMS community.

- *Earth Science Models for K6-12 (17 animations with teacher notes, developed by PhET).*
- *Hydrological Processes Spreadsheet Exercises (includes labs on precipitation, evapotrnspiration and infiltration, all have both topical learning objectives as well as quantitative modeling and data skills objectives, 4 labs total)*
- *Vlab (online hands-on calculations of hydraulics and hydrology; including about 300 equations for water surface, pipe flow and sediment transport, and water quality contributed by Victor Ponce).*
- *WILSIM (web-based landscape evolution modeling with special focus on the Grand Canyon, and WILSIM cellular automata on general landscape evolution processes, 2 codes, both developed by Wei Luo).*
- *Coastal Processes Labs (web-based coastal engineering models, including waves, seiche, storm surge and many others, 22 codes total, contributed by Robert Dalrymple).*
- *Sinking Deltas (on sea level rise and land subsidence processes, all have both topical learning objectives as well as quantitative modeling and data skills objectives, 2 labs).*
- *Flow Routing (on modeling of flow over a raster DEM, random walk, steepest descent, D8, Dinf theory, web-based, 1 lab, 1 activity).*
- *River Flow and Sediment Transport and Impacts of Vegetation (concepts of river discharge, flow velocity, critical shear stress, impacts of vegetation, including Mannings equation and a web-based interactive model of vegetation and flow velocity), material developed for Teacher Workshop in August 2015).*
- *Agent-Based Models in Netlogo. This points to resources on the CoMSES model repository and introduces students to agent-based modeling to capture human interactions with the natural system. Particularly the Swidden farming model (contributed by Randall Boone)*

The short course on 'Rivers and Vegetation in the Arid West' was developed jointly by Greg Tucker, Mariela Perignon and Irina Overeem with support from both CSDMS and a NSF-Hydrology award. The short course includes 3 lectures on rivers in the Arid US West, the case-study of the Rio Puerco, New Mexico, and on the theory of river water and sediment transport. Two hands-on components include sandbox experiments and spreadsheets and numerical modeling experiments. This material is geared toward secondary science teachers, with application to curriculum in earth science, physics and biology. The short course material was presented to K12 teachers as part of a 1-day professional development course through the University of Colorado, CIRES and CSDMS outreach program. Five K12 teachers participated in the short course and helped evaluate the teaching material; their backgrounds were dominantly in the physical sciences and math. Material can be used with grades 6-8, as well as more in-depth with grades 9-12. All material has been shared online, and is self-contained for use.
https://csdms.colorado.edu/wiki/TeacherWS2015

Figure 3.3.1 Teachers discussing hands-on learning and learning objectives at the August 2015 Teachers Short Course on 'Rivers and Vegetation in the Arid West'.

Advanced Modeling Labs for Senior Undergraduate and Graduate Students
Advanced labs serve to introduce students to running research grade models on the CSDMS High Performance Computing System. These labs essentially use the CDMS Web Modeling Tool. Basic tutorials on the CSDMS WMT have been updated to the most recent developments. We use open source visualization software for classroom use: Panoply netCDF, HDF and GRIB Data Viewer. The package works cross platform to plot georeferenced as well as non-referenced data. A tutorial on the use of Panoply for WMT users builds basics skills with this package. These two tutorials feature prominently in the CSDMS Educational Repository to get new users started with the CSDMS modeling packages.

Labs are designed to be ~3 hrs in duration and feature a summary of skills and learning objectives, include a presentation on the specific model or the physical concepts, include notes for students to do the numerical experiments, and have a series of questions to guide the exercises.

The online labs using the Web Modeling Tool and ran through the CSDMS HPCC system has grown from 12 to 19 over this last year. It now includes more labs with the new hydrology components of TOPOFLOW, and a mini-series of labs using a simple configuration of the Regional Ocean Modeling System intended for new users (ROMS-Lite).

The labs as of July 2016 include:

1. *Get Started with the Unix Shell*
2. *Get started with Python*
3. *Get started with version control*
4. *Get Started with WMT (basic skills working with WMT)*
5. *Visualize NetCDF Output from WMT (basic skills working with WMT)*
6. *River Sediment Supply Modeling (with HydroTrend)*
7. *Future Sediment Flux of the Ganges River (with HydroTrend)*
8. *Hydrology and Energy Balance (with new TOPOFLOW components)*
9. *Hydrology and Flow Routing (with new TOPOFLOW components)*
10. *Stream Response to Rain (with new TOPOFLOW components)*
11. *ROMS-Lite modeling: learning about grids (with new ROMS-Lite component)*
12. *ROMS-Lite modeling: settling rates and shear stress (with new ROMS-Lite component)*
13. *ROMS-Lite Modeling; wave forcing (with new ROMS-Lite component)*
14. *ROMS-Lite Modeling; river forcing (with new ROMS-Lite component)*
15. *Modeling River Plumes (with PLUME)*
16. *Longshore Sediment Transport and Barrier Coastlines (with CEM and Waves)*
17. *River-Delta Interactions (with coupled Avulsion, Waves and CEM)*
18. *Modeling Stratigraphy in 2-D cross-sections (with Sedflux)*
19. *Modeling of Delta Stratigraphy in 3-D (with Sedflux*
20. *Landscape Evolution Modeling Part 1 (with CHILD)*
21. *Landscape Evolution Modeling Part 2 (with CHILD*
22. *Landscape Evolution Modeling Part 3 (with CHILD*

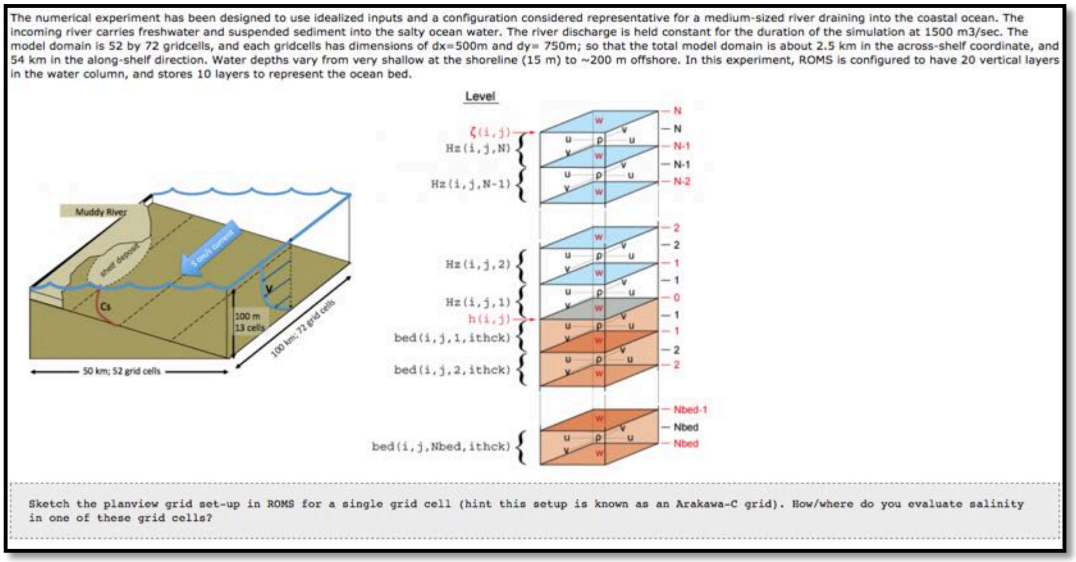


Figure 3.3.2 Example of online lab notes for the regional Ocean Model-Lite
https://csdms.colorado.edu/wiki/Labs_WMT_ROMSLIte_RiverPlume

A number of the labs are organized as mini-series of sequential labs in which increasingly complex processes are addressed. There are now several labs on landscape evolution (CHILD-mini-series), on hydrological processes (TOPOFLOW mini-series), on coastal processes (CEM labs), stratigraphy (Sedflux-2D and 3D) and on ocean processes (ROMS-Lite mini series).

Each of these series of labs have been presented at clinics at the CSDMS annual meeting in 2014-2015 and 2016, as well as at the respective NCED Summer Institutes and 'early adoptors' have now been using them at their own classes at other US universities. Prof. John Jaeger at the University of Florida used the stratigraphic model experiments and WMT, Prof. Patrick Belmont at Utah State university in Logan, used the CHILD landscape evolution labs. Feedback on the use and adoption of these resources has been actively sought at the meeting and this will prompt some additional development of resources.

Figure 3.3.3 Clinic on the newly developed labs using the Regional Ocean Modeling System (ROMS-Lite) at the CSDMS Annual Meeting 2016.

Science on a Sphere

The Community Surface Dynamics Modeling System has a mandate to share state-of-the-art surface process modeling results with large audiences. One platform CSDMS uses to reach audiences outside of the science community is through museum displays. CSDMS has developed model simulation datasets for the 'Science on a Sphere' (SOS) system. SOS is a 4 ft diameter suspended globe on which global and regional simulations can be projected, it is developed by NOAA and is now featured in >100 locations worldwide, mostly at science museums and large research facilities. The SOS team at the Earth System Research Lab of NOAA estimates that > 33 million people see these displays every year. In addition, the data catalogue features stand-alone downloadable movies and educational materials for teachers to use in their own class-rooms.

We contributed global simulations and datasets to the Science on a Sphere catalogue. Examples include hydrological processes, coastal processes, and human interactions with the environment. Model simulations of a global hydrological and sediment transport model (WBM-SED) illustrate global river discharge patterns. WAVEWATCH III simulations have been specifically processed to show the impacts of hurricanes on ocean waves, with focus on hurricane Katrina and superstorm Sandy. A large world dataset of dams built over the last two centuries gives an impression of the profound influence of humans on water management.

Visualizations are developed with Python scripts and comply to well-published data submission protocols of NOAA. Most scripts are unique for each specific model dataset. Datasets story boards and teacher follow-up materials associated with the simulations are developed to address common core science K-12 standards. CSDMS contributions aim to familiarize large audiences with the use of numerical modeling as a tool to create understanding of environmental processes. We plan to use Science on a Sphere explorer for online use of the developed resources.

The EKT repository lists CSDMS contributions to the NOAA 'Science on a Sphere' data repository. The developed datasets are listed (See Table 3.3.2) and quick links to the NOAA data catalogue and teaching materials are provided. We advertise these new teaching resources on the CSDMS web portal front page and have explicitly solicited further contributions from CSDMS members at the CSDMS annual meetings in 2015 and 2016. To more broadly make the Earth Surface Processes science community aware of these resources, we have presented the CSDMS Science on a Sphere approach and datasets at the AGU Fall 2015 meeting in the AGU Education sessions.

Data Set Title	ID	Web link
Dams and Reservoirs 1800-2010	472	http://sos.noaa.gov/Datasets/dataset.php?id=472
Dams and Reservoirs Mississippi River 1800-2010	476	http://sos.noaa.gov/Datasets/dataset.php?id=476
Dams and reservoirs Yangtze River 1800-2010	477	http://sos.noaa.gov/Datasets/dataset.php?id=477
Rivers Daily Discharge	555	http://sos.noaa.gov/Datasets/dataset.php?id=555
Flood Events 2000-2009*	109	http://sos.noaa.gov/Datasets/dataset.php?id=109
Wave Heights 2012	488	http://sos.noaa.gov/Datasets/dataset.php?id=488
Wave Power 2012	487	http://sos.noaa.gov/Datasets/dataset.php?id=487
Wave heights Hurricane Katrina 2005	490	http://sos.noaa.gov/Datasets/dataset.php?id=490
Wave heights Hurricane Sandy 2012	489	http://sos.noaa.gov/Datasets/dataset.php?id=489
A closer look at El Nino & La Nina	Live Program	http://sos.noaa.gov/Datasets/dataset.php?id=563

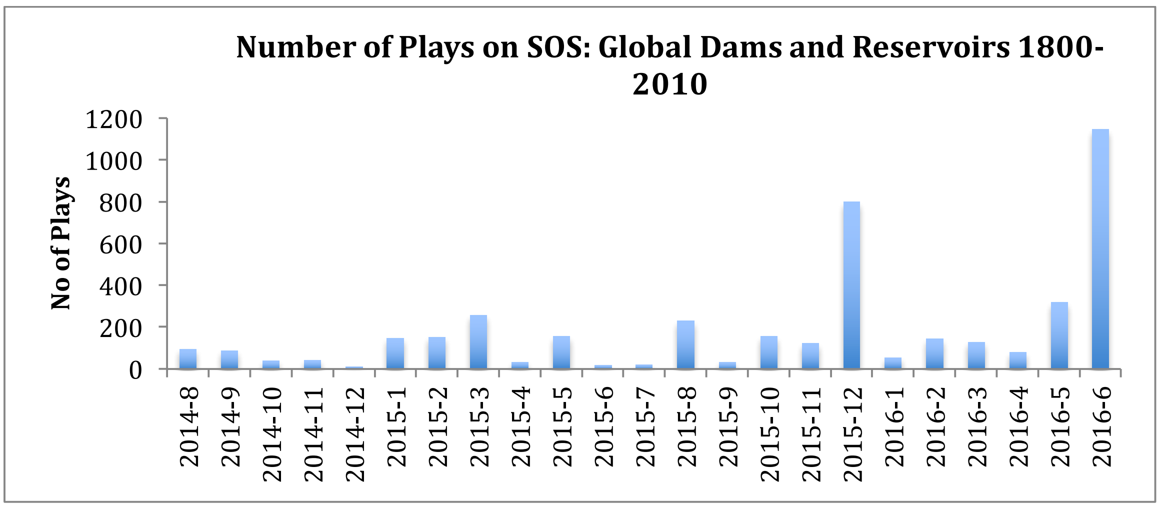
*Table 3.3.2. CSDMS contributions to Science on a sphere dataset catalogue (*data maintained by DFO and CSDMS)*

Three new datasets on 1) the expansion of open water and sea ice free days, 2) vulnerability of deltas, and 3) sea flood properties are to be launched in Fall 2016. A subset of all Science on a Sphere systems (43 reporting installations, out of 102 installations) report data usage in an automated way to the main dataserver at NOAA. These data usage metrics are made available online and allow the contributors to evaluate the impact of their submissions.

Standard parameters that are being reported on each dataset:

- number of plays (when a dataset is being shown by a Science on a Sphere tour guide)
- number of autoplays (when a dataset is shown to bypassers with only the play and the associated presentation but without a tour guide explanation)
- duration of plays

CSDMS' top animation is Wave Heights 2012, as calculated from WAVEWATCH III simulations. The animation has been played 9026 times, over 15 days cumulatively (as of late June, 2016). Metrics on use of the online resources are being kept and can be useful, but for now there is no analysis tool associated with this particular use of the teaching resources.



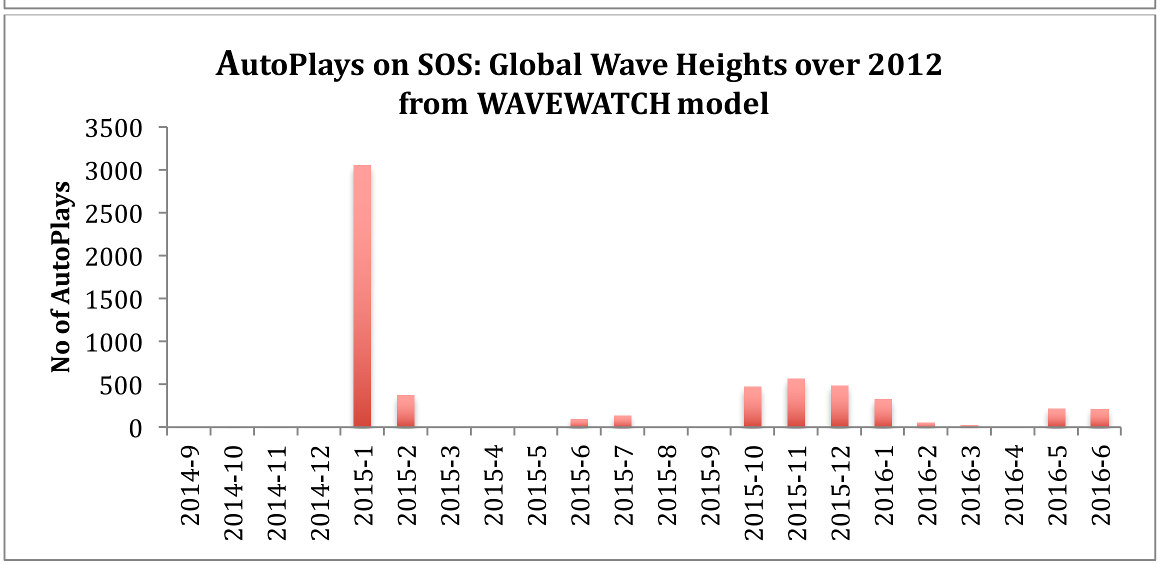


Figure 3.3.4. Usage metrics of Science on a sphere of two popular dataset contributed by CSDMS. Both datasets have been played 1000's of times over the last 2 years.

3.4 CSDMS Experimental Supercomputer

Over the last year 69 individuals were given a new account on the CSDMS High-Performance Computing Cluster, ***beach***. In total now 597 CSDMS members have an account.

To obtain an account on ***beach*** users meet the following criteria:

- Run a CSDMS model(s) to advance science
- Develop a model that will ultimately become part of the CSDMS model repository
- Develop a new data systems or visualization in support of the CSDMS community

The CSDMS High Performance Computing Cluster (HPCC) System ***beach*** (Syvitski is PI) is an SGI Altix XE1300 with 88 compute nodes (704 cores, 3.0 GHz Harpertown processors ≈ 8 Tflops). 64 nodes have 16 GB of memory each; 16 nodes have 32 GB of memory each. Internode communication uses a non-blocking InfiniBand fabric. Each compute node has 250 GB of local temporary storage and can access 72TB (raw) of RAID storage through NFS. Beach provides GNU and Intel compilers as well as their MPI counterparts (mvapich2, mpich2, and openmpi). ***Beach*** is supported by the CU ITS Managed Services (UnixOps) under contract to CSDMS. CPU Utilization rates on Beach average 70%.

The larger Janus supercomputing cluster (Syvitski is Co-PI) consists of 1368 nodes, each containing two 2.8 GHz Intel Westmere processors with six cores each (16,416 cores total) and 24GB of memory (2 GB/core) per node. Nodes are connected using a non-blocking quad-data rate InfiniBand interconnect, and 1 PB of parallel temporary disk storage. Beach is connected to the Janus cluster through a private 10 Gb/s network. The system enables Beach to quickly share large data sets using the Janus 1PB lustre file system. The Janus system CU Research Computing manages Janus.

Top beach users since 1 July 2015

Investigator	Institution	Processor Days
Jim McElwaine	University of Cambridge, UK	32897
Omer Yetemen	University of Washington, USA	1808
Fei Xing	Water Institute of the Gulf, USA	948
Xiujuan Liu	China University of Geoscience, China	748
Frances Dunn	University of Southampton, UK	279
Ahmad Alsinan	University of Santa Barbara, USA	278
Taylor Winchell	University of Colorado, USA	168
Charles Shobe	University of Colorado, USA	122
Katy Barnhart	University of Pennsylvania, USA	80
Qinghuan Zhan	University of Colorado, USA	66

3.5 CSDMS Web Portal Statistics csdms.colorado.edu/wiki/Special:Statistics

CSDMS uses mediawiki open software for its website. The wiki provides the capability to collaborative make modifications of the content, using a web browser. By simply using a web browser CSDMS encourages its members to contribute to the CSDMS project. Some statistics of the wiki:

Content Pages	1,780
Total Pages	12,551
Uploaded Files	3,838
Page Edits	278,346

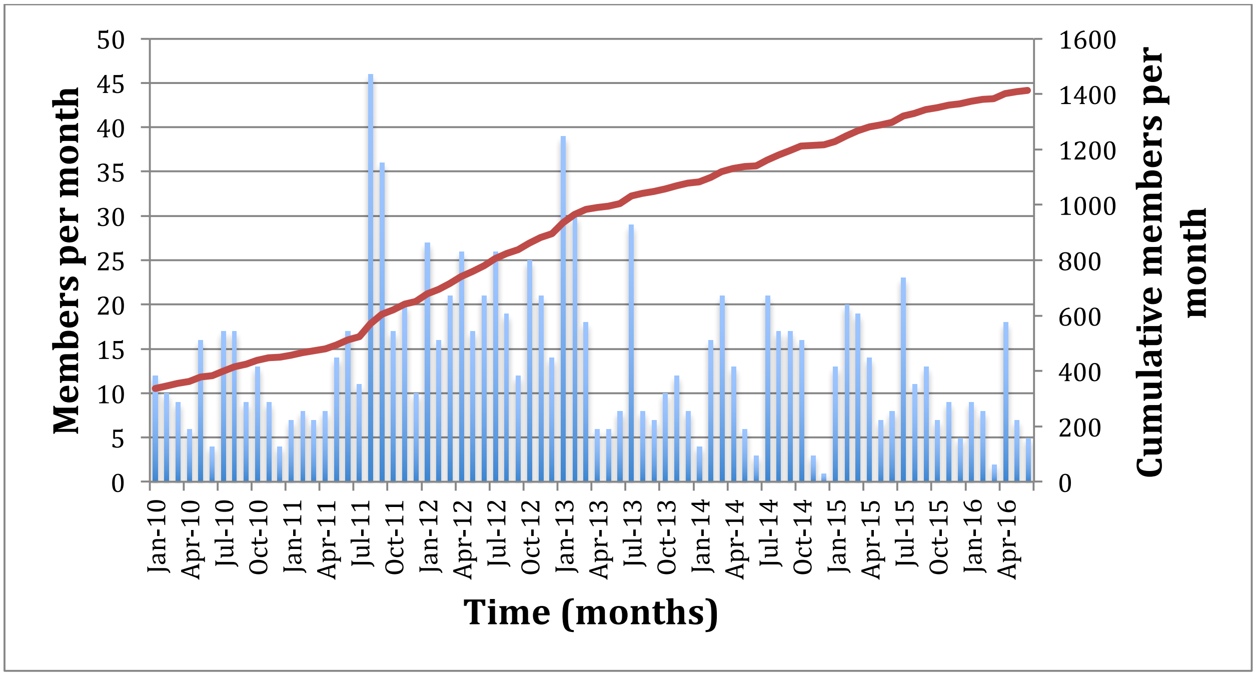


Fig. 3.5.1 Active membership per month as of January 2010. CSDMS has 1414 members as of June, 2016.

Fig. 3.5.2 Spatial representation of all CSDMS members as of June 2016 (interactive version is available through the CSDMS web portal: https://csdms.colorado.edu/wiki/All_CSDMS_members_spatial).

3.6 CSDMS YouTube Statistics http://www.youtube.com/user/CSDMSmovie

CSDMS YouTube channel (introduced in December 2010) hosts its (model) animations, laboratory experiments, real events and conference talks. As of June 2016, 236 people have subscribed to the channel to stay informed about new uploads (61 new subscribers since previous annual report). The channel contains

228 short movies, which in total have been viewed 285,077 times. Over the last year the CSDMS YouTube channel had 52,817 new views, totaling ~48.8 days of CSDMS content viewing time. CSDMS started this channel to make people aware of how illustrative and sophisticated model simulations or associated movies can be. The movies on the CSDMS YouTube channel are integrated into the CSDMS website, and can be viewed through the CMSDS movie portal: http://csdms.colorado.edu/wiki/Movies_portal or directly through YouTube: http://www.youtube.com/user/CSDMSmovie. 25% of the movies are viewed through embedded sites and 75% directly through YouTube.

Top 10 most viewed CSDMS YouTube movies: Of the viewers of the top 10 most viewed movies, most came from the United States (44%), followed by Denmark (10%), the UK (5.5%) and Canada (4.6%). The table below shows the total views as of December 2010 (*Total*) as well as views over the last year (*Last yr*).

Movie title:	***Total:***	***Last yr:***	***link:***
Global circulation	106,625	21,615	http://www.youtube.com/watch?v=qh011eAYjAA
Laurentide Ice Sheet	25,458	6,792	http://www.youtube.com/watch?v=wbsURVgoRD0
World dams since 1800	12,286	3,216	http://www.youtube.com/watch?v=OR5IFcSsaxY
Sand Ripples	11,099	2,948	http://www.youtube.com/watch?v=rSzGOCo4JEk
Delta formation	8,887	701	http://www.youtube.com/watch?v=eVTxzuaB00M
Spit Evolution	7,373	478	http://www.youtube.com/watch?v=N_LBeJPWqFM
Bedload sedim. transpo.	5,727	1,591	https://www.youtube.com/watch?v=is-qcxrKKBI
Floodplain evolution	5,667	382	https://www.youtube.com/watch?v=_G9i_NjYVrQ
Barrier Island	5,161	803	http://www.youtube.com/watch?v=VCX_SzPydsw
Allier river meander	4,621	626	http://www.youtube.com/watch?v=i0KByNRGv_8

Figure 3.6.1 2016 CSDMS Software Carpentry Bootcamp

4.0 CSDMS 2.0 Year 4 Progress

4.1 The CSDMS Python Modeling Toolkit (PyMT)

The CSDMS IF has repurposed the CSDMS model-coupling framework, which was written for use exclusively by the Web Modeling Tool (WMT), to make it more easily used directly by model developers. We call this new framework the PyMT (Python Modeling Toolkit). The PyMT provides a Python interface to our coupling framework that can be used not only by the WMT but also by model developers who wish to couple and develop models within a scripting language without the need for the WMT. Instead, the primary interface for PyMT is through an API that consists of a set of Python models and classes accessed directly by the Python programmer.

PyMT is the fundamental package needed for model coupling of BMI-enabled models. It contains:

- Tools necessary for coupling models of disparate time and space scales
- Time-steppers that coordinates the sequencing of coupled models
- Exchange of data between BMI-enabled models
- Wrappers that automatically load BMI-enabled models into the PyMT framework
- Utilities that support open-source interfaces (UGRID, SGRID, Standard Names, etc.)
- A set of community-submitted models, written in a variety of programming languages, from a variety of process domains

The PyMT framework forms the backbone of the Web Modeling Tool. Whereas the WMT provides a graphical user interface that creates a description of how model components will be coupled and run, PyMT realizes the actual coupling. Given a description of a simulation, the WMT uses PyMT to instantiate each of the constituent components, coordinate the exchange of data between each component (both spatially and temporally), and sequence the advancement of components through time until the simulation is complete.

4.1.1 PyMT is written in Python

The benefit of basing PyMT on Python is that it leverages the capabilities of a popular, powerful, and easy-to-use programming language available for development of new Earth-surface components and applications. PyMT-developed components and applications become available to other developers. PyMT is a hub that contains and organizes models from the large and diverse Earth-system modeling community. Experts are able to build new models in their area of expertise and make those models available to be used by a wide user-base that may be outside the niche in which the model was initially developed.

4.1.2 PyMT is for developers

The Web Modeling Tool provides a user-friendly graphical interface for model coupling. While the WMT targets users who may not be familiar with programming languages but are interested in only running existing models, it does not lend itself well to rapid model development or coupling of models in novel ways, which may be unavailable through the WMT. This is the niche that PyMT targets.

4.1.3 PyMT brings coupling technologies together

The PyMT brings coupling technologies together in a single framework. As one example, PyMT uses the powerful ESMF mappers to translate values from the grid of one component to that of another component that is based on a different grid. Other examples are:

- Standard Names for intelligently connecting component input and output data
- Unit conversion through UDUNITS
- UGRID and SGRID NetCDF data formats
- Time interpolators (these are currently only available offline but will be fully part of the coupling framework in the coming months)

4.1.4 PyMT.components

Although the PyMT is based in Python, it incorporates the BMI-enabled components written in other languages. The Python BMI bindings for these components are generated using the CCA tools (principally, Babel). This allows the instantiation of components, regardless of their source langauge, in a standard object-oriented way. Within the PyMT, the original source language of a component, whether it is C, C++, Fortran, Java, or Python, is opaque to the end-user - all the user sees is Python. The standard PyMT distribution comes with a pre-loaded set of BMI-enabled components. New components can be dynamically added through a plugin system.

In addition, within the PyMT framework, BMI components are augmented with additional capabilities that make them easier to use and run. For instance, PyMT components are provided with:

- An interface that is more "Pythonic"; that is, it follows the accepted standards of the Python programming community
- Dynamically-generated documentation that makes it easier for users to understand
- Setup methods that allows users to easily configure model simulations (manage input/output files, set parameters, etc.)

4.1.5 Get PyMT

The PyMT is available as source code from GitHub (MIT License),

- https://github.com/csdms/pymt

Or as a pre-compiled binary from the CSDMS channel on Anaconda Cloud,

- https://anaconda.org/csdms/pymt

The pre-compiled version is easily installed with the `conda` program and includes pre-built versions of all its dependencies. This includes the CCA toolchain (Babel, ccaffeine, etc.), the ESMF mappers, and component models (sedflux, child, CEM, etc.). Thus far, these binaries are available and regularly built and tested, on Linux and Mac operating systems. The distribution of these binaries represents a significant advancement. The building of the complete CSDMS software stack from source is a time-consuming and difficult process that, for the most part, has been the purview of only the CSDMS IF. The distribution of a pre-compiled version of the stack allows for quick and easy installation for model developers.

4.1.6 PyMT successes

PyMT is used by groups outside of the CSDMS Integration Facility. A recent success is in the development of a new delta avulsion model (Rafem) and it's coupling with a coastal evolution model (CEM). Because the Rafem model was actively being developed to achieve this coupling, its linking with CEM would not have been feasible through the WMT.

Researchers from Duke University developed a new morphodynamic delta model that links fluvial, floodplain, and coastal dynamics over large spatial and time scales. By wrapping their model with a BMI, and adding it to the PyMT, they were able to couple it with the Coastline Evolution Model. In Rafem, the river course is determined using steepest-descent methodology, and elevation changes along the river profile are modeled as a linear diffusive process. An avulsion occurs when the riverbed becomes super-elevated relative to the surrounding floodplain, but only if the new steepest-descent path to sea level is shorter than the prior river course. CEM uses alongshore sediment transport gradients to distribute sediment flux from the river mouth along the coastline. A visualization of outputs from the Rafem-CEM coupling is shown in Figure 4.1.1.

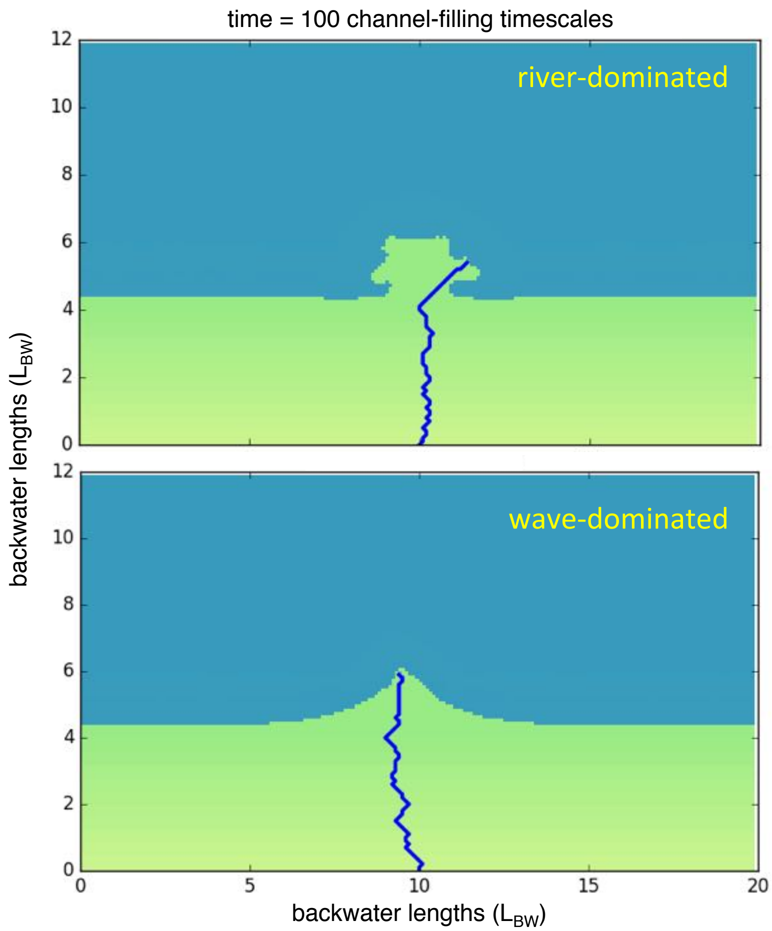


Figure 4.1.1. Building a delta with the Rafem-CEM coupling under two different wave/river climates.

4.2 Software Distribution

CSDMS now distributes its complete software stack as pre-compiled, ready-to-run binary packages (for Mac and Linux) distributed with the Anaconda package manager. Packages include: community-contributed software, externally developed dependencies, and CSDMS software. This distribution system opens up the CSDMS software stack and model coupling framework to a wider audience that includes, importantly, model developers who are able to contribute back to CSDMS and help maintain a stable code base. Through the new PyMT, users may also interactively run models, through the Basic Modeling Interface, from within a Python interpreter.

A complete list of the packages distributed by CSDMS can be found on the CSDMS channel of Anaconda Cloud (https://anaconda.org/csdms). CSDMS currently maintains a collection of over 50 packages built for both Linux and OSX operating systems. CSDMS also maintains both a stable and a development version of each package. The development version is updated whenever new changes are commited to its code base, while the stable versions are updated less frequently and correspond to software releases.

A list of the build recipes for the CSDMS Stack (https://github.com/csdms/csdms-stack) is also on GitHub. Moving forward, the CSDMS will continue to add new packages to the stack as more codes are submitted to the CSDMS repository. The current collection of packages is principally core packages required to run

CSDMS software. However, packages that can run independantly of CSDMS software will also be available through this repository.

Anaconda Cloud is an online package management service where users store, among other things, PyPI and conda packages. These packages typically consist of pre-compiled versions of programs that are easily discoverable and accessable - primarily through the Anaconda Client command line interface (conda). The Anaconda Cloud is provided for free and the conda command line utilities are open source (https://github.com/conda).

4.3 CSDMS Software Stack on Other HPC Clusters

In Spring 2016, the CSDMS IF worked with Jian Tao, Jim Chen, and Sam Bentley of the Louisiana State University (LSU) Coastal Resilience Collaboratory (CRC) to install the CSDMS software stack on ***philip.hpc.lsu.edu***, a cluster within LSU's high-performance computing organization, HPC@LSU (http://www.hpc.lsu.edu). ***Philip*** is currently available as an executor—the WMT computational resource—for the **wmt-hydrology** instance (for more on WMT instances, see Section 4.4):

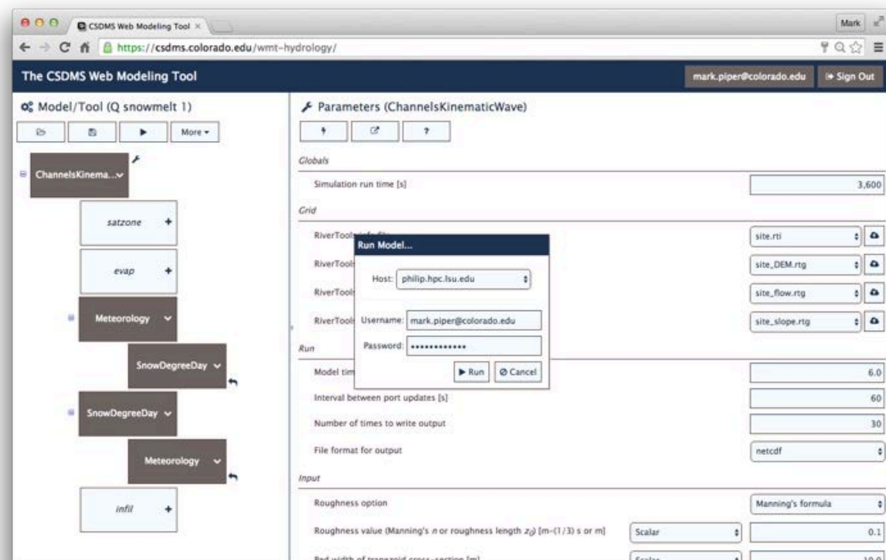


Figure 4.3.1. Preparing to submit a model run from WMT to an HPC cluster at LSU.

Now, when a user of the **wmt-hydrology** instance would like to execute a model they've designed and configured in WMT, they can choose to submit the job to the CSDMS HPCC, ***beach***, or to ***philip***, assuming that they have the proper credentials and an allocation for computing time on either of these HPC clusters[1]. Just as when running a job on *beach*, a job that completes on ***philip*** is packaged as an archive file and transferred to the CSDMS data server, ***diluvium***, where it can be downloaded by the user.

Deploying the CSDMS software stack on other HPC systems, such as HPC@LSU, helps to increase the stability, accessibility, and sustainability of the CSDMS Web Modeling Tool, and of the model-coupling framework developed at CSDMS that it employs.

[1] An allocation for testing and development on *philip* has gratefully been provided to the CSDMS-IF by Dr. Jian Tao of the CRC.

4.4 The CSDMS Web Modeling Tool (WMT)

Version 1.0 of the CSDMS Web Modeling Tool (WMT) was released in September 2015, with announcements on the CSDMS portal, newsletter, and social media channels. WMT was also highlighted in a poster presentation at the 2015 AGU Fall Meeting (http://abstractsearch.agu.org/meetings/2015/FM/IN13B-1841.html). Version 1.1 of WMT, incorporating improvements to the client interface and server-side code, along with bug fixes, will be released in September 2016. To increase trust in the continued development and maintenance of WMT, we plan to continue to issue yearly updates.

To get a sense of WMT's use in the community, in the interval between September 2015 and June 2016, there have been

- 56 unique usernames registered,
- 318 models created by users, and
- 303 jobs submitted.

One significant update to WMT since the 1.0 release was driven by community feedback: we have reintroduced the notion of projects, which are groups of related components organized by an administrator. CMT, the precursor to WMT, used projects, but they had not, until now, been included with WMT. The WMT URL, https://csdms.colorado.edu/wmt, now directs to a landing page, as shown below in Figure 4.4.1. From the landing page, a user can select from a set of several WMT instances, each representing a project containing a group of logically related components. The eight active and planned projects are:

- **wmt-analyst**: The primary WMT instance, containing the complete set of CSDMS components, for users who prefer unrestricted access to the CSDMS components. (Active)
- **wmt-coastlines**: Simulate coastline evolution under influence of river and wave action. This project allows coupling between the HydroTrend, Avulsion, CEM, and Waves components. (Planned)
- **wmt-deltas**: Simulate river and coastal processes, and how deltaic coastlines change, with the HydroTrend, Avulsion, River, CEM, Waves, RCDELTA, Sedflux2D, Sedflux3D, and Plume components. (Planned)
- **wmt-ed**: A group of components with reduced parameter sets designed for classroom use. (Planned)
- **wmt-hydrology**: Simulate hydrological processes such as precipitation, evapotranspiration, infiltration, and runoff on short time scales with TopoFlow components. (Active)
- **wmt-roms**: Simulate mesoscale dynamics of oceanic and coastal processes with the Regional Ocean Modeling System (ROMS). (Active)
- **wmt-stratigraphy**: Simulate geological-scale landscape evolution and basin fills, and study stratigraphy, with HydroTrend, River, CHILD, Sedflux2D, and Sedflux3D. (Planned)
- **wmt-uncertainty**: Use Dakota to apply sensitivity analysis and uncertainty quantification techniques to components. (Prototype)

The CSDMS community has found projects useful for modeling processes in particular subdomains. Projects are also well suited for teaching; for example, Irina Overeem of the CSDMS IF used the **wmt-hydrology** and **wmt-roms** instances to teach two hands-on clinics at the 2016 CSDMS Annual Meeting.

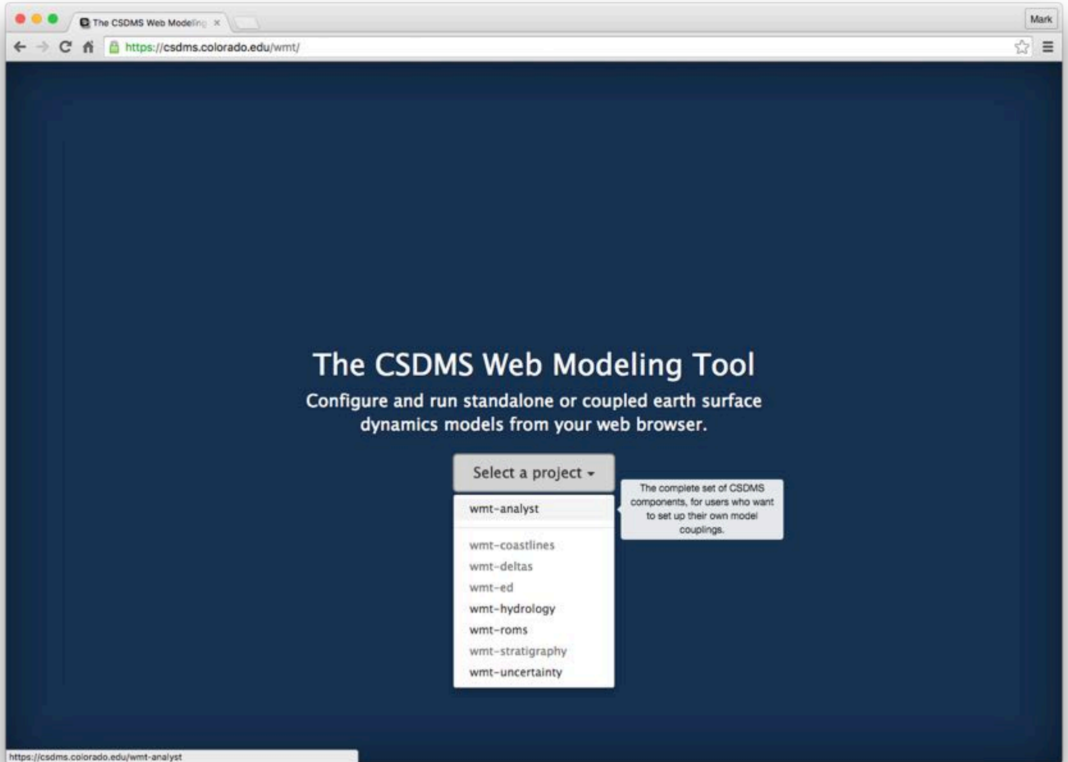


Figure 4.4.1. The WMT landing page, showing the project selector.

WMT continues to be actively developed. Since the version 1.0 release in September 2015, there have been

- 262 commits to GitHub,
- 13 issues reported (6 of which have been resolved), and
- 148 files changed, with 10899 insertions (+) and 2389 deletions (-).

WMT development is divided into five GitHub repositories:

- **wmt**, the database and data servers
- **wmt-exe**, the execution server
- **wmt-client**, the web client
- **wmt-metadata**, the metadata for components listed in WMT
- **wmt-selector**, the WMT landing page

These repositories, each open-sourced under the MIT License, can be found under the CSDMS organization on GitHub, https://github.com/csdms. We encourage CSDMS members to fork these projects to add their own features, enhancements, and improvements, and then create pull requests to merge them back into the original CSDMS projects.

Several improvements have been made to the WMT client since its 1.0 release in September 2015.

- The client now includes an installer script, written in Python, allowing an administrator to build a client for a WMT instance without knowledge of the Java build process.

- Developer documentation for the WMT client has been written, using Javadoc, and is available online at http://csdms.colorado.edu/docs/wmt-client. This documentation will help other developers in the community to understand and improve the code used to make the WMT client.
- A model parameter can now be designated *global*. A global parameter is set in the driver component of a model, and is applied to all other components. An example is run_duration – setting this parameter as global forces all components in a model to run for the same amount of time. This is an improvement over explicitly entering and checking the run duration of each model component.
- The client includes new composite widgets, *group* and *selector*, which allow complex model parameters to be represented visually. Both widgets are used, for example, in the **wmt-topoflow** instance.
- The WMT API provides an improved status page for a model run. (See Figure 4.4.2 below.) The page provides console output from the executor that can be helpful in debugging a failed run. It also refreshes automatically.
- For security, all HTTP requests are redirected automatically to HTTPS.
- When uploading an input file used by a model, the user is only prompted once to save the model. This is a minor update, but it removes a major annoyance to the user.

The CSDMS IF strives to respond to feedback from the user community, and continually attempts to improve the usability and the utility of WMT.

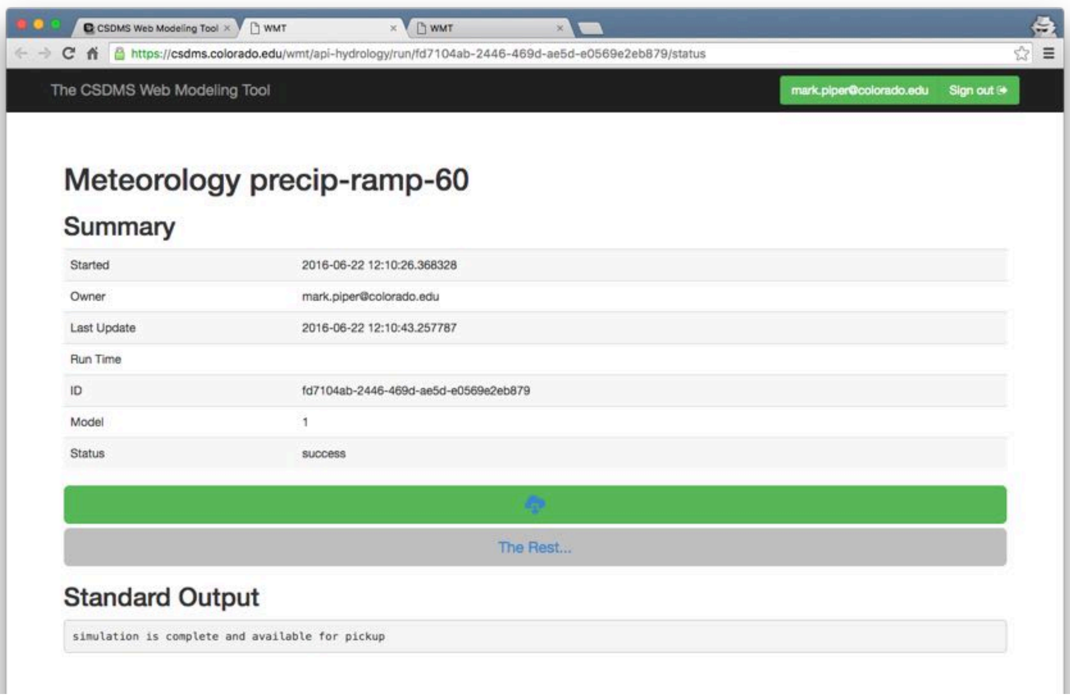


Figure 4.4.2. The improved WMT simulation status page.

4.5 Automated Wrapping for Moving BMI Components into PyMT

The CSDMS IF continues to automate and simplify the building and wrapping of BMI-enabled components so that they are available from within the PyMT framework. In addition to the BMI-to-PyMT bridge which wraps a BMI-enabled Python object (see section 4.1), newly developed tools automate the building of the necessary language bindings (Python – but other language bindings such a C/C++ are also generated as a side effect) and deployment (to the CSDMS channel on Anaconda Cloud). The Python interface for these components are then available as standalone modules or as Python components within the PyMT package.

4.6 Automated BMI Generation

The CSDMS IF has extended the *bmi-builder* so that it is able to generate template code for Python implementations of the BMI. As with the previous version, which generated implementation code for C/C++, bmi-builder reads metadata (as YAML-formatted text) that describes the new BMI and generates files with boilerplate code that contains stubs for the developer to fill in based on their specific model.
In addition to *bmi-builder* advancements, the CSDMS IF has added utilities to the CSDMS software stack that will make it easier for Python developers to wrap existing Python components with a BMI or to create new BMI models from scratch. For instance, the *basic-modeling-interface* package provides a base class for Python implementations of the BMI. Python developers need only create a new class that inherits from this base class and implement the necessary methods. The basic-modeling-interface package is publically available on PyPI (https://pypi.python.org/pypi/basic-modeling-interface), and can be installed with `pip` or `conda`.

In support of increasing the ease with which developers can create BMI-enabled models, The CSDMS IF has created several examples that provide complete examples of Python code that developers can use to create their own BMI-enabled components. The CSDMS IF has used these examples as part of clinics, which are published online, that walk participants through the process of adding a BMI to their model; for example:

- BMI Tutorial (https://github.com/mcflugen/bmi-tutorial)
- BMI Live! (https://github.com/csdms/bmi-live)

The CSDMS-IF has created a new BMI-Tester command-line tool that will check a BMI implementation for conformance to the current BMI standards. Given a BMI-enabled model with Python bindings, the BMI-Tester will instantiate the model and check each of its methods to make sure they, for instance, are implemented, expose the expected calling signature, and return the expected variables.

- bmi-tester on GitHub (https://github.com/csdms/bmi-tester)

4.7 New Components

The CSDMS IF continues to add models with a BMI to the CSDMS modeling framework. The following components either have been added, or will be added, to the CSDMS framework and made available in WMT by the end of the current funding year:

- **RomsLite**: ROMS is a Free-surface, terrain-following, orthogonal curvilinear, primitive equations ocean model. Its dynamical kernel is comprised of four separate models including the nonlinear, tangent linear, representer tangent linear, and adjoint models. It has multiple model coupling (ESMF, MCT) and multiple grid nesting (composed, mosaics, refinement) capabilities. The code uses a coarse-grained parallelization with both shared-memory (OpenMP) and distributed-memory (MPI) paradigms coexisting together and activated via C-preprocessing.
- **Ku**: This model provides an implementation of the approximate solution to the Stefan problem as presented by Kudryavtsev et al. (1974). It can be used for estimating maximum annual thawing depth and mean annual temperature at the permafrost interface (or at the bottom of the active layer). The model assumes the ground thermal regime is in a steady state. Kudryavtsev's model considers the influences of several factors, including snow cover, vegetation, soil moisture, and soil thermal properties, allowing it to be applied over a wide variety of climatic conditions. It has been developed for use at a single site and for spatial simulation.
- **FrostNumber**: The dimensionless "frost number" (Nelson and Outcalt, 1983) is computed from monthly average temperature and precipitation data in order to provide an objective definition for the presence or absence of continuous permafrost over wide geographic regions. The FrostNumber

model, coded in Python, is capable of generating frost numbers either at individual stations or, using NCEP reanalysis data, across the state of Alaska.

- **The River Avulsion and Floodplain Evolution Model (Rafem)**: Rafem is a cellular model that simulates river and floodplain morphodynamics over large space and timescales. Cell size is larger than the channel belt width, and natural levees, which maintain a bankfull elevation above the channel bed, exist within a river cell. The river course is determined using a steepest-descent methodology, and erosion and deposition along the river profile are modeled as a linear diffusive process. An avulsion occurs when the riverbed becomes super-elevated relative to the surrounding floodplain, but only if the new steepest-descent path to sea level is shorter than the prior river course. If the new path to sea level is not shorter, then a crevasse splay is deposited in the adjacent river cells. Domain-wide uniform floodplain deposition and subsidence are additional components of RAFEM. The model has been designed to couple with the Coastline Evolution Model through the CSDMS Basic Model Interface. We will use the two-way coupling to explore the long-term combined effects of sea-level rise, climate change, and anthropogenic influences on river, floodplain, delta, and coastal morphodynamics over multi-avulsion timescales.

The Landlab project is a Python-based library with utilities for creating grid-based models. Although the Landlab component interface is modeled after the BMI, it does not match perfectly. However, the Landlab team has created a bridge that makes a Landlab component appear as a generic BMI component. Some potential new Landlab BMI components include:

Hillslope geomorphology

- **LinearDiffuser**: model soil creep using "linear diffusion" transport law (no depth dependence).
- **PerronNLDiffuse**: model soid creep using implicit solution to no-linear diffusion law.

Fluvial geomorphology

- **FastscapeEroder**: compute fluvial erosion using stream power theory ("fastscape" algorithm).
- **StreamPower**: compute fluvial erosion using stream power theory (explicit forward-difference solution).
- **SedDepEroder**: compute fluvial erosion using "tools and cover" theory.

Flow Routing

- **FlowRouter**: calculate flow direction and accumulation from topography.
- **DepressionFinderAndRouter**: handle depressions in terrain by calculating extent and drainage of "lakes".
- **PotentiallityFlowRouter**: find flow directions and accumulation using potential-field theory.

Shallow water hydrodynamics

- **OverlandFlow**: model shallow water flow over topography using the numerical approximation of de Almeida.: model shallow water flow over topography
- **OverlandFlowBates**: model shallow water flow over topography using the numerical approximation of Bates.

Land surface hydrology

- **Radiation**: Calculate solar radiation on topography given latitude, date, and time.
- **PotentialEvapotranspiration**: compute potential evapotranspiration using the Priestly-Taylor method.
- **SoilMoisture**: compute he space-time evolution of soil water content.

Vegetation

- **Vegetation**: model plant dynamics using single representative species.
- **VegCA**: simulate vegetation dynamics with cellular automation model of grass, shrubs, and trees.

Precipitation

- **PrecipitationDistribution**: generate random sequence of precipitation events.

Terrain Analysis

- **SteepnessFinder**: calculate steepness and concavity indices from gridded topography.
- **ChiFinder**: Perform chi-index analysis for gridded topography.

Tectonics

- **Flexure**: calculate elastic lithosphere flexure multiple under loads (assumes uniform flexural rigidity).
- **GFlex**: compute elastic lithosphere flexure with variable rigidity.

Fire

- **FireGenerator**: generate random sequences of fire events.

Initial conditions

- **FractureGrid**: Generate random fracture patterns on a regular raster grid.

SedGrid: A component for storing stratigraphy

The CSDMS IF has created a new service component, SedGrid, based on the *sedflux* modeling framework. Essentially, the core architecture within the *sedflux* model that stores sediment layering has be removed, refactored and given a BMI. SedGrid is a *service component*, in that it is not a model in itself but rather is used to provide a service to other components. Through its BMI, SedGrid is able to store evolving three-dimensional stratigraphy generated by other models. SedGrid now has a fully functional BMI that is able to accept deposition and erosion rates from other components and record the resulting stratigraphy.

The SedGrid BMI is available as a Python class within the CSDMS modeling framework, PyMT. As with other CSDMS software products, it is freely available as source code (through GitHub), or as a pre-compiled binary (through Anaconda Cloud).

4.8 Analysis of Model Uncertainty

The CSDMS-IF is actively developing a Python interface for Dakota, the CSDMS Dakota interface (https://github.com/csdms/dakota). Since the introduction of this software (version 0.1) at the 2015 CSDMS annual meeting, there have been:

- 89 Commits
- 2 issues reported (0 of which have been resolved)
- 103 files changed, 6906 insertions(+), 3032 deletions(-)

Many of the recent updates to the software focus on making the interface easier to understand and use; for example, better default values have been assigned to frequently used properties, and some methods have been combined to form composite helper methods. Three Jupyter Notebooks that demonstrate how to use the software have also been added to the repository.

Currently, the CSDMS Dakota interface is structured such that any model that accepts an input configuration file (or files), and produces output files, can be added as a plugin and run within the interface. This allows developers to use the software outside of the CSDMS modeling framework. However, the software does not currently use a model's BMI, which makes it unusable with the CSDMS modeling framework. By the end of the fiscal year, the software will be updated to use a model's BMI, then wrapped as a service component into the CSDMS modeling framework.

A portion of the work on the CSDMS Dakota interface is funded by a CISE/ACI CIF21 Venture Fund for Software Reuse grant. Work on this part of the software includes adding three new Dakota analysis methods:

- Sampling
- Polynomial chaos
- Stochastic collocation

An implementation of the Sampling method has been written, tested, documented, and added to the software. Two other methods will be included by the end of the fiscal year.

To enhance the long-term sustainability of the CSDMS Dakota interface, we use web services that are triggered every time a pull request is made into its GitHub code repository. These services include:

- Travis CI, which runs the unit tests (currently 148) defined for the software,
- Coverage, which checks what parts of the code are hit by the unit tests,
- Landscape, which scores the health of the code, and
- Read the Docs, which rebuilds the developer documentation and publishes it at http://csdms-dakota.readthedocs.io.

By employing these services, the CSDMS-IF can continually monitor the status of this software, and attempt to address code rot before it occurs.

Over the past year, the CSDMS-IF has been active in helping the community use Dakota to explore model uncertainty.

- CSDMS-IF collaborated with Chris Sherwood (USGS) to create an example of testing the parallelized SWASH model with Dakota (https://github.com/mdpiper/dakota-swash-parameter-study).
- Mark Piper (CSDMS-IF) gave a guest lecture on Dakota to the students of Greg Tucker's GEOL 5700 class at the University of Colorado (http://mdpiper.github.io/dakota-seminar).
- CSDMS-IF is helping two graduate students, Katherine Ratliff (Duke) and Charlie Shobe (CU), apply Dakota to models they've developed in their PhD research.
- CSDMS-IF has been assembling a library of Dakota examples, demonstrating how to use various Dakota analysis methods, in https://github.com/mdpiper/dakota-experiments.
- An undergraduate research assistant jointly funded and hosted by the Perma Toolbox and CSDMS IF works with the IF over the summer of 2016 to explore optimization techniques in Dakota for two permafrost models.
- Dakota functionality in the WMT will be demonstrated at the NCED summer institute August 2016, to 40 US and international students and early career participants.
- CSDMS-IF is developing instructions for using Dakota on the CSDMS HPCC, ***beach*** (http://csdms.colorado.edu/wiki/Dakota).

4.9 Model Benchmarking & Model Inter-comparison

Model intercomparison and benchmarking is of key importance to understanding the strength and weaknesses of a particular numerical model, as well as a suite of comparable models or modeling frameworks. Once models are increasingly used in predictive manner or for scenario modeling to guide policy-making, the importance of benchmarking individual models and comparison of models and modeling frameworks becomes paramount. Large modeling frameworks also need to be used in large ensembles to investigate internal model dynamics. Yet, model benchmarking and intercomparison projects are prevalent in some domains of the surface processes modeling community and much less practiced in others.

Knowledge Transfer about model intercomparison and benchmarking practices
The CSDMS Annual Meeting 2016 was focused on 'Capturing Climate Change' and thus provided an opportunity to highlight predictive Earth Surface modeling efforts, which commonly involves model intercomparisons. Several keynote talks showcased a number of model intercomparison efforts in the terrestrial, hydrology and coastal/marine climate modeling domains:

- Bette Otto-Bliesner *Climate Dynamics of tropical Africa*
- Enrique Curchitser *Regional and Global Ramifications of Boundary Current Upwelling*
- Mark Rounsevell *Integrative Assessment Modeling*

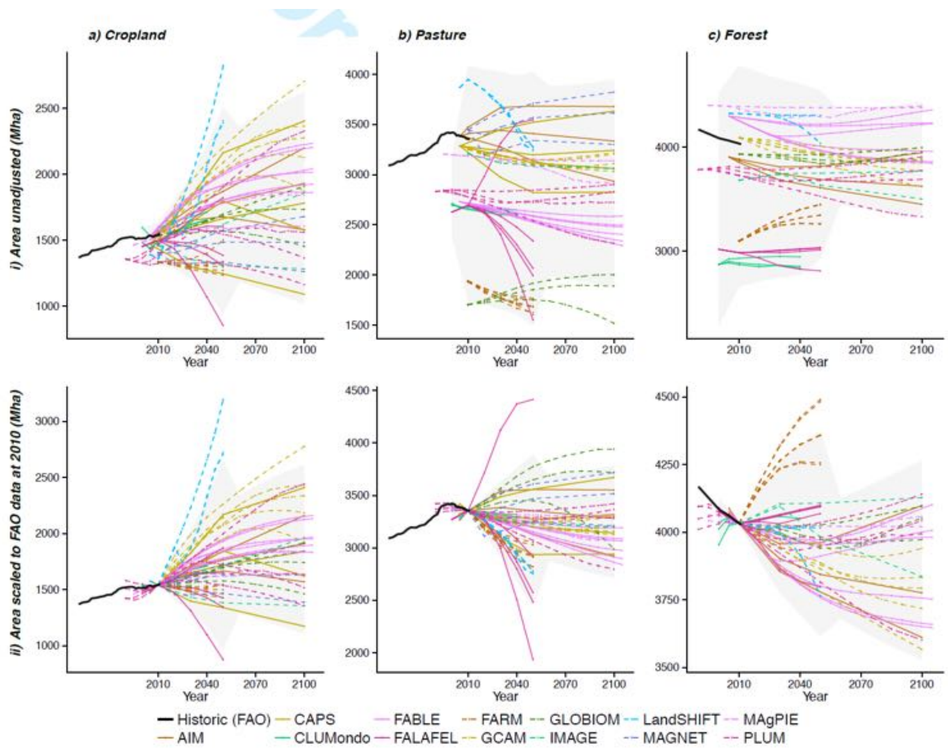


Figure 4.9.1 Large uncertainty in 21st century predictions of a suite of global scale land-use change models aimed at assessing changes in cropland, pasture, forest (adapted from Rounsevell, 2016 talk at CSDMS 2016 meeting).

Other keynotes explained approached for model benchmarking using field datasets and explicit efforts of the global coupled ocean-atmosphere modeling community to deal with natural variability and model uncertainty within a single coupled model by using a suite of 32 model realizations (i.e. in the Large Ensemble of the Community Earth Surface Modeling System).

- Nikki Lovenduski *Ocean Carbon Uptake and Acidification: Can we Predict the Future?*
- Jon Pelletier *Modeling the impact of vegetation changes on erosion rates and landscape evolution*

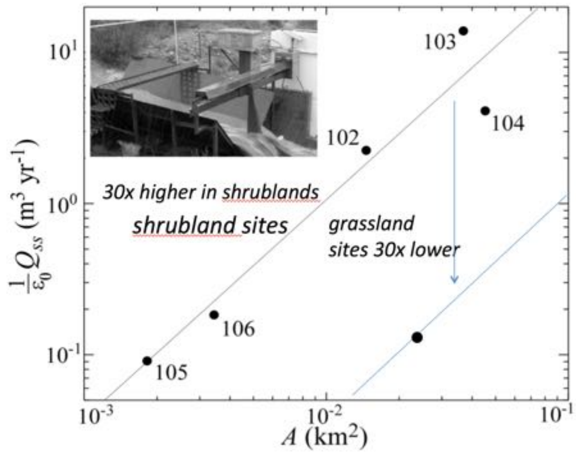


Figure 4.9.2 Erosion and sediment transport modeling with benchmark data from Walnut Gulch in Arizona shows that vegetation cover changes in arid regions of the US West leads to dramatic changes in erosion rates and topography (adapted from Pelletier, 2016 talk at CSDMS 2016 meeting).

Benchmark Datasets and Analytical Solutions

It has been well recognized that tank experiments can function as model benchmark datasets. The most widely known examples are lock-release experiments. Documenting tank experiments for possible future use by numerical modelers for model testing is an important charge. CSDMS strengthened collaboration with the EarthCube RCN Sediment Experimentalists Network in 2016 by having a joint meeting. In addition CSDMS IF staff participates in the SEN steering committee. CSDMS provides the modelers needs perspective in the design process of best practices for data collection and management. http://earthcube.org/group/sen The SEN Knowledge Base now features ~24 documented datasets, and 22 more datasets in development. The CSDMS data catalogue directly links to the SEN Data catalogue.

In 2015, the Cyberinformatics Working Group initiated a CSDMS Model Solution Library, a collection of analytical or closed-form solutions to a variety of mathematical models, which are popular in the surface processes domain. The Library includes now 27 entries with pointers to more detailed information, and varies for more general processes to specific domains:
http://csdms.colorado.edu/wiki/Model_Solution_Library

CSDMS Integration Facility Benchmarking Efforts

In Spring 2016, CSDMS-IF purchased an additional network attached storage unit with 37 TB of RAID 2 hard disk space for the CSDMS HPPC, ***beach***. This unit will house benchmark data, as well as sample model input and output files that can be used for testing and for model intercomparison. CSDMS-IF has begun collecting data and files used with components in the CSDMS modeling framework. The storage unit is mounted as **/nas/data** on ***beach***, and is available to all users.

The International Land Model Benchmarking (ILAMB; http://ilamb.org) project strives to improve the performance of land surface models though enhanced benchmarking against observational data. The ILAMB project personnel have developed a software tool that allows researchers to compare CMIP5-compatible model output with a set of benchmark datasets, focusing on variables such as gross primary production of carbon, precipitation, albedo, and soil moisture. CSDMS IF has installed the ILAMB benchmarking software on ***beach***. CSDMS-IF will use the ILAMB software in the Permafrost Benchmark System, a collaboration with NSIDC personnel, to conduct benchmarking studies of permafrost models. The ILAMB software, which is modular and open source, will be evaluated for developing model benchmarking tools developed by CSDMS, as discussed in Section 7.2.

4.10 CSDMS Portal

From July 2015 – June 2016, the CSDMS website had an average of 462 page views per day, which is a small increase to last reporting year (with 1348 as maximum page views per day, which occurred the first day of the CSDMS annual meeting). Typically, the CSDMS web portal has 29% returning viewers and 71% new viewers. The top 3 countries from where the CSDMS website is mostly visited are similar like last year: United States (44%), followed by China (6%) and India (4%), of which the majority used a desktop (92.8%) and only a small percentage used mobile devises (5.7%) or a tablet (1.5%). The CSDMS website is the first to come up in a Google search, automatically displaying 6 site links, which are the most visited sections of the website (CSDMS annual meeting; CSDMS Model repository; Models; Data; CSDMS community, and CSDMS Modeling Web Tool). Site links are shown on privilege by Google (so not controllable in Google search) and are only shown for nr. 1-search hits, when pages' lifetime exceeds 2 years, and has a Google page rank of at least 2. Site links typically provide more exposure.

Last year, CSDMS became even more involved with the community by: 1) posting CSDMS related job opportunities (133); reporting upcoming events like symposia, conferences and workshops (42); and tweeting CSDMS related messages to 133 (https://twitter.com/CSDMS).

Web Portal Improvements

a) H-index for models (*implemented*). Similar as assigning DOIs to open source code, CSDMS is now the first to provide citation indices for each individual model that is listed in the CSMDS model repository. These indices are estimated similar like citation indices that are available for authors at e.g. 'Google Scholar' or 'Web of Science' and based on publication citations (https://goo.gl/LYJNig).

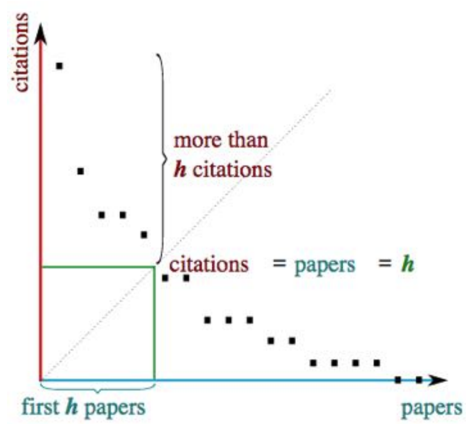


Fig. 4.10.1. Illustration on how a model h-index is determined

The model citation indices are based on three classes of publications: a) **module overview** publication, describing a module, b) **a module application description** where a model is applied to a study and c) **citation of a model itself when a DOI** is associated to the model source code. CSDMS-IF welcomes references to publications describing *module related theory* but these references are not considered when citation indices are estimated. Indices will be updated every 24hours. The following indices are estimated:

- ***Citations***
- ***h-index***

The ***citations*** indicate the total citations a model has received. The ***h-index*** is named after the physicist Jorge Hirsch and is also called the ***Hirsch number***. The h-index as implemented at CSDMS reflects the use (or penetration of a model within a community) and its impact (how often a publication about the model is cited). More information about the h-index can be found at: https://en.wikipedia.org/wiki/H-index.

Citation indices	CHILD
Citations:	3937
h-index:	28

Part of our reasoning to develop a h-index for models is so CSDMS can provide the community with a robust evaluation tool of e.g. how often a model is applied in scientific studies. Therefore, we encourage the community to add model references to the CSDMS portal and the CSDMS-IF will try to incorporate as many publication references as well to make the h-index for models more robust. For ease of use and consistency in submitting data to the reference database a 'Publication' form has been developed. It is beyond the scope of the CSDMS project to automate the process of adding model references to a database. This will take too much resources as for example a simple search on model name to get all references is impossible given that many models are given common names (Child, Waves, Avulsions, etc.). So far 733 model references are added to the CSDMS reference database. Once a model reference is added to the CSDMS reference database, a unique code gets assigned to assure regular updates of the number of citations, using data from Google Scholar. This will be also done for open source code models of which the source code is not hosted by CSDMS but that are listed in the repository. Another advantage is that CSDMS provides all references for each model on its model description page.

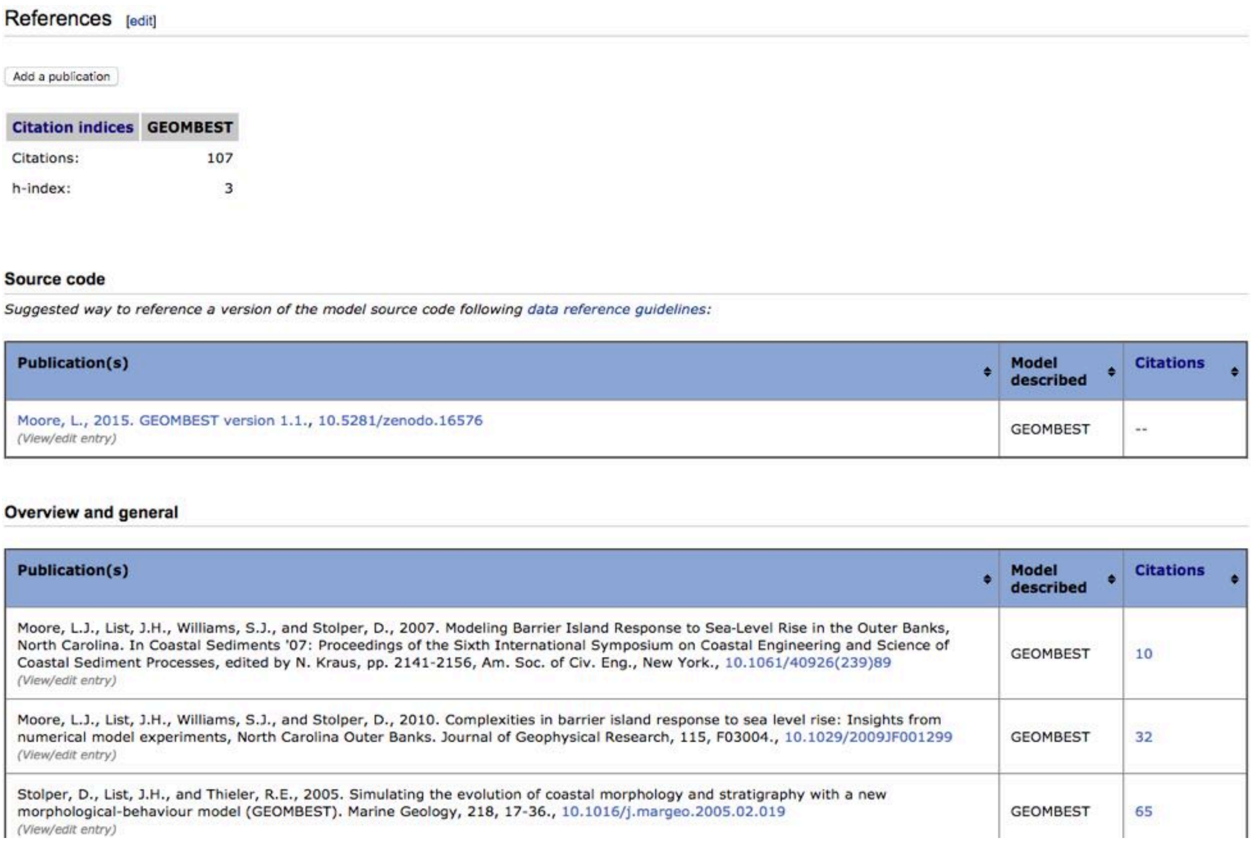


Fig. 4.10.2. Illustrating how references of the GEOMBEST model are presented on its model page.

b) Web portal API (*implemented*). Mediawiki and Semantic MediaWiki provide Application Programming Interfaces (APIs) that allows users to query, add, and edit information on the CSDMS portal. CSDMS-IF has added an article on how to use Mediawiki's Ask APIs for the portal (http://csdms.colorado.edu/wiki/Querying_the_CSDMS_model_repository), along with a set of examples (http://csdms.colorado.edu/wiki/Examples_of_querying_the_CSDMS_model_repository), and a GitHub repository with Python examples (https://github.com/csdms/ask-api-examples). In Spring 2016, CSDMS-IF assisted Jian Tao (LSU) in using the Ask API to programmatically obtain model metadata from the CSDMS Model Repository. Dr. Tao used the model metadata to set up Docker containers, which he uses to build the models for the NSF funded SIMULOCEAN project. A YouTube video (https://www.youtube.com/watch?v=5RkMeYt2pjM), demonstrates how, for example, HydroTrend can be used within SIMULOCEAN.

c) CSDMS portal now hosted on new server. We are happy to announce that the CSDMS Integration Facility has purchased and taken into us a state of the art web server together with additional funding from the Dartmouth Flood Observatory (DFO, mainly NASA funded). The PowerEdge R730 Dell Server is serving the CSDMS portal since last November 2015. The Dell Server contains: 8 x 16GB RAM memory capacity; two Intel® Xeon® E5-2630 v3 2.4GHz, 20M Cache, 8.00GT/s QPI, Turbo, HT, 8 core/16T

(85W) processors; and 8 x 4TB hard drives configured as a RAID 6 to minimize data loss in the event of a hard drive failure. Less than one fifth of the hard disk space is currently used, so there is enough hard disk space for growth. Critical data (for example, that served by the websites) are backed-up daily through a backup server supported by the CSDMS program. A seven-year hardware warranty is included to guarantee that the server is only minimal time off line in the event of a major hardware failure.

d) Change look and feel of the CSDMS portal (*in progress, will be further developed and implemented by early 2017).* Web portal designs are subject to fashion; portals that once looked acceptable might now look outdated. New technology improves user experience, making web use easier and more intuitive. By adopting newer designs, users can be more focused in pursuing what they are after, instead of trying to find out how a website works (e.g. how to submit a comment). Along those lines, CSDMS is developing a new *skin*. This *skin* will provide the same information stored in the underlying databases, but simply presents it with a new, friendlier to use user interface. We have adopted the 'Twitter Bootstrap 3' skin and keep the Mediawiki SQL underlying databases. The Twitter Bootstrap technology has been around for some years (so most bugs are solved) and skin extensions that have been developed for Mediawiki, can be used and build upon by the CSDMS-IF. Furthermore, the Twitter Bootstrap 3 html, CSS, and JS framework supports all common browser environments (Internet Explorer, Chrome, Safari) as well as various devises (desktop, mobile, tablet).

A test web portal site has been setup to insure that development, modification and integration of the skin to the underlying web database will go smoothly without interrupting performance of the current CSDMS web portal. Adoption of the Twitter Bootstrap 3 skin will also provide a friendlier mobile web experience. We aim to implement the new CSDMS skin and fully integrate with the existing website by early 2017.

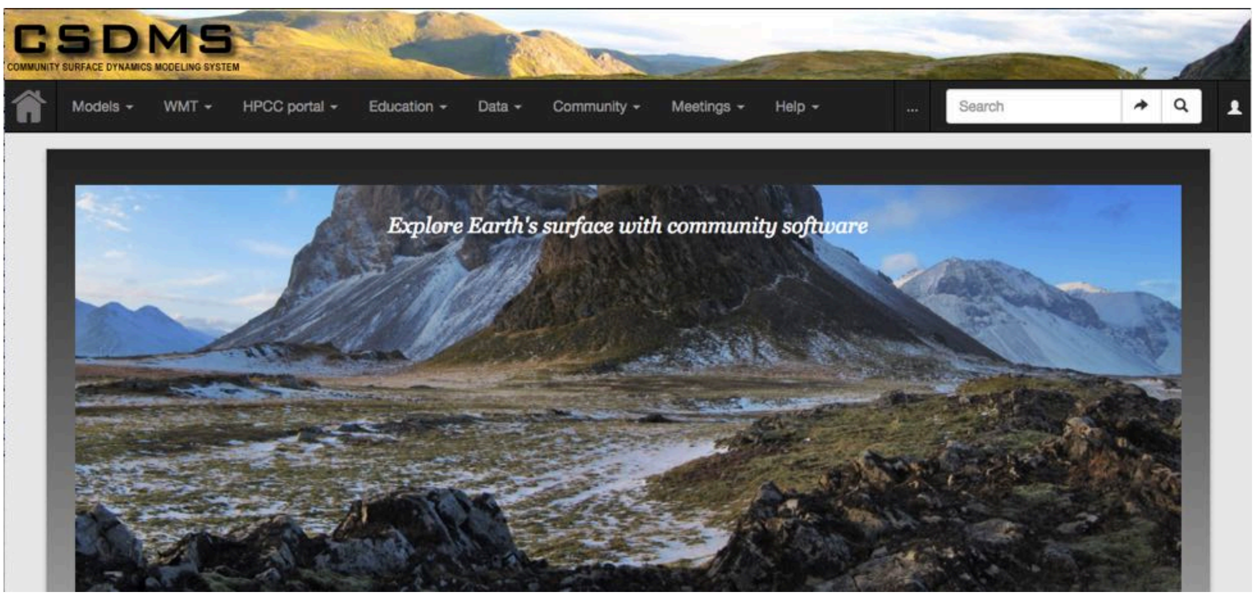


Fig 4.10.3. Example of the new CSDMS web portal skin based on Twitter Bootstrap 3 web design framework.

e) Reform HPCC requests (*in progress, will be implemented before start of next project year).* CSDMS is in the process to streamline the HPCC uses. By implementing a web based form for people to fill out. Only those forms that contain the required information will be given an account. This should also reduce the workload of the CSDMS HPC, as requirements can be better controlled, and will increase the source code contribution towards the CSDMS repository (as we can better enforce the requirement to get meta data of newly developed models).

f) Develop query tools to substitute or extend the current repository lists (*in progress, will be implemented before start of next project year).* It becomes more difficult to find for example the right model for a scientific problem with the increase numbers of models in the repository. CMSDS is therefore in the process to develop better search query tools. Query tools will be integrated in the web portal.

Web Portal Maintenance

CSDMS cyber infrastructure uses the open software package Mediawiki (http://www.mediawiki.org) and numerous third-party extensions (59 extensions as of now; a reduction of 1 compared to last year) to extend cyber infrastructure capability and to provide the latest cyber tools to web visitors to guarantee the easiest experience to interact through the web. At the same time CSDMS tries to reduce the dependency on third-party extensions as they could cause cyber infrastructure instabilities. About every year the core software (mediawiki) is significantly upgraded and with it most third party software extensions, to guarantee performance, security, and to incorporate new features. It is required by the University of Colorado (CU) to upgrade cyber infrastructure to a newer version when a security upgrade becomes available, to reduce possible cyber-attacks directed to CU. CSDMS executed the latest major cyber infrastructure upgrade (upgraded to mediawiki v1.26.2, see http://csdms.colorado.edu/wiki/Special:Version) to conform to CU standards. Outdated extensions were replaced to guarantee functionality.

4.11 Developing a QSD Educational Toolbox

CSDMS has a defined EKT mission to enable computer model use and development for research in the earth surface processes. CSDMS strives to widen the use of quantitative techniques and numerical models and promote best coding practices. This key objective is met through CSDMS Framework development, making models easier to use through the Web Modeling Tool (addressed elsewhere in this report), and tight integration between the WMT and model theory, metadata, and help pages as an online resource.

CSDMS aims to enable undergraduate and graduate students (and their instructors) to more easily use models. The Quantitative Surface Dynamics Educational Toolbox combines educational material at different tiers but with cross-cutting themes. Complexity in teaching resources in the QSDE toolbox steps up from a basic level; real-world surface process movies and simple model animations, to small spreadsheet model exercises, to web-based models with few parameters to vary, to the most advanced level WMT teaching labs. The educational repository contains a suite of resources on each of these levels.

Over 2015 and 2016 we have made 18 hydrology components compatible with the Web Modeling Tool (i.e. TOPOFLOW components). This allowed us to pair previously existing spreadsheet exercises to more advanced modeling labs. We have also developed the ROMS-Lite component explicitly for inexperienced users to explore coastal and shallow marine processes and learn about ocean modeling with a simplified instance of ROMS-the Regional Ocean Modeling System. These components are organized in dedicated 'projects': wmt-hydrology and 'wmt-roms'

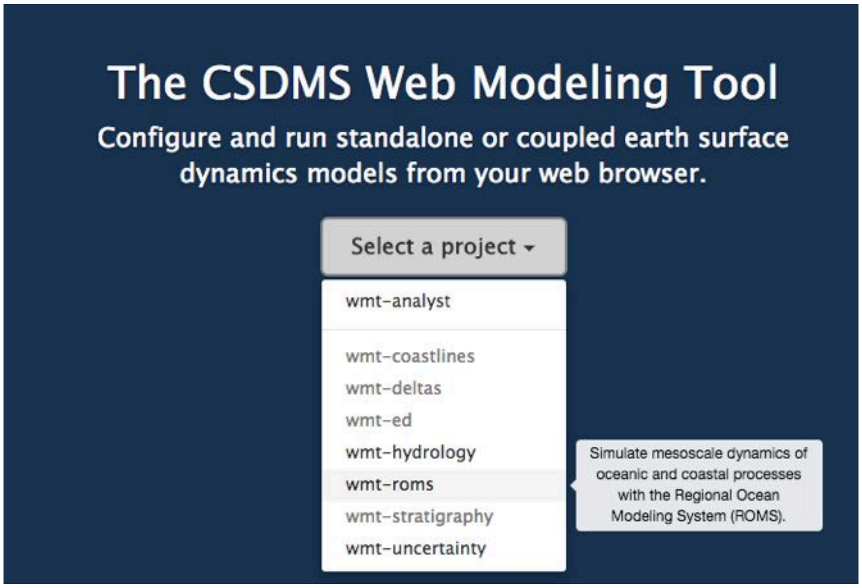


Figure 4.11.1 the CSDMS Web Modeling Tool organized in dedicated projects to facilitate disciplinary labs in for example hydrology and coastal processes, https://csdms.colorado.edu/wmt/

New updates to the movie repository to complete these QSDE toolbox themes in both hydrology and coastal modeling will be completed in August –September 2016. The NCED Summerinstitute August 2016 at the St Anthony Falls lab is to be used as a test ground to see whether the concepts are efficient as teaching tools With those additions, there are QSDE themes for the terrestrial domain, both short-term and long-term processes, for the coastal and marine domains, and for hydrology. All these resources are hosted in a database structure to be searchable by crosscutting theme as well as by intended level.

CSDMS has developed new framework functionality to allow model sensitivity testing and uncertainty quantification by incorporating the Dakota Tools (explained in detail in other sections of this annual report). Our community needs to be guided in the use of this functionality. Education and good documentation of these tools is a priority and is essential for adaptation of this modeling 'philosophy'. We have developed a preliminary lab for the use of Dakota Tools, and used it within the framework of a Sediment Transport Modeling class at the University of Colorado (attended by 8 graduate students). The developed lesson material will result in a number of dedicated online labs, and exposure of a significant group of graduate student to uncertainty & sensitivity in modeling (~40 students in August 2016). Over summer of 2016, the CSDMS Integration Facility hosts an undergraduate student (through the REU program) to work on optimization techniques with the Dakota Tools. Additional basic material on these concepts in spreadsheet exercises is to be completed in Fall 2016. Whereas the EKT repository has model animation, model spreadsheets and WMT model teaching labs for all of the working group domains, further organizing of the resources is still a priority to make the progression of the material more evident.

4.12 Development of CSDMS Earth Surface Modeling Course Material

All short course materials, i.e. lectures, labs and associated reading materials, which were developed for specific course CSDMS short courses in 2015 -2016 are posted online. New short courses included:

'Modeling River-Coastal Processes' at the NCED Summer Institute on Earth System Dynamics, Tulane University, New Orleans, August 2015 (~40 participants, 1 day, instructor Irina Overeem).
This course aims to familiarize earth sciences, coastal and oceanography and engineering graduate students with concepts of surface modeling and a number of numerical surface process models and hydrological models available through Community Surface Dynamics Modeling System. The course introduces participants to use of these software tools for their own research and teaching purposes. Participants learned about the following surface processes:

- River sediment supply
- Coastal evolution and longshore transport and wave processes
- Stratigraphic modeling

At the end of this course, students are able to design and run simulations for independently designed research questions on sediment supply, coastline evolution and marine stratigraphic processes. In addition, students have learned basic skills of submitting modeling jobs to a High Performance Computing System and for many this short course is their first exposure to remote access of a supercomputer.

Coastal and shallow marine sediment transport modeling with 'ROMS-Lite'
An additional CSDMS short course on coastal and shallow marine sediment transport with 'ROMS-Lite' implemented through the CSDMS WMT has been designed in 2014-2015 in collaboration with Courtney Harris and Julia Moriarty at the Virginia Institute of Marine Sciences. A series of 3 hands-on labs have the following topics:

- Shallow marine sediment transport and waves
- Interactions of River Plume with waves
- Numerical modeling and the Boundary conditions

This short course has been presented in May 2016 and used in a clinic at the annual meeting.

All course material is shared through the EKT repository. We will be using this material in the NCED 2016 Summer Institute and have identified two early adopters, who are faculty at other universities and are willing to test the labs with small groups of students in the 2016-2017 Academic year.

'Rivers and Vegetation Dynamics in the Arid US West' at University of Colorado Continuing Education, October 2014 (6 participants, 1 day, instructors Irina Overeem, Greg Tucker, Mariela Perignon).
New course material is shared online based on a 1-day Teacher training workshop. The resources are intended for advanced K12 students but are comprehensive enough to be used in introductory earth sciences classes or classes for non-majors. Additional description of this course is presented under the EKT repository advances for 2016.

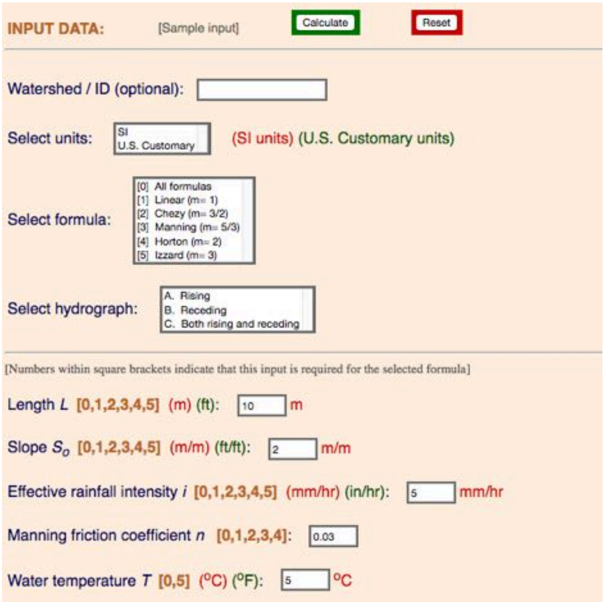


Figure 4.12.1 Spreadsheet exercise on engineering hydrology to calculate overland flow using a Manning equation as used in the Rivers & Vegetation short course (adopted from Vlab, contributed by Victor Ponce)

CSDMS Bootcamp (20 participants, 1 day, instructors Mariela Perignon and Mark Piper)
CSDMS hosted a Pre-conference one-day Software Carpentry bootcamp with the objective to teach basic programming skills useful for scientific computing and model development. This is designed as an intensive, hands-on workshop covering basic elements of:

1. The Unix bash shell,
2. Python programming and NumPy, and
3. Github for version control.

This workshop is now taught by CSDMS IF staff, whom are earth scientists and have familiarity with the CSDMS framework, such that lessons and examples are targeted toward relevant problems in CSDMS participants field. The bootcamp intentionally precedes the CSDMS meeting, so the skills participants developed are useful in the clinics during the meeting. We performed a post-bootcamp survey and have included the analysis of the survey as Appendix 6 to this annual report.

4.13 Knowledge Transfer to Industry Partners and Government Agencies

CSDMS IF Staff has reached out to industry and governmental agencies and participated in meetings on more than 8 occasions over this reporting period 2015-2016 (see list of IF Staff meetings). Presentations on the CSDMS community, software protocols and modeling framework services, as well as educational resources were shared with most of these partners, including ARCUS, IARCP, BOEM, USGS, AAPG/SEPM, Worldbank, Statoil, and Deltares as well as several organizations that reach out to future stakeholders of CSDMS modeling domains.

In general, the tools developed in CSDMS support the surface processes research community. However, there is ongoing work to develop a prototype application of an open-access, science-based, integrative modeling framework. This is specifically done for delta systems at the CSDMS IF under separate funding of the Belmont Forum. The prototype is called the Delta Risk Assessment and Decision Support Tool. This tool is to be a service component on top of the CSDMS open-source modeling framework, i.e. the WMT. A prototype service component for Delta-RADS would help facilitate delta risk modeling. Such service components, described below, will shortly be incorporated into WMT and released as Delta-RADS after testing. These service components include a GIS modeling system to support quantitative mapping and definition of functional relationships of the biophysical environment of deltas as well as their social and economic dynamics, which is a long-term CSDMS goal and would be especially relevant to policy-makers. We developed tools to generate GeoTIFFs and shapefiles of relevant GIS based datasets for delta modeling, which users can download to use in other studies or convert into model input file formats for simulations in WMT in 2015. This toolkit now includes linked datasets of topography, climate and antropogenic factors. The toolkit will be demonstrated to regional stakeholders and possible end-users at a workshop in NY, September 2016.

CSDMS IF links to the recently established NSF-funded STEPPE. STEPPE (Sedimentary Geology, Time, Environment, Paleontology, Paleoclimatology, Energy) is an NSF-supported consortium whose purpose is to promote multidisciplinary research and education on Earth's deep-time sedimentary crust. CSDMS IF staff participated in the STEPPE ONE-DELTA meeting, January 2016, to share modeling advances with other investigators. CSDMS members serve on the respective steering committee and board and thus ensure there will be a fruitful connection between future science endeavors of the two initiatives.

CSDMS Director, Syvitski, presented stratigraphic modeling developments in Norway at a scientific symposium and visited with Statoil headquarters in May 2016. Discussions there have led to plans to advance model physical properties frameworks to further advance 3D space and deep time storage of subsurface characteristics both for industry and science needs.

5.0 Conferences & Publications

5.1 CSDMS Staff Participation In Conferences & Meetings Aug 2015 through July 2016

08/2015	9th Symp. River Coastal & Estuarine Morphodynamics (RCEM)	Iquitos, Peru	(Syvitski)
08/2015	Boulder Creek CZO Annual Sci Day	Bolder, CO	(Tucker)
08/2015	Rivers and Vegetation Dynamics Teacher WS	Boulder, CO	(Overeem,Tucker, Perignon)
08/2015	Modeling River-Coastal Processes & Stratigraphy NCED Summer Institute 2015	New Orleans, LA	(Overeem)
09/2015	3rd Workshop Sustainable Software for Science	Boulder, CO	(Tucker)
09/2015	EarthLab Meeting CU Boulder, Grand Challenges	Boulder, CO	(Overeem)
09/2015	Colorado Geomorphology Org Meeting	Denver, CO	(Overeem,Kettner)
10/2015	John R Mather Visiting Scholar Lecture	Newark, DE	(Syvitski)
10/2015	Slingfest: Sediment from Mountain to Sea	State College, PA	(Tucker)
10/2015	Science discovery, Boulder Public Library	Boulder, CO	(Overeem,Higgins)
11/2015	Coastal & Estuarine Research Fed Meeting	Portland, OR	(Syvitski)
11/2015	Arctic Observing Open Science Meeting	Seattle, WA	(Overeem)
12/2015	GRIOS-Greenland Ice-Ocean Observing WS	San Francisco,CA	(Overeem)
12/2015	Belmont Forum DELTAS Meeting	San Fransisco,CA	(Overeem,Higgins)
12/2015	AGU Fall Meeting	San Fransisco, CA	(CSDMSStaff)
01/2016	CSDMS Interagency WG Meeting	Washington, D.C.	(Syvitski,Tucker)
01/2016	ONE-Delta Conference	Nashville, TN	(Overeem,Perignon)
02/2016	SI2 Principle Investigator's Meeting	Arlington, VA	(Tucker)
02/2016	AGU 2016 Ocean Sciences Meeting	New Orleans, LA	(Syvitski)
02/2016	Louisiana State University Lecture & Meetings	Baton Rouge, LA	(Syvitski,Piper)
03/2016	International Soil Modeling Consortium Meeting	Austin, TX	(Overeem)
03/2016	Ambiguous Geographies Symposium	Indianapolis, IN	(Rogers)
04/2016	Entanglements Lecture Series: "How do we (re)Make our Planet"	Indianapolis, IN	(Syvitski,Rogers)
04/2016	Ostrom Workshop Lecture	Bloomington, IN	(Syvitski,Rogers)
04/2016	Anthropocene Working Group Meeting	Oslo, Norway	(Syvitski)
04/2016	2nd Conference on Forward Modeling of Sedimentary Systems	Trondheim, Nway	(Syvitski)
04/2016	Statoil Meeting	Trondheim, Nway	(Syvitski)
05/2016	International Society for Ecological Modeling	Baltimore, MD	(Syvitski, Tucker)
05/2016	Japan Geoscience Union Meeting 2016	Tokyo, Japan	(Overeem)
05/2016	CSDMS 2016 Annual Meeting	Boulder, CO	(CSDMSStaff)
05/2016	Human Dimensions FRG Workshop: Linking Earth System Dynmcs & Social System Modeling	Boulder, CO	(Syvitski,Kettner,Rogers)
05/2016	2nd Intl Workshop on Coastal Subsidence	Venice, Italy	(Syvitski,Higgins)
06/2016	AAPG/SEPM 2016 Annual Conference	Calgary, Alberta	(Syvitski)

06/2016	24^{th} Biennial American Quanternist As. Meeting	Santa Fe, NM	(Syvitski)
06/2016	FESD Annual Meeting	Baton Rouge, LA	(Perignon)
07/2016	Newcastle University Jeffery Lecture	Newcastle, ENG	(Syvitski)

5.2 Integration Facility Staff Book Chapters, Journal papers and Newsletters:

Submitted/in review July 2015 to June 2016: (IF Staff in bold)

Wang, YP, JT Liu, **JPM Syvitski**, J Du, J-h Gao, J Jia, Z Zhang, G Hu, Y Yang, S Gao, in prep, The world's "Coastal Zone Filter" traps more sediment than expected, *Nature Geoscience.*

Wang HJ, N Bi, S Li, P Yuan, A Wang, X Wu, Y Saito, Z Yang, Z Yu, S Liu, **Syvitski, JPM**, in prep, Dam-orientated Water Sediment Regulation Scheme of the Yellow River, China: A review and perspective. *Earth Science Reviews*

Steffen W, R Leinfelder, J Zalasiewicz, CN Waters, M Williams, C Summerhayes, AD Barnosky, A Cearreta, M Edgeworth, EC Ellis, IJ Fairchild, A Gałuszka, J Grinevald, A Haywood, J Ivar do Sul, C Jeandel, JR McNeill, E Odada, N Oreskes, A Revkin, DB Richter, **J Syvitski**, D Vidas, M Wagreich, SL Wing, AP Wolfe, HJ Schellnhuber, submitted, Stratigraphic and Earth System Approaches to Defining the Anthropocene. *Earth's Future*

Kettner AJ; S Cohen; **I Overeem**; BM Fekete; **GR Brakenridge; JPM Syvitski**; in review, Increases in flood frequency by the 21st century: A global modeling assessment. *AGU book Chapter*

Overeem, I, Briner, J.P., **Kettner, AJ, Syvitski, JPM**, (in rev. 2015). High-Latitude Valley Fills: A case-study of Clyde fjordhead, Baffin Island, Arctic Canada. In: *SEPM Spec. Publ.*, Latitudinal Controls on Stratigraphic Models and Sedimentary Concepts.

Rennermalm, A., Mikkelsen, A., **Overeem, I.**, Chu, V., Smith, L.C., van As, D., Mote, T., Hasholt, B., (in rev. 2015). Spatial variation of Greenland ice sheet meltwater export inferred from river discharge observations. *Geophysical Research Letters.*

Accepted/in press July 2015 to June 2016:

Allison, M, B Yuill, T Törnqvist, F Amelung, T Dixon, G Erkens, R Stuurman, G Milne, M Steckler, **J Syvitski**, P Teatini, *2016*, Global risks and research priorities in Coastal Subsidence, EOS Transactions.

Syvitski JP, AJ Kettner, I Overeem, GR Brakenridge, S Cohen, in prep, Latitudinal controls on siliciclastic sediment production and transport, *SEPM Special Issue Latitudinal Controls on Stratigraphic Models and Sedimentary Concepts*

Williams M, J Zalasiewicz, CN Waters, M Edgeworth, C Bennett, AD Barnosky, EC Ellis, MA Ellis, A Cearreta, PK Haff, JA Ivar do Sul, R Leinfelder, JR McNeill, E Odada, N Oreskes, A Revkin, D deB Richter, W Steffen, C Summerhayes, **JP Syvitski**, D Vidas, M Wagreich, SL Wing, AP Wolfe, A Zhisheng in press The Anthropocene: a conspicuous stratigraphical signal of anthropogenic changes in production and consumption across the biosphere. *Earth's Future*

Day, JW, J Agboola, Z Chen, C D'Elia, DL Forbes, L Giosan, P Kemp, C Kuenzer, RR Lane, R Ramachandran, **J Syvitski**, A Yañez-Arancibia, *in revision*, Approaches to Defining Deltaic Sustainability in the 21st Century. Sustainability of Future Coasts and Estuaries, Special Issue of Estuarine, Coastal and Shelf Science.

Syvitski, J, Kettner, AJ, **Overeem, I, Brakenridge,GR**, Cohen,S., (accepted). Latitudinal controls on Siliciclastic Sediment Production and Transport. . In: *SEPM Spec. Publ.*, Latitudinal Controls on Stratigraphic Models and Sedimentary Concepts.

Published July 2015 to June 2016:

Bai, X, van der Leeuw, S, O'Brien, K, Berkhout, F, Biermann, F, Broadgate, W, Brondizio, E, Cudennec, C, Dearing, J, Duraiappah, A, Glaser, M, Steffen, W, **Syvitski, JP**, 2016, Plausible and Desirable Futures in the Anthropocene, *Global Environmental Change, doi:10.1016/j.gloenvcha.2015.09.017*

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Chen, Y, **Overeem, I, Kettner**, AJ, Gao, S, and **Syvitski, JPM**, 2015. Reconstructing the Flood History of the Yellow River, China: A simulation based on uncertainty and sensitivity analysis. *J Geophysical Research- Earth Surface* 120: 1321–1351.

Duvall, A., and **Tucker, G.E**. (2015) Dynamic Ridges and Valleys in a Strike-Slip Environment. *Journal of Geophysical Research* 120: 2016-2026, doi:10.1002/2015JF003618.

Ebel, B., Rengers, F.K., and **Tucker, GE** (2015) Aspect-Dependent Soil Saturation and Insight Into Debris-Flow Initiation During Extreme Rainfall in the Colorado Front Range. *Geology* 43, 659-662.

Harris, N., and **Tucker, GE** (2015) Soils, slopes, and source rocks: application of a soil chemistry model to nutrient delivery to rift lakes. *Sedimentary Geology* 323, 31-42.

Hudson, B. Overeem, I, Syvitski, J 2016 A novel technique to detect turbid water and mask clouds in Greenland fjords. *International Journal of Remote Sensing* 37: 1730-1746.

Hutton, EWH, MD Piper, SD Peckham, I Overeem, AJ Kettner, JPM Syvitski, 2015, Building Sustainable Software - The CSDMS Approach. Journal of Open Research Software *WSSSPE2* **arXiv:1407.4106v2**

Jenkins, C. 2016. Sediment Drainage Streams Important in Benthic Seafloor Classification. In: Wright, D. (Ed.), *Ocean Solutions, Earth Solutions, 2nd editio*n. ESRI Press, Redlands, USA, 431-440. [DOI: 10.17128/9781589484603]

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Langston, A.L., **Tucker, GE,** Anderson, RS, and Anderson, SP (2015) Evidence for climatic and hillslope-aspect controls on vadose zone hydrology and implications for saprolite weathering. *Earth Surface Processes and Landforms* 40: 1254–1269, doi: 10.1002/esp.3718.

Overeem, I., Hudson, B., Welty E., Mikkelsen, A., Pedersen, D., LeWinter, A., Hasholt, B., 2015. River Inundation Suggests Ice Sheet Runoff Variations, *Journal of Glaciology*, 61 (228): 776-788.

Papili, S., **Jenkins, C.,** Roche, M., Wever, T., Lopera, O. & Van Lancker, V. 2015. Influence of shells and shell debris on backscatter strength: Investigation using modeling, sonar measurements and sampling on the Belgian Continental Shelf. *Proc. Inst. Acoustics* 37(1), 304-310.

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Rengers, F.K., Lunacek, M., and **Tucker, GE** (2016) Application of an Evolutionary Algorithm for Parameter Optimization in a Gully Erosion Model. *Environmental Modelling and Software* 80: 297-305.

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Seitzinger, SP, O Gaffney, G Brasseur, W Broadgate, P Ciais, M Claussen, J Willem Erisman, T Keifer, C Lancelot, PS Monks, K Smyth, **J Syvitski**, M Uematsu, 2016. International Geosphere-Biosphere Program and Earth system science: three decades of co-evolution *Anthropocene*.

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Waters, CN, J Zalasiewicz, C Summerhayes, AD Barnosky, C Poirier, A Gałuszka, I Hajdas, A Cearreta, M Edgeworth, E Ellis, MA Ellis, C Jeandel, R Leinfelder, JR McNeill, DB Richter, W Steffen, **J Syvitski**, D Vidas, M Wagreich, M Williams, A Zhisheng, J Grinevald, E Odada, and N Oreskes. 2016, The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science* 351(6269)

5.3 Abstracts *July 2015 to June 2016:*

Syvitski, JPM, SA Higgins F Xing. 2015 Monitoring and Modeling of Sinking Deltas, 19th INQUA Congress, Quaternary Perspectives on Climate Change, Natural Hazards and Civilization; 26 July – 2 August 2015 Nagoya, Japan, T00271.

Syvitski, JPM, 2015, The Anthropocene and Future Earth, 19th INQUA Congress, Quaternary Perspectives on Climate Change, Natural Hazards and Civilization; 26 July – 2 August 2015 Nagoya, Japan.

Syvitski, JPM, 2015, Use of Surface-Dynamic Models for Identifying Environmental Indicators and Processes. 3rd GEOSS Stakeholders & Technology; Mar 23-26, Norfolk VA

Syvitski, JPM, 2015, Systems Science for Sustainable Transitions, IGBP-IIASA; Apr 29, 2015, Laxenburg/Vienna, Austria

Syvitski, JPM & Higgins SA, 2015, Challenges of Deltas under pressure. 36th IAHR World Congress, 29-30 June 2015; The Hague, The Netherlands.

Syvitski, JPM, 2015, Deltas – from multiple pressures to integrated solutions; July 1-3 Utrecht University, The Netherlands.

Syvitski, JPM, 2015, The Amazon --- An Incredible Tropical River System, 9th Symposium on River Coastal and Estuarine Morphodynamics (RCEM), Aug 30 – Sept 3, 2015, Iquitos, Peru

Kettner, AJ, Syvitski, JP, Overeem, I, 2015, Morphological changes due to flooding: the Indus River, 9th Symposium on River Coastal and Estuarine Morphodynamics (RCEM), Aug 30 – Sept 3, 2015, Iquitos, Peru

Syvitski, JPM 2015, Building Capacity in the Social Sciences a CSDMS perspective, Washington DC

Syvitski, JP 2015, The Anthropocene, John R. Mather's Visiting Scholars Lecture, Oct 22, 2015, U Delaware, Newark

Syvitski, JPM, 2015: Lessons learned from 25 years of international collaboration in LOICZ; CERF 2015 conference, Nov 8-12, Portland, OR

Syvitski, JPM, 2015: Delta dynamics in the Anthropocene; CERF 2015 conference, Nov 8-12, Portland, OR

Cohen, S., **Syvitski, JPM, Kettner, AJ**, 2015, Global scale modeling of riverine sediment loads: tropical rivers in a global context. EGU General Assembly, Apr 12-17, Vienna, Austria

Brakenridge R, A Kettner, J Syvitski, I Overeem. 2015. Flood risk and climate change: The contributions of remote sensing, 14-18 Dec 2015 Fall Meeting, AGU, San Francisco, CA, NH13D-1968

Piper, M, E Hutton, I Overeem, J Syvitski. 2015. WMT: The CSDMS Web Modeling Tool, 14-18 Dec 2015 Fall Meeting, AGU, San Francisco, CA, IN13B-1841

Kettner, AJ, J Syvitski. 2015. Global suspended sediment and water discharge dynamics between 1960 and 2010: Continental trends and intra-basin sensitivity, 14-18 Dec 2015 Fall Meeting, AGU, San

Francisco, CA, EP33A-1046

Rogers, K, JPM Syvitski. 2015 Linking river basin modifications and rural soil and water management practices in tropical deltas to sea level rise vulnerability, 14-18 Dec 2015 Fall Meeting, AGU, San Francisco, CA, GC41F-1154.

Higgins, S, I Overeem, JP Syvitski. 2015. Impacts of the Indian Rivers Inter-link Project on sediment transport to river deltas, 14-18 Dec 2015 Fall Meeting, AGU, San Francisco, CA, GC44C-06.

Cohen, S., **Syvitski, JPM, Kettner, AJ,** 2015, Global suspended sediment and water discharge dynamics between 1960 and 2010: Continental trends and intra-basin sensitivity, 14-18 Dec 2015 Fall Meeting, AGU, San Francisco, CA, EP33A-1046

Tessler, Z., C. Vörösmarty, M. Grossberg, I Gladkova, H Aizenman**, J Syvitski** and E Foufoula-Georgiou, 2015 The Geophysical, Anthropogenic, and Social Dimensions of Delta Risk: Estimating Contemporary and Future Risks at the Global Scale, 14-18 Dec 2015 Fall Meeting, AGU, San Francisco, CA, GC44C-01

Bondre, N, and **J Syvitski**, 2015, What's the big deal with the Anthropocene? 14-18 Dec 2015 Fall Meeting, AGU, San Francisco, CA,

Syvitski, JPM, 2016, The community surface dynamics modeling system. The International Society for Ecological Modeling Global Conference, May 8-12, 2016, Baltimore USA.

Syvitski, JPM, H.G. Arango, C.K. Harris, E.H. Meiburg, **C.J. Jenkins, E.W.H. Hutton,** G. Auad, Fei Xing, 2016, Modeling of Sediment Transport in the Gulf of Mexico due to the Influence of Hurricanes. EAGE 2nd Conference on Forward Modelling of Sedimentary Systems, Trondheim, Norway, 25-28 April 2016.

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Cohen, S., **Syvitski, JPM, Kettner, AJ,** 2016, Predicting Water, Sediment & Nutrient Flux Dynamics to Global Oceans with a Spatially and Temporally Explicit Modeling Framework, 2016 Ocean Sciences, New Orleans USA

Syvitski, JPM, Higgins, S. 2016, Land subsidence in deltaic areas. 2nd International Workshop on Coastal Subsidence, Venice Italy, May 30-June 1, 2016.

Higgins, S, Syvitski, JPM, others 2016 TITLE 2nd International Workshop on Coastal Subsidence, Venice Italy, May 30-June 1, 2016.

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Syvitski, JPM 2016, Latitudinal Controls on Siliciclastic Sediment Production and Transport. AAPG/SEPM Annual Convention, Calgary, Canada, June 19-22, 2016.

Adams, J.M., Gasparini, N.M., Hobley, D., **Tucker, G.E., Hutton, E.W.H.,** Istanbulluoglu, E., and Nudurupati, S.S. (2016) Integrating a 2-D hydrodynamic model into the Landlab modeling framework. Paper presented at Joint CSDMS-SEN Meeting: Capturing Climate Change, Boulder, Colorado, May 2016.

Gasparini, N.M., Adams, J.M., **Tucker, G.E.,** Hobley, D., **Hutton, E.W.H.,** Istanbulluoglu, E., and Nudurupati, S.S. (2016) Landlab: A numerical modeling framework for evolving Earth surfaces from mountains to the coast. Paper presented at the Ocean Sciences Meeting, New Orleans, LA, Feb 2016.

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Gray, H., **Tucker, G.E.,** Mahan, S. (2015) Traveling at the Speed of Light: Using Luminescence to Estimate Sediment Transport Rates. Paper presented at American Geophysical Union Fall Meeting, San Francisco, December 2015.

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McCoy, S.W., Struble, W., Hobley, D.E.J., and **Tucker, G.E.** (2015) Tectonics From Topography: Strong Correlation Between Mountain Front Steepness and Holocene Slip Rates Along the Wasatch Normal Fault, USA. Paper presented at American Geophysical Union Fall Meeting, San Francisco, December 2015.

Nudurupati, S.S., Istanbulluoglu, E., Adams, J.M., Hobley, D.E.J., Gasparini, N.M., **Tucker, G.E., Hutton,** E. (2015) Elevation Control on Vegetation Organization in a Semiarid Ecosystem in Central New Mexico. Paper presented at American Geophysical Union Fall Meeting, San Francisco, December 2015.

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Sato, M., Shobe, C.M., and **Tucker, G.E.** (2015) The Influence of Hillslope Steepness on Sediment Supply Size Distribution along Rivers Draining the Colorado Front Range. Paper presented at American Geophysical Union fall meeting, San Francisco, December 2015.

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Shobe, C.M., **Tucker, G.E.,** and Anderson, R.S. (2015) Big Blocks and River Incision: A Numerical Modeling Perspective. Paper presented at American Geophysical Union fall meeting, San Francisco, December 2015.

Overeem, I. 2016. Sediment Grainsize Trends in Delta Networks. JpGU Annual Meeting, Tokyo, Japan, May 24-27th, 2016.

INVITED: Overeem, I., 2016. Community Surface Dynamics Modeling System, International Soil Modeling Workshop, March, 29-30th, Austin TX,

Overeem, I., 2016. Numerical Modeling grounded in Field Observations, ONE-DELTA Steppe Workshop, January 20-23th, 2016, Nashville, TN.

Overeem, I., Brakenridge, B., Hudson, B., 2015. Satellite-based Observation of Arctic River Dynamics, AGU Annual Meeting, San Francisco, December 2015.

Overeem, I., Borkowski, L., Kettner, A.J., Rusell, B., Peddicord, H., 2015. Bringing earth surface processes

simulations to large audiences. AGU Annual Meeting, San Francisco, December 2015.
INVITED: Overeem, I., 2015. What's new in the Arctic Coastal Zone? Arctic Observing Open Science Meeting, Seattle, November 17-19 2015.
INVITED: Overeem, I. 2015. Sedimentation Patterns in the Ganges-Brahmaputra Delta System, Colorado Geomorphology Organization, Denver, CO, September24th, 2015.
EarthLab-Kick-off meeting University of Colorado Grand Challenge, September 18th, 2015.
Overeem, I., 2015. Modeling River-Coastal Processes and Stratigraphy. NCED Summer Institute 2015, Tulane University, New Orleans, August 2015.
Overeem, I., 2015. Greenlandic Rivers and Ice Sheet Melt, Greenland Institute of Natural Resources Seminar, Nuuk, Greenland, June 19 2015.
Interactive Workshop for K6-12 teachers on River and Vegetation Dynamics, August 2015.

6.0 CSDMS 2.0: Working Groups & Focus Research Groups

6.1 CSDMS Terrestrial Working Group

The Terrestrial Working Group (TWG) met during the 2016 All Hands meeting in a 90-minute breakout session. The discussion focused primarily on: (1) how can we improve communication among the TWG members? (2) How can we increase interaction between TWG members and the CSDMS integration team? (3) The integration of data and models.

Communication among TWG members

Discussion with TWG members revealed that the CSDMS repository is used in very diverse ways. Some members noted that they use CSDMS repository model code to learn about how to create and package software, without actually running the model that they are learning from. These users may also take existing codes and change them so that they fit specific research needs. There are also members who use models without changing the code at all.

These are great uses of the CSDMS repository, and we want to encourage these workflows. The TWG members felt one way to facilitate all of these practices would be improved communication among TWG members. For example, some members said that they would be happy to use existing models, but sometimes the specific model they need does not currently exist. As such, members may take parts of a model and build on it. Many models that are in development may also be useful to other users. This illustrated the need for members of the group to be aware of ongoing projects. In other cases, when users are taking advantage of off-the-shelf models, they would appreciate communication with other model users on the tricks and nuances of using a specific code. This illustrates a need to connect potential or new model users with experienced model users. At the time of the meeting there was no obvious method for group communication.

Although the CSDMS model web pages are an editable wiki, most members did not know this. The group felt that a more general communication tool was needed. As an initial attempt to address the need for better communication, the TWG email list serve has been opened up so that all subscribers can post to the (moderated) list. All TWG members are automatically made part of this list when they join the TWG. However, it has historically been used as a one-way communication tool for disseminating information from the TWG chair to members. By opening the list, we hope to spawn connections amongst members who have questions and those who have answers. The list serve is also open to posting of job ads, meeting sessions, and other relevant information.

Interaction between TWG members and the CSDMS integration team

Some of the more novice coders and numerical modelers in the TWG group would like more help to develop models than just learning from existing codes in the repository. Many members do not view themselves primarily as modelers, but they want to build and use models to better understand a data set, field area or process. These members are a key demographic for expanding the CSDMS community and would benefit from working directly with the CSDMS integration team. Most TWG members were not aware that funding to support a member of the CSDMS integration facility team can be included in proposals. Many members of the group expressed a desire to pursue opportunities with the CSDMS team in the future.

Using data with numerical models

TWG members are enthusiastic about using data from SEN and also linking models and data in general. This follows on the theme from the CSDMS 2015 annual meeting. However, in contrast to the 2015 discussion, some challenges previously highlighted are now more manageable. For example, during the discussion at the 2015 meeting members noted that it can be difficult to use data and metadata with different formats and the need for some standardization (see 2015 annual report). The presence of SEN at the 2016 meeting illustrated that standard metadata formats are being developed, and data from physical experiments are easily searchable using the SEN tools. TWG members are very optimistic about the potential for linking numerical and physical models and want to work in this direction. At least one new collaboration was spawned between a data scientist and a modeler from this meeting. (These scientists have contacted the TWG chair following the meeting to keep her abreast of their plans.)

TWG members felt that it still remains challenging to build collaborations between modelers and non-modelers. How we can better integrate with our sister scientists using different tools to explore similar scientific questions remains an open challenge, and this is of course a broad challenge in interdisciplinary science. However, the success of the linked meeting between CSDMS and SEN illustrates one way in which these connections can be fostered. The TWG members felt strongly that including SEN in the annual meeting was a great success and expressed the desire for similar connections at future meetings.

6.2 Coastal Working Group & Coastal Vulnerability Initiative

Because the goals and activities of the Coastal Working Group (WG) and the Coastal Vulnerability Initiative (CV) overlap, we are reporting on the progress and plans for these two efforts jointly, with items especially relevant for CV in red.

Activities and Accomplishments

Select research and modeling progress in the community: toward WG and CVI goals

We focus here on select accomplishments most relevant for the community-defined WG and CV priorities in the CSDMS Strategic Plan, especially those related to short-term goals for 2016 articulated at a Working Group/Vulnerability Initiative meeting in 2015 (shown in green):

- Specific Science Goal 1 (SSG1) involves developing a medium-complexity suite of coupled models to explore "delta evolution on decadal to millennial time scales, as affected by couplings between terrestrial, fluvial, coastal, wetland, floodplain, subsidence, ecological and human processes (Figure 1)".
    - Katherine Ratliff has developed a model component for dynamic river profile evolution and river avulsions, and working with Eric Hutton, has coupled it to the Coastline Evolution Model (CEM) during 2016. The river module incorporates existing knowledge about long-term fluvial floodplain deposition dynamics, although improving knowledge on this key topic remains an open priority. Using the coupled model, Katherine is examining how avulsion patterns, delta shapes, and delta sizes depend on wave climate, river sediment delivery, and rates of sea level rise.
    - Complementary delta modeling efforts abound, including those of Doug Edmonds, William Nardin, and others using Delft3D; Man Liang using a reduced complexity model (DeltaRCM), Rebecca Lauzon adding vegetation dynamics to DeltaRCM, Anthony Longjas and other using network models, Jaap Nienhuis and Andrew Ashton using CEM (and Delft3D), and Ehab Meselhe and others using the applied Integrated Compartment Model.

- SSG2 addresses how the "morphology, ecology, and human components of sandy coastal environments co- evolve under different scenarios of changing storm climate, sea level rise, and human manipulation—including coastal environments ranging from urban to undeveloped."
    - Laura Moore, Orencio Duran, Peter Ruggiero, Elsemarie DeVries, Evan Goldstein and others have continued to develop the Coastal Dune Model (CDM), and to analyze model results and field data to explore questions including what factors determine the vulnerability of specific dune and barrier island systems to changes in climate forcing.

  - Progress toward coupling CDM and XBeach continues (Laura Moore, Orencio Duran, Evan Goldstein, Peter Ruggiero, Nick Cohn, Danno Roelvink, and others).
  - Efforts to measure effects of development on storm-driven sediment fluxes, and model the long-term consequences for and feedbacks with the morphological and ecological evolution of sandy coastal environments, resulted in an initial paper. (Paper focusing on NJ after Sandy, and related modeling: Rogers, Moore, Goldstein, Hein, Lorenzo-Trueba, Ashton).
  - A team of economists and geomorphologists (Marty Smith, Brad Murray, Dylan McNamara, Sathya Gopalakrishnan, Laura Moore, Andy Keeler, and Craig Landry) continue to address couplings between physical/ecological and socio-economic processes on developed sandy coastlines.
  - The Coastline Evolution Model (CEM) and the Barrier Island Model (BIM) were coupled as part of an effort to forecast how increasing rates of sea level rise, changing wave climates, and localized shoreline stabilization efforts, might affect the Virginia coastline in the next 50 years (Margaret Jones, Laura Moore, Dylan McNamara, Brad Murray, and others). Results will be broadly available online as part of The Nature Conservancy's Coastal Resilience Tool.

- SSG3 involves modeling rocky and soft-cliff evolution, including the effects of human manipulations from river damming to coastal armoring.
  - As part of these efforts, Eric Hutton is applying a Basic Model Interface (BMI) to a unified version of the Coastline Evolution Model (CEM) that can address rocky coastlines and beach-cliff interactions, as well as delta-related processes (and numerous other relatively new capabilities.

- We are developing plans for a book (+ other media) addressing vulnerability to climate change and 'adaptation science' in the coastal context (led by Vice Chair for Coastal Vulnerability Hans Peter Plag and Working Group Chair Brad Murray).
  - The book will involve multiple academic and applied communities and multiple chapter authors. Existing liaisons between the WG/CVI and various groups, as well as representatives from other communities, will be recruited for participation.
  - The book will address natural and developed coastlines,
  - And will address observational as well as modeling opportunities and needs.

Community engagement next steps

- Building on the experience Vice Chair for Community Engagement Chris Thomas has had with the Newsletter, we will to try to increase the breadth of active participants and spur new collaborations and new ideas involving coupling between different environments or processes by turning the WG/CVI email lists into a moderated list that members can use for timely, and brief communications of success stories, opportunities, and ideas. The Newsletter will be transformed into a cumulative archive.

- Planning the coastal component of CSDMS 3.0:
  - At the 2016 CSDMS meeting, the attending members of the WG and CVI discussed plans for the next incarnation of CSDMS. These plans include the likely continuation of select existing goals and activities, as well as new themes and questions outlined in the appendix below.

- These themes and questions have been circulated to the full memberships of the WG and CVI in the form of a google document that all are invited to contribute to. We will continue the online brainstorming and discussion into the fall, with periodic email prompts. We intend to craft our next set of visions and aspirations as a community.
- These (and likely other) themes will be translated into science goals that can spur collaborations and proposals to address compelling questions and lead to the development of new models and new couplings between models (of different environments or different sets of processes), which will ultimately increase CSDMS's usefulness to the research community.

Appendix: Plans for Coastal WG and CVI in CSDMS 3.0; synthesis of in-person discussion
Toward CSDMS 3.0— Context: Frontline of Global Change;
Need to address coastal change and vulnerability,
Both basic science and place-specific forecasts

Possible Themes (discussion to be continued on line):

- How can modeling incorporate new high-res observations?

  Data 'supernova'; e.g. lots of high-res remote sensing

  End member approaches: models become higher res; or incorporate/synthesize observations into empirically based parameterizations

- Fine and mixed sediment, stratigraphy: how does it affect coastal change (e.g. erosion)?

  Fine, cohesive sediment plays key roles in models addressing coastal marshes and bays—but can we improve the way erosion, transport, and deposition are treated? How about the role of sandy sediment in these environments?

  In addition, models of coastline dynamics often assume all coarse sediment. Stratigraphy into which the shoreline/shoreface erodes typically includes a mix of grain sizes—which affects erosion rates, and creates feedbacks with alongshore-transport dynamics.

- How can event-scale modeling synergize with longer-term modeling (past and future)?

  e.g. we can model hydrodynamic processes like tides and surge well, especially given the present landscape shape as a boundary condition. Modeling such event-scale processes, including associated short-term sediment fluxes, could potentially be very valuable in a model of longer-term evolution of coastal environments. But how to marry the two, when past or future boundary conditions are not as well defined, and time scales contrast?

  Not only do we not know the future landscape and ecosystem configurations well, but in developed coastlines, the development itself and associated structures build to protect development from event-scale hazards (from constructed dunes to seawalls to nourishment) are key elements of the boundary conditions for event-scale modeling; e.g. surge patterns and associated sediment fluxes are dictated by these boundary conditions. What will the human components of the coastal system look like decades or a century in the future?

The configuration of the human components depends partly on how the landscape and ecosystems evolve—which depends on how the human components evolve… need to treat human components as dynamic rather than as static snap shots (see next bullet)

- Need more coupling between Earth-surface scientists and:

  - Social scientists (economists to demographers), to incorporate dynamics of human components in long-term models

  - Hazards/resilience community (event focused); Human actions taken to reduce vulnerability of coastal environments/development on the event timescale can directly affect the longer-term evolution of the landscape—and therefore future event-timescale risks, and the future development… Actions that reduce vulnerability on the event timescale can increase vulnerability over longer timescales (e.g. on barrier coasts).

6.3 Marine Working Group

- A series of short-term (1-2 yr.) objectives outlined in the CSDMS Strategic Plan, including:
  - Developing a set of models that can be coupled via BMI.

    Project context to raise priority at Deltares for the development of a BMI interface for the current structured grid Delft3D-FLOW engine is currently lacking. However, Delft3D-FLOW Flexible Mesh, which is to be released in open source later this year by Deltares. This version will include a BMI compatible interface, and other components will likely follow over time.

    Marine working group has interest in having an atmospheric / wind model available via BMI, and also interest in having morphodynamic models.

  - Providing a hydrodynamic model to the CSDMS that is easier to use.

    An idealized continental shelf model has been provided that uses ROMS (the Regional Ocean Modeling System) to calculate hydrodynamics, salinity, and sediment transport fields for an idealized, planar shaped continental shelf onto which a freshwater plume flows. A pre-compiled version of the model, with necessary input files, was ported to the CSDMS supercomputer, beach. We call this implementation "ROMS-LITE". The implementation can now be run within the WMT, and users have choices to modify some key sediment transport parameters via the WMT GUI.

    The ROMS-LITE forms the basis of a series of Lesson Plans developed with input from the CSDMS EKT working group. In 2016, these lesson plans were made available for use by the CSDMS community. Instructors from several universities have expressed interest in using the ROMS – LITE lesson plans during the 2016 – 2017 academic year.

- The Marine Working Group encourages participation by members at the American Geophysical Union's 2016 Fall Meeting, especially within the context of a special session proposed jointly with the Chesapeake Research Group, and the Coastal Working Group titled: *Bridging Boundaries in Surface Dynamics of Estuarine, Coastal, and Marine Systems using Models, Laboratory Studies, and Observations.*

- Summary of Marine Working Group Resources:
  - The repository currently lists fifty-two marine models and 6 marine modeling tools.
  - Models that have BMIs and are allied with Marine Working Group interests include SWAN, SedFlux, OceanWaves, CEM, ROMS-Lite.

6.4 Education and Knowledge Transfer Working Group

Accomplishments Over June 2015-2016

1. TOPOFLOW components have been completed and associated lesson materials for 3 hands-on labs and lectures using the WMT have been published on the CSDMS EKT labs page. TOPOFLOW components are organized in a separate 'hydrology' project in WMT. https://csdms.colorado.edu/wiki/Labs_portal

2. ROMS-Lite is completed for use in the WMT. Four associated labs and lectures on learning about grids, settling rates, river and wave forcing have been presented on the CSDMS web page.

3. The CSDMS IF Facility staff presented clinics on the Basic Model Interface, on the new TOPOFLOW components in WMT, on ROMS-Lite. The CSDMS developers and EKT specialist received working group feedback on future improvements and ease-of-use.

4. CSDMS IF staff has taught a 1-day bootcamp for students on introductory shell scripting, HPCC use, Python programming and version control use for model developers. This bootcamp targets beginning modelers and has examples specifically designed for earth scientists. The lesson material is posted for online use through the CSDMS wiki.

5. BMI

6. CHILD and Sedflux labs have been successfully used by early adopter faculty (Patrick Belmont and John Jaeger) in graduate courses at other universities (University of Utah, Logan and University of Florida).

7. **CSDMS Science on a Sphere** datasets contributed to the catalogue have been advertised at the Educational Session at AGU 2015.

Short-term Goals

- Advertise/publicize EKT resources. The EKT WG chair organizes a session at AGU: ***ED018: Earth surface modeling for education: adaptation, successes, and challenges***. *Conveners: Wei Luo, Mariela C. Perignon, Peter N. Adams, Carol J. Ormand*

- Strengthen the link to SERC at Carleton College (a primary entry point for geoscience educators) as a way to reach out broader audiences. This can partly be done through just linkages, but would be more efficient by joint strategies. One idea was to link the CSDMS Science on a Sphere data sets to SERC online resources.

- Encourage all CSDMS members to participate in EKT activities. The EKT WG chair will use strategic email messages to the whole working group membership to make announcements of opportunities, new products and other outreach.

- Develop metrics of use of teaching resources for evaluation. For example, keep better track of how many times models are run in WMT.

- ROMS lite run in classroom by several early adopters/faculty at universities outside of Colorado in 2016-2017. We have identified 4 faculty to use this resource and pair the labs with pre- and post lab questions.

- Instrument development/rubric assessment. Proof-of-concept on the CSDMS wiki?

- Youtube channel is being well used, metrics of views testify of use. Further this resource and make it more explicit to the CSDMS community.

Long-term Goals

- *Survey community about needs.*

- *Mapping or GDAL like tool to import rasters to topoflow. This request was emphasized by the users*

- *Webinar: a theme per semester: topoflow? ROMS-Lite?*

- *Assessments more formally with educational researchers.*

Ideas for CSDMS3.0

- *Develop lesson material for a 'certificate in earth surface process modeling'*

- *Collaborative class across different universities, distance learning for 3.0 proposal*

- *Summer school or hacking marathon. This could be inspired by different themes each year: involvement of the EKT WG members to be mentors of capstone projects, or teach in the school itself.*

6.5 Cyberinformatics and Numerics Working Group

The Cyberinformatics and Numerics Working Group currently has 201 members. In September 2015, Tian-Jian Hsu (Tom) was elected as WG Chair and Scott Peckham will continue serving as the Vice Chair. Under previous Chair Eckart Meiburg and Vice Chair Scott Peckham's leadership in the past many years, the working group has established two major purposes/tasks:

a. Our working group served as the liaison between the broad CSDMS community and the integration facility personnel regarding cyberinformatics and numerics demands.
b. The group has tackled difficult research issues on multi-scale modeling and model benchmarking for earth surface processes, in particular, the emphasis on using Computational Fluid Dynamics to tackle cross-scale multi-physics problems.

At the 2016 CSDMS Annual Meeting in Boulder, we had useful discussions during the breakout sessions. We will continue strengthening the two major tasks discussed above. In particular, we discussed and reviewed the role of our working group in CSDMS:

1. Many other working groups have a science focus. In addition to its science focus, our group also serves as the liaison between the CSDMS community and the Integration facility personnel for the community's cyberinfomatics needs. We should better communicate with other WGs, particular the chair and co-chair regarding this issue.

2. Established by previous chair and group member, our group's focus on how computation fluid dynamics can improve our understanding on earth surface processes. Under this main objective, we focus on
   a. Model benchmarking: an analytical solution database has established; some of the datasets in the CSDMS data repository can be used as model benchmarking. Currently, there are 77 field and laboratory data in the Data Repository. Since last year, we observed that there were several field data and (one) laboratory data that has been formally added to the CSDMS data repository. We can form a closer tie with SEN (sediment experimentalists network), they have a lot of laboratory data and field data that can be used for benchmarking (see item 3).
   b. Bridging the scales in earth surface modeling. This objective is clearly important for all the working groups. However, our group may provide and improve the methodology on how to effectively bridge scales. We believe this important subject should remain of key scientific importance in the upcoming CSDMS 3.0. For example, how to up-scale? How to use small-scale models (turbulence-resolving, wave-phase-resolving, boundary layer resolving, particle-resolving) to provide improved parameterization and closures for large-scale models. How to effectively use adaptive mesh techniques? (e.g., coupling hydro-static and nonhydrostatic coastal models with adaptive mesh; a keynote on similar subject was presented by Dr. Randy LeVeque last year). A session related to this science subject has been accepted by the upcoming AGU meeting. The title of the session is "EP028. Moving Down the Chain - Studying Earth Surface Processes using Computational Fluid Dynamics Approaches across Scales" (convener: Tian-Jian Hsu, Eckart Meiburg, Scott Peckham, Xiaofeng Liu). We plan to use this session to gather researchers to tackle this problem and get more ideas.

3. Reach out to Sediment Experimentalists Network (SEN): We welcome, SEN, now part of the earthcube, to be more involved and join force with CSDMS. We see this development as very positive since our WG have considered modeling benchmarking as one of the main emphasis. Having stronger interaction with SEN is consistent and can strengthen our key scientific objective. We should somehow incorporate experiments from SEN into the CSDMS data repository (having data uploaded, or at least provide a link to a particular webpage in SEN).

6.6 Interagency Working Group

The goal of the Interagency Working Group (IWG) is to build relationships between Federal and State agencies and CSDMS. CSDMS stands to benefit from these interactions directly through input of agency resources, and indirectly by demonstrating the utility of CSDMS science and technology. Agencies benefit by taking advantage of CSDMS technology and resources to advance their mission. Chris Sherwood (USGS, Woods Hole) was nominated as Chair of the IWG last year, and is working to strengthen ties between CSDMS and agencies. A strategy for IWG activities was developed and is being implemented, as described below.

Encourage existing relationships between CSDMS and agencies

There have been several successful CSDMS research programs with significant agency involvement, but agency involvement is CSDMS has waned a little. The Sandia National Laboratories Dakota software continues to be a valuable resource. The USGS is supporting the IWG and exploring the possibilities of developing coastal morphological models in the LandLab framework. BOEM's work on a coupled model for turbidity flows in submarine canyons is being completed this year.

<u>Develop at least one, ideally two, new projects where agencies leverage CSDMS resources or infrastructure toward agency mission.</u>

Ideas were solicited from both agency and CSDMS scientists and reported at the Annual meetings in 2015 and 2016. Progress has been made on two opportunities, as follows.

- Progress on the use of CSDMS model-coupling technology to develop a coupled model of coastal morphologic evolution that combines the recent advances in marine and coastal sediment transport has been made. A special session at AGU Ocean Sciences on coastal morphology was organized by Sherwood and others, and invited presenters included LandLab developers (Gasparini) and Coastal Dune Model users (Moore). An agreement to explore coupling coastal processes within the LandLab framework was reached. This model system would be used to evaluate short-term (event- to decadal time scales) evolution of coastal systems. Interested agencies might include ONR, USGS, BOEM, NPS, FWS, and USACOE.

- Chesapeake Bay Focus Research Group Chair Raleigh Hood lead a successful workshop proposal to the Chesapeake Bay Scientific and Technical Advisory Committee. The workshop will explore modeling options for the next phase of the Chesapeake Bay Program. IWG Chair Sherwood is on the steering committee for the workshop, and one topic that will be considered is used of the CSDMS model coupling technology to enable various combinations of alternative estuarine, watershed, and airshed models. Interested agencies might include EPA, USGS, NOAA, and state agencies from the CB watershed.

<u>Conduct an Interagency Working Group Meeting in Washington</u>

An Interagency Working Group meeting was held at NSF Headquarters in Arlington, VA on January 13, 2016. Attendees from NSF included Richard Yuretich, Paul Cutler, Eva Zanzerkia, Barbara Ransom, and others. Representatives from other agencies included Chris Sherwood (USGS and CSDMS), Reggie Beach (ONR), David Lesmes and Dorothy Kock (DOE), and Raleigh Hood (U. Maryland, Chesapeake Bay Community Modeling Program, and CSDMS) and Guillermo Auad (BOEM). CSDMS representatives (Syvitski, Tucker, Hutton) presented overviews of CSDMS program and technology. Beach, Lesmes, Auad, and Hood presented background information on their agencies research interests and potential links with CSDMS. Follow-up from that meeting will include e-mails to attendees and other potentially interested agency representatives, encouraging them to articulate research objectives that might be incorporated into the CSDMS 3.0 proposal.

6.7 Carbonate Focus Research Group

<u>Initiatives</u>

The Carb FRG began a newsletter this year, distributing news of group initiatives, information about available models, and notices of up-coming meetings. Additionally, the profile of the group was improved on web sites.

The co-chairs proposed broadening the FRG to “Carbonates and Biogenics”. This is to strengthen the membership and leadership base of the group, and increase its relevance to neighbouring fields such as climate, oceanography, biogeochemistry, whole-earth chemistry, geophysical sensing. The change was approved in a poll of members and will be pushed forward.

<u>Meetings</u>

There will be a C-FRG sponsored session at the AGU 2016 fall meeting on ocean acidification and carbonate forward modelling. This is planned as an opportunity to move forward with collaboration with the Ecosystem Dynamics FRG; there are clear parallels given that the carbonate FRG modelling efforts involve a significant degree of ecosystem modelling.

New Model Developments

Development of the CarboCAT suite of carbonate forward models under the C-FRG Carbo* framework is ongoing in Royal Holloway University of London, and now University of Liverpool. Most recent progress has been made by graduate students in Royal Holloway working on multi-scale carbonate models demonstrating how carbonate strata form on a basin and platform scale adding various processes to the forward models poisoning and suppression of carbonate production by siliciclastic input (Fig. 1) and control on carbonate production rates by active faulting and carbonate ion concentration in the water column. Initial steps were been taken to componentize a carbonate code by exporting a portion of CarboCAT code for inclusion into the Coastline Evolution Model. Further work is required on this, with input from CSDMS staff. A new release of CarboCAT, including some of the features described above, will be made on the CSDMS model repository in 2016-2017.

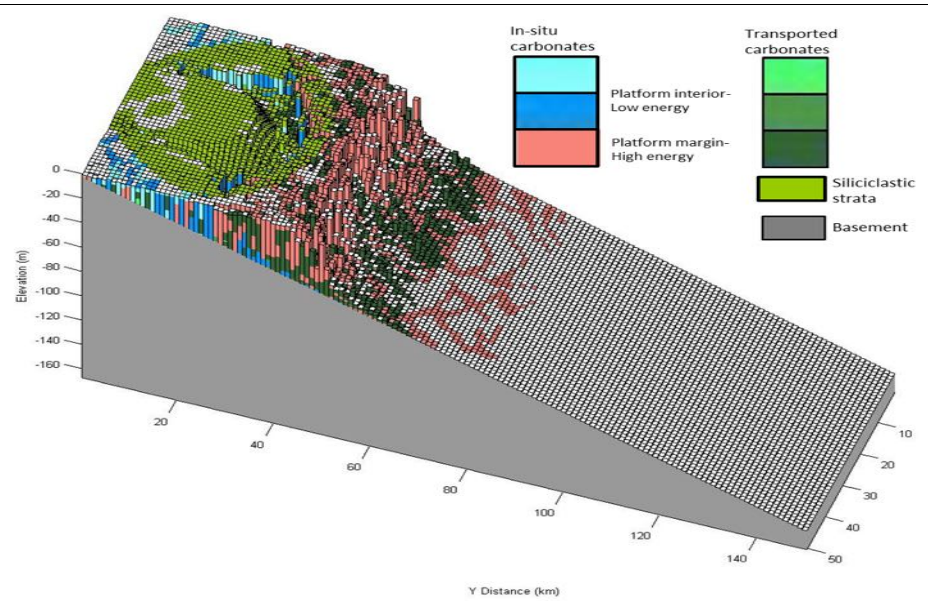


Fig 6.7.1 Output from CarboCAT showing an attached carbonate platform with platform margin (pink) and platform interior (blue) factories interacting with input of siliciclastic sediment (green) that is transported as a suspended plume across the platform interior, tending to decrease carbonate production where it is present.

Model-Data Linkages

The dbSEABED project, affiliated with CSDMS, has prepared global and regional coverages of seafloor carbonate contents (Fig. 2). They take into account a huge amount of new data since earlier compilations (e.g., by D. Archer), account for areas of rock and nodule, and cover shallow-water zones for the first time. The gridded data have been distributed through channels of the US Ocean Carbon & Biogeochemistry Program (OCB, "www.us-ocb.org"), where they will be applied in climate and carbon budget models.

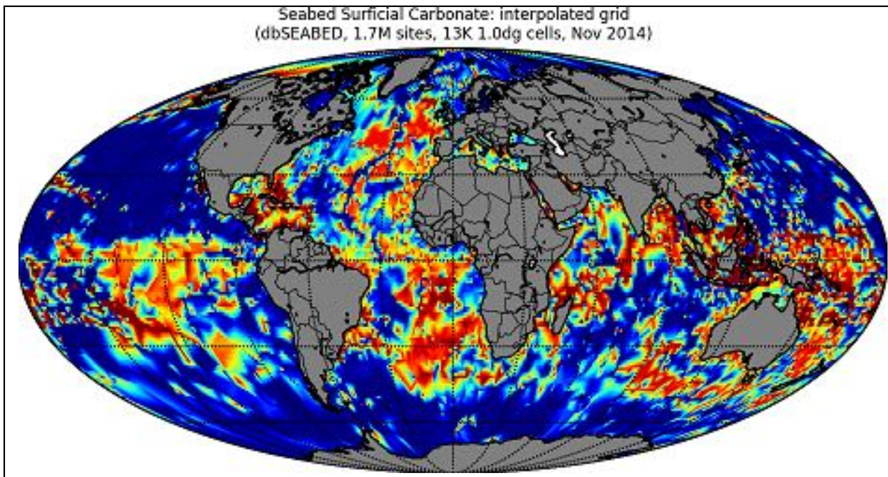


Fig. 6.7.2 New global mapping of seafloor surficial carbonate values distributed in cooperation with the US Ocean Carbon & Biogeochemistry Program for application in climate and other models.

6.8 Human Dimensions Focus Research Group

The HDFRG accomplished 2 major goals for Year 4:

- Include human dimensions model examples/talks/clinics at the annual CSDMS meeting
- Conduct a workshop on linking human systems models and earth surface dynamics models

The 2016 CSDMS Annual Meeting included its highest number of presentations (8) related to human dimensions and interdisciplinary modeling of coupled natural-human systems:

Keynote Addresses (first author name and affiliation):
~ *Extending Agent Based Modeling Approaches to National and Continental Scales* (Mark Rounsevell, University of Edinburgh—CSDMS HDFRG Co-Chair)
~*From Relative Sea Level Rise to Coastal Risk: Estimating Contemporary and Future Flood Risk in Deltas* (Zach Tessler, City University of New York)

Posters:
~*Effects of the Anthropogenic Landscape on Global Scale Suspended Sediment Flux* (Shawn Carter, University of Alabama)
~*Impacts of River Linking on Sediment Transport to Indian Deltas* (Stephanie Higgins, University of Colorado)

~*Methods for Visualizing Landscape Desiccation as a Result of Over-pumping with Application to the High Plains Aquifer in Western Kansas* (Missy Porter, University of Kansas)
~*A Composite Vulnerability Index for Urban Areas in Deltaic Regions: An Application in the Amazon Delta* (Andressa Vianna Mansur, Samapriya Roy, Indiana University Bloomington)
~*Human Impacts to Coastal Ecosystems in Puerto Rico: Development of Ecohydrological Model* (Shimelis Setegn, Florida International University)
~*Rejuvenating Poldered Landscapes: A Numerical Model of Tidal River Management in Coastal Bangladesh* (Chris Tasich, Vanderbilt University)

The HDFRG also planned and conducted their first major workshop on My 23-25, 2016 in Boulder, Colorado, titled **Linking Earth System Dynamics and Social System Modeling**. The workshop immediately followed the CSDMS Annual Meeting. Funding was provided by CSDMS, Future Earth/AIMES, and NSF, and brought together a group of 35 experts in diverse earth and social sciences with the shared objective of developing a blueprint for advancing global-scale coupled human systems and biogeophysical models.

Figure 6.8.1 Participants of Workshop: Linking Earth System Dynamics and Social System Modeling

The workshop was used as the starting point in developing a research strategy and plan with a timetable for the integration of human systems models with Earth system models. This plan is currently being developed into a White Paper. The forward-looking plan is based on establishing a distributed network of researchers with the cross-and trans-disciplinary skills to implement this ambitious project. Hence, we have now begun the process of developing a joint modeling effort that represents the effects of human activities on environmental change in better ways than is done currently.

The workshop identified a number of key issues that should underpin future research activities:

1. It is important to understand more about the role of the heterogeneity of decision making actors and the role of behavioral mechanisms in underpinning decision making;

2. Social system models need to represent a wider range of social processes than they do now, e.g. social interaction, power and control, cooperation/communication, competition, learning, etc.;
3. Keystone actors are very important in understanding human-environment systems;
4. Studies of changes in the past (e.g. land use change) would benefit the development of Earth system modeling of change in the future;
5. There is a need to endogenize institutions within social system models, especially as models are up-scaled from the local to global;
6. Inconsistency in baseline input data, including thematic definitions, is an important limitation to modeling;
7. There is much debate to be had around the issues of complexity and its representation versus simplicity in models, including whether to couple or not to couple models with different modeling approaches;
8. Understanding the sensitivity of biophysical models to human processes such as land management is critical in supporting the development of the next generation of coupled human-environment models.

A number of actions were identified for further development, including writing the White Paper on taking the community forward, writing a paper on model coupling, organizing follow-up meetings/workshops, establishing branding and communications plans, and exploring funding opportunities for the network. It was agreed that a follow-up meeting should be based on the White Paper, with a focus on a broader range of science presentations, including the identification of research gaps that could form the basis of a perspective paper. The next meeting is planned to coincide with the next CSDMS annual meeting in 2017. Before this, the AGU conference in December 2016 is a good opportunity for a sub-set of the group to meet up to: a) discuss the white paper, b) take the agenda forward for the larger CSDMS annual meeting related workshop.

The ways in which we brand and identify ourselves as a community is critical in supporting collaboration with other, existing communities. For example, we will avoid using the Earth System Model label, since this means something very specific to the climate science community. There are also potential tensions with the Integrated Assessment Modeling (IAM) community, indicating the importance of highlighting the differences between what we are seeking to achieve and what is already done by IAMs, e.g. we are cross-scale (multi-scalar), we focus on behavioral processes and system feedbacks, we address a broader range of human-dimensions issues, we are more interested in experiments to explore processes rather than 'predictions', etc.

A name for the group was proposed: the Computational Human and Earth System Science (CHESS) community. CSDMS is supporting the establishment/upkeep of a website/wiki for the CHESS community (contact: Albert Kettner) that includes the materials from the workshop. A subset of the workshop participants is currently working on a paper about model coupling methods with examples (to be submitted by the end of 2016). We are also exploring additional paper ideas: a) a Global Environmental Change editorial (CHESS community authored), and b) a longer multi-authored, position article (perspective piece) on the issues/ways forward. This paper will aim to be radical, but also evidence-based with a potential focus on the Sustainable Development Goals (SDG), which requires human dimensions research to be underpinned by better capacity building within research communities. The paper will also discuss links with IAMs and focus on the local level in order to put individuals back into models along with associated feedbacks (the research gap need). Thus, the CHESS community will identify the big holes, or what we're not doing now, and provide concrete examples to resolve these gaps.

Goals for Year 5:

Members of the HDFRG are chairing a session at the 2016 AGU Fall Meeting in San Francisco, CA based on the theme of the workshop:

Advances in Integration of Earth System Dynamics and Social System Models Conveners: Rogers, K.G. Ullah, I., Kettner, A. and Rounsevell, M.
The dynamics of the Earth's atmosphere, geosphere and biosphere are increasingly affected by human activities. At the same time, the outcome of these dynamics significantly impact human decisions and societies. Process models improve our ability to simulate how our planet is shaped, but have typically considered humans as exogenous to the Earth system. We know, however, that complex bidirectional feedbacks between human and natural processes greatly affect the system and the people inhabiting it. We invite contributions presenting diverse, interdisciplinary examples that push the boundaries of coupled social and biogeophysical modeling. We encourage both numerical and conceptual models, including socio-ecological and socio-hydrologic systems, integrated assessment, agent-based approaches, dynamic networks, and social informatics. These may address successes and challenges arising from scaling local processes to global dynamics, time lags, socio-natural feedbacks, disentangling complexity, multi-scalar problems, and emergent properties produced by coupled social-biogeophysical models.

Other goals for the HDFRG include:

- Increase the visibility of the HDFRG both within the CSDMS and the greater scientific community by publishing a white paper on the HDFRG workshop, with the intention of using the paper to seed funding for collaborative research and establishing a research center for coupled human-natural systems modeling
- Continue to feature human dimensions models, keynote talks and clinics at upcoming annual CSDMS meetings and ensure more contributions by women
- Host a workshop co-sponsored by the HDFRG and the Coastal Vulnerability Initiative of the Coastal Working Group
- Expand the Human Dimensions FRG efforts and visibility in CSDMS 3.0

6.9 Chesapeake Focus Research Group

The Chesapeake Focus Research Group (CFRG) currently has 68 members who are all active scientists and/or managers. The CFRG is integrated with the Chesapeake Community Modeling Program (CCMP), and so the CCMP Steering Committee provides oversight for both the CCMP and the CFRG. Over the past year the CCMP/CFRG has been working toward a goal of convening a "visioning workshop" that will provide a comprehensive review of the status of the current Chesapeake Bay Program (CBP) management modeling system and discuss future directions for management modeling in the CBP with a view toward developing a roadmap for future CBP modeling beyond 2018.

Description of Workshop:
CCMP, CSDMS/CFRG and the CBP have been funded by the CBP Scientific and Technical Advisory Committee (STAC) to convene a three-day workshop in 2017 to undertake a comprehensive review the status of the current CBP management modeling system and discuss future directions for management modeling in the CBP with a view toward developing a roadmap for future CBP modeling beyond 2018. This workshop will be guided by the following overarching questions:

1. *Description of needs:* What are the mandates and the scientific, computational, and data management challenges the CBP faces in the coming years and what critical changes and upgrades will have to be made to the CBP modeling system to meet these challenges?

2. *Review of advice:* How can information and recommendations from previous workshops and committee reports and organizations like the STAC, National Research Council (NRC), CCMP and CSDMS be brought to bear to address these needs?

3. *Description of resources:* What human and infrastructure resources are going to be available to meet these future needs and challenges? How can resources be used more efficiently and collaboration among government, private, and academic partners be maximized? What additional resources might be needed and how might the various stakeholders and partners work most effectively to find these?

4. *Visioning for 2015 and beyond:* Can a well-informed, realistic, and unified vision for future CBP modeling be created to guide us into the future?

This meeting will begin with a plenary session that will review the purpose of the CBP models, the current state of the CBP modeling system, and the goals of the workshop. In this plenary there will also be presentations and discussion related to overarching considerations, like how new technologies and modeling approaches can be used to address CBP modeling needs.

Most of the workshop time will be spent in breakout sessions, organized around each of the major components of the CBP modeling system (land use, watershed, airshed, estuarine physics and water quality, living resources, and socio-economic). These breakout groups will address all four of the overarching workshop questions. A final plenary session will consist of concise reports from the breakouts and a discussion of the compatibility between proposed components, with a view toward formulating a realistic and unified vision for future CBP modeling that can be used to guide us into the future.

Justification for Proposed Topics and Management Implications:
The CBP's reliance on the modeling system as a planning tool to inform strategic management decisions and adaptation toward Bay restoration will continue into the foreseeable future. Yet it has been more than a decade since STAC has convened a dedicated workshop to discuss future directions for modeling in the CBP (http://www.chesapeake.org/pubs/modbay2010report.pdf).

Moreover, there have been rapid advances in physical process understanding, computer science, and modeling techniques in recent years. There have also been several workshop activities and resulting reports that have provided recommendations for how the CBP Modeling Work Group (MWG) should consider evolving the modeling system in the future to keep up with the state-of-the-art in land use, watershed, airshed, estuarine, living resources, and socio-economic modeling for its restoration efforts. These include STAC sponsored workshops on multiple/ensemble modeling, shallow water modeling and uncertainty assessment. They also include an NRC-motivated report and recommendations from the Modeling Laboratory Action Team (MLAT) on how the CBP might reorganize its modeling infrastructure. In addition, the CCMP has long advocated that the CBP should continue efforts to more fully adopt open-source and community modeling approaches. There have also been two recent NSF-funded projects in Chesapeake Bay on the development of approaches for engaging stakeholder communities in the model development process. And, finally, the NSF-funded CSDMS CFRG brings state of the art modular modeling approaches and tools to the table along with the CSDMS Interagency Working Group (IAWG), which seeks to engage federal, state, and local agencies in model development efforts. All of these new technologies, approaches and recommendations should be considered in planning for the future.

Looking back on the last visioning workshop and the subsequent developments, it is clear that it is time to motivate another workshop along these lines. Indeed, based on past workshop experience and what has been learned since, we believe that this workshop will be highly successful in formulating a vision for future CBP modeling that can be used to guide us into the future.

Moreover, the CBP's Phase 6 modeling effort for setting nutrient reduction targets and TMDLs is well underway with the 2017 Midpoint Assessment (MPA) looming, which will continue through all of 2018. Immediately after the MPA the CBP MWG will begin the next phase of the development of its modeling system using the latest science, data, tools, and modeling approaches. Although the CBP is understandably focused on the 2017/2018 MPA, it is now time to start thinking about how the CBP's modeling suite should be changed and upgraded beyond 2018 to meet future management needs.

Potential Speakers:

The Steering Committee for the workshop (see below) will identify potential speakers that have expertise in (1) the Bay Program's modeling system (and/or other similar models), (2) multiple/ensemble modeling, (3) shallow water modeling, (4) uncertainty assessment, (5) open source and community modeling, (6) stakeholder engagement and social science, (7) modular modeling approaches and (8) CBP management needs for a post 2018 modeling system. In addition, the Steering Committee will invite speakers who were/are members of the CSDMS CFRG, the NRC-motivated MLAT and the CSDMS IAWG. The selected speakers will address the workshop objectives and will be asked to significantly contribute to the workshop products. The Steering Committee will specifically seek experts from regions outside of the Chesapeake Bay watershed to offer new perspectives and knowledge to the workshop.

Detailed Description of Workshop Products:

The workshop will generate specific recommendations for CBP MWG to consider for how the CBP's modeling suite might be changed and upgraded beyond 2018 to meet future management needs. The workshop will develop recommendations specific to each component of the CBP modeling system (land use, watershed, estuarine physical and water quality, living resources, and socio-economic). These recommendations will include consideration of the potential benefits of state-of-the-art modeling approaches and the potential need for changing the CBP modeling infrastructure. The recommendations, along with a justification and priority for each, will be developed into a workshop report and submitted to the CBP within 90 days of the workshop. Another major outcome/product of this workshop will be a peer-reviewed paper summarizing the major findings and recommendations.

Logistics:

The workshop will be invitation-only, and we estimate that 40-50 participants will attend. The workshop will be held over a three-day period in May 2017. All STAC and CCMP members will be invited along with selected NRC MLAT, and CSDMS CFRG and IAWG members. The workshop steering committee, STAC, CRC and the CCMP will contribute to the selection of people to attend. The workshop steering committee is considering locations near Annapolis, MD, and VIMS, Gloucester Point, VA. The steering committee convened its first meeting on June 25, 2016 to begin planning for the workshop with support from STAC. Subsequent meetings will be convened monthly until the workshop is convened.

Workshop Steering Committee:

Bill Ball: Bill is Executive Director of the Chesapeake Research Consortium (CRC), where he has been since January 2015, and also continues his role as a professor of environmental engineering within the Department of Geography and Environmental Engineering at Johns Hopkins University, where he has been since 1992. Bill's research revolves around physical-chemical processes controlling water quality.

Peter Claggett: Peter is a Research Geographer with the USGS and has worked at the CBP since 2002. Peter coordinates the CBP Land Use Workgroup and leads the CBP Land Data Team that conducts research on land change characterization, analysis, and modeling in the Chesapeake Bay Watershed.

Lora Harris: Lora is an associate professor at the University of Maryland Center for Environmental Science Chesapeake Biological Laboratory (UMCES CBL) where she has worked since 2007. Lora's research interests revolve around marine systems ecology, theoretical ecology, ecosystem modeling and primary production variability.

Raleigh Hood (Workshop co-Chair): Raleigh is a professor at UMCES Horn Point Laboratory (UMCES HPL) where he has worked since 1995. He is also the program manager and steering committee chair of the CCMP, and chair of the CSDMS/CFRG. Raleigh's research interests revolve around coupled physical-biogeochemical and ecosystem modeling.

Tom Ihde: Tom is a staff scientist at the NOAA Chesapeake Bay Office (NCBO) where he has worked since 2009, and he is also currently a member of the CBP STAC. Tom has worked in marine fisheries on a wide variety of subjects and he is currently working on the development and application of a full ecosystem simulation model (Atlantis) in Chesapeake Bay.

Lewis Linker: Lewis Linker is the CBP Modeling Coordinator, and works with colleagues throughout the CBP to develop linked models of the airshed, watershed, estuary, and living resources of the Chesapeake region.

Gary Shenk (Workshop co-Chair): Gary is a hydrologist with the USGS and has worked at the CBP since 1995. Gary leads the watershed model development and application team at the CBP.

Chris Sherwood: Chris is an oceanographer with USGS in Woods Hole where he has worked since 2001. He is also the Chair of the CSDMS/IAWG. Chris' research interests revolve around measuring and modeling sediment and contaminant transport in the coastal ocean.

Lisa Wainger: Lisa Wainger is a research professor at UMCES CBL where she has worked since 1997, and she is also currently the chair of the CBP STAC. Lisa's research interests revolve around regional-scale ecological and economic modeling.

6.10 Geodynamics Focus Research Group

The Geodynamics Focused Research Group (FRG) currently has 100+ members, many of whom where able to attend the 2016 CSDMS Annual Meeting in Boulder. Jean Braun gave a Keynote lecture on *Linkages between mantle convection, tectonics, erosion and climate*, highlighting recent work on efficient parallel methods for solving the stream power law equation and linking it to large-scale 3D geodynamic simulations. Also discussed were new methods for coupling surface processes, hydrology, and chemical dissolution.

At the Geodynamics FRG breakout session at the Annual Meeting a major topic of discussion was forging better linkages with the Long-term Tectonics working group at CIG. CIG-3 has recently been funded for another 5 years and with the CSDMS 3.0 proposal due in mid 2017 this was viewed as an excellent time to bring the communities together to work toward the next generation of coupled geodynamic/surface processes models. Several specific development issues were discussed including: how easily different codes could be coupled, different approaches to parallelization in geodynamic and surface process codes, and what datasets are available to test coupled models. To help foster interactions between the communities a joint CSDMS-CIG workshop was proposed. Mark Behn has followed up on this with CIG Director Louis Kellogg and the Long-term Tectonics working group with the hope of planning a workshop for winter/spring 2017.

Another issue discussed at the breakout session was the need for the Geodynamics FRG to articulate specific key research questions that could be incorporated into the CIG-3 proposal. A few examples discussed included:

- When does reworking of surface topography feedback to influence fault/tectonic evolution?
- Can surface landscapes be used to infer deeper processes (e.g., lower crustal flow)?
- Why do old mountain ranges exist?

- How are surface processes linked to short-term tectonics (e.g., what is the relationship between earthquakes and landslides)?

These and other scientific questions motivating the development of future coupled geodynamic/surface processes models will be refined over the next 12 months in preparation for the CIG-3 proposal.

Over the last year, several open source geodynamic model descriptions have been added to the CSDMS website (http://csdms.colorado.edu/wiki/_Geodynamic_models). In addition, a pre GSA short course *Introduction to Numerical Modeling of Lithospheric Deformation in Matlab® (Course #524)* will be offered by several members of the Geodynamics FRG. Details on this course can be found at: http://community.geosociety.org/gsa2016/science-careers/courses#collapse24

Finally, members of the Geodynamics FRG have submitted several proposals for special sessions at the 2016 Fall AGU Meeting including: *Connecting geodynamics and surface processes: theoretical and field-based approaches* (P. Upton, J.-A. Olive, S. Roy, L. Malatesta) and *Linking Surface and Upper Crustal Kinematics to Deeper Crust and Mantle Flow in Collisions* (D. Young, R. Bendick, A. Duvall).

6.11 Hydrology Focus Research Group

The Hydrology Focus Research Group is involved in numerous activities that are highlighted in the following paragraphs

(1) The funding for CSDMS comes from many different directorates at NSF and this underscores the inter-disciplinary nature of CSDMS. People are encouraged to write proposals that use the CSDMS framework and the CSDMS Integration Facility (CSDMS-IF) as well as contribute back (two-way synergy). CSDMS also will write letters of support for proposals related to its priorities.

(2) The NOAA National Water Center (NWC) serves as a catalyst for the Integrated Water Resources and Science Services (IWRSS) partnership, of which NOAA, the US Geological Survey (USGS), and the Army Corps of Engineers are the initial members. NWC offers tremendous opportunity for the Hydrology FRG for collaboration. Proposals that involve the NWC are encouraged as well as meeting with and getting to know the NWC leadership in the coming months. (Search for NWC director is underway).

(3) The Consortium of Universities for the Advancement of Hydrological Sciences (CUAHSI) has established a summer program with NWC. CUAHSI established the Community Hydrological Modeling Platform (CHyMP) a few years ago (a major proposal was not written). This could be revived, and CSDMS could play a role in this process. The tri-chairs of CHyMP were Famiglietti, JPL; Lakshmi, USC; and Murdoch, Clemson. This could include using platforms such as WRF-Hydro as well as set up benchmark data set access.

(4) The participants for the Hydrology FRG meeting (05-18-2016) in Boulder CO were asked to list their most important concerns/areas of research for CSDMS 3.0 (the next proposal to be submitted Summer 2017 to NSF). These were their issues-

   a. Understanding differences in models by collecting the meta-data of the 60 plus hydrological models in the CSDMS model repository. The question arises - Is it realistic and productive to do the same for all models?
   b. Data to hydrological models remain the most important element in simulations. These include data for calibration and validation. One of the most important data for hydrological models is precipitation – from various sources – gages, radar and satellite. A logical next step would be to couple input data with models. CSDMS has successfully experimented with this using the previous version of the model-coupling tool (CMT), Figure 1. Something like this in an extended form could be proposed for the Web Modeling Tool (WMT).
   c. Recent work has suggested that nearly all existing models are plagued by unrealistic numerical artifacts. These artifacts are generally characterized as nonlinearities until their

cause is discovered, and result in models being more nonlinear than the real world they represent. These artifacts can greatly complicate model analysis methods such as sensitivity analysis, calibration, data needs assessment, and uncertainty evaluation, and often obscure the effect of realistic simulated nonlinearities. An example is shown in figure 2. Entities such as CSDMS need to play a large role in showing modelers the consequences of such artifacts and encouraging next generation models that have fewer numerical artifacts and are thus both more convenient and more accurately reflect environmental systems.

d. Ensure that hydrological models in the CSDMS repository have all major physical processes represented

e. New data sets that are coming online include satellite data and data from unmanned aerial vehicles (UAVs or drones). The data from UAV can be used for land surface topography, vegetation, surface temperature and soil moisture to name a few.

    i. The Hydrology FRG can set up standardization of data sets like weather underground – establish observer network of hydrological observations such as river stage and/or discharge and provide convenient ways for the data to be translated into model input or formatted for use in calibration.

    ii. CSDMS can have a software warehouse for software needed in the operation of instruments such as LIDAR, UAV etc.

f. Consider the models in CSDMS from the perspective of addressing environmental crisis – both sudden, such as floods, volcanic eruptions, and earthquakes, and slowly evolving, such as depleted aquifers and changing climate. Potentially consider response scenarios.

(5) There was a discussion about using the operations command center facilities at NWC during a summer as a drill-operation to coordinate prediction and rescue/warning activities associated with (a) Hurricane (b) Levee breach (c) Flooding using past historical data and a host of models and CSDMS tools. This would be a planned activity (as a result of a proposal) with legwork prior to arriving at the NWC from setting up models and data sets so that at the “event workshop” the teams could react in real-time.

(6) Two examples of cross cutting research themes are illustrated below.

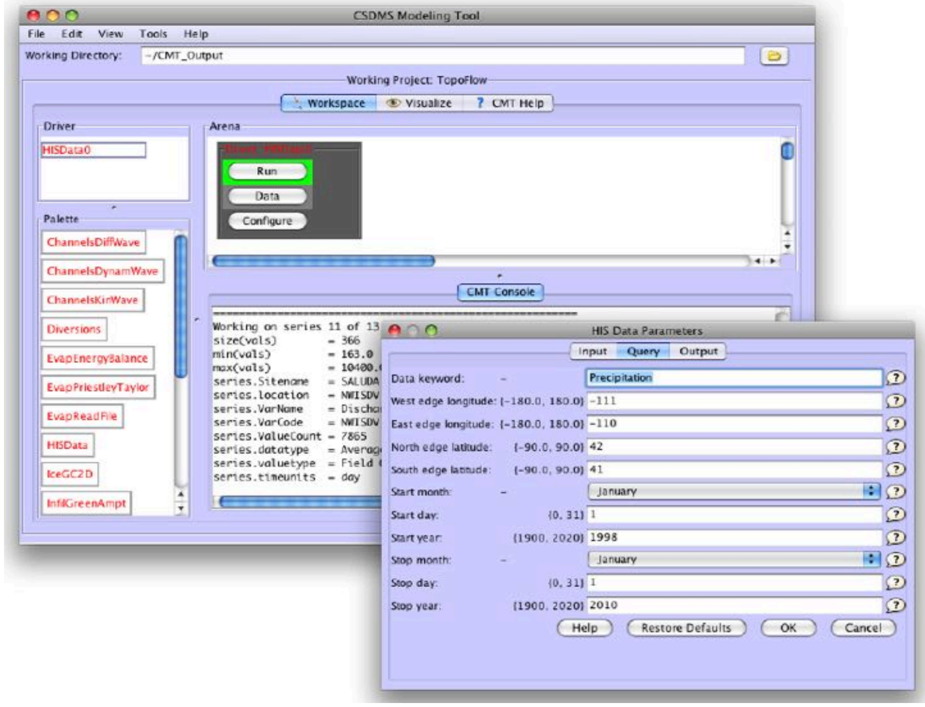


Figure 6.11.1. Example of procedure to couple the data component CUASHI-HIS (Consortium for the Advancement of Hydrologic Science - Hydrological Information System) to a model in the previous model coupling tool (CMT). (After Peckham and Goodall, 2013).

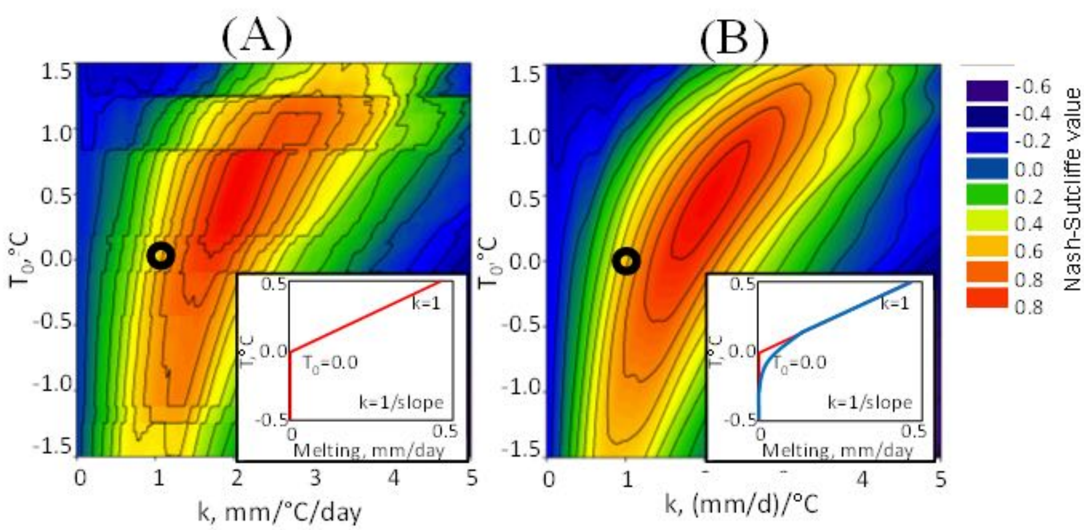


Figure 6.11.2. (A) The mathematical relation between melting and temperature is conceptualized using a bi-linear function with a discontinuity at T0. Finding the best-fit solution requires sampling methods and hundreds or even thousands of solutions. (B) The mathematical relation between melting and temperature is conceptualized as bilinear, with a smoothed transition. The smoothing more realistically represents conditions in any field situation, and best-fit parameters can be identified using 10s of model runs using gradient-based methods. The ease of solution makes it easier to investigate data from alternative sites and seasons, for example. (from Hill et al. 2015)

References

Hill, M. C., Dmitri Kavetski, Martyn Clark, Ming Ye, Mazdak Arabi, Dan Lu, Laura Foglia, and Steffen Mehl. 2015. Practical use of computationally frugal model analysis methods. *Groundwater*. DOI: 10.1111/gwat.12330

Peckham, S.D., and Goodall, J.L., 2013. Driving plug-and-play models with data from web services: A demonstration of interoperability between CSDMS and CUAHSI-HIS. Computers & Geosciences, v53, 154-161. DOI: 10.1016/j.cageo.2012.04.019

6.12 Ecosystem Dynamics Focus Research Group

The Ecosystem Dynamics Focus Research Group was launched in November 2015. The FRG, co-sponsored by the International Society for Ecological Modeling (ISEM - www.isemna.org), fills a gap in the existing CSDMS expertise in ecological and biological modeling.

During the past year the main focus was on building recognition for the newly formed research group. It was the first full year in existence for Ecosystem Dynamics and we now have 51 members from 14 countries. This is up from 30 members from 9 countries at the time of last year's report. Four specific activities were undertaken to increase the awareness of the group. First, as Editor in Chief of the journal *Ecological Modeling*, I have added a sentence in all letters of acceptance informing authors of the group and encouraging them to join and consider sharing their model with CSDMS. Second, the homepage for the journal now has a news item referring to the possibility to join Ecosystem Dynamics at CSDMS. The link has this information: http://www.journals.elsevier.com/ecological-modelling/news/community-surface-dynamics-modeling-system-csdms-and-ecologi. A similar link will be placed on the website for the International Society for Ecological Modeling (ISEM). ISEM is a co-sponsoring organization for the Ecosystem Dynamics FRG. The link was supposed to be operational already but there has been some difficulty with the Webmaster making changes. This should be resolved soon. The third item is that James Syvitski, Executive Director for CSDMS, was invited and gave a keynote presentation to the ISEM conference held at Towson University in May 2016. The conference is the biennial conference for the society and had around 350 participants. The talk, titled: The Community Surface Dynamics Modeling System, introduced the CSDMS to the ISEM delegates. James and Greg Tucker both attended the conference and were available throughout to discuss with participants. This was an effective way to spread the benefits of CSDMS. Lastly, Ecosystem Dynamics FRG Chair, Brian Fath, attended the CSDMS annual meeting in Boulder in May 2016. Upon recommendation, Don DeAngelis provided a keynote presentation at CSDMS touching on the topic of agent based modeling in ecology and how this can connect with other participants at the annual meeting. It was apparent that meeting research directions included ABMs and also included linkages to ecological processes. Further integration of these methods and disciplines is expected.

7.0 CSDMS 2.0 Year 5 Priorities and Management of Resources

7.1 CSDMS 2.0 Year 5 Goals — CSDMS Portal

Develop community plaza tools

CSDMS has become the place to go when it comes down to web searches for modeling Earth surface processes. Just a few years ago we had on average about 100 unique web portal views a day. This increased to over 460 views currently on a daily base. The CSDMS portal was also mentioned as the go-to-place by early career scientists during the joint CSDMS-SEN annual meeting, May 2016. We want to maintain and extend this momentum by offering additional information to our diverse group of members. One method to do this is by offering information all scientists are interested in, namely funding opportunities. From discussions with other large community projects (e.g. STEPPE program funded by NSF) it was noticed that clearly presented funding opportunity information is highly appreciated by members. This additional information should make it easier for CSDMS members to be even more successful in pursuing their goals in trying to explore Earth's surface by developing and using community software.

Improve and CSDMS portal functionality

a) **Change look and feel of the CSDMS portal** (*in progress, will be further developed and implemented by early 2017).* Web portal designs are subject to fashion. New technology improves user experience, making the web use easier and more intuitive. Therefore, CSDMS is developing a new *skin*. This *skin* will provide the same information stored in the underlying databases, but simply presents it with a new, friendlier to use user interface. We have adopted the 'Twitter Bootstrap 3' skin and keep the Mediawiki SQL underlying databases.
A test web portal site has been setup already to insure that development, modification and integration of the skin to the underlying web database will go smoothly without interrupting performance of the current CSDMS web portal. Adoption of the Twitter Bootstrap 3 skin will also provide a friendlier mobile web experience. It is the intention to implement the new CSDMS skin and fully integrate with the existing website by early 2017.

b) **Portal maintenance** (*ongoing*). The open software packages used for the CSDMS web portal require maintenance to guarantee performance and security. To conform University of Colorado standards, new upgrades and security patches will be installed when needed. Reference citation indexes will be kept updated to guarantee up to date information.

c) **Informing the community** (*ongoing*). CSDMS advertises job opportunities, meetings, new material that is submitted to the repositories, and highlights innovative findings made by the community. Minor resources are requested towards this to ensure continuity of informing the community.

Milestones:

1 Further develop community plaza tools. Set up and integrate a funding opportunity information page that will be updated frequently.

2 Change look and feel of CSDMS portal by developing and integrating a new, friendlier to use user interface.

3 Portal maintenance, installation of upgrades and security patches.

4 Maintain providing information to the community on a day-to-day basis.

Resources: 0.5 FTE Web Specialist.

7.2 CSDMS 2.0 Year 5 Goals — Cyber Plans

In the coming year, the CSDMS IF software engineers will focus on three tasks:

1. Expand and develop PyMT service components (such as a model uncertainty component for WMT using Dakota, and SedGrid).
2. Develop a benchmarking service component for WMT.
3. Continue to BMI models and them to WMT.
4. Continue to deploy the CSDMS stack on other HPC systems.

Develop a model uncertainty component for WMT using Dakota. As reported in Section 4.8, CSDMS IF is continuing to develop a Python interface to Dakota functionality. CSDMS IF software engineers will expand this interface to work with any model that exposes inputs and outputs through a BMI, thus ensuring access not only to HydroTrend, but also to other CSDMS components. The updated interface will be added as a service component to the **wmt-uncertainty** project described in Section 4.4. This will require significant changes to the WMT client, as it will need to be able to dynamically gather Dakota inputs from the CSDMS components being analyzed.

Milestones:

1. Modify the CSDMS Dakota interface to access the BMI of a model. Test with HydroTrend and other components available in PyMT.
2. Add the Dakota-based model uncertainty service component to PyMT.
3. Add a user interface to run Dakota from the WMT client.

Resources: 0.75 FTE software engineer.

Develop a benchmarking service component for WMT. As reported in Section 4.9, CSDMS-IF has installed the ILAMB benchmarking software on the CSDMS HPCC, *beach*. The ILAMB software, which is modular and open source, will be evaluated as a platform on which a benchmarking service component can be built. ILAMB requires that both benchmark datasets and model outputs conform to CMIP5 standard output, which includes metadata requirements and a controlled vocabulary. CSDMS-IF software engineers will write a service component that translates the NetCDF output from the models in the CSDMS framework into CMIP5-compatible NetCDF output. ILAMB can then be wrapped with a BMI and included as a service component in the CSDMS framework.

Milestones:

1. Determine whether ILAMB can be used for benchmarking CSDMS models.
2. Write a service component to convert arbitrary NetCDF model output to CMIP5-compatible output.
3. Wrap ILAMB with a BMI and include in the CSDMS framework.
4. Add the ILAMB service component to WMT.

Resources: 0.25 FTE software engineer.

Continue to BMI models and add them to WMT. In the coming budget year, the CSDMS IF software engineers will continue to wrap models in the CSDMS repository with a BMI and add them as components to WMT.

Milestones:

1. Identify candidate models and write BMI wrappers for them.
2. Bring BMI-ed models into the CSDMS framework.
3. Ensure the new components work in WMT.

Resources: 0.25 FTE software engineer.

Continue to expand and develop the CSDMS PyMT/WMT Framework: As reported in Section 4.1, the CSDMS-IF has created a Python-based model-coupling framework. In the coming year, CSDMS software engineers will continue to expand the framework's capabilities and increase its usability. In addition, CSDMS will make PyMT for visible to the community and expand its usage within the CSDMS community.

Milestones:

1. Complete user API documentation for PyMT with examples.
2. Increase PyMT functionality by adding the ability for components to run in parallel, when possible.
3. Enhance/add service components to aid data exchange between models with different data assumptions (angle transformations, time/date calendars).

Resources: 0.25 FTE software engineer.

Continue to deploy CSDMS stack on other HPC systems. In the coming budget year, CSDMS IF will engage the community to identify new HPC systems on which the CSDMS stack can be installed. One possibility currently being explored is at Virginia Tech, under the auspices of Prof. Robert Weiss. Using the software distribution method described in Section 4.2, CSDMS IF software engineers will install the stack on any new HPC systems identified and include it as an executor in WMT.

Milestones:

1. Identify one or more new HPC systems on which the CSDMS stack can be installed.
2. Obtain permission and install the CSDMS stack on the new HPC system.
3. Include the new HPC system as an executor for WMT.

Resources: 0.1 FTE software engineer.

Supplemental work plan -- SedGrid: A component for storing stratigraphy.

As outlined above, the CSDMS-IF has created a service component that is able to track stratigraphy and is available within the CSDMS modeling framework, PyMT. In the coming year, CSDMS software engineers will continue work on SedGrid by expanding its capabilities and make it more user-friendly.

Milestones:

1. Expand the number of grain types that SedGrid can track to be an arbitrary number.
2. Add SedGrid to the CSDMS testing framework and software stack distribution.
3. Create an example of a model-coupling that uses the SedGrid, and accompanying documentation.
4. Complete user API documentation.

Resources: 0.15 software engineer.

7.3 CSDMS 2.0 Year 5 Goals — Education and Knowledge Transfer

EKT task 3 Enhance the Quantitative Surface Dynamics Toolbox

For year 5, we propose to complete the Quantitative Surface Dynamics Educational Toolbox, which combines educational material at different tiers but with crosscutting themes. We aim to have complete sets of labs and short-course material in all pillars of the CSDMS community: terrestrial, coastal, marine, human dimensions. Re-organization of the material on the CSDMS website, which better tags, improved search functionality and organization of material cross cutting themes and concepts.

One set of teaching labs will be formally assessed with Pre- and Post Lab Survey Questions on the most advanced levels in the QSD Toolbox to allow rubrics for simple assessment. This mini-series of coastal processes modeling using ROMS-Lite was selected in the EKT WG for the most rigorous testing by 4 independent faculty members at different US institutions in undergraduate and graduate level classes. We aim to present the results of this effort in a manuscript to an educational journal.

IF Staff Resources: 0.4 FTE Education and Knowledge Transfer Specialist, 0.1 FTE Web Specialist

EKT Task 2 Develop blackboard/spreadsheet labs on concepts of model uncertainty and sensitivity

CSDMS has received support from the Software Reuse Venture Fund FY15 for further focus of development of tools to deal with model assessment and uncertainty quantification techniques. We have already design online labs highlighting the uncertainty tools using the WMT over 2016,

For year 5, we aim to add textbook references, lectures, and develop more basic level hands-on teaching material (i.e. spreadsheet labs) on modeling uncertainty in earth surface process modeling.

0.1 FTE Education and Knowledge Transfer Specialist

EKT Task 3 Foster CSDMS tool development for planners and policy-makers

CSDMS EKT in general provides materials to teach and to facilitate critical evaluation of model assumptions and outputs. A proof-of-concept coupled data modeling system to assess river drainage basin changes will be completed in year 5. In addition, the EKT specialist will work with the Interagency Committee to accelerate adoption of CSDMS framework tools by explicit use a dedicated government research project.

0.1 FTE Education and Knowledge Transfer Specialist, 0.1 FTE Software Engineer

7.4 CSDMS 2.0 Year 5 Goals — CSDMS Sessions 2016 AGU Fall Meeting

CSDMS Working Group and Focus Research Group chairs and members submitted 11 Session Proposals to the AGU 2016 Fall Meeting and 10 Sessions were accepted. With almost 25,000 attendees, **AGU's Fall Meeting** is the largest earth and space science meeting in the world. The meeting will take place December 12-16, 2016 in San Francisco, California. Session descriptions follow:

EP028: Moving Down the Chain - Studying Earth Surface Processes Using Computational Fluid Dynamics Approaches Across Scales
Conveners: *Tian-Jian Hsu, Scott Peckham, Eckart Meiburg, Xiaofeng Liu*

Related to CSDMS group: ***Cyberinformatics and Numerics Working Group***
Modeling the dynamics of surface processes, e.g., the movement of fluids, and the flux of sediment and solutes requires a multi-scale approach. From a sand grain to regional scales, computational fluid dynamics (CFD) is a vital tool in the understanding of competing mechanisms, their interactions as well as accurate predictions. CFD has been applied to understand processes relevant to geomorphology and sediment source to sink, such as sedimentation, resuspension and turbidity currents. A grand challenge, e.g., as has been addressed by the Community Surface Dynamics Modeling System (CSDMS), is to effectively integrate key processes of different scales through parameterizations, model coupling, adaptive mesh refinement, and assimilative methodology. The purpose of this session is to get together researchers who use CFD to tackle earth surface processes. Particularly, we welcome abstracts addressing how model development and applications at different scales can collectively improve our physical understanding and prediction of earth surface processes.
Session ID: **13554**. URL: https://agu.confex.com/agu/fm16/preliminaryview.cgi/Session13554

GC012: Advances in Integration of Earth System Dynamics and Social System Models
Conveners: *Kimberly G Rogers, Isaac Ullah, Albert J. Kettner, Mark D.A. Rounsevell*

Related to CSDMS group: ***Human Dimensions Focus Research Group***
The dynamics of the Earth's atmosphere, geosphere and biosphere are increasingly affected by human activities. At the same time, the outcome of these dynamics significantly impact human decisions and societies. Process models improve our ability to simulate how our planet is shaped, but have typically considered humans as exogenous to the Earth system. We know, however, that complex bidirectional feedbacks between human and natural processes greatly affect the system and the people inhabiting it. We invite contributions presenting diverse, interdisciplinary examples that push the boundaries of coupled social and biogeophysical modeling. We encourage both numerical and conceptual models, including socio-ecological and socio-hydrologic systems, integrated assessment, agent-based approaches, dynamic networks, and social informatics. These may address successes and challenges arising from scaling local processes to global dynamics, time lags, socio-natural feedbacks, disentangling complexity, multi-scalar problems, and emergent properties produced by coupled social-biogeophysical models.
Session ID: **12792**. URL: https://agu.confex.com/agu/fm16/preliminaryview.cgi/Session12792

EP011: Connecting Geodynamics and Surface Processes: Theoretical and Field-Based Approaches
Conveners: *Phaedra Upton, Samual Roy, Jean-Arthur L. Olive, Luca C. Malatesta*

Related to CSDMS group: ***Geodynamics Focus Research Group***
Understanding the feedbacks between solid-Earth deformation, surface processes and landscape evolution requires a process-based approach that integrates observations and models across all spatial and temporal scales. The Earth's surface is a dynamic interface that evolves through the influence of tectonic and geomorphic drivers. Changes in tectonic forcings generally have spectacular geomorphological consequences. In turn, processes of surface erosion and transport can alter the near-surface stress field and influence fault evolution, uplift/subsidence patterns and surface heat flow. These mechanisms feed back on topography, and thus on the activity of geomorphic agents. This session sets out to explore current research into coupled problems of geomorphology, surface processes and geodynamics. We welcome contributions utilizing a combination of field, experimental, analytical and numerical approaches.
Session ID: **12254**. URL: https://agu.confex.com/agu/fm16/preliminaryview.cgi/Session12254

ED018: Earth Surface Modeling for Education: Adaptation, Successes, and Challenges
Conveners: *Wei Luo, Mariela C. Perignon, Peter N. Adams, Carol J. Ormand*

Related to CSDMS group: ***Education and Knowledge Transfer (EKT) Working Group***
Earth's surface is the ever-changing, dynamic interface between lithosphere, hydrosphere, cryosphere, and atmosphere. Surface dynamics models (SDMs) enable researchers to predict the movement of water and the flux of sediment and solutes in the environment. SDMs can also help students understand complicated surface processes and their interactions by exploring different scenarios and observing the associated outcomes. In addition, modeling exposes students to quantitative analysis and associated uncertainty, which are critical skills to master. However, for SDMs to be useful for education (especially at the undergraduate level), simplifications and adaptations are necessary. Furthermore, the efficacy of SDMs in enhancing students' learning should be documented with classroom assessment statistics. The proposed session aims to bring together researchers/educators to discuss the latest efforts in adapting SDMs for educational purposes, successes as demonstrated by classroom use, and challenges and issues to be addressed in the future.
Session ID: **12451**. URL: https://agu.confex.com/agu/fm16/preliminaryview.cgi/Session12451

H011: Advancing Decision Making Techniques and Environmental Future Projections to Better Address and Reduce Uncertainty
Conveners: *Albert J. Kettner, David Groves, Joseph R. Kasprzyk, Mary C. Hill*

Related to CSDMS group: ***Hydrology Focus Research Group***
Management of coupled natural-human systems increasingly focused on building resilience in coupled natural-human systems to climate change and other severe stressors. Supporting numerical projections the natural-human coupled systems, including hydrology, can be at best considered deeply uncertain. Although scenario-based planning is helpful in creating narratives of plausible futures for such systems, decision makers do not know or cannot agree on the full suite of risks in the system. This session welcomes advances in bottom-up, robust decision making approaches and contributions on state of the art numerical methods to estimate hydrological future projections: (i) methodological advances in decision making and other bottom-up approaches, especially relating to combating climate change, (ii) interdisciplinary case studies that include stakeholder engagement, (iii) uncertainty quantification approaches to support decision making, (iv) advances in quantifying changes in freshwater availability and hydrological extremes (both droughts and floods), and (v) new methods for evaluating uncertainties in hydrological projections.
Session ID: **12970**. URL: https://agu.confex.com/agu/fm16/preliminaryview.cgi/Session12970

EP026: Modeling Benthic Sedimentary Ecosystems under Ocean Acidification
Conveners: *Christopher J. Jenkins, Donald C. Potts*

Related to CSDMS group: ***Carbonate Focus Research Group***
A session focusing on dissolution of skeletal carbonates and derived sediments under ocean acidification. It is in response to recently published papers arguing for better understanding of the carbonate substrates / grounds that seawater interacts with. The session covers shallow- and deep-water ocean areas.
Dissolution affects carbonate grains and frameworks differently depending on location, exposure, mineralogy, biologic factors, and aspects like porosity and sediment turnover rates. The availability of materials for dissolution over coming decades and centuries affects projections of ocean CO2 uptake and the pH response. We seek papers on models that integrate benthic population ecology, structural integrity of coral reefs, the role of seawater saturation states, carbonate sediment ecosystems, seafloor physical properties, ocean acidification, and dissolution rates and effects. Papers showing a transdisciplinary approach (e.g. within the Community Surface Dynamics Modeling System, CSDMS), combining observational and modeling fields, or with novel computing methods are especially welcome.
Session ID: **13735**. URL: https://agu.confex.com/agu/fm16/preliminaryview.cgi/Session13735

C025: New Frontiers in Process Modeling of the Polar Regions
Conveners: *Irina Overeem, Alexandra Jahn, Elchin E. Jafarov, Jan Lenaerts*

Related to CSDMS group: ***Polar (Potential CSDMS 3.0 initiative)***
Glacial, permafrost landscapes, and sea ice controlled coastal zones of the polar regions are all uniquely dominated by prolonged freezing and short-lived thaw. The polar environment is rapidly responding to warming and shifts in these freeze-thaw dynamics. Rapid change causes an urgent need to improve our predictability of the polar system at several scales, global, regional and local. This session aims to highlight new developments in numerical modeling of Arctic climate, sea-ice, ice-sheet and permafrost and periglacial processes, which can ultimately lead to improved predictability of the polar system. We welcome contributions on detailed process modeling of the Arctic natural system, as well as more integrated models of the polar system. This session will have a special focus on new approaches to model-data comparison, techniques for uncertainty quantification, scaling and model intercomparison.
Session ID: **12814**. URL: https://agu.confex.com/agu/fm16/preliminaryview.cgi/Session12814

EP027: Modeling the Terrestrial Landscape
Conveners: *Gregory E. Tucker, Nicole M. Gasparini, Erkan Istanbulluoglu*

Related to CSDMS group: ***Terrestrial Working Group***
This session explores computational models for earth-surface processes, and data sets that can be used to test them. Models for a wide variety of terrestrial systems, including geomorphic, hydrologic, biogeochemical, fluvial, sedimentary, eolian, cryospheric, ecologic, and morphotectonic, continue to advance in both explanatory power and sophistication. We welcome contributions that deal with the various facets of models and model-data comparison: creating and exploring new models and concepts, comparing models with data sets, new data sets that demand better models, community modeling projects that foster connection and collaboration, novel computational algorithms, new data that challenge current models, models that capture (or fail to capture) the essence of a particular pattern or phenomenon, models that explore a previously underappreciated process or feedback, and beyond. Especially encouraged are studies that examine the coupling between processes and/or domains, as enabled for example by advances such as the Community

Surface Dynamics Modeling System's model-coupling technology.
Session ID: **13538**. URL: https://agu.confex.com/agu/fm16/preliminaryview.cgi/Session13538

OS024: Recent Advances in Ocean Biogeochemical and Ecosystem Modeling
Conveners: *Nicole S. Lovenduski, John P. Dunne*

Related to CSDMS group: ***Biogeochemistry (Potential CSDMS 3.0 initiative)***
Ocean biogeochemistry-ecosystem models are powerful tools to study biogeochemical cycling, ocean carbon uptake and transport, and the impacts of environmental change on marine ecosystems through multiple stressors including warming, hypoxia, acidification and other factors. Such models are now widely used in both global earth system and regional modeling studies. This session will highlight recent advances in ocean biogeochemical and ecosystem modeling, including, but not limited to: advances in high resolution, ensemble approaches for prediction and detection/attribution, regional configurations and mesh refinements, and advances in biogeochemical and ecosystem comprehensiveness and robustness. Further, we welcome submissions related to ocean biogeochemical and ecological model skill assessment using hydrographic, underway, autonomous, and satellite data products.
Session ID: **12511**. URL: https://agu.confex.com/agu/fm16/preliminaryview.cgi/Session12511

EP007: Bridging Boundaries in Surface Dynamics of Estuarine, Coastal, and Marine Systems using Models, Laboratory Studies, and Observations
Conveners: *Courtney K. Harris, Raleigh R. Hood, A. Brad Murray, Patricia Wiberg*

Related to CSDMS group: ***Coastal Working Group; Marine Working Group; Chesapeake Focus Research Group***
Researchers investigating morphodynamics and transport in specific environments increasingly must consider impacts of neighboring domains, either as parts of an integrated system or as boundary conditions or forcing. This is especially true along continental margins, where the coastline, continental shelf, and estuaries themselves mark boundaries between terrestrial, fluvial, and oceanic domains; and experience feedbacks with atmospheric systems. Understanding coastal systems depends on observational and lab studies that bridge spatial or disciplinary divides to characterize interactions of system components and fluxes across geographic boundaries. Advances in numerical modeling have also facilitated such transdisciplinary research through model coupling and nesting, e.g., Community Surface Dynamics Modeling System (CSDMS) provides tools for combining modeling approaches for system components. This session highlights coastal-system research that explores processes and feedbacks across traditional disciplinary and environmental boundaries. Observational, laboratory, and modeling studies bridging spatial domains, or interdisciplinary studies that blend physical, chemical, and biological processes are welcome.
Session ID: **13623**. URL: https://agu.confex.com/agu/fm16/preliminaryview.cgi/Session13623

8.0: NSF Revenue & Expenditures ($K with rounding errors)

	~ $K Year 6	~ $K Year 7	~ $K Year 8	~ $K Year 9
A. Salaries & Wages				
Executive Director:	$57	$56	$48	$50
Software Engineers:	$144	$164	$164	$170
Communication Staff*	$100	$100	$90	$90
Admin Staff**	$72	$42	$62	$72
Total Salaries	**$373**	**$362**	**$364**	**$382**
B. Fringe	**$103**	**$100**	**$102**	**$118**
D. Travel				
Center Staff:	$10	$15	$15	$18
Steering Committee	$6	$10	$8	$8
Executive Com.	$10	$15	$30	$18
Total Travel	**$26**	**$40**	**$53**	**$44**
E. Annual Meeting	**$70**	**$72**	**$72**	**$78**
F. Other Direct Costs				
Materials & Supplies	$1	$1	$1	$1
Publication Costs	$2	$1	$1	$1
Computer Services:	$25	$20	$14	$17
Non Capital Equipment	$2	$6	$5	$1
Official Function,	$0	$1	$2	$1
Total Other Costs	**$30**	**$29**	**$23**	**$21**
G. Total Direct Costs	**$602**	**$603**	**$614**	**$643**
H. Indirect Cost	**$271**	**$271**	**$276**	**$288**
I. Total Costs	**$879**	**$880**	**$943**	**$932**
J. Carry Over	**$21**	**$41**	**($3)**	**($32)**[&]

Notes:

1) Estimates include salaries projected 3 months to the end of the CSDMS fiscal year.
2) * Communication Staff includes Cyber + EKT Scientists
3) ** Admin Staff includes Executive Assistant + System Administrator + Accounting Technician.
4) CU completes a preliminary estimate of expenditures after 60 days of a time marker. CU provides a finalization typically within 90 days of a fiscal year.
5) [&] Overage covered by NSF Supplemental Venture Funding

Additional Funds Received by CSDMS IF Staff and Associates (see Section 2.4)

Year 6:

NASA: Threatened River Delta Systems: $143K,
Accelerating Changes in Arctic River Discharge $75K
BOEM: Shelf-Slope Sediment Exchange, Numerical Models for Extreme Events $75K
NSF: Governance in Community Earth Science $85K;
A Delta Dynamics Collaboratory $126K,
River plumes as indicators of Greenland Ice Sheet Melt $90K
U. Colorado: Salary support for the CSDMS Integration Facility: $73K

Year 7:

NASA: Threatened River Delta Systems: $143K,
Accelerating Changes in Arctic River Discharge $75K
BOEM: Shelf-Slope Sediment Exchange: Numerical Models for Extreme Events $75K
NSF: A Delta Dynamics Collaboratory $126K,
River plumes as indicators of Greenland Ice Sheet Melt $90K
U. Colorado: Salary support for the CSDMS Integration Facility: $73K

Year 8:

NASA: Threatened River Delta Systems: $143K
BOEM: Shelf-Slope Sediment Exchange: Numerical Models for Extreme Events $95K
NSF: A Delta Dynamics Collaboratory $126K,
Software Reuse Venture Fund FY14 $200K
River plumes as indicators of Greenland Ice Sheet Melt $60K
U. Colorado: Salary support for the CSDMS Integration Facility: $83K

Year 9:

NASA: Permafrost Benchmark System to Evaluate Permafrost Models $114K
NSF: A Delta Dynamics Collaboratory $280K,
Software Reuse Venture Fund FY15 $120K
Towards a Tiered Permafrost Modeling Cyberinfrastructure $162K
Impacts of Vegetation and Climate Change on Dryland Rivers: $10K
Tectonics in the Western Anatolia - sequence stratigraphic modeling: $20K
NSF/Belmont: Sustainability of deltaic systems with an integrated modeling framework: 65K
World Bank: Improving access, query and visualization of flood info for African regions: $25K
U. Minnesota: Predicting highly regulated deltas: the Colorado $25K
U. Colorado: Salary support for the CSDMS Integration Facility: $85K

Appendix 1: Institutional Membership — those in marked in blue have joined CSDMS between August 2015 and July 2016.

U.S. Academic Institutions: Current total of 132 with 4 new members as of August 2015

1. Arizona State University
2. Auburn University, Alabama
3. Binghamton University, New York
4. Boston College, Massachusetts
5. Boston University, Massachusetts
6. Brigham Young University, Utah
7. California Institute of Technology, Pasadena
8. California State University - Fresno
9. California State University - Long Beach
10. California State University – Los Angeles
11. Carleton College, Minneapolis
12. Center for Applied Coastal Research, Delaware
13. Chapman University, California
14. City College of New York, City University of New York
15. Coastal Carolina University, South Carolina
16. Colorado School of Mines, Colorado
17. Colorado State University
18. Columbia/LDEO, New York
19. Conservation Biology Institute, Oregon
20. CUAHSI, District of Columbia
21. Desert Research Institute, Nevada
22. Duke University, North Carolina
23. Florida Gulf Coast University
24. Florida International University
25. Franklin & Marshall College, Pennsylvania
26. George Mason University, VA
27. Georgia Institute of Technology, Atlanta
28. Harvard University
29. Idaho State University
30. Indiana State University
31. Indiana University, Indiana
32. Iowa State University
33. Jackson State University, Mississippi
34. John Hopkins University, Maryland
35. Louisiana State University
36. Massachusetts Institute of Technology
37. Michigan Technological University
38. Monterey Bay Aquarium Research Inst.
39. Murray State University, Kentucky
40. New Mexico Institute of Mining and Technology, New Mexico
41. North Carolina State University
42. Northern Arizona University
43. Northern Illinois University
44. Northwestern University, Illinois
45. Nova Southeastern University, Florida
46. Oberlin College, Ohio
47. Ohio State University
48. Oklahoma State University
49. Old Dominion University, Virginia
50. Oregon State University
51. Pennsylvania State University
52. Portland State University, Oregon
53. Princeton University, New Jersey
54. Purdue University, Indiana
55. Rutgers University, New Jersey
56. San Diego State University, CA
57. San Fransisco State University, CA
58. San Jose State University, California
59. Scripps Institution of Oceanography, California
60. South Dakota School of Mines
61. Stanford University, CA
62. Virginia Polytechnic Institute and State University
63. Syracuse University, New York
64. Texas A&M, College Station
65. Texas Christian University
66. Towson University, Maryland
67. Tulane University, New Orleans
68. United States Naval Academy, Annapolis
69. University of Alabama - Huntsville
70. University of Alaska – Fairbanks
71. University of Arkansas
72. University of Arizona
73. University of California – Berkeley
74. University of California – Davis
75. University of California – Irvine
76. University of California – Los Angeles
77. University of California – San Diego
78. University of California – Santa Barbara
79. University of California – Santa Cruz
80. University of Colorado – Boulder
81. University of Colorado – Denver
82. University of Connecticut
83. University of Delaware
84. University of Florida

85. University of Houston
86. University of Idaho
87. University of Illinois-Urbana – Champaign
88. University of Iowa
89. University of Kansas
90. University of Louisiana – Lafayette
91. University of Maine
92. University of Maryland – Baltimore County
93. University of Memphis
94. University of Miami
95. University of Michigan
96. University of Minnesota – Minneapolis
97. University of Minnesota – Duluth
98. University of Nebraska – Lincoln
99. University of Nevada – Reno
100. University of New Hampshire
101. University of New Mexico
102. University of New Orleans
103. University of North Carolina – Chapel Hill
104. University of North Carolina – Wilmington
105. University of North Dakota
106. University of Oklahoma
107. University of Oregon
108. University of Pennsylvania – Pittsburgh
109. University of Pittsburgh
110. University of Rhode Island
111. University of South Carolina
112. University of South Florida
113. University of Southern California
114. University of Tennessee – Knoxville
115. University of Texas – Arlington
116. University of Texas – Austin
117. University of Texas – El Paso
118. University of Texas – San Antonio
119. University of Utah
120. University of Virginia
121. University of Washington
122. University of Wyoming
123. Utah State University
124. Vanderbilt University
125. Villanova University, Pennsylvania
126. Virginia Institute of Marine Science (VIMS)
127. Virginia Polytechnic Institute, VA
128. Washington State University
129. West Virginia University
130. Western Carolina University
131. Wichita State University
132. William & Mary College, VA

U.S. Federal Labs, Agencies, State and Local Government, Non-Profit: 25 with 3 new members as of August 2015

1. Argonne National Laboratory (ANL)
2. Idaho National Laboratory (IDL)
3. Los Alamos National Laboratory (LANL)
4. National Aeronautics & Space Administration (NASA)
5. National Center for Atmospheric Research (NCAR)
6. National Forest Service (NFS)
7. National Science Foundation (NSF)
8. National Oceanic & Atmospheric Administration (NOAA)
9. National Oceanographic Partnership Program (NOPP)
10. National Park Service (NPS)
11. National Weather Service (NWRFC)
12. Naval Research Laboratory
13. Oak Ridge National Laboratory (ORNL)
14. Sandia National Laboratories (SNL)
15. South Florida Water Management District
16. U.S. Army Corps of Engineers (ACE)
17. U.S. Army Research Office (ARO)
18. U.S. Department of Agriculture (USDA)
19. U.S. Department of the Interior – Bureau of Reclamation
20. U.S. Department of the Interior – Bureau of Ocean Energy Management (BOEM)
21. U.S. Environmental Protection Agency (EPA)
22. U.S. Geological Survey (USGS)
23. U.S. Nuclear Regulatory Commission (NRC)
24. U.S. Office of Naval Research (ONR)
25. Woods Hole Research Center, MD

U.S. Private Companies: 29 with 3 new members as of August 2015

1. Airlink Communications, Hayward CA
2. Aquaveo LLC, Provo, Utah
3. ARCADIS-US, Boulder, CO
4. BP America, USA
5. Chevron Energy Technology, Houston, TX
6. ConocoPhillips, Houston, TX

7. Deltares, USA
8. Dewberry, Virginia
9. DHI, Solana Beach, CA
10. Everglades Partners Joint Venture (EPJV), Florida
11. ExxonMobil Research and Engineering, Houston, TX
12. Fugro Marine GeoServices, Inc., USA
13. Geological Society of America Geocorps
14. Leonard Rice Engineers, Inc., Denver, CO
15. Idaho Power, Boise
16. PdM Calibrations, LLC, Florida
17. Philip Williams and Associates, Ltd., California
18. RPS Group Plc
19. Schlumberger Information Solutions, Houston, TX
20. Science Museum of Minnesota, St. Paul, MN
21. Shell USA, Houston, TX
22. Straus Consulting, Boulder, CO
23. Stroud Water Research Center, Avondale, PA
24. Subsurface Insights, Hanover, NH
25. URS–Grenier Corporation, Colorado
26. The Von Braun Center for Science & Innovation, Inc.
27. UAN Company
28. Warren Pinnacle Consulting, Inc., Warren, VT
29. Water Institute of the Gulf, Baton Rouge, LA

Foreign Membership: Current total of 334 with 19 new members from August 2015 – July 2016 (**66** countries outside of the U.S.A.: Algeria, Argentina, Armenia, Australia, Austria, Bangladesh, Belgium, Bolivia, Brazil, Bulgaria, Cambodia, Canada, Chile, China, Colombia, Cuba, Denmark, Egypt, El Salvador, France, Germany, Ghana, Greece, Hungary, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Japan, Jordan, Kenya, Malaysia, Mexico, Morocco, Myanmar, Nepal, Netherlands, New Zealand, Nigeria, Norway, Pakistan, Peru, Philippines, Poland, Portugal, Qatar, Romania, Russia, Saudi Arabia, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Thailand, Netherlands, Turkey, UK, United Arab Emirates, Uruguay, Venezuela, Việt Nam).

Foreign Academic Institutes: 223 with 13 new members as of August 2015

1. Aberystwyth University, Wales, UK
2. Adam Mickiewicz University (AMU) Poznan, Poland
3. AGH University of Science and Technology, Krakow, Poland
4. AgroCampus Ouest, France
5. Aix-Marseille University, France
6. Anna University, India
7. ANU College, Argentina
8. Architectural Association School of Architecture, UK
9. Aristotle University of Thessaloniki, Greece
10. Australian National University, Australia
11. Babes-Bolyai University, Romania
12. Bahria University, Islamabad, Pakistan
13. Banaras Hindu University, India
14. Bangladesh University of Engineering and Technology, Dhaka, Bangladesh
15. Birbal Sahni Institute of Palaeobotany, India
16. Bonn University, Germany
17. Blaise Pascal University, Clermont, France
18. Brandenburg University of Technology (BTU), Cottbus, Germany
19. British Columbia Institute of Technology (BCIT), Canada
20. Cardiff University, UK
21. Carleton University, Canada
22. Chengdu University of Technology, China
23. China University of Geosciences- Beijing, China
24. China University of Petroleum, Beijing, China
25. Christian-Albrechts-Universitat (CAU) zu Kie, Germany
26. CNRS / University of Rennes I, France
27. Cracow University of Technology, Poland
28. Dalian University of Technology, Liaoning, China
29. Dankook University, South Korea
30. Darmstadt University of Technology, Germany
31. Delft University of Technology, Netherlands
32. Democritus University of Thrace, Greece
33. Diponegoro University, Semarang, Indonesia
34. Dongguk University, South Korea

35. Durham University, UK
36. Earth Sciences Federal University of Parana, Brazil
37. East China Normal University, China
38. Ecole Nationale Superieure des Mines de Paris, France
39. Ecole Polytechnique, France
40. Eidgenossische Technische Hochschule (ETH) Zurich, Switzerland
41. Eötvös Loránd University, Hungary
42. FCEFN-UNSJ-Catedra Geologia Aplicada II, Argentina
43. Federal Ministry of Environment, Nigeria
44. Federal University of Itajuba, Brazil
45. Federal University of Petroleum Resources, Nigeria
46. Federal University Oye-Ekiti, Nigeria
47. Federal University of Santa Catarina, Brazil
48. First Institute of Oceanography, SOA, China
49. Free University of Brussels, Belgium
50. Glasgow University, UK
51. Guanzhou University, Guanzhou, China
52. The Hebrew University of Jerusalem, Israel
53. Helmholtz-Zentrum University Gees
54. Heriot-Watt University, Edinburgh, UK
55. Hohai University, Nanjing, China
56. Hong Kong University, Hong Kong
57. IANIGLA, Unidad de Geocriologia, Argentina
58. Imperial College of London, UK
59. India Institute of Technology – Bhubaneswar, India
60. India Institute of Technology – Delhi
61. Indian Institute of Technology – Gandhinagar
62. India Institute of Technology – Kanpur
63. India Institute of Technology - Kharangpur
64. India Institute of Technology – Madras
65. India Institute of Technology – Mumbai
66. Indian Institute of Science – Bangalore
67. Indian Institute of Technology– Bombay
68. Institut Univ. Europeen de la Mer (IUEM), France
69. Institute of Engineering (IOE), Nepal
70. Institute of Geology, China Earthquake Administration
71. Instituto de Geociencias da Universidade Sao Paulo (IGC USP), Brasil
72. Kafrelsheikh University, Kafrelsheikh, Egypt
73. Karlsruhe Institute of Technology (KIT), Germany
74. Katholieke Universiteit Leuven, KUT, Belgium
75. King's College London, UK
76. King Fahd University of Petroleum and Mineral, Saudi Arabia
77. Kocaeli University, Izmit, Turkey
78. Kwame Nkrumah University of Science and Technology (KNUST), Ghana
79. Lanzhou University, China
80. Leibniz-Institute fur Ostseeforschung Warnemunde (IOW)/Baltic Sea Research, Germany
81. Leibniz Universitat Hannover, Germany
82. Loughborough University, UK
83. Lund University, Sweden
84. McGill University, Canada
85. Mohammed V University-Agdal, Rabat,Morocco
86. Mulawarman University, Indonesia
87. Nanjing University of Information Science & Technology (NUIST), China
88. Nanjing University, China
89. National Cheng Kong University
90. National Taiwan University, Taipei, Taiwan
91. National University of Cordoba, Spain
92. National University (NUI) of Maynooth, Kildare, Ireland
93. National University of Sciences & Technology, Pakistan
94. National University of Sciences & Technology, (NUST), Pakistan
95. Natural Resources, Canada
96. Northwest University of China, China
97. Norwegian University of Life Sciences, Norway
98. Ocean University of China, China
99. Padua University, Italy
100. Paris Diderot University, France
101. Peking University, China
102. Pondicherry University, India
103. Pukyong National University, Busan, South Korea
104. Royal Holloway University of London,

UK
105. RWTH Aachen University, Germany
106. Sejong University, South Korea
107. Seoul National University, South Korea
108. Shihezi University, China
109. Simon Fraser University, Canada
110. Singapore-MIT Alliance for Research and Technology (SMART), Singapore
111. Southern Cross University, United Arab Emirates (UAE)
112. Sriwijaya University, Indonesia
113. SRM University, India
114. Stockholm University, Sweden
115. Tarbiat Modares University, Iran
116. The Maharaja Sayajirao University of Baroda, India
117. Technical University, Hamburg, Germany
118. Tianjin University, China
119. Tsinghua University, China
120. Universidad Agraria la Molina, Peru
121. Universidad Complutense de Madrid, Spain
122. Universidad de Chile, Chile
123. Universidad de Granada, Spain
124. Universidad de Guadalajara, Mexico
125. Universidad de la Republica, Uruguay
126. Universidad de Oriente, Cuba
127. Universidad de Zaragoza, Spain
128. Universidad Nacional Autónoma de México
129. Universidad Nacional de Catamarca, Argentina
130. Universidad Nacional de Rio Negro, Argentina
131. Universidad Nacional de San Juan, Argentina
132. Universidad Politecnica de Catalunya, Spain
133. Universidade de Lisboa, Lisbon, Portugal
134. Universidade de Madeira, Portugal
135. Universidade do Minho, Braga, Portugal
136. Universidade Estudual de Campinas, Brazil
137. Universidade Federal do Rio Grande do Sul (FRGS), Brazil
138. Universit of Bulgaria (VUZF), Bulgaria Pescara, Italy
139. Universita "G. d'Annunzio" di Chieti-Pescara, Italy
140. Universitat Potsdam, Germany
141. Universitat Politecnica de Catalunya, Spain
142. Universitas Indonesia, Indonesia
143. Universite Bordeaux 1, France
144. Université de Bretagn Occidentale, France
145. Université de Grenoble, France
146. Universite de Rennes (CNRS), France
147. Universite du Quebec a Chicoutimi (UQAC), Canada
148. Universite Joseph Fourier, Grenoble, France
149. Universite Montpellier 2, France
150. Universiteit Gent, Ghent, Belgium
151. Universiteit Stellenosch University, South Africa
152. Universiteit Utrecht, Netherlands
153. Universiteit Vrije (VU), Amsterdam, Netherlands
154. Universiti Teknologi Mara (UiTM), Mayalsia
155. Universiti Malaysia Pahang, Malaysia
156. University College Dublin, Ireland
157. University of Bari, Italy
158. University of Basel, Switzerland
159. University of Bergen, Norway
160. University of Bremen, Germany
161. University of Brest, France
162. University of Bristol, UK
163. University of British Columbia, Canada
164. University of Calgary, Canada
165. University of Cambridge, UK
166. University of Cantabria, Spain
167. University of Concepcion, Chile
168. University of Copenhagen, Denmark
169. University of Dhaka, Bangladesh
170. University of Dundee, UK
171. University of Edinburgh, Scotland
172. University of Edinburgh, UK
173. University of Exeter, UK
174. University of Geneva, Switzerland
175. University of Ghana, Ghana
176. University of Guelph, Canada
177. University of Haifa, Israel
178. University of Ho Chi Minh City
179. University of Hull, UK
180. University of Kashmir, India
181. University of Lethbridge, Canada
182. University of Liverpool, UK

183. University of Manchester, UK
184. University of Malaya, Kuala Lumpur, Malaysia
185. University of Milano-Bicocca, Italy
186. University of Natural Resources & Life Sciences, Vienna, Austria
187. University of Newcastle, Australia
188. University of Newcastle upon Tyne, UK
189. University of New South Wales, Australia
190. University of Nigeria, Nsukka, Nigeria
191. University of Padova, Italy
192. University of Palermo, Italy
193. University of Pavia, Italy
194. University of Portsmouth, UK
195. University of Potsdam, Germany
196. University of Queensland (UQ), Australia
197. University of Reading, Berkshire, UK
198. University of Rome (INFN) "LaSapienza", Italy
199. University of Science Ho Chi Minh City, Viet Nam
200. University of Southampton, UK
201. University of St. Andrews, UK
202. University of Sydney, Australia
203. University of Tabriz, Iran
204. University of Tehran, Iran
205. University of the Philippines, Manila, Philippines
206. University of the Punjab, Lahore, Pakistan
207. University of Twente, Netherlands
208. University of Waikato, Hamilton, New Zealand
209. University of Warsaw, Poland
210. University of West Hungary - Savaria Campus, Hungary
211. University of Western Australia, Australia
212. University of Western Ontario, Canada
213. Victoria University of Wellington, New Zealand
214. Vietnam Forestry University, Vietnam
215. VIT (Vellore Institute of Technology) University, Tamil Nadu, India
216. VUZF University, Bulgaria
217. Wageningen University, Netherlands
218. Water Resources University, Hanoi, Vietnam
219. Wuhan University, Wuhan, China
220. Xi-an University of Architecture & Technology, China
221. York University, Canada
222. Yuzuncu Yil University, Turkey
223. Zhejiang University, China

Foreign Private Companies: 32 with 1 new member as of August 2015

1. Aerospace Company, Taiwan
2. ASR Ltd., New Zealand
3. Bakosurtanal, Indonesia
4. BG Energy Holdings Ltd., UK
5. Cambridge Carbonates, Ltd., France
6. Deltares, Netherlands
7. Digital Mapping Company, Bangladesh
8. Energy & Environment Modeling, ENEA/UTMEA, Italy
9. Environnement Illimite, Inc., Canada
10. Excurra & Schmidt: Ocean, Hydraulic, Coastal and Environmental Engineering Firm, Argentina
11. Fugro-GEOS, UK
12. Geo Consulting, Inc., Italy
13. Grupo DIAO, C.A., Venezuela
14. Haycock Associates, UK
15. H.R. Wallingford, UK
16. IH Cantabria, Cantabria, Spain
17. InnovationONE, Nigeria
18. Institut de Physique de Globe de Paris, France
19. Institut Francais du Petrole (IFP), France
20. Jaime Illanes y Asociados Consultores S.A., Santiago, Chile
21. METEOSIM, Spain
22. MUC Engineering, United Arab Emirates (UAE)
23. Petrobras, Brazil
24. Riggs Engineering, Ltd., Canada
25. Risk Management Solutions Inc., India
26. Saipem (oil and gas industry contractor), Milano, Italy
27. Shell, Netherlands
28. SEO Company, Indonesia
29. Soluciones en Technologia Empresarial (STE), Peru
30. Statoil, Norway

31. Tullow Oil, Ireland
32. Vision on Technology (VITO), Belgium

Foreign Government Agencies: 79 with 5 new members as of August 2015

1. Agency for Assessment and Application of Technology, Indonesia 2. Bedford Institute of Oceanography, Canada
2. Arpa-Emilia-Romagna, Italy
3. Bedford Institute of Oceanorgraphy, Canada
4. Bhakra Beas Management Board (BBMB), Chandigarh, India
5. British Geological Survey, UK
6. Bundesanstalt fur Gewasserkunde, Germany
7. Bureau de Recherches Géologiques et Minières (BRGM), Orleans, France
8. Cambodia National Mekong Committee (CNMC), Cambodia
9. Center for Petrographic and Geochemical Research (CRPG-CNRS), Nancy, France
10. CETMEF/LGCE, France
11. Channel Maintenance Research Institute (CMRI), ISESCO, Kalioubia, Egypt
12. Chinese Academy of Sciences – Cold and Arid Regions Environmental and Engineering Research Institute
13. Chinese Academy of Sciences – Institute of Mountain Hazards and Environment, China
14. Chinese Academy of Sciences – Institute of Soil and Water Conservation, China
15. Chinese Academy of Sciences – Institute of Tibetan Plateau Research (ITPCAS), China
16. Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia
17. Consiglio Nazionale delle Ricerche (CNR), Italy
18. French Agricultural and Environmental Research Institute (CEMAGREF)
19. French Research Institute for Exploration of the Sea (IFREMER), France
20. Geological Survey of Canada, Atlantic
21. Geological Survey of Canada, Pacific
22. Geological Survey of Israel, Jerusalem, Israel
23. Geological Survey of Japan (AIST), Japan
24. Geosciences, Rennes France
25. GFZ, German Research Centre for Geosciences, Potsdam, Germany
26. GNS Science, New Zealand
27. GNU VNIIGiM, Moscow, Russia
28. Group-T, Myanmar
29. Helmholtz Centre for Environmental Research (UFZ), Germany
30. Indian National Centre for Ocean Information Services (INCOIS), India
31. Indian Space Research Organization
32. Institut des Sciences de la Terre, France
33. Institut National Agronomique (INAS), Algeria
34. Institut National de la Recherche Agronomique (INRA), France
35. Institut Physique du Globe de Paris, France
36. Institut Teknologi Bandung (ITB), Indonesia
37. Institute of Atmospheric Sciences and Climate (ISAC) of Italian National Research Council (CNR), Italy
38. Institute for Computational Science and Technology (ICST), Viet Nam
39. Institute for the Conservation of Lake Maracaibo (ICLAM), Venezuela
40. Institute of Earth Sciences (ICTJA-CSIC), Spain
41. Instituto Hidrografico, Lisboa, Lisbon, Portugal
42. Instituto Nacional de Hidraulica (INH), Chile
43. Instituto Nazionale di Astrofisica, Italy
44. International Geosphere Biosphere Programme (IGBP), Sweden
45. Iranian National Institute for Oceanography (INIO), Tehran, Iran
46. Italy National Research Council (CNR),

Italy

47. Japan Agency for Marine-Earth Science Technology (JAMSTEC), Japan
48. Kenya Meteorological Services, Kenya
49. Korea Ocean Research and Development Institute (KORDI), South Korea
50. Korea Water Resources Corporation, South Korea
51. Lab Domaines Oceanique IUEM/UBO France
52. Laboratoire de Sciences de la Terre, France
53. Marine Sciences For Society, France
54. Ministry of Earth Sciences, India
55. Nanjing Hydraulics Research Institute, China
56. National Geophysical Research Institute, India
57. National Institute of Water and Atmospheric Research (NIWA), Auckland, New Zealand
58. National Research Institute of Science and Technology for Environment and Agriculture, France
59. National Institute for Space Research (INPE), Brazil
60. National Institute of Oceanography (NIO), India
61. National Institute of Technology Rourkela, Orissa, India
62. National Institute of Technology Karnataka Surathkal, Mangalore, India
63. National Institute of Water and Atmosphere (NIWA), New Zealand
64. National Marine Environmental Forecasting Center (NMEFC), China
65. National Oceanography Centre – Liverpool, UK
66. National Research Centre for Sorghum (NRCS), India
67. National Research Council (NRC), Italy
68. National Space Research & Development Agency, Nigeria
69. Qatar National Historic Environment Project
70. Scientific-Applied Centre on hydrometeorology & ecology, Armstatehydromet, Armenia
71. Secretaria del Mar, Ecuador
72. Senckenberg Institute, Germany
73. Shenzhen Inst. of Advanced Technology, China
74. South China Sea Institute of Technology (SCSIO), Guanzhou, China
75. The European Institute for Marine Studies (IUEM), France
76. The Leibniz Institute for Baltic Sea Research, Germany
77. UNESCO-IHE, Netherlands
78. Water Resources Division, Dept. of Indian Affairs and Northern Development, Canada
79. World Weather Information Service (WMO), Cuba

Appendix 2: 2016 CSDMS Annual Meeting Abstracts (Keynotes and Posters)

The 2016 Annual Meeting was attended by 145 individuals, an increase of 32% over the 2015 meeting and the largest CSDMS Annual Meeting to date. For the first time, the meeting was co-sponsored by the Sediment Experimentalist Network (SEN). Wonsuck Kim, SEN Chair, University of Texas, provided a keynote lecture and an SEN clinic. Twenty-eight attendees were fully supported by SEN. All plenary keynote presentations were recorded and provided through the CSDMS YouTube channel that is also embedded in the CSDMS web portal for people to view at their convenience.

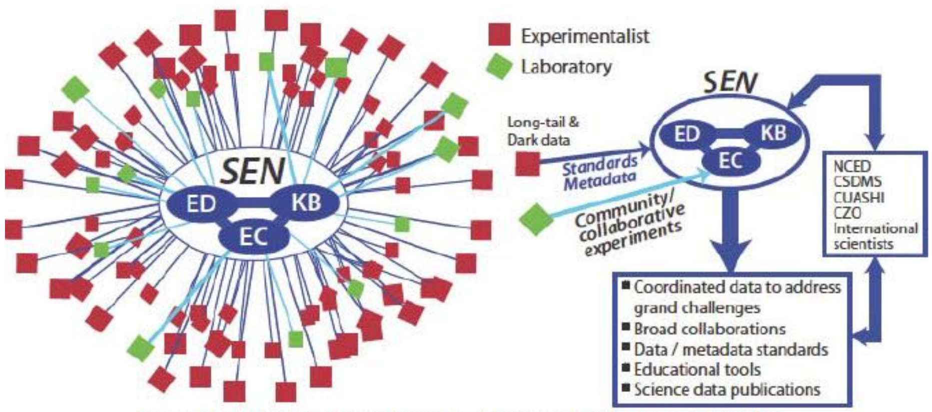


Figure 1: The main components of SEN and expected synergies.

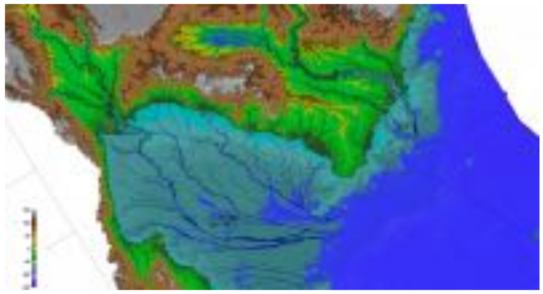
2016 CSDMS Annual Meeting Abstracts (Keynotes and Posters)

Quaternary Morphodynamics of Fluvial Dispersal Systems Revealed: The Fly River, PNG, and the Sunda Shelf, SE Asia, simulated with the Massively Parallel GPU-based Model 'GULLEM'.

Rolf Aalto*, Exeter, University of Exeter, United Kingdom.* rolf.aalto@exeter.ac.uk

During glacial-marine transgressions vast volumes of sediment are deposited due to the infilling of lowland fluvial systems and shallow shelves, material that is removed during ensuing regressions. Modelling these processes would illuminate system morphodynamics, fluxes, and 'complexity' in response to base level change, yet such problems are computationally formidable. Environmental systems are characterized by strong interconnectivity, yet traditional supercomputers have slow inter-node communication -- whereas rapidly advancing Graphics Processing Unit (GPU) technology offers vastly higher (>100x) bandwidths.
GULLEM (GpU-accelerated Lowland Landscape Evolution Model) employs massively parallel code to simulate coupled fluvial-landscape evolution for complex lowland river systems over large temporal and spatial scales. GULLEM models the accommodation space carved/infilled by representing a range of geomorphic processes, including: river & tributary incision within a multi-directional flow regime, non-linear diffusion, glacial-isostatic flexure, hydraulic geometry, tectonic deformation, sediment production, transport & deposition, and full 3D tracking of all resulting stratigraphy.
Model results concur with the Holocene dynamics of the Fly River, PNG -- as documented with dated cores, sonar imaging of floodbasin stratigraphy, and the observations of topographic remnants from LGM conditions. Other supporting research was conducted along the Mekong River, the largest fluvial system of the Sunda Shelf. These and other field data provide tantalizing empirical glimpses into the lowland landscapes of large rivers during glacial-interglacial transitions, observations that can be explored with this powerful numerical model.

GULLEM affords estimates for the timing and flux budgets within the Fly and Sunda Systems, illustrating complex internal system responses to the external forcing of sea level and climate. Furthermore, GULLEM can be applied to most ANY fluvial system to explore processes across a wide range of temporal and spatial scales. The presentation will provide insights (& many animations) illustrating river morphodynamics & resulting landscapes formed as a result of sea level oscillations.



http://www.geomorphology.com

Integrating a 2-D Hydrodynamic Model into the Landlab Modeling Framework.

Jordan Adams, Tulane University, New Orleans, LA jadams15@tulane.edu

Landscape evolution models often generalize hydrology by assuming steady-state discharge to calculate channel incision. While this assumption is reasonable for smaller watersheds or larger precipitation events, non-steady hydrology is a more applicable condition for semi-arid landscapes, which are prone to short-duration, high-intensity storms. In these cases, the impact of a hydrograph (non-steady method) may be significant in determining long-term drainage basin evolution. This project links a two-dimensional hydrodynamic algorithm with a detachment-limited incision component in the Landlab modeling framework. Storms of varying intensity and duration are run across two synthetic landscapes, and incision rate is calculated throughout the hydrograph. For each case, peak discharge and total incision are compared to the values predicted by steady-state to evaluate the impact of the two hydrologic methods. We explore the impact of different critical shear stress values on total incision using the different flow methods. Finally, a watershed will be evolved to topographic steady-state using both the steady- and non-steady flow routing methods to identify differences in overall relief and drainage network configuration. Preliminary testing with no critical shear stress threshold has shown that although non-steady peak discharge is smaller than the peak predicted by the steady-state method, total incised depth from non-steady methods exceeds the steady-state derived incision depth in all storm cases. With the introduction of an incision threshold, we predict there will be cases where the steady-state method overestimates total incised depth compared to the non-steady method. Additionally, we hypothesize that watersheds evolved with the non-steady method will be characterized by decreased channel concavities. This work demonstrates that when modeling landscapes characterized by semi-arid climates, choice of hydrology method can significantly impact the resulting morphology. **PDF of presentation:** pdf *

Flood Inundation Modeling in a Changing Climate.

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Karim Alizad, University of Central Florida Orlando Florida, United States. kalizad@knights.ucf.edu
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Coastal regions around the world are susceptible to a variety of natural disasters that can cause devastating flooding. It is anticipated that the exposure of coastal cities to more frequent flooding will increase due to the effects of climate change, and in particular sea level rise (SLR). A novel framework was developed to generate a suite of physics-based storm surge models that include projections of coastal floodplain dynamics under climate change scenarios: shoreline erosion/accretion, dune morphology, salt marsh migration, and population dynamics [Bilskie et al., 2014; Passeri et al., 2014; Passeri et al., 2015].

First, the storm surge inundation model was extensively validated for present-day conditions with respect to astronomic tides and hindcasts of Hurricane Ivan (2004), Dennis (2005), Katrina (2005), and Isaac (2012). The model was then modified to characterize the potential future outlook of the landscape for four climate change scenarios for the year 2100 (B1, B2, A1B, and A2). Each climate change scenario was linked to a sea level rise of 0.2 m, 0.5 m, 1.2 m, and 2.0 m from Parris et al. [2012]. The adapted model was used to simulate hurricane storm surge conditions for each climate scenario using a diverse suite of tropical cyclones. The collection of results shows the intensification of inundation area, depth of flooding, and the vulnerability of the coast to potential future climate conditions. The methodology developed herein to assess coastal flooding under climate change can be performed across any low-gradient coastal region worldwide, and results provide awareness of areas vulnerable to extreme inundation in the future.

References

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*Passeri, D. L., S. C. Hagen, S. C. Medeiros, M. V. Bilskie, K. Alizad, and D. Wang (2015), The dynamic effects of sea level rise on low gradient coastal landscapes: a review, Earth's Future, 3.

Implications Of Fault Damaged Bedrock To Tectonic and Landscape Evolution In Coastal Alaska.

Annie Boucher, *University of Maine Orono Maine, United States. anne.l.boucher@maine.edu*

Bedrock material strength properties heavily impact erosion rates in temperate glacial environments. We focus on the influence of localized tectonic crustal weakening in southeast Alaska on modern glacial erosion rates, thereby quantifying a primary feedback in tectonic/climatic coupling. Southeast Alaska, with its coincident high strain rates, vigorous glacial erosion and rapid sedimentation rates, provides an excellent setting in which to evaluate this interaction.

To characterize the relationship between fault damage and glacial incision, we collected data in transects across the strike-slip Fairweather Fault in Yakutat and Disenchantment Bays, in deglaciated valleys below the Mendenhall, Herbert, Ptarmigan, and Lemon Creek Glaciers on the perimeter of the Juneau Icefield, and on deglaciated nunataks on the Echo and Vaughan Lewis Glaciers in the interior of the Juneau Icefield. The mechanical properties of the bedrock are characterized by estimates of fault spacing and material cohesion. In structurally-controlled bedrock valleys exploited by glaciers, fracture spacing may vary by several orders of magnitude across fault damage zones, from more than 10 m to less than 0.1 m. Analysis of active and quiescent fault zones indicate that this variation approximates a power law relationship and correlates with a gradient in cohesive strength varying from greater than 50 MPa to less than 50 kPa between intact bedrock and the core of fault damage zones. The width and orientation of the damage zones is highly variable and we have chosen our field sites to sample zones of very large total displacement, up to kilometers along the Fairweather Fault, and substantially smaller displacements, down to centimeters for the Juneau Icefield locales. We further use elevation variance analysis (EVA) to extrapolate these field observations to an orogeny-scale estimate of variation of cohesion strength.

Using a Cordilleran Ice sheet model to extend our modern observations into last glacial maximum conditions, we predict both erosion rates and sediment provenance for a material strength pattern influenced by tectonically induced fault damage. Compared to an earth model of homogeneous strength properties, our fault damage model predicts high spatial heterogeneity of erosion rates and sediment yield that changes as

Cordilleran ice sheet thickness decreases from last glacial maximum to modern conditions. Understanding erosion dynamics through a changing climate helps us to better define the tectonic/climatic coupling.

Effects of the Anthropogenic Landscape on Global Scale Suspended Sediment Flux.

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Human industry and agriculture have long-term effects on the erosion and transport of sediment from the continental surface to the ocean. Suspended sediment flux can be increased where soils are exposed to erosion but can also be trapped behind reservoirs. There are literature and frameworks available which estimate the amount of suspended sediment that is effected by anthropogenic land-use and engineering, but they are generally limited to single river basins, regions, or continents. This paper provides the framework to analyze and the analytical results of the spatially explicit impact of anthropogenic landscapes on global suspended sediment flux.

Quantifying suspended sediment flux at the global scale is complicated by a lack of gaging stations and observed data sets. Modeling provides a pathway which allows researchers to investigate the flux of sediment from the terrestrial environment to the coastal ocean where there is a lack of observed records. Modeling also allows exploration of how individual factors and parameters affect a natural phenomenon by isolating and/or eliminating those factors. Arguably, the BQART model as currently implemented in the Water Balance Model (WBMplus) (as WBMsed) framework provides the strongest prediction of suspended sedment flux at the global scale. However, BQART lacks a spatially and temporally explicit factor to describe the effect of anthropogenic disturbance on the landscape and its effects on suspended sediment flux.

This paper describes the process and development of a new anthropogenic factor which increases the importance of land-use in the WBMsed simulation of suspended sediment flux. This new anthropogenic factor is constructed from readily available and regularly updated land-use/land-cover datasets. Development of a land-use parameter in the WBMsed model will facilitate more accurate simulations of suspended sediment flux changes following land-use change and/or conversion and explore where suspended sediment is increased through human agriculture and industry.

How Does Delta Shoreline Sinuosity Respond to Changes in River Discharge Variability?

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Michael Lamb, California Institute of Technology, Pasadena California, United States. mpl@gps.caltech.edu

Climate-driven changes in storm-induced flood events are amplified on coastal river deltas, where standing water downstream creates a region of non-uniform flow that is sensitive to river discharge regime. The sinuosity of modern and ancient delta shorelines, i.e. shoreline rugosity, is a potential imprint of discharge variability, especially where marine waves and tides are not dominant processes. We hypothesize that river-dominated deltas built through construction of depositional lobes develop a characteristic shoreline rugosity that is determined by long-term patterns in channel avulsion location, avulsion timing, and lateral migration, all of which can be strongly influenced by discharge variability within the backwater zone. Scaling arguments predict that shoreline rugosity should increase linearly with avulsion timescale, inversely with avulsion lengthscale, and inversely with lateral migration rate. We present results from two scaled flume experiments that confirm this hypothesis, and furthermore illustrate the importance of discharge variability in controlling the dominant rates and scales in a growing delta. Under conditions of variable floods that maintain a dynamic backwater zone, river avulsions occur at a fixed distance from the shoreline, resulting in the construction of lobes of constant size even during shoreline progradation. In addition, erosion caused by drawdown hydrodynamics during floods eliminates alternating bars, which slows lateral migration of the channels and allows for more elongate delta lobes. Based on these results, and a compilation of modern river-dominated deltas, we propose a new dimensionless phase space for evaluating the impact of discharge variability on the shoreline rugosity of river-dominated deltas. Ongoing work focuses upon expanding this framework to deltas experiencing changes in base level.

Computational Modeling of the Hydraulics of a Realistic Subglacial Conduit in Arctic.

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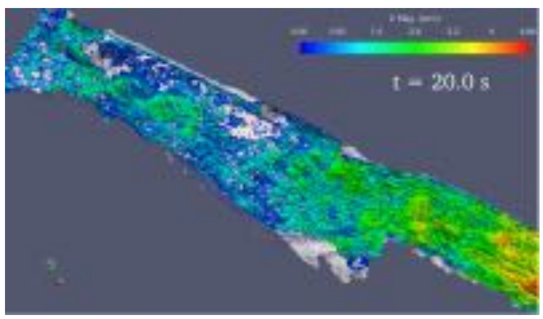
Understanding the hydraulics of subglacial conduits is important for accurately estimating the conduit evolution and changing speed of glaciers. Among those hydraulics problems, parameterizing the surface roughness, sinuosity, and cross-sectional contraction and expansion, and relating those parameters to the development of turbulent boundary layer and hydraulic roughness height are especially crucial. This paper introduces the parametrized surface features of a realistic subglacial conduit under the Arctic, and the preliminary results obtained from large-eddy simulation based on the real conduit geometry. The surface data shows that the small-scale roughness relates larger scale roughness by a scaling law, and can be uniquely determined by horizontal length scales (l_x and l_y) and vertical roughness scales (σ_{zx} and σ_{zy}). The sinuosity and cross-sectional variations along the streamwise direction are also calculated based on a self-developed Matlab code. The simulation data shows that there exists a thick boundary layer near the wall, but the influences of the surface parameters on the layer thickness and in-layer velocity is still under studying.



The near wall flow structures of a realistic subglacial conduit in Arctic at t = 20s.

Exploring Post-Fire Hydrology Using a Multiphysics Modeling Framework.

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Understanding the impact of disturbance on hydrology is of critical importance for many regions, but especially the US Southwest. Increasing fire intensity, size, and frequency, along with insect infestation and ecosystem demography change all result in significant short and long-term changes in hydrology. Understanding and predicting this impact requires a rich set of process models with complex, uncertain coupling. We present the use of the Advanced Terrestrial Simulator (ATS), an ecosystem hydrology model, to understand changes to the Jaramillo Watershed, a primary watershed in northern New Mexico, after the Thompson Ridge Fire in 2013. We demonstrate how ATS's multiphysics management code, Arcos, uses interfaces and dependency graphs to allow model structure uncertainty to be explored. New process representation is quickly developed and coupled to existing model components in tightly coupled ways. Finally, we show a series of numerical experiments that decouple the roles of litter, duff, and canopy on immediate post-fire hydrology in the Upper Jaramillo.

An experimental investigation of mouth bar formation with vegetation.

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Wonsuck Kim, The University of Texas at Austin Austin Texas, United States. delta@jsg.utexas.edu

Delta networks are systems of interconnected channel-island nodes, their size and organization dictating delta morphology. When a sediment-laden channel enters slack water, it loses momentum and carrying capacity, dropping its sediment. As sediment accumulates, flow moves around it and a mouth bar island forms. While this process has been numerically modeled, physical experiments of this process have proven challenging. We present an experimental investigation using the Sediment Transport and Earth-surface Processes (STEP) basin. We made mouth bar deposits with a jet flow at a range of discharges (0.1-0.5 l/s) over intermittent flood-interflood cycles. The experiment has a flat, 5 cm thick sediment layer confined on three sides and open on the downstream end, a 5 cm flow depth above the sediment, and a backing berm at angle of repose so the opening angle can self-organize. Over the course of high and low discharge events, the deposit reworks from a parabolic to a barchanoid mouth bar.

In natural systems, vegetation plays an important role in generating and damping sediment transport, but these effects have not yet been applied to mouth bar formation and their consequences for delta island evolution. More work will be conducted on the effects vegetation has in turbulent production and the effect on sediment routing and island evolution.

Morphodyanmics of Intra-floodplain Chute Channels.

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The formation of chute channels has been demonstrated to play an essential role in regulating river sinuosity and initiating the transformation from a single to multi-thread planform river geometry. Most chute channels occur within the active channel belt, but growing evidence suggests that chute channels can extend far outside of the channel belt, called intra-floodplain chute channels. The origin and function of these chute channels to the fluvial system is not clear. Towards this end we have initiated an empirical and theoretical study of floodplain chute channels in Indiana, USA. Using elevation models and satellite imagery we mapped 3064 km2 of floodplain in Indiana, and find that 37.3% of mapped floodplains in Indiana have extensive intra-floodplain chute channel networks. These chute channel networks consist of two types of channel segments: meander cutoffs of the main channel and chute channels linking the cutoffs together. To understand how these chute channels link meander cutoffs together and eventually create floodplain channel networks we use Delft3D to explore floodplain morphodynamics. Our first modeling experiment starts from a generic floodplain prepopulated with meander cutoffs to explore what conditions promote and suppress intra-chute channel formation. We find that chute channel formation is optimized at an intermediate flood discharge. If the flood discharge is too large the meander cutoffs erosively diffuse, whereas if the floodwave is too small, channel initiation does not occur. A moderately sized floodwave reworks the sediment surrounding the topographic lows, enhancing the development of floodplain chute channels. Our second modeling experiments explore how floodplain chute channels evolve on the West Fork of the White River, Indiana, USA. We find that the floodplain chute channels are capable of conveying the entire 10 yr floodwave (Q=1330m3/s) leaving the inter-channel areas dry. Moreover, the chute channels can incise into the floodplain while the margins of channels are aggrading, creating levees. Our results suggest that under the right conditions, chute channel formation can be extensive enough to create channel networks across the floodplain.

Ecological Applications of Agent-Based Models.

Donald DeAngelis, USGS, United States. don_deangelis@usgs.gov

The last two decades have been a period of enormous growth of agent-based (or individual-based) (ABM) modeling in ecology. ABMs allow mechanistic detail to be represented for many aspects of variation of individual organisms. ABMs are suited to spatially explicit modeling of populations, communities, and ecosystems, taking into account both the complexity of the environment and the physiological and behavioral adaptations of organisms. Thus, ABMs can include links between effects of environmental factors on plants and animals and makes ABMs essential in projecting how climate change will affect ecological systems. Key studies using ABMs to both understand ecological systems and project future changes will be discussed. These ecological applications include forest dynamics, species conservation, and preservation of biodiversity. This will include a prognosis of the future directions.

FREEWAT, a HORIZON 2020 Project to Build Open Source Tools for Water Management: the View from a Classroom at KU.

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Iacopo Borsi, Tea Sistemi Pisa, Italy.
Violeta Velasco Mansilla, Idaea-CSIC Barcelona, Spain.
Steffen Mehl, California State University Chico California, United States.
Rudy Rossetto, Scuola Superiore Sant'Anna Pisa, Italy.
Mary Hill, University of Kansas Lawrence Kansas, United States. mchill@ku.edu

FREEWAT is a HORIZON 2020 EU project. FREEWAT's main result will be an open source and public domain GIS (QGIS) integrated modelling environment for the simulation of water quantity and quality in surface water and groundwater with an integrated water management and planning module. FREEWAT aims to promote water resource management by simplifying the application of the EU Water Framework Directive and related Directives. Specific objectives of the project are to coordinate previous EU and national funded research to integrate existing software modules for water management in a single environment into the GIS based FREEWAT and to support the FREEWAT application in an innovative participatory approach gathering technical staff and relevant stakeholders (policy and decision makers) in designing scenarios for application of water policies. The open source characteristic of the platform creates an initiative "ad includendum", as further institutions or developers may contribute to the development.

Through creating a common environment among water research/professionals, policy makers, and implementers, FREEWAT's main impact will be on enhancing a science- and participatory approach and evidence-based decision making in water resource management, hence producing relevant and appropriate outcomes for policy implementation which is critical for sustainable management of water resources. Here we discuss the use of FREEWAT in a US classroom at the University of Kansas. The image below shows the FREEWAT work environment.

Temporal Changes in Channel Migration and the Influence of Temporal Measurement-Scale.

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Increased availability of landscape-scale aerial photography and high-resolution topography (HRT) have enabled scientists to document landscape and riverine change over broad spatial and temporal scales. Contemporary geomorphic research has focused on fluvial changes and their connection to anthropogenic land-use shifts using aerial photographs and HRT. However, the community has overlooked the impact of temporal and spatial measurement scales in results, and thus, inferences on measured geomorphic change. Biases resulting from different temporal measurement scales have resulted in false conclusions for research on sedimentation rates (Sadler, 1981; Gardner et al., 1987). As the uprising of historical and contemporary datasets aid our attempts to understand landscape-scale changes over the past century, we must discern new obstacles in our haste to utilize such unique datasets. As researchers increasingly utilize the combination of historical and contemporary datasets, we must discern biases arising from differing measurement scales in order to avoid widespread fallacies in studies relating anthropogenic and fluvial change. Analyzing 11 sets of aerial photographs for measurements of lateral migration over space and time indicates that migration rates do not exhibit a systematic shift over time, but specific river zones are relatively more active. Furthermore, measurement-scale biases indeed arise from the time elapsed between measurements. Future work will combines these results with previously published datasets of lateral migration (based on aerial photographs) to answer whether such scaling effects are similar for all datasets, and if a universal scaling principle may be adopted for such measurements of channel change.

A Simple Land-building Model for Suspended Sediment in Coastal Diversions.

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We use sediment cores, grain-size data and time-lapse bathymetry maps from Cubit's Gap and the West Bay Diversion on the lowermost Mississippi River, to inform a simple advection settling model to investigate patterns of land construction at diversions. In this model, sediment used for land-building is suspended sediment sourced from the upper fraction of the river's water column. We couple the record of deposition in Cubit's Gap, which opened in 1862, with the shorter record available from the West Bay Diversion, which was opened in 2003. Bathymetry and grain-size data from sediment cores show that mud-rich riverine sediment was distributed as a blanketing deposit over a low-sloping subaqueous clinoform.

Using flow hydraulics and channel geometries at these sites, and neglecting the effects of waves and tides, computed advection lengths of well-suspended sediment range from just under 1 km for 100¬µm sand to more than 8km for 44µm silt. This is in good agreement with grain-size patterns and deposition rates at both sites. The settling velocity of the median particle size in deposits is used in a 2-D advection settling model to compute deposition rates. We use published values and field observations to constrain suspended sediment concentrations, outlet depth and current velocity, the other variables required in this model. Sediment concentration near the bed is taken to be twice the average sediment concentration for a turbulent, well-mixed water column in the Mississippi River. We use the pre-existing bathymetry at these two sites as the basal surface upon which we build deposition.

Contrary to the traditional prograding delta model, blanketing deposition and net shallowing of the basin is dictated by the hydrodynamics of well-suspended sediment at the diversion outlet. This lengthens the time-scale associated with land emergence, but once the basin is sufficiently shallow emergent deposits can ,"pop up," over a very short span of time.

Transient Responses of Chemical Erosion Rates to Perturbations in Physical Erosion Rates in a Simple Model of Regolith Mineralogy.

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Regolith-mantled hillslopes respond to tectonic and climatic perturbations in a variety of ways over a variety of time scales. Here I explore the response of chemical erosion rates in regolith to transient perturbations in physical erosion rates using a simple numerical model for regolith mineralogy. In this 1-D column model, weathered regolith is eroded from the surface at a prescribed physical erosion rate E(t), which drives responses in the rate at which solutes are flushed from the regolith at a chemical erosion rate W(t). To explore the response of W to perturbations in E, I impose a Gaussian pulse in physical erosion rates and compute the time-varying response in W. This model predicts that changes in W lag changes in E by a time comparable to the regolith residence time. As a consequence of this lag, there is a hysteresis in the modeled response of W to perturbations in E, with different relationships between W and E over different periods of time during and after the pulse. This model also predicts that the resulting relationships between W and E should depend on the initial value of E relative to a maximum possible regolith production rate. That is, transient increases in E generate increases in W for some initial values of E, and generate decreases in W for other initial values of E. To the extent that this model reflects the behavior of chemical erosion rates in nature, these results imply that transient perturbations in physical erosion rates can complicate interpretation of the relationships between W and E inferred from fluvial solute and sediment flux measurements and from sediment cores.

Blocks Control Hillslope Evolution in Layered Landscapes.

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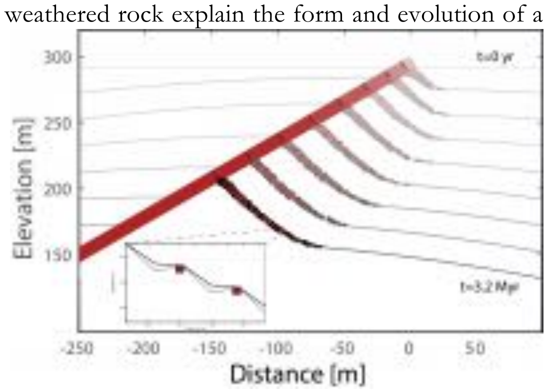
Rocky hillslopes dotted with large blocks and covered by a thin, non-uniform soil are common in both steep landscapes and arid environments, as well as on other planets. While the evolution of soil-mantled, convex hillslopes in uniform lithology can be well-modeled, the influence of lithology and geologic structure on hillslope form and evolution has yet to be properly addressed. Landscapes developed in layered rocks feature landforms such as mesas and hogbacks that exhibit steep, linear-to-concave up ramps scattered with blocks derived from the resistant rock layers. Beyond the ramp, no blocks are to be found. This morphology serves as a strong target for numerical modeling. Our hybrid continuum-discrete numerical model shows that interactions between resistant blocks and underlying easily weathered rock explain the form and evolution of a hogback, a tilted feature that exemplifies this class of landforms. Our model consists of a dipping hard rock layer sandwiched between less resistant layers. The hard layer releases resistant blocks that then armor the underlying rock from weathering. Fine sediment transport is treated with a traditional soil depth-dependent continuum hillslope flux law, while movement of individual resistant blocks is treated discretely. Blocks interfere with the flow of soil, damming it upslope, and developing a wake of thinning soil downslope into which the block eventually moves. We find that feedbacks between block release, weathering of blocks and soft rock, and sporadic downslope movement of blocks are necessary to capture the essence of these landscapes. Insights from our numerical model lead to a simple analytical solution that predicts the steady state hillslope form and slope angle from block size, spacing, rate of weathering, and the efficiency of soil transport. Our results illuminate previously unrecognized hillslope feedbacks, improving our understanding of the detailed geomorphology of rocky hillslopes and the large-scale evolution of landscapes developed in layered rock.



Hogback evolution through time in our numerical model, plotted every 400,000 years. The adjoining slope reaches steady state, parallel retreat by 1.6 Myr in which slope and release rate remain constant.

Ongoing Investigations into the Connections Between Mineral Luminescence and Geomorphic Processes.

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A main component of modern geomorphic research is centered on testing of conceptual and numerical models with the hopes of better developing predictions of landscape and landform evolution. A key issue for testing these geomorphic models is a lack of simplified means to quantify common Earth surface processes such as sediment transport in rivers and on hillslopes. One possible avenue is to use a property of minerals known as luminescence. Luminescence is a phenomenon that arises when electrons are displaced and, ”trapped” within the crystal lattice due to exposure to background ionizing radiation. These electrons only gain the energy needed to escape these traps when exposed to sunlight, heat, or pressure, yielding measurable photons in the process, thus ,’luminescence.’ This property has been used as a geochronometer for the past ~35 years. In this presentation, we show results from numerical modeling of geomorphic transport of quartz and feldspar fine sand (90-250 ¬µm grain size) in rivers and in hillslopes and the expected luminescence for each grain of sand. We explore the distributions and magnitudes of luminescence measurements and show how they can be quantitatively tied to geomorphic process. In particular, we show that researchers can extract virtual river velocities and rates of exchange with floodplain storage centers and estimate vertical diffusivities in hillslope soils. Current work to test these results with independently obtained values is ongoing and we show that our preliminary results match model predictions. There exists significant potential to use luminescence as a process-sensitive geomorphic tracer.

A Shift in the Paradigm: Assessing & Mitigating the Impact of Climate Change to Salt Marshes.

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Global satellite altimetry indicates that the rate of global mean sea level rise has increased from approximately 1.6 to 3.4 mm/year (Church & White, 2006). Over the 20th century the largely linear rate of eustatic sea level rise has been a function of an increase in the average annual global temperature that resulted in thermal expansion of seawater. Atmospheric carbon emission scenarios of the 21st century will increase global average temperatures and ultimately introduce additional contributions (e.g., land ice loss and changes in land water storage). The additions to thermal expansion will result in higher sea levels. And the increases in sea level will be attained by further accelerations in the rate of the rise (Passeri et al. 2015). Over the land mass the increased temperatures lead to changes in precipitation rates and patterns, etc. To properly assess the impacts of sea level change to bays and estuaries, we must accommodate global climate change in general. This presentation will explain our approach to assessing impacts of global climate change (as opposed to just an assessment of the impacts from sea level change) to a fluvial dominated estuary and bay, and demonstrate adaptation strategies that can enhance coastal resiliency.

Our study focuses on the Apalachicola River, estuary and bay, located in the eastern end of the Florida panhandle. The Apalachicola River is formed by the confluence of the Chattahoochee and Flint Rivers, and has the largest discharge in Florida. The river feeds into an array of salt marsh systems and ultimately empties into the Apalachicola Bay. Sediment is eroded and transported from overland areas, especially during extreme rainfall events, and carried through the Apalachicola River and surrounding tributaries. The salt marsh serves to filter out large quantities of sediment before the bay. The marsh surface is elevated by these infusions of sediment, which with rising sea levels prolongs its viability (Morris et al. 2002).

We have developed the hydro-MEM model to couple tidal hydrodynamics with the marsh equilibrium model (Alizad et al. 2016 & Hagen et al. 2013) to assess impacts from sea level change and introduce a means of mitigating the impacts. For this region we have assessed global climate changes to precipitation (Wang et al. 2013). Further, we have clearly demonstrated the nonlinear responses found by including population dynamics through land use and land cover changes when evaluating historical and future storm surge events (Bilskie et al. 2014 & Hovenga et al. 2016). Herein we formally incorporate global carbon emission scenarios such that our projections of eustatic sea level rise, precipitation and runoff, land use and land cover, etc. are all interconnected. The result is a coastal engineering tool that more completely evaluates the impact of global climate change to estuarine systems.

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Investigating the Role of Near-Fault Relief and Vertical Uplift in Strike-Slip Landscape Development.

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Strike-slip faults have long been observed to create distinctive fluvial landforms, such as offset, diverted, and captured streams, as well as near-fault relief features such as shutter ridges and sag ponds. These landforms, particularly offset streams, have been used to identify faults, assess fault activity and determine slip rates. However, not every active strike-slip fault shows a clear landscape signature of its presence, and strike-slip motion on a fault may not be wholly responsible for the occurrence and form of these features. Here, we attempt to constrain the factors that influence the production of strike-slip landforms. We use the Channel-Hillslope Integrated Landscape Development model (CHILD) to investigate specifically the effects of vertical uplift and relief across a fault. We model a scenario in which a strike-slip fault cuts a linear mountain ridge, offsetting a set of subparallel streams. By varying uplift rates and bedrock erodibility across the fault, we consider both how different ratios of vertical to horizontal fault motion affect the landscape and how the presence of landforms such as shutter ridges and sag ponds affect the development of the fluvial network along the fault, including stream offsets and capture events.

Of the parameters tested, relief on the downhill side of the fault has the strongest effect on the landscape. When relief is low and shutter ridges are very small or not present, offsets are very short and stream capture occurs frequently. As a consequence, drainage spacing remains short because long offsets do not cause adjacent drainages to merge. We compare these results to landscapes in the Marlborough Fault System of New Zealand, which is a suite of four parallel strike-slip faults that vary in slip rate from 3 to 20 mm/yr from north to south. At sites analogous to our models, relief on the downhill side of the fault broadly correlates to channel offset length. These results show that the presence of topography or lithologic contrasts that can enhance the landscape signature of a strike-slip fault. Pre-existing characteristics of the landscape may damp or exaggerate the production of stream offsets and the occurrence of stream captures.

Delivery of Sediment to the Continental Slope Via Plume Delivery and Storm Resuspension: Numerical Modeling for the Northern Gulf of Mexico.

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The supply of sediment from the continental shelf to deeper waters is of critical importance for building continental margin repositories of sediment, and may also factor into episodic events on the continental slope such as turbidity currents and slope failures. While numerical sediment transport models have been developed for coastal and continental shelf areas, they have not often been used to infer sediment delivery to deeper waters. A three-dimensional coupled hydrodynamic - suspended sediment transport model for the northern Gulf of Mexico has been developed and run to evaluate the types of conditions that are associated with delivery of suspended sediment to the continental slope. Accounting for sediment delivery by riverine plumes and for sediment resuspension by energetic waves and currents, the sediment transport calculations were implemented within the Regional Ocean Modeling System (ROMS). The model domain represents the northern Gulf of Mexico shelf and slope including the Mississippi birdfoot delta and the Mississippi and DeSoto Canyons. To investigate the role of freshwater pulses and storms in driving down-slope sediment fluxes, model runs that encompassed fall, 2007 through late summer, 2008 were analyzed. During this time period, the study experienced a period of elevated river discharge, several winter storms, and the passage of two hurricanes (Ike and Gustav). Sediment delivery to the continental slope was triggered by the passage of large storm events, and enhanced during periods of elevated freshwater delivery. Additionally, a climatological analysis indicates that storm track influences both the wind-driven currents and wave energy on the shelf, and as such plays an important role in determining which storms trigger delivery of suspended continental shelf sediment to the adjacent slope.

Impacts of River Linking on Sediment Transport to Indian Deltas.

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In response to water scarcity and a growing population, the Indian government has begun a project to link India's largest rivers together in the most ambitious water diversion scheme ever proposed. The Indian Rivers Interlink project has been under consideration since 1980, but the plan has new momentum since a 2012 Supreme Court decision ordered the project to move forward. The first link was completed in Sep. 2015, transferring water from the Godavari to the Krishna River. If the interlinking project is fully realized, fourteen canals will ultimately divert water from tributaries of the Ganges and Brahmaputra rivers to areas in the west, where fresh water is needed for irrigation. Additional canals would transport the water more than 1000 km south to the southern tip of the Indian subcontinent. Here, we investigate the impacts of the proposed diversions on water and sediment transport to the Ganges-Brahmaputra, Mahanadi, Godavari, Krishna, and Kaveri river deltas. We map the changing river network and all proposed new nodes and connections. Additionally, we present the cumulative potential impact of the project's new dams on population displacement and forest land. Changes in sediment due to the proposed canals are simulated using HydroTrend, a climate-driven hydrological water balance and transport model that incorporates drainage area, discharge, relief, temperature, basin-average lithology, and anthropogenic influences. Simulated river discharge is validated against current observations from the Central Water Commission of the Government of India. We also quantify changes in contributing areas for the outlets of nine major Indian rivers, showing that more than 50% of the land in India will contribute a portion of its runoff to a new outlet should the entire canal system be constructed.

Toward a Unifying Constitutive Relation for Sediment Transport Across Environments.

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Landscape evolution models typically parse the environment into different process domains, each with its own sediment transport law: e.g., soil creep, landslides and debris flows, and river bed-load and suspended-sediment transport. Sediment transport in all environments, however, contains many of the same physical ingredients, albeit in varying proportions: grain entrainment due to a shear force, that is a combination of fluid flow, particle-particle friction and gravity. We present a new take on the perspective originally advanced by Bagnold, that views the long profile of a hillslope-river-shelf system as a continuous gradient of decreasing granular friction dominance and increasing fluid drag dominance on transport capacity. Recent advances in understanding the behavior and regime transitions of dense granular systems suggest that the entire span of granular-to-fluid regimes may be accommodated by a single-phase rheology. This model predicts a material-flow effective friction (or viscosity) that changes with the degree of shear rate and confining pressure. We present experimental results confirming that fluid-driven sediment transport follows this same rheology, for bed and suspended load. Surprisingly, below the apparent threshold of motion we observe that sediment particles creep, in a manner characteristic of glassy systems. We argue that this mechanism is relevant for both hillslopes and rivers. We discuss the possibilities of unifying sediment transport across environments and disciplines, and the potential consequences for modeling landscape evolution.

Solving Data and Model Integration Challenges with Communities of Practice: The Sediment Experimentalist Network (SEN) and the USGS Community for Data Integration (CDI).

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Active research in Earth surface dynamics is increasingly interdisciplinary and collaborative, making it necessary to find and integrate data and models from many different sources. Discovering and integrating data and models from disparate sources is often a time-consuming and near-impossible process. Scientific communities of practice such as the Sediment Experimentalist Network (SEN) and the USGS Community for Data Integration (CDI) help users to make collaborative connections and solve data and model integration challenges. These communities accelerate the discovery of existing data and tools, expose common questions and answers to a wide audience, and collectively tackle shared community challenges such as standards for description and integration. This poster presents outcomes from SEN and CDI that may be useful for the Community Surface Dynamics Modeling System (CSDMS).

Sediment Experimentalist Network: http://earthcube.org/group/sen
USGS Community for Data Integration: http://www.usgs.gov/cdi/

Python Coding for GIS Researchers.

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This course was developed with the goal to teach non-programmers how to write Python scripts and programs to process Geographical Information Systems (GIS) data.

Modelling Workflow: Hurricane Effects at the Seafloor.

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The subsea infrastructure of the US N Gulf of Mexico is exposed to risks of seabed flowage under extreme storm events. Numerical assessments of the likelihood, location and severity of those phenomena would help in planning. A project under BOEM, couples advanced modelling modules in order to begin such a system. The period 2008-10 was used for test data, covering hurricanes Gustav and Ike, in the Mississippi to De Soto Canyons region. Currents, tides and surface waves were computed using the Regional Ocean Modeling System (ROMS) and river discharges from WBMsed. The Community Sediment Transport Model (CSTMS) calculated the concurrent regional patterns of sediment erosion-transport-deposition. Local sediment properties were provided from the dbSEABED database. The preferred paths of near-bottom sediment flows were based on a TauDEM channel analysis of the bathymetry. Locations and timings of suspended sediment gravity flow were identified by applying energy flow ignition criterea. Wave-induced mass failure and subbottom liquefaction

were also assessed using geotechnical models. These tests of ignition are bundled in the model suite HurriSlip. The persistence, densities and velocities of turbidity flows yielded by the disruption of the sediment masses were calculated using high-Reynolds Number adaptations of LES/RANS-TURBINS models (Large-Eddy Simulation / Reynolds Averaged Navier-Stokes). A very important step here was the transfer of these advanced models from laboratory to geographic scales.
As known, much of the shelf sediment mantle is suspended and/or moved during hurricanes, consistent with the modeling results. Many short-lived gravity-flow ignitions occur on the shelf; many at the shelf edge will ignite into fast, erosive and persistent currents. Sediment patchiness and vagaries of hurricane path mean that the pattern of ignitions alters from event to event. To understand the impact on the deep-water infrastructure, numerical process-based modelling is essential - along the lines this project explored and developed. A valuable experience in the project was devising workflows and linkages between these advanced, but independent models.

Investigating the Relationship Between Carbonate Facies Belts and Mosaics.

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The spatial patterns of facies within a carbonate depositional system provide a geologic record of climatic and oceanographic conditions. The classic textbook model describes such a system as a series of shore- or margin-parallel facies belts whose occurrence strongly correlates with water depth. While clearly useful for describing broad-scale spatial patterns and reconstructing geologic history, including sea-level curves, the belt model does not adequately capture the fine-scale spatial heterogeneity of facies arrangements observed in real-world systems. This limitation of the belt model led to the proposal the facies mosaic model as an alternative description for carbonate depositional systems. A facies mosaic is defined as, ,"an arrangement of lithological elements lacking significant linear trends in element arrangement, but showing some statistically significant relationship between element size and frequency of occurrence." This definition is a useful starting point for refining our understanding of these sedimentary systems, yet it too is limited. In particular, there is an implicit assumption that belt systems and mosaics are distinct end-members on a spectrum of possible facies configurations, yet it remains unclear whether this assumption is true or not. Further muddling the issue is the fact that facies belts can exhibit the statistically significant relationship between element size and frequency of occurrence inherent to the mosaic model. Thus, there is a need to revisit these two models to better understand their relationship to address the aforementioned issues. This is important because if they do represent distinct configurations, then one must ask if they represent different sets of environmental controls. If they do, then the criteria for distinguishing the two endmembers require refinement to ensure reliable interpretation of the sedimentary record. This study investigates the relationship between the belt and mosaic models using real-world observations of lateral facies patterns from a modern isolated carbonate platform.

The Impact of Climate Change on Riverine Flooding.

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Flooding is the most common natural hazard worldwide, affecting 21 million people every year. River induced flooding typically occurs when streamflow exceeds bankfull stage at a certain stretch along a river at a given point in time. While some, mostly large-scale, flooding events are relatively perennial most are highly transient. This makes flooding difficult to predict. Although hydrological models can quite accurately estimate streamflow conditions, overbanking is dependent upon localized river morphology and hydraulics, both difficult to ascertain. Recent advances in characterization and modeling of river-floodplain interactions now allows us to provide a spatially and temporally explicit first order estimates of the location, magnitude, frequency, and duration of floods of global rivers.

Here we apply the global Water Balance Model (WBM) to quantify a) location, frequency and magnitude of flooding and b) the impact of future predicted climate change on this quantification. Among others, WBM simulates daily riverine streamflow at 6 arcminutes spatial resolution. The bankfull water discharge is estimated for each river location by determining the 2year flood frequency return interval based on the Log-Pearson Type III Distribution. Similarly, globally discharges that mimic the 10, 25, 50 and 100 year flood event were established. Flood magnitude and frequencies of the last 30 years (1975-2004) are determined and compared to future simulated floods (2070-2099).

Effects of In-stream Mixing on Carbon Photo-mineralization in Arctic Rivers.

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Photo-mineralization, the oxidation of dissolved organic carbon (DOC) to CO2 by light, is an important mechanism of CO2 production in arctic inland waters. Current estimates of arctic CO2 production assume that DOC is well-mixed in the water column, which overlooks circumstances when vertical mixing is not strong enough to replenish DOC in the photo-active near-surface region. To determine conditions for which the well-mixed assumption is valid, we used a physically based model that numerically computes whole-stream effective reaction rates as an integrated effect of spatial patterns of photo-chemical reaction and mixing limitations, and quantified the difference in these rates with and without mixing limitations. The well-mixed assumption holds when the mixing timescale is sufficiently smaller than photo-mineralization timescale. However, mixing limits effective whole-stream photo-mineralization rates when total light attenuation over depth is strong and when the reaction rate is faster than the mixing rate. We applied this analysis to estimate whole-system photo-mineralization of DOC in the Kuparuk River, Alaska. We found that the well-mixed assumption is valid for photo-mineralization of DOC in the main stem of the Kuparuk River, and upscaling of available observations with this assumption yields a total DOC photo-mineralization rate of 1.26√ó105 mol CO2 day-1. Scaling analysis indicates that photo-mineralization rates in other arctic systems with similar photon attenuation over depth but longer mixing timescales will be limited by hydrodynamic mixing rates.

Extraction of Multi-thread Channel Networks Using a Reduced-complexity Flow Model.

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Channels with multiple, interwoven threads are common features of river valleys and alluvial and submarine fans. The geometry of multi-thread channel networks is a basic constraint for modeling stream flow and sediment transport, and is used in applications including fisheries management and flood and debris flow hazards. Understanding the adaptability of multi-thread channel geometry is also important for interpreting landscape response to ancient and modern climate change. Multi-thread channels have been hypothesized to adjust their planform and cross section geometry to accommodate increases in discharge. However, manually measuring channel geometry (e.g., from aerial photos) to test this hypothesis is often time-consuming and subjective. Existing automated approaches to multi-thread channel mapping identify the channel extent using inundation. I will present an alternative framework to automatically and objectively extract multi-thread channel geometry from topography, provided that the data partially or fully resolves the channel cross section. The approach uses a reduced-complexity flow algorithm, similar to those developed for braided river modeling, to reveal the spatial structure of multi-thread channel networks with locally divergent flow paths. Importantly, the flow model highlights abandoned channels that are common in arid climates and landscapes with shifting channel belts. The channel extraction approach is tested for case studies including an experimental submarine fan; a natural braided river near Flathead Lake, MT; and the large-scale anabranching canyon system of Kasei Valles, Mars. These examples range in spatial scale from 1 m to 100 km, and in digital elevation model resolution from 1 mm to 100 m. By repurposing a reduced-complexity flow model, the new channel extraction approach offers a unified framework for testing how multi-thread channels respond to changing discharge in numerical models, laboratory experiments, and natural landscapes.

An Entropy Based Quantification of Delta Channel Network Complexity.

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River deltas across the world exhibit an astonishing variety of morphologies in response to different forcings (e.g., river, tides and waves), sediment composition, incoming flow variability, sea level rise, etc. Understanding and quantifying the patterns imprinted on the landform would enable us to infer processes from observed imagery. Galloway [1975] introduced a qualitative diagram to classify deltas, showing how the balance of upstream (fluvial) and downstream (waves and tides) forcings dictates the delta form, depicted most distinctively in the coastline morphology. Recently, we presented a rigorous framework [Tejedor et al., 2015a,b] based on spectral graph theory to study delta channel networks, enabling us to extract important structural and dynamics-related information of river deltas. Using that information, we are able to introduce a suite of metrics to quantify channel network complexity, including entropic-based metrics measuring the complexity in terms of the uncertainty in the splitting and rejoining paths and fluxes, enhancing the comparison of deltas and process from form inference. Finally using the above mentioned framework, we are able to construct vulnerability maps that depict the relative change of sediment and water delivery to the shoreline outlets in response to possible perturbations in hundreds of upstream links. We show that an inverse relationship exists between entropy and vulnerability, reinforcing the idea that entropy is a surrogate of the capacity of the system to undergo changes.

Earth Surface Modeling for Education: is it Effective? Two Semesters of Classroom Tests with WILSIM-GC.

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Earth's surface is the ever-changing, dynamic interface between lithosphere, hydrosphere, cryosphere, and atmosphere. Earth surface modeling can help researchers predict the movement of water and sediments and understand the processes that shape the landform we see today. Modeling can also be employed to help students understand the complicated surface processes and their interactions because it allows students to explore different scenarios and observe the associated outcomes. However, for modeling to be useful in teaching (especially at the undergraduate level), simplifications and adaptations are necessary. The Web-based Interactive Landform Simulation Model - Grand Canyon (WILSIM-GC, http://serc.carleton.edu/landform/) is a simplified version of a physically-based model that simulates bedrock channel erosion, cliff retreat, and base level change. It takes advantage of the recent developments in Java technology (e.g., Java OpenGL, Trusted Applet, and multithreaded capability) that allows for fast computation and dynamic visualization. Students can change the erodibility of the bed rock, contrast in erodibility between hard and soft rock layers, cliff retreat rate, and base level dropping rate. The impact and interaction of these changes on the landform evolution can be observed in animation from different viewing geometry. In addition, cross-sections and profiles at different time intervals can be displayed and saved for further quantitative analysis.

Our initial results of testing WILSIM-GC in classroom in the fall of 2014 showed promising results (Luo et al., 2016). Improvements have been made since then and here we report new results from fall of 2015 (semester 1) and spring of 2016 (semester 2). The same quasi-experimental design was followed: students were randomly assigned to a treatment group (using WILSIM-GC simulation) or a control group (using traditional paper-based material) to learn the land-forming processes in the Grand Canyon. Pre- and post-tests were administered to measure students' understanding of the concepts and processes related to Grand Canyon formation and evolution. Results from the ANOVA showed that for both groups there were statistically significant growth in scores from pre-test to post-test [$F(1, 47) = 25.82$, $p < .001$], but the growth in scores between the two groups was not statistically significant [$F(1, 47) = 0.08$, $p = .774$]. In semester 1, the WILSIM-GC group showed greater growth, while in semester 2, the paper-based group showed greater growth. Additionally, a significant time √ó group √ó gender √ó semester interaction effect was observed [$F(1, 47) = 4.76$, $p = .034$]. Here, in semester 1 female students were more strongly advantaged by the WILSIM-GC intervention than male students, while in semester 2, female students were less strongly advantaged than male students (and, in fact, females in the WILSIM-GC condition showed a lower rate of growth than females in the paper-based condition).

The new results are consistent with our initial findings and others reported in the literature, i.e., simulation approach is at least equally effective as traditional paper-based method in teaching students about landform evolution. Survey data indicate that students prefer the simulation approach. Further study is needed to investigate the reasons for the difference by gender.

Modeling Landscape Evolution and Climate: How Erosion and Precipitation are Linked in Active Orogens (preliminary results).

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The tectonic history and the climate driven erosional processes acting in a region are the primary controls on the evolution of a landscape. Quantifying these controls is essential to our understanding of uplift and erosion histories in mountain ranges. While tectonic processes are generally dependent on the location of plate boundaries, the controls on erosion are less constrained. We implement a numerical modeling approach to investigate these processes by coupling a high-resolution climate model, Weather Research and Forecasting Model (WRF), and a landscape evolution model, Landlab. The Andes act as the climatic setting for this study, due to the variation in climate along the length of the orogen, and serve as a natural laboratory to test controls on erosion. With the help of the hydrologic model WRF Hydro, we pass discharge and topography data between the models, which allows for a feedback relationship to form between topography and precipitation. We will present our preliminary model runs that result from an asynchronous model coupling approach. These results will allow us to run further experiments to test feedbacks between topography and climate by monitoring topographic metrics and erosion histories. This work provides a necessary next step in landscape evolution modeling by using an actively evolving climate to model real precipitation dynamics. This next step allows for modeling more accurate representations of precipitation and the role orography and precipitation play in changing one another.

Revisiting Salt Marsh Resilience to Sea Level Rise: Are Ponds Responsible for Permanent Land Loss?

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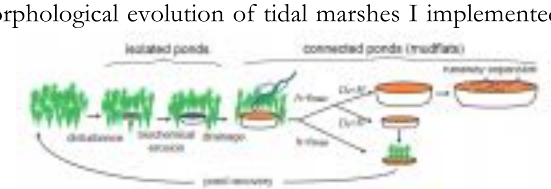
Ponds are un-vegetated rounded depressions commonly present on marsh platforms. In order to study how ponds affect the long-term morphological evolution of tidal marshes I implemented a simple model for pond vertical and planform dynamics. Even if the vegetated platform keeps pace with Relative Sea Level Rise (RSLR), episodic disturbances of the marsh vegetation cause the formation of small (1-10 m) ponds. Isolated ponds deepen and enlarge because of biochemical processes that prevent vegetation growth and decompose the existing organic sediment. Ponds eventually connect to the channel network and re-establish a biochemistry conducive for vegetation growth. Recovery occurs if, at the time of drainage, the pond lies above the limit for vegetation growth, or if the inorganic deposition rate is larger than the rate of RSLR. If ponds cannot recover they will enlarge and eventually enter the runaway erosion by wave



edge retreat. A large tidal range, a large sediment supply, and a low rate of RSLR favor pond recovery. The model suggests that inorganic sediment deposition alone controls pond recovery, even in marshes where organic matter dominates accretion of the vegetated platform. Because permanent loss by pond expansion can occur even if the vegetated platform keeps pace with RSLR, I conclude that marsh resilience to RSLR is less than previously quantified and that increasing the availability of inorganic sediment is necessary to sustain high rates of RSLR.

Linear Scaling of Wind-driven Sand Flux with Shear Stress.

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Wind-driven sand transport generates atmospheric dust and sculpts dunes, yet models for this process generally perform poorly. A paradigm underlying most such models is that particle speed increases linearly with wind shear velocity, resulting in the long-established nonlinear scaling of sand flux to the three-halves power of wind shear stress.

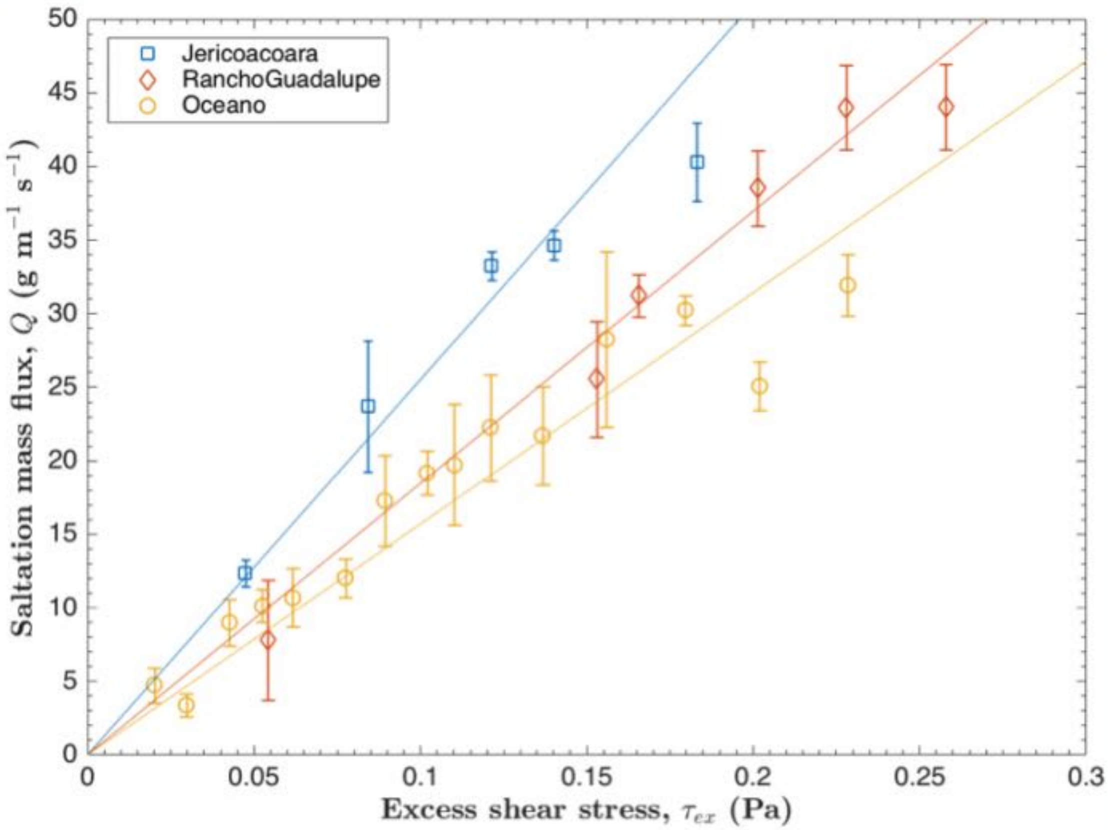

Figure 2. Saltation mass fluxes (Q) versus excess shear stresses, $\tau_{ex} = \tau - \tau_{it}$. Data are binned into ranges of τ_{ex} with bars denoting standard errors for each bin. The impact threshold stress (τ_{it}) was computed separately for each site.

Here, we present comprehensive measurements at three field sites showing that characteristic particle hop heights, and thus particle speeds, remain approximately constant with shear velocity. This result implies a linear dependence of wind-blown flux on wind shear stress, which we confirm by direct observation of the stress-flux relationship at all sites. Models for dust generation, dune migration, and other processes driven by wind-blown sand on Earth, Mars, and several other planetary surfaces should be modified to account for linear stress-flux scaling.

Experimental Reproducibility of Results of Flow Intermittency on Delta Dynamics.

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In order to simplify the complex hydrological variability of flow conditions, experiments modeling delta evolution are often conducted using a representative ,"channel-forming," flood flow and then results are related to field settings using an intermittency factor, defined as the fraction of total time at flood conditions. Although this intermittency factor makes it easier to investigate how variables, such as relative base level and/or sediment supply, affect delta dynamics, little is known about how this generalization to a single flow condition affects delta processes. With changes in climate causing changes in magnitude, as well as variability, of the hydrology of these coastal systems, it is important to understand how intermittent flows will affect these environments. We conducted a set of laboratory experiments with periodic flow conditions to determine the effects of intermittent discharges on delta evolution. Because the Sediment Experimentalist Network (SEN) has stated that reproducibility of experimental results is one of the grand challenges facing our scientific community, we have conducted similar experiments at both the University of Texas at Austin and the University of Wyoming to compare and determine generalized conclusions. During these experiments, flood periods with a set water discharge and sediment supply, cycles between periods of base flow where the sediment supply is turned off. We find that during base flow periods, channels tend to incise resulting in a small yet finite amount of shoreline progradation even though sediment is not input to the system. On the other hand, channels will aggrade during floods when sediment is turned back on. The system must adjust between these two different equilibrium states for each flow condition. These results suggest that the adjustment timescale between differing flow conditions is a factor in determining the overall shape of the delta and behavior of the fluviodeltaic channels. We conclude, periods of base flow when topset sediment is reworked, may be just as important to delta dynamics as periods of flood when sediment is supplied to the system.

Climate Change Consequences on Seabird Population (With Emphasis on Distributional Changes in Seabirds in South Africa).

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Climate change is already having a profound impact on the world's oceans-disrupting the complex oceanographic phenomena and cycles that govern marine ecosystems. Seabirds are key indicators as to the magnitude of climate-induced changes in the marine realm, at the same time; they may also be uniquely vulnerable to its impacts. Numerous scenarios exist regarding the extent of climatic change consequences on seabird population. Over the past 100 years, the global mean surface temperature has increased by 0.6¬∞C and scientists believe that there will be further increases 1.4 to 5.8¬∞C over the next 100 years. Birds have already been affected by changes in breeding success, distribution and migration timing due to climate change.

This paper aims to research into consequences climate change has on seabirds, responses, and predictions of future direct and indirect impacts. It also touches upon (as a case study) climate change impacts on distributional changes in seabird population in South Africa. In terms of methodology, secondary data have been used in this presentation and analysis is descriptive in nature. The paper concludes that along with impacts due to changes in weather, seabirds will also be indirectly affected by the impacts of climate change on their ecosystems. This includes the marine ecosystem that contains the main prey of seabirds and also the various ecosystems that provide the diverse range of seabird breeding habitats. Many predictions are based on the documented effects on seabirds during short warming events. With reference to climate change impacts on distributional changes in seabird population in South Africa, the paper finds that in the mid-1990s, breeding of Leach's storm petrel Oceanodroma leucorhoa was recorded in the Western Cape, the first record for the Southern Hemisphere. Further, in the early 2000s, there was a decrease in numbers of Cape gannets Morus capensis breeding in the Western Cape, but a large increase in the Eastern Cape.

The Roles of Resuspension and Redistribution on Nutrient Cycling in the Northern Gulf of Mexico: Results From A Coupled Hydrodynamic-Sediment Transport - Biogeochemical Numerical Model.

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Transport of particulate organic matter within and through coastal marine environments depends on the relative effects of supply, storage in the seabed, subsequent resuspension, and advection within the water column, as well as biogeochemical reactions. These transport processes are often invoked to explain spatial or temporal variations in biogeochemical fluxes, but the extent to which resuspension and advection affect water-column biogeochemistry and carbon remineralization is debated and can be challenging to measure. A modeling approach promises a means of quantifying these fluxes for a range of conditions, and enables extrapolation beyond point observations. Typically, however, water column biogeochemistry models have used simplifying assumptions to represent benthic boundary conditions, and have neglected resuspension and subsequent advection of particulate organic matter and nutrients. Yet, sensitivity tests have shown that estimates of biogeochemical cycling in dynamic coastal environments are sensitive to how sediment processes are represented in models.

To evaluate the role of seabed resuspension and subsequent advection on biogeochemical fluxes, we developed a coupled model within the Regional Ocean Modeling System (ROMS) framework. The coupled model includes hydrodynamic, sediment transport, and biogeochemical processes. To link the sediment transport and water column biogeochemical modules, a diagenetic model was added to the seabed. The coupled model accounts for processes including advection, resuspension, diffusion within the seabed and at the sediment-water interface, and organic matter remineralization. Here, we implemented coupling between hydrodynamics, sediment transport, and a biogeochemical model within a full three-dimensional numerical model to investigate the relative effects of supply, resuspension, and advection on biogeochemical fluxes within the riverine-influenced Gulf of Mexico. Preliminary results indicate that seabed and bottom boundary layer oxygen consumption increased where and when particulate organic carbon accumulates on the shelf. Ongoing work includes analyzing results for nitrogen fluxes and from time-periods with low-oxygen conditions.

Predicting Coastal Deltaic Change on a Global Scale.

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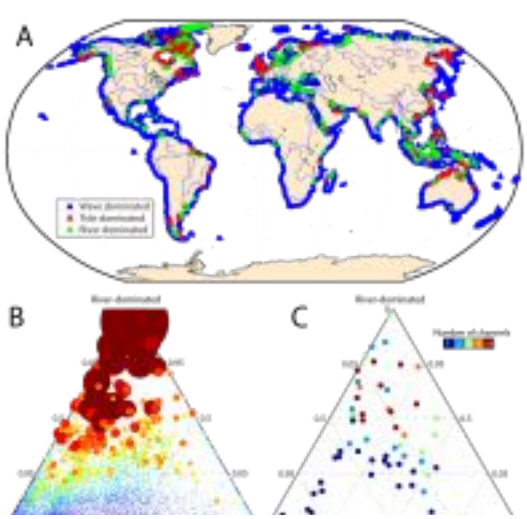

Predicted morphology of about 140000 deltas/river mouths globally. B) Location in Galloway Ternary

Coastal deltaic change is expected to be one of the major Earth-surface hazards of the 21st century as deltas around the world face large changes in sediment supply due to river damming, land-use changes, and climate change. We have quantified the effect of waves, tides, and fluvial sediment supply on delta morphology to predict future changes to deltaic coasts. Simple parameterizations and key insights from global wave, tide, and fluvial sediment data have allowed us to make morphologic predictions around the globe for every delta on Earth. We find that without human interference many deltas with decreased sediment loads are expected to be reworked by waves into barrier islands or by tides into alluvial estuaries. Other deltas are projected to experience increased sediment flux, and, in some cases these growing deltas could transition to river-dominated morphologies. This unified, global picture of future deltaic change will aid local management of deltaic areas and also provide opportunities for inclusion of morphologic change into Earth system and climate models.

Mechanisms of Shrub Encroachment explored in Southwestern United States using Landlab Ecohydrology.

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Arid and semi-arid grasslands of southwestern United States have changed dramatically over the last 150 years due to woody plant encroachment. Driven by overgrazing, reduced fire frequency, and climate change, shrub encroachment is considered as a major form of desertification. In Landlab we represent ecohydrologic plant dynamics, fires, grazing, and resource distribution (erosion/deposition) in separate components. In this work, we demonstrate their utility for studying shrub encroachment using three examples. In the first example, a simple stochastic cellular automata model with two state variables, vegetation cover and soil resource storage, are used to model shrub patterns based on probabilistic establishment-mortality interplay, mediated by resource redistribution, while explicit roles of climate were neglected. In the second example, physically based vegetation dynamics model is used to simulate biomass production based on local soil moisture and potential evapotranspiration driven by daily simulated weather, coupled with a cellular automata plant establishment. While climate is included as forcing, the model disregards resource redistribution, except for seed dispersal. In the third example, we coupled the latter two models to examine the roles of disturbances and resource distribution in a dynamic ecohydrologic context. Inferences are drawn on how encroachment factors and model complexity affect shrub pattern in space and time.

Feedbacks Between Mass Wasting and Abyssal Hill Growth on Seismic Cycle and Geological Time Scales.

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Javier Escartin, CNRS, France.

Feedbacks between surface processes and tectonics are well established in a variety of subaerial geodynamic settings, yet they remain largely unexplored in submarine contexts. Here we investigate potential feedbacks between mass wasting and the growth of abyssal hills, the most common landform on the Earth's surface. Abyssal hills form as lithosphere-scale normal faults uplift newly accreted magmatic terrains near the axis of mid-ocean ridges. In order to assess the effect of mass wasting on fault-induced topography, we analyze the morphology of ~2000 normal fault scarps identified in cross-axis multibeam bathymetry profiles from the intermediate-spreading Chile Ridge. This large population samples the entire life span of a hill-bounding fault, from initiation to abandonment.

We first calculate a running median of the scarp dip population, and find that it spans a range (0-30¬∫) that is clearly distinct from the expected dip of active normal faults (45-60¬∫). Further, median scarp dips tend to increase with increasing scarp throw, until they plateau around 25¬∫ for scarp throws exceeding 500 m. This trend is best explained by a model where abyssal hill uplift competes with mass wasting parameterized as a non-linear diffusion process. Specifically, we assume that the local transport of degraded scarp material is a non-

linear function of slope that is essentially infinite at a critical value of 25¬∫, and quasi-linear for slopes shallower than ~20¬∫. This model captures the time-integrated effects of rockslides triggered by failure on supercritical slopes (‚â•25¬∫). Our best-fitting model predicts that ~0.6 km2 of basaltic material gets degraded per km along-axis during the growth of a 1-km high abyssal hill (100 kyr).

We then assess potential links between mass wasting events and seismogenic slip on hill-bounding faults. We first evaluate the frequency-magnitude distribution of earthquakes on the Chile Ridge using the ANSS teleseismic earthquake catalog (USGS). We then attempt to relate earthquake recurrence and cumulated volumes of degraded materials. In our simplest scenario, the measured long-term scarp degradation rate can be accounted for if a rockslide displacing ~104 m3 of debris is triggered whenever an earthquake of magnitude ‚â•3 occurs on the ridge. Such rockslides have been documented along the walls of the Mid-Atlantic Ridge axial valley. In more complex models, we assume that rockslide volumes (V) follow a Gutenberg-Richter distribution of the form: log10(N≥V) = a - b log10(V). Such a distribution of mass wasting events can produce cumulated volumes of degraded materials that match the diffusion model when using a b-value of ~2/3.

Lastly, we evaluate the effect of mass wasting on the mechanical state of hill-bounding faults and their long-term evolution. We carry out numerical simulations of mid-ocean ridge normal faulting that incorporate magmatic emplacement at the axis and topography diffusion at the seafloor. Our models suggest that scarp degradation at rates documented on the Chile Ridge enhance the life span, spacing and throw of abyssal hills by ~10% relative to a scenario where fault-induced topography remains intact. We thus argue for a subtle, yet quantifiable effect of mass wasting on mid-ocean ridge tectonics that may be exacerbated in ultraslow-spreading settings.

Climate Dynamics of Tropical Africa: Paleoclimate Perspectives and Challenges.

Bette Otto-Bliesner, NCAR, Boulder, Colorado. United States. ottobli@ucar.edu

Water - too little, too much - will likely be the biggest future climate challenge for the world. This will be particularly true in vulnerable regions in Africa, where the response of rainfall to increasing greenhouse gas concentrations is a critical socio-economic issue, with implications for water resources, agriculture, and potential conflict. The geological record finds tropical Africa at times hyperarid and at other times covered with large megalakes, with abrupt transitions between these humid and dry states. Climate modeling allows us to explore the processes that combined to produce these past changes. In this talk, I will highlight what has been learned about the glacial-interglacial variations of African hydroclimate from models and data. Together, they provide a perspective on projections of future precipitation changes over tropical Africa. **PDF of presentation:** pdf *

Prediction of Coastline Retreat in Arboletes, Southern Caribbean Coast of Colombia, for a Climate Change Scenario.

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Accurate quantification of coastal hazards remains a crucial issue in the light of predicted future sea level rise due to climate change. Most drastic up-to-date predictions have proposed for 2100 a global mean sea level in ~1 m above pre-industrial levels. This may increase the likelihood of related coastal impacts, especially on vulnerable coastlines of developing countries. Along the soft-cliffs of Arboletes town, southern Caribbean coast of Colombia, recent research has quantified historical retreat rates and predicted future coastline positions for the climate change related acceleration in global mean sea level.

The aim of present study is to improve upon those results by including a more accurate quantification of local mean sea level rise and variations in top-cliff coastline elevations. Latter item allowed the calculation, under several assumptions, of the amount of sediment that would be released to the nearshore from cliff erosion. By using a validated model that relates the rates of retreat and sea-level rise, future positions were calculated for ~1 km of coastline located at the Minuto de Dios neighborhood (MD) of Arboletes town. Overall, mean end-point retreat at MD between 1938 and 2010 was 1.7¬±0.4 m/a, which would increase to 2.9¬±0.7 m/a between 2010 and 2046 due to the acceleration in global mean sea level rise. This may imply a future mean coastline recession distance of 104.4¬±25.2 m and a release of 720,000 m3 of rock.

Future coastline retreat of the order of magnitude herein presented could produce important impacts over local infrastructure, including the loss of around 100 socio-economically vulnerable urban constructions of MD. In addition, 2046 coastline may be located as close as 50 m from the main road that connects Arboletes town with Monteria city. To the knowledge of the authors, these predictions provide compelling evidence that climate change may exacerbate already important coastal hazards along the littoral of MD. Indeed, aforementioned results may inform policy makers and could eventually lead to coastal management solutions for this region.

Filtering the Hydrograph Through Sediment Transport and Channel Geometry.

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Spatial and temporal variations in rainfall are hypothesized to influence landscape evolution via their control on erosion and river sediment transport. Short hydrological records and limited empirical observations have led to exploring the relations between rainfall, climate and river erosion through numerical models. To this end, modeling the relationship between rainfall and river dynamics requires a greater understanding of the feedbacks between flooding and a river's capacity to transport sediment. We investigate this with field and experimental data.

We analyzed channel geometry and stream-flow records from 186 coarse-grained rivers across the United States. We find that channels adjust their geometry such that floods slightly exceed the stress required to transport bed sediment - regardless of widely-varying climatic, tectonic, and lithologic controls. Remarkably, the distribution of fluid stresses associated with floods is consistent, indicating that self-organization of near-critical channels filters the climate signal evident in discharge. These findings suggest that a fixed-magnitude steady flood event with an intermittency factor may be adequate for modeling the influence of a variable hydrograph on sediment transport over long timescales.

In tandem, we explore the role of hydrograph unsteadiness on bed load sediment transport through laboratory flume experiments. We find that unsteady flows demonstrate an array of complex transport phenomena even under the conditions of a narrow unimodal grain size distribution and constant sediment supply. However, despite complex transport phenomena at instantaneous timescales within unsteady floods, the total amount of sediment transported per flood depends only on the total integrated excess stress (the flood impulse) and is independent of the flood's shape. Under these experimental conditions, a steady flow may be substituted for a complicated hydrograph.

Reducing the role of climate to an intermittency factor and steady flow is at first glance an oversimplification, however these results suggest this recipe for modeling the impact of climate on river channels may be just simple enough. At the very least these results suggest that this approach could serve as the null hypothesis against which to test more complicated modeling strategies.

Discharge Controls on Plant Distribution and Channel Network Formation in Vegetated Delta Experiments.

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Increasing rates of relative sea level rise are depleting coastal land, causing scientists and engineers to propose solutions, such as river diversions, for coastal restoration. Success in delta restoration projects largely depends on the understanding of interactions between physical and biological processes that can drastically change delta morphology. However, the effects of vegetation on delta dynamics and morphology are still poorly understood. Here we show that there are clear differences in delta morphology between experiments conducted with high and low discharges but that vegetation has the same effects on large-scale delta morphology regardless of discharge. Lower discharge experiments had more, narrower channels that created more small, sparse patches of vegetation that aided in increased channel bifurcation. Deltas created with higher water and sediment discharges had fewer, wider channels that created fewer large, dense patches of vegetation that instead steered channels. Vegetation in both experiments made wider deltas and smoother shorelines, regardless of the differences in patch distribution, compared to experiments without plants. These results are important for coastal restoration as engineers decide whether to implement few large diversions of many small diversions: the discharge controls the morphology and the distribution of vegetation relative to the flow, and vegetation can change the channel processes and feedbacks to make a more or less distributive network of channels to build new land.

Methods for Visualizing Landscape Desiccation as a Result of Over-pumping with Application to the High Plains Aquifer in Western Kansas.

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Mary Hill, University of Kansas Lawrence Kansas, United States.

Resource scarcity is becoming ever-more pertinent as environmental assets like arable land and water have been developed extensively. For example, major agricultural centers in western Kansas have seen the saturated thickness of the High Plains Aquifer (HPA) decline rapidly, which has resulted in landscape desiccation. Yet even in such a dramatically affected area, many people are still unaware of the consequences of large-scale groundwater depletion. Combining open data sources with modern computer technology will enable the development a visual representation of data that will aid in understanding the impacts of historical, current, and future decisions of pumping. An online, time-evolving, interactive map correlating climatic conditions and pumping the HPA with the timing of the conversion of perennial streams to ephemeral will be an effective platform for portraying receding streams as groundwater is depleted without the recharge necessary to replenish it. Interactive aspects will include control of the spatial and temporal display, along with selection of point-specific series plots, which will allow the evolution of this resource to be more visceral than has previously been possible. The methods developed for this work will result in a fluid interface to improve community education and an effective tool to assist in policy-making as stakeholders are enabled to clearly see the relations between data and landscape.

Comparison of 2D and 3D Numerical Models with Experiments of Tsunami Flow through a Built Environment.

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A series of tsunami wave basin experiments of flow through a scale model of Seaside, Oregon have been used as validation data for a 2015 benchmarking workshop hosted by the National Tsunami Mitigation Program, which focused on better understanding the ability of tsunami models to predict flow velocities and inundation depths following a coastal inundation event. As researchers begin to assess the safety of coastal infrastructures, proper assessment of tsunami-induced forces on coastal structures is critical. Hydrodynamic forces on these structures are fundamentally proportional to the local momentum flux of the fluid, and experimental data included momentum flux measurements at many instrumented gauge locations. The GeoClaw tsunami model, which solves the two-dimensional shallow water equations, was compared against other codes during the benchmarking workshop, and more recently a three-dimensional computational fluid dynamics model using the open-source OpenFOAM software has been developed and results from this model are being compared with both the experimental data and the 2D GeoClaw results. In addition, the 3D model allows for computation of fluid forces on the faces of structures, permitting an investigation of the common use of momentum flux as a proxy for these forces. This work aims to assess the potential to apply these momentum flux predictions locally within the model to determine tsunami-induced forces on critical structures. Difficulties in working with these data sets and cross-model comparisons will be discussed. Ultimately, application of the more computationally efficient GeoClaw model, informed by the 3D OpenFOAM models, to predict forces on structures at the community scale can be expected to improve the safety and resilience of coastal communities.

Exploring Delta Morphodynamics with a Coupled River-Ocean Model.

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Often densely populated, deltas are important for agriculture, resource extraction, and transportation, yet they are increasingly vulnerable to natural disasters (e.g., flooding, storm surges) and submergence. Many natural processes influence large-scale delta morphology, yet the relative importance of anthropogenic influences in shaping modern deltas is unknown. To explore the long-term combined effects of sea-level rise, climate change, and anthropogenic influences, we have developed a new morphodynamic delta model that links fluvial, floodplain, and coastal dynamics over large space and timescales. Using the CSDMS Basic Modeling Interface, we couple the River Avulsion and Floodplain Evolution Model (RAFEM) with the Coastline Evolution Model (CEM). In RAFEM, the river course is determined using steepest-descent methodology, and elevation changes along the river profile are modeled as a linear diffusive process. An avulsion occurs when the riverbed becomes super-elevated relative to the surrounding floodplain, but only if the new steepest-descent path to sea level is shorter than the prior river course. CEM uses alongshore sediment transport gradients to distribute sediment flux from the river mouth along the coastline. Preliminary results indicate that anthropogenic manipulations of the river (e.g., levees) can propagate hundreds of kilometers upstream and affect shoreline morphology. Climate change impacts on delta morphology are modeled through changing storminess (affecting the wave climate) and varying sea-level rise rates.

Investigating Sediment Mobilization in Dammed Fluvial Systems Using Smoothed Particle Hydrodynamics.

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When dams are removed, the resulting sediment mobilization alters downstream fluvial dynamics and disrupts critical zone processes. Most methods used to model fluvial hydrodynamics are restricted to one or two dimensions, which limits description of small-scale motion and nuanced flow regimes that contribute to sediment advection. Smoothed particle hydrodynamics (SPH) provides solutions to the Navier-Stokes equations and allows interactions between weakly-compressible fluids and solid structures to be resolved in three-dimensional space. By adapting smoothed particle hydrodynamics simulations to fluvial systems, the sediment mobilization potential associated with dam removal can be investigated for dammed fluvial systems in Maine's Penobscot River. By rendering natural environments as boundary conditions using LiDAR coupled with bathymetric data, SPH simulations can be calibrated with observed fluvial hydrodynamics in the Penobscot River. Incorporating sediment advection, periodic boundary conditions, and buoyant incompressible solids into the SPH framework provides detailed solutions which will be used to simulate the acute impacts of dam removal on the Penobscot River's hydrodynamics and biological habitats.

Statistical Source Inversion of Tsunamis based on DART Buoy Data

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Probabilistic Tsunami Hazard Assessment (PTHA) performs statistical analysis of tsunami hazards based on a statistical likelihood of earthquake slip distributions. An important component of PTHA is the estimation of such probability distributions based on actual events. Using open-source software package GeoCLAW, we estimate a posterior distribution of a Tsunami event under the Bayesian inference framework, using DART (Deep-ocean Assessment and Reporting of Tsunamis) Buoy data from previous events. We use dimension reduction techniques that allow fast and accurate sampling of the GeoCLAW output for given slip parameters.

Cretaceous Deepwater Formation: Processes and Sensitivities.

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It has been hypothesized that the warm Cretaceous Greenhouse climate with higher sea levels led to the breakdown of shelf front breaks and a thinning of the well mixed Ekman layer in continental shelf seas. Such a thinning would mean that shelf seas would have a more stratified structure, similar to that of the open oceans. With warmer climate, evaporation on stratified continental shelf seas could cause cascading of dense, high-salinity coastal waters, forming the oxygenated deep waters and leading to contour following currents in the intermediate waters below the pycnocline. Seismic surveys of the Upper Cretaceous Chalk group of the North Sea region suggest that the shallow Chalk Sea in which the group was deposited was under the influence of such contour following currents.

In order to test the hypothesis that dense water formation and cascading were a mechanism for deep water formation and contour following current forcing in the Chalk Sea, we developed an idealized model of the sea. The model, which was first proposed at the 2015 CSDMS meeting, simulates hydrodynamic and sediment transport processes, and is forced by climatic conditions (wind direction and strength, surface freshwater flux, salinity and temperature) informed by GCM modelling of the late Maastrichtian. Sediment properties are derived from experimental values.
Here we present the final model and a range of sensitivity studies to demonstrate the feasibility of our hypothesis.

A Composite Vulnerability Index for Urban Areas in Deltaic Regions: An Application in the Amazon Delta

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Deltas are complex socio-ecological systems subject to a wide range of human pressures and hazards, where population density is many-folds that of other regions. Urban development patterns, urban growth, river damming & sediment control coupled with climate change are increasing flood risks and the degree of vulnerability in many deltas of the world. The need for integrated vulnerability assessments that capture both socio-economic and geophysical elements in deltas is emergent. This study presents a composite index for the vulnerability assessment of the urban Amazon Delta (AD) based in three dimensions of vulnerability: flood exposure, socio-economic sensitivity and infrastructure. The vulnerability index was developed using the Analytical Hierarchy process (AHP), which helps to gage level of interdependence and the role of different dimensions of vulnerability. The index combines data from public databases at the most disaggregated level of analysis of census data (n = 2938 census sectors) and uses a methodology based on data from Shuttle Radar Topography Mission (SRTM) to assess and characterize sectors based on their flood risks. Results indicate that over 60% of the urban sectors within the AD present high degree of vulnerability, reaching a population of over one million inhabitants. This degree of urban vulnerability defines and reiterates the impacts of future climate changes across society and as it extends beyond the urban areas of the AD. The methodology proposed in this study contributes to a multi-dimensional assessment of urban vulnerability and it can be applied to other urban areas, allowing for cross-site comparison of vulnerabilities across urban spaces within deltaic systems. Depending on particular case study of an urban area, a more context specific sub set of model indicators can be selected to assess vulnerability. Some indicators can be adapted to individual urban systems thereby providing a useful tool to assess vulnerability in a particular case study while developing a broader model. Future work will involve additional emphasis on time dependent land cover changes and their effects on urban vulnerability based on compositional and configurational changes to the landscape.

Modeling the Effects of In-Stream Sediment Retention on Rates of River Incision and Strath Terrace Formation.

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Fluxes in water discharge and sediment supply have long been known to influence river incision. However, recent studies in several Pacific Northwest rivers measured elevated incision rates over the past 100 years that correlate with the timing of wood loss - the historical deforestation and removal of in-channel wood. Increased bedrock exposure from the lowered sediment retention associated with wood may thus have an important and previously unexplored effect on rates of river incision. Field evidence in the form of geomorphic mapping and terrace ages supports the formation of a historical strath terrace triggered by deforestation, the loss of in-channel wood, and the associated lowered in-stream sediment storage. Reduced in-channel wood loads can also be triggered by climatic changes, disease, and wildfires in addition to anthropogenic deforestation, and so river incision rates are likely affected by changes to sediment retention over much longer time periods as well. We use a 1-D finite difference numerical model to test the influence of changes in sediment retention on river incision rates over 100,000s of years, and contrast it with the effects of changes to sediment supply and water discharge. The model simulates fluvial long profile development while recording valley width in such a way that terrace surface information can be extracted. Bedrock is eroded based on unit stream power as well as the probability of bedrock exposure, which is controlled by the scour depth through surface alluvium and the sediment retention. Spatial hotspots of high sediment retention represent log jams and decrease the probability of bedrock exposure to erosion, thus reducing incision rates and retarding strath terrace formation. Temporally, the degree of sediment retention is varied to reflect sudden losses such as produced by fire or deforestation which promote strath terrace formation. Our results expand on the role of wood, sediment, and water in controlling river incision rates and suggest landscape evolution, driven by stream incision, can be affected by the flux of in-stream wood. Future 2-D modeling using LandLab will be implemented to consider additional complexity in the system, utilizing existing LandLab components such as storm and wildfire generators, and more accurately representing valley widening within 2-D space.

Lithologic and Tectonic Controls on the Influence of Exhuming Paleo-Relief in Landscape Evolution.

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The susceptibility of a landscape to denudation is known to vary widely with lithology.
In eroding landscapes, where exhumation brings a variety of bedrock types to the surface, this can play a first-order role in the development of drainage patterns. No more spectacularly is the influence of lithology on landscape evolution displayed than in regions of inverted relief. In these cases, indurated valley fill is 'inverted' by subsequent erosion of less competent ridges, leaving a landscape where former channel bottoms occupy significantly higher topography than currently active channels. We describe these features as the product of topographic inheritance. While inverted relief is observed on Earth as well as Mars, the mechanisms that promote relief inversion are only intuitively understood. We hypothesize that the ratio of erodability between preserved and active landscape lithologies, present-to-paleo drainage orientation, and fluvial incision rate interact, with varying levels of importance, to drive relief inversion. To explore this hypothesis, a series of numerical experiments are designed to exhume a buried landscape of preexisting topography. The erodablity of

the buried landscape as well as the rate and style of uplift in the model domain will be varied systematically to determine the conditions that promote topographic inheritance in eroding landscapes.

Human Impacts to Coastal Ecosystems in Puerto Rico: Development of Ecohydrological Model.

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The main goal of the project entitled "human Impacts to Coastal Ecosystems in Puerto Rico (HICE-PR)" which was funded by NASA is to evaluate the impacts of land use/land cover changes on the quality and extent of coastal and marine ecosystems (CMEs) in two priority watersheds in Puerto Rico (Manatí and Guánica).The main objective of this study is to develop ecohydrological model, Soil and Water Assessment Tool (SWAT) for the analysis of hydrological processes in the Rio Grande de Manatí river basin. SWAT (soil and water assessment tool) is a spatially distributed watershed model developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds. The model was calibrated and validated using Sequential Uncertainty Fitting (SUFI-2) calibration and uncertainty analysis algorithms. The model evaluation statistics for streamflows prediction shows that there is a good agreement between the measured and simulated flows that was verified by coefficients of determination and Nash Sutcliffe efficiency greater than 0.5.

A Mass-conservation Approach to Predicting the Distance to River Mouth Channel Bifurcations.

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Channel bifurcation is an important process in fluvio-deltaic morphodynamics and resulting stratigraphic architecture of prograding river deltas. We develop and test a new theory for the formation of channel bifurcations based on fluid mass conservation and system-averaged transport conditions rather than local hydrodynamics. 29 experimental deltas were built under a variety of boundary conditions to examine the inception and growth of bars and channel bifurcations. From the initial condition of water and sediment entering a still basin of uniform depth as a wall-bounded turbulent jet, delta growth begins with the formation of a lunate bar as predicted by the hydrodynamics of jet spreading. However, the lunate bar diverts water and sediment laterally causing the bar to widen into a radially symmetric flow expansion extending from the channel axis to the flume walls. This feature is stable to perturbations, and its distal limit progrades basinward while maintaining a roughly constant flow depth of ~10 times the median grain diameter (H=2-3 mm). Bar formation and channel bifurcation occur on top of the apron at the distance where shear stress applied by radially-averaged flow velocity falls below the threshold of sediment motion. Our model predicts that the distance to the first channel bifurcation should scale with water discharge, scale inversely with flow depth over the apron, and scale with median grain diameter to the negative one half.

Boulders and Bedrock: Modeling Dynamic Feedbacks Between Hillslope-derived Blocks and Transient Channel Evolution

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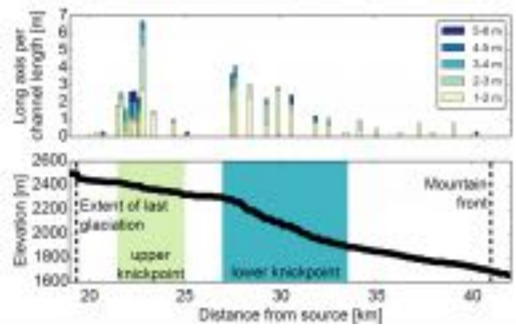
Steep reaches of mountain rivers often host clusters of large (>1 m) blocks of rock despite having high transport capacity (Fig. 1). We argue that this distribution of blocks is a manifestation of a previously unrecognized negative feedback in which fast vertical river incision steepens adjacent hillslopes, which deliver large blocks to the channel. Blocks in the channel inhibit incision by both shielding the bed and enhancing form drag. We explore this feedback with one- and two-dimensional numerical models of channel-reach

erosion in which block delivery by hillslopes depends on the river incision rate. Block dynamics in the channel are modeled explicitly, and form drag exerted on blocks is detracted from shear stress used to erode the channel bed. Hillslope block delivery is treated probabilistically, with the mean number of blocks delivered per channel length per time treated as a function of incision rate in the adjacent channel. When block delivery by the hillslopes is significant relative to the baselevel lowering rate, both the form of the channel reach and the timescales of reach profile evolution differ noticeably from the predictions of current theory. Results indicate that incision-dependent block delivery can explain the block distribution along Boulder Creek, Colorado, USA. The proposed negative feedback may significantly slow knickpoint retreat, channel adjustment to perturbations, and landscape response in comparison to rates predicted by current theory. We suggest that the influence of hillslope-derived blocks may complicate efforts to extract baselevel histories from transient river profiles. Future work includes construction of Landlab components to more explicitly treat hillslope block delivery processes in models of river incision.



Grain size and longitudinal profile data from Boulder Creek. Each bar represents sum of long axes of all grains >1m found in channel (10M channel length). Stars show sites with no blocks >1m. Shaded regions indicate steepened reaches or knickzones. >1m grains more prevalent in knickzone.

The Quandary of an Under-filled Basin: Investigating the Roles of Local Hydrology and Incipient Topography on Channel Path Selection in Sylhet Basin, Bangladesh.

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Sylhet Basin, a seasonally flooded, tectonically influenced sub-basin within the Ganges-Brahmaputra-Meghna delta (GMBD) in northeastern Bangladesh, has experienced as many as three occupations of the Brahmaputra River during the Holocene. The active braidbelt has predominantly been routed along the proximal (west) margin of the basin, bypassing most of the water and sediment and leaving the central basin under-filled in spite of a favorable topographic gradient and active subsidence. We investigate this quandary with perturbations of several physical parameters within a simple 1D channel profile model and a 2D depth-averaged hydrodynamic model (FREHD) to determine preferential flow path selection between two possible pathways. A large body of water is created within the basin center to simulate seasonal flooding and to test the impact of a local backwater effect and reduced water surface slope on channel path preference. A hydrologic barrier effect does not appear to be plausible unless water depths are increased to values that exceed the physical dimensions of Sylhet Basin. Additionally, reduction of the topographic slope along two pathways in a simple bifurcation setup does not appear to enhance the local backwater effect on flow path selection. However, the introduction of a levee along the western margin flow path (and thus a lower elevation) than the basin center path creates a strong preference for bypass of the basin, in spite of a steeper path of descent towards the basin center. Additional tests on variable fan topography and asymmetry further illustrate the preference of the channel to follow a lower (entrenched) elevation bed surface, regardless of surface slope. These results corroborate field evidence in Sylhet Basin that antecedent topography within the GBMD exerts a primary control on Holocene river path selection, such that incision of the Pleistocene surface has impacted fluvial system dynamics more than local climate and tectonics. Future model runs will incorporate sediment transport to investigate the impacts of lake infilling on sediment bypass and mass extraction.

Experimental Investigation of the Effect of Climate Change and Tectonic Anisotropy on Landscape Evolution.

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Based on a series of controlled laboratory experiments conducted at the St. Anthony Falls laboratory, University of Minnesota, we study the effect of changing external forcing such as the temporal pattern (i.e. increase/decrease) of precipitations as well as spatial distribution of uplift rates on landscape evolution at the short and long-time scales. These experiments were designed to create an evolving and self-organized complete drainage network by the growth and propagation of erosional instabilities (e.g. fluvial knickpoint retreat, hillslope erosion) in response to such external forcing. High resolution digital elevation (DEM) recorded every 5 min allowed following this evolution in both space and time. First, we focus on the investigation of how changes in the frequency and magnitude of large precipitation events affect the geomorphic and topologic re-organization of landscape across a range of scales. Our results show distinct signatures of extreme climatic fluctuations on the statistics and geometry of topographical features which are evident in widening and deepening of channels and valleys, change in drainage patterns within a basin and change in the probabilistic structure of, "hot-spots" of change contributing to mass-wasting events, such as, landslides and debris flows. These results suggest a regime shift during the onset of the transient state in the transport processes on the fluvial regime of the landscape, i.e., from supply-limited to transport-limited. Finally, we investigate drainage reorganization in response to an asymmetric relative uplift rate with emphasis on the main drainage divide dynamics. This is achieved through the lowering of base levels at different rates on each side of the experiment. In response to such base level fall, the main drainage divide migrates towards the side of low base level fall rate. Such example provide experimental constraint on the evolution of a landscape under large-scale increase/decrease in drainage area on the sides of an orogen.

Extending the CSDMS Standard Names Template to Include Aquatic Chemistry Terms.

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The CSDMS standard names support component coupling within the CSDMS modeling framework by supplying a common language bridge, or lingua franca, for input and output semantic variable matching. In this work we extend the rules for constructing CSDMS standard names to include the aquatic chemistry terms used by the Water Quality Portal, a collaborative database that brings together water quality data collected by the USGS, EPA, and USDA. This effort will result in the addition of at least 5,000 new unique standard names, providing a wider breadth of model discovery and coupling capabilities.

Numerical Modelling of Secondary Currents of Second Type Caused by Bed Roughness Variations.

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Secondary current in open channels have been long recognized as an important mechanism to alter the path of sediment particle motion and consequently change the river and land surface evolution. Researchers have identified two different kinds of secondary current: the first kind due to curvature in a river bend and the second kind due to turbulence anisotropy. This study demonstrates numerical investigations of the second kind in straight open channels, induced by bed roughness variations. The study incorporates a non-linear fourth-order $k - \omega$ model able to capture anisotropy of turbulence. The $k - \omega$ formulation of the model enables implementation of roughness and resolving the near wall flow. This study benefited from an experimental case study to calibrate the roughness parameter implemented in the model. Based on these calibrations, a new range of roughness parameter was introduced enable the model to simulate 3-D flow structure of open channels with rough and smooth strips. For the validation purpose, the model and the new roughness parameter were tested on different case studies. Not only the patterns and mean flow and turbulence statistics were predicted, but also the model was capable of producing almost similar velocity profile for both transverse and vertical directions, along the vertical lines, which have been never shown in previous numerical studies. The results suggest that the arbitrary proposed values in literature are not suitable for simulating open channel flows with different roughness strips on the walls. The calibrated simulation results are further used for more detailed analysis on the momentum and vorticity budget. These analyses would help investigating hypotheses on mechanism of initiation of secondary currents. Furthermore, the data provided by the model will be utilized to model the sediment transport caused by this kind of secondary current in open channels.

GeoClawSed: A Model with Finite Volume Method for Tsunami Sediment Transport.

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The shallow-water and advection-diffusion equations are commonly used for tsunami sediment-transport modeling. GeoClawSed is based on GeoClaw and adds a bed updating and avalanching scheme to the two-dimensional coupled system combining the shallow- water and advection-diffusion equations, which is a set of hyperbolic integral conservation laws. The modeling system consists of three coupled model components: (1) the shallow-water equations for hydrodynamics; (2) advection-diffusion equation for sediment transport; and (3) an equation for morphodynamics. For the hydrodynamic part, the finite-volume wave propagation methods (high resolution Godunov-type methods) are applied to the shallow-water equations. The well-known Riemann solver in GeoClaw is capable of dealing with diverse flow regimes present during tsunami flows. For the sediment-transport part, the advection-diffusion equation is employed to calculate the distribution of sediment in the water column. In the fully-coupled version, the advection-diffusion equation is also included in the Riemann solver. The Van Leer method is applied for calculating sediment flux in each direction. The bed updating and avalanching scheme (morphodynamics) is used for updating topography during tsunami wave propagation. Adaptive refinement method is extended to hydrodynamic part, sediment transport model and topography. GeoClawSed can evolve different resolution and accurately capture discontinuities in both flow dynamic and sediment transport. Together, GeoClawSed is designed for modeling tsunami propagation, inundation, sediment transport as well as topography change. Finally, GeoClawSed is applied for studying marine and terrestrial deposit distribution after tsunami wave.

Consolidation and Stratification within a Muddy, Partially Mixed Estuary: A Comparison between Idealized and Realistic Models for Sediment Transport in the York River Estuary, Virginia.

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The York River estuary is a partially mixed semi-diurnal tidal tributary of the Chesapeake Bay with salinities ranging from 0 to 26 psu and an ~0.8 m tidal range. Sediment within many estuaries, including the York River, Virginia, is dominated by mixtures of mud. Due to its cohesive nature, estimating sediment fluxes for mud is a complex problem that can be addressed using numerical models such as the Community Sediment Transport Modeling System (CSTMS), which incorporates suspended sediment transport, erosion, and deposition within the hydrodynamic Regional Ocean Modeling System (ROMS). One version of the CSTMS accounts for cohesive processes via consolidation and swelling of the sediment bed, which changes the critical shear stress of the seafloor in response to sedimentation. Additionally, the effects of sediment-induced stratification can be included within the model via adjusting the vertical momentum equation to include the combined water-suspended sediment density. We will examine the degree to which these processes, i.e. bed consolidation and sediment-induced stratification, influence fine-grained sediment transport in the York River, VA using both an idealized, and a more realistic model implementation.

Initial investigation into the relative impacts of bed consolidation and swelling, and sediment-induced stratification on spatial and temporal sediment distribution was done with an idealized two-dimensional estuary designed to mimic the primary features of the York River. This represented a longitudinal section, and accounted for a freshwater source, tides and estuarine circulation, but neglected across-channel variation. Results showed that when bed consolidation and sediment-induced stratification were neglected, the model produced unrealistic amounts of erosion and deposition. The incorporation of bed consolidation alone lowered the amount of erosion and deposition but values remained high. Sediment-induced stratification alone produced more realistic values but higher than observed in the York River. Only the combination of bed consolidation and sediment-induced stratification produced reasonable estimates of erosion and deposition along the estuary. Thus, while sediment-induced stratification had a higher impact, it is the combination of the two processes that produced the most realistic scenario.

Will this hold true in a more realistic numerical representation of the York River estuary? To determine the answer, a full three-dimensional model of the York River, which included hydrodynamics, physical forcings, and sediment transport, was used. The boundary conditions were forced with localized tidal elevation, salinity, and wind measurements. Relative to the idealized model, the impacts of sediment-induced stratification and bed consolidation may be muted due to additional driving forces incorporated in the three-dimensional model.

Rejuvenating Poldered Landscapes: A Numerical Model of Tidal River Management in Coastal Bangladesh.

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The low-lying, coastal region of Bangladesh has relied on poldering (the creation of embanked islands) since the 1960s to mitigate the effects of tidal inundation, storm surge, and, more recently, sea level rise. Poldering has increased the total arable land and the ability to sustain food production for one of the most densely populated countries in the world. However, it has had the unintended consequence of starving embanked landscapes of sediment. Previous studies show empirical and modeled evidence that these landscapes can recover in ~10 years if a direct connection with the tidal channel is restored. Tidal River Management (TRM) provides an alternative and more sustainable solution. To combat declining polder elevations and aggrading channels, some polder inhabitants have attempted TRM to allow water and sediment exchange with the tidal network. Anecdotal reports claim great success for these small-scale engineering projects in some locations, but not in others.

Here, we tested the applicability of TRM on the poldered landscapes of southwest Bangladesh using a numerical model of tidal inundation and subsequent sediment accretion. We employed a mass balance Monte Carlo simulation with parameters of tidal inundation height, suspended sediment concentration (SSC), dry bulk density (ρ), and settling velocity (ws). Tidal height was varied as a function of projected sea level rise. Furthermore, we constrained timing of inundation to simulate a controlled TRM project. Preliminary results suggest, under some circumstances, TRM is a viable solution to help combat elevation offset due to sea level rise and poldering. However, under the most extreme sea level rise scenarios, TRM may not be a feasible solution.

Quantifying Delta Complexity Toward Inference and Classification.

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Delta channel networks self-organize to a variety of stunning and complex patterns in response to different forcings (e.g., river, tides and waves), sediment composition, incoming flow variability, sea level rise, etc. Recently, we presented a rigorous framework based on spectral graph theory to study delta channel networks from a topologic (channel connectivity) and dynamic (flux exchange) perspective for advancing our understanding of deltas as complex systems [Tejedor et al., 2015a,b]. The question that we aim to answer in this work is how the complexity of delta channel networks evolves as the delta grows and how it depends on a specific physical parameter namely the incoming sediment size. To explore the dependence of complexity with sediment composition, we have used numerical modeling (Delft3D) where the different geomorphic parameters can be controlled and/or isolated. We have analyzed the channel networks of river-dominated deltas that arise from using different size distributions of the incoming sediment. The results of our analysis show how complexity metrics (topologic and dynamic) are able not only to capture the variability in the delta structure, but also quantify the increase of complexity when the sediment composition transitions to coarser grains. Furthermore, from a joint analysis of field and simulated deltas within this quantitative framework, we showed encouraging results and provided preliminary evidence toward a path for quantitative delta classification by exploring similarities and discrepancies in the underlying processes and the resulting network complexity.

From Relative Sea Level Rise to Coastal Risk: Estimating Contemporary and Future Flood Risk in Deltas.

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Deltas are highly sensitive to local human activities, land subsidence, regional water management, global sea-level rise, and climate extremes. In this talk, I'll discuss a recently developed risk framework for estimating the sensitivity of deltas to relative sea level rise, and the expected impact on flood risk. We apply this framework to an integrated set of global environmental, geophysical, and social indicators over 48 major deltas to quantify how delta flood risk due to extreme events is changing over time. Although geophysical and relative sea-level rise derived risks are distributed across all levels of economic development, wealthy countries effectively limit their present-day threat by gross domestic product-enabled infrastructure and coastal defense investments. However, when investments do not address the long-term drivers of land subsidence and relative sea-level rise, overall risk can be very sensitive to changes in protective capability. For instance, we show how in an energy-constrained future scenario, such protections will probably prove to be unsustainable, raising relative risks by four to eight times in the Mississippi and Rhine deltas and by one-and-a-half to four times in the Chao Phraya and Yangtze deltas. This suggests that the current emphasis on short-term solutions on the world's deltas will greatly constrain options for designing sustainable solutions in the long term. **PDF of presentation:** pdf *

Reconciling Geomorphic Observations with Simulations of a Modern Landslide-Dam Outburst Flood using GeoClaw Software, E

astern Himalaya.

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High-magnitude (>10^5 m^3/s) outburst floods have the potential to dramatically alter landscapes and greatly impact human lives and infrastructure. Numerical modeling can help us understand the hydraulics of these infrequent and difficult to observe floods, but their scale makes simulation challenging and computationally expensive, particularly where rugged mountain topography produces complex flow hydraulics. Here we simulate the second largest historical outburst flood on record using GeoClaw open source software for modeling geophysical flows, and ground-truth the results of these simulations using observations and geomorphic evidence of the event. This landslide-dam outburst flood was sourced in Tibet on the Yigong River in June 2000, scouring vegetation, triggering landslides and depositing flood sands in hydraulically sheltered areas downstream. We mapped these features in the field and remotely using Google Earth and Landsat-7 imagery, and simulated the flood with a reconstructed 2 km^3 impounded lake using instantaneous dam failure. Our simulations overestimate the reported peak discharge just downstream of the outburst, but produce flow depths that match reported flood stage at locations up to 450 km downstream. Key flood characteristics for hazard prediction like downstream patterns of inundation and flow depth are relatively insensitive to the chosen roughness parameter in GeoClaw. While the magnitudes of simulated velocities and momentum fluxes can vary greatly as a function of the chosen Manning coefficient, the spatial patterns of velocity and momentum flux are robust over a range of chosen values. GeoClaw simulations (1) produce peak velocities and momentum fluxes in locations that correlate with landslides that were observed directly after the event and (2) produce inundation patterns and flow depths consistent with the style of deposition observed in locations far downstream, displaying a clear link between flood hydraulics and geomorphic change due to erosion and deposition. Results suggest that GeoClaw can accurately simulate high-magnitude outburst flood events through mountainous topography, showing the potential of this modeling approach to improve both hazard predictions and our understanding of the geomorphic impact of outburst floods.

A Composite Vulnerability Index for Urban Areas in Deltaic Regions: An Application in the Amazon Delta.

***Andressa Vianna Mansur**, Indiana University Bloomington Indiana, United States. andressavmansur@gmail.com*

Deltas are complex socio-ecological systems subject to a wide range of human pressures and hazards, where population density is many-folds that of other regions. Urban development patterns, urban growth, river damming & sediment control coupled with climate change are increasing flood risks and the degree of vulnerability in many deltas of the world. The need for integrated vulnerability assessments that capture both socio-economic and geophysical elements in deltas is emergent. This study presents a composite index for the vulnerability assessment of the urban Amazon Delta (AD) based in three dimensions of vulnerability: flood exposure, socio-economic sensitivity and infrastructure. The vulnerability index was developed using the Analytical Hierarchy process (AHP), which helps to gage level of interdependence and the role of different dimensions of vulnerability. The index combines data from public databases at the most disaggregated level of analysis of census data (n = 2938 census sectors) and uses a methodology based on data from Shuttle Radar Topography Mission (SRTM) to assess and characterize sectors based on their flood risks. Results indicate that over 60% of the urban sectors within the AD present high degree of vulnerability, reaching a population of over one million inhabitants. This degree of urban vulnerability defines and reiterates the impacts of future climate changes across society and as it extends beyond the urban areas of the AD. The methodology proposed in this study contributes to a multi-dimensional assessment of urban vulnerability and it can be applied to other urban areas, allowing for cross-site comparison of vulnerabilities across urban spaces within deltaic systems. Depending on particular case study of an urban area, a more context specific sub set of model indicators can be selected to assess vulnerability. Some indicators can be adapted to individual urban systems thereby providing a useful tool to assess vulnerability in a particular case study while developing a broader model. Future work will involve additional emphasis on time dependent land cover changes and their effects on urban vulnerability based on compositional and configurational changes to the landscape.

Vertically Continuous Mass Conservation in Morphodynamic Modeling of Upper Regime.

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The vast majority of the morphodynamic models that account for the non-uniformity of the bed material are based on some form of the active layer approximation, which was first introduced in the 1970s and has been modified in different ways to meet different needs. In active layer-based models the deposit is divided in two or more layers with uniform characteristics in the vertical direction. The topmost layer is the active layer proper, which can interact with the bed material transport and whose characteristics can change in time. The other layers cannot interact with the bed material transport; they can exchange sediment with the other layers if the mean elevation of the deposit changes in time. In other words, the characteristics of these layers can only change in case of aggradation or degradation and the vertical sediment fluxes associated with e.g. bedform migration, infiltration of fine material and the dispersal of natural tracers and contaminants are not accounted for. To overcome the limitations associated with the discrete nature of the active layer approximation, Parker, Paola and Leclair introduced a continuous morphodynamic framework (PPL framework) that quantifies the vertical sediment fluxes within the deposit in terms of probability density functions of bed elevation, entrainment and deposition. The PPL framework was first implemented to model the grain size stratigraphy associated with dune migration at laboratory scale. However, due to the lack of information on the shape and the characteristics of the probability functions, the vertical sediment fluxes due to dune migration, changes in bedform size and aggradation/degradation were computed with sub-models. The use of sub-models has a serious drawback: the computational costs quickly become too expensive as the spatial scales increase. We recently demonstrated that if the probability density functions of entrainment and deposition are known, the computational costs for field scale applications of the PPL framework are comparable with those of active layer based models. Here we present an attempt to implement the PPL framework to describe the morphodynamics of the upper plane bed regime at laboratory scale. Our probability density functions are determined from time series of bed elevation measured in laboratory experiments performed at the University of South Carolina. The probability functions are implemented in a numerical model that is applied to compare the dispersal of tracer stones in the case of bed configurations changing from upper plane bed to sheet flow. Future work is needed to relate the probability functions to the flow and sediment characteristics and to extend the results to the case of non-uniform bed material.

Bedload Sediment Modeling at a Global Scale Based on the WBMsed Model.

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Sagy Cohen, University of Alabama Tuscaloosa Alabama, United States.

River sediment dynamics is a key driver in fluvial and terrestrial research. Sediment indicators are often used in determining river change regime and sequentially river evolution. Since only a small fraction of global rivers are monitored for their sediment dynamics, our understanding of the processes and drivers affecting large global rivers is still lacking. Numerical modeling can remedy some of these observational deficiencies but remain a challenge, particularly at large, global scales. Bedload transport accounts for less than 10% of the fluvial sediment transferred from continental uplands to continental margins on a continental scale, however it is an important component of fluvial sediment budget for its important role in many fluvial processes and its key influence on river morphodynamics.
Here we present a first-order global scale riverine bedload flux model. We are developing a bedload module within the WBMsed modeling framework based on existed bedload formulas. One of the key challenges in accurately solving bedload formulae at course spatial scales is accurate description of riverbed slope. We also present a novel global riverine slope layer which we will use as input to the WBMsed model. Future work will include an extensive validation procedure based on observed data and global scale analysis of bedload flux dynamics.

A Dynamical-Statistical Approach to Forecasting Regional Glacier Response to Projected Warming: an Example from the Cordillera Real, Bolivia.

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Alpine glaciers in many mountain ranges around the globe have been retreating in recent decades partially as a consequence of increasing temperatures. Small glaciers are particularly sensitive to climate changes and will likely disappear sooner than larger glaciers and levy more immediate impacts. In regions where the mass balance of glaciers is correlated with air temperature, estimating changes is more feasible because temperature projections are more confidently and robustly projected by global climate models (GCMs) than other variables. One major challenge facing the prediction of responses of small alpine glaciers to climate change is that their responses are highly variable, due in part to local aspect and microclimate effects, and in part because of their subdecadal response times to years with anomalous precipitation or temperature. For example, in the Cordillera Real, Bolivia, satellite imagery analyzed over 1985-2005 shows a systematic increase in ice loss with glacier size, but the scatter around this trend is marked, and makes prediction of glacier response based on climate model projections highly uncertain.

Here, we test a modeling approach to evaluate the collective response of these glaciers to a particular temperature timeseries by treating the glaciers of a given massif as an ensemble, and quantifying the variability around the temperature response due to local effects (e.g., aspect, precipitation variability), initial state of transience, and internal dynamics. Our approach couples a surface energy-mass balance model and dynamical flow model to simulate a group of glaciers on a real or synthetic topography, allowing glaciers to have different sizes and response times as simulated by the dynamical model. We compare a control run (glaciers in steady state at start of run) to a run with a starting condition forced with a randomly perturbed climate, so that the state of each glacier at the beginning of the study period is variable and dependent on its local climatic factors and internal dynamics. We then impose a temperature change drawn from reanalysis data during the 1985-2005 period covered by the satellite imagery, and evaluate the scatter of individual glacier response around that trend. We compare this variability to that evaluated from the satellite imagery to quantify the contributions due to internal dynamics and/or the transient state of glaciers prior to the study period. We then evaluate the magnitude of local climatic effects needed to explain any remaining variability.

This approach is in the early experimental stages, and we look forward to discussions and feedback from the CSDMS community.

The Influence of Elevation on the Isotopic Composition of Orographically Enhanced Precipitation.

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Windward isotope proxies of precipitation preserved in the geologic record are commonly used to determine the uplift history of a mountain range. In a 2D model of orographic precipitation, the incoming air is lifted and cooled, and the heavier isotopes are preferentially condensed and rained out along the windward path. Windward isotope-based paleoaltimetry assumes that changes in elevation do not significantly alter the distribution of the precipitation and the isotopic composition of that precipitation. Studies have shown that increased elevation acts to shift orographic precipitation upstream of the mountain range and that the isotopic composition of that precipitation diverges from Rayleigh condensation models. Pure orographic precipitation is rare though; more common is orographically enhanced precipitation. Using the Weather Research and Forecasting (WRF) model V3.5.1 we test how changes in elevation and topographic configuration can affect the distribution of orographically enhanced precipitation and isotopic composition on the windward face of mountain ranges. We use the Baroclinic Wave model in WRF, an idealized model that establishes a storm system that dominates weather in the mid-latitudes. The model includes two modifications: the addition of topography to the model setup and an isotope physics calculation included into the full microphysics scheme. The isotope physics are incorporated in the pre-existing Kessler microphysics scheme within WRF, which is altered to include a Perfect Precipitation model (PPM). Precipitation is generated in the PPM when a gridpoint reaches saturation, the water vapor is condensed and falls out as precipitation. Isotope tracers for the initial water vapor mixing ratio and Œ¥18O are added to the PPM and advected and modified within the full microphysics scheme. The isotopic fractionation takes place upon condensation according to temperature-dependent equilibrium factors.

Evolution of River Valleys and Terraces: a Geometric Approach.

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River terraces are prominent flat surfaces formed at old persistent river bed elevations. They correlate with changes related to past sediment supply and base-level and therefore climate and tectonics. The goal here is to create a reduced-complexity model that obeys the physics of geomorphic processes while generating terrace surfaces for direct comparison and interpretation of river systems in the field. A simple set of rules that includes aggradation, incision, lateral migration, and angle of repose, can, when applied in sequence, reproduce many of the most salient observables of the fluvial landscape.

Investigating Bed Erosion from Pyroclastic Density Currents.

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Pyroclastic density currents (PDCs) are ground-hugging mixtures of hot gas and rock that can reach temperatures > 800 and speeds of 200 m/s. These flows are capable of eroding and entraining the underlying bed material into the flow, which can strongly influence flow momentum, runout distance, and hazards associated with PDCs. However, the mechanism of erosion remains poorly constrained, with proposed mechanisms including under-pressure following the head of the fluidized current, force chain enhanced stresses at the bed, and discrete particle impacts and friction. The interactions between PDCs and the bed have been difficult to observe in the field, as their infrequent occurrence, opacity, and hostile environment make real-time measurement difficult. This study is aimed at obtaining a better understanding of the interactions between PDCs and the bed through lab experiments. Our experimental apparatus consists of a rotating cylindrical flume of radius 22 cm, within which gas-rich granular material flows along the interior of the cylinder as it rotates. The grain size and speed of the drum in this gas-particle mixture can be varied to examine variable degrees of fluidization of the mixture. By using a rotating cylinder, we are able to simulate long-duration flows, allowing us to observe impact and sliding forces at the bed as well as bed erosion rates over timescales comparable to the flow duration of natural PDCs. To measure the distribution and evolution of forces imparted by the flow on the bed, we constructed a cylindrical insert with a non-erodible bed in which we embedded force sensor arrays parallel and perpendicular to the direction of flow. To measure the erosion of the bed by the flow, we constructed a second cylindrical insert with a concrete erodible bed that can be removed from the flume and weighed before and after experiments. To measure the forces felt by the particles in the flow, we added ,"smart particles," 25 to 50 mm in diameter to the flow. Each smart particle contains a three-axis accelerometer and a micro SD card enclosed in a spherical plastic casing, and possesses a density similar to that of the pumice in the experimental flow. Each smart particle also contains a three-axis magnetometer which permits its location to be tracked by means of a unique applied magnetic field. Ultimately, data from these experiments will provide a robust basis for the sensitivity of bed erosion from bed and flow parameters such as bed roughness, particle size, degree of fluidization, and the distribution of forces imparted by the flow on the bed.

Effect of Waves on Shear Stress over the Offshore Shoal in the Southern Yellow Sea.

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To obtain the accurate estimation of critical shear stress (τcr) based on in situ observations and evaluate effect of waves over the tide-dominated offshore shoal, water depth, near-bed current velocity (0.3m above the seabed), suspended sediment concentrations (SSCs), wave parameters and bottom sediment compositions were measured in the southern Yellow Sea. Based on these data, we calculated bottom shear stresses generated by current (τc), wave (τw), and wave-current interaction (τcw). Values of τcw were calculated according to the Grant-Madsen model and the Soulsby model, both giving a quite close tendency. It showed that during the observation period, sediment movements were influenced by current, wave or wave-current action for different tidal cycle. However, due to the mild weather condition and sheltering of the huge sand ridge, waves can only influence sediments when winds were strong or during slack shallow water when there was easily wave penetration onto seabed at the lowest water depth. SSCs in present research were larger than particular values for most of the time, suggesting the existence of background SSCs no matter whether tidal currents were strong or not. Through SSC time series, the background SSCs at stations d1, s1, d2 and s2 were estimated as 0.17, 0.20, 0.13 and 0.05 kg/m3, respectively. Combing the Rouse profile, background SSCs were also estimated. Giving reasonable estimations of τcr and settling velocity (ws), the results turned out that background SSCs obtained from the Rouse profile were the same as the method of SSC time series. Meanwhile, the harmonic analysis method was then used in order to solve semi- (representing advection) and fourth-diurnal (representing local resuspension) constituents of SSC time series. By comparing the amplitude of semi-diurnal and fourth-diurnal constituents, results showed that except for station s2, SSCs were mainly controlled by local resuspension. At station s2, the SSC was dominated by advection, may due to the specific geomorphology. Obvious resuspensions were observed in the flood stage or ebb stage or both. Therefore, combining synchronous variations between SSCs and τcw, the temporal-changed critical shear stress (τcr) at each station was identified and the average τcr were estimated as 0.13, 0 .08, 0.08, 0.07 N/m2 for stations d1, s1, d2, s2. According to the classical method based on bottom grain size, the critical shear stress (τ*) was 0.18, 0.15, 0.14, 0.15 N/m2 for stations d1, s1, d2, s2. Since the classical method only produced one constant value, it suggested the necessity of in situ estimation of τcr. This study also emphasized the importance of combining wave and current into sediment dynamics of coastal environment.

Large-Eddy Simulation of Wave-breaking Induced Turbulent Coherent Structures and Suspended Sediment Transport on a Barred Beach.

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To better understand the interaction between wave-breaking induced turbulent coherent structures and suspended sediment transport, we report a 3-D Large-Eddy Simulation (LES) study of wave-breaking over a near-prototype scale barred beach. The numerical model is implemented using the open-source CFD toolbox, OpenFOAM®. The numerical model is validated with measured free surface elevation, turbulence averaged flow velocity, turbulent kinetic energy, and for the first time, the intermittency of breaking wave turbulence on the bar crest. Simulation results confirm that as the obliquely descending eddies (ODEs) approach the bed, significant bottom shear stress is generated. Remarkably, the collapse of ODEs onto the bed also causes drastic spatial and temporal changes of dynamic pressure which may encourage momentary bed failure and a reduction of bed shear strength via upward-directed pore pressure gradient. By allowing sediment to be suspended from the bar crest, intermittent high sediment suspension events and their correlation with high turbulence and/or high bottom shear stress events are investigated. The simulated intermittency of sediment suspension is similar to previous field and large wave flume observations. Model results suggest that high sediment suspension events near the bottom (2% of the local water depth) is mainly controlled by bottom shear stress, while moving further away from the bottom (23% of the local water depth), sediment suspension becomes more affected by breaking wave turbulence.

CSDMS Annual Meeting - James Syvitski Updates to Community

Appendix 3: 2016 CSDMS Annual Meeting Clinic Abstracts

Using TopoFlow in the Classroom
Irina Overeem & Mark Piper
CSDMS Integration Facility, INSTAAR, University of Colorado Boulder

TopoFlow is a spatially distributed hydrologic model that includes meteorology, snow melt, evapotranspiration, infiltration and flow routing components. It can model many different physical processes in a watershed with the goal of accurately predicting how various hydrologic variables will evolve in time in response to climatic forcings. In the past year, CSDMS IF staff integrated TopoFlow into the CSDMS Web Modeling Tool (WMT, https://csdms.colorado.edu/wmt) and developed new lesson plans for use with it.

The first part of this clinic focuses on the technical aspects of working with TopoFlow in WMT, including how to: load and couple components, get information on a component, set parameters, upload data files, save a model, and run a model. We'll discuss features of the TopoFlow implementation in WMT, and explain choices that were made in bringing TopoFlow to the web.

Dr. Irina Overeem presenting clinic.

In the second part of the clinic, we'll focus on science and education. We will run several TopoFlow simulations on the CSDMS HPCC through WMT. Participants will explore parameter settings, submit runs, and view netCDF output using NASA's Panoply tool.

The learning outcomes of this clinic are to have better insight into the behavior of TopoFlow components, and the implementation of these in WMT. Participants will learn how to do TopoFlow model runs, and will have access to TopoFlow online labs and teaching resources lesson plans.

PDF of clinic: pdf *

Coastal Ecosystem Integrated Compartment Model (ICM): Modeling Framework
Ehab Meselhe & Eric White
The Water Institute of the Gulf

The Integrated Compartment Model (ICM) was developed as part of the 2017 Coastal Master Plan modeling effort. It is a comprehensive and numerical hydrodynamic model coupled to various geophysical process models. Simplifying assumptions related to some of the flow dynamics are applied to increase the computational efficiency of the model. The model can be used to provide insights about coastal ecosystems and evaluate restoration strategies. It builds on existing tools where possible and incorporates newly developed tools where necessary. It can perform decadal simulations (~ 50 years) across the entire Louisiana coast. It includes several improvements over the approach used to support the 2012 Master Plan, such as: additional processes in the hydrology, vegetation, wetland and barrier island morphology subroutines, increased spatial resolution, and integration of previously disparate models into a single modeling framework. The ICM includes habitat suitability indices (HSIs) to predict broad spatial patterns of habitat change, and it provides an additional integration to a dynamic fish and shellfish community model that quantitatively predicts potential changes in important fishery resources. It can be used to estimate the individual and cumulative effects of restoration and protection projects on the landscape, including a general estimate of water levels associated with flooding. The ICM is also used to examine possible impacts of climate change and future environmental scenarios (e.g. precipitation, Eustatic sea level rise, subsidence, tropical storms, etc.) on the landscape and on the effectiveness of restoration projects. The ICM code is publically accessible, and coastal restoration and protection groups interested in planning-level modeling are encouraged to explore its utility as a computationally efficient tool to examine ecosystem response to future physical or ecological changes, including the implementation of restoration and protection strategies.

MODFLOW: Example Applications and What We can Learn from this Amazingly Successful Piece of Environmental Modeling Software.

Mary Hill; *University of Kansas*

Geoscience Paper of the Future: Training Session on Best Practices for Publishing Your Research Products

Scott Peckham & Allen Pope
Univ of CO & USC, ISI

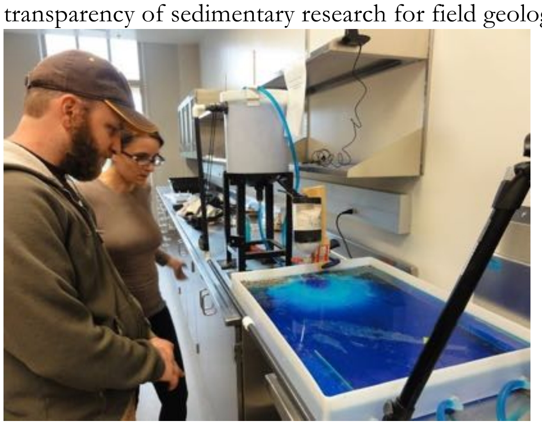
The Geoscience Paper of the Future (GPF) Initiative was created to encourage geoscientists to publish papers together with their associated digital research products following best practices of reproducible articles, open science, and digital scholarship. A GPF includes: 1) Data available in a public repository, including metadata, a license specifying conditions of use, and a citation using a unique and persistent identifier; 2) Software available in a public repository, with documentation, a license for reuse, and a unique and citable using a persistent identifier; 3) Provenance of the results by explicitly describing method steps and their outcome in a workflow sketch, a formal workflow, or a provenance record. Learn to write a GPF and submit to a special section of AGU's Earth and Space Sciences Journal. More at http://www.ontosoft.org/gpf/.

SEN: Take only Measurements. Leave only Data

Wonsuck Kim, Brandon McElroy, Kimberly Miller, Raleigh Martin & Leslie Hsu
The Univ. of TX, Univ. of WY, Univ. of WY, Univ. of CA, USGS

Wonsuck Kim, University of Texas, Austin
Brandon McElroy, University of Wyoming, Laramie
Kimberly Miller, University of Wyoming, Laramie
Raleigh Martin, University of California, Los Angeles
Leslie Hsu, USGS

The Sediment Experimentalist Network (SEN) integrates the efforts of sediment experimentalists to build a Knowledge Base for guidance on best practices for data collection and management. The network facilitates cross-institutional collaborative experiments and communicates with the research community about data and metadata guidelines for sediment-based experiments. This effort aims to improve the efficiency and transparency of sedimentary research for field geologists and modelers as well as experimentalists.



SEN mobile flume used during clinic.

The first part of this clinic will include a hand-on experiment using a desktop flume. We will create a physical model of a delta in a small flume on-site during the meeting. Fitting with the annual meeting theme, we will explore how delta morphology and stratigraphy capture climate change. The major goals will be to discuss the lifecycle of data and data management for experiments and to generate an example dataset for numerical model testing. Discussion will include practical aspects such as metadata requirements and naming variables.

In the second part, participants will learn how to engage in the SEN Knowledge Base and create an entry either using the collected data from the clinic experiment or participants' own research data. We will focus our data usage and entry activities around the science theme of our experiments and associated model efforts: How do

delta morphology and stratigraphy respond to external perturbations generated by climate change? We will explore www.sedexp.net to discover data from the experimentalist community, workflows, laboratory facilities and their capabilities for potential collaborations. This second part will also include discussion about a best practice for data preservation and reuse through the current infrastructure (e.g., SEN, SEAD, institutional data repositories). After getting to know the Knowledge Base and other cyberinfrastructure, we will discuss the possibility of experimentalist-modeler collaborations to address our science theme and achieve solutions to grand challenge goals.
The following google drive contains material of the clinic:
http://tinyurl.com/CSDMS-SEN

Enrollees will be contacted a couple weeks prior to the CSDMS meeting to engage in some brief pre-workshop activities to prepare for the clinic. There will be a short survey at the end about how to enhance collaborations between modeler and experimentalist communities.

More about SEN:
http://earthcube.org/group/sen
http://sedimentexperiments.blogspot.com
http://dx.doi.org/10.1016/j.geomorph.2015.03.039

BMI: Live!
Eric Hutton & Mark Piper
CSDMS Integration Facility, INSTAAR, University of Colorado Boulder

CSDMS has developed the Basic Model Interface (BMI) to simplify the conversion of an existing model in C, C++, Fortran, Java, or Python into a reusable, plug-and-play component. By design, the BMI functions are straightforward to implement. However, in practice, the devil is in the details.

In this hands-on clinic, we will take a model -- in this case, an implementation of the two-dimensional heat equation in Python -- and together, we will write the BMI functions to transform it into a component. As we develop, we'll unit test our component with nose, and we'll explore how to use the component with a Jupyter Notebook. Optionally, we can set up a GitHub repository to store and to track changes to the code we write.

To get the most out of this clinic, come prepared to code! We have a lot to write in the time allotted. We recommend that clinic attendees have a laptop with the Anaconda Python distribution installed. We also request that you skim:

↠ BMI description (http://csdms.colorado.edu/wiki/BMI_Description)

↠ BMI documentation (http://bmi-forum.readthedocs.io/en/latest)

↠ BMI GitHub repo(https://github.com/csdms/bmi-live)

before participating in the clinic.

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Regional Ocean Modeling System (ROMS): An Introductory Web-based Model Implementation
Courtney Harris, Julia Moriarty & Irina Overeem and Eric Hutton
VIMS & Univ. of Colorado

Participants in this clinic will learn how to run a Regional Ocean Modeling System (ROMS) test case for an idealized continental shelf model domain within the CSDMS Web Modeling Toolkit (WMT). The model implementation that we will use includes wave forcing, a riverine source, suspended sediment transport.

ROMS is an open source, three-dimensional primitive equation hydrodynamic ocean model that uses a structured curvilinear horizontal grid and a stretched terrain following vertical grid. For more information see https://www.myroms.org. It currently has more than 4,000 registered users, and the full model includes modules for sediment transport and biogeochemistry, and several options for turbulence closures and numerical schemes. In part because ROMS was designed to provide flexibility for the choice of model parameterizations and processes, and to run in parallel, implementing the code can seem daunting, but in this clinic, we will present an idealized ROMS model that can be run on the CSDMS cluster via the WMT. One goal is to provide a relatively easy introduction to the numerical modeling process that can be used within upper level undergraduate and graduate classes to explore sediment transport on continental shelves.

As a group, we will run an idealized ROMS model on the CSDMS computer, Beach. The group will choose a modification to the standard model. While the modified model runs, we will explore methods for visualizing model output. Participants who have access to WMT can run the model themselves. Clinic participants who have access to Matlab and/or Panoply will be able to browse model output files during the clinic.

Following the clinic, participants should have access to an example ROMS model run, experience running ROMS within the WMT and with ROMS input and output files, and. ROMS lesson plans.

PDF of presentation: pdf *

Modeling Coastal Processes using OpenFOAM®

Zheyu Zhou, Xiaofeng Liu & Tom Hsu
Univ. Delaware, Penn State, Univ. Delaware,

OpenFOAM® is an open-source computational fluid dynamic platform, built upon a finite-volume framework with Messaging Passing Interface (MPI). In the past decade, OpenFOAM® has become increasingly popular among researchers who are interested in fluvial and coastal processes. In this clinic, recent progress in developing OpenFOAM® for several coastal applications will be discussed. In particular, we will focus on three subjects: (1) wave-induced seabed dynamics (pore-pressure response), (2) stratified flow application, particularly laboratory scale river plume modeling, and (3) 3D large-eddy simulation of wave-breaking and suspended sediment transport processes.

Xiaofeng Liu, Penn State University

In particular, hand-on exercise will be given for 3D large-eddy simulation of wave-breaking processes to illustrate several important insights on how to use OpenFOAM® to carry out high quality large-eddy simulations. Some cautionary notes and limitations will also be discussed.

PPT of presentation:
Part1 ppt *
Part2 ppt *

PDF of presentation:
part1 pdf *
part2 pdf *

Modeling Earth-Surface Dynamics with LandLab

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Landlab is a Python-language programming library that supports efficient creation of two-dimensional (2D) models of diverse earth-surface systems. For those new to Landlab, this clinic will provide a hands-on introduction to Landlab's features and capabilities, including how to create a grid, populate it with data, and run basic numerical algorithms. For experienced Landlab users, we will review some of the new features in this first full-release version, explore how to created integrated models by combining pre-built process components, and learn the basics of writing new components. Participants are encouraged to install Landlab on their computers prior to the clinic. Installation instructions can be found at: http://landlab.github.io (select "Install" from the menu bar at the top of the page). Clinic participants who have particular questions or applications in mind are encouraged to email the conveners ahead of the CSDMS meeting so that we can plan topics and exercises accordingly.

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Interactive Data Analysis with Python (PANDAS)

Monte Lunacek
National Renewable Energy Laboratory

There are many recent additions to Python that make it an excellent programming language for data analysis. This tutorial has two goals. First, we introduce several of the recent Python modules for data analysis. We provide hands-on exercises for manipulating and analyzing data using pandas and scikit-learn. Second, we execute examples using the Jupyter notebook, a web-based interactive development environment that facilitates documentation, sharing, and remote execution. Together these tools create a powerful, new way to approach scientific workflows for data analysis.

GeoClaw Software for Depth Average Flow

Randy LeVeque
University of Washington, Seattle

GeoClaw (http://www.geoclaw.org) is an open-source software package for solving two-dimensional depth-averaged equations over general topography using high-resolution finite volume methods and adaptive mesh refinement. Wetting-and-drying algorithms allow modeling inundation or overland flows. The primary applications where GeoClaw has been used are tsunami modeling and storm surge, although it has also been applied to dam break floods and it forms the basis for the debris flow and landslide code D-Claw under development at the USGS Cascades Volcano Observatory.

This tutorial will give an introduction to setting up a tsunami modeling problem in GeoClaw including:

- Overview of capabilities,
- Installing the software,
- Using Python tools provided in GeoClaw to acquire and work with topography datasets and earthquake source models,
- Setting run-time parameters, including specifying adaptive refinement regions,
- Options to output snapshots of the solution or maximum flow depths, arrival times, etc.
- The VisClaw plotting software to visualize results using Python tools or display on Google Earth.

GeoClaw is distributed as part of Clawpack (http://www.clawpack.org), and available via the CSDMS model repository. Those who wish to install the software in advance on laptops, please see http://www.clawpack.org/installing.html. Link to the GeoClaw Tutorial.

Appendix 4: 2016 CSDMS Annual Meeting Awards

Professor Mary Hill

The 2016 CSDMS Lifetime Achievement Award in Earth Surface Dynamics Modeling was presented to **Professor Mary Hill (University of Kansas)** in Boulder, Colorado, as part of the 2016 CSDMS Annual Meeting. Presenters included Dr. Martyn Clark (NCAR), Professor Bill Gray (USC Emeritus), Dr. Laura Foglia (UC Davis), and Professor James Syvitski.

Citation: "For the development and application of numerical approaches for the study of environmental systems, and for developing systems to better inform resource management decision. Professor Hill has investigated the worth of data, advanced methods for exploring complex model dynamics, and to quantify model simulation uncertainty. Mary received her MSE-Civil Engineering in 1978 and her PhD in 1985, both from Princeton University. She has many outstanding journal and USGS publications and is the recipient of the ASCE Walter L Huber Engineering Research Prize, National Groundwater Distinguished Darcy Lecturer, NGWA M King Hubbert Award, the International Hydrology Prize and various USGS awards. Professor Hill is also a Fellow of the GSA." - Professor James Syvitski, CSDMS Executive Director

The CSDMS Program Director's Award was given to Professor Joseph Kravitz

Professor Joseph Kravitz

Citation: "For success in funding and coordinating the three pillars of quantitative MG&G science: 1) process studies, 2) the preserved record, & 3) numerical modeling. Educated at Syracuse University and George Washington University, Joe has offered drive and determination. He managed numerous programs, with stern and caring leadership, at both the Office of Naval Research and the National Oceanic and Atmospheric Administration, including the now famous STRATAFORM, CSDMS's precursor. Joe nurtured investigators to employ their best creative talents, to become more quantitative, while addressing the nation's security needs." - Professor James Syvitski, CSDMS Executive Director

The 2016 CSDMS Student Modeler Award

Adam Damsgaard

Anders Damsgaard received the 2016 Student Modeler Award for his submission, "Grain-scale Numerical Modeling of Granular Mechanics and Fluid Dynamics and Applications in a Glacial Context," which models glacier flow over a soft-sediment beds from the single grain scale. Bed deformation plays a major role in this process and the novel model was applied to provide insights on the precise interaction of sediment grains and fluids under pressure at the glacier bed. A discrete element method was used to simulate the granular phase on a per-grain basis and the model treats pore water as a compressible Newtonian fluid. The model is in Python and is open source code. Findings from a set of model simulations show that the extremely low viscosity of water means that deformational of dense granular material, like subglacial till, is governed by inter-grain mechanics. The porosity of the sediment packing evolves towards a critical-state value with increasing shear strain. Changes in porosity cause deviations from the hydrostatic pressure if the rate of porosity change exceeds the rate of pressure diffusion, which is impacted by both the local porosity and permeability. The built-up to a critical state, and subsequent temporal changes in sediment strength may explain observed variability in glacier movement.

His research was done as part of his PhD thesis at Aarhus University, Denmark. He is now a postdoctoral fellow at Scripps Oceanographic Institute. Damsgaard was also involved in a recent paper in Computers and Geosciences on advancing glacier models by using graphics cards.

The Best Poster Award for the CSDMS Annual Meeting 2016

Sai Siddartha Nudurupati

Was given to Sai Siddartha Nudurupati for his submission, "Mechanisms of Shrub Encroachment explored in Southwester United States using Landlab Ecohydrology." Professor Patricia Wiberg, CSDMS Steering Committee Chair, presented Nudurupati with a 4GB portable hard-drive at the CSDMS Annual Meeting.

Appendix 5: CSDMS 3.0 Breakout Discussions CSDMS Annual Meeting 2016 Notes

Planning for CSDMS 3.0

During the 2016 CSDMS meeting, which was held jointly with the Sediment Experimentalist Network (SEN), a series of breakout-group discussions were held with the purpose of generating ideas and community feedback on the near-future shape of CSDMS. Participants divided into ten breakout groups, each with a volunteer facilitator and scribe. Notes from these breakout sessions are included below in this Appendix. The following is a distillation of some of the common themes and ideas to emerge from the discussions.

Science Themes

The discussions touched on my different science themes, but among them two stand out in particular:

1. Prediction, forecasting, and application to societal needs.
2. Human activity, decision-making, and feedbacks with earth-surface dynamics.

Each of these themes arose independently in more than half of the breakout sessions.

Prediction, Forecasting, and Applications

This first theme reflects a desire on the part of the community to take advantage of the technical and scientific advances that CSDMS has promoted by bringing the power of coupled modeling to bear on "wicked problems" that involve the coupling of multiple systems, challenges to sustainability, and the need for decision-making under uncertainty. Some groups noted that for some of these issues, the state of the science is far ahead of the state of practice. For example, one group noted that watershed models that are currently used for estimating critical environmental parameters such as water quality are out of date, yet routinely relied on for management actions. Others noted that CSDMS' Chesapeake Bay Focus Research Group is an example of an area where CSDMS members and technology are already actively contributing to an important coupled problem, but that there are a number of other such opportunities. These include issues such as coastal inundation, tsunami impacts, wildfires, storms, and floods: all examples of planning for and adapting to various natural hazards.

One motivation for this theme is the recognition that our communities are rapidly moving from a data-poor environment to a data-rich one. For example, when CSDMS first began in 2007, high-resolution LiDAR topography data sets were comparatively rare. Today, the volume of LiDAR data continues to grow rapidly, and multi-temporal data are beginning to become a reality. Several papers presented at the Annual Meeting presented striking examples of the kinds of detailed, high-resolution morphodynamic data that are now becoming available, such as drone-based coastal morphology imagery, and a high-resolution, multi-temporal, Pan-Arctic digital elevation model derived from WorldView satellite imagery. Such data sets will challenge the surface-dynamics modeling community to move beyond qualitative model-data comparisons, to identify flaws in the current generation of models, and to use these new data sources to improve both our understanding and our models. To accomplish these aims, the community will need supporting techniques and technologies, ranging from standardized tools for data input to software for model calibration, validation, and uncertainty analysis.

Human Dimensions of Environmental Change and Management

The discussion groups also highlighted the opportunity for modeling the role of humans in environmental change. Examples noted included the dynamics of cholera spread, droughts, the impacts of urbanization, and "Anthropocene issues" more generally. Some of these research questions bear on understanding and forecasting the impacts of human activities on earth-surface dynamics. For instance, how does reduction in river sediment yield due to retention behind dams impact the morphodynamic evolution of deltas? Others involve two-way feedbacks between environmental dynamics and human decisions. The latter was the focus of the three-day workshop on Human Dimensions during the week following the CSDMS annual meeting (outcomes of that workshop will be reported elsewhere).

Other Science Themes

Other science themes that were noted during the breakout sessions included:

- Climate change and links with atmospheric processes (the theme of the annual meeting)
- Natural hazards (including planning and adaptation)
- Food-Water-Energy nexus
- Critical-zone science and continuing to improve links with the Critical Zone Observatories through the CZO Focus Research Group
- Feedbacks between vegetation and surface dynamics
- Polar processes
- River sedimentation
- Drought
- "Paleo events" (such as climate excursions, periods of rapid sea-level change, etc.)

Among these, we note that although CSDMS does not presently have a polar/cryosphere focus group, there has been considerable polar-oriented activity among members and in the wider community. Moreover, the recent *Memorandom for the Heads of Executive Departments and Agencies, Office of Science and Technology Policy (M-15-16)*, recommended science themes.

Similarly, the Food-Water-Energy nexus is a high priority within the National Science Foundation. It is an area where computational modeling will be a critical component, and to which CSDMS has the potential to make important contributions.

Methods and Approaches

The breakout-group discussions identified several methods and approaches that would be worth considering as themes in CSDMS 3.0. One prominent topic was uncertainty quantification, which has already been the subject of Integration Facility effort in CSDMS 2.0: the CSDMS software stack now incorporates the Department of Energy's DAKOTA software package, which provides a comprehensive platform for model analysis, parameter optimization, sampling, and uncertainty quantification. We anticipate that as the community moves increasingly toward more sophisticated comparisons of models and data sets, the need for support for uncertainty analysis and related capabilities will grow rapidly.

Other methodological themes identified include:

- Model intercomparison
- Benchmarking
- Quantitative comparison of models with experimental data sets
- Model inversion
- High-resolution remote sensing data
- Lidar data
- Data obtained from Unmanned Aerial Systems

This list of methodological themes suggests a broader vision within the community, which speaks to the current rapid expansion in the quantity, quality, and resolution of environmental data sets. As noted above, the "data explosion" brings the potential for a much deeper and more rigorous practice of testing models against data, and improving them accordingly.

Technology and the CSDMS Integration Facility

Data integration, visualization, and workflows

The breakout groups generated a number of ideas related to cyberinfrastructure. The most common theme was the need for better integration between models and data. Issues include a need for more efficient pre- and/or post-processing, data assimilation, and resources for finding the right kinds of data. Phrases like "integration" and "coupling with data" again suggest a desire on the part of the community to increase the rigor of our evaluations of model performance. Other data-related themes include translation between formats, visualization, and sharing of input data sets from published model-based studies or for benchmarking.

Several discussion groups noted that Google Earth software (and the related Google Earth Engine, as well as the "pro" version) are powerful and transformative products for visualizing earth's surface. An ability to visualize model output in the same format would be advantageous, though it was also noted that investing public funds in visualizing output using a proprietary commercial product might not be an ideal solution.

Some noted the importance of workflows, and the documentation of steps used in performing (for example) an analysis using a particular model in conjunction with a particular set of data. CSDMS could potentially play a role in archiving/sharing such workflows.

Community interaction with the CSDMS Integration Facility

One common theme was a desire for direct interaction with CIF staff, to help provide technical expertise. By working directly with CIF personnel, researchers can make faster progress and potentially engineer more efficient solutions to problems that arise in coupled modeling. In fact, CIF staff already frequently host informal visits from community members. The process could be advertised more broadly, and made somewhat more formally, so that more members of the community are aware of the opportunity and understand how to take advantage of it.

Other CIF-Related Ideas

Among the other ideas raised were:

- Lowering the bar to using the Web Modeling Tool
- Providing a workshop(s) on model wrapping (BMI) and coupling (actually such clinics have been offered in the past, though generally in the ~2-hour format of annual meeting clinics rather than in a longer, deeper way)
- CIF curation of "name brand" models (which the community would have to identify, and the developers agree)
- Addition of smaller, single-process components to the Coupling Framework
- Funding of a CSDMS Postdoc to conduct demonstration projects

Education and Knowledge Transfer

"Hackathon" Workshops

Six of the ten breakout groups independently raised the idea of "hackathon"-type workshops. Though the concept was expressed somewhat differently among the groups, the common vision is of informal workshops that are significantly longer than the clinics that have been run at the annual meeting (which are typically only two or three hours long), and that have a working focus. Such workshops could, for example, bring a group of researchers together with CIF staff or other CSDMS working group members, with the purpose of wrapping a particular model or constructing a particular type of coupled model from component parts. We read this as indicating that (a) the community is hungry to learn and to perform the computational work needed for cutting-edge modeling, and (b) feel that the most efficient pathway would be to work with CIF engineers to accomplish their goals. As noted above, CSDMS already occasionally hosts researcher visits on an informal and ad hoc basis; this process could be formalized so as to be more broadly accessible.

Software Carpentry for Geoscientists

The pre-conference workshop hosted by Software Carpentry appears to have been both successful and popular. More than half the discussion groups expressed a desire for more of these workshops, ideally with a geoscience-related flavor (as opposed to a "generic" version).

A similar theme was the idea of a CSDMS-hosted summer school, perhaps similar to the highly successful Summer Institute series that were hosted by the National Center for Earth-Surface Dynamics (NCED). Here the emphasis would be focused on imparting core computational modeling skills to graduate students and postdocs.

Online Resources

Several of the groups pointed out the value of online resources for training in diverse CSDMS-oriented topics. Such resources could, for example, be provided as a by-product of workshops and hackathons, or designed from the ground up as online materials. The CIF has already built up a considerably body of online resources in the EKT repository; clearly, there is demand in the community for more of this, and in particular more material that focuses on imparting technical know-how at the graduate to professional levels.

Building Community

Meetings

The discussion groups expressed widespread appreciation for the current format of the annual meetings. The mix of keynote talks, student talks, posters, and clinics appears to be successful. The most common theme to emerge regarding future meetings was a desire to add smaller, more focused workshop-style meetings, as discussed above.

Working Groups and Focus Research Groups

At least two of the discussion groups expressed the view that the working and focus groups have the potential to do even more than they currently do on behalf of the community. Each of the original Working Groups now has over 200 members, far more than was expected when CSDMS first began. The Focus Research Groups range in size from 53 members (Ecosystem Dynamics) to 529 members (Hydrology). These groups embody considerable talent within each represented community. One suggestion from the breakout groups was to form a leadership team within each group, so as to take some of the burden off the chair/co-chairs. Members of the leadership team could then take responsibility for leading various Group initiatives and projects. Another suggestion was to have cross-cutting, problem-focused groups.

Communications

The issue of communication arose in several different contexts. The CSDMS web portal is an effective vehicle for communication, but discussants also noted other communication-oriented activities that could enhance CSDMS' impact. Among these ideas were:

- Online guidelines about how to work with the CSDMS Integration Facility on projects and/or proposals
- More information about CSDMS tools and technology
- Email listservs and/or discussion forums for questions and answers on technical issues

- Blogs
- Working/Focus Group newsletters (some groups are already doing this)

While the ideas listed above are diverse, the common thread seems to be a desire for more communication both among CSDMS members and between members and the CIF.

Other Concepts and Ideas
A short report cannot do justice to the full suite of ideas that were raised during the breakout-group discussions. Nonetheless, it is worth highlighting a few other emergent themes that do not necessarily fit within any of the broad categories listed above.

Some groups discussed the issue of academic credit, noting that the academic system's current reward structure has been slow to recognize contributions that come in the form of software or associated products such as documentation. One idea was for CSDMS to offer some type of award or other formal recognition for software and cyberinfrastructure contributions. Another was to highlight successes by identifying and promoting a "simulation of the month."

Some groups raised the issue of diversity, noting that CSDMS can continue to play a role in helping to promote diversity the geoscience workforce by seeking diversity among chairs and keynote speakers.

Notes

1.) Improved communication & greater collaboration is necessary

- There's a lack of overlap/communication across communities
    - Data collection is not informed by modelers
    - Multiple people need to be involved in the data collection process from the beginning (the PI, the data collection team, and the modeler). This will ensure that data is in the correct format and includes the correct metadata.

2.) Educational needs

- Beginning at the undergraduate level, students need to be trained in data processing and data management (scientific programming, Linux, R, Python, MATLAB, etc.)
- Many students feel they are working with a limited amount of data
- Students should get into the field, even if their work is completely model based
- Continuing education is necessary for everyone
- People in the field need to learn about model parameterization needs
- Everyone should consult with statisticians regarding comparing models and data
- Students need desktop stations
    - It is unreasonable for students to run a model and/or parse large datasets on personal laptops (CSDMS facilitating supercomputer access is helpful here)
- Direction is needed on how to standardize metadata
- Models should be simplified for teaching

3.) Other concerns regarding data and models

- Observationalists may not be collecting the right data
- There is a need for descriptions of how the data will be used
- Models may be lagging behind our understanding of the physics
- Scientists do not always release data in a timely fashion

    - Releasing data is easy when there is a system in place, but is difficult/time consuming if not
- Lack of metrics that extract information from data and/or models
    - Well defined metrics can be bridges to overcoming abstraction of models and build direct connection between model outputs and field-specific data sets
- Metadata standards are lacking and so are model code standards
- Code used to process or 'clean up' raw data should be made public
- Where is EarthCube data? There is still a lot of confusion regarding EarthCube's role in the modeling community
- Modeling almost always runs ahead of data availability
- Data access policies are a barrier
- Disagreement between model and data happens at subgrid processes
- Scaling experimental data to field-scale, which is necessary for models, can be difficult
- It can be difficult for data gathers to run models, which causes a disconnect
- Processed data is hard to get
- Raw data is there but takes lots of time/computer power to process
- Raw data is not enough
- Uncertainty is often missing for processed data

4.) Solutions and Suggestions

- Digital Object Identifiers are very helpful
- Data collectors need to publish data with metadata and DOIs; version control for data
- Datasets can be assigned a DOI
- Assigning data "asset" numbers allows it to be linked into Google Earth and downloaded
- Those collecting field data should collect as much information as possible, and could possibly create a permanent DOI for their field data
- The version of the data the DOI is pointing to should be documented so changes to the original dataset can be traced
- A metadata standard needs to be established for both data and models
- Data needs to be searchable in time and space
- Models should be easy to run
- Datasets need to come packaged with better parsing and processing tools (e.g. Python library)
- Data should come with uncertainties
- There needs to be a place for capturing input files
- Attach a license to data so others know how it can be used and how to properly attribute
- Need measurements that modelers can extract data from
- Need a way of resolving spatial and temporal scale differences between field data and the models
- Open-source standards and standard names are helpful
- Google and data.gov represent new way of archiving science data, replacing libraries and academic journals
- NIH data management plan created a plan for storing data
- NIH requires that data and papers are published with open access
- NSF data policies will be helpful
- In SEN, you can search and find all metadata (not all data is online yet because of storage limitations)
- PIs need to insist on collaboration between modelers and the data community

- CZO groups have a standardized procedure for collecting field data
- More effort is needed in creating and revising conceptual models
- The development of conceptual models should be prioritized
- We can leverage opportunities presented by new technology (radio tags, satellite instruments, drones for various sensors, etc.)
- Scaling methods need to be identified so that modelers can downscale their models to make them relevant for field-based validation
- Need more stringent requirements for controlling error propagation; assessing uncertainty
- Model code needs to evolve as our understanding of natural phenomena evolves
- More interdisciplinary initiatives are needed to encourage data collectors and modelers to collaborate
- Modelers must make it clear that data collection is critical for modeling
- Should we work toward a larger community-based cloud-computing engine that's specifically focused on developing the capabilities of students?
- Case studies with models that show value in terms of collecting new data need to be documented and advertised
- Could agencies set standards for best practices in their fields?
- GEOSS is working on a document to define a list of essential variables. Users can identify which variables are essential.

5.) Specific data related needs from CSDMS discussion groups

- Long time series in geomorph and landscape
- Detailed surface dynamic data w/ time stamps
- High-resolution satellite data needs to be available in U.S.
- Long-term soil carbon data time records for various depths
- Age control for dating
- Uncertainty for processed data
- Measurements of size distributions and density of sediment
- A global lidar dataset with yearly updates
- Data from below ground surface (stratigraphy, groundwater)
- Social data/data measuring human impact needs to be gathered
- Monitoring of active faults (earthquake fault monitoring, landsliding, and river sediments)
    - E.g. Collection of pre-quake data from Nepal or Alpine faults

Appendix 6: CSDMS Software Bootcamp

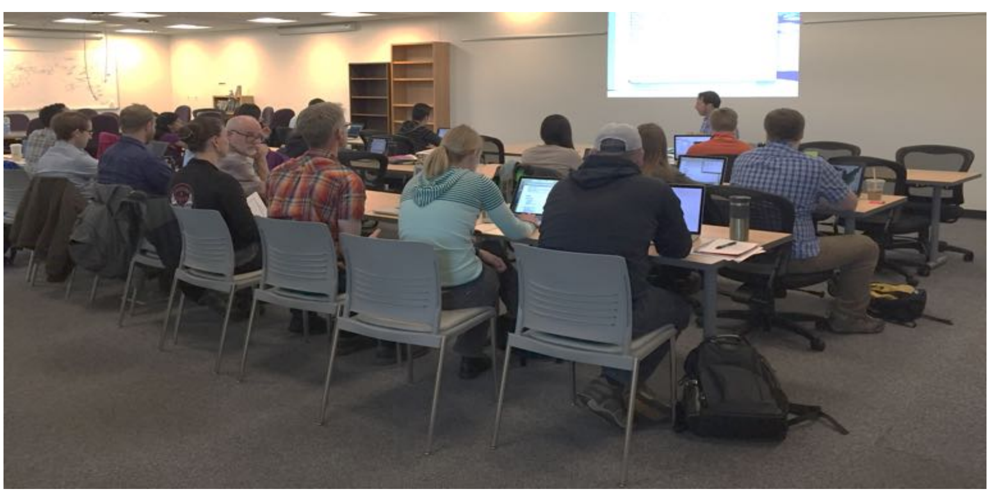
In May 2016, CSDMS-IF hosted a one-day "bootcamp"-style course on introductory scientific programming for 20 members of the CSDMS community. The event took place the day before the CSDMS Annual Meeting on the University of Colorado campus. Workshop participants were primarily graduate students and early-career scientists, and came from 15 universities in the United States, one university in Europe, and one U.S. government agency. All conduct research that utilizes numerical modeling to study earth surface processes. Participants were divided equally among genders (Male: 55%, Female: 45%).

The CSMDS workshop was modeled after bootcamps held by Software Carpentry, a volunteer organization that teaches the core skills of scientific programming during two-day events. Both instructors are CSDMS-IF staff who are also certified instructors for Software Carpentry, having received training in the basics of educational psychology and instructional design as applied to computer science and mentoring from more experienced instructors. Other CSDMS-IF staff assisted participants one-on-one as needed during the workshop.

The material covered in the CSDMS workshop included introductory programming practices, shell scripting, basics of High-Performance Computing and use of the CSDMS HPCC ("beach"), Python programming, and version control with Git and Github. Lessons were customized to use examples relevant to numerical modeling and the CSDMS community, such as the application of finite difference methods to evolve topography through diffusion. This approach was valued and one of the participants commented: "I *really loved the applied intro to Python via the 1D profile diffusion example!*"

Instructors requested feedback from participants twice during the workshop using free-form comment cards. One week after the event, the CSDMS-IF also sent out a 15-question survey to all participants to assess satisfaction with this workshop and gauge interest in other CSDMS educational programs.

The response rate for the survey was 45% (9 responses out of 20 participants). Overall, the workshop was rated as excellent (4.8/5.0). When asked why they signed up for the workshop, participants universally expressed a need to rapidly improve their computational skills by learning Python and version control. Their previous experience with programming was primarily in Matlab, with 44% having "Some knowledge" and 33% having "Extensive knowledge" of this proprietary software.



Mark Piper, IF Staff, leading Bootcamp session.

Before the workshop, participants knowledge of shell scripting was equally distributed between "Little to no knowledge" (33%), "Some knowledge" (44%), and "Extensive knowledge" (22%). Their previous experience using an HPCC was equally split between "Little to no knowledge" (44%) and "Some knowledge" (44%). Many had "Some knowledge" (55%) of Python beforehand, with the rest split equally between "Little to no knowledge" (22%) and "Extensive knowledge" (22%). Large gains were made with respect to version control, because most participants had "Little to no knowledge" (66%) of version control/Git, while a few had "Some knowledge" (22%) and "Extensive knowledge" (11%).

Feedback indicates that participants found the workshop to be at the right skill level and the hands-on exercises to be helpful for learning. They particularly appreciated learning about shell scripting, version control and tools for interactive Python programming. The instructors received overwhelmingly positive reviews in the survey, with comments specifically valuing clarity and enthusiasm. Critical comments indicate that the pace of the bootcamp was too fast for some participants and that others would have liked to continue on to more advanced topics in Python and version control.

After the workshop, participants reported that their knowledge of most topics "Increased some" (88% for shell scripting, HPCC, and Python), with a few participants suggesting that their knowledge "Increased a lot" (11% for shell scripting and HPCC, and 22% for Python). For version control/Git, most survey participants indicated that their knowledge "Increased a lot" (55%), while the rest stated that it "Increased some" (44%).

Participants expressed strong interest in attending CSDMS workshops on other topics. There is clearly a need in our community for building skills, one respondent echoed this notion: "*It would have been nice to go to these bootcamps and clinics when I first started grad school!"* From the survey, all participants were interested in learning intermediate Python and more than half wanted to learn about supercomputing and parallelization. Multiple survey responses also mentioned a desire for workshops in software development, using numerical models, and other programming languages.

Appendix 7: CSDMS Visiting Scientists

Between August 2015 and July 2016, several scientists visited the CSDMS Integration Facility:

Date	Visitor
06/2015-08/2015	Randy Leveque, University of Washington
06/2016-08-2016	Albert van Dijik, Australian National University
08/2015	Michael Barton, Arizona State University
08/2015	Dena Smith, STEPPE (Sedimentary Geology, Time, Environment, Paleontology, Paleoclimatology, Energy)
09/2015	Joel Sholtes, Colorado State University
09/2015	Cecelia Deluca, NOAA
09/2015	Rocky Dunlap, NOAA
11/2015-01/2016	Rogger Escobar Correa, EAFIT University, Columbia
11/2015	Anne Castle, Water and Science at DOE
11/2015	Patricia Corcoran, CIRES, CU Boulder
01/2016-present	Hang Deng, Colorado School of Mines
03/2016-08/2018	Kang Wang, Lanzhou University, China
03/2016	Mette Bendixon, University of Copenhagen
03/2016	Kevin MacKay, National Inst. Water and Atmospheric Research, New Zealand
03/2016&06/2016	Bill Ross, Exploration Landmark Software Services
04/2016-present	Jose Silvestre, University of Texas, UNAVCO RESESS
05/2016-07/2016	Mary Hill, University of Kansas
06/2016	Robert Weiss, Virginia Tech
06/2016-07/2016	Juan Restrepo, EAFIT University, Columbia

Appendix 8: CSDMS Diversity Efforts 2015-2016

The Community Surface Dynamics Modeling System is a national and international community of students, scientists and governmental employees from all parts of the world. As of June 2013, CSDMS members came from 123 U.S. universities, 21 U.S. Federal Labs, 22 U.S. corporations, 275 foreign research institutions from more than 63 different countries. Members come dominantly from the United States, but include many Asian, European and Latin-American nationals, countries in the Middle East and Africa are less prevalent, but growing.

Diversity at the CSDMS Annual Meeting

CSDMS has not (yet) recorded data on diversity from their members or from meeting attendees. Overall, women and minorities are traditionally underrepresented in the STEM sciences, and form between 17-23% in the Geophysical Sciences (Rhodes, 2010; NSF Advisory Committee for Geosciences, 2014). We speculate that these numbers are likely even lower in the field of earth surface process modeling with emphasis on modeling and the analysis of "big data," and increasingly high performance computing.

CSDMS features a significantly higher representation of women in meeting attendees than the average published representation of women in the Geophysical Sciences. At our CSDMS Annual Meeting 2015, 33% of attendees were women, including women scientists at all career levels: students, PDF's, assistant professors, and full professors or senior scientists.

Annual Meeting Attendees

92-male
45-female
1-non binary

Academic 122
1 undergraduate student
43 graduate students
15 post-doctoral fellows
47 assistant to full professors
17 research scientists

Non-academic institutions
10 Government Agency
2 Industry
2 Non-profit Research

Engaging a diverse student population in the CSDMS Annual Meeting

CSDMS has reached out more widely over the last 2 years to encourage students from all walks of life to participate in the CSDMS Annual Meetings. CSDMS has awarded 3 student scholarships to underrepresented students with the explicit goal to increase diversity in the field of surface dynamics modeling. Stipends allowed these students to attend the entire annual meeting 2016, and present on their research.

For the first time in 2016, undergraduate students of CU Boulder were recruited to assist in logistical tasks, such as registration. Eight students volunteered and were invited to attend all keynote talks and poster sessions. We will expand upon this opportunity next year and reach out to honor programs of several departments at CU Boulder.

Last year, we consulted about CSDMS strategies to broaden participation with Dr. Barbara Kraus, who is employed in the Colorado Diversity Initiative in Science, Math and Engineering. As a result of these interactions, we have posted announcements on the annual student scholarship to gateways typically used by underrepresented students to become familiar with targeted opportunities in the STEM sciences. These included:

1) NSF Alliances for Graduate Education and the Professoriate (AGEP), Institute for Broadening participation, its mission is: "*to increase diversity in the Science, Technology, Engineering and Mathematics (STEM) workforce. We design and implement strategies to increase access to STEM education, funding, and careers, with special emphasis on reaching underserved communities and diverse underrepresented groups.* **www.PathwaysToScience.org** *makes it easy for faculty and administrators to access resources that can assist them in their efforts to reduce barriers to participation, create environments rich in the positive factors that support student success on the STEM pathway, and conduct outreach to underserved communities and underrepresented groups by implementing recruitment and retention strategies that broaden participation and increase diversity.* "

2) AGEP listserv, especially for underrepresented groups at CU Boulder

Diversity and representation in CSDMS leadership

Bell and Karsten (2004) found that of all employed PhD in the geosciences only 13% were women, whereas this study is now a decade old, and representation may have improved over the last 10 years to 17-23% (Rhodes, 2010), it is likely still a valid estimate for women scientists in a career stage where they are called upon for leadership roles. Many of the CSDMS Working Groups and Focus Research Group chairs, and thus its executive committee are women (with new chairs of 2016, we are now at 29%), and we now have a more diverse group of chairs as well. The CSDMS steering committee is chaired by and features 40% women. Overall, a broad participation of scientists and students from underrepresented groups remains a priority, and likely role models in leadership roles help towards an open-minded CSDMS community.

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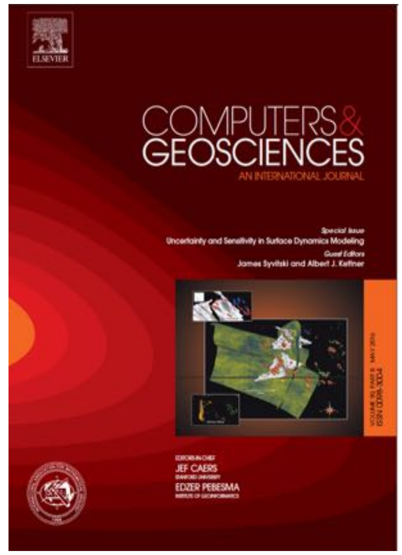
Bell, R., Karsten, K., 2004. Righting the Balance: Gender Diversity in the Geosciences ADVANCE library Paper 47.

Rhodes, D.D., 2010., Changes in the demographic characteristics of AGU membership 2006-2010. AGU Fall Meeting 2010, abstract #ED31B-0666.

Appendix 9: CSDMS Special Issue

Uncertainty and Sensitivity in Surface Dynamics Modeling took place May 20-22, 2014 in Boulder Colorado. One of the outcomes was a special issue of Computers & Geosciences, volume 90 part B, ISSN 0098-3004, published April, 2016. Below is an overview of the 15 papers including the abstracts.



Content

Uncertainty and Sensitivity in Surface Dynamics Modeling
Albert J. Kettner and James P.M. Syvitski

(Editorial, no abstract)

Uncertainty quantification in modeling earth surface processes: more applicable for some types of models than for others *A. Brad Murray, Nicole M. Gasparini, Evan B. Goldstein, and Mick van der Wegen*

In Earth-surface science, numerical models are used for a range of purposes, from making quantitatively accurate predictions for practical or scientific purposes ('simulation' models) to testing hypotheses about the essential causes of poorly understood phenomena ('exploratory' models). We argue in this contribution that whereas established methods for uncertainty quantification (UQ) are appropriate (and crucial) for simulation models, their application to exploratory models are less straightforward, and in some contexts not relevant. Because most models fall between the end members of simulation and exploratory models, examining the model contexts under which UQ is most and least appropriate is needed. Challenges to applying state-of-the-art UQ to Earth-surface science models center on quantifying 'model-form' uncertainty—the uncertainty in model predictions related to model imperfections. These challenges include: 1) the difficulty in deterministically comparing model predictions to observations when positive feedbacks and associated autogenic dynamics (a.k.a. 'free' morphodynamics) determine system behavior over the timescales of interest (a difficulty which could be mitigated in a UQ approach involving statistical comparisons); 2) the lack of available data sets at sufficiently large space and/or time scales; 3) the inability to disentangle uncertainties arising from model parameter values and model form in some cases; and 4) the inappropriateness of model 'validation' in the UQ sense for models toward the exploratory end member of the modeling spectrum.

Morphological impact of a storm can be predicted three days ahead *F. Baart, M. van Ormondt, J.S.M. van Thiel de Vries, and M. van Koningsveld*

People living behind coastal dunes depend on the strength and resilience of dunes for their safety. Forecasts of hydrodynamic conditions and morphological change on a timescale of several days can provide essential information to protect lives and property. In order for forecasts to protect they need be relevant, accurate, provide lead time, and information on confidence. Here we show how confident one can be in morphological predictions of several days ahead. The question is answered by assessing the forecast skill as a function of lead time. The study site in the town of Egmond, the Netherlands, where people depend on the dunes for their safety, is used because it is such a rich data source, with a history of forecasts, tide gauges and bathymetry measurements collected by video cameras. Even though the forecasts are on a local scale, the methods are generally applicable. It is shown that the intertidal beach volume change can be predicted up to three days ahead.

Shelf sediment transport during hurricanes Katrina and Rita
Kehui Xu, Rangley C. Mickey, Qin Chen, Courtney K. Harris, Robert D. Hetland, Kelin Hu, and Jiaze Wang

Hurricanes can greatly modify the sedimentary record, but our coastal scientific community has rather limited capability to predict hurricane-induced sediment deposition. A three-dimensional sediment transport model was developed in the Regional Ocean Modeling System (ROMS) to study seabed erosion and deposition on the Louisiana shelf in response to Hurricanes Katrina and Rita in the year 2005. Sensitivity tests were performed on both erosional and depositional processes for a wide range of erosional rates and settling velocities, and uncertainty analysis was done on critical shear stresses using the polynomial chaos approximation method. A total of 22 model runs were performed in sensitivity and uncertainty tests. Estimated maximum erosional depths were sensitive to the inputs, but horizontal erosional patterns seemed to be controlled mainly by hurricane tracks, wave–current combined shear stresses, seabed grain sizes, and shelf bathymetry. During the passage of two hurricanes, local resuspension and deposition dominated the sediment transport mechanisms. Hurricane Katrina followed a shelf-perpendicular track before making landfall and its energy dissipated rapidly within about 48 h along the eastern Louisiana coast. In contrast, Hurricane Rita followed a more shelf-oblique track and disturbed the seabed extensively during its 84-h passage from the Alabama–Mississippi border to the Louisiana–Texas border. Conditions to either side of Hurricane Rita's storm track differed substantially, with the region to the east having stronger winds, taller waves and thus deeper erosions. This study indicated that major hurricanes can disturb the shelf at centimeter to meter levels. Each of these two hurricanes suspended seabed sediment mass that far exceeded the annual sediment inputs from the Mississippi and Atchafalaya Rivers, but the net transport from shelves to estuaries is yet to be determined. Future studies should focus on the modeling of sediment exchange between estuaries and shelves and the field measurement of erosional rates and settling velocities.

Reprint of: A numerical investigation of fine sediment resuspension in the wave boundary layer—Uncertainties in particle inertia and hindered settling *Zhen Cheng, Xiao Yu, Tian-Jian Hsu, and S. Balachandar*

The wave bottom boundary layer is a major conduit delivering fine terrestrial sediments to continental margins. Hence, studying fine sediment resuspensions in the wave boundary layer is crucial to the understanding of various components of the earth system, such as carbon cycles. By assuming the settling velocity to be a constant in each simulation, previous turbulence-resolving numerical simulations reveal the existence of three transport modes in the wave boundary layer associated with sediment availabilities. As the sediment availability and hence the sediment-induced stable stratification increases, a sequence of transport modes, namely, (I) well-mixed transport, (II) formulation of lutocline resembling a two-layer system, and (III) completely laminarized transport are observed. In general, the settling velocity is a flow variable due to hindered settling and particle inertia effects. Present numerical simulations including the particle inertia suggest that for a typical wave condition in continental shelves, the effect of particle inertia is negligible. Through additional numerical experiments, we also confirm that the particle inertia tends (up to the Stokes number St = 0.2) to attenuate flow turbulence. On the other hand, for flocs with lower gelling concentrations, the hindered settling can play a key role in sustaining a large amount of suspended sediments and results in the laminarized transport (III). For the simulation with a very significant hindered settling effect due to a low gelling concentration, results also indicate the occurrence of gelling ignition, a state in which the erosion rate is always higher than the deposition rate. A sufficient condition for the occurrence of gelling ignition is hypothesized for a range of wave intensities as a function of sediment/floc properties and erodibility parameters.

Sensitivity of a third generation wave model to wind and boundary condition sources and model physics: A case study from the South Atlantic Ocean off Brazil coast
S. Mostafa Siadatmousavi, Felix Jose, and Graziela Miot da Silva

Three different packages describing the white capping dissipation process, and the corresponding energy input from wind to wave were used to study the surface wave dynamics in South Atlantic Ocean, close to the Brazilian coast. A host of statistical parameters were computed to evaluate the performance of wave model in terms of simulated bulk wave parameters. Wave measurements from a buoy deployed off Santa Catarina Island, Southern Brazil and data along the tracks of Synthetic Aperture Radars were compared with simulated bulk wave parameters; especially significant wave height, for skill assessment of different packages. It has been shown that using a single parameter representing the performance of source and sink terms in the wave model, or relying on data from only one period of simulations for model validation and skill assessment would be misleading. The model sensitivity to input parameters such as time step and grid size were addressed using multiple datasets. The wind data used for the simulation were obtained from two different sources, and provided the opportunity to evaluate the importance of input data quality. The wind speed extracted from remote sensing satellites was compared to wind datasets used for wave modeling. The simulation results showed that the wind quality and its spatial resolution is highly correlated to the quality of model output. Two different sources of wave information along the open boundaries of the model domain were used for skill assessment of a high resolution wave model for the study area. It has been shown, based on the sensitivity analysis, that the effect of using different boundary conditions would decrease as the distance from the open boundary increases; however, the difference were still noticeable at the buoy location which was located 200–300 km away from the model boundaries; but restricted to the narrow band of the low frequency wave spectrum.

Understanding hydrological flow paths in conceptual catchment models using uncertainty and sensitivity analysis *Eva M. Mockler, Fiachra E. O'Loughlin, and Michael Bruen*

Increasing pressures on water quality due to intensification of agriculture have raised demands for environmental modeling to accurately simulate the movement of diffuse (nonpoint) nutrients in catchments. As hydrological flows drive the movement and attenuation of nutrients, individual hydrological processes in models should be adequately represented for water quality simulations to be meaningful. In particular, the relative contribution of groundwater and surface runoff to rivers is of interest, as increasing nitrate concentrations are linked to higher groundwater discharges. These requirements for hydrological modeling of groundwater contribution to rivers initiated this assessment of internal flow path partitioning in conceptual hydrological models.

In this study, a variance based sensitivity analysis method was used to investigate parameter sensitivities and flow partitioning of three conceptual hydrological models simulating 31 Irish catchments. We compared two established conceptual hydrological models (NAM and SMARG) and a new model (SMART), produced especially for water quality modeling. In addition to the criteria that assess streamflow simulations, a ratio of average groundwater contribution to total streamflow was calculated for all simulations over the 16 year study period. As observations time-series of groundwater contributions to streamflow are not available at catchment scale, the groundwater ratios were evaluated against average annual indices of base flow and deep groundwater flow for each catchment. The exploration of sensitivities of internal flow path partitioning was a specific focus to assist in evaluating model performances. Results highlight that model structure has a strong impact on simulated groundwater flow paths. Sensitivity to the internal pathways in the models are not reflected in the performance criteria results. This demonstrates that simulated groundwater contribution should be constrained by independent data to ensure results within realistic bounds if such models are to be used in the broader environmental sustainability decision making context.

Reprint of: Active subspaces for sensitivity analysis and dimension reduction of an integrated hydrologic model *Jennifer L. Jefferson, James M. Gilbert, Paul G. Constantine, and Reed M. Maxwell*

Integrated hydrologic models coupled to land surface models require several input parameters to characterize the land surface and to estimate energy fluxes. Uncertainty of input parameter values is inherent in any model and the sensitivity of output to these uncertain parameters becomes an important consideration. To better understand these connections in the context of hydrologic models, we use the ParFlow-Common Land Model (PF-CLM) to estimate energy fluxes given variations in 19 vegetation and land surface parameters over a 144-hour period of time. Latent, sensible and ground heat fluxes from bare soil and grass vegetation were estimated using single column and tilted-v domains. Energy flux outputs, along with the corresponding input parameters, from each of the four scenario simulations were evaluated using active subspaces. The active subspace method considers parameter sensitivity by quantifying a weight for each parameter. The method also evaluates the potential for dimension reduction by identifying the input–output relationship through the active variable – a linear combination of input parameters. The aerodynamic roughness length was the most important parameter for bare soil energy fluxes. Multiple parameters were important for energy fluxes from vegetated surfaces and depended on the type of energy flux. Relationships between land surface inputs and output fluxes varied between latent, sensible and ground heat, but were consistent between domain setup (i.e., with or without lateral flow) and vegetation type. A quadratic polynomial was used to describe the input–output relationship for these energy fluxes. The reduced-dimension model of land surface dynamics can be compared to observations or used to solve the inverse problem. Considering this work as a proof-of-concept, the active subspace method can be applied and extended to a range of domain setups, land cover types and time periods to obtain a reduced-form representation of any output of interest, provided that an active subspace exists.

Hydrological model uncertainty due to spatial evapotranspiration estimation methods *Xuan Yu, Anna Lamačová, Christopher Duffy, Pavel Krám, and Jakub Hruška*

Evapotranspiration (ET) continues to be a difficult process to estimate in seasonal and long-term water balances in catchment models. Approaches to estimate ET typically use vegetation parameters (e.g., leaf area index [LAI], interception capacity) obtained from field observation, remote sensing data, national or global land cover products, and/or simulated by ecosystem models. In this study we attempt to quantify the uncertainty that spatial evapotranspiration estimation introduces into hydrological simulations when the age of the forest is not precisely known. The Penn State Integrated Hydrologic Model (PIHM) was implemented for the Lysina headwater catchment, located 50°03′N, 12°40′E in the western part of the Czech Republic. The spatial forest patterns were digitized from forest age maps made available by the Czech Forest Administration. Two ET methods were implemented in the catchment model: the Biome-BGC forest growth sub-model (1-way coupled to PIHM) and with the fixed-seasonal LAI method. From these two approaches simulation scenarios were developed. We combined the estimated spatial forest age maps and two ET estimation methods to drive PIHM. A set of spatial hydrologic regime and streamflow regime indices were calculated from the modeling results for each method. Intercomparison of the hydrological responses to the spatial vegetation patterns suggested considerable variation in soil moisture and recharge and a small uncertainty in the groundwater table elevation and streamflow. The hydrologic modeling with ET estimated by Biome-BGC generated less uncertainty due to the plant physiology-based method. The implication of this research is that overall hydrologic variability induced by uncertain management practices was reduced by implementing vegetation models in the catchment models.

Multi-scale characterization of topographic anisotropy
S.G. Roy, P.O. Koons, B. Osti, P. Upton, and G.E. Tucker

We present the every-direction variogram analysis (EVA) method for quantifying orientation and scale dependence of topographic anisotropy to aid in differentiation of the fluvial and tectonic contributions to surface evolution. Using multi-directional variogram statistics to track the spatial persistence of elevation values across a landscape, we calculate anisotropy as a multiscale, direction-sensitive variance in elevation between two points on a surface. Tectonically derived topographic anisotropy is associated with the three-dimensional kinematic field, which contributes (1) differential surface displacement and (2) crustal weakening along fault structures, both of which amplify processes of surface erosion. Based on our analysis, tectonic displacements dominate the topographic field at the orogenic scale, while a combination of the local displacement and strength fields are well represented at the ridge and valley scale. Drainage network patterns tend to reflect the geometry of underlying active or inactive tectonic structures due to the rapid erosion of faults and differential uplift associated with fault motion. Regions that have uniform environmental conditions and have been largely devoid of tectonic strain, such as passive coastal margins, have predominantly isotropic topography with typically dendritic drainage network patterns. Isolated features, such as stratovolcanoes, are nearly isotropic at their peaks but exhibit a concentric pattern of anisotropy along their flanks. The methods we provide can be used to successfully infer the settings of past or present tectonic regimes, and can be particularly useful in predicting the location and orientation of structural features that would otherwise be impossible to elude interpretation in the field. Though we limit the scope of this paper to elevation, EVA can be used to quantify the anisotropy of any spatially variable property.

Predicting uncertainty in sediment transport and landscape evolution – the influence of initial surface conditions *G.R. Hancock, T.J. Coulthard, and J.B.C. Lowry*

Numerical landscape evolution models were initially developed to examine natural catchment hydrology and geomorphology and have become a common tool to examine geomorphic behaviour over a range of time and space scales. These models all use a digital elevation model (DEM) as a representation of the landscape surface and a significant issue is the quality and resolution of this surface. Here we focus on how subtle perturbations or roughness on the DEM surface can produce alternative model results. This study is carried out by randomly varying the elevations of the DEM surface and examining the effect on sediment transport rates and geomorphology for a proposed rehabilitation design for a post-mining landscape using multiple landscape realisations with increasing magnitudes of random changes. We show that an increasing magnitude of random surface variability does not appear to have any significant effect on sediment transport over millennial time scales. However, the random surface variability greatly changes the temporal pattern or delivery of sediment output. A significant finding is that all simulations at the end of the 10,000 year modelled period are geomorphologically similar and present a geomorphological equifinality. However, the individual patterns of erosion and deposition were different for repeat simulations with a different sequence of random perturbations. The alternative positions of random perturbations strongly influence local patterns of hillslope erosion and evolution together with the pattern and behaviour of deposition. The findings demonstrate the complex feedbacks that occur even within a simple modelled system.

LORICA – A new model for linking landscape and soil profile evolution: Development and sensitivity analysis *Arnaud J.A.M. Temme, and Tom Vanwalleghem*

Soils and landscapes evolve in tandem. Landscape position is a strong determinant of vertical soil development, which has often been formalized in the catena concept. At the same time, soil properties are strong determinants of geomorphic processes such as overland erosion, landsliding and creep. We present a new soilscape evolution model; LORICA, to study these numerous interactions between soil and landscape development. The model is based on the existing landscape evolution model LAPSUS and the soil formation model MILESD. The model includes similar soil formation processes as MILESD, but the main novelties include the consideration of more layers and the dynamic adaption of the number of layers as a function of the soil profile's heterogeneity. New processes in the landscape evolution component include a negative feedback of vegetation and armouring and particle size selectivity of the erosion–deposition process. In order to quantify these different interactions, we present a full sensitivity analysis of the input parameters. First results show that the model successfully simulates various soil–landscape interactions, leading to outputs where the surface changes in the landscape clearly depend on soil development, and soil changes depend on landscape location. Sensitivity analysis of the model confirms that soil and landscape interact: variables controlling amount and position of fine clay have the largest effect on erosion, and erosion variables control among others the amount of chemical weathering. These results show the importance of particle size distribution, and especially processes controlling the presence of finer clay particles that are easily eroded, both for the resulting landscape form as for the resulting soil profiles. Further research will have to show whether this is specific to the boundary conditions of this study or a general phenomenon.

First-order uncertainty analysis using Algorithmic Differentiation of morphodynamic models *Catherine Villaret, Rebekka Kopmann, David Wyncoll, Jan Riehme, Uwe Merkel, and Uwe Naumann*

We present here an efficient first-order second moment method using Algorithmic Differentiation (FOSM/AD) which can be applied to quantify uncertainty/sensitivities in morphodynamic models. Changes with respect to variable flow and sediment input parameters are estimated with machine accuracy using the technique of Algorithmic Differentiation (AD). This method is particularly attractive for process-based morphodynamic models like the Telemac-2D/Sisyphe model considering the large number of input parameters and CPU time associated to each simulation.

The FOSM/AD method is applied to identify the relevant processes in a trench migration experiment (van Rijn, 1987). A Tangent Linear Model (TLM) of the Telemac-2D/Sisyphe morphodynamic model (release 6.2) was generated using the AD-enabled NAG Fortran compiler. One single run of the TLM is required per variable input parameter and results are then combined to calculate the total uncertainty.

The limits of the FOSM/AD method have been assessed by comparison with Monte Carlo (MC) simulations. Similar results were obtained assuming small standard deviation of the variable input parameters. Both settling velocity and grain size have been identified as the most sensitive input parameters and the uncertainty as measured by the standard deviation of the calculated bed evolution increases with time.

Towards uncertainty quantification and parameter estimation for Earth system models in a component-based modeling framework *Scott D. Peckham, Anna Kelbert, Mary C. Hill, and Eric W.H. Hutton*

Component-based modeling frameworks make it easier for users to access, configure, couple, run and test numerical models. However, they do not typically provide tools for uncertainty quantification or data-based model verification and calibration. To better address these important issues, modeling frameworks should be integrated with existing, general-purpose toolkits for optimization, parameter estimation and uncertainty quantification.

This paper identifies and then examines the key issues that must be addressed in order to make a component-based modeling framework interoperable with general-purpose packages for model analysis. As a motivating example, one of these packages, DAKOTA, is applied to a representative but nontrivial surface process problem of comparing two models for the longitudinal elevation profile of a river to observational data. Results from a new mathematical analysis of the resulting nonlinear least squares problem are given and then compared to results from several different optimization algorithms in DAKOTA.

Exploring temporal and functional synchronization in integrating models: A sensitivity analysis
Getachew F. Belete, and Alexey Voinov

When integrating independently built models, we may encounter components that describe the same processes or groups of processes using different assumptions and formalizations. The time stepping in component models can also be very different depending upon the temporal resolution chosen. Even if this time stepping is handled outside of the components (as assumed by good practice of component building) the use of inappropriate temporal synchronization can produce either major run-time redundancy or loss of model accuracy. While components may need to be run asynchronously, finding the right times for them to communicate and exchange information becomes a challenge. We are illustrating this by experimenting with a couple of simple component models connected by means of Web services to explore how the timing of their input–output data exchange affects the performance of the overall integrated model. We have also considered how to best communicate information between components that use a different formalism for the same processes. Currently there are no generic recommendations for component synchronization but including sensitivity analysis for temporal and functional synchronization should be recommended as an essential part of integrated modeling.

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Appendix 10: Projects that Use the CSDMS Experimental Supercomputer

Based on account requests, a total of 25 research projects and 6 educational courses that have used during the last year, or are still using, the CSDMS HPCC ***beach***. The majority of those projects are part of Masters or PhD thesis work. Nine projects are new, so have been started after last year's annual report 2015.

(Ongoing) A Geo-Semantic Framework for Integrating Long-Tail Data and Models

Peishi Jiang, University of Illinois at Urbana-Champaign

http://goo.gl/3zjUww

Our vision is to develop a decentralized knowledge-based platform that can be easily adapted across geoscience communities comprised of individual and small group researchers, to allow semantically heterogeneous system to interact with minimum human intervention. It will allow the automatic reference of data from data resources to model by: (i) leveraging the Semantic Web; (ii) developing an automated semantic mediation tool; and (iii) developing a semantic knowledge discovery system that can be used by long-tail models. The developed approach will be evaluated based on a case study of integrating two examples of long-tail modeling and data: the Community Surface Dynamic Modeling System (CSDMS) and Sustainable Environment Actionable Data (SEAD).

(Ongoing) CHESROMS BGC

Hao Wang, UMCES

Funded by NOAA COMT

http://goo.gl/520LdU

We are using ROMS to simulate the 3D salinity, temperature, dissolved oxygen, chlorophyll, NH4,NO3 for long term time period in Chesapeake Bay, to provide guidance for the public nutrient reduction and future operational work.

(Ongoing) Chesapeake Bay FVCOM-ICM

Blake Clark, UMCES

Funded by NASA

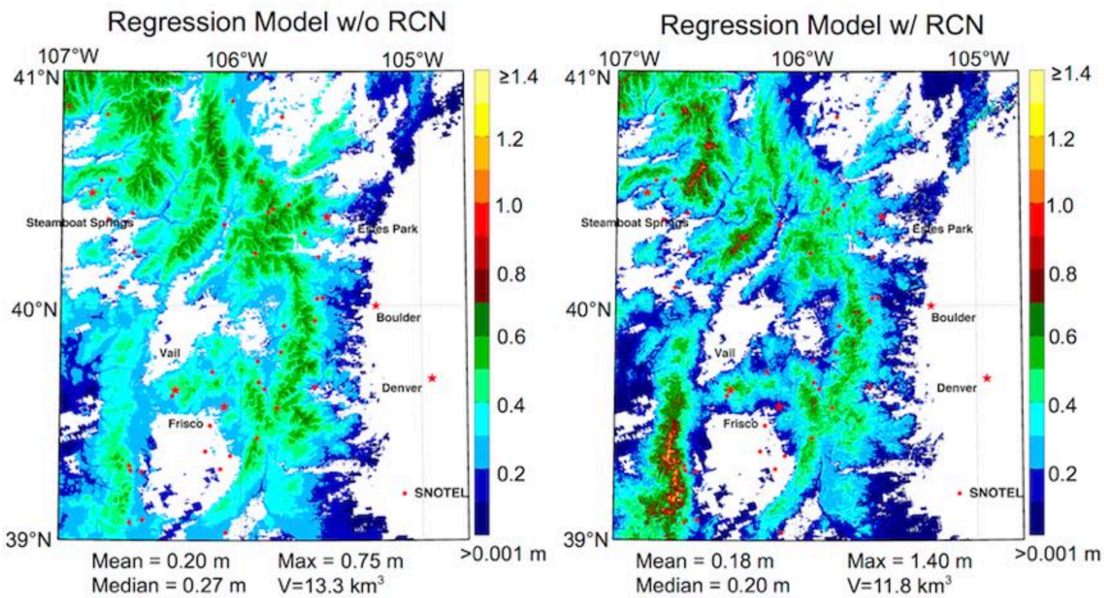
http://goo.gl/Q8K12r

I am working in collaboration with multiple institutions and PIs to model the coastal ocean carbon cycle, particularly with respect to marsh-estuary dynamics in Chesapeake Bay. We use FVCOM for 3d hydrodynamics and coupled offline to ICM for a carbon based biogeochemical model. A model to simulate SAV and sediment diagenesis is in development. The model developed here will be adapted for use in a broad range of coastal systems.

(Ongoing) Combining a MODIS-based snow water equivalent product and statistical interpolation methods to estimate snowpack and streamflow conditions in the Colorado headwaters

Dominik Schneider, University of Colorado, Noah P. Molotch, University of Colorado
Funded by NOAA

http://goo.gl/fZuBSN



We are seeking to develop a SWE monitoring technique that can leverage both point scale measurements and spatially explicit patterns of SWE from remote sensing in near real-time. Current estimates of SWE distribution are frequently interpolated from point measurements based on physiographics with a observations of SCA occasionally used to constrain modeled values. Statistical models relating physiography and SNOTEL SWE only explain up to ~15% of the observed variability and thus these techniques provide limited credibility for water resource applications. Recent improvements in SWE estimates have been obtained using SWE reconstruction models whereby satellite data of SCA are coupled with fully distributed energy balance modeling to reconstruct peak snow mass. The first goal of this project is to combine a statistical interpolation model with remote-sensing based spatially distributed reconstructed SWE to augment resources available to water managers. The second goal of this project is to incorporate explicitly modeled patterns of SWE and use it as a spatial distribution field for winter precipitation in a streamflow modeling exercise. The intention is to examine the sensitivity and potential improvement in simulated streamflow timing and volume due to an improved representation of the physiographic distribution of SWE.

(Ongoing) Coupled modelling of surface, subsurface hydrology and atmosphere in Jordan

Shadi Moqbel, Al-Isra Private University, Jordan

http://goo.gl/mFwG9r

The project will study the effect of past and future climate changes on the eastern watersheds of Jordan. Watersheds under study will cover part of the desert and easter ridges of the mountainous area east of the Jordan valley. Project will evaluate water resources in the area, changes in the climate and its effect on the water storage and the expansion of the eastern desert of Jordan.

(Ongoing) Estimation of sediment discharge in Mexican coastal basins larger than 500 km2, at high resolution

Miguel Angel Delgadillo-Calzadilla, Instituto de Ingeniería UNAM

http://goo.gl/F0HvK5

This research would estimate the sediment discharge, into coastal basins to evaluate the condition of sand beaches along the Mexican littoral.

(NEW) Examining the landscape of the lower Chanduy Valley, Ecuador

Chris Blair

http://goo.gl/IxECyf

Archaeological research in southwest Ecuador over the last 50 years has revealed the underpinnings and life ways of the Valdivia culture. Research in the 1970's and 1980's focused on full-scale site excavations, but also in identifying regional site distributions. Research has demonstrated that Valdivia sites are riverine-oriented, often located in or near floodplains. This project aims to analyze a localized area in southwest Ecuador known as the Chanduy Valley using geospatial data in order to better understand its social and physical environment.

This project seeks to identify changes to the physical and social environment of the Chanduy Valley from a landscape archaeology prospective. Fieldwork was conducted during July, 2015 in order to collect high-resolution orthomosaic information using a fixed-wing drone. The data will be analyzed in the CHILD landscape model in the CSDMS web modeling tool (WMT) utilizing a high performance computing cluster.

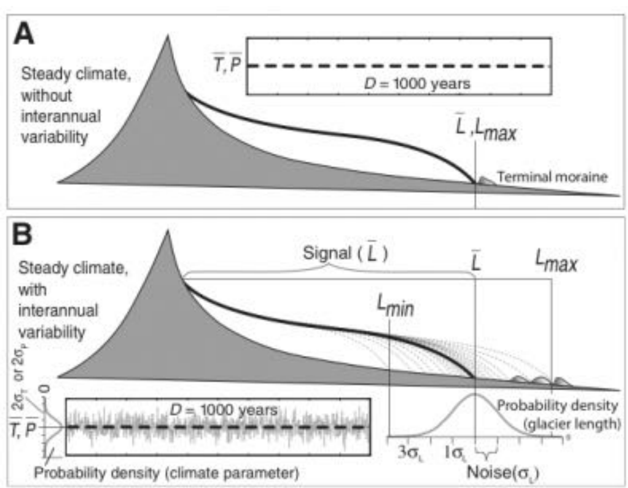
The results of this project will be published in a forthcoming master's thesis.

(NEW) Interannual variability and Glacier Modeling

Leif Anderson, University of Colorado

National Science Foundation (NSF) grant DGE- 1144083 (GRFP)

http://goo.gl/qcN9bi



Valley glacier moraines are commonly used to infer past mean annual precipitation and mean melt-season temperature. However, recent research has demonstrated that, even in steady climates, multi-decadal, kilometer-scale fluctuations in glacier length occur in response to stochastic, year-to-year variability in mass balance. When interpreting moraine sequences it is important to include the effect of interannual weather variability on glacier length; moraines record advances that are forced either by interannual variability or by a combination of climate change and interannual variability. Our hope is to help establish the metrics needed to determine if a past glacier advance was caused by interannual variability or a climate change.

Objectives:

1. Assess the importance of year-to-year climate variability (weather) on glacier length in a variety of climate settings

2. Create quantitative metrics to test if a glacier length change could be caused by weather variability.

We are using 1 and 2D Matlab-based numerical glacier models. The models are used in both idealized and geographical settings with a variety of parameterizations for glacier mass balance. We are primarily using a 2D debris-covered glacier code to determine the importance of debris-cover on glacier length. Beach allows us to explore a wide parameter range efficiently and is therefore imperative for the success of this project. We will also be using gc2D.

Results:

Interannual variability in mean melt-season temperature and annual precipitation can cause kilometer scale fluctuations in glacier length independent of climate change [e.g. Oerlamans, 2000 and Roe and O'Neal, 2009]. We perform model simulations to gauge the uncertainty in mean glacier length, the length over a given time period which represents the long-term climatologically relevant extent, for the Younger Dryas (YD) and LGM ice extents in the Rakaia valley, NZ. We used a 1D flowline model (e.g. Oerlemans, 2000) with variable width forced by independent white noise realizations [Oerlemans, 2000; Roe and O'Neal, 2009; Anderson et al., 2014]. One white noise realization was modified by the standard deviation of mean summer (DJF) temperature (σT = 1.1 °C) from the Lake Coleridge weather station (location info), and the other realization was bracketed by estimates of the standard deviation of annual precipitation from a representative weather station. The variability of annual precipitation increases with higher annual precipitation amount [e.g. Burke and Roe, 2013]. Because of the strong orographic precipitation gradient and rain shadow in New Zealand, precipitation amounts range from greater than 6 m a-1 west and near the topographic divide to less than 1 m a-1 in some locations east of the divide (Fig. 3) [Ummenhofer and England, 2007]. Data derived from lowland meteorological stations on the east side of the divide do not capture the modern variability in annual precipitation in the glacial accumulation zone. We use a standard deviation of annual precipitation based on meteorological station data with a mean annual precipitation of 5.5 m a-1 and standard deviation of annual precipitation amount (σP of .87 m a-1) [Woo and Fitzharris, 1992]. This data is from a meteorological station on the west side of the drainage divide and was chosen because annual precipitations amounts in the accumulation are likely to be larger near the divide than the data from this station so the standard deviation of annual precipitation is a minimum estimate. We use a mass balance profile derived from the energy balance methods outlined in Plummer and Phillips et al., 2003 and perturb the profile with using a meltfactor of .7 m °Cyr-1. This meltfactor is the most often occurring melt factor based on a global compilation of modern meltfactors for ice [Anderson et al., 2014].

Younger Dryas Results: The glacier leaving the YD ice extent in the Rakaia valley had a complicated geometry. Three distinct glaciers join within 3km of the maximum glacier extent. We modeled all three glaciers and fed the two smaller glaciers into the main stem to capture the terminus fluctuations derived from asynchronous response times between the three glaciers (after MacGregor et al., 2000). We allowed each white noise-model coupled simulation to run for 1000 years [Kaplan et al., 2013]. Because it is impossible to know the exact pattern of year-to-year fluctuations in annual precipitation and mean melt season temperature during the Younger Dryas in New Zealand we ran 1000, 1000-year simulations to estimate the most probable mean glacier length for the small parameter space we explore. The most likely mean length for the Younger Dryas extent in the Rakaia valley was ~ 550m (or 6.5%) upvalley from the YD terminal extent. The standard deviation of this mean length from the most likely mean length was 170 m and the standard deviation of glacier length was 260 m. The mean length results for the YD are lower than those discussed by Anderson et al. [2014] largely because of the reduced duration of the white noise climate forcing (Anderson et al. [2014] used a most likely climate duration of 4000 years for the LGM) and the limited parameter space explored.

Last Glacial Maximum Results: We allowed each white noise-model coupled simulation to run for 4000 years [e.g. Anderson et al., 2014]. We ran 400, 4000-year simulations to estimate the most probable mean glacier length for the small parameter space we explore as represented in the assumed mass balance profile, meltfactor, and flow law parameter. The most likely mean length for the LGM extent in the Rakaia valley was 1.7 km (or 2.2%) upvalley from the LGM terminal moraine. The standard deviation of this mean length from the most likely mean length was 410 m and the standard deviation of the glacier length through the model runs was 770 m. The mean length results for the LGM are lower than those discussed by Anderson et al. [2014] largely because the LGM glacier modeled here is significantly larger in volume and has a longer response time than the largest glacier modeled in the Colorado Front Range. This discrepancy may also result because of the limited parameter space explored.

Discussion: Glaciological modeling studies extracting paleoclimate estimates should use the mean glacier length as opposed to the maximum glacier length. Modeling to the actual maximum ice extent will provide a maximum estimate of climate change. To date, the Rakaia LGM glacier is the longest (~80 km) and largest volume glacier modeled with white noise year-to-year variability, which is present in all climate states, past or present. While the magnitude of the most likely fluctuation is larger for the LGM glacier (even when taking into account the different durations of the YD and LGM simulations (1000 yrs versus 4000 yrs)) these fluctuations represent a smaller percentage of the maximum length of the glacier when compared to the YD glacier [e.g. Anderson et al., 2014]. Though we cannot make a rigorous examination of this effect here it appears that larger glaciers with longer response times tend to produce the most reliable paleoclimate estimates when the modeling to the maximum ice extent. The variability of annual precipitation and melt season temperature are large compared to other studies, implying that variability will likely have an important effect on the fluctuations of advances less extensive than the YD advance. Further modeling efforts should be preformed to test whether smaller advances could be explained by interannual variability and potentially independent of actual climate changes. We use white noise forcing for these simulations. Our current meteorological records do not cover a long enough time span to confidently test for memory (or correlation from year-to-year) [e.g. Burke and Roe, 2013]. If there actually is memory in year-to-year mean melt-season temperature or accumulation season precipitation the magnitude of these noise-forced glacier fluctuations would be greatly enhanced.

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(Ongoing) HAMSOM to South Atlantic

Joaquim Pereira Bento Netto Junior, Federal University of Parana

Phd scholarship from CNPq-DAAD program from Brazil

http://goo.gl/RQ50eF

(Ongoing) Hydraulic Bore into Shear

Zach Borden, University of Santa Barbara

http://goo.gl/JpfThm

We are expanding Zach Borden's work on the circulation model onto the case of hydraulic bores propagating into shear.

(NEW) Improving Representations of Snow-Vegetation Interactions

Adrian Harpold

Applying LiDAR-derived vegetation datasets to verify and improve snow-vegetation interactions in land surface models.

Objectives:

1. Run Noah-MP using LiDAR-derived vegetation information from four sites in the Western U.S.
2. Investigate how resolution of vegetation information effects water and energy fluxes during winter.

NSF EAR Postdoctoral Fellow (EAR#1144894)

http://goo.gl/zcPpwJ

(Ongoing) Landscape Evolution Modeling of Terrain Modified by Agricultural Terracing

Jennifer Glaubius, University of Kansas

http://goo.gl/bX0k8O

(NEW) Landscape Evolution for Southern Africa

Jessica Stanley, University of Colorado

http://goo.gl/J1IWlb

Predicting the landscape evolution for southern Africa over a 150 my time period. This will be investigated with the erosion model Fastscape (Braun and Willet, 2013) coupled with a thermal module that can predict cooling ages for different thermocrhonometers. It also predicts topography and sedimentary flux volumes of the major river deltas. These model outputs can be compared to real thermocrhonology and sedimentary flux data from southern Africa. The model can also be run as an inversion to decipher which set(s) of model parameters best predict the observed data. From this inversion we can learn about the timing of uplift for southern Africa and also about the relationships between model parameters and therefore about the system. These inversions, especially long ones with many model parameters, are computationally intensive and I am interested in using the HPCC to perform some of these inversions.

Used models: Fastscape, PLEM, and Pecube

(NEW) Large River Floodplains

Dan Parsons, University of Hull Internal funding (UK)

http://goo.gl/FzJ7Be

This project is examining connections between large rivers and their vast floodplains.

Models in use: HydroTrend, WBMSed

(Ongoing) Modeling stream capture in strike-slip fault settings

Sarah Harbert, University of Washington

http://goo.gl/oHIo7M

Investigating the effect of stream size and sediment supply on stream capture.

(Ongoing) Multiscale stratigraphic and statistical characterization of fluvial systems

Jesse Pisel, Colorado School of Mines, Chevron Center of Research Excellence, Rocky Mountain Association of Geologists, Colorado School of Mines, The Geological Society of America, Gulf Coast Section SEPM, Rocky Mountain Section SEPM, AAPG Grants in Aid

http://goo.gl/ALqJMr

Many different statistics are currently used to compare numerical and physical models of fluvial systems to outcrop datasets. This project focuses on evaluating the current methods and determining the most robust and accurate way to quantitatively compare models to outcrops.

(New) NCEP data read

Taylor Winchell, University of Colorado

http://goo.gl/76HIWH

The goal of this project is to parse NCEP global meteorological files and assemble the parsed results into a data frame that can be used to characterize rain-snow threshold curves.

This data will be analyzed in R

Funding: NSF GRFP

(New) Quantitative analysis of deepwater depositional systems

Ningjie Hu, University of Texas at Austin

http://goo.gl/dTylO8

My project will employ the modeling tools in CSDMS to delineate the evolution of and controls on deepwater depositional systems.

Objectives:

1. Employ models for quantitative analysis toward an improved model to better understand and predict deepwater architecture.

2. Benefit the community and related research.

This study will use Sedflux-2D and 3D

(Ongoing) River plumes in Ecuadorian coast

Willington Renteria, Secretaria Techica del Mar, Ecuador

The project is funding by Secretaria del Mar, as an investment project from Ecuadorian Government

http://goo.gl/odCSAz

The project is focused in understand of the effect of river plumes in ecosystems of ecuadorian coast. A lot of nutrients are carried out by rivers to the marine-coastal ecosystems, some of them affecting the marine reserves in the coast. Moreover, the Humboldt current is present in the south of the coast also carrying out a lot of nutrients. The interaction between the Humboldt current and the river plumes is poorly understood, the focus of this project is try to quantify this interaction.

(Ongoing) Simulation of Granular Flows

Jim McElwaine, University of Cambridge

Funded by University of Cambridge

http://goo.gl/KCxvSX

Granular flows are ubiquitous in the environment. In some cases interaction with the ambient fluid is critical, for example debris flows, turbidity currents and powder snow avalanches. In other cases the flow dynamics are governed only by the dry granular material, for example, rock-slides and dense avalanches. In both cases accurate theories are necessary for the describing the granular material, but there is no known governing equation for granular matter in the way that the Navier-Stokes equations describes fluids. The aim of this project is to study granular systems by direct simulation using the Discrete Element Method (also known as Molecular Dynamics), in which the equation of motion for each individual grain in integrated in time accounting for solid contacts and interactions with the ambient fluid.

(Ongoing) Spatial Distribution of Solar Radiation as a Driver of Hillslope Asymmetry Across Latitudes

Omer Yeteman, University of Washington

This research is supported by NSF through grants: NSF-EAR 0963858, NSF-ACI 1148305.

Ecohydrologic roles of incoming solar radiation on landscape evolution in a semi-arid ecosystem are demonstrated by Yetemen et al. [2015] with CHILD (Channel-Hillslope Integrated Landscape Development) landscape evolution model. In this framework, the CHILD model which is equipped with a solar radiation-driven ecohydrologic vegetation dynamics model and a vegetation-modulated fluvial incision model, is sufficient to reproduce first-order characteristic of aspect-related observed vegetation distribution and hillslope and catchment-scale geomorphic patterns in New Mexico [Istanbulluoglu et al., 2008].

Poulos et al. [2012] investigated hillslope asymmetry across the American Cordillera from 60°N to 60°S latitude. They described hillslope asymmetry with an index, HAI (Hillslope Asymmetry Index) which is a comparison of median slope of different aspects (N versus S, or E versus W). They calculated HAI of N-to-S, HAIN-S through the American Cordillera based on 90-m DEM by using a 5 km by 5 km sliding window, the HAIN-S is nearly 0 at the equator, and systematically increases toward the North Pole which means steeper north-facing slopes than south-facing slopes, and systematically decreases toward the South Pole which means steeper south-facing slopes than north-facing ones. The absolute value of HAIN-S maximizes at mid-latitudes, and then begin to decreases toward the poles, finally sign changes further than 49°N and 40°N latitudes on the Northern and Southern Hemisphere, respectively.

In this project, we want to further explore the ecohydrologic role of solar radiation on landscape development at different latitudes, from 45°N to 45°S, for a range of semi-arid climatology, mean annual precipitation from 200 mm to 500 mm. To achieve this goal, the model will be adjusted based on required changes including the amount of incoming solar radiation, timing of wet season, and storm characteristics etc. At the end of this project, we will answer following questions: What is the role of solar radiation on landscape evolution at different latitudes? What is the role of mean annual precipitation on this role?

Publications:

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- Collins, D. B. G., R. L. Bras, and G. E. Tucker (2004), Modeling the effects of vegetation-erosion coupling on landscape evolution, J Geophys Res-Earth, 109, F03004, doi:10.1029/2003JF000028.
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- Istanbulluoglu, E., and R. L. Bras (2005), Vegetation-modulated landscape evolution: Effects of vegetation on landscape processes, drainage density, and topography, J Geophys Res-Earth, 110, F02012, doi:10.1029/2004JF000249.
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(Ongoing) Teaching basics of modeling in earth systems

Sarah Harbert, University of Washington

Funded by the University of Minnesota Office of Equity and Diversity

http://goo.gl/KkdneY

We are using CSDMS in a course offered at University of Minnesota Duluth titled 'Creative problem solving in earth science.' This is a project based course, focused on providing an overview of quantitative tools and models and how to start creating them.

(Ongoing) Terrestrial Hydrology

Theodore Barnhart, University of Colorado, Noah P. Molotch, University of Colorado, Adrian Harpold, University of Colorado, John Knowles, University of Colorado, Suzanne Anderson, University of Colorado

Funded by:

- NSF EAR Boulder Creek CZO (DEB-9810218)
- USDA-NSF Water Sustainability and Climate Grant (2012-67003-19802)
- NSF Niwot Ridge LTER (DEB-1027341)
- NSF Hydrologic Sciences EAR (1141764)

http://goo.gl/ssNHxu

Snowmelt is the primary source of surface water in the western United States and many other regions on Earth. Climate warming is forecast to impact the amount of precipitation that falls as snow and forms the mountain snowpack. Climate change induced alterations to snowpack translate to changes in snowpack magnitude, the timing of snowmelt, and changes in snowmelt rate. We ask how these perturbations may impact how snowmelt is partitioned between evapotranspiration (ET) and runoff (R) at Como Creek, a snowmelt dominated catchment on the Colorado Front Range. Como Creek is a 4.5 km^2 headwater catchment spanning 2900-3560 m and is part of the Niwot Ridge Long Term Ecological Research Station and the Boulder Creek Critical Zone Observatory. We use observations of snow water equivalent (SWE), ET, and precipitation (P) from Niwot Ridge, CO, and discharge from Como Creek to explore relationships between snowpack dynamics and snowmelt partitioning. Measurements of ET are collected adjacent to Como Creek at the Niwot Ridge Ameriflux site and are assumed representative of the hydrologic fluxes in Como Creek. Analyses from point data show that years with higher peak SWE/P ratios partition proportionally more snowmelt to ET (pValue: 0.045). For example, water year (WY) 2005 has a peak SWE/P ratio of 0.49 and a growing season ET normalized by WY precipitation (ET/P) ratio of 0.48 while WY 2008 has a peak SWE/P ratio of 0.83 and an ET/P ratio of 0.82. Observations also show that years that experience later peak SWE (DOY=142) partition proportionally less snowmelt into ET (ET/P=0.42) compared to years that experience earlier peak SWE (DOY=86) and partition proportionally more snowmelt to ET (ET/P=0.56). Further point analyses also suggest that more rapid snowmelt results in proportionally less snowmelt partitioned to ET and more partitioned to runoff. To explore the underlying processes responsible for these relationships at the catchment scale we use the Regional Hydro-Ecologic Simulation System (RHESSys) to model how snowmelt is partitioned between ET and R under observed conditions and under a variety of climate change induced snowmelt timing, magnitude, and rate scenarios.

(Ongoing) Understanding sediment delivery to deltas under environmental changes using WBMsed and HydroTrend

Frances Dunn, University of Southampton

Funded by University of Southampton, Southampton Marine and Maritime Institute (SMMI)

http://goo.gl/ksLW9m

This project is focused on increasing understanding of how environmental changes affect sediment flux to the world's more vulnerable deltas. Relative sea-level change is affected by sediment deposition (aggradation) along with subsidence, isostatic, and eustatic changes. This means that the sustainability of delta environments relies in part on the rates of aggradation, which in turn are affected by sediment delivery from catchments feeding deltas.

(NEW) Varanasi

Ashok Shaw, IIT Kharagpur, India

http://goo.gl/mZXHdP

The project is to understand the role of the Ganges evolution in the development of the Varanasi city. Since the city is situated along the banks of river Ganges, the fluvial geomorphology plays a significant role in controlling the stratigraphy of the city. I would like to understand the role of processes (climate/tectonic) which controls the Ganges evolution (especially Ganges avulsion).

Application of geoscientific methods to delineate the extent of growth phases of Varanasi civilization Understanding the effect of evolution of the Gangetic plain in the development and sustenance of Varanasi Integration of these past information in understanding the future growth of the city

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(NEW) Vortex pairs interaction with density interface

Christina Schmitt, University of California, Santa Barbara

http://goo.gl/CRZfN3

The dynamics of vortex flows in uniform density are reasonably well observed. But the impact of them on a boundary surface of fluids with different densities is also of interest. In this project, the impact of a vortex pair on a density interface is investigated. When the vortex pair approaches to the interface, counterrotating vorticity develops at the interface. For high density differences, the interaction of the vortex pair with the density interface is comparable to the interaction with a solid wall. If the density difference of the fluids is smaller, the vortex pair penetrates the interface. The ratio between the strength of the density difference and the vortex strength and the angle at which the vorticies approach the interface are varied. The effect of changing the viscosity (Reynolds number) will also be examined.

Links: https://sites.google.com/site/ucsbcfdlab/

(NEW) Teaching WMT course at University of Florida

John M. Jaeger, University of Florida

(NEW) Teaching WMT course at Utah State University

Patrick Belmont, University of Florida

(NEW) Bootcamp at the University of Colorado, day before annual meeting

Mariela Perignon, Mark Piper, University of Colorado

http://goo.gl/n6Xhy5

20 Participants attended.

(NEW) Three-day WMT modeling introduction during NCED summer course

Irina Overeem, University of Colorado

Approximately 40 participants attended.

(NEW) Two 3hour clinics made use of the HPCC during the annual meeting

Irina Overeem, Mark Piper, Eric Hutton, University of Colorado

http://goo.gl/Y3YMWH

Approximately 56 participants attended these clinics.

Appendix 11: Human Dimensions FRG Workshop Notes and Agenda

Workshop Report: Linking Earth System Dynamics and Social System Modeling

23-25 May 2016, Boulder, Colorado
Organizers: Human Dimensions Focus Research Group, CSDMS
Funders: NSF, CSDMS and AIMES/FE

Context
Aim. *To bring together a diverse group of researchers from multiple disciplinary backgrounds to push forward the boundaries of global-scale, coupled social and biogeophysical modeling.* The workshop was used to develop a strong research plan and timetable for the integration of human systems models with Earth system models. This was based on establishing a distributed network of researchers with the cross-and trans-disciplinary skills to implement this ambitious project. The workshop began the process of developing a joint modeling effort that represents the effects of human activities on environmental change in better ways than is done currently.

Purpose: *To assess the intellectual, informatics, and material resources needed to develop global models of human systems dynamics and couple them with models of Earth system dynamics in order to further understanding of the interactions and feedbacks within the integrated human-environmental system that dominates the globe today.* Coupled human and Earth system models will help us better understand and anticipate consequences of changes in both social and natural drivers of coupled social/natural systems (e.g., climate, policy changes, etc.). The workshop was used to establish an interdisciplinary scientific network with the expertise needed to build integrated Human-Earth System Models (HESMs) to carry this initiative forward.

Outcomes: *A three-year research plan and timetable written into a White Paper to identify the most tractable components for modeling of the coupled Human-Earth system that can be scaled up from the local to the global.* In addition, the workshop supported further development of a US national center for advanced social informatics and analytics.

Output: *Recommendations for modeling priorities and resource needs, and a new community of modelers of global-scale coupled human and Earth system models.* The workshop agenda is given in Annex 1, and the full participant list in Annex 2.

Background
Projections indicate that the global population may grow to 9-14 billion by 2100, with global GDP per capita increasing from an average US$10,000 today to US$35-155,000 in 2100(1), increasing global demands for water, food and energy. Global demand for crops is expected to rise 60-110% by 2050 (2, 3) fueling a projected 50% increase in water demand (4) while at the same time, the use of crops or crop area for the production of bioenergy creates an additional pressure. Climate change and associated increases in extreme weather events will also impact the availability and quality of water resources (5), agricultural production and associated demands for irrigation (6), and ecosystems, resulting in total economic losses estimated to reach 5-20% of GDP by 2100 (7). These losses could be reduced significantly if the global mean temperature rise were to be constrained to 2°C above pre-industrial levels (8). On the other hand, the collapse of states, the chance of major pandemics in addition to erratic climate events may throw this business as usual scenario into disarray. Against these alternative background scenarios, the UN has proposed sustainability goals

including "Ensure availability and sustainable management of water and sanitation for all" (goal 6); "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" (goal 2); and provide "access to affordable, reliable, sustainable and modern energy for all" (goal 7); whilst at the same time reducing "climate change and its impacts" (goal 13) and ensuring "sustainable consumption and production patterns" (goal 12) (9). This raises the question: what can the scientific community provide in terms of knowledge and modelling tools in support of achieving these goals?
The Earth system (coupled processes of the atmosphere, geosphere, and biosphere) is increasingly dominated by human action, and at the same time Earth system processes continue to significantly impact human life and well being (10). This creates an urgent need for closer coupling of social simulation models representing human behavior with Earth system models (ESMs) that focus on biogeophysical process representation (11). Advances in ESM science is giving us invaluable insights into Earth system dynamics and helping us better plan for future conditions. But, existing models typically consider humans as external to the Earth system, allowing for few (if any) feedbacks based on the diverse human decisions and activities that might amplify or dampen environmental changes. Human managed land-cover is initialized in land components of ESMs and estimates of anthropogenic greenhouse gases (e.g., Representative Concentration Pathways) are injected into ESMs at different time intervals. At the same time, most current global models of human action focus on the social world of economic markets, resource extraction, agriculture, energy production/consumption, etc.; biophysical phenomena are considered as externalities or as boundary conditions 2.

Yet we know that Earth system processes have effects on human societies, and social response to these dynamics (e.g., climate change or ocean circulation) impacts biophysical systems; we need to acknowledge and understand the bidirectional feedbacks between them (11). Thus, it is important to develop a new generation of integrated human and Earth system models (HESMs), coupling the dynamics of both biogeophysical and social systems of human decisions and actions (12). This is essential for new insights into the multi-scale interactions among markets, atmospheric physics, energy consumption, terrestrial hydrology, water use, soil biochemistry, land-use, and other societal and biophysical processes (11, 13). To accomplish such a goal requires a diverse set of social, natural, and computational scientists to work together, to learn one another's languages, and integrate methods from these different disciplines.

There is a growing awareness of the importance of considering social and biogeophysical processes as a single, complex, global system. For example, the National Flood Interoperability Experiment is collecting and synthesizing data at a continental scale on the impacts of the atmospheric component of the Earth system on human systems, so that local and regional authorities can better anticipate and plan for extreme weather. However, only the one-way effects of weather on society are considered. There is no consideration of the feedbacks of human actions back to the climate system, or how those feedbacks would, in turn, affect weather hazards. The new NSF-wide FEW Nexus initiative is a more comprehensive effort to begin to capture the two-way interactions between some of the human and natural components of the modern Earth system. However, there is no indication in the initial 'dear colleague' letter for this program of an intent to support research on the evolution of current ESMs into HESMs.

Hence, the overall aim of this workshop was to bring together a diverse group of researchers from multiple disciplinary backgrounds to push forward the boundaries of global-scale, coupled social and biogeophysical modeling. The workshop was used to develop a strong research plan and timetable for the integration of human systems models with Earth system models. This will be based on establishing a distributed network of researchers with the cross- and trans-disciplinary skills to implement this ambitious project. The workshop will begin the process of developing a joint modeling effort that represents the effects of human activities on environmental change in better ways than is done currently.

It is important to recognize that much of the current development and application of biogeophysical ESMs within the US takes place in national facilities such as the National Center for Atmospheric Research or Oakridge National Laboratory. Indeed, facilities developing and managing ESMs are aware of the importance of human processes to the Earth system, as evidenced by the CESM Social Dimensions Working Group at the National Center for Atmospheric Research, and the iESM group at Oakridge National Laboratory and Lawrence Berkeley National Laboratory. However, while these centers employ small numbers of social scientists, their primary missions and scientific expertise focus primarily on the biophysical components of the Earth system. Thus, it is not surprising that we still lack models at the global scale that represent human behavioral processes. This underscores the need for a national initiative, with specialized knowledge and capacity in social informatics and human systems, to develop and maintain global-scale models of decisions and behaviors that could be integrated with existing biophysical model code for the Earth system. Scientists engaged in building these more comprehensive HESMs could also lead the creation of science-based scenarios to support decision makers in identifying robust strategies for societal sustainability in a changing world. The workshop began this process. The workshop consisted of leading representatives from computational social science communities and Earth system modeling communities in the US and internationally. This included collaboration with national laboratories that have an interest in the human dimensions of the Earth system (see list of participants in Annex 2).

Content

Approach: The workshop established a set of seven interdisciplinary scientific research issues and key questions through facilitation. Following identification of the issues, break out groups were asked to address each of four questions: What is the scope of the scientific questions in your overall issue? What are the methods needed to address the issues? What are the best opportunities to take the set of issues forward? What are the funding opportunities? The outcomes of the breakout groups are presented in the following.

1. The purpose of linking models (Chair, Hill): The purpose of developing a linked modeling effort include: to answer questions, generate questions (new realizations, discovery) and test hypotheses in order to create more representative models that are more accurate and useful. This would serve to broaden the conversation, rather than to steer the conversation, and would require the development of a new modeling community. But, we are still not clear about how to develop such models. We do know, however, that if we want to inform new model development, then we need more on the human science side; we can't simplify out humans. We also know, that without impact, this type of research will not be funded.

Another purpose of linked models is to prioritize. For example, what information does a decision-maker need to do their job better? The process then is not just about incorporating human decision-making into ESMs, but also in providing tools to make decisions. Flint, Michigan is a good example of the breakdown between human and natural systems, arising from non-responsible government, since no model was available to test the impact of decisions taken. With better models, both problems and solutions become more visible as a guide to decision-making.

We need to be clear about why these new linked models are different. Model diversity is good, but it is also valuable to understand why models are different. Humans dimension models can produce inputs for existing Earth system models (including feedbacks) or reproduce a known human system process (e.g. agricultural intensification, demographic transition, evolution of technology, urbanization). But, we need to have clear goals concerning integration of human dimension processes in ESMs. A big advantage of models, however, is that they force people to work together and confront one another's ideas, processes, capabilities, etc. Models are often built as part of a large, governmental or corporate infrastructure. There are benefits to developing a single community model because people contribute to this collectively and are supported by the community. But this assumes that the utility of the modeling process is to produce a tool that will be used by everyone. Conversely, a new community could be an umbrella for coordinating a range of different human models. So, we need to ask ourselves whether the purpose of developing new models is to converge the science or diverge the science.

2. Land and water issues (Chair, Barton): Modeling human dimensions of dynamics in Earth's land and water systems potentially engages all critical zone systems except the atmosphere. Hence, this group tried to identify a more tractable scope for a near-term science plan. Initially, we focused on examples of land and water dynamics that could benefit most from coupling biophysical and human systems models. But, because humans now have such a significant impact on terrestrial and aquatic systems, realistically modeling very many of these systems requires consideration of the human component (see Figure 1).

We therefore selected three land/water subsystems related to important issues of human well-being in the near-term future: agricultural land-use for food security, access to surface fresh water, and the growth of urban systems. We recognize that many other dimensions of land and water systems than these could be better understood through coupling models of human and earth systems. Nonetheless, these three domains of social-natural dynamics and their broader consequences encompass much of the range of issues that could be addressed through better modeling efforts and could serve as initial proof of concept to justify subsequent expansion of modeling. Moreover, there are important interaction dynamics between each of these three subsystems.

For example, access to surface fresh water for irrigation has significant impacts on the kinds of agricultural land use practiced, and its ability to produce adequate food, especially in arid and semi-arid climate zones that are forecast to grow in extent over the next century. Conversely, agricultural land use has significant impacts on surface water availability, with irrigation reducing flows in rivers and streams and agricultural runoff affecting both sediment load and water quality. At the same time, rapidly urbanizing regions create increased demand on fresh water sources. Many of the world's largest urban areas are located on deltas at the mouths of major rivers. Urban land use is increasing rates of subsidence in deltas, agriculture can increase sediment load that increases the rate of delta formation, and damming of large rivers - to provide more secure water availability for farming and for urban use - reduces river flows and decreases the rate of delta formation. In these complex systems, the interplay between agriculture, water management, and urbanism will have significant impacts on a large fraction of the Earth's population in the coming years.

We also recognize that these three domains leave out the greatest part of the earth's critical zone, the oceans. Again, however, we have greater current knowledge and more existing modeling programs that deal with terrestrial systems than with human-biophysical coupling in marine systems. Especially for coastal environments, it will be increasingly important to support new research and modeling of human-biophysical interactions for marine systems.

For each of the three land/water subsystems chosen for more intensive focus, we discussed current modeling programs and development needs for coupling human and earth systems models.

Agricultural Land-use: There are numerous process-based models for different dimensions of the human and biophysical interactions of agricultural land-use and its consequences. These generally fall into three broad categories: economic models of agricultural commodity markets (including integrated assessment models), crop (and livestock) models that represent the growth and productivity of edible plants (and animals) under different land-use practices and edaphic conditions (weather, soil, moisture, etc), and physical models of landscape evolution (e.g., soil conditions, hydrology) and climate that can affect crop productivity. Some of models in each general class can also incorporate simplified representations of a few dynamics of other categories, but in general, the phenomena represented in each category treats the phenomena in other categories as exogenous input. That is, the components of sophisticated coupled human-biophysical models of agricultural land-use and landscapes currently exist in one form or another, but there is little in the way of dynamic coupled modeling across these components. This seems to be a domain in which scientific insight with significant benefits for food security can be realized rapidly through coordinated efforts to integrate existing modeling capacity.

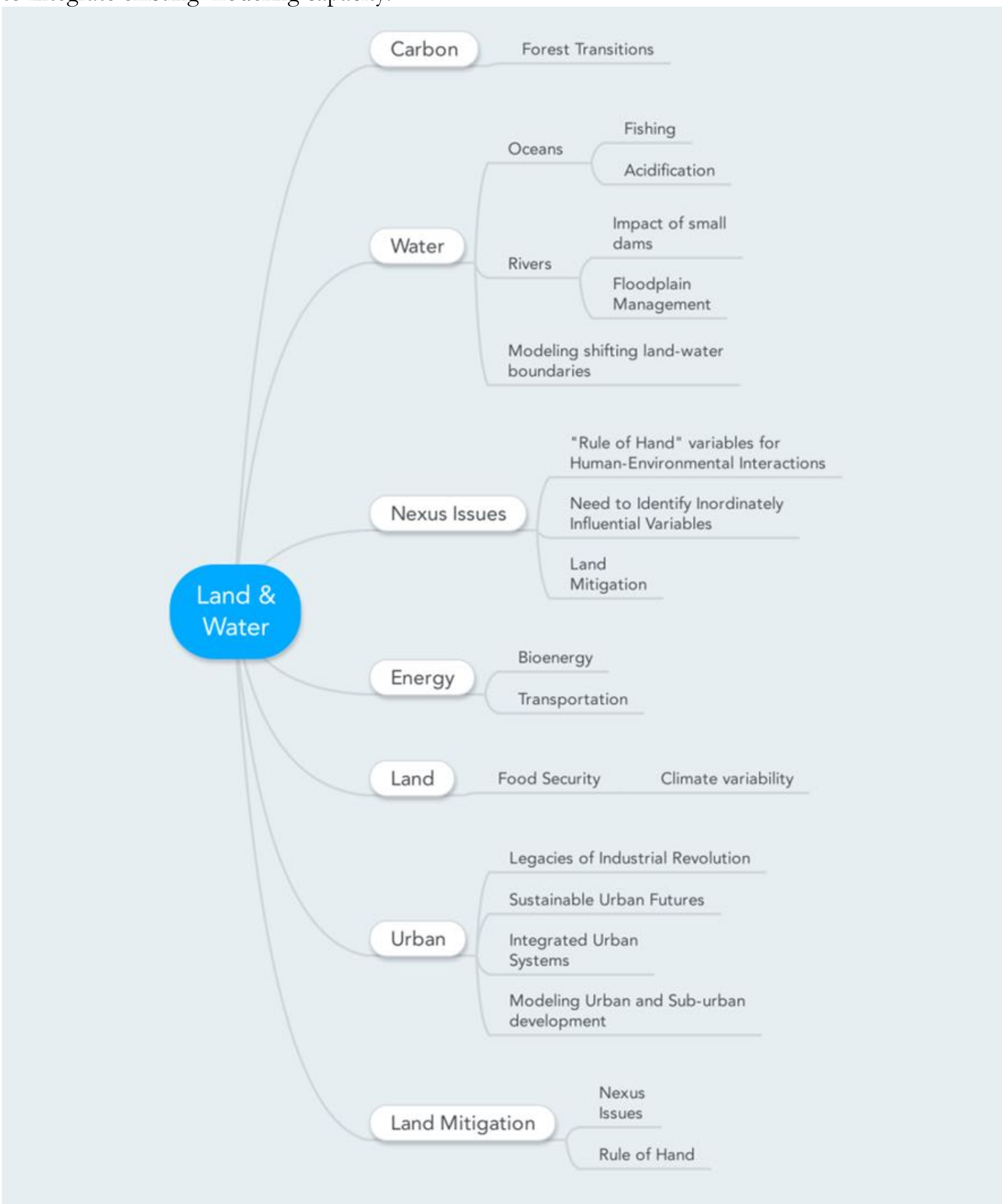

Figure 1. *Examples of land and water systems where coupled biophysical and human modeling would be particularly beneficial.*

Important methodological issues that need to be overcome are especially those of spatial/temporal scale. Many (but not all) physical models of environmental dynamics important to crops and livestock are spatially explicit, and have variable time steps that can range from minutes to years. Many crop models are spatially explicit in only a very limited sense, representing conditions in a single farm field or pasture, but can potentially be transformed to deal with spatially more extensive, gridded landscapes. Relevant time steps range from daily to monthly to seasonal to annual. Economic models of land-use decision-making are often (but not always) largely aspatial or aggregate decisions and markets at very coarse spatial scales (e.g. all of North America or western Europe). Time steps commonly range from annual to decadal. An important requirement of coupling these different modeling categories involves developing reliable and systematic ways to upscale and downscale spatially, to operate at common time steps, or to aggregate and disaggregate across different temporal intervals. In developing better ways to couple these components, it is important to note that when aggregating or upscaling, variation might be more useful than the more normally calculated mean or medians.

Availability of Surface Water: There are many, highly developed, and extensively tested, hydrological models for surface water flow at multiple scales. There is also a mature - even if less standardized and less widely used - modeling technology for representing water demand for human consumption, agriculture, and industry. However, there is very little in the way of coupling across the human and biophysical ends of these systems. Issues needed to combine these two classes of models are less clear than for agricultural land use. However, probably similar mismatches in spatial and temporal scale are equally important here. Also, water users encompass a greater range of social and economic heterogeneity than found in the agricultural sector, and will need to be represented in adequate ways. A further challenge will be addressing the importance of coupling models of water use/demand and water flow/management to agricultural land-use systems discussed above. As access to water becomes even more important in coming decades, it will be impossible to sustainably manage this critical resource without finding a way to integrating models of the primary drivers of terrestrial surface water dynamics - human social action - with models of the biophysical dynamics of streams, rivers, and lakes.

Urbanization of Land: Much representation of the futures of cities is qualitative and expressed as narratives. Most extant quantitative representations primarily take the form of GIS models that are empirically-based 'snapshots' of future states rather than modeling the dynamics of urban systems. There are a few exceptions to this characterization, including the modeling work of Marina Alberti and Michael Batty. In all models of urbanization, however, there is little if any consideration of the biophysical dynamics of urban areas. Additionally, there is little in the way of biophysical, Earth-systems-like modeling of urban environments beyond attempts to estimate urban heat properties - currently, in very simplified and spatially coarse-grained ways.

Conversely, large and complex data sets on urban characteristics (AKA 'big data') are being used in innovative ways to better understand the growth of cities across large geographic regions. This 'urban scaling' research, best known from the work of Luis Bettancourt and colleagues, is beginning to also produce (as yet simple) generative models to account for widespread empirical patterns in the data.

The current state of affairs presents significant challenges - and significant opportunities - for modeling urban systems and the urbanization of the Earth as coupled socio-ecological systems. The limited availability of generative models for the human components of urban dynamics and the lack of biophysical models for urban regions underscores the need for considerable model development from the ground up for urban land-use. On the other hand, this same situation means that there are fewer legacy issues and path dependencies in existing modeling that need to be overcome. Finally, the use of big data for human systems seems more advanced in urban research than in the other two domains.

Taking it forward: In order to lay the groundwork for a 3 to 5-year science plan, we discussed current modeling efforts that might serve as exemplars or partners in developing coupled models of human and earth systems for agricultural land-use, surface water, and urbanizing regions. Numerous research teams are working on modeling crops and *agricultural land-use*, including IPFRI (CGIAR), IIASA, PIK, and the participants in the AGMIPS program. NCAR and PNNL have land models that can potentially provide Earth system dynamics for crop models and agricultural sector economic models. The NCAR THESIS Project (NSF EaSM2 program) is developing tools for integrating data from IAM (iPETS), crop models (from UIUC), and Earth system models (CESM). At more local scales, a number of the landscape evolution and hydrology models maintained in the CSDMS Integration Facility could also be coupled with human systems and crop models.

Some of the same groups provide useful starting points for integrating human and Earth system models for surface *water accessibility*. NCAR and PNNL are applying biophysical atmospheric and land models (CESM) to water availability at global and regional scales. CSDMS also manages a suite of regional to local scale physical models for surface water. John Riley's group at MIT and Charles Vorosmarty's team at CUNY are working on integrated models for water use and availability.
Marina Alberti's research group at the University of Washington and Michael Batty's team at UCL stand out as leading modelers of *urban systems*. Urban scaling research, emphasizing empirical big data, but beginning to link this to modeling is being led by Luis Bettencourt and Geoffrey West at SFI, collaborating with Jose Lobo and others at ASU and elsewhere. The ASU Decision Center for a Desert City is also emphasizing modeling of urban areas as socio-ecological systems. These groups could provide solid starting points for developing coupled human and earth systems models of the planet's rapidly proliferating urban regions.

3. Coupling Human and Earth System Models (Chair, DiVittorio): The participants in this group represented in depth experience with the issues of model coupling in general, and integrating models of human decision/action with biophysical models in particular, and at multiple scales. The discussion began with participants briefly summarizing examples of model coupling at different scales. Allen DiVittiorio gave an overview of the iESM project to couple CESM and GCAM. Brian O'Neil reviewed the THESIS Toolkit project to rescale and integrate outputs from global scale IAM (iPETS) and Earth systems (CESM) models. Carsten Lemmen described a project integrating human land-use and land cover change at continental scales. Peter Verberg reviewed his work combining human systems and biophysical models at regional scales. Michael Barton and Isaac Ullah presented the coupled human and earth systems modeling at local scales in the MedLanD Modeling Laboratory (MML). Albert Kettner discussed CSDMS work at coupling different kinds of Earth systems models.
Scaling: This initial discussion of participant experiences allowed the group to identify several key, interrelated issues related to both the technical and information quality dimensions of model coupling. Scaling was most discussed. Existing earth systems models (including vegetation and crop models) operate at point, one-dimensional (in space), two-dimensional, or three+ dimensional spatial scales, but most discussion focused on spatially explicit two+ dimensional models. These can also operate at spatial resolutions ranging from centimeters to several degrees of latitude/longitude. Many human systems models (especially economic models like IAMs and CGEs) are aspatial or semi-spatial, using a small number of irregular spatial units defined by political boundaries (e.g., GCAM has 151 units and iPETS has 9 for the entire world, while CESM has 129,600 cells at a 1° resolution). However, some human systems models are also grid based and can operate at relatively high spatial resolutions (e.g. Carsten Lemmen's project and the MedLanD project). Coupling human systems models and different Earth system models requires sophisticated aggregating or downscaling routines to produce meaningful results. The iESM and THESIS Toolkit projects are actively working through these issues for global scale models.

Scaling is not just about space, however. Different models can have different time steps. For example, CESM has a 30-minute time step and GCAM has a five-year time step. Crop models may need diurnal variation in conditions, or monthly or seasonal values. The MML landscape evolution component operates at a one-year time step, aggregating information on precipitation amount and intensity. But other surface process models run at steps of storm events. Harmonizing different time steps can be as complicated as synchronizing spatial scales.

Stochasticity: Related to issues of temporal scaling is the recognition that some models are strongly deterministic, so that the results are essentially the same for any run with the same initial parameters. This is the case for many Earth system models and some human system models (especially econometric style models). Other models have algorithms that generate stochasticity to represent uncertainty in processes. Many agent-based/individual-based models and some cellular automata fall into this category. For models with inherent stochasticity, best practice calls for repeated runs for each set of initial conditions so that a distribution of output results can be evaluated. This can be complicated when stochastic models are coupled with deterministic models. Should a coupled model system be run repeatedly or should the stochastic component of a coupled model be run repeatedly (as if it had a shorter time step) and an aggregate result (e.g. mean) be sent to the coupled deterministic model?

Feedbacks: The ability to represent feedbacks between human and Earth systems is a significant reason for coupling these different kinds of models. Such feedbacks can make models much more (or much less) dynamic and sensitive to changes in parameter values. In most cases, models of human systems and the Earth system are only loosely coupled at best. Carsten Lemmen's project and the MML exemplify the few cases of tight, dynamic coupling in these different kinds of modeling frameworks. The CSDMS also provides software tools to create different degrees of coupling between Earth science models. The scale and stochasticity issues need to be resolved in order to have information passing between human and Earth system models with sufficient reliability to study feedbacks. There also needs to be decisions about what kind of information is passed and what is not passed between models or model components. Even when these issues are resolved, allowing for feedbacks can cause previously stable models to become highly unstable as small variations become amplified in a coupled system, as learned in MML development.

Consistency: Because Earth system models and human systems models sometimes attempt to simulate similar phenomena, like land cover, coupling existing models can encounter significant problems of consistency. By making different initial assumptions and incorporating different processes into models, very different values for the same phenomenon can be generated by different models. Such consistency issues have been identified in the iESM and THESIS Toolkit projects, for example. While model coupling ultimately can help to harmonize and resolve such consistency issues, it will require decisions about which processes to represent and which to leave out when coupling models. Furthermore, other components of a model may depend on values of a phenomenon being within a given range that is not the case when the same phenomenon is modeled in a different way.

Methods: The group discussed a number of technical issues related to successfully coupling human and Earth systems models. It also discussed a number of social issues that are equally important for implementing a multi-year science plan to accomplish this. Three types of approaches to integrating human and Earth system models had the most discussion: off-line coupling by integrating data outputs, tight coupling of models in a single platform for a well-defined set of research and applications goals, and plug-and-play coupling that would allow different models to be connected for different objectives by focusing on community-standard APIs and coupling software (middleware).

Integrating Model Outputs: The NSF funded THESIS Toolkit project is an example of the off-line coupling approach. This is being done by creating software tools that can rescale data output from different kinds of human and Earth system models so that they can be analyzed in an integrated way. This provides new ways to study possible relationships between human systems and the Earth system. It also provides a way to develop pilot versions of downscaling or aggregating methods that could potentially be used to couple models dynamically. It does not, however, allow feedbacks between human and Earth systems to be explored. It also does not provide an environment to resolve consistency issues very well, although there are ongoing efforts to reduce intermodal inconsistencies. Current work is focused on global scale models.

Tight Coupling/Unitary Model Approaches: Most of the examples of coupled human and Earth system models presented by participants use the single model approach, including iESM, Lemmen's modeling system, and the MML. While distinct, stand-alone models are coupled together in such environments (at least for iESM and the MML), the models are fairly tightly 'hard-wired' together such that it would involve considerable work to switch out GCAM for another IAM in iESM, for example, although this is potentially doable. This is because knowledge of what parameters to pass between models and routines for rescaling are built into the code that connects different models into a hybrid modeling system. This means that these unitary model approaches require the scope and scale of modeling efforts to be well defined. The MML uses a kind of middleware "Knowledge Interchange Broker (KIB)" to connect different model components, but this is insufficiently generic to allow for easy swapping between different human or Earth system models. So it is considered under single model approaches for now.

The tight coupling and built-in rescaling code means that feedbacks are operating and changing coupled model behavior in these systems - though the amount of feedback permitted can be controlled by limiting the kinds and amounts of information passed between component models or by introducing damping filters. Stochasticity does not seem to be addressed (or possibly not an issue) for iESM. For the MML, the entire modeling system is run multiple times for each set of initial conditions and aggregate results analyzed. Even though there is much less stochastic variability in the Earth system components of the MML, stochasticity in the human systems component can have a variable impact on the Earth system component - sometimes significantly altering variability and at other times not so much. Consistency issues are also handled in different ways. The iESM project attempts to resolve consistency issues between GCAM and CESM through iteratively running the coupled model until consistency is achieved. In Lemmen's system and the MML, there is no overlap in the phenomena modeled by different components, so no inconsistencies are possible.

Plug-and-Play with Common APIs and Middleware: The advantages of tight coupling and well-defined scope and scale of single model approaches are also their greatest limitations. Human systems and the Earth system are diverse, complex, and multi-scalar. By design, unitary modeling approaches can only represent a predefined subset of potentially important phenomena and only at a single scale without significant recoding of model processes, information passing (and filtering, if relevant) routines, rescaling routines, and even data structures. An alternative approach to coupling is to focus on defining common APIs and sophisticated middleware that would allow any model that conforms to a set of coding standards to be coupled with any other model that conforms to the same standards. The CSDMS has invested considerable resources in developing this approach for Earth system models. It should be noted that even CESM has a "flux coupler" middleware and the MML has the KIB. But, the goal of the CSDMS efforts go beyond these to develop generic modeling coupling approaches that could allow many different models to be plugged together to study coupled human and Earth systems in diverse dimensions and scales.

That said, even if different models conform to a common API standard, the plug-and-play approach to model coupling must still resolve issues of temporal and spatial rescaling, variation across the stochastic/deterministic continuum andpotentials for consistency problems when two different models represent the same phenomenon. There will still be the potential for feedbacks between models to introduce unexpected instabilities. While such instabilities could be informative, they can also cause model representations to deviate far from reality. Hence, while common API standards could be developed—and probably are a good way forward—middleware to couple human and Earth system models will need to deal with rescaling, consistency, and stochasticity/determinism on a case-by-case basis.

Taking it Forward: Overall, while developing algorithms to better rescale and integrate outputs of human systems models and Earth systems models was considered to be an essential development step, the general consensus was that evidence from existing coupled modeling projects suggest it would be valuable to create modeling frameworks that could represent bi-directional feedbacks between human systems and the Earth system. Multiple initiatives already in progress could be leveraged to create proof-of-concept for the returns for science and policy of integrating models of human systems and the Earth system, and also provide testbeds for developing solutions to the coupling issues described above, as well as others not discussed. The fact that in-progress initiatives are taking place at multiple scales is a valuable asset for these objectives. The iESM project (PNNL and collaborators) is not currently funded, but new work could build on that code. There is also a new Social Dimensions Working Group for CESM that could also help guide and accelerate tests of modeling integrated systems at global scales. Breakout participants Carsten Lemmen, Jed Kaplan, and Peter Verberg are all working at regional scales in Europe and could help guide model coupling tests at that scale. The MedLanD project's MML operates at local scales and could also serve as a proof-of-concept project at that scale.

All of these ongoing efforts are best thought of as effectively *tight coupling/unitary modeling* approaches. The CSDMS, however, has committed significant resources to the development of API standards and middleware that could provide the framework for creating a more flexible *plug-and-play* approach. So far, the CSDMS has focused almost exclusively on coupling different kinds of Earth system models, but its cooperative agreement with CoMSES Net (Network for Computational Modeling in Social and Ecological Sciences) and CSDMS' new Human Dimensions Focus Research Group offer the possibility of applying CSDMS technologies to human systems models so that they could be integrated with Earth system models. Most CSDMS (and CoMSES Net) models operate at local to regional scales, but solving plug-and-play integration of human and Earth systems should be scalable to a global level. The group suggested that deltas-agriculture-urbanism or hydrology-water demand/use could be tractable starting places for this work.

Several participants expressed concern that, if it became too easy technically to couple different kinds of models, then some users might do so in ways that would lead to misleading or meaningless results. They suggested that we consider some form of control that would encourage or force users to carefully consider the consequences of spatial/temporal scale, parameter passing, stochasticity, consistency, and related issues when coupling models of human and Earth systems. There are potential ways to design APIs for model communication that can communicate different model requirements in this regard. However, as we know from experience, there is no way to design software that can completely prevent people from using it in inappropriate, stupid, but also innovative ways. The best way to resolve this issue is to also support better training of human and Earth system scientists, and to encourage collaborations between domain experts in different fields.

Related to the importance of interdisciplinary collaboration for successful integration of human and Earth systems modeling, several participants noted that it is currently not a level playing field. There are many more resources and, hence, active modeling efforts in the Earth sciences than in human systems science. Some of the participants have encountered Earth science modeling groups that seem to only want to add human systems as a required, but insignificant appendage to large biophysical models. Thus, Earth system scientists need to work closely with human system scientists to understand the kinds of information needed and the kinds of information that can be provided by models of human systems. Moreover, the most scientifically and socially valuable results of integrated modeling require that both Earth system models and human systems models be modified and enhanced to work together. The collaborative model development that this entails involves social interactions, two-way communications, and mutual respect for needed domain knowledge as well as technical solutions. In this regard, there needs to be scientific, professional, and policy incentives for <u>all</u> members of the interdisciplinary teams needed to develop successful integrated modeling. In this respect, another dimension that was not discussed, but also important is the value of both Earth and human systems scientists working with members of the computer science community, particularly those with expertise in modeling and simulation, informatics, and cyber infrastructure.

Finally, participants felt that the discussion, and comparison of ongoing projects that are coupling models of human and Earth systems was of significance, not just for themselves, but also potentially for the wider scientific community. For this reason, the participants are planning to write a joint paper for a major scientific journal outlining challenges and potential returns of integrated modeling of human and Earth systems.

4. Extreme events and migration (Chair, Arneth): Extreme events (either social or biophysical) can trigger major LUC decisions and affect the vulnerability and resilience of societies. Past extreme events triggered by climate change or other stresses have been demonstrated to have had considerable consequences. An initial goal in modeling extremes could be to explore agricultural responses to climate variability. In doing this, both the level of complexity and uncertainty is important. There is also a need to differentiate between extreme events, probabilities and surprises. For example, there was little or no probability of the breakup of the Soviet Union, which came as a complete surprise. We also need to address a number of factors associated with the nature of extreme events themselves and how to model them. This includes deep uncertainty (i.e. unknown processes/drivers of change), scenarios versus process models of extreme events, variability versus state-change, rates of change (including intensity, duration and frequency), social institutions helping or hindering resilience and the role of influential outlier agents (people) leading to constructive or destructive amplification

Population migration: Demographic feedbacks are currently hard-wired into scenarios. But, if we are going to simulate a human dominated world, we need to know where people are located and how they move around. We also know that modeling feedbacks can drastically change outcomes. Issues of importance here include the dynamic nature of cultures and their effects on decision-making, gender issues, and the use of coupled models to understand whether/when human migration is adaptation. The key questions include, how large of a climate change induced migration is plausible? What are the impacts of migration on ecosystems, agriculture, etc.? Do we need novel prognostic models of population or are dynamic demographic models needed or important? What can we learn from the past? Will the past help us to understand the drivers of migration and the effects of migration on society and natural system feedbacks? There are numerous examples from the past of how social unrest and wars have been triggered by inequality and have led to migration. We can also speculate about how future changes in obesity, malnourishment and changing mortality rates might affect population movements.

Scoping/Issues: What is an extreme event in a socio-economic-natural system? We need to address both natural events and human-induced events, as well as exploring the effects of cascading events, i.e. where one event leads to another. What are the timescales of events and how does cultural memory affect this? What are risks/disasters - expected versus unexpected risks? For example, what is the impact of climate change on agriculture over different timescales? Who is responding and how? Are those responding individuals or groups? Do droughts in livestock agricultural systems lead to increased migration and re-greening of pastures? What do we understand about rural to urban migration? Overall, we need to understand how/when extreme events and surprises fundamentally change coupled systems as well as understanding the sensitivity of the system to shocks. Can environmental change plausibly drive large-scale migration? If yes, then how can we scale-up these processes from the local/national level to econometric modeling at global scale levels?

Methods: Methods should address emergent properties that happen after thresholds are crossed, and drivers that occur in human/natural systems, but are not currently modeled. As part of this we need to decide what to internalize in a model and what to treat exogenously through scenarios. The impact of an asteroid (as a shock event) should clearly be treated as an exogenous force, but what of other potential shock drivers, e.g. economic collapse, geopolitical change,? We also need to take advantage of large amounts of local data from case studies. Such cases could be the basis for an extreme events meta-analysis, as well as helping us to embrace the Big Data community. Overall, however, we will need to design new research methods to address the impacts of extreme events.

Taking it Forward for migration: There is a lot of current work on migration. How can we better interact with the migration/hazards/risk community? Are there existing funded research efforts on climate induced migration? Large-scale migration has been occurring in delta urban regions, but can we model this? What are the potential consequences of sea level rise for the coastal population? What are the important aspects that are not currently modeled? For example, what is the role of gender issues in forced or economically induced migration? Modeling efforts that may be useful in addressing these questions include the NCAR/CSM climate induced migration project, the UMich Ryan Kellogg Residential Location Choice Model with climate, and the EPA model. There are also lots of case studies with modeling such as demonstrated at the Migration Modeling workshop on climate & migration (France, Dec 2016), the CESM Social Dimensions Working Group linking physical and social science in ESMs, Future Earth, which has 8 pilot projects such as the pilot Urban Extreme events from climate to society and the ABM/IAM EMF Snowmass meeting. Possible funding for research in this field includes NSF (CNH has a RCN track), the Belmont forum, and SESNYC synthesis.

5. Decisions, Behaviors, and Institutional Change (Chair, Janssen): A set of issues emerged around the modeling of processes, such as how to include feedbacks and human decisions/needs in ESM models; how to deal with complexity, that is, the community of modelers is not able to capture global scale complexity at the moment. A need was identified to build models that are simpler to test, with a simple logic and which can be nested and up-scaled from the local to the global. There are also issues of scaling in outcome measures and other scaling issues such as temperature being smooth while irrigation falls along gradients. There are also issues of experimental and scenario testing quality.

There are also issues concerning the science and theory of decision-making. This includes the challenges associated with, for example, the heterogeneity among agents, but also the need to accommodate Keystone Actors. Keystone Actors represent an agent type that functions in a particular way, has a disproportionate impact on a system (relative to their numbers), and that may or may not yet be represented theoretically. We also need to identify what are the other key behaviors besides ‘rationality' in agents. There are many large-scale actors that are not influenced by nations (non-governmental actors) for example. Traditional social science models may be outdated due in part to the limitation of theory. Furthermore, there is the problem that documentation of behavioral processes may be lacking as well as a lack of quantitative data more generally (this is changing, but not yet at the level of Earth sciences). Finally, we need to address how to build capacity in the social sciences and how to break down the old schisms between, e.g. human and physical geographers.

Issues (Methods): A series of general methodological issues emerged and include the need to first identify where disconnects are between different communities. There is a qualitative understanding of human processes, but is there a way of bridging the gap to models by having ES modelers say "here is a problem we want to understand, what are the relevant human systems"? This could perhaps be achieved by identifying the relevant human or physical processes and scales of processes in linked research questions. Second, how to connect input to outputs? Do the results make sense, given the input data (e.g. population data sets at multiple scales)? How to get around the disconnect between the social science communities and the physical world? Once we identify this, we may come to understand what is missing. Third, conduct a meta-analysis of social survey work, rules, actors, important ecosystem processes, as a part of project. For example, there is a need for information about how to optimize for prestige, risk-avoidance, maximization of economic returns, and changes to all of these.

Regarding modeling itself, emerging ideas included developing a human dimensions 'module'; potentially an agency module, and; develop infrastructure to link the social science and ESM communities: Michael Barton is actively seeking funding to build such an infrastructure. Do we need an NCAR for Social Science? Should there be a Standardized classification scheme for agents? Should we encourage people who are willing to rewrite their code to match social science models (if the idea is to build upon what is there, rather than starting from the ground up)? A possible model for this is to identify what is relevant for ESMs that impacts/reflects on human decision-making, e.g. Land use and land cover change. We would then need to explore the human decisions around these themes that go into ESMs, and what are the questions that social scientists are interested in?

Taking this forward: We need to explore the different formulations of decision-making and the different goals of actors within our models. For this, we need different groups of people doing the testing. We could develop decision-making modules that plug and play to support model comparison (e.g. fishery to pastoralism livelihoods). We might develop a COMMUNITY framework to inform the construction of a model that scales from individual agency and behavioral types. But, we should certainly attempt to build capacity in early career social science students to do modeling. This would require funding for the development of interdisciplinary models and the training of modelers.

Vital questions remain. How important are the spatial configurations of the individual factors included in the model? How do we match input variables to the question? What direction is energy transferred in the models including edge effects and micro-climates. In Global Models change is typically located in particular regions, i.e. biomes. The basic rules in the Global Scale Human models (e.g. economic) are fundamentally flawed. We need to ask instead, what are the mechanisms occurring at each scale that are producing the outcomes that we observe? Governance occurs at many levels: how does it influence the outcome? How do you include the impacts of governance across scale levels (both spatially and temporally)? What are the ecological influences that are meaningful to the population/agents we want to include? What is the lag time for policy uptake and influence? When do we assume rational agents? When does rationality hold true, when does it not? What are the assumptions behind our choices of modeling about the rationality of our agents? Rationalism and optimism are under the same umbrella; how to write algorithms…what are you trying to optimize? What are the decision-making algorithms? What are the tradeoffs? When do we assume policy suggestions (or policy in general) makes a difference? How do we translate these behavioral mechanisms and social norms into modeling code? How do we incorporate barriers to behavior in our models? A critical constraint is how to link those who collect data to those who run the models? Would it be simpler to start with rural planning rather than urban planning?

Needs Identified: We need to identify what social dynamics are currently NOT included in land use models. We also need to identify and classify human-natural system interactions and feedbacks. For example, ESMs have delivered output, but they do not currently capture interactions. Can we identify a human decision-making process that determines how the natural system responds? Should there be basic training of Earth system modelers in understanding the human decision making process in order to produce models that are useful for policy application (e.g. for adaptation, resilience and capacity building in vulnerable communities). There is a need to better understand one another's languages to improve communication, as well as more respect between Earth system modelers and the human systems communities.

6. Multi-scalar, impact assessment methods (Chair, Lawrence): Impact assessment is important in order to explore, holistically, a wide range of the effects of global environmental change. From an ESM perspective impact assessment is done very simply, with a limited number of variables. Assessment is based primarily on the outcomes of physical models (e.g. of the climate system) being applied to sectors (usually one sector at a time without consideration of the effects of cross-sectoral interactions or indirect impacts). We need to move away from these rather simplistic approaches to explore impacts on people, societies and their well-being. This requires more insight into, and definition of, the concept of well-being, and the identification of appropriate metrics to assess it. Impact assessment also needs to address scale and extent issues, identify the key processes of interest, explore connectivity across spatial and temporal scales and processes and understand cascading effects across scales.

Scoping: There are a number of critical issues that need to be addressed to advance impact assessment methods. Uncertainty in ESMs is important, but so to is the effect of this uncertainty for human impact models and the propagation of errors in coupled systems. There may be a need for alternative modeling approaches, compared with what we have now to deal with the uncertainty propagation issue. But, we also need to be confident that we are able to evaluate the success/utility of human system impact models. This includes how we address aspects such as risk, vulnerability, exposure, feedbacks, the limits to aggregation and temporal lags.

Solutions: Capacity building through training is paramount. This will ensure that teams of experts include the right people from the outset, i.e. people who understand model limitations, the role of stakeholders and who can identify proper data, models and variables. This would be facilitated by the creation of networks of experts that use a common language to support communication. It would be useful to foster such networks by developing guidelines to establish appropriate problem statements, as well as identifying the right people and methods. This would contribute to the further development of impact assessment methods. In this respect there is a need to do much more integrated Impact, Adaptation and Vulnerability (IAV) assessment that considers interactions across sectors for multiple drivers, i.e. moving away from the single sector/scale/driver approach that is current at present, to multi-sector/scale/driver assessments. This might be facilitated by, for example, replacing the current IPCC process with a problem-driven assessment. Hence, do we need a National Academy Panel to evaluate frameworks and priorities for coupled human natural systems? This could be useful in identifying and removing barriers to integrated, human-natural system science. It could also help to define the highest priorities for assessment, e.g. existential threats to society, ecosystems and the physical climate.

7. Model evaluation (Chair, Hill): A long-term goal (after 10 years) is for a new generation of models that reproduce human systems at least as well as we currently reproduce vegetation dynamics. Such models would make human decision-making visible and useful in evaluating, for example, whether policy measures have the desired outcomes. Thus, these models would support the translation of research into practice. An important step in advancing methods to evaluate human system models is to collate datasets on human dimension research. This could help to parametrize, but also to test the role of prices/wages, economic structures, technological development, psychology (preferences traits) and social structures.

Human system model evaluation should employ idealized experiments and scenarios, test against observational data quantitatively, and develop and use appropriate testing metrics. We also need to ensure that models work properly/as expected (verification), and accredit models that do, i.e. guarantee that the models work correctly. Model validation and testing also needs to consider input validation, as well as output validation and to use sensitivity analysis to test whether a result is achieved for the right reason. Since we are at such an early stage of human system modeling, we should do whatever we can just to incite people to become involved and try out their own approaches to model evaluation.

Summary
A number of lessons learned emerged from the workshop discussions, including:

9. It is important to understand more about the role of the heterogeneity of decision making actors and the role of behavioral mechanisms in underpinning decision making;
10. Social system models need to represent a wider range of social processes than they do now, e.g. social interaction, power and control, cooperation/communication, competition, learning, …;
11. Keystone actors are very important in understanding human-environment systems;
12. How can studies of the past (e.g. land use change) benefit, but also support, modelling of Earth system change in the future?
13. There is a need to endogenize institutions within social system models, especially as one up-scales models from the local to global;
14. Inconsistency in baseline input data, including thematic definitions, is an important limitation to modeling;
15. There is a need for meta studies of human case studies of power, learning, decision-making, etc. by and among individuals, institutions, governance structures, etc
16. There is much debate to be had around the issues of complexity and its representation versus simplicity in models, including whether to couple or not to couple models with different modeling approaches;
17. Understanding the sensitivity of biophysical models to human processes such as land management is critical in supporting the development of the next generation of coupled human-environment models.

Next steps
Actions. A number of actions were identified for further development, including writing a white paper on taking the community forward, writing a paper on model coupling, organising follow-up meetings/workshops, establishing branding and communications plans, and exploring funding opportunities for the network. It was agreed that a follow-up meeting should be based on the white paper, with a focus on a broader range of science presentations, including the identification of research gaps that could form the basis of a perspective paper. Internationalisation of this meeting could be supported with funding from the NSF international office. We will plan the next meeting to coincide with the next CSDMS meeting. Before this, the AGU conference in December 2016 is a good opportunity for a sub-set of the group to meet up to: a) discuss the white paper, b) take the agenda forward for the larger CSDMS annual meeting related workshop. But, this meeting would need to be scheduled during the official AGU programme.

Community building/identity. We agreed that the ways in which we brand and identify/communicate ourselves as a community is critical in supporting collaboration with other, existing communities. For example, we should avoid using the Earth System Model label, since this means something very specific to the climate science community. There are also potential tensions with the Integrated Assessment community, indicating the importance of highlighting the differences between what we are seeking to achieve and what is already done by IAMs, e.g. we are cross-scale (multi-scalar), we focus on behavioral processes and system feedbacks, we address a broader range of human-dimensions issues, we are more interested in experiments to explore processes rather than 'predictions', …

Two names for the group were proposed: Computational Human and Earth System Science (CHESS), i.e. the CHESS community, or, Community for Human and Earth System Science (CHESS). CSDMS will support the establishment/upkeep of a website/wiki (contact: Albert Kettner) that will include the materials from this workshop, as well as webcast presentations, links to people pages, links to other relevant communities, bibliography links … In support of the CHESS identity, we will write a piece about this workshop to be posted on the website (contact: Kimberly Rogers). This piece could also form the basis of a workshop report to the AGU journal (EOS) if completed within 2 months of the workshop dates. A subset of the workshop participants will work on a paper about modeling coupling methods with examples (hopefully submitted by the end of year). A Skype call will be organized to discuss this further (contact: Derek Robinson).

We will also explore additional papers ideas: a Global Environmental Change editorial (CHESS community authored), a longer multi-authored, position article (perspective piece) on the issues/ways forward (it is possibly too early at present for such a paper since we need to develop the novelty and further results – wait for whiter paper outcomes). This paper should be radical, but also evidence-based. Perhaps focus on the SDG framework, which requires human dimensions research to be underpinned by better capacity building within research communities to achieve this. The paper should also discuss links with IAMs and focus on the local level in order to put individuals back into models along with associated feedbacks (the research gap need). Thus, the CHESS community needs to identify the big holes, or what we're not doing now, and provide concrete examples to resolve these gaps. We also have the results of a short summary of the workshop participants: https://docs.google.com/spreadsheets/d/1FD9k9_-6h86L9sYBbDmx45al3k8Pl8b9TrQYquZmxPk/edit?usp=sharing

We also identified a number of potential funding opportunities, and everyone in the CHESS community is encouraged to explore funding to support our collective aspirations (See Annex 3).

Potential new members to include in future CHESS community activities are: Yoshiki Yamagata (http://www.cger.nies.go.jp/gcp/members.html), Navin Ramankutty (http://ires.ubc.ca/person/navin-ramankutty/) and Dale Rothman (http://www.du.edu/korbel/faculty/rothman.html).

Potential funding and endorsement opportunities. In progressing the community and its intellectual aims, we identified a number of potential funding schemes that are listed in Annex 3.

Timeline. The following was agreed for implementation of the actions discussed above:

1. Coupling paper Skype (asap) Derek
2. AGU journal (EOS) workshop report paper (within 2 months of now) - Kimberly
3. Draft white paper distributed for comment (30 June 2016) – Kathy, Mark, Michael
4. Video-conference to discuss white paper (1st week of August 2016) – Albert can set-up the infrastructure,
5. Final draft white paper (comments incorporated) (end September 2016) – Kathy, Mark, Michael
6. AGU sub-set meeting (December 2016) – Kimberly to follow-up on timing/rooms
7. CESM annual workshop (Feb 2017) – potential CHESS involvement
8. CSDMS annual meeting and a full CHESS meeting (May 2017)

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Annex 1: Workshop agenda

Monday 23 May (9h-17h30)

Session 1 (Kathy Galvin): Welcome and introductions (9h-10h30)

Welcome and about the workshop + Q&A, Kathy Galvin & Mark Rounsevell (20 min + 10)
Kathy: why we need to connect across global issues, e.g. SDGs, Future Earth, and social sciences processes; the need to focus on solutions; how did we get here (CSDMS etc)?
Mark: the major gaps in upscaling human decision processes (in models) to global scale levels; goals of the meeting; a walk through the agenda, and objectives of the meeting
Introduction to the participants: tour de table (10 mins)
Community Surface Dynamics Modelling System (CSDMS), Focal Research Groups (FRGs), funders, white paper, James Syvitski (5 mins)
Scene setting talk 1 (15 min): The Network for Computational Modeling for Socio-Ecological Science (CoMSES Net), Michael Barton
Scene setting talk 2 (15 min): Perspectives from Future Earth (Josh Tewkesbury via Skype)
Q&A (15 mins)

Coffee break (10h30-11h)

Session 2 (Michael Barton): where are we now? An overview of current major global modelling types (11h-12h30)

An overview of current global human dimension methods: Land use and land cover change models, Peter Verburg, GLP (15 min)
An overview of current global human dimension methods: integrated assessment models, Brian O'Neill, NCAR (15 min)
Recent developments in Digital Global Vegetation Models (DGVMs): C/N dynamics and crops yields, Almut Arneth, KIT (15 mins)
The spectrum of Earth system dynamics models, James Syvitski (15 min)
Panel discussion: what we do well now and what could we do better? (30 mins)

Lunch (12h30-14h)

Session 3 (Mark Rounsevell): where are we now? Examples of specific modelling approaches (14h-15h15)

Agent-Based Modelling of rural and urban land systems at the landscape scale, Dan Brown (15 min)
The human dimensions of reconstructing past land use and land cover change, Jed Kaplan (15 min)
Global scale agricultural systems: the role of diet, trade and food waste, Peter Alexander (15 min)
Panel discussion: what do we do well now and what could we do better? (30 mins).

Coffee break (15h15-15h45)

Session 4 (Kathy Galvin): where are we heading? (15h45-17h30)

How can social science methods and models and methods be scaled to global levels, Marco Janssen (15 min)
Extending ABM approaches to national and continental scales, Mark Rounsevell (15 mins)
Massive Agent-Based Models, Rob Axtel (15 mins)
Panel discussion: what can we learn from these and other approaches? (30 mins)
General discussion: What have we learned from the day so far? (30 mins)

Tuesday 24 May (9h-17h30)

Session 1 (Mark) Identifying key issues/questions (9h-10h30)

Recap and introduction to the day (15 mins), Kathy, Mark
Facilitated session on emerging issues/questions for discussion: collecting ideas, clustering and prioritizing these and planning the subsequent breakout sessions (75 mins)

Some possible issues/questions include:

1. Coarse-graining/scaling social processes to tractable scales for global modelling. What ARE tractable scales? Maybe they are not so coarse.

2. What aspects of human systems give the most ROI to start with? What are the low hanging fruit? Possibilities include land use and its impact on land cover, GHG emissions, energy use, water use, health and epidemiology. What about economic markets? These are generally treated at national or supranational scales. Is there a benefit to downscaling this to 1 degree or less? Not sure.
3. To what extent do we want to model human systems components as emergent properties that respond to ESMs vs. researcher-specified parameters to set up and run experiments of different socio-ecological scenarios?
4. What modelling frameworks/"formalisms" are most useful for integrating with ESMs? My guess is CA of some kind. Are there other candidates? Should mobile agents be considered, at least for some things? Stick with a single global framework or integrated different ones for different aspects of human systems (e.g., like atmosphere, land, ocean models)?
5. How can human systems models be coupled with earth systems models? Currently, there are some human systems components embedded into the land models of ESMs. But these are generally static. Should they be pulled out and moved to a HSM? Can we have couplers (or APIs) that allow a community human systems model (CHSM) be coupled to different ESMs like CESM, ACME, Hadley, etc?
6. How best can we represent social processes in models that emerge from individual behaviour and choices?

Coffee break (10h30-11h)
Session 2 Discussion of key issues/questions (11h-12h30)
Break out groups on 3 key issues/questions (chairs to be nominated in Session 1) (75 mins)
Group report backs (max 5 mins each group)
Lunch (12h30-14h)
Session 3 Discussion of key issues/questions (14h-15h30)
Break out groups on a further 3 key issues/questions (chairs to be nominated in Session 1)
Group report backs (max 5 mins each group)
Coffee break (15h30-16h)
Session 4 Outcomes of discussions on key issues/questions
Further breakout sessions with report back (if needed), and general discussion on outcomes and setting research priorities

Weds 25 May (9h-12h30)
Session 1 (Michael) Developing a research plan, the distributed network and the timetable (9h-10h30)
What we need, e.g. resources, person power, infrastructure, meetings. What kind of social/technical infrastructure is needed to develop and maintain a CHSM? Some things might include: versioning server(s), software engineering, organization to vet code and decide what does and does not get into CHSM, organization to oversee integration with ESMs and decide which experiments are run
Financing: what do we have now? What do we need in the future? What are the funding sources?
Establishing a network of researchers (communication and interaction)
Coffee break (10h30-11h)
Session 2 (Kathy/Mark) Planning continued with wrap-up and actions (11h-12h30)
Discussion on BC21 and CSDMS 3
The research plan and timetable
Actions: who does what and when?
Close of workshop

Annex 2: Participant list & contact details

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Annex 3. Potential funding and endorsement sources

1. CSDMS3 (logistical support, meeting/workshop support, software design…) – need to contribute to funding proposal
2. Future Earth (KANs, AIMES, GLP, iLEAPS,)
3. NSF programmes, e.g. joint US-UK grants
4. NSF STC (Science and Technology Centre) (potential for a human dimensions part, physically located, as part of a broader CSDMS proposal), 10 years max (up to $50m)
5. NSF RCN (Research Coordination Network) – CNH track possible (dynamics of Coupled Natural Human systems)
6. National Institute of Health (NIH) - Office of behavioural and social science research (under NIH)
7. USDA – unique calls on food security, including the need for international collaboration
8. COST Actions – networking grants within the EU (meetings, database development, infrastructure, synthesis)
9. European Commission Horizon2020 – consortia research grants (call-based)
10. European Commission Framework 7 grants (on-going, potential funding for workshops, supporting webinars)
11. European Research Council (ERC) – individual starter, consolidator and advanced grants with international collaboration (fundamental research €1.5-2M)
12. European National research councils (UK, Germany, Netherlands, etc)
13. Belmont Forum grants
14. Rockefeller Brothers Foundation (www.rockefellerfoundation.org/our-work/initiatives)
15. Hoover Foundation; Sloan Foundation (urban); Hewlett Foundation; Clinton Foundation (environmental degradation); Gordon Moore Foundation (Conservation International) – need to be focused on Foundation aims
16. Wellcome Trust call – European and global challenges (environment and Health) - https://wellcome.ac.uk/funding/europe-and-global-challenges
17. International Social Science Council – global reach (no national limitations), e.g. social transformations call, and human-environment interactions
18. Global Carbon project (outreach to non-North American/European researchers)
19. Graduate students, Masters, PhDs, … - NRT funding for groups of grad students

Student winter/summer School's (Marco's, Peyresq)