CSDMS
COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

CSDMS 2.0 FINAL REPORT (2013-17)

ANNUAL REPORT (2017-18)

NSF COOPERATIVE AGREEMENT 1226297

Executive Summary

CSDMS (Community Surface Dynamic Modeling System) is a NSF-supported, international and community-driven effort to transform the science and practice of earth-surface dynamics modeling. CSDMS is now a Keystone component of the earth surface community. It is particularly needed in a complex, changing earth: the earth's surface is where we will experience the change; the CSDMS modeling foundry has become essential in helping to anticipate future states and guide alternative futures. The broad overview of modeling-based research gained by CSDMS is of fundamental importance to the identification and implementation of interdisciplinary research connections.

This CSDMS 2.0 Final Report (2013 to 2017) and Annual Report (2018) provides a review of the past six years of the CSDMS project. The report documents the organizational structure and finances (Chapters 1, 2, 9, 10), the cyber infrastructure advances (Chapters 3, 4, 5, 6, 8), education and knowledge transfer achievements (Chapter 7), and scientific accomplishments (Chapters 11).

CSDMS2.0 Final Report

Chapters

Chapter 1: CSDMS Mission and Community

1.1 Mission & Goal

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.

CSDMS goal: Create a unified capacity to model Earth-surface processes by empowering a broad community of scientists and students with computational tools and knowledge, streamlining the process of idea generation and hypothesis testing through linked surface dynamics models, tailored to specific settings, scientific problems, and time scales. The community is to include geoscientists with expertise and interests in the fields of hydrology, fluvial processes, biogeochemistry, sedimentology, stratigraphy, geomorphology, glaciology, oceanography, coastal processes, ecosystem dynamics, human dimension science, marine geology, climate forcing, active tectonics, surface geophysics, remote sensing, geomathematics, computational fluid dynamics, computer science, and environmental engineering.

1.2 Science Questions and Community Functions

Some fundamental questions motivating CSDMS scientists:

1. How do transport processes interact with properties of morphology, geology, ecology, climatology, oceanography and human activities?
2. What processes support self-organization and pattern formation in surface systems?
3. How do material fluxes and surface evolution vary across time and space scales? How are these fluxes recorded in sedimentary deposits?
4. How are physical, ecological & human processes coupled within surface systems and constrained by Earth's interior and Earth's atmospheric dynamics?

To address these questions the Integration Facility supports 8 CSDMS2.0 community functions:

1. Capacity building and community networking;
2. Maintenance and enrichment of open-source repositories (models, tools, data, education);
3. High perform computing cluster access and support;
4. Development and maintenance of education and knowledge products;
5. Maintenance or advancement of community protocols for model development and coding practice, along with a web-based GUI for to run standalone or coupled model simulations;
6. Community model reuse including model coupling through advanced architectures, language neutral compilers, and a component-based framework designed for plug and play model simulations;
7. Development of service tools in support of model benchmarking, model intercomparisons, and determining model skill and model-data uncertainties;
8. Develop and employ semantic mediation protocols and ontologies in aid in coupling data-model or model-model.

1.3 The CSDMS2.0 International Community

CSDMS is a growing national/international community. The 1721 members (as of July 2018) represent 601 institutions from 69 countries. Membership is growing at a rate of ~150 new members per year. Most (1004) members are based in the US (58%), representing 213 U.S. institutions (145 academic, 33 private, 35 government/NGO). There are now 388 foreign research institutions (263 academic, 34 private, 91 government/NGO). Outlined below, in blue, are new institutions/countries that have joined CSDMS during the final funding cycle (2017-2018).

Members per country

1. United States (1004)
2. China (88)
3. United Kingdom (87)
4. India (49)
5. Canada (47)
6. Netherlands (43)
7. France (41)
8. Germany (34)
9. Italy (34)
10. Spain (18)
11. Australia (17)
12. Brazil (13)
13. Korea, South (12)
14. Indonesia (12)
15. Bangladesh (11)
16. Chile (9)
17. Norway (8)
18. Portugal (8)
19. Argentina (8)
20. Poland (8)
21. Greece (7)
22. Pakistan (7)
23. Nigeria (7)
24. New Zealand (7)
25. Japan (7)
26. Belgium (7)
27. Switzerland (7)
28. Denmark (7)
29. Colombia (7)
30. Ireland (6)
31. Egypt (6)
32. Vietnam (6)
33. Israel (6)
34. Sweden (5)
35. Malaysia (4)
36. Russia (4)
37. Iran (4)
38. Peru (4)
39. Hungary (4)
40. Turkey (4)
41. Romania (3)
42. Singapore (3)
43. Thailand (3)
44. South Africa (2)
45. United Arab Emirates (2)
46. Philippines (2)
47. El Salvador (2)
48. Ghana (2)
49. Mexico (2)
50. Cuba (2)
51. Venezuela (2)
52. Uruguay (2)
53. Nepal (2)
54. Saudi Arabia (2)
55. Bulgaria (2)
56. Ecuador (1)
57. Bolivia (1)
58. Qatar (1)
59. Iraq (1)
60. Jordan (1)
61. Burma (1)
62. Kazakhstan (1)
63. Armenia (1)
64. Austria (1)
65. Algeria (1)
66. Kenya (1)
67. Morocco (1)
68. Cambodia (1)
69. Uzbekistan (1)

1.4 Institutional Membership.

U.S. Academic Institutions:

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 NY, City University of New York
15 Coastal Carolina U, 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 Kansas State University
36 Louisiana State University
37 Marquette University, Wisconsin
38 Massachusetts Institute of Technology
39 Michigan Technological University
40 Montana State University
41 Montclair State University, New Jersey
42 Monterey Bay Aquarium Research Inst.
43 Murray State University, Kentucky
44 New Mexico Institute of Mining and Technology, New Mexico
45 North Carolina State University
46 Northern Arizona University
47 Northern Illinois University
48 Northwestern University, Illinois
49 Nova Southeastern University, Florida
50 Oberlin College, Ohio
51 Ohio State University
52 Oklahoma State University
53 Old Dominion University, Virginia
54 Oregon State University
55 Pennsylvania State University
56 Portland State University, Oregon
57 Princeton University, New Jersey
58 Purdue University, Indiana
59 Rice University, Texas
60 Rutgers University, New Jersey
61 San Diego State University, CA
62 San Fransisco State University, CA
63 San Jose State University, California
64 Scripps Institution of Oceanography, CA
65 South Dakota School of Mines
66 St. Mary's College of Maryland
67 Stanford University, CA
68 Syracuse University, New York
69 Texas A&M, College Station
70 Texas Christian University
71 Towson University, Maryland
72 Tulane University, New Orleans
73 United States Naval Academy, Annapolis
74 University of Alabama - Huntsville
75 University of Alaska – Fairbanks

76 University of Arkansas
77 University of Arizona
78 University of Buffalo, New York
79 University of California – Berkeley
80 University of California – Davis
81 University of California – Irvine
82 University of California – Los Angeles
83 University of California – San Diego
84 University of California – Santa Barbara
85 University of California – Santa Cruz
86 University of Central Florida
87 University of Colorado – Boulder
88 University of Colorado – Denver
89 University of Connecticut
90 University of Delaware
91 University of Denver, Colorado
92 University of Florida
93 University of Houston
94 University of Idaho
95 University of Illinois – Chicago, Illinois
96 University of Illinois-Urbana – Champaign
97 University of Iowa
98 University of Kansas
99 University of Kentucky
100 University of Louisiana – Lafayette
101 University of Maine
102 University of Maryland – Baltimore County
103 University of Memphis
104 University of Miami
105 University of Michigan
106 University of Minnesota – Minneapolis
107 University of Minnesota – Duluth
108 University of Nebraska – Lincoln
109 University of Nevada – Reno
110 University of New Hampshire
111 University of New Mexico
112 University of New Orleans
113 University of North Carolina – Chapel Hill
114 University of North Carolina – Wilmington
115 University of North Dakota
116 University of Notre Dame, Indiana
117 University of Oklahoma
118 University of Oregon
119 University of Pennsylvania – Pittsburgh
120 University of Pittsburgh
121 University of Rhode Island
122 University of South Carolina
123 University of South Florida
124 University of Southern California
125 University of Tennessee – Knoxville
126 University of Texas – Arlington
127 University of Texas – Austin
128 University of Texas – El Paso
129 University of Texas – San Antonio
130 University of Utah
131 University of Virginia
132 University of Washington
133 University of Wyoming
134 Utah State University
135 Vanderbilt University
136 Villanova University, Pennsylvania
137 Virginia Institute of Marine Science (VIMS)
138 Virginia Polytechnic Institute and State U
139 Washington State University
140 West Virginia University
141 Western Carolina University
142 Wichita State University
143 William & Mary College, VA
144 Woods Hole Oceanographic Inst.
145 Yale University, Connecticut

U.S. Federal Labs, Agencies, State and Local Government, Non-Profit:

1. Argonne National Laboratory (ANL)
2. Brookhaven National Laboratory (BNL)
3. California Coastal Commission
4. Global Facility for Disaster Reduction and Recovery
5. Idaho National Laboratory (IDL)
6. Institute for Social and Environmental Transition
7. Los Alamos National Laboratory (LANL)
8. National Aeronautics & Space Administration (NASA)

9. National Center for Atmospheric Research (NCAR)
10. National Forest Service (NFS)
11. National Science Foundation (NSF)
12. National Oceanic & Atmospheric Administration (NOAA)
13. National Oceanographic Partnership Program (NOPP)
14. National Park Service (NPS)
15. National Weather Service (NWRFC)
16. Naval Research Laboratory
17. Oak Ridge National Laboratory (ORNL)
18. Pacific Northwest National Laboratory (PNNL)
19. Sandia National Laboratories (SNL)
20. South Florida Water Management District
21. U.S. Army Corps of Engineers (ACE)
22. U.S. Army Research Office (ARO)
23. U.S. Department of Agriculture (USDA)
24. U.S. Department of the Interior – Bureau of Reclamation
25. U.S. Department of the Interior – Bureau of Ocean Energy Management (BOEM)
26. U.S. Environmental Protection Agency (EPA)
27. U.S. Geological Survey (USGS)
28. U.S. Nuclear Regulatory Commission (NRC)
29. U.S. Office of Naval Research (ONR)
30. Utah Geological Survey
31. World Bank, Washington D.C.

U.S. Private Companies:

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 Idaho Power, Boise
15 Leonard Rice Engineers, Inc., Denver, CO
16 Moffat & Nichol
17 PdM Calibrations, LLC, Florida
18 Philip Williams and Associates, Ltd., California
19 RPS Group Plc
20 Raincoast Scientific
21 Schlumberger Information Solutions, Houston, TX
22 Science Museum of Minnesota, St. Paul, MN
23 Shell USA, Houston, TX
24 Straus Consulting, Boulder, CO
25 Stroud Water Research Center, Avondale, PA
26 Subsurface Insights, Hanover, NH
27 URS–Grenier Corporation, Colorado
28 Target Source
29 The Von Braun Center for Science & Innovation, Inc.
30 UAN Company
31 Warren Pinnacle Consulting, Inc., Warren, VT
32 Water Institute of the Gulf, Baton Rouge, LA

Foreign Membership:

Foreign Academic Institutes:

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 U of Thessaloniki, Greece
10. Asian Institute of Technology, Thailand
11. Australian National University, Australia
12. Babes-Bolyai University, Romania
13. Bahria University, Islamabad, Pakistan
14. Banaras Hindu University, India
15. Bangladesh University of Engineering and Technology, Dhaka, Bangladesh
16. Beijing Normal University, China
17. Birbal Sahni Institute of Palaeobotany, India
18. Bonn University, Germany
19. Blaise Pascal University, Clermont, France
20. Brandenburg University of Technology (BTU), Cottbus, Germany
21. British Columbia Institute of Technology (BCIT), Canada
22. Cardiff University, UK
23. Carleton University, Canada
24. Chengdu University of Technology, China
25. China University of Geosciences- Beijing, China
26. China University of Mining & Technology, China
27. China University of Petroleum, Beijing, China
28. Christian-Albrechts-Universitat (CAU) Kiel, Germany
29. CNRS / University of Rennes I, France
30. Cracow University of Technology, Poland
31. Dalian University of Technology, Liaoning, China
32. Dankook University, South Korea
33. Darmstadt University of Technology, Germany
34. Delft University of Technology, Netherlands
35. Democritus University of Thrace, Greece
36. Diponegoro University, Indonesia
37. Dongguk University, South Korea
38. Dresden Technology University, Germany
39. Durham University, UK
40. Earth Sciences Federal University of Parana, Brazil
41. East China Normal University, China
42. Ecole Nationale Superieure des Mines de Paris, France
43. Ecole Polytechnique, France
44. Eidgenossische Technische Hochschule (ETH) Zurich, Switzerland
45. Eötvös Loránd University, Hungary
46. FCEFN-UNSJ-Catedra Geologia Aplicada II, Argentina
47. Federal University of Itajuba, Brazil
48. Federal University of Petroleum Resources, Nigeria
49. Federal University Oye-Ekiti, Nigeria
50. Federal University of Rio de Janeiro, Brazil
51. Federal University of Santa Catarina, Brazil
52. First Institute of Oceanography, SOA, China
53. Free University of Brussels, Belgium
54. Friedrich Shiller Universitat, Jena, Germany
55. Glasgow University, UK
56. Guanzhou University, Guanzhou, China
57. The Hebrew University of Jerusalem, Israel
58. Helmholtz-Zentrum University Germany
59. Heriot-Watt University, Edinburgh, UK
60. Hohai University, Nanjing, China
61. Hong Kong University, China
62. IANIGLA, Unidad de Geocriologia, Argentina
63. IHE, Delft Institute for Water Research
64. Imperial College of London, UK
65. India Institute of Technology – Bhubaneswar
66. Indian Institute of Technology– Bombay
67. India Institute of Technology – Delhi
68. Indian Institute of Technology – Gandhinagar
69. India Institute of Technology – Kanpur
70. India Institute of Technology - Kharangpur
71. India Institute of Technology – Madras
72. India Institute of Technology – Mumbai
73. Indian Institute of Technology - Roorkee
74. Indian Institute of Science – Bangalore
75. Indian Institute of Science - Delhi
76. Institut Univ. Europeen de la Mer (IUEM), France
77. Institute of Engineering (IOE), Nepal
78. Institute of Geology, China Earthquake Administration
79. Instituto de Geociencias da Universidade, Brazil
80. Institute of Marine Environment & Resources, Vietnam
81. Instituto Superior Technico, Portugal
82. Interacademy Partnership, Uzbekistan Academy of Science
83. Kafrelsheikh University, Kafrelsheikh, Egypt
84. Karlsruhe Institute of Technology (KIT), Germany
85. Katholieke Universiteit Leuven, KUT, Belgium
86. Kerala University of Fisheries and Ocean Science, India
87. King's College London, UK
88. King Fahd University of Petroleum and Mineral, Saudi Arabia
89. Kocaeli University, Izmit, Turkey
90. Kwame Nkrumah University of Science and Technology (KNUST), Ghana
91. Lanzhou University, China
92. Leibniz-Institute fur Ostseeforschung Warnemunde (IOW)/Baltic Sea Research, Germany
93. Leibniz Universitat Hannover, Germany
94. Loughborough University, UK

95. Lund University, Sweden
96. Massey University, New Zealand
97. McGill University, Canada
98. McMaster University, Canada
99. Melbourne University, Australia
100. Mohammed V University-Agdal, Rabat, Morocco
101. Montreal University, Canada
102. Mulawarman University, Indonesia
103. Nanjing Normal University, Japan
104. Nanjing University of Information Science & Technology (NUIST), China
105. Nanjing University, China
106. National Cheng Kong University
107. National Taiwan University, Taiwan, China
108. National University Columbia, Columbia
109. National University of Cordoba, Spain
110. National University (NUI) of Maynooth, Kildare, Ireland
111. National University of Sciences & Technology, Pakistan
112. National University of Sciences & Technology, (NUST), Pakistan
113. National University of Singapore, Singapore
114. NIIT University, India
115. Niger Delta University, Nigeria
116. North Maharashtra University, SSUPS Science College, India
117. Northwest University of China, China
118. Norwegian University of Life Sciences, Norway
119. Ocean University of China, China
120. Padua University, Italy
121. Paris Diderot University, France
122. Peking University, China
123. Pondicherry University, India
124. Pukyong National University, S. Korea
125. Prince Songkla University, Thailand
126. Pune University, India
127. Royal Holloway University of London, UK
128. RWTH Aachen University, Germany
129. Sejong University, South Korea
130. Saint Francis Xavier University, Canada
131. Seoul National University, South Korea
132. Shihezi University, China
133. Simon Fraser University, Canada
134. Singapore-MIT Alliance for Research and Technology (SMART), Singapore
135. Southern Cross University, United Arab Emirates (UAE)
136. Sriwijaya University, Indonesia
137. SRM University, India
138. Stockholm University, Sweden
139. Tarbiat Modares University, Iran
140. The Maharaja Sayajirao University of Baroda, India
141. Technical University, Hamburg, Germany
142. TERI School of Advanced Studies, India
143. Tianjin University, China
144. Tohoku University, Japan
145. Tripura University, India
146. Tsinghua University, China
147. Ulster University, UK
148. Universidad Agraria la Molina, Peru
149. Universidad Austral de Chile, Chile
150. Universidad Complutense de Madrid, Spain
151. Universidad de Chile, Chile
152. Universidad de Granada, Spain
153. Universidad de Guadalajara, Mexico
154. Universidad de la Republica, Uruguay
155. Universidad de Oriente, Cuba
156. Universidad de Zaragoza, Spain
157. Universidad Nacional Autónoma de México
158. Universidad Nacional de Catamarca, Argentina
159. Universidad Nacional de Rio Negro, Argentina
160. Universidad Nacional de San Juan, Argentina
161. Universidad Politecnica de Catalunya, Spain
162. Universidad Politecnica Catolica de Chile, Chile
163. Universidade de Lisboa, Lisbon, Portugal
164. Universidade de Madeira, Portugal
165. Universidade do Minho, Braga, Portugal
166. Universidade Estudual de Campinas, Brazil
167. Universidade Federal do Rio Grande do Sul (FRGS), Brazil
168. Universit of Bulgaria (VUZF), Bulgaria
169. Universita "G. d'Annunzio" di Chieti- Pescara, Italy
170. Universitat Potsdam, Germany
171. Universitat Politecnica de Catalunya, Spain
172. Universitat Tubingen, Germany
173. Universitas Indonesia, Indonesia
174. Universite Bordeaux, France
175. Université de Bretagn Occidentale, France
176. Université de Grenoble, France
177. Université de Lousanne, Switzerland
178. Universite de Rennes (CNRS), France
179. Universite de Toulouse, France
180. Universite du Quebec a Chicoutimi, Canada
181. Universite Grenoble Alps, France
182. Universite Joseph Fourier, Grenoble, France
183. Universite Montpellier 2, France
184. Universiteit Gent, Ghent, Belgium
185. Universiteit Stellenosch University, South Africa
186. Universiteit Utrecht, Netherlands
187. Universiteit Vrije (VU), Amsterdam, Netherlands
188. Universiti Teknologi Mara (UiTM), Mayalsia
189. Universiti Malaysia Pahang, Malaysia
190. University College Dublin, Ireland
191. University of Bari, Italy

192. University of Basel, Switzerland
193. University of Bergen, Norway
194. University of Bremen, Germany
195. University of Brest, France
196. University of Bristol, UK
197. University of British Columbia, Canada
198. University of Calgary, Canada
199. University of Cambridge, UK
200. University of Cantabria, Spain
201. University of Concepcion, Chile
202. University of Copenhagen, Denmark
203. University of Dhaka, Bangladesh
204. University of Dundee, UK
205. University of Edinburgh, UK
206. University of Exeter, UK
207. University of Geneva, Switzerland
208. University of Ghana, Ghana
209. University of Guelph, Canada
210. University of Haifa, Israel
211. University of Ho Chi Minh City, Vietnam
212. University of Hull, UK
213. University of Kashmir, India
214. University of KwaZulu-Natal, South Africa
215. University of Leeds, UK
216. University of Lethbridge, Canada
217. University of Liverpool, UK
218. University of Manchester, UK
219. University of Malaya, Kuala Lumpur, Malaysia
220. University of Milano-Bicocca, Italy
221. University of Natural Resources & Life Sciences, Vienna, Austria
222. University of Newcastle, Australia
223. University of Newcastle upon Tyne, UK
224. University of New South Wales, Australia
225. University of Nigeria, Nsukka, Nigeria
226. University of Nottingham, UK
227. University of Padova, Italy
228. University of Palermo, Italy
229. University of Pavia, Italy
230. University of Portsmouth, UK
231. University of Potsdam, Germany
232. University of Queensland (UQ), Australia
233. University of Reading, Berkshire, UK
234. University of Rome (INFN), "LaSapienza", Italy
235. University of Saskatchewan, Canada
236. University of Science Ho Chi Minh City, Viet Nam
237. University of Southampton, UK
238. University of St. Andrews, UK
239. University of Sydney, Australia
240. University of Tabriz, Iran
241. University of Tehran, Iran
242. University of the Philippines, Manila, Philippines
243. University of the Punjab, Lahore, Pakistan
244. University of Twente, Netherlands
245. University of Victoria, Canada
246. University of Waikato, Hamilton, New Zealand
247. University of Warsaw, Poland
248. University of West Hungary – Savaria Campus, Hungary
249. University of Western Australia, Australia
250. University of Western Ontario, Canada
251. Victoria University of Wellington, New Zealand
252. Vietnam Institute of Seas and Islands
253. Vietnam Forestry University, Vietnam
254. VIT (Vellore Institute of Technology) University, Tamil Nadu, India
255. VUZF University, Bulgaria
256. Wageningen University, Netherlands
257. Waseda University, Japan
258. Water Resources University, Hanoi, Vietnam
259. Wuhan University, Wuhan, China
260. Xian University of Architecture & Technology, China
261. York University, Canada
262. Yuzuncu Yil University, Turkey
263. Zhejiang University, China

Foreign Private Companies:

1. ASR Ltd., New Zealand
2. Aerospace Company, Taiwan
3. Bakosurtanal, Indonesia
4. BG Energy Holdings Ltd., UK
5. Cambridge Carbonates, Ltd., France
6. Deltares, Netherlands
7. Digital Mapping Company, Bangladesh
8. Dynamic Flow Technologies, UK
9. Energy & Environment Modeling, ENEA/UTMEA, Italy
10. Environment Illimite, Inc., Canada
11. Excurra & Schmidt: Ocean, Hydraulic, Coastal and Environmental Engineering Firm, Argentina
12. Fugro-GEOS, UK
13. Geo Consulting, Inc., Italy
14. Grupo DIAO, C.A., Venezuela
15. Haycock Associates, UK
16. H.R. Wallingford, UK
17. IH Cantabria, Cantabria, Spain
18. InnovationONE, Nigeria
19. Institut de Physique de Globe de Paris, France
20. Institut Francais du Petrole (IFP), France

21. Jaime Illanes y Asociados Consultores S.A., Santiago, Chile
22. METEOSIM, Spain
23. Mott MacDonald, UK
24. MUC Engineering, United Arab Emirates (UAE)
25. Petrobras, Brazil
26. Riggs Engineering, Ltd., Canada
27. Risk Management Solutions Inc., India
28. Saipem (oil and gas industry contractor), Italy
29. Shell, Netherlands
30. SEO Company, Indonesia
31. Soluciones en Technologia Empresarial (STE), Peru
32. Statoil, Norway
33. Tullow Oil, Ireland
34. Vision on Technology (VITO), Belgium

Foreign Government Agencies:

1.
2. Agency for Assessment and Application of Technology, Indonesia
3. Alfred Wegener Institute for Polar & Marine Research, Germany
4. Arpa-Emilia-Romagna, Italy
5. Bedford Institute of Oceanography, Canada
6. Bhakra Beas Management Board (BBMB), Chandigarh, India
7. British Geological Survey, UK
8. Bundesanstalt fur Gewasserkunde, Germany
9. Bureau de Recherches Géologiques et Minières (BRGM), Orleans, France
10. Cambodia National Mekong Committee (CNMC), Cambodia
11. Center for Petrographic and Geochemical Research (CRPG-CNRS), Nancy, France
12. CETMEF/LGCE, France
13. Channel Maintenance Research Institute (CMRI), ISESCO, Kalioubia, Egypt
14. Chinese Academy of Sciences – Cold & Arid Regions Environmental and Engineering Research Institute
15. Chinese Academy of Sciences – Institute of Mountain Hazards and Environment, China
16. Chinese Academy of Sciences – Institute of Soil and Water Conservation, China
17. Chinese Academy of Sciences – Institute of Tibetan Plateau Research (ITPCAS), China
18. Coastal Research Institute, Egyptian Shore Protection Authority, Egypt
19. Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia
20. Consiglio Nazionale delle Ricerche (CNR), Italy
21. Federal Ministry of Environment, Nigeria
22. French Agricultural and Environmental Research Institute (CEMAGREF)
23. French Research Institute for Exploration of the Sea (IFREMER), France
24. Geological Survey of Canada, Atlantic
25. Geological Survey of Canada, Pacific
26. Geological Survey of Israel, Jerusalem, Israel
27. Geological Survey of Japan (AIST), Japan
28. Geosciences, Rennes France
29. GFZ, German Research Centre for Geosciences, Potsdam, Germany
30. Global Institute for Water Security, Canada
31. GNS Science, New Zealand
32. GNU VNIIGiM, Moscow, Russia
33. Greenhood Nepal, Nepal
34. Group-T, Myanmar
35. Helmholtz Centre for Environmental Research (UFZ), Germany
36. Indian National Centre for Ocean Information Services (INCOIS), India
37. Indian Space Research Organization

38. Institut des Sciences de la Terre, France
39. Institut National Agronomique (INAS), Algeria
40. Institut National de la Recherche Agronomique (INRA), France
41. Institut Physique du Globe de Paris, France
42. Institut Teknologi Bandung (ITB), Indonesia
43. Institute Atmospheric Sciences & Climate (ISAC) of Italian National Research Council (CNR), Italy
44. Institute for Computational Science and Technology (ICST), Viet Nam
45. Institute for the Conservation of Lake Maracaibo (ICLAM), Venezuela
46. Institute of Earth Sciences (ICTJA-CSIC), Spain
47. Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, Bulgaria
48. Instituto Hidrografico, Lisboa, Lisbon, Portugal
49. Instituto Nacional de Hidraulica (INH), Chile
50. Instituto Nazionale di Astrofisica, Italy
51. Instituto Nazionale di Geofisica e Vulcanologia, Italy
52. International Geosphere Biosphere Programme (IGBP), Sweden
53. Iranian National Institute for Oceanography (INIO), Tehran, Iran
54. Israel Oceanographic & Limnological Research, Israel
55. Italy National Research Council (CNR), Italy
56. Japan Agency for Marine-Earth Science Technology (JAMSTEC), Japan
57. Kenya Meteorological Services, Kenya
58. Korea Ocean Research and Development Institute (KORDI), South Korea
59. Korea Water Resources Corporation, South Korea
60. Lab Domaines Oceanique IUEM/UBO France
61. Laboratoire de Sciences de la Terre, France
62. Marine Sciences For Society, France
63. Ministry of Earth Sciences, India
64. Nanjing Hydraulics Research Institute, China
65. National Geophysical Research Institute, India
66. National Institute for Environmental Studies, Japan
67. National Institute of Water and Atmospheric Research (NIWA), Auckland, New Zealand
68. National Research Institute of Science and Technology for Environment and Agriculture, France
69. National Institute for Space Research (INPE), Brazil
70. National Institute of Oceanography (NIO), India
71. National Institute of Technology Rourkela, Orissa, India
72. National Institute of Technology Karnataka Surathkal, Mangalore, India
73. National Institute of Water and Atmosphere (NIWA), New Zealand
74. National Marine Environmental Forecasting Center (NMEFC), China
75. National Oceanography Centre – Liverpool, UK
76. Natural Resources, Canada
77. National Research Centre for Sorghum (NRCS), India
78. National Research Council (NRC), Italy
79. National Space Research & Development Agency, Nigeria
80. Netherlands eScience Center, Netherlands
81. Qatar National Historic Environment Project
82. Scientific-Applied Centre on hydrometeorology & ecology, Armstatehydromet, Armenia
83. Secretaria del Mar, Ecuador
84. Senckenberg Institute, Germany
85. Shenzhen Inst. of Advanced Technology, China
86. South China Sea Institute of Technology (SCSIO), Guanzhou, China
87. The European Institute for Marine Studies (IUEM), France

88. The Leibniz Institute for Baltic Sea Research, Germany
89. UNESCO-IHE, Netherlands
90. Water Resources Division, Dept. of Indian Affairs and Northern Development, Canada
91. World Weather Information Service (WMO), Cuba

Independent Researchers (both U.S. and Foreign): 31 members self-identify as independent researchers.

1.5 CSDMS2.0 Community Initiatives:

CSDMS2.0 grew to a new level of integrative science and community coordination.

1) An **Ecosystem Dynamics Focus Research Group** (**FRG**) was launched in November 2015, co-sponsored by the International Society for Ecological Modelling (ISEM www.isemna.org). Membership has surpassed 100 during the last 2.5 years, with efforts focused on developing capacity, and getting ISEM and CSDMS to be familiar with each other's approaches. In 2017 the Ecosystem Dynamics FRG offered up keynote lectures and clinics at both the CSDMS and ISEM open meetings. The group supports integrated studies of the cycling of water, carbon, nutrients, the impacts of vegetation on morphodynamics, and efforts to investigate feedbacks between climate, biogeochemical processes, and ecosystems dynamics. Some examples of recent papers include

1. De Mutsert, K. Lewis, K.A., Buszowski, J., Steenbeek, J. and S. Milroy. Using ecosystem modeling to evaluate trade-offs in coastal management: effects of large-scale river diversions on fish and fisheries. Ecological Modelling 360:14-26. doi:10.1016/j.ecolmodel.2017.06.029
2. Gruss, A., Rose, K.A., Simons, J., Ainsworth, C.H., De Mutsert, K., Himchak, P., Kaplan, I.C., Froeschke, J., Zetina Rejon, M.J., and D. Chagaris. 2017. Recommendations for ecosystem modeling efforts aiming to inform ecosystem-based fisheries management and restoration projects. Marine and Coastal Fisheries. doi: 10.1080/19425120.2017.1330786
3. De Mutsert, K., Steenbeek, J., Cowan, J.H. Jr., and V. Christensen. 2017. Using ecosystem modeling to determine hypoxia effects on fish and fisheries. Chapter 14 *In*: D. Justic, K.A. Rose, R.D. Hetland, and K. Fennel (eds). Modeling Coastal Hypoxia: Numerical Simulations of Patterns, Controls and Effects of Dissolved Oxygen Dynamics. Springer, New York
4. Vasslides, J.M., De Mutsert, K., Christensen, V., and H. Townsend. 2016. Using the Ecopath with Ecosim modeling approach to understand the effects of watershed-based management actions in coastal ecosystems. Coastal Management *45 (1)*: 1-12. doi: 10.1080/08920753.2017.1237241.
5. Lewis, K.A., De Mutsert, K., Cowan, J.H., Steenbeek, J. and J. Buszowski. Employing ecosystem models and Geographic Information Systems (GIS) to investigate the response of changing marsh edge on the historical biomass of estuarine nekton in Barataria Bay, Louisiana, USA. Ecological Modelling *331*: 129-141. doi: 10.1016/j.ecolmodel.2016.01.017.
6. De Mutsert, K., Steenbeek, J., Lewis, K., Buszowski, J., Cowan, J.H. Jr., and V. Christensen. 2016. Exploring effects of hypoxia on fish and fisheries in the northern Gulf of Mexico using a dynamic spatially explicit ecosystem model. Ecological Modelling *331*: 142-150. doi: 10.1016/j.ecolmodel.2015.10.013.

2) A **Geodynamics FRG** was launched in 2014, co-sponsored by NSF's GeoPRISMS. The Geodynamics FRG is developing new initiatives with NSF's CIG to facilitate the understanding of the interplay between climatic, geomorphic, and geological/tectonic processes in governing Earth surface processes and landscape evolution. The Geodynamics FRG has grown to 161 members, and is focused on coupling models that offer the capability of tracking paleotopography, geology, substrate lithology, crustal deformation, climate, vegetation, runoff production, and ensuing sediment transport and storage. The FRG is closely aligned to the CSDMS Terrestrial Working Group,

offering the following goals: 1) build up a community, and identify key questions and how existing codes might fit into the CSDMS framework; 2) develop robust coupled geodynamic-landscape evolution model(s); and 3) build a community around these model(s), benchmark these models and train users. In April 2018, the Geodynamics FRG teamed with the Community Infrastructure for Geodynamics to convene a 3-day workshop titled, "Coupling of Tectonic and Surface Processes". The meeting was attended by 100 on-site participants and an additional 50 remote participants. The goal of the workshop was to survey both questions and state of the art numerical techniques that simulate surface processes and long-term tectonic (LTT) processes in an attempt to define a framework for the development of efficient numerical algorithms that couple across multiple length and time scales. The workshop provided a unique opportunity for researchers to develop collaborations and proposal ideas and by doing so, enhance and increase the impact of both the CIG and CSDMS communities. A white paper that will be submitted to NSF is currently in the final stages of review. The white paper will serve to set the stage for new educational and method development efforts, including submission of a NSF Research Collaboration Network proposal. Some examples of recent Geodynamics FRG publications include:

1. Booth, A.M., LaHusen, S.R., Duvall, A.R., Montgomery, D.R. (2017) Holocene history of deep-seated landsliding in the North Fork Stillaguamish River valley from surface roughness analysis, radiocarbon dating, and numerical landscape evolution modeling. Journal of Geophysical Research: Earth Surface, 122 (2), pp. 456-472.
2. Kravitz, K., Upton, P., Mueller, K., Roy, S. (2017) Topographic controlled forcing of salt flow: Three-dimensional models of an active salt system, Canyonlands, Utah, J. Geophys. Res. Solid Earth, 122, 710– 733, doi:10.10 02/2016JB013113.
3. Langston, A.L., Tucker, G.E., Anderson, R.S. (2015) Interpreting climate-modulated processes of terrace development along the Colorado Front Range using a landscape evolution model Journal of Geophysical Research F: Earth Surface, 120 (10), pp. 2121-2138.
4. Logan, L.C., Lavier, L.L., Choi, E., Tan, E., Catania, G.A. (2017) Semi-brittle rheology and ice dynamics in DynEarthSol3D. Cryosphere, 11 (1), pp. 117-132.
5. Rengers, F.K., Tucker, G.E., Mahan, S.A. (2016) Episodic bedrock erosion by gully-head migration, Colorado High Plains, USA. Earth Surface Processes and Landforms, 41 (11), pp. 1574-1582.
6. Roy, S. G., G. E. Tucker, P. O. Koons, S. M. Smith, and P. Upton (2016), A fault runs through it: Modeling the influence of rock strength and grain-size distribution in a fault-damaged landscape, *Journal of Geophysical Research: Earth Surface*, *121*(10), 1911-1930, doi:10.1002/2015JF003662.
7. Roy, S.G., Koons, P.O., Osti, B., Upton, P., Tucker, G.E. (2016) Multi-scale characterization of topographic anisotropy. Computers and Geosciences, 90, pp. 102-116.
8. Sutherland, R., Townend, J., Toy, V., Upton, P., Coussens, J. and the DFDP-2 Science Team (2017), Extreme hydrothermal conditions at an active plate-bounding fault, *Nature*, *advance online publication*, doi:10.1038/nature22355.
9. Zeitler, P.K., Koons, P.O., Hallet, B., Meltzer, A.S. (2015) Comment on "Tectonic control of Yarlung Tsangpo Gorge revealed by a buried canyon in Southern Tibet" Science, 349 (6250), p. 799b

3) An Anthropocene FRG was launched in 2013 and the FRG was rebranded as the **CSDMS Human Dimensions FRG** in 2016 to develop mechanistic models of the influence(s) of human actions on landscapes and ecosystems. The initiative was designed to fill in the critical gap in most surface process models with explicit consideration of the role of humans. Some hydrological models have accounted for such influences as the impact of humans on the flux of terrestrial sediment to the global coastal ocean. However, few models have attempted to account for the dynamic role of humans in landscape change. Coupling of human and landscape models should simulate, for example, management styles, restoration opportunities, locating reservoirs, forestry practices, coastal construction, marine activity, fisheries, and coastal protection. CoMSES net, the open agent-based

modeling community co-sponsored the FRG, along with the Analysis, Integration, and Modeling of the Earth System or AIMES international project of Future Earth. The group currently has 109 (very active) members. The FRG has been particularly active with model development meetings in Boulder, Kyoto, and Potsdam. Human interactions in shaping the earth surface became our 2017 Annual meeting theme. A number of publications reflect this activity including:

1. Robinson DT, ADi Vittorio, P Alexander, A Arneth, C M Barton, DG. Brown, A Kettner, C Lemmen, BC. O'Neill, M Janssen, TAM Pugh, SS Rabin, M Rounsevell, JP Syvitski, I Ullah, PH Verburg submitted Modelling feedbacks between human and natural processes in the land system. Earth Syst. Dynam., https://doi.org/10.5194/esd-2017-68
2. Waters, CN, J Zalasiewicz, C Summerhayes, IJ Fairchild, NL Rose, N Loader, A Cearreta, M Head, , J Syvitski, M Williams, M Wagreich, AD Barnosky, A Zhisheng, R Leinfelder, C Jeandel, A Gałuszka, JA Ivar do Sul[5], F Gradstein, W Steffen, JR McNeill, C Poirier, M Edgeworth, in review, Palaeoenvironmental archives and their differing suitabilities to provide candidate Global Boundary Stratotype Sections and Points (GSSPs) for the Anthropocene. Earth Science Reviews.
3. 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), 11 pg.
4. 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, 2016. The Anthropocene: a conspicuous stratigraphical signal of anthropogenic changes in production and consumption across the biosphere. *Earth's Future* 4(3): 34-53.
5. Verburg, P.H., J Dearing, J Syvitski, S van der Leeuw, S Seitzinger, P Matrai, W Steffen, 2016, Methods and approaches to modelling the Anthropocene, *Global Environmental Change 39: 328–340*
6. 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 39: 351–362*.

4) A **Coastal Vulnerability Modeling Initiative**, with emphasis on deltas and their multiple threats and stressors was launched in 2013 as part of the much larger Coastal Working Group (membership of >600), and has 121 active members. With most of the world's megacities and a majority of the world's population living near the coast, sea-level rise and other environmental stressors are having profound societal and economic consequences globally and could lead to large (between 25% and 70%) losses of the world's wetlands. The Belmont Forum of Global Environmental Funders, and NSF's Delta Dynamics Collaboratory supported this CV modeling initiative. The CSDMS Coastal Working Group is coordinating these efforts to develop a modeling framework by coupling multiple components of the delta system that capture the multiple and necessary time-scales and hierarchal spatial scales. A suite of 1D (reduced complexity) to 3D (ecogeomorphodynamic flow and sediment transport) models were developed, along with a "fingerprinting" system to identify hot spots of key delta systems as they respond to environmental stressors, as supported by NASA funding. Some recent papers:

1. Higgins, S., Overeem, I., Rogers, K., Kalina, E., (in rev. 2017). Impacts of India's National River Linking Project on Rivers and Deltas. *Elementa*.
2. Tessler, Z., C. Vörösmarty, M. Grossberg, I Gladkova, H Aizenman, J Syvitski and E Foufoula-Georgiou, 2015, Profiling Risk and Sustainability in Coastal Deltas of the World. *Science* 349 (6248): 638-643.

3. Xing, F, Syvitski, JP, AJ Kettner, EA Meselhe, JH Atkinson, A Khadka, *in review,* Morphodynamic Impacts of Hurricanes on the Wax Lake Delta, Louisiana, *Elementa*

4. 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, 2016, Approaches to Defining Deltaic Sustainability in the 21st Century. *Coastal and Shelf Science* 183B: 275–291.

5. Giosan, L., Syvitski, J, Constantinescu, S, Day, J, 2014, Climate Change: Protect the world's deltas, *Nature* 516: 31-33.

6. Renaud, F, Syvitski JPM, Sebesvari Z, Werners SE, Kremer H, Kuenzer C, Ramesh R, Jeuken A, Friedrich J, 2013, Tipping from the Holocene to the Anthropocene: how threatened are major world deltas? *Current Opinion in Environmental Sustainability* 5: 644-654.

5) A **Continental Margin Modeling Initiative,** with 65 members, was developed to capture extreme oceanic and atmospheric events generating turbidity currents. With support of the Marine Working Group, CSDMS upscaled a high-resolution large-eddy-simulation (LES) turbidity current model (*TURBINS*) to a coarser resolution Reynolds-averaged Navier-Stokes (RANS) ocean circulation model *ROMS* with the *Community Surface Transport Model* enabled. The project was funded through the Bureau of Ocean Energy Management (BOEM). Model runs offered insights into areas most likely to be impacted by turbidity currents, and the factors that precondition or trigger the flow. The Gulf of Mexico has >3500 oil platforms and >28,000 miles of underwater pipes exposed to different types of structural damage, most of them associated with extreme oceanic and atmospheric events. About 5% of the pipelines are broken or damaged by sudden and violent cascading of sediments.

6) A **Critical Zone Focus Research Group** was established in 2014 to maintain compatibility between CSDMS architecture and protocols and Critical Zone Observatory-developed models and data. CZO scientists (http://criticalzone.org/national/) are beginning to explore feedbacks among hillslope hydrology, physical and chemical weathering processes, plant and microbial activity, and nutrient cycling. There is important synergy between participants in CZO and CSDMS. In 2017 co-sponsorship was extended with the support of the International Soil Modeling Consortium (https://soil-modeling.org). The CSDMS CZO FRG has more than 100 members.

1.6 CSDMS Collaboration - Support of NSF Research Projects

The CSDMS Integration Facility offered model guidance to more than 100 CSDMS2.0-related software development teams (see below).

1. Collaborative Research: Grand Canyon's Muav Gorge as a Natural Experiment: Linking Geomorphology, Thermochronology, and Structural Geology to Probe River Incision into Layered Rock

2. Collaborative Research: Linking geomorphology, thermochronology, and structural geology in the Muav Gorge: a keystone to understanding Grand Canyon incision

3. RAPID: Collaborative Research: Deepwater Horizon: Simulating the three dimensional dispersal of aging oil with a Lagrangian approach

4. Collaborative Research: Coastal Geomorphic Consequences of Wave Climate Change

5. Interpretation of Arctic North Slope Permafrost Borehole Thermal Evolution in Light of Spatial and Temporal Variation in Surface Temperature Fields

6. Boulder Creek CZO II: Evolution, Form, Function, and Future of the Critical Zone

7. Boulder Creek CZO Renewal: Weathered Profile Development in a Rocky Environment and Its Influence on Watershed Hydrology and Biogeochemistry

8. EAGER: Collaborative Research: Developing a Community Computational Infrastructure for Earth System Model Research and Applications

9. Collaborative Research: Investigating Human and Climate Influences on Delta Evolution Using Fluvial Discharge and Coastal Evolution Models

10. GP-IMPACT: Earth Lab: Enabling Undergraduate Pathways through Accelerated Discovery Geosciences

11. Geoinformatics: GEON 2.0: A Data Integration Facility for the Earth Sciences

12. Collaborative Research: 3D Dynamics of Buoyant Diapirs in Subduction Zones

13. CZO: Transformative Behavior of Water, Energy and Carbon in the Critical Zone: An Observatory to Quantify Linkages among Ecohydrology, Biogeochemistry, and Landscape Evolution

14. Collaborative Research: The legacy of transience: Understanding dynamic landscape adjustment following mountain uplift in two CZO field areas

15. EarthCube Building Blocks: CyberConnector: Bridging the Earth Observations and Earth Science Modeling for Supporting Model Validation, Verification, and Inter-comparison

16. Collaborative Research: Tracing the Geomorphic Signature of Strike-Slip Faulting in Marlborough Hill Country, South Island, New Zealand

17. MARGINS Post-Doctoral Fellowship: A synthesis model for the Fly River dispersal system, Papua New Guinea

18. ETBC Collaborative Research: Feedbacks between nutrient enrichment and intertidal sediments: erosion, stabilization, and landscape evolution

19. EAGER: Collaborative Research: Developing a Community Computational Infrastructure for Earth System Model Research and Applications

20. The evolution of hummocky moraine landscapes: a modeling study

21. Interactions of Estuarine Physics, Sediment, and Organic Matter in Determining Suspended Particle Properties, Their Spatial and Temporal Distribution, and Resulting Water Clarity

22. Improved Observation, Analysis and Modeling of Fine Sediment Dynamics in Turbid, Biologically Active Coastal Environments

23. Collaborative Research: SI2-SSI: Landlab: A Flexible, Open-Source Modeling Framework for Earth-Surface Dynamics

24. Collaborative Research: The legacy of transience: Understanding dynamic landscape adjustment following mountain uplift in two CZO field areas

25. Collaborative Research: SI2-SSE: Component-Based Software Architecture for Computational Landscape Modeling

26. Collaborative Research: Modeling and monitoring of landscape evolution along a climate gradient: Kohala Peninsula, Hawaii

27. EarthCube Building Blocks: Collaborative Proposal: GeoSoft: Collaborative Open Source Software Sharing for Geosciences

28. EarthCube Building Blocks: Software Stewardship for the Geosciences

29. EAGER: Collaborative Research: Developing a Community Computational Infrastructure for Earth System Model Research and Applications

30. Coastal SEES Collaborative Research: Multi-scale modeling and observations of landscape dynamics, mass balance, and network connectivity for a sustainable Ganges-Brahmaputra delta

31. Belmont Forum-G8 Collaborative Research: DELTAS: Catalyzing action towards sustainability of deltaic systems with an integrated modeling framework for risk assessment

32. Acquiring Airborne Lidar data to study hydrologic, geomorphologic, and geochemical processes at three Critical Zone Observatories (CZO)

33. Coastal SEES Collaborative Research: Changes in actual and perceived coastal flood risks due to river management strategies

34. MRI Collaborative Consortium: Acquisition of a Shared Supercomputer by the Rocky Mountain Advanced Computing Consortium

35. Collaborative Research: Watershed, estuarine, and local drivers of coastal marsh establishment and resilience

36. Collaborative Research: The effect of sand fraction and event evolution on fine-sediment transport and the depositional record in wave-supported mud flows

37. EarthCube Building Blocks: Collaborative Proposal: A Geo-Semantic Framework for Integrating Long-Tail Data and Models

38. Collaborative Research: The effect of sand fraction and event evolution on fine-sediment transport and the depositional record in wave-supported mud flows

39. Evolution of Small Scale Seafloor Toography and Sediment Transport Under Energetic Waves: Ripples to Sheet Flow

40. Collaborative Research: SI2-SSI: An Interactive Software Infrastructure for Sustaining Collaborative Community Innovation in the Hydrologic Sciences

41. Collaborative Research: SI2-SSI: Landlab: A Flexible, Open-Source Modeling Framework for Earth-Surface Dynamics

42. Collaborative Research: SI2-SSE: Component-Based Software Architecture for Computational Landscape Modeling

43. Towards a Tiered Permafrost Modeling Cyberinfrastructure

44. C1F21 DIBBS: Porting Practical Natural Language Processing (NLP) and Machine Learning (ML) Semantics from Biomedicine to the Earth, Ice and Life Sciences

45. Collaborative Research: Population Ecology Models for Carbonate Sediments

46. Collaborative Research: The rise and topographic evolution of the High Plains and Southern Rockies: Cryptic orogeny or 'anorogenic' surface uplift?

47. International Research Fellowship Program: Determining Bedrock Incision Rates using Cosmogenic Isotope \3He\ Analysis to Chronologically Constrain the Wetland Development Cycle in

48. Collaborative Research: Investigating Human and Climate Influences on Delta Evolution Using Fluvial Discharge and Coastal Evolution Models

49. RCN: Building a Sediment Experimentalist Network (SEN)

50. Collaborative Research: Sea-level Rise and Vegetation Controls on Deltaic Landform Evolution: A Coupled Experimental and Numerical Modeling Study

51. Collaborative Research: Rivers, Faults, and Growing Mountains: Dynamic Feedback between Crustal Deformation, Rock Strength, and Erosion

52. Collaborative Proposal: Modeling Sediment Production from Glaciers off south-central Alaska during Quaternary Climate Oscillations

53. Collaborative Research: 3D Deformation, Material Strength and Landscape Evolution

54. EarthCube Building Blocks: Collaborative Proposal: A Geo-Semantic Framework for Integrating Long-Tail Data and Models

55. Collaborative Research: WILSIM2, The Next Generation Landform Simulator

56. EarthCube Building Block: GeoDataspace: Simplifying Data Management for Geoscience Models

57. Collaborative Research: Coastal Geomorphic Consequences of Wave Climate Change

58. Collaborative Proposal; Environment, Society, and Economy: Modeling New Behaviors Emerging from Coupling Physical Coastal Processes and Coastal Economies

59. Collaborative Research: Computational techniques for nonlinear joint inversion

60. Collaborative Research: Double-diffusive sedimentation

61. Gravity Currents and Related Phenomena: A Circulation-Based Modeling Framework

62. Gravity and Turbidity Currents Interacting with Interfaces of Free Surfaces

63. Formation and Evolution of Sediment Waves: Integration of Quantitative Modeling and Field Observations

64. FESD Type I: A Delta Dynamics Collaboratory

65. Climatic Controls on Snow-Vegetation Interactions Across an Elevational Gradient

66. Collaborative Research:The Role of Ecomorphodynamic Feedbacks in Barrier Island Response to Climate Change

67. Collaborative Research: Coastal Geomorphic Consequences of Wave Climate Change

68. Collaborative Research: Sea-level Rise and Vegetation Controls on Deltaic Landform Evolution: A Coupled Experimental and Numerical Modeling Study

69. RAPID: Collaborative Research: Deepwater Horizon: Simulating the three dimensional dispersal of aging oil with a Lagrangian approach

70. Hyperpycnal River Plumes – an opportunity to study their transport and deposition in a controlled dam-removal experiment

71. Coastal SEES Collaborative Research: Multi-scale modeling and observations of landscape dynamics, mass balance, and network connectivity for a sustainable Ganges-Brahmaputra delta

72. Belmont Forum-G8 Collaborative Research: DELTAS: Catalyzing action towards sustainability of deltaic systems with an integrated modeling framework for risk assessment

73. Modeling Floodplain Dynamics: Can the Ganges-Brahmaputra Delta Keep Up with the 21st Century Sea Level Rise?

74. River Plumes as Indicators for Greenland Ice Sheet Melt

75. Summit Meeting for Surficial Earth Process Cyberinfrastructure

76. CAREER: The Delta Connectome: Structure and Transport Dynamic of Delta Networks across Scales and Disciplines

77. EarthCube Building Blocks: Collaborative Proposal: A Geo-Semantic Framework for Integrating Long-Tail Data and Models

78. EarthCube Building Blocks: Earth System Bridge: Spanning Scientific Communities with Interoperable Modeling Frameworks

79. EAGER: Collaborative Research: Developing a Community Computational Infrastructure for Earth System Model Research and Applications

80. COLLABORATIVE RESEARCH: Clarifying the ingredients and significance of nonlocal versus local sediment transport on steepland hillslopes

81. Collaborative Research: Incorporating hillslope transport into laboratory landscape experiments

82. SEES Fellow: Linking Rural Smallholder Soil and Water Management Practices in Tropical Deltas to Sea Level Rise Vulnerability

83. Science-Driven Cyberinfrastructure: Integrating Permafrost Data, Services, and Research Applications

84. Collaborative Research: Reconstructing ancient passive margin dynamics by relating geomorphic and stratigraphic surfaces: a combined laboratory and field study

85. Collaborative Research:Reproducible research and educational software for geoscience data analysis in spherical and planar geometry

86. CAREER: From Robust, Reproducible Geophysical Inference to Geological Interpretation: New Perspectives on the Continental Lithosphere

87. Collaborative Research: Catchments and Coastlines–The Influence of Sediment Load and Type on Delta Morphodynamics and Deposits

88. Tectonics in the Western Anatolian Extensional Province from sequence stratigraphic modeling of multichannel seismic data in the Gulf of Kusadasi

89. Collaborative Research: The North Anatolian Fault system in the Marmara Sea, Turkey – Insights from the Plio-Quaternary evolution of a multi-stranded transform

90. PIRE: Life On A Tectonically-Active Delta: Convergence Of Earth Science And Geohazard Research In Bangladesh With Education And Capacity Building

91. Collaborative Research: Why is a massif rising in the Himalayan foreland? Tectonics, uplift and erosion of the Shillong Anticlinorium, India

92. Collaborative Research: Reconstructing deformation and landscape evolution using paleosurfaces and high-sensitivity Be10 methods in Calabria, Italy and Shillong, India

93. Computational Infrastructure for the Community Surface Dynamics Modeling System

94. Collaborative Research: CDI Type II: Scaling Up: Introducing Community Governance into Community Earth Science Modeling

95. NRT-DESE: Integrated Modeling and Analysis for the Anthropocene

96. IGERT: Interdisciplinary Modeling and Analysis for the Anthropocene

97. Collaborative Research: SI2-SSI: An Interactive Software Infrastructure for Sustaining Collaborative Community Innovation in the Hydrologic Sciences

98. Collaborative Research: SI2-SSE: Component-Based Software Architecture for Computational Landscape Modeling

99. Collaborative Research: Normal-Fault Facets as Recorders of Erosion and Tectonics

100. Impacts of Vegetation and Climate Change on Dryland Rivers: Lesssons from the Rio Puerco, New Mexico

101. WSC-Category 3: Impacts of Climate and Vegetation Change on Rivers in the Arid Southwest

102. MRI-Consortium: Acquisition of a Supercomputer by the Front Range Computing Consortium

103. The internal structure of deposits emplaced under upper plane bed / sheet flow transport conditions: Laboratory experiments and numerical modeling

104. Collaborative Research: Tsunami and Tropical Storm Sediment Dynamics and Products

105. Sensitivity of Braided River Morphodynamics to Sediment Supply

106. Collaborative Research: The legacy of transience: Understanding dynamic landscape adjustment following mountain uplift in two CZO field areas

107. Coastal SEES Collaborative Research: Multi-scale modeling and observations of landscape dynamics, mass balance, and network connectivity for a sustainable Ganges-Brahmaputra delta

108. Collaborative Research: Linking erosional and climatic processes in regions of active mountain building

Chapter 2: CSDMS2.0 Management and Oversight

CSDMS operates under a set of Bylaws first adopted in 2007, updated in 2013 and again in 2016. The **CSDMS Steering Committee** consists of representatives of U.S. Federal Agencies, Industry, and Academia. The **CSDMS Executive Committee** is comprised of organizational chairpersons.

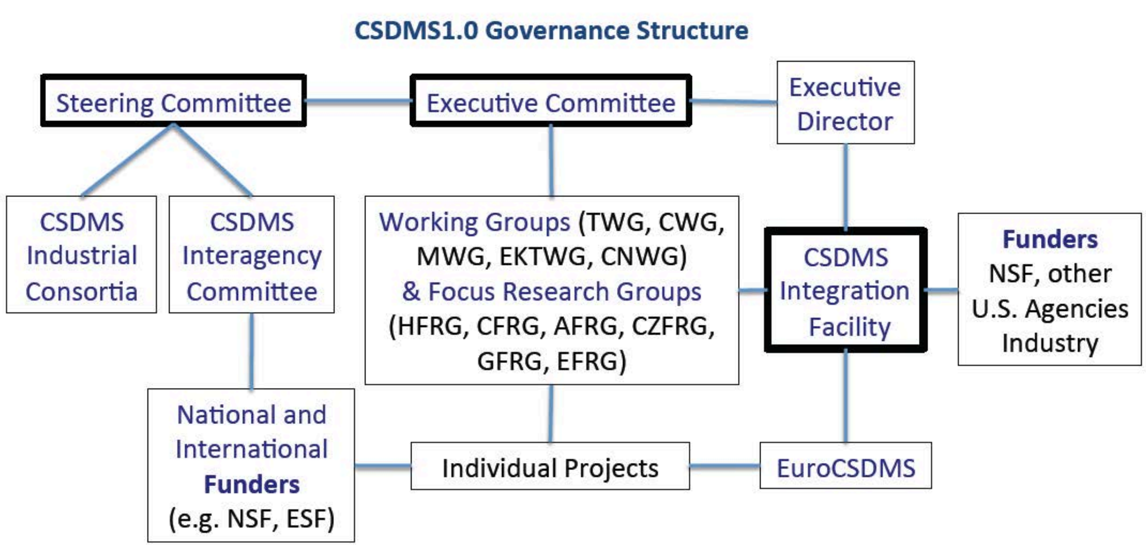


Fig. 2.1 CSDMS Governance Structure

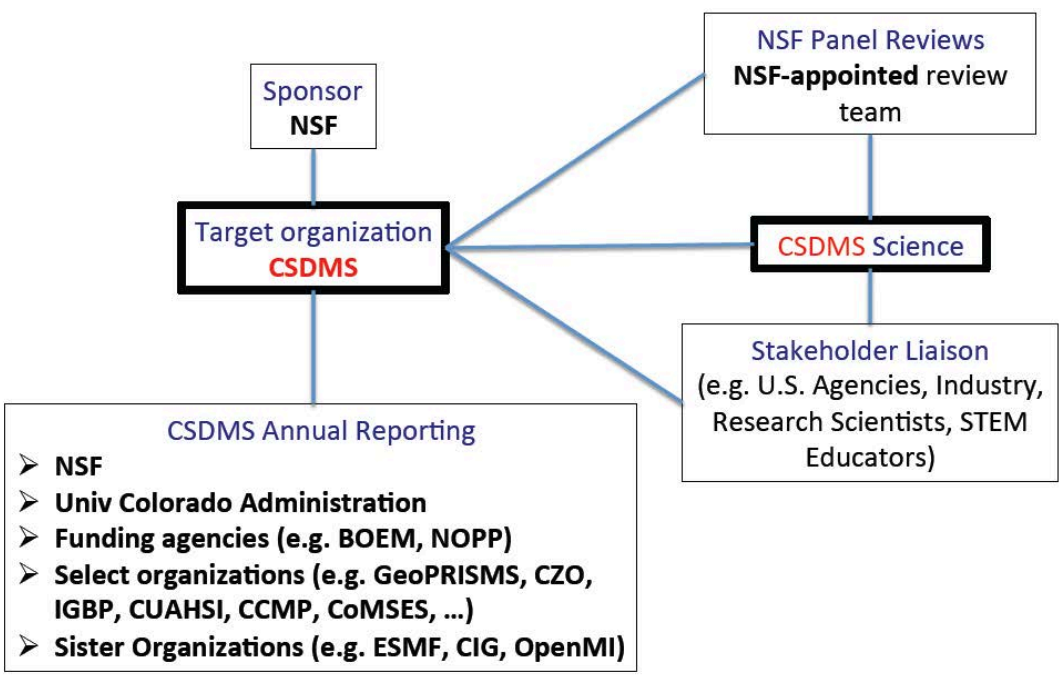


Fig. 2.2 CSDMS Reporting Structure

2.1 The CSDMS Steering Committee (as Oct 2017)

- **Brad Murray** (August 2017 —), SC Chair, Duke U., Durham, NC
- **Tom Drake** (April 2007—), U.S. Office of Naval Research, Arlington, VA
- **Bert Jagers** (April 2007—), Deltares, Delft, The Netherlands
- **Marcelo Garcia** (Dec. 2012—), U. 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—), U. Oregon, Eugene, OR
- **Guillermo Auad** (Jan. 2013—), Bureau of Ocean and Energy Management, Herndon, VA
- **Efi Foufoula-Georgiou** (March 2016—), U. California, Irvine, CA
- **David Mohrig** (March 2016—), U. Texas, Austin, TX
- **Greg Tucker** (*ex-officio* Oct. 2017 -), CSDMS, U. Colorado, Boulder, CO
- **Richard Yuretich** (*ex-officio),* National Science Foundation

Past SC members (2013-2017)

- **Patricia Wiberg** (2012 - 2017), SC Chair, U. Virginia, VA
- **Jai Syvitski** (2012 - 2017), CSDMS Executive Director, U. Colorado, Boulder, CO
- **Marty Perlmutter** (2009 - 2015), Chevron, Houston TX

The CSDMS Steering Committee or SC comprises 10 members: 8 selected by the EC to represent the spectrum of relevant Earth science and computational disciplines, and 2 selected by Partner Membership. The cognate NSF program officer or his/her designate, and the Executive Director or his/her designate, serve as ex officio members of the SC. The Steering Committee meets once a year to assess the competing objectives and needs of the CSDMS; will comment on the progress of CSDMS in terms of science (including the development of working groups and partner memberships), management, outreach, and education; and will comment on and advise on revisions to the 5-year strategic plan. The Steering Committee provides a report to the Executive Director at the close of its meeting.

2.2 The CSDMS Executive Committee (as of July 2018):

- **Greg Tucker** (Oct. 2017—) Chair ExCom & CSDMS Executive Director, CIRES, U. Colorado
- **Irina Overeem** (Oct. 2017—) Deputy Director CSDMS Integration Facility, INSTAAR, U. Colorado
- **Brad Murray** (August 2017—) Chair CSDMS Steering Committee, Duke U., NC
- **Chris Sherwood** (Sept. 2014—) Chair CSDMS Interagency WG, USGS, Woods Hole, MA
- **Nicole Gasparini** (April 2016—) Chair Terrestrial WG, Tulane U., New Orleans, LA
- **Andrew Ashton** (August 2017—) Co-Chair Coastal WG & Coastal Vulnerability Initiative, Woods Hole Oceanographic Institution, Woods Hole, MA
- **Eli Lazarus** (August 2017—) Co-Chair Coastal WG & Coastal Vulnerability Initiative, U. Southampton, UK
- **Courtney Harris** (April 2012—) Chair Marine WG & Continental Margin Initiative, VIMS, VA
- **Tom Hsu** (Sept. 2015—) Co-Chair Cyberinformatics & Numerics WG, U. Delaware, Newark,

DE
- **Scott Peckham** (April 2017—) Co-Chair Cyberinformatics & Numerics WG, U. Colorado – Boulder, CO
- **Wei Luo** (Sept. 2015—), Chair Education & Knowledge Transfer WG, N. Illinois U., Dekalb, IL
- **Brian Fath** (Nov. 2014—), Co-Chair Ecosystem Dynamics FRG, Towson U., Towson, MD & International Institute for Applied Systems Analysis, Laxenburg, Austria
- **Kim deMutsert** (August 2016—) Co-Chair Ecosystem Dynamics FRG, George Mason U., Fairfax, VA
- **Peter Burgess** (Sept. 2008—) Co-Chair Carbonate & Biogenics FRG, U. Liverpool, UK
- **Chris Jenkins** (Nov. 2015-) Co-Chair Carbonate & Biogenics FRG, U Colorado– Boulder, CO
- **Venkat Lakshmi** (Sept. 2015 —) Co-Chair Hydrology FRG, U. South Carolina, Columbia, SC
- **Mary Hill**, (March 2017—) Co-Chair Hydrology FRG, U. Kansas, Lawrence, KS
- **Raleigh Hood** (July 2014—) Chair Chesapeake FRG, U. of Maryland, Cambridge, MD
- **Alejandro Flores** (Oct. 2014—) Co-Chair Critical Zone FRG, Boise State U., ID
- **Michael Young** (July 2017—) Co-Chair Critical Zone FRG, U. Texas— Austin, TX
- **Mark Rounsevell** (Nov. 2014 —) Co-Chair Human Dimensions FRG, Karlsruhe Inst. Tech., Germany
- **Moira Zellner** (August 2016—) Co-Chair Human Dimensions FRG, U. Illinois— Chicago, IL
- **Phaedra Upton** (March 2013—) Co-Chair Geodynamics FRG, GNS, Lower Hutt, New Zealand
- **Mark Behn** (March 2013—) Co-Chair Geodynamics FRG, Woods Hole Oceanographic Inst., MA

Past ExCom members (2013-2017)

- **Jai Syvitski**, Chair ExCom & CSDMS Executive Director, INSTAAR, U. Colorado – Boulder
- **Patricia Wiberg** (April 2012-August 2017) Chair CSDMS Steering Committee, U. Virginia, VA
- **Eckart Meiberg** (April 2009-August 2015) Chair Cyberinformatics & Numerics WG, UC Santa Barbara CA
- **Chris Duffy, (**Mar, 2013—Dec 2015), Chair, Critical Zone Focus Research Group, Penn State, PA
- **Samuel Bentley** (Sept, 2012—June 2015), Chair, Education & Knowledge Transfer WG, LSU, Baton Rouge LA
- **Michael Ellis** (Jan, 2013—July 2014), Co-Chair, Anthropocene Focus Research Group, British Geol. Survey, UK
- **Kathleen Galvin** (Jan, 2013—July 2016), Co-Chair, Human Dimensions Focus Research Group, Colorado State U, CO

The Executive Committee is the primary decision-making body of CSDMS, and ensures that the NSF Cooperative Agreement is met, oversees Bylaws & Operational Procedures, and the annual science plan. ExCom approves business reports, management plan, budget, and other issues that arise in the running of CSDMS. During CSDMS1.0 the CSDMS ExCom was a committee of eight. At the end of CSDMS2.0, 24 people populate the committee.

2.3 CSDMS Working and Focus Research Groups (as of July 2018)

CSDMS Membership is organized within 6 working groups (Terrestrial, Coastal, Marine, Education and Knowledge Transfer, Cyberinformatics and Numerics, Interagency) and 7 focus research groups (Human Dimensions, Carbonate & Biogenics, Hydrology, Critical Zone, Geodynamics, Chesapeake, and Ecosystem Dynamics).

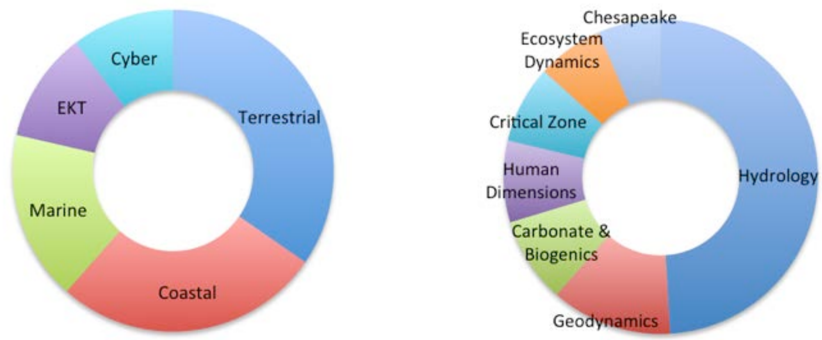


Figure 2.3. *(L) Membership distribution per working group with EKT = Education and Knowledge Transfer group. (R) Membership distribution per focus research group.*

Terrestrial	827 (+252%)	Geodynamics	214 (new)
Hydrology	648 (+270%)	Carbonate & Biogenics	117 (+213%)
Coastal	634 (+245%)	Human Dimensions	130 (new)
Marine	397 (+210%)	Critical Zone	116 (new)
Education	267 (+264%)	Ecosystem Dynamics	126 (new)
Cyber	250 (+240%)	Chesapeake	86 (+221%)

All the CSDMS1.0 groups have doubled in membership, and the newest Focus Research Groups have each established their community. Members provide model code and support tools, educational material, and data for model initialization, testing and benchmarking, and assessing contributed models. The Annual and rolling Strategic Plans transparently reflect input from members.

2.4 2017 – 2018 Group Activities

Terrestrial Working Group

During 2017-2018, the Terrestrial Working Group (TWG) began improving communication among the members. We are exploring ways to best share ideas, and in the past year we experimented with sending emails that highlight relevant papers and meetings. We have also begun the process of electing a co-chair to co-lead the 800+ person group. TWG members helped to plan and organize the NSF sponsored Coupled Tectonics Surface Processes (CTSP) meeting. TWG members also gave talks at the CTSP meeting and are contributing to the writing of the follow-up white paper.

In the coming year we plan to continue improving communication with the help of the new co-chair. We will also work with the Integration Facility to develop webinars for our members. This would be a new offering from the TWG, and it stems from TWG members' continual thirst for learning opportunities beyond the traditional academic setting. We will also initiate seasonal member spotlights to encourage TWG participation.

Coastal Working Group

The bridge year brought two new co-chairs (Andrew Ashton & Eli Lazarus) to the Coastal Working Group. At the CSDMS annual meeting in May, 2018, the Working Group session was attended by ~30 people, of whom approximately two-thirds were new to a CSDMS meeting. We discussed reshaping future Working Group activity around cross-disciplinary science questions as a way to connect different Working Groups and Focus Research Groups with overlapping thematic concerns. Going forward, there are clear and tractable links to the Human Dimensions Focus Research Group (especially given initiatives like "Coasts and People" [CoPe] taking shape at NSF), and likewise to the new CSDMS initiative on machine learning (a significant number of demonstrated/published applications of ML techniques are in coastal settings).

Geodynamics Focus Research Group

The Geodynamics FRG partnered with the Computational Infrastructure for Geodynamics (CIG) to host the Coupled Tectonics and Surface Dynamics workshop at the Integration Facility in April 2018. We had ~150 participants, nearly 100 in person and another 50 online around the globe. The workshop included a series of keynote lectures (available on the CSDMS website), posters presentations, and break-out group discussions. Discussions focused on numerical techniques and reproducibility in model development, the degree to which mass transport properties are constrained, as well as new scientific directions (e.g., the role of climate in modulating tectonic processes, and linkages between landscape evolution and biodiversity). Bringing the tectonics and surface processes communities together facilitated more than just technical discussions of code development; it enabled new scientific perspectives to existing questions and ideas. The workshop organizers and others are currently working on a White Paper summarizing the themes and outcomes of the workshop. The White Paper is expected to be completed this fall.

Under CSDMS 3.0, the Geodynamics FRG plans to build on the success of the workshop and continue to strengthen our ties to the tectonics communities. Community building will encompass knowledge transfer between the groups, skill transfer, communication and, hopefully, some joint tutorials and models. We intend to open discussions with short-term tectonics researchers who model processes which impact landscape evolution on timeframes of seconds to days to year – earthquakes, tsunami and volcanic eruptions.

Interagency Working Group

The Interagency Working Group was established to promote interaction among CSDMS and Federal agencies. Normally, that consists of hosting an IWG meeting to update interested agency representatives on CSDMS activities, and helping to establish productive links between potential agency users of CSDMS technology and CSDMS researchers. Because of the interim nature of 2018 funding, the annual meeting was not held, and agency interactions were mostly limited to the USGS. However, the IWG coordinated with the Chesapeake Bay Focus Group to introduce CSDMS technology to the Chesapeake Bay Model Visioning Workshop, held in January 2018. Dr. Eric Hutton presented *"Nimble Modeling: Modularity and Linkages"* to the 70 attendees at the workshop.

Chesapeake Focus Research Group

The Chesapeake Focus Research Group (CFRG) currently has 87 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 organized and convened a "visioning workshop" that provided a comprehensive review of the status of the current Chesapeake Bay Program (CBP) management modeling system and discussed future directions for management modeling in the CBP with a view toward developing a roadmap for future CBP modeling beyond 2025.

The overarching goal of the workshop was to create a vision for modeling in 2025 and beyond. To prepare the workshop participants to achieve this goal, significant workshop time was invested in reviewing background material related to the status of the current CBP management modeling system and previous recommendations and discussing likely management needs in 2025 and beyond.

The workshop planning was 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 2018 and beyond:* Can a well-informed, realistic, and unified vision for future CBP modeling be created to guide us into the future?

The workshop began with a full day plenary session, supplemented by pre-recorded video presentations that were viewed by participants prior to the workshop that addressed the first three questions above. The presentations and discussion reviewed the purpose of the CBP models, the current state of the CBP modeling system, and the goals of the workshop. In this plenary there were also presentations and discussions related to overarching considerations, like management goals and challenges, how new technologies and modeling approaches can be used to address CBP modeling needs, and what a 2025 Phase 7 modeling system might look like. The second day of the workshop was spent in breakout sessions, organized around each of the major components of the CBP modeling system (land use, watershed nitrogen, watershed phosphorus, watershed sediment, estuarine physics and water quality, and living resources). These breakout groups were charged to consider the needs and resources of the CBP partnership along with prior advice to develop a vision for future modeling. A final half-day plenary session consisted 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 in 2025 and beyond.

The results of the workshop have been compiled into a draft report. The first section on *Findings* highlights factual conclusions and the consensus of professional opinion that emerged from the workshop presentations and discussion. Those findings consider management perspectives, cross-cutting topics (e.g., the challenge of incorporating living resources and socio-economics into CBP models, the benefits of doing participatory modeling, the benefits of adopting modular approaches, and the need to enable local scale decision support, and assess uncertainty and risk), the strengths and weaknesses of the current Chesapeake Bay Program modeling system, previous STAC advice, and a potential strawman for a 2025 modeling system. The second section on *Recommendations* presents specific actions that workshop participants recommended to advance CBP's modeling system for TMDL development in 2025 and beyond.
Another major outcome/product of this workshop will be a peer-reviewed paper summarizing the major findings and recommendations.

2.5 The CSDMS Integration Facility (IF) (as of July 2018)

CSDMS IF Staff: The Integration Facility maintains the CSDMS repositories and facilitates community communication and coordination, public relations, and product penetration. The Facility 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 2018, the CSDMS IF staff includes:

- Executive Director, Prof. **Greg Tucker** (April, 2016 —)
- Deputy Director and EKT Scientist Dr. **Irina Overeem** (Sept. 2007—)
- Senior Software Engineer, Dr**. Eric Hutton** (April 2007—)
- Software Engineer, Dr. **Mark Piper** (Oct. 2013—)
- Cyber Scientist, Dr. **Albert Kettner** (July 2007—)
- Executive Assistant, **Lynn McCready** (Dec. 2015 —)
- Research Scientist, Dr. **Kimberly Rogers** (March 2012—)
- Director, Flood Observatory, Dr. G **Robert Brakenridge** (Jan. 2010—)
- Senior Research Scientist, Dr. **Christopher Jenkins** (Jan. 2009—)
- Systems Administrator, **Chad Stoffel** (April 2007—)
- Accounting Technician, **Lindsay McCandless** (March 2017—)

Departures

- Executive Director, Prof. Jai Syvitski (Apr 2007-Sept 2017)
- Dr. Scott Peckham (Apr 2007-July 2013)
- Executive Assistant, Ms. Marlene Lofton (Aug. 2008- Jan 2013)
- Executive Assistant, Lauren Borkowski (Jan. 2014 – Oct 2015)
- Accounting Technician Mary Fentress (Apr 2007- Jan 2013)
- PostDoc Fellow Stephanie Higgins (Sept 2010— Sep 2017)
- PostDoc Fellow Elchin Jafarov (June 2015 — Dec 2016)
- Doctoral student Ben Hudson (May 2010- Dec 2014)
- Doctoral student Fei Xing (July 2010-Apr 2015)
- Accounting Technician, Chrystal Pochay (Jul 2013 – Feb 2017)
- Research Associate, Dr. Mariela Perignon (June 2015 —)

2.6 Integration Facility Visiting Scholars:

Date	Visitor
2013	Pat Limber, USGS
2013	Pat Wiberg, VIMS
2013	Brad Murray, Katherine Ratliff, Duke University
2013	Randy Leveque, University of Washington
2013	Architha Reddy, Colorado State University
2013	Mike Steckler, Lamont-Doherty, Columbia University
2013	Fedor Baart, Deltares, SWAN, Delft3D
2013	Landlab Team, Tulane U, U of Washington, U of Colorado
2013	Harutyun Shahumyan, U of Maryland, SESYNC
2013	Wei Yu, David Gochis, UCAR
01/2014 - 01/2015	Xiujuan Liu, China University of GeoSciences
03/2014 - 07/2015	Gary Willgoose, University of Newcastle
08/2014	Mark Bryden, Iowa State University and Ames Laboratory
01/2015	Chris Kees, US ACOE - Coastal Hydraulics Laboratory
05/2015	Konrad Hafen, University of Washington
06/2015-08/2015	Randy Leveque, University of Washington
06/2016-08-2016	Albert van Dijik, Australian National University
07/2015	Mary Hill, University of Kansas
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, Colombia
11/2015	Anne Castle, Water and Science at DOE
11/2015	Patricia Corcoran, CIRES, CU Boulder
01/2016	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, Natl Inst. Water & Atm Research, NZ
03/2016	Bill Ross, Exploration Landmark Software Services
04/2016	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, Colombia
06/2016	Bill Ross, Exploration Landmark Software Services
7/2016	Lejo Flores, Boise State University, ID
8/2016	Michael Barton, Arizona State University, AZ
8/2016	Dale Rothman, University of Denver, CO
8/2016	Juan Restrepo, EAFIT University, Medellin, Colombia
8/2016	Josh Tewksbury, Future Earth, US Secretariat, CO
8/2016	Dimitrios Stampoulis, JPL NASA, Pasadena, CA
8/2016	Ruangdech Poungprom, World Food Program, Bangkok, Thailand
8/2016	Lara Prades, World Food Program, Rome, Italy
8/2016	Dan Slayback, NASA, Washington, D.C.
8/2016	Sarah Muir, World Food Program, Rome, Italy
8/2016	Amy Chong, World Food Program, Bangkok, Thailand

8/2016	Andrea Amparore, World Food Program, Rome, Italy
9/2016	Mike Steckler, Lamont-Doherty Earth Observatory, NY
10/2016	Kathy Hibbard, NASA, PNNL, Richland, WA
10/2016	Andy Large, Newcastle University, UK
10/2016	Guy Schumann, Remote Sensing Solutions
03/2017	Jed Brown, CU, Boulder, Department of Computer Sciences
04/2017	Ben Livneh, CU, Civil, Environmental and Arch. Engineering
05/2017	Michael Young, Intl Soil Modeling Consortium, U. Texas, Austin
06/2017	Megan Melamed, Intl Global Atmospheric Chemistry, CU, Boulder
06-11/2017	Lutz Schirrmeister, AWI, Potsdam, Germany
07/2017	Juan Restrepo, EAFIT University, Medellin, Colombia
08/2017	Randall LeVeque, University of Washington
09/2017 - 09/2018	Ziyue Zing, Tsinghua University, Beijing, China
09/2017 - 09/2019	Jordan Adams, Tulane University
09/2017	Mark Hansford, Colorado School of Mines
10/2017	Mike Steckler, Lamont-Doherty, Columbia University
10/2017	Elchin Jafarov, Los Alamos National Laboratory
11/2017	Paul Liu, North Carolina State University
11/2017	Alexa van Eaton, USGS Cascades Observatory
11/2017	Twila Moon, National Snow Ice Data Center, SEARCH
11/2017	Rafe Pomerance, Polar Research Board
01/2018	Caroline Le Bouteiller, National Research Inst. of Sci & Tech for Env & Ag, France
01/2018 - 12/2018	Margaux Mouchene, Tulane University
02/2018 - 02/2021	Mette Bendixen, University of Copenhagen, Denmark
04/2018 - 04/2019	Lei Zheng, University of Wuhan, China
04/2018	Oscar Fernando Sierra Garcia, EAFIT University, Medellin, Colombia
04/2018	Phaedra Upton, GNS New Zealand
04/2018	Craig Tweedie, University of Texas, El Paso
05/2018	Edgardo Latrubesse, University of Texas
05/2018	Duncan Livesy, University of Leeds, UK
06/2018	Mason Fried, University of Texas, Austin
07/2018	Min Chen, Songshan Yue, Fengyan Zhang, Jin Wang, Yi Huang, Yuwei Cao, Nanjing Normal University, China
07/2018	Simon Kubler, Munich University

Chapter 3: CSDMS Cyber Infrastructure

3.1 Model Metadata Standards

The CSDMS Model Metadata provides a detailed and formalized description of a model. This includes information about:

- Identifying information about the model: model author(s), citations for the model, URL to the source code, etc.
- A description of the model API, if it has been wrapped with a Basic Model Interface. This includes how to build the model, depending on the language, and the include statements that are needed.
- A description of input file parameters. This includes default values, acceptable parameter ranges, and units.
- Template input files that contain special markup where parameters from the metadata parameter description can be placed.
- A description of how to run the model from the command line.

The CSDMS Model Metadata is extensible with new metadata additions expected. Current specifications minimally describe a model as being either standalone or one able to be coupled to another model(s). Whereas the BMI answers run-time queries of a model (e.g. the current time of a model simulation, the value of a particular output variable), the CSDMS Model Metadata provides a static description of a model. The Model Metadata, along with a BMI implementation, allows a model to automatically be incorporated as a component in the CSDMS Python Modeling Toolkit (PyMT).

3.2 Basic Model Interface (BMI) Standards

The Basic Model Interface (BMI) is a simple model interface standard that developers are asked to implement. In this context an interface is a named set of functions with prescribed function names, argument types and return types. The BMI functions make a model self-describing and fully controllable by a modeling framework. The BMI functions include:

- Model Control Functions (i.e. initialize, update and finalize),
- Model Information Functions,
- Variable Information Functions,
- Variable Getter and Setter Functions, and
- Grid Information Functions.

Several of these functions utilize the new CSDMS Standard Names, described below. BMI is documented with examples on the CSDMS wiki and in Peckham et al. (2013).

BMI functions are straightforward to implement in any of the languages supported by CSDMS: C, C++, Fortran (all years), Java and Python. Even though some of these languages are object-oriented and support user-defined types, BMI functions use only simple (universal) data types. The BMI functions are noninvasive. A BMI-compliant model does not make any calls to CSDMS components or tools and is not modified to use CSDMS data structures. BMI therefore introduces no dependencies into a model and the model can still be used in a "stand-alone" manner.

3.3 Model Metadata Tools

The CSDMS model Metadata Python package provides tools for working with CSDMS Model Metadata:

- Reading and parsing model metadata that follow the CSDMS Model Metadata Standards.
- Setting up model simulations either programmatically or through a command line interface. Although model metadata may describe models with different interfaces, the model metadata tools provide a common interface for staging simulations.
- Validating input parameter units, ranges, and type checking. If, for instance, a user provides an input value that is out of range, an error can be issued.
- Running simulations, which have already been staged, through a common interface.

These tools are currently used by:

- The Web Modeling Tool (WMT) server to validate input parameters and stage model simulations.
- The CSDMS Execution Server and the Python Modeling Tool (PyMT) for running BMI-enabled models.
- Command Line utilities for querying model metadata, and staging model simulations.

The source code is available under the MIT license at GitHub at:
https://github.com/csdms/model_metadata

3.4 Language support within the CSDMS Modeling Framework

Babel provides the foundation for inter-language communication in the CSDMS Modeling Framework, and is the core of the **Babelizer** (https://github.com/bmi-forum/babelizer), which transforms BMI-wrapped models into CSDMS components. With an upgrade from Babel 1.4 to Babel 2.0, CSDMS software engineers have updated the BMI bindings for Fortran 90/95 and created a new set of fully object-oriented bindings for Fortran 2003.

Though Fortran 90/95 has the concept of an interface, it doesn't allow procedures to be included within types. This is difficult to reconcile with BMI, which, in Fortran, would ideally be implemented as a collection of procedures in a type. Thus, the Fortran 90/95 BMI is set up as an example that a user can copy and modify, substituting their code for code in the example. The Fortran 2003 BMI implementation acts a true interface—it can be imported as a type from a module into a Fortran program and its methods overridden. We recommend using the Fortran 2003 bindings; however support will continue for the Fortran-90/95 bindings for users in the CSDMS community who are not comfortable using the object-oriented features of Fortran 2003. Both BMI implementations are backward compatible with Fortran 77:

- Fortran 90/95 BMI: https://github.com/csdms/bmi-f90
- Fortran 2003 BMI: https://github.com/csdms/bmi-fortran

A new build process for the Java BMI bindings uses *maven*. Instructions for building, installing, and testing the bindings are available at : https://github.com/csdms/bmi-java . These bindings can be imported into any Java program and their methods overridden.

3.5 CSDMS software stack on other HPC clusters

The CSDMS software stack is built on several different operating systems including Mac and Linux. The software stack provides the tools necessary for:

- Building C, C++, Fortran, and Python bindings for BMI models, regardless of their source language.
- Wrapping BMI models so that they can be incorporated into the CSDMS modeling framework.
- Running coupled model simulations, including grid mapping as provided by the ESMF.
- Executing coupled simulations generated with the CSDMS Web Modeling Tool.
- Uploading model results to the Web Modeling Tool server.

The software stack has been installed on large high-performance computing clusters such as ***Beach*** (CSDMS), ***Janus*** (Research Computing - University of Colorado), the **HPC@LSU** systems (http://www.hpc.lsu.edu), and ***Yellowstone*** (NCAR-Wyoming Supercomputing Center), ***Summit*** and ***Blanca*** (Research Computing - University of Colorado), and NSF's XSEDE Jetstream cloud computing service (https://jetstream-cloud.org). We also continue to test these tools on personal workstations. The source code for the CSDMS Coupling Framework is hosted on GitHub at https://github.com/csdms/wmt-exe. The CSDMS software stack installer is located on https://github.com/csdms/wmt-exe/blob/master/scripts/install.

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. Developing code is updated whenever new changes are committed to its code base, while 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 on GitHub.

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 accessible - 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).

3.6 The CSDMS Bakery

The CSDMS IF has expanded the scope and size of its repository of distributed software. The CSDMS *Bakery* now includes not only recipes that describe how to build software packages but also how to build, test, and deploy these software packages on a regular basis ranging from once a day to once a month. In addition, the Bakery incorporates continuous integration so that software is also rebuilt, retested, and redeployed whenever changes are pushed to their corresponding repositories on GitHub.

- List of recipes in the CSDMS bakery: https://github.com/csdms/csdms-stack
- Build, test, deploy and model status: https://travis-ci.org/csdms-stack

- The conda package manager: https://github.com/conda

CSDMS will add new packages to the stack as 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 independently of CSDMS software are also included in the Bakery as a service to the community and to encourage model submission.

3.7 Docker Files

CSDMS maintains a GitHub repository of Dockerfiles (https://github.com/csdms/dockerfiles) used to build Docker images used by CSDMS. Dockerfiles contained in this repository fall into one or more of the following categories:

- They provide the basic tools used to build the CSDMS Software Stack. This includes particular versions of compilers (gcc, gfortran, etc.) and particular versions of operating systems.
- They provide images of the complete CSDMS Software Stack built (and tested) on various operating systems with a range of compilers.
- Images to be deployed that either run the CSDMS execution server, or the WMT server.
- General purpose images used by CSDMS or that the CSDMS community may find useful.

3.8 The CSDMS Web Modeling Tool (WMT)

The CSDMS Web Modeling Tool (WMT; https://csdms.colorado.edu/wmt) is the web-based successor to the desktop Component Modeling Tool. WMT is a web application that provides an Ajax client-side graphical interface (the **WMT client**) and a RESTful server-side database and API (the **WMT server**) that allows users to build and run coupled Earth system models on a high-performance computing cluster (HPCC) from a web browser.

WMT was designed with four objectives:

1. *Accessibility*. As a web-based application, if you have access to the Internet, you have access to WMT.
2. *Integration*. Easily hyperlink from WMT to resources on the CSDMS portal—including model documentation, labs, lectures, tutorials and movies—or to other resources on the Internet.
3. *Portability*. WMT has a native JavaScript interface, so it can be accessed on any modern web browser, including tablet and mobile versions of browsers.
4. *Maintenance*. Because modern browsers tend to adhere to web standards, which lead to fewer cross-compatibility issues than operating systems, only one version of WMT needs to be developed and maintained.

With WMT, a user can:

- Select a Common Component Architecture (CCA) component model from a list to run in standalone mode;
- Build a coupled model from multiple CCA components organized as nodes of a tree structure;
- View and edit the parameters of the model components;
- Save models to a server, where they can be accessed on any computer connected to the Internet;
- Share saved models with others in the community;
- Run a model by connecting to a remote HPCC where the components are installed.

The **WMT client** is designed using the model-view-presenter (or MVP) pattern, which separates the domain logic of an application, where rules are set for how data are stored and modified, from the user interface, where the user interacts with data. This separation of responsibilities makes it easier to test, modify and maintain an application. The WMT client is written with GWT, a toolkit that allows Ajax applications to be developed in Java, thereby enabling the author to employ object-oriented design principles and mature Java development tools such as Ant, Eclipse and JUnit. For deployment on the web, the GWT compiler translates the Java code to optimized and obfuscated JavaScript. GWT emphasizes cross-browser compatibility, and is supported on all modern browsers.

The WMT client interface is divided into three panels:

1. The *Header panel* provides email and password boxes for a user to sign in to WMT. First-time users are asked to repeat their password for confirmation. Note that the WMT sign is separate from the sign in for the HPCC on which models are run.
2. The *Model panel* is where a standalone or a coupled model can be created. To design a model, an instance of a component is chosen at the root of this panel's tree structure. Once included in the tree, the component displays its CCA uses ports as leaves on the tree. By choosing other components that provide ports for these open leaves, a coupled model can be created. A component instance that provides feedback to the coupled model is displayed as a link. The panel also furnishes a set of buttons that allow a user to open, save, and run models.
3. The parameters of the model components displayed in the Model panel can be viewed and edited in the *Parameters panel*. Type and range checks are performed immediately on any parameter that is modified.

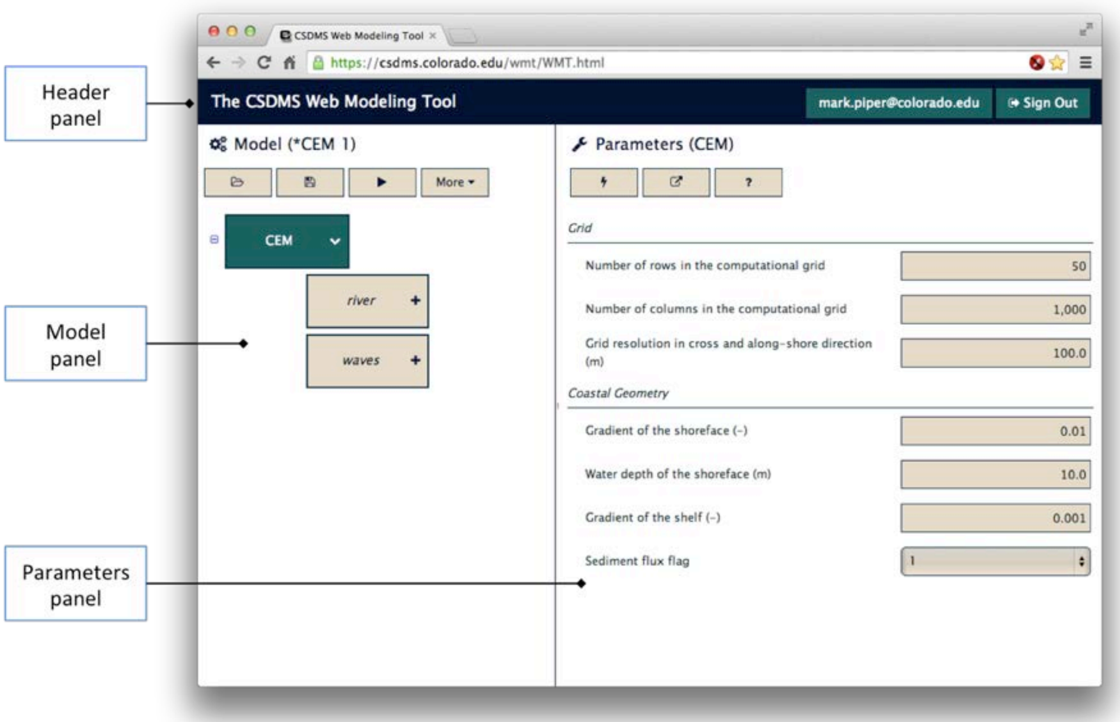


Figure 3.2 Example of the WMT client interface, with primary components highlighted.

Information on using the WMT client can be found on the CSDMS portal, including a help document (http://csdms.colorado.edu/wiki/WMT_help) and a basic tutorial (http://csdms.colorado.edu/wiki/WMT_tutorial).

The **WMT server** is a RESTful web application that provides a uniform interface through which client applications interact with the CSDMS model-coupling framework. Although opaque to a client, behind the WMT server is a layered system that consists of the following resources:

- A *database server* that contains component, model, and simulation metadata;
- One or more remote *execution servers* on which simulations are launched;
- A *data server* on which simulation output is stored and can be downloaded.

Each of these layers exposes a unique web service API. The **database server** provides, as JSON-encoded messages, the component metadata necessary for an end user to couple components, and set input parameters. The metadata includes descriptions of component exchange items, uses and provides ports, as well as user-modifiable input parameters. The database server is intentionally separated from the execution server so that it may be easily and quickly accessed without need to connect to a potentially firewalled or inaccessible execution server.

Execution servers are computational resources that contain the software stack needed to run a coupled or uncoupled model simulation. These servers can range from large high performance computing clusters, to smaller web servers, or even to an end-user's personal computer. The requirements are only that the WMT server has network access to the execution server and that the CSDMS software stack is installed on the server. This includes the CCA-toolchain, the CSDMS framework tools, and compiled shared libraries for each of the component models. Once a simulation completes, its output is packaged and uploaded to a data server where it is stored and from which the end-user is able to download it as a single compressed archive file. The relationship between the WMT client and the WMT server is depicted in Figure 3.2.

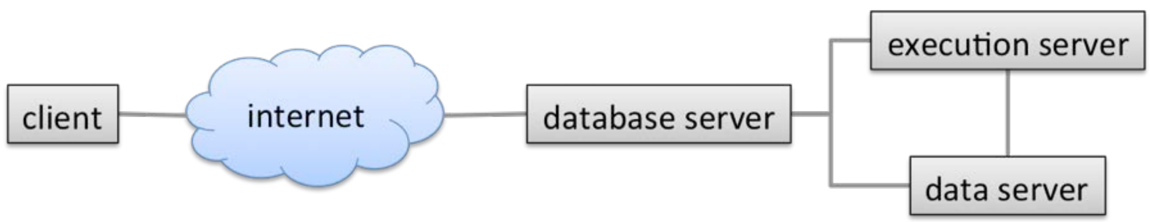


Figure 3.2. The relationship between the WMT client and the WMT servers.

Because the WMT server provides an API for each of its layers, other clients—besides the WMT client developed at the CSMDS IF—could access it. Both the WMT client and the WMT server are open source projects, released under the MIT License, with source code available on Github. 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. Version 1.1 was similarly released in Sept 2016 that incorporated improvements to the client interface and server-side code, along with bug fixes. Information on this release is given on the CSDMS portal:

WMT 1.1: http://csdms.colorado.edu/wiki/WMT_1.1_release

WMT development is divided into five GitHub repositories:

- Database and data servers: https://github.com/csdms/wmt
- Execution server: https://github.com/csdms/wmt-exe
- Web client: https://github.com/csdms/wmt-client
- Metadata for components: https://github.com/csdms/wmt-metadata

- WMT landing page: https://github.com/csdms/wmt-selector

Examples of active WMT projects include:

- **wmt-analyst**: The primary WMT instance, containing the complete set of CSDMS components, for users who prefer unrestricted access to the CSDMS components.
- **wmt-coastlines**: Simulate coastline evolution under influence of river and wave action. This project allows coupling between the HydroTrend, Avulsion, CEM, and Waves components.
- **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.
- **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.
- **wmt-roms**: Simulate mesoscale dynamics of oceanic and coastal processes with the Regional Ocean Modeling System (ROMS).
- **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.
- **wmt-permafrost**: Is affiliated Permafrost Modeling Toolkit and Permafrost Benchmarking System projects. It is currently populated with six components, with additional components under development. Access this new project through Main WMT site, https://csdms.colorado.edu/wmt, or https://csdms.colorado.edu/wmt-permafrost.

When a user of the **wmt-hydrology** 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 (LSU HPCC)***, assuming that they have the proper credentials and an allocation for computing time on either of these HPC clusters. 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.

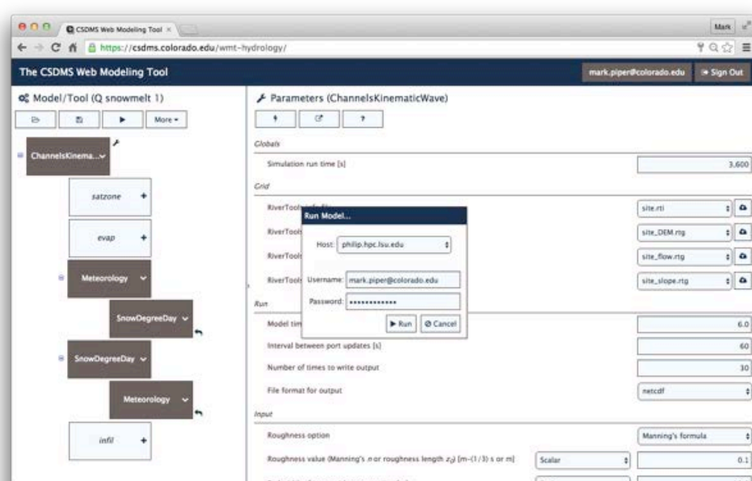


Figure 3.3. Preparing to submit a model run from WMT to an HPC cluster at LSU.

3.9 The CSDMS Python Modeling Toolkit (PyMT-Beta)

The CSDMS model-coupling framework, which was written for use exclusively by the Web Modeling Tool (WMT), was repurposed for model developers. This new framework, called PyMT-Beta (Python Modeling Toolkit), provides a Python interface to our coupling framework allowing model coupling and development within a scripting language without the need for the WMT. The primary interface for PyMT-Beta 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:

- 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 exposes 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, 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.

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.

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.

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)

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.)

Get PyMT-Beta

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-stack/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.

PyMT-Beta 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.

3.10 The CSDMS Framework

To help describe and clarify the process of transforming a model provided by a community member into a CSDMS plug-and-play component, a flow diagram was created (Fig 3.4):

1. A model developer who has submitted their model to the CSDMS Model Repository employs instructions found on the CSDMS Portal (https://csdms.colorado.edu/wiki/BMI_Description) to add a BMI to their model, using the supported language of their choice (C, C++, Fortran, Java, or Python). If they implement a C or a Python BMI, they can use the BMI Tester to test their BMI. Note that the model and its BMI are separate; the model can still be run without its BMI.
2. Next, the model developer works with a CSDMS IF software engineer to add BMI metadata (see Section 2.2) for their model. This metadata helps describe the model within the CSDMS Modeling Framework.
3. The model and its metadata can now be run through the *Babelizer* (https://github.com/bmi-forum/babelizer) to create a Python-wrapped component. The *Babelizer* is built upon the CCA Toolchain, including *babel*, *cca-spec-babel*, *bocca*, and *ccaffeine*, and provides inter-language communication. The result of this step is a CSDMS component.
4. Binary versions of both the BMI-ed model and the Babelized component are built for Linux and macOS, and stored and distributed through the CSDMS *Bakery* (Section 3.7).
5. The Python Modeling Tool (PyMT, see Section 3.10), a Python package that provides services for coupling CSDMS components, provides the run environment.
6. The new component can be included in the CSDMS Web Modeling Tool (Section 3.9), which consists of an executor, a server, and a client (the user's web browser). PyMT forms the basis for the executor of the model coupling triad. Starting from the model's BMI metadata, a CSDMS IF software engineer seeks the input of the model developer to create WMT metadata, in order to ensure the component's parameters are organized, described, and displayed correctly in WMT.

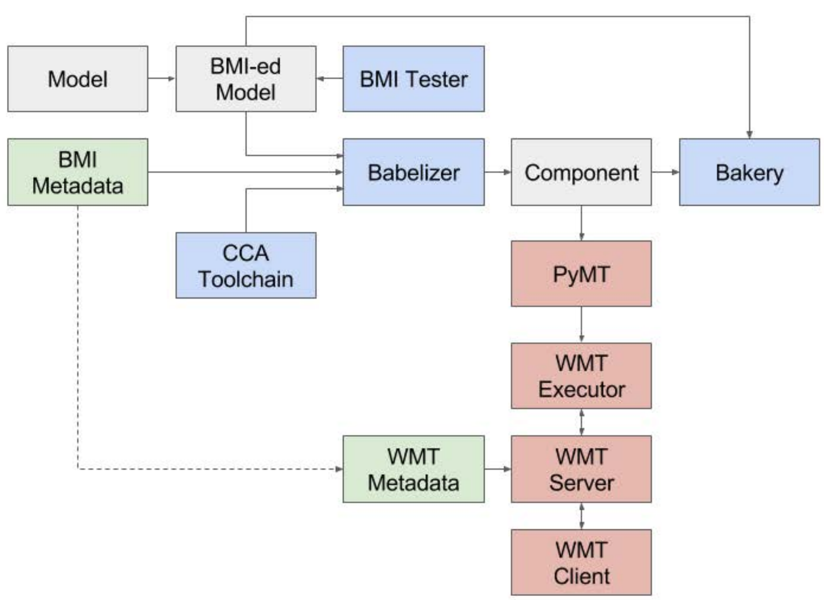


***Figure 3.4.** A flow diagram describing steps taken to transform a model into a CSDMS plug-and-play component.*

PyMT plugins are components that expose the CSDMS Basic Model Interface and provide CSDMS Model Metadata. With these two things, third-party components can be imported into the PyMT modeling framework. By default PyMT searches a package named csdms, if it exists, for possible plugins that implement a BMI. The corresponding model metadata for each plugin is assumed to be located under share/csdms in a folder named for that plugin. This is the file structure that the CSDMS babelizer tool uses when wrapping models.

Although components written in Python can be processed with the babelizer to bring them into PyMT, this step should not be necessary as they are already written in Python with a BMI. Standard plugins (those contained in the csdms package) are automatically loaded while other plugins are dynamically loaded with the pymt load_plugin function.

The initial release of the CSDMS PyMT-Beta focused mainly on the integration of BMI-enabled components, written in a variety of languages (C, C++, the Fortrans, Python, Java), into a single Python based framework (the PyMT) that is targeted to model developers. Since the initial Beta release, the CSDMS IF has worked to incorporate of the CSDMS model-coupling tools into this framework in a way that is easy for developers to use. Of note are the following utilities:

- **Grid mapping:** CSDMS uses the grid mappers developed by the Earth System Modeling Framework (ESMF) for mapping values from one grid to another. The newest version of PyMT uses the latest (2017) release of the ESMF grid mappers as well as adding an easy to use interface that extends the familiar *set_value* interface of the BMI.
- **Time interpolator:** For models that are unable to run at a specified time step (for instance if the specified time step is not a multiple of a model's fixed time step), PyMT is able to linearly interpolate in time to the requested time. This is now done automatically without user intervention.
- **Unit conversion:** PyMT uses the cfunits package developed by Unidata to convert between units. As with grid mappers, the latest version of PyMT extends familiar BMI methods to specify what units to use. For example, the *get_value* method in PyMT now accepts a *units* keyword that a user can use if they require a value to be returned with particular units.

PyMT uses the CSDMS model_metadata package, to incorporate CSDMS Model Metadata into BMI-enabled components when they are imported into PyMT. This ensures that:

- Identifying model information stays with the component as it appears within the CSDMS Modeling Framework. This ensures that the original author of the model is given appropriate credit and not forgotten in the wrapping of their model. In addition, a citation(s) is clearly displayed for the model. This ensures that a user running the model, either through PyMT or otherwise, will properly cite the original work that describes to model when publishing results that use the model.
- Model input parameters are validated and model input files are properly constructed when preparing a model simulation

3.11 Automated Wrapping for Moving BMI Components into PyMT

Before a BMI model can be run within the CSDMS modeling framework (or any other modeling framework), two things must be done:

- The BMI implementation must provide the necessary language bindings (Python, in the case of the CSDMS modeling framework)
- Provide the necessary interface for the particular modeling framework (a slightly modified version of BMI, in the case of the CSDMS modeling framework)

In the past, these two steps were done by hand, which made the process difficult to maintain, was time consuming, led to errors, and made it difficult to update any part of the workflow that brings a model into the CSDMS modeling framework. To remedy this, and make a more robust and sustainable product, the CSDMS IF automated this process.

Model BMI metadata now accompanies the BMI source code in the form of a YAML-formatted text file. Required metadata includes:

- Description of the model: Author(s), web page, version, license, etc.
- List of the input parameters and files
- Description of the steps needed to build the library

With this information, the automated wrapper is able to fetch the model source code, build it, create Python language bindings, decorate it in the BMI so that the CSDMS model-coupling framework can use it, and finally import it into the framework. For BMI projects that are hosted on GitHub, authors need only provide the metadata in a folder with the name *.bmi*. This identifies the project as one that provides a BMI and so can be automatically built. The source code for this project is available at https://github.com/bmi-forum/bmi-babel.

To aid the building of a BMI model (either new or existing), the CSDMS IF has built a tool that auto-generates template code necessary to implement a BMI in the CSDMS supported languages. This tool, *bmi-builder*, reads metadata (as YAML-formatted text) that describes the new BMI and generates a series of files with boilerplate code that contains stubs for the developer to fill in based on their specific model.

By automating this process, the *bmi-builder* not only makes writing a new BMI easier but more:

- Accurate: The generated BMI is guaranteed to satisfy the latest BMI specification.
- Maintainable: If there are changes to either the BMI specification or the model, the boilerplate code can easily be regenerated.

Currently the new BMI builder works with C and C++. However, before the end of this year the CSDMS IF will add a Python generator. The *bmi-builder* source is hosted on GitHub at https://github.com/bmi-forum/bmi-builder.

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. Work in progress includes the creation of templates for the Fortran 90/95 and Fortran 2003 BMIs (that assist the *Babelizer* in making Python-wrapped components.

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 Fortran code that developers can use to create their own BMI-enabled components. The new BMI examples include sample implementations for Fortran 90 and 95 (semi-Object Oriented) and 2003 (Object Oriented). These complement the previous collection of examples written in the other *babel*-supported languages.

The CSDMS IF has used these examples as part of clinics (such as that given at the 2017 CSDMS Annual Meeting), which are published online, that walk participants through the process of adding a BMI to their model; for example:

- BMI Live! (https://github.com/csdms/bmi-live-2017)
- BMI Tutorial (https://github.com/mcflugen/bmi-tutorial)

The CSDMS-IF has extended the BMI-Tester command-line tool, which checks a BMI implementation for conformance to the current BMI standards, to include a wider range of tests that more fully tests a BMI implementation. In addition, the BMI-Tester is now more integrated into the PyMT. (https://github.com/csdms/bmi-tester)

3.12 Service Components

FileWriter Component. Writes model output variables that vary in time, including 0D (time series), 1D (profile series), 2D (grid stack) and 3D (cube stack) to NetCDF files that contain descriptive metadata (e.g. CF and CSDMS standard names)

CSDMS Time Interpolator. Addresses "temporal misalignment" between two or more model outputs. Uses ***noninvasive*** (not called from within a model's source code) methods automatically invoked (as a service component) when needed by the CSDMS framework (as determined from BMI function calls).

Timeline. The timeline service component orchestrates the timing and execution of a component and its connected service and model components. The timeline component determines the execution time step of a component's uses ports to either a user-requested time step or to a time step based on the time steps of the connected components. In addition, the timeline component is able to cope with 2-way (or circular) couplings. Although not yet implemented, the timeline was written to accommodate future parallelism. In such a scenario, a component's uses ports could, if possible, be executed in parallel with the timeline coordinating the execution and gathering of data.

Time interpolator for grid stacks. The grid stack interpolator service component reads a UGRID formatted grid from a local or remote NetCDF file and provides the data through a BMI to other components. If necessary, the data can also be interpolated in time to provide grids at times that are not provided by the original data file.

The CSDMS IF then worked with the Landlab team (NSF award number 1450412) to develop and add new data structures to *Landlab* that track the deposition and erosion of heterogeneous sediment layers. Each layer tracks a range of user-defined sediment properties (e.g. porosity, bulk density, cohesion, age of deposition), as well as the distribution of multiple sediment types. Within *Landlab*, a sediment type is defined as sediment that is described by a particular set of sediment properties. These properties are similar to the bulk properties of a layer but describe the property for a homogeneous package of sediment.

Landlab provides functions for calculating bulk sediment properties of layers from the distribution of grain types within that layer. A bulk property may be a simple weighted average of the properties of the constituent sediment types, or could be, say, a maximum or minimum value. For most properties we assume a layer is a linear mixture of sediment types such that the bulk property is a (weighted) sum of the individual properties. Future possibilities include calculating the bulk properties of well mixed layers whose bulk property is a non-linear combination of its components. Thus far, there are two implementations of layering. The first saves all layers for a simulation while the second averages layers to a user-specified vertical resolution.

A layer for every time step

In the case of non-binned layers, sediment layers are tracked at full resolution. That is, a layer is saved no matter how large or small it is and is saved at every grid cell - even where grid cells may see zero deposition. Although this provides a lossless record of the evolving stratigraphy, it can also be memory intensive since a layer is saved - over the entire grid - for every time step of the model. The non-binned layer tracking procedure was designed for, and is being used by the NSF funded project, *Tectonics in the Western Anatolian Extension Province from sequence stratigraphic modeling of multichannel seismic data in the Gulf of Kusadasi* (NSF award number 1559098). As part of the modeling component of this award, a new model is being written using the landlab modeling toolkit that will track the evolution of the Gulf of Kusadasi and match existing seismic records.

Binned Layers

Because of the high memory overhead of the non-binned layer method, *landlab.layers* also implements a binned layer method. In this case, a user specifies a vertical resolution over which layers are combined. As sediment is deposited, the sediment is combined with the topmost layer in the sediment column until the combined layer reaches the user-specified resolution. After this point, a new bin is added to the top of the sediment column into which new sediment is added. This method may be in some cases computationally more expensive but can significantly reduce the amount of memory used by a model simulation.

3.13 New Plug and Play Model Components

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

- **AnugaSed**: ANUGA, developed by the Australian National University and Geosciences Australia, is an open-source Python package capable of simulating small-scale hydrological processes such as dam breaks, river flooding, storm surges, and tsunamis. Because of its modular structure, additional components have been incorporated into ANUGA that allow it to model suspended sediment transport and vegetation drag.
- **BottomWaveVelocity**: Calculate sea bottom orbital velocity and period from significant wave height and period using a parametric spectrum formulation (the user can choose between either Donelan or JONSWAP formulations).
- **BRaKE**: The Blocky River and Knickpoint Evolution Model (BRaKE) is a 1-D bedrock channel profile evolution model. It calculates bedrock erosion in addition to treating the delivery, transport, degradation, and erosion-inhibiting effects of large, hillslope-derived blocks of rock. It uses a shear-stress bedrock erosion formulation with additional complexity related to flow resistance, block transport and erosion, and delivery of blocks from the hillslopes.
- **CEM+**: The Coastline Evolution Model (or CEM) is a one-contour line model that focuses on sandy, wave-dominated shoreline evolution, simulates the plan-view evolution of a coastline due to gradients in alongshore sediment transport. A unique aspect of CEM, by dividing the plan-view domain into a 2-dimensional cell array, is its ability to process an arbitrarily sinuous shoreline, allowing the simulation of complex shoreline features including spits and capes. The model is exploratory in nature, designed to simulate large-scale (10^3 to 10^6 m) and long-term (10^2 to 10^5 yr) shoreline evolution. CEM+ is a new version of CEM, written from the ground up and BMI compliant that adds additional process as cliff rock erosion and barrier overwash.
- **ChannelsDiffWave**: This component uses the diffusive wave method to compute flow velocities for all channels in a D8-based river network. This method is similar to the kinematic wave method for modeling flow in open channels, but instead of a simple balance between friction and gravity, this method includes the pressure gradient that is induced by a water-depth gradient in the downstream direction. This means that instead of using bed slope in Manning's equation or the law of the wall, the water-surface slope is used. One consequence of this is that water is able to move across flat areas that have a bed slope of zero. Local and convective accelerations in the momentum equations are still neglected, just as is done in the kinematic wave method.
- **ChannelsDynamWave**: The dynamic wave method is the most complete and complex method for modeling flow in open channels. This method retains all of the terms in the full 1D momentum equation, including the gravity, friction and pressure gradient terms, as well as local

and convective acceleration terms. It is assumed that the flow directions are static and given by a D8 flow grid.

- **ChannelsKinWave**: The kinematic wave method is the simplest method for modeling flow in open channels. This method combines mass conservation with the simplest possible treatment of momentum conservation, namely that all terms in the general momentum equation (pressure gradient, local acceleration and convective acceleration) are negligible except the friction and gravity terms. For these flows the water surface slope, energy slope and bed slope are all equal.

- **CMIP**: A prototype data component processed from the Climate Model Intercomparison Project - 5, also called CMIP 5. Data presented include the mean annual temperature for each gridcell, mean July temperature and mean January temperature over the period 1902 -2100. This dataset presents the mean of the CMIP5 models, and the original climate models were run for the representative concentration pathway RCP 8.5.

- **Compaction**: Compact sediment layers, and corresponding porosity variations, following the method of Bahr et al. (2001) where the rate of compaction is proportional to the weight of the overlying sediment load (minus excess pore-water pressure). This compaction component is written in Python and makes use of the newly available landlab layers package.

- **CRUAKTemp**: This component provides access to a netCDF file containing spatially resampled CRUNCEP monthly mean surface temperature fields for Alaska. It has been developed as a prototype for a BMI-enabled dataset in the CSDMS Modeling Framework.

- **Diversions** and **DiversionsFraction**: These components provide three different types of flow diversions: sources, sinks and canals. Sources are locations such as natural springs where water enters the watershed. Similarly, sinks are point locations where water leaves the watershed. Canals are generally man-made reaches that transport water from one point to another, typically without following the natural gradient of the terrain.

- **EvapEnergyBalance** and **EvapPriestleyTaylor**: These components use the energy balance and Priestley-Taylor methods, respectively, of estimating losses due to evaporation. The **EvapReadFile** component provides a way to read in files containing parameters used to model the evaporation process.

- **FrostNumberModel**: 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.

- **GC2D**: GC2D is a two-dimensional finite difference numerical model that is driven by a calculations of glacier mass balance (snow precipitation - melt rate). The model calculates ice surface elevations above a two-dimensional terrain by solving equations for ice flux and mass conservation using explicit methods.

- **Geombest**: GEOMBEST is a morphological-behaviour model that simulates the evolution of coastal morphology and stratigraphy resulting from changes in sea level and sediment volume within the shoreface, barrier, and estuary. Originally written in Matlab, the code could not be incorporated into the CSDMS Modeling Framework. However, the CSDMS IF has translated much of the code into Python. Once complete, GEOMBEST will be freely available using an Open Source language and be ready to be given a BMI and incorporated into PyMT.

- **ILAMB**: The International Land Model Benchmarking (ILAMB) project is a model-data intercomparison and integration project designed to improve the performance of land models and, in parallel, improve the design of new measurement campaigns to reduce uncertainties associated with key land surface processes. ILAMB software can be used to quantitatively compare CMIP5-compatible model outputs with a set of benchmark datasets. Skill scores computed by ILAMB are returned in both tabular and graphical formats. Both ILAMB1.0 written in NCL, and LAMB2.0 completely rewritten in Python, have been componentized.

- **InfilGreenAmpt** and **InfilSmithParlange**: These components model infiltration using the Green-Ampt and Smith-Parlange techniques, respectively. These methods are based on the infiltrability-depth approximation or IDA, which uses the cumulative infiltrated depth as a replacement for time. These methods are not well-suited to modeling redistribution between events or drying of surface layers by evaporation. They are best used for single events.
- **InfilRichards1D**: This component models infiltration by computing the time evolution of 1D (vertical, subsurface) profiles for soil moisture θ, pressure head ψ, hydraulic conductivity K and vertical flow rate v. These equations can be combined into one nonlinear, parabolic, second-order PDE known as the one-dimensional Richards' equation.
- **KuModel**: 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.
- **KuGeoModel** and **FrostNumberGeoModel**: These components are extensions of the existing KuModel and FrostNumberModel that operate over a geographical area. FrostNumberGeoModel can be coupled with the CRUAKTemp component.
- **Meteorology**: This component computes meteorological variables such as vapor pressure, net shortwave radiation, net longwave radiation, and emissivity, using calculations based on celestial mechanics and widely-used empirical relationships.
- **Permafrost Benchmark System**: The **Permafrost Benchmark System** (PBS) wraps the command-line ILAMB benchmarking software and adds tools for uploading CMIP5-compatible model outputs and benchmark datasets. The PBS allows users to access and run ILAMB remotely, without having to install software or data locally; a web browser on a desktop, laptop, or tablet computer is all that's needed.
- **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.
- **SatZoneDarcyLayers**: This component models horizontal subsurface groundwater flow in the saturated zone via Darcy's Law.
- **SnowDegreeDay** and **SnowEnergyBalance**: These components calculate snow melt rate, snow depth, snow water equivalent, and cold content using degree day and energy balance techniques, respectively.
- **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.

- **TopoFlow**: TopoFlow is a spatially distributed hydrologic model that evolved from the merger of a previous rainfall-runoff model based on DEM-derived D8 flow grids and a model called ARHYTHM that was designed and tested for modeling Arctic watersheds. It offers sophisticated methods for modeling temperature-dependent processes such as snowmelt, evaporation, infiltration (frozen ground) and shallow subsurface flow. TopoFlow is highly modular and was designed to be user-extensible.

- **WindWaves**: Calculate significant wave height and peak period using the JONSWAP wave spectrum method (Haseelmann et al., 1973) with gam = 33.

- **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.

3.14 Automated Sensitivity and Uncertainty in the Cloud

CSDMS received a supplemental award to create a tool that would automatically provide uncertainty quantification statistics when a user ran a model. This work has not been completed. However, we provide here a detailed plan for how we will complete this task before the end of the CSDMS 2.0 award period.

The core functionality of the tool will be provided by Dakota, described in Section 4.1 below. The tool will be wrapped with Python bindings and integrated into PyMT (Section 3.9). To configure a model's initial conditions, PyMT provides an `initialize` method. The tool will be an object of configuration parameters passed to `initialize` through a keyword, thus presenting a natural interface to the user. The tool will allow users to assign uncertainties, in the form of density functions, to model variables. The user provides the distribution type (uniform, normal, lognormal) and values to create the density functions. To assess the effects of the input uncertainties, the user selects output variables from the model and a single statistic (e.g., mean, median, min, max), calculated for each output, to characterize the run. Dakota uses these output statistics to provide a summary of the study, showing the influence of the input uncertainties on the model outputs. The tool will be designed to run locally on a laptop or desktop computer, on the the CSDMS HPC (which will require a user's login credentials), or on an XSEDE Jetstream instance (using a startup allocation which we have secured for this task). As described in Section 3.5, the CSDMS Modeling Ftamework has been installed on these computational resources. For the remote processing options, connection and job submission will be performed through SSH, and results retrieved through SFTP.

The overall theme guiding the development of this tool is to deliver seamless uncertainty quantification statistics along with a typical model run, through a design that has empathy for the user.

Chapter 4: Model Uncertainty & Model Intercomparison

4.1 Analysis of Model Uncertainty

To support model uncertainty studies at CSDMS, version 6.1 of the Dakota iterative systems analysis toolkit (https://dakota.sandia.gov/) was been installed on the CSDMS HPCC, ***beach (now decommissioned)*** and installation is in progress on HPCC ***blanca*** and ***summit***. Dakota has a file-based command-line interface, available to all ***beach*** users, for communicating with computational models. This interface was tested with several sensitivity analyses and uncertainty quantification experiments using HydroTrend and Delft3D.

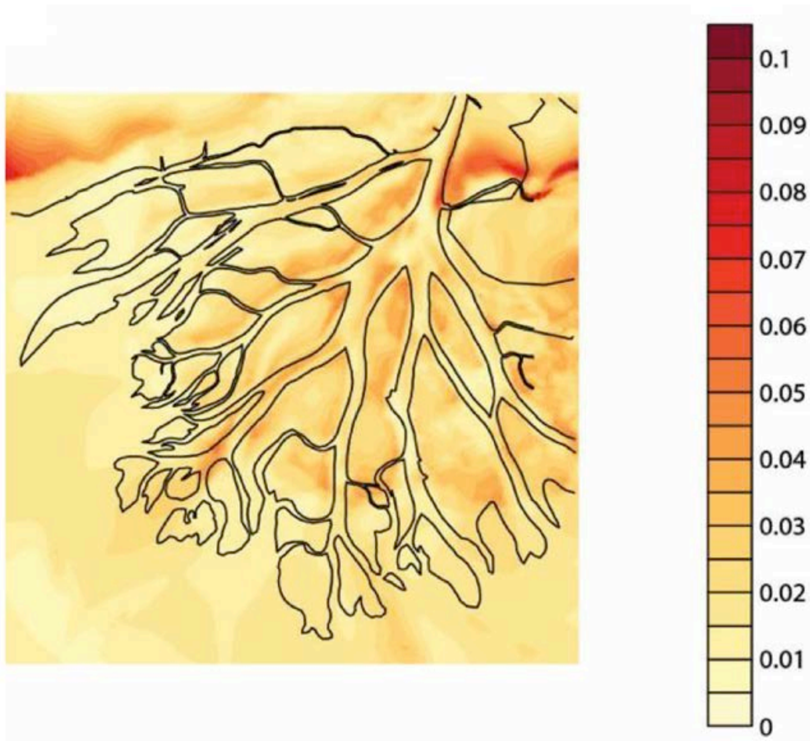


Fig. 4.1 *Spatial uncertainty of surface elevation, characterized by its standard deviation (meters), in the Wax Lake Delta in the aftermath of Hurricane Rita, from 81 Delft3D simulations. Excerpted from Fei Xing's PhD dissertation.*

To streamline access to the Dakota command-line interface, the CSDMS IF has developed a Python framework, Dakotathon, within which Dakota analysis methods and CSDMS models can be wrapped. Dakotathon includes code to call any CSDMS model component, as well as seven Dakota analysis methods. The framework can be extended to include other Dakota analysis methods by adding new classes that describe the keywords of the analysis method. Dakotathon is MIT-licensed open source software, freely available on GitHub at https://github.com/csdms/dakota. Documentation for the framework can be found at http://csdms-dakota.readthedocs.org. Dakotathon is also a CSDMS component that can be called from PyMT in a WMT executor. The call to the BMI *initialize* method sets up the Dakota experiment, including writing a **dakota.in** file. The call to *update* runs the entire Dakota experiment. The *finalize* method cleans up any intermediate files produced by Dakota. The Dakotathon repository on GitHub contains several other examples in the form of Python scripts and Jupyter Notebooks; see https://github.com/csdms/dakota/tree/master/examples.

To ensure the long-term sustainability of Dakotathon, 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.

Within the CSDMS 2.0 award period, the CSDMS-IF has been active in helping the community use Dakota to explore model uncertainty.

- Mark Piper (CSDMS-IF) gave an oral presentation on Dakotathon at the 2016 AGU Fall Meeting (http://abstractsearch.agu.org/meetings/2016/FM/H34E-06.html).
- 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 gave a guest lecture on Dakota to the students of Bob Anderson and Greg Tucker's GEOL 5700 class at the University of Colorado (http://mdpiper.github.io/dakota-seminar).
- CSDMS-IF has helped three graduate students, Fei Xing (CU), 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).

CSDMS IF has created a working prototype for using Dakota in WMT, available at https://csdms.colorado.edu/wmt-dakota, and previewed in Figure 4.2. The prototype uses the Python framework described above, and hence allows experiments to be created with HydroTrend and the three currently implemented Dakota analysis methods.

A tutorial on using the Dakota command-line interface, the CSDMS Python framework, and the WMT prototype was developed for the 2014 CSDMS annual meeting, and is available for download on GitHub at https://github.com/mdpiper/dakota-tutorial.

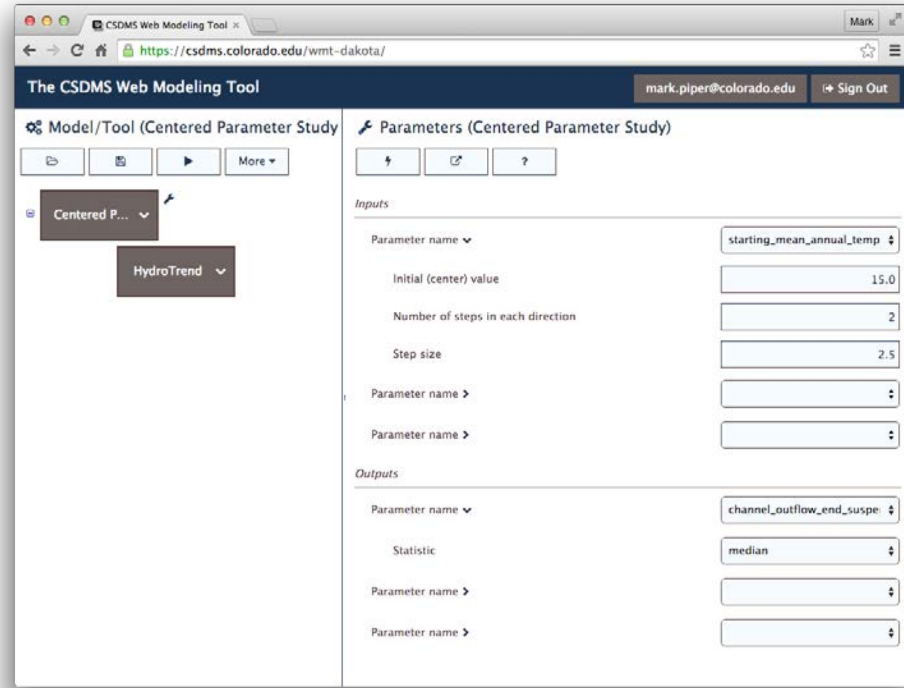


Fig. 4.2 A screenshot of the development prototype for using Dakota in WMT.

4.2 CSDMS special issue

A CSDMS special issue on **Uncertainty and Sensitivity in Surface Dynamics Modeling** was published in Computers & Geosciences, Volume 80, Part B, May, 2016 (Editors J Syvitski & AJ Kettner) 172 pp.

1) Uncertainty and Sensitivity in Surface Dynamics Modeling, Pages 1-5, A.J. Kettner & J.P.M. Syvitski

2) Uncertainty quantification in modeling earth surface processes: more applicable for some types of models than for others, Pages 6-16, A. B. Murray, N.M. Gasparini, E.B. Goldstein, M. van der Wegen

- In some Earth-science modeling contexts, uncertainty quantification (UQ) faces challenges.
- The ability to evaluate model-form uncertainty can be limited.
- Limitations arise when autogenic dynamics dominate.
- Limitations arise when scales of interest exceed those for which observations exist.
- Uncertainties from model parameter values and model form can be entangled.

3) Morphological impact of a storm can be predicted three days ahead, Pages 17-23, F. Baart, M. van Ormondt, J.S.M. van Thiel de Vries, M. van Koningsveld

3) Shelf sediment transport during hurricanes Katrina and Rita, Pages 24-39, K. Xu, R.C. Mickey, Q. Chen, C.K. Harris, R.D. Hetland, K. Hu, J. Wang

- Erosional depths were sensitive to both erosional rates and settling velocities.
- Local resuspension and deposition dominated the sediment transport mechanisms.
- East of hurricane tracks has stronger winds, taller waves and deeper erosions.

- Hurricanes suspended seabed sediment mass far exceeding the annual river inputs.

4) A numerical investigation of fine sediment resuspension in the wave boundary layer—Uncertainties in particle inertia and hindered settling, Pages 40-56, Z. Cheng, X. Yu, T.-J. Hsu, S. Balachandar
- Hindered settling can increase sediment load and laminarize the boundary layer.
- Gelling ignition can occur at low gelling concentration and low critical stress.
- Particle inertia can be neglected for conditions in typical continental shelves.

5) 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, Pages 57-65, S. M. Siadatmousavi, F. Jose, G. Miot da Silva
- Uncertainty in wind data and wave boundary conditions were evaluated.
- Model sensitivity to different formulations of white capping and wind input were examined.
- Buoy and remote sensing data were used for model skill-assessment.
- Importance of having several measured dataset in evaluation of model performance is shown.

6) Understanding hydrological flow paths in conceptual catchment models using uncertainty and sensitivity analysis, Pages 66-77, E.M. Mockler, F.E. O'Loughlin, M. Bruen
- Groundwater simulations and parameter sensitivities for 3 models were compared.
- Of 3 models calibrated to total flow, SMART captured groundwater contribution best.
- Internal flow partitioning varies greatly between models and parameter sets.
- Independent data on flow paths should inform calibration of conceptual models.

7) Active subspaces for sensitivity analysis and dimension reduction of an integrated hydrologic model, Pages 78-89, J.L. Jefferson, J.M. Gilbert, P.G. Constantine, R.M. Maxwell
- Active subspaces identify important input parameters and how they relate to output.
- Proof-of-concept domains show potential for dimension reduction of land surface.
- Important land surface parameters depend on land cover and flux type.
- Land surface inputs and energy flux outputs can be related by a quadratic polynomial.
- Lateral flow has negligible effect on the land surface parameter–flux relationship.

8) Hydrological model uncertainty due to spatial evapotranspiration estimation method, Pages 90-101, X. Yu, A. Lamačová, C. Duffy, P. Krám, J. Hruška
- We quantify the uncertainty of hydrological modeling due to spatial ET estimation.
- We present a series of forest management probabilities from historic forest age maps.
- The plant physiology-based ET estimation reduced hydrologic uncertainty.
- Reduced uncertainty suggests the importance of forest growth in water use studies.

9) Multi-scale characterization of topographic anisotropy, Pages 102-116, S.G. Roy, P.O. Koons, B. Osti, P. Upton, G.E. Tucker
- We quantify topographic anisotropy using multidirectional multiscale variograms maps.
- Our method takes advantage of GPU acceleration through parallel CUDA code.
- Spatial anisotropy signals reflect distinct tectonic, climatic, erosional conditions.

10) Predicting uncertainty in sediment transport and landscape evolution – the influence of initial surface conditions, Pages 117-130, G.R. Hancock, T.J. Coulthard, J.B.C. Lowry
- The effect of DEM surface roughness was examined using a landscape evolution model.
- Different surface roughness in the DEM produced variability in sediment output.
- All simulated landscapes were similar suggesting a geomorphic equifinality.
- The initial catchment shape exerts a first-order control over landscape evolution.

11) LORICA – A new model for linking landscape and soil profile evolution: Development and sensitivity analysis, Pages 131-143, A.J.A.M. Temme, T. Vanwalleghem

- We present a new soil–landscape model: LORICA.
- Model assumptions and equations are discussed.
- Example results appear satisfactory.
- Global sensitivity analysis is performed.
- Soil and landscape development are intimately linked.

12) First-order uncertainty analysis using Algorithmic Differentiation of morphodynamic models, Pages 144-151, C. Villaret, R. Kopmann, D. Wyncoll, J. Riehme, U. Merkel, U. Naumann

- A first-order second moment method (FOSM) is applied to quantify uncertainty.
- The method uses Algorithmic Differentiation (AD) and a Tangent Linear Model (TLM).
- The method is compared with Monte Carlo analysis in a trench migration test case.
- A TLM of the Telemac-2d/Sisyphe morphodynamic model has been applied.
- The FOSM/AD method is an efficient alternative to Monte Carlo simulations.

13) Towards uncertainty quantification and parameter estimation for Earth system models in a component-based modeling framework, Pages 152-161, S.D. Peckham, A. Kelbert, M.C. Hill, E.W.H. Hutton

- Integration of modeling frameworks and uncertainty analysis toolkits is discussed.
- General-purpose uncertainty analysis toolkits such as DAKOTA are discussed.
- Two models for longitudinal elevation profiles of rivers are analyzed with DAKOTA.
- New nonlinear least squares' results are given for river elevation profile models.
- Enhanced modeling frameworks will make it easier to analyze model uncertainty.

14) Exploring temporal and functional synchronization in integrating models: A sensitivity analysis, Pages 162-171, G.F. Belete, A. Voinov

- We coupled predator and prey models using Web services.
- Integration of models is highly sensitive to the time steps assigned to each models.
- Integration output is sensitive to numeric integration methods used by components.
- Integration output is sensitive to functional responses used by participating models.

4.3 Model Benchmarking and Model Inter-comparison

Model inter-comparison 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. As 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 often are used in larger ensembles of other models to investigate internal model dynamics. Model benchmarking and inter-comparison projects are prevalent in some domains of the surface processes modeling community and much less practiced in others. CSDMS aims to instill a culture of practice in consistent model benchmarking through analytical solutions and standard, consistent test cases. Knowledge transfer efforts of CSDMS aim to provide CSDMS members with examples of best practices on model benchmarking and inter-comparison.

As one example of such best practices in 2015, CSDMS highlighted the model contribution of Dr. Elena Tolkova, a tsunami modeler with NorthWest Research Associates. She had recently published and contributed her tsunami model, CLIFFS, to the CSDMS model repository. The model code is well-documented, and maintained in a Github repository, but in addition it explicitly included benchmark datasets which were assembled for the May 2011 National Tsunami Hazard Mitigation Program

Workshop. These benchmark data, which include theoretical problems, wave tank experiments, and a field case, were archived and are available through Github (https://github.com/rjleveque/nthmp-benchmark-problems).

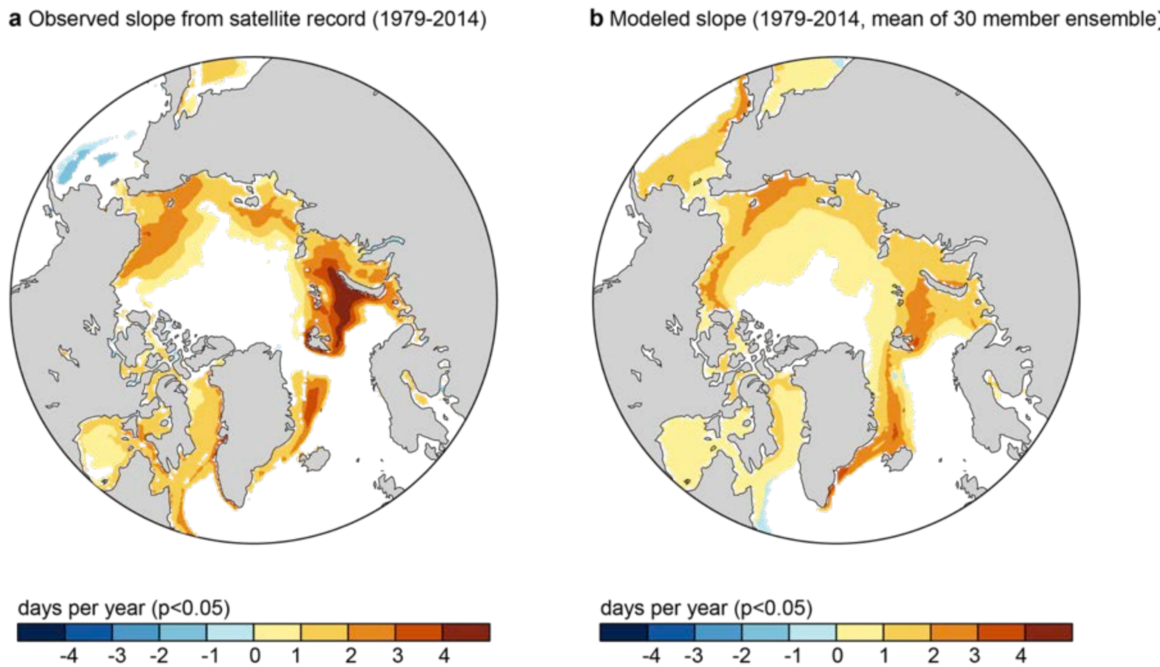


Fig. 4.3 Example of CSDMS surface process modelers analyzing the Community Earth System Model -Large Ensemble simulations for sea ice-free days as an important control on Arctic coastal processes (Barnhart et al., in rev). Panel A shows the changes in sea ice free conditions from observed data, panel B shows the mean changes in sea ice free conditions over 30 model simulations.

To further educate our community on ongoing model benchmarking and inter-comparison efforts, the CSDMS Annual Meeting 2015 featured 'Models meet Data, Data meet Models' as a theme. The CSDMS Annual Meeting 2015 facilitated breakout groups discussing the needs of modelers from the data community. Three keynote talks focused explicitly on model benchmarking and model inter-comparison efforts in the terrestrial, hydrology and coastal/marine modeling domains:

- Forrest M. Hoffman, *International Land Model Benchmarking Project*
- Mary Hill, *Testing model analysis frameworks*
- Randy LeVeque, *The GeoClaw Software*

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*

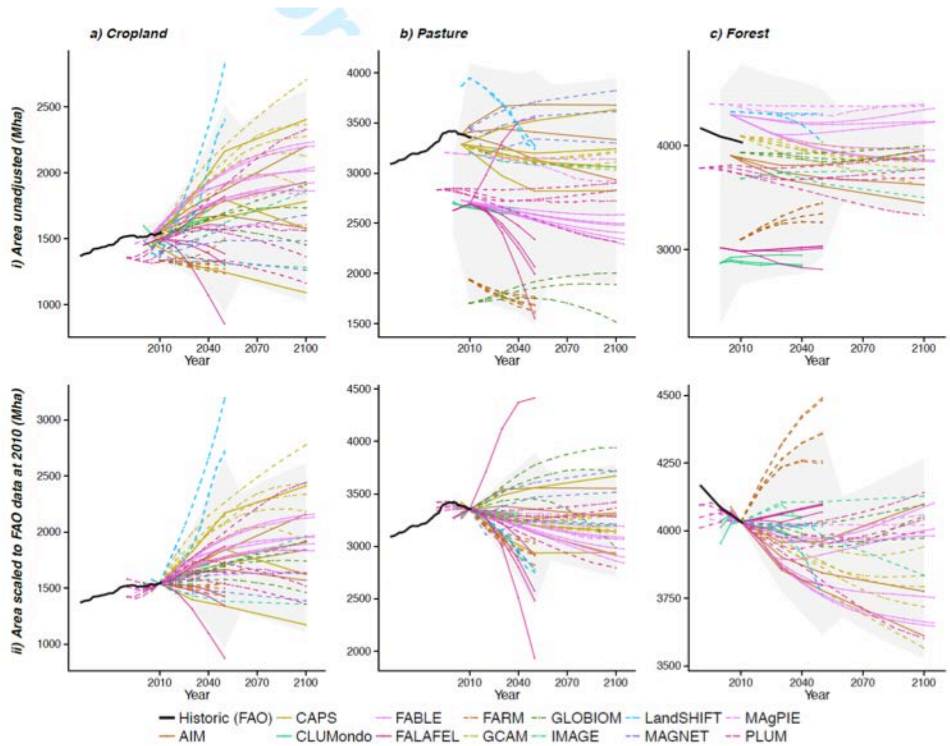


Figure 4.41 Large uncertainty in 21st century predictions of a suite of global scale land-use change models aimed at assessing changes in cropland, pasture, forest (adapted from Rounsevell, 2016 talk at CSDMS 2016 meeting).

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*

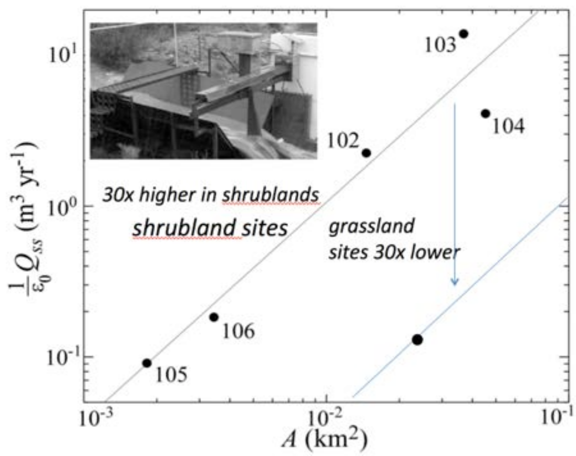


Figure 4.5 Erosion and sediment transport modeling with benchmark data from Walnut Gulch in Arizona shows that vegetation cover changes in arid regions of the US West leads to dramatic changes in erosion rates and topography (adapted from Pelletier, 2016 talk at CSDMS 2016 meeting).

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

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 (now decommissioned), blanca*** and ***summit***. 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.

CSDMS-IF personnel, along with researchers from the National Snow and Ice Data Center and Los Alamos National Laboratory, are conducting benchmarking studies of permafrost models through a collaborative project, the Permafrost Benchmark System (PBS; NASA award 14-CMAC14-NNX16AB19G). Key to the PBS project is the use of software from the International Land Model Benchmarking (ILAMB) project. ILAMB project personnel have developed a modular and open source 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. Version 1 of the ILAMB software, though written in the NCAR Command Language (NCL), was wrapped with a Python BMI by the CSDMS IF software engineers and componentized. It can be accessed through the **wmt-permafrost** instance of WMT (see Section 2.3). Version 2 of the ILAMB software was completely rewritten in Python, and rolled out at the 2016 AGU Fall Meeting. The BMI for this version of ILAMB is under development, and will be completed by the end of the fiscal year.

Chapter 5: Semantic Mediation and Ontologies

5.1 CSDMS Standard Names

CSDMS Standard Names consist of Model Variable Names and Model Metadata Names. ***Model Variable names*** are constructed from valid Object Names, Operation Names and Quantity Names, that often include a Process Name. ***Model Metadata Names*** attempt to provide complete metadata for describing key attributes of a model other than the input and output variable names and are stored in Model Metadata Files. The Model Metadata Names include additional metadata to support the variable names, such as units, object name source and geo-referencing data (e.g. standard ellipsoid, datum and projection names) as well as many different types of Assumption Names. Each of these parts is fully documented on the CSDMS wiki.

Main Page:	http://csdms.colorado.edu/wiki/CSDMS_Standard_Names
Basic Rules:	http://csdms.colorado.edu/wiki/CSN_Basic_Rules
Object Names:	http://csdms.colorado.edu/wiki/CSN_Object_Templates
Operation Names:	http://csdms.colorado.edu/wiki/CSN_Operation_Templates
Quantity Names:	http://csdms.colorado.edu/wiki/CSN_Quantity_Templates
Process Names:	http://csdms.colorado.edu/wiki/CSN_Process_Names
Assumption Names:	http://csdms.colorado.edu/wiki/CSN_Assumption_Names
Metadata Names:	http://csdms.colorado.edu/wiki/CSN_Metadata_Names
Model Metadata Files:	http://csdms.colorado.edu/wiki/CSN_MMF_Example

The CSDMS Standard Names can be viewed as a ***lingua franca*** that provides a bridge for mapping variable names between models. They play an important role in the Basic Model Interface (BMI) developed by CSDMS. Model developers are asked to provide a BMI interface that includes a mapping of their model's internal variable names to CSDMS Standard Names and a Model Metadata File that provides model assumptions and other information. If widely adopted, this naming system could also provide other benefits, such as a better discovery mechanism for finding models on the web.

CSDMS IF has written a Python package for use with the CSDMS Standard Names. This package will become the Source code for the project is on GitHub: https://github.com/csdms/standard_names. The standard names package provides tools for working with standard names. With this package users are able to:

- Decompose a standard name into it's constituent parts (object, quantity, quantity operator)
- Compose standard names from constituent parts
- Validate standard names
- Query the standard name database

In addition, the master list of current CSDMS standard names (currently numbering over 900) is also housed on GitHub at: https://github.com/csdms/standard_names/blob/master/data/master.txt.

The new CSDMS Web API provides an interface to a CSDMS Standard Names relational database. Through a RESTful interface the web service allows users to query the Standard Names database, parse names into their constituent parts, search by name or name-element and add new names. Coupled with the rest of the CSDMS Web Services, users can also query which models use or provide a particular name, or which names a particular model uses and provides.

The database of standard names has grown over the last year. Groups that are using Standard Names have also increased over the last year and represent an increase in the breadth of represented disciplines. Over the last year the following projects have begun including CSDMS Standard Names into their work:

1. EarthCube Building Blocks: Earth System Bridge: Spanning scientific communities with interoperable modeling frameworks, **NSF-1550966**, Peckham is PI.
2. EarthCube Building Blocks: Collaborative Proposal: GeoSoft 2: Collaborative Open Source Software Sharing for Geosciences, **NSF-1552359**, Peckham is co-PI.
3. EarthCube Building Blocks: Collaborative Proposal: A Geo-Semantic Framework for Integrating Long-Tail Data and Models, **NSF-1552158**, Peckham is co-PI.
4. Marine Metadata Interoperability (MMI). John Graybeal is PI
5. National Socio-Environmental Synthesis Center (SESYNC). Moeckel & Shahumyan PIs

The Earth System Bridge project works with CUAHSI to create a crosswalk (or mapping) from the CUAHSI VariableName CV to the CSDMS Standard Names and from the CF Convention Standard Names to the CSDMS Standard Names. This project has added 1000+ new variable names to the CSDMS Standard Names (current total is 2653) including new names for river deltas, the new "tilde" delimiter, over 1000 standard assumption names, extensive updates to the wiki pages, and connections to the ISO International Standard of Quantities (ISO 80000). Teams from the above three Earth Cube projects are working to create an ontology for the CSDMS Standard Names, that can be extended/edited by others (via GitHub). This ontology will be available in OWL and RDF formats.

5.2 CSDMS Standard Names — Basic Rules

Every standard name has an object part that describes a particular object and a quantity part that describes a particular attribute of that object that can be quantified with a number. A large collection of examples can be viewed on the Examples page. Numerous templates, patterns and rules for constructing object names and quantity names are provided on the CSDMS Quantity Templates and CSDMS Object Templates pages. Quantity names are sometimes constructed using one of the CSDMS Process Names.

A standard name may have an optional operation prefix applied to its quantity name part that always ends with the reserved word "_of". This creates a new quantity from an existing quantity. See the CSDMS Operation Templates page for more information.

Standard names consist of lower-case letters and digits. They contain no blank spaces. As of February 2015, there are only 3 non-alphanumeric characters allowed in a standard name, underscores, hyphens and tildes. Each has a distinct purpose, as explained below.

A single underscore is used to delimit separate words in a standard name. In the object part of the name, underscores separate objects and sub-objects, and in most cases can be read as "has a" or "could have a".

A double underscore is used between the object part and the quantity part of the name. This serves as a unique delimiter between the object and quantity parts and also helps with alphabetization of objects and sub-objects.

Hyphens (as of July 23, 2014) are used in the following ways. (1) To indicate that the words in multi-word object name refer to a single object, as in "water_carbon-dioxide__solubility". This allows the object name to be parsed (on underscores) into multiple objects (often one being within or part of another). (2) To indicate that a set of words should be bundled into one concept or adjective, as in "channel_water__volume-per-length_flow_rate" or "air__mass-per-volume_density". Note that "per" is a reserved word.

Tildes (as of February 2015) are used to distinguish nouns and adjectives in the object (including sub-object) names that occur in the object part of a name. A new rule replaces any object name of the form "adjective-adjective-noun" with the form "noun~adjective~adjective". Object names must now begin with a noun and may be followed by any number of adjectives, separated by tilde characters. This rule leads to better alphabetization and logical ordering. For example, "incoming-longwave-radiation", "alaskan-black-bear" and "suspended-sediment" become "radiation~incoming~longwave", "bear~alaskan~black" and "sediment~suspended".

The ISO International System of Quantities (ISQ, ISO 80000) defines many different terms and phrases such as quantity, base quantity, derived quantity, quantity dimension and kind of quantity. For example, the eight fundamental base quantities are: length, mass, time, electric current, thermodynamic temperature, amount of substance, luminous intensity and currency.

The rightmost word (possibly hyphenated) in an object name is called the root object. This is the object to which the quantity applies, or on which the quantity is measured. Preceding object names typically indicate "container objects" and are used to establish context.

The rightmost word (possibly hyphenated) in a "quantity name" is called the root quantity. There are a limited number of root quantities (roughly 100-150), that are carefully chosen to unambiguously indicate the type of quantity. Additional words in the quantity name add meaning to identify a specific, unique quantity of that type. The phrase root quantity is used here to avoid conflict with base quantity, as defined by ISO 80000. Also in keeping with ISO 80000, many root quantities are the same kind of quantity, despite having different definitions. Examples include: length, width, distance, radius, diameter, perimeter, amplitude, wavelength (of the kind "length); height, depth, thickness, elevation, altitude, level (of the kind "height"); fee, price, income (of the kind "currency"); duration, age, period, time (of the kind "time"); force, weight (of the kind "force"); pressure, stress (of the kind "pressure"); angle, latitude, longitude (of the kind "angle"). Other root quantities with specific meanings are: speed, slope, mass, temperature, energy, power, count (for non-negative integer quantities), index (for statistical "measures"), constant (for mathematical and physical constants), number (for dimensionless numbers), coefficient (for multiplicative factors), exponent, parameter, capacity, mole, density, frequency, wavenumber, charge, voltage, current, conductivity, resistance, albedo, reflectance, absorptance, transmittance, viscosity, vorticity, area and volume. Note that the terms fraction, ratio, rate (per unit time) and flux (per unit area and time) may be used in the construction of root quantity names, as in "volume-flux" and "volume-flow-rate".

Note: "Quantity suffixes" have been deprecated almost completely, but "time_step" is an exception. If the rightmost word in a quantity name is a quantity suffix (e.g. step) then the last two words are the root quantity (e.g. time_step). See the CSDMS Quantity Templates for an explanation of "quantity suffix".

There are several short reserved words such as as, at, in, of, on (or and?), or, per, to and vs. These are used within patterns that deal with various issues as described in the CSDMS Object Templates, CSDMS Quantity Templates and CSDMS Operation Templates. The words reference and standard may also be reserved. See the Reference Quantities template.

Many CSDMS Standard Names contain a person's last name. If the last name ends with the letter "s" — as in Burgers, Gibbs, Huygens, Jones, Potts, Reynolds, Shields and Stokes — then it is retained. However, a possessive "s" is never added to the name, so we would use "newton" vs. "newtons" in a standard name.

Acronyms and abbreviations are sometimes used in standard names, but are generally avoided for clarity. Note that "leq" is currently used as an abbreviation for "liquid-equivalent" and "x-section" is used instead of "cross-section". Standard symbols for the chemical elements (but lower-case, like "h" and "c") can be used in naming quantities like "bond_angle" that involve multiple atoms in a molecule. See Attributes of Molecules on the CSDMS Quantity Templates page.

Numbers may be used as part of an object name or in adjectives. Examples include "cesium~133" and "air_light~550-nm-wavelength__refraction_index". In the second example, "550-nm-wavelength" would be preferable to "yellow".

As explained at the top of the CSDMS Process Names page, the "ing" ending on process names such as "shearing" and "melting" is often dropped for quantities like "shear_stress" and "melt_rate" that use the Process_name + Quantity Pattern. However, the "ing" ending may be retained when the same word is used in a quantity like "melting_point_temperature" (vs. "melt_temperature").

Word order in object names. Starting with a base object, adjectives are added to the right after a tilde character (as of February 2015) in an effort to construct an unambiguous and easily understood object name. The addition of each adjective produces a more restrictive or specific name from the previous object name. For example: bear; bear~black; bear~black~alaskan, or spider; spider~black-widow

However, object names may contain either a single object name or multiple object names. In the Part of Another Object Pattern, there is generally some sort of "containment" and the separate object names (with their adjectives, separated by tildes) are ordered from the general to the specific (or superset to subset), left to right.

In addition, some quantities — like concentration, partial pressure and solubility — require specifying multiple objects. The last two object names in the object part should be the two (or more) required objects in such cases. Each of these quantities has a template that explains how words are ordered. For example, the "kinetic_friction_coefficient" associated with two objects that are in contact (e.g. rubber and pavement) doesn't imply an ordering, so the ordering is alphabetical in order to avoid multiple names for the same thing.

Alphabetization. It is easier to find standard names that refer to the same object if there is some alphabetical ordering. The left to right "containment" rule in the object part supports this, as does the new rule (see above) that uses the tilde character to add adjectives after nouns. The leftmost object name often refers to a domain or medium such as atmosphere, land, lithosphere, sea or soil.

Parsability. While standard variable names are used primarily for semantic matching, which does not require any parsing, CSDMS recognizes the many advantages of being able to automatically parse a standard name (e.g. with a small Python program) and deconstruct it into its various parts. One advantage is that it will then be easier to map the names to other formats or lists of names or to build an ontology from them. Another advantage is that a "smart framework" can then use subsets of names (typically by removing words from the left-hand side) to find potentially valid but inexact matches and present them to users. All of the CSDMS name construction rules attempt to honor this parsability. This is sometimes achieved through the use of special delimiters or reserved words like "__" and "_of_" or through the ability to distinguish nouns (sub-objects in an object name) from the adjectives that act on them. These same rules allow the names to be parsed visually by the people who use them. For example, the word "of" is used as a verbal delimiter in spoken math.

Word order in quantity names. Starting with a base quantity (which could end with a quantity suffix), adjectives are added to the left in an effort to construct an unambiguous and easily understood quantity name. The addition of each new word (or words) produces a more restrictive or specific name from the previous name. For example: conductivity; hydraulic_conductivity; saturated_hydraulic_conductivity; effective_saturated_hydraulic_conductivity

The order in which adjectives/modifiers are added to the left may not always be clear, but in this example "hydraulic_conductivity" and "saturated_hydraulic_conductivity" are two fundamental quantities that would be used in a groundwater model and "effective" could be applied to either of them to indicate application at a given scale. Note also that "saturated" could have been applied to "soil", the associated object, but in models "saturated_hydraulic_conductivity" is a fundamental quantity. In addition, names starting with "saturated_soil" would be alphabetically separated from those starting with "soil".

Remove Objects from Quantity Names Rule. There are many quantity names in common use that include an object in the name, such as "water_content" or "liquid_water_equivalent". In such cases a standard name is constructed so that the named object is moved into the object part of the name. This has many advantages, one of which is that it allows a commonly used quantity concept to be used more generally. For example, "liquid_equivalent_precipitation" (without the word "water") is a quantity name that can be used for water in Earth's atmosphere or for methane in Titan's atmosphere. Similarly, the quantity name "relative saturation" is general and makes no reference to a particular substance/object, while "relative humidity" is only valid for water, even though it doesn't include the word water explicitly.

Object vs. Adjective Rule. There are many cases where an adjective refers directly to a specific object. Examples include:

atmospheric, atmosphere:	mars_atmosphere_thickness
axial, axis:	earth_axis__tilt_angle
basal, base:	glacier_bottom__shear_stress
orbital, orbit:	earth_orbit__eccentricity
refractive, refraction:	air_light~550-nm-wavelength__refraction_index
sectional, section:	channel_x-section__area
solar, sun:	earth-to-sun_line__distance (vs. earth_to_sun_distance)

Instead of using this type of adjective in a quantity name, the corresponding object name is used (as in the examples above), usually within the Part of Another Object Pattern. This will sometimes result in an instance of the Process_name + Quantity Pattern since process names are nouns/objects. (As in "air_light~550-nm-wavelength__refraction_index" above.)

State of Matter Rule. For some standard names it is important to clarify the relevant (or assumed) state of matter. See: State of matter. In such cases, placing an adjective like "gas" or "liquid" before the object name (e.g. "liquid_nitrogen") would disrupt alphabetical grouping. To preserve alphabetical grouping, words like "vapor", "liquid", "ice" or "solid" are used with a preceding tilde, as in: "carbon-dioxide~gas", carbon-dioxide~ice", "nitrogen~liquid", "water~vapor" and "water~liquid". For quantities that do not depend on the state/phase of matter, like "temperature", this extra word to indicate the phase is not needed. Whenever the words "gas", "vapor", "liquid", "ice" and "solid" are preceded by a tilde, they are interpreted as indicating the phase of the substance before the tilde.

Patterns and rules for constructing the quantity name part of a CSDMS Standard Name are provided at the top of the CSDMS Quantity Templates page. Also see the CSDMS Process Names and CSDMS Operation Templates pages.

Patterns and rules for constructing the object name part of a CSDMS Standard Name are provided at the top of the CSDMS Object Templates page.

Chapter 6: CSDMS Model, Data and Community Portal

6.1 Open-Access Software Repository

The CSDMS Model Repository is portal for information and access on earth-surface dynamics models including open-source modeling tools, and plug-and-play components. About 35% of all models and 80% of all tools 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 CSDMS2.0 Model Repository has grown steadily in both open-source models and open source tools (Fig. 6.1).

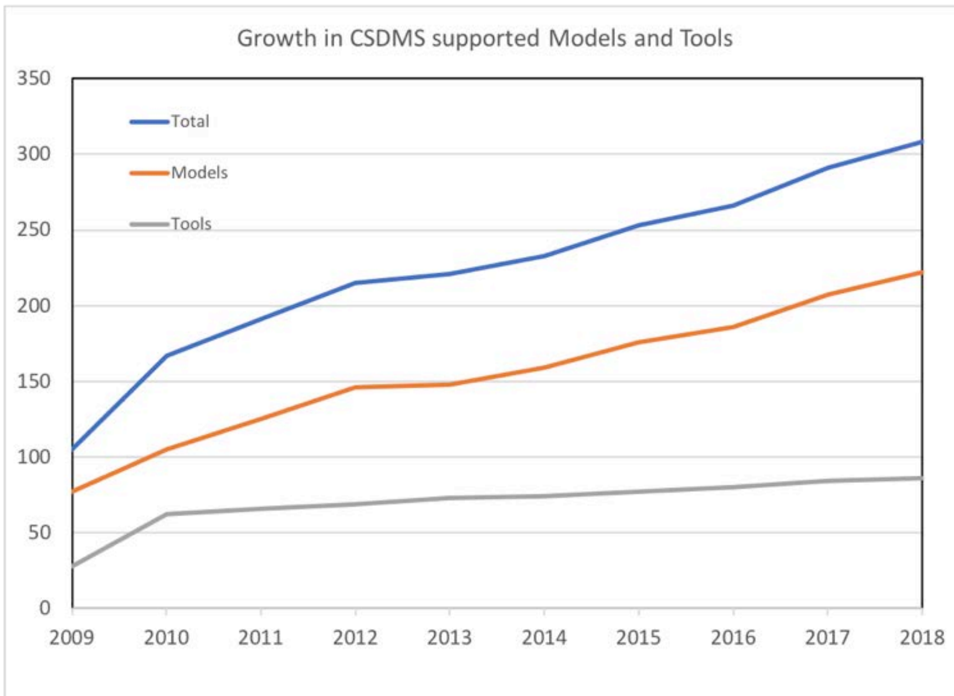


Figure 6.1. *Growth in the CSDMS Model Repository*

There are 308 source code projects in the CSDMS Model Repository. A model or tool project could reside in multiple domains. Subdivided into environmental domains with overlap, the repository offers:

Terrestrial models: 99, Tools: 76, WMT compliant: 9

Type: Landscape evolution models, avulsion models, sediment transport models, advection diffusion models, ice sheet evolution models, lithospheric flexure models, groundwater models, surface water-quality models, water balance models, etc.

Coastal models: 69, Tools: 7, WMT compliant: 9

Type: Coastline evolution models, delta sedimentation models, tidal flat models, storm surge models, plume models, tubidity current models, stratigraphic models, wave refraction models, etc.

Hydrological models: 72, Tools: 48, WMT compliant: 24
Type: Hydrologic models, stream avulsion models, flow routing models, groundwater models, fluvial sediment transport models, etc.

Marine models: 52, Tools: 7, WMT compliant: 4
Type: Basin circulation models, gravity flow models, wave models, stratigraphy models, etc.

Geodynamic models: 15, Tools: 1, WMT compliant: 1
Type: Fault, lithospheric flexure, lithosphere deflection, Mantle Evolution Model, etc.

Climate models: 12, Tools: 5, WMT compliant: 3
Type: Climate models, weather models

Carbonates and Biogenics models: 3, Tools: 4, WMT compliant: 1
Type: Carbonate cyclicity model

Landlab components and models: 7, Tools: 1, WMT compliant: 2
Type: Earth Surface Process Models

GitHub, founded in 2008, is the online source code sharing service we employ. It is free to use when contributing code in the public domain. GitHub uses a simple graphic user interface. At its core is Git, a decentralized version control system that manages and stores revisions of source code projects. CSDMS migrated from *SubVersion* to *GitHub* to reduce in-house management and maintenance tasks. GitHub allows CSDMS source code to be easily managed by its code developers including CSDMS-IF staff.

The most used function in GitHub is '**forking**', for copying source code from one account to another person's account. This enables the user to make changes to one's version of the code. If changes are made and you would like to share, you can send the original code developer a '**pull request**'. That user can, with a click of a button, '**merge**' the changes with the original source code. These 3 commands, operated by a graphical interface over the web, are all that is necessary to contribute to a source code project. GitHub keeps track of who made what changes and adds that to a user profile as well, so GitHub can be used as some sort of coding resume. For those who want to keep it even simpler, any version of the source code can be easily downloaded as a zipped package on a machine; all you need is to be online. Additionally, you can setup GitHub with an integrated 3rd party DOI provider, making it possible to generate DOIs for source code in minutes (see below). With the migration to GitHub, CSDMS lost some of its management capabilities of tracking model downloads, when, and how often for a specific model. It remains our intension to integrate this functionality soon.

CSDMS is in the process to develop alternative ways to select a model or module of interest through the CSMDS web. Currently people select a model based on a model domain, e.g. hydrology, coastal, marine or terrestrial. Once a domain is defined a user gets list of models displayed and has to select a specific model to find out if the model is sufficient for his or her project. With this alternative way of searching and selecting a model the user can define multiple criteria to specify the needs. For example, what spatial dimensions are of interest for the user or is it of importance to exclude or include models that can run on multiple processors. In this regard keywords are added to each model such that e.g. all 'landscape evolution models' can be selected. A prototype with java interface has been implemented to analyze its capability and to test web performance (Fig. 6.2).

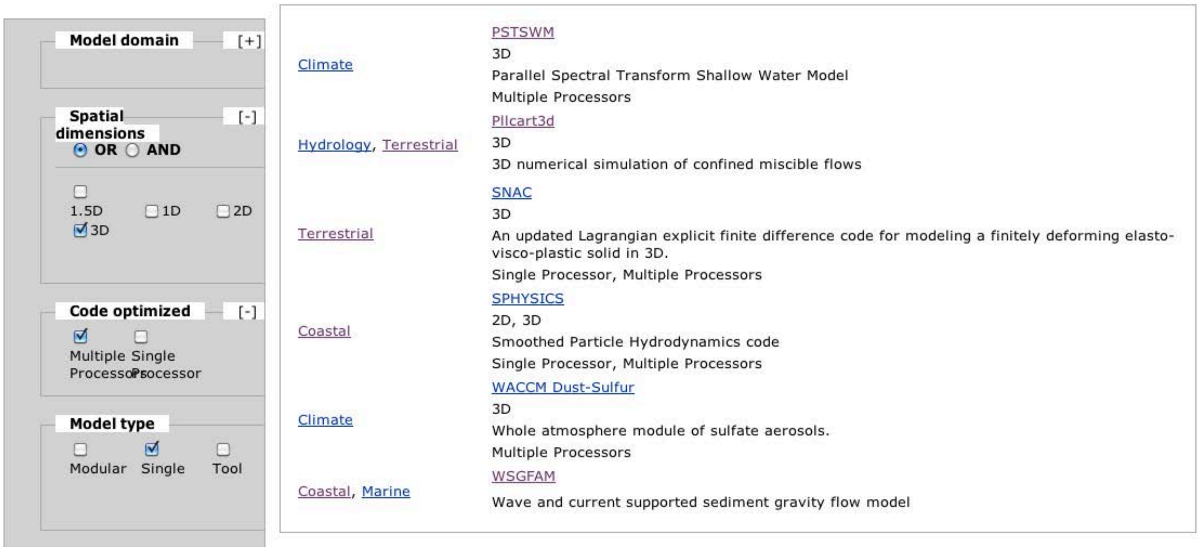


Figure 6.2. An example of how to select a model based on specific criteria

Fifteen new models have been submitted to the CSDMS2.0 repository and source code can be found on the CSDMS github site or is made available through external sites. The new models and tools of 2018 are:

Model	Description	Developer
1D Particle-Based Hillslope Evolution Model	1D probabilistic, particle-based model of hillslope evolution for studying hillslope equilibration and response to perturbations.	Jacob Calvert
Barrier Inlet Environment (BRIE) Model	Coastal barrier island transgression model	Jaap Nienhuis
CVPM, A.k.a. Control Volume Permafrost Model	Multidimensional heat-transfer modeling system for permafrost with advanced unfrozen water physics	Gary Clow
ErosionDeposition A.k.a. Landlab ErosionDeposition component	Landlab component for fluvial erosion/deposition.	Charles Shobe
GEOMBEST++	Geomorphic model of barrier, estaurine, and shoreface translations plus dynamic marsh plus waves	Rebecca Lauzon
GrainHill A.k.a. Grain Hill	Cellular automaton model of hillslope evolution	Gregory Tucker
MarshMorpho2D	2D long-term marsh evolution model based on tidal dispersion	Giulio Mariotti
Nitrate Network Model	Nitrate and organic carbon dynamics on a wetland-river network	Jonathan Czuba
OTTER	Evolution of a river profile with dynamic width	Brian Yanites

OlaFlow A.k.a. olaFoam	Wave generation and active absorption interaction with porous structures framework	Pablo Higuera
OverlandFlow A.k.a. Landlab OverlandFlow component	Component simulating overland flow using a 2-D numerical approximation of the shallow-water equations following the de Almeida et al., 2012 algorithm for storage-cell inundation modeling.	Jordan Adams
RiverMUSE A.k.a. River Mussel-Sediment Interaction Model	Simulates freshwater mussel populations' response to changes in suspended sediment	Jon Schwenk
SPACE A.k.a. Landlab Stream Power with Alluvium Conservation and Entrainment component	Conservation and Entrainment component Landlab component for 2-D calculation of fluvial sediment transport and bedrock erosion	Charles Shobe
SoilInfiltrationGreenAmpt A.k.a. The Landlab SoilInfiltrationGreenAmpt component	Landlab component that calculates soil infiltration based on the Green-Ampt solution.	Francis Rengers

Tool	Description	Developer
CMIP, A.k.a. CMIP-temp	Data component provides monthly mean temperature for Permafrost Region 1902-2100	Irina Overeem
Drainage Density, A.k.a. Landlab Drainage Density tool	Component for calculating drainage density in Landlab given a channel network	Charles Shobe

Markup languages (e.g. LaTeX) are supported on the CSDMS website to display equations in a readable format, for information displayed by the CSDMS model questionnaire, or within the model help pages displayed within the CSDMS Web Modeling Tool (WMT). Mathematical functions entered into the CSDMS web management system are delivered as MathML output to the browsers, with fallback to SVG or PNG images respectively. CSDMS uses RESTful API Mathoid services from the external party to render MathML or SVG formats, in part to reduce software maintenance costs.

H-index for models.

CSDMS was the first community effort to provide citation indices for individual models listed in the CSMDS model repository. These indices are estimated similarly to citation indices available for authors (e.g. 'Google Scholar' or 'Web of Science') but based on model publication citations. 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. Indices will be updated every 24-hours.

The ***h-index*** is named after the physicist Jorge Hirsch and called the ***Hirsch number***. The h-index as implemented at CSDMS reflects the penetration of a model within our community and its impact. For ease of use and consistency in submitting data to the reference database a 'Publication' form has been developed. Approximately 1030 model references comprise the CSDMS reference database.

Automatically enter Reference by DOI   ***Manually*** enter Reference

Citation indices	Sedflux
Citations:	523
h-index:	13

Publication(s)	Year	Model described	Type of Reference	Citations
--. The impact of floods and storms on the acoustic reflectivity of the inner continental shelf: A modeling assessment. Continental Shelf Research, 27, 542–559. 10.1016/j.csr.2005.12.018 (View/edit entry)	--	HydroTrend Sedflux	Model application	9
--. Modeling Continental Shelf Formation in the Adriatic Sea and Elsewhere. Oceanography, 17, 118–131. 10.5670/oceanog.2004.09 (View/edit entry)	--	HydroTrend Sedflux	Model application	11
--. Stratigraphic variability due to uncertainty in model boundary conditions: A case-study of the New Jersey Shelf over the last 40,000 years. Marine Geology, 224, 23–41. 10.1016/j.margeo.2005.06.044 (View/edit entry)	--	HydroTrend Sedflux	Model application	22
--. The link between abrupt climate change and basin stratigraphy: a numerical approach. Global and Planetary Change, 28, 107–127. 10.1016/s0921-8181(00)00068-0 (View/edit entry)	--	HydroTrend Sedflux	Model application	34
--. Inverse modeling of post Last Glacial Maximum transgressive sedimentation using 2D-SedFlux: Application to the northern Adriatic Sea. Marine Geology, 234, 233–243. 10.1016/j.margeo.2006.09.011 (View/edit entry)	--	HydroTrend Sedflux	Model application	24
Kettner, A.J.; Gomez, B.; Hutton, E.W.H.; Syvitski, J.P.M., 2008. Late Holocene dispersal and accumulation of terrigenous sediment on Poverty Shelf, New Zealand. Basin Research, 21, 253–267. 10.1111/j.1365-2117.2008.00376.x (View/edit entry)	2008	HydroTrend Sedflux	Model application	5
Overeem, I.; Syvitski, J.P.M.; Hutton, E.W.H.;, 2005. Three-dimensional numerical modeling of deltas.. River Deltas: concepts, models and examples. Volume 83. (View/edit entry)	2005	AquaTellUs Sedflux	Model overview	45
--. Sedflux 2.0: An advanced process-response model that generates three-dimensional stratigraphy. Computers & Geosciences, 34, 1319–1337. 10.1016/j.cageo.2008.02.013 (View/edit entry)	--	Avulsion Diffusion Plume Sedflux Subside	Model overview	39
--. 2D SEDFLUX 1.0C:. Computers & Geosciences, 27, 731–753. 10.1016/s0098-3004(00)00139-4 (View/edit entry)	--	Diffusion Sedflux	Model overview	79
--. High-frequency sea level and sediment supply fluctuations during Termination I: An integrated sequence-stratigraphy and modeling approach from the Adriatic Sea (Central Mediterranean). Marine Geology, 287, 54–70. 10.1016/j.margeo.2011.06.012 (View/edit entry)	--	HydroTrend Sedflux	Model application	25
2003. Failure of Marine Deposits and their Redistribution by Sediment Gravity Flows. pure and applied geophysics, 160, 2053–2069. 10.1007/s00024-003-2419-8 (View/edit entry)	2003	Sedflux	Model overview	14
--. Advances in the numerical modeling of sediment failure during the development of a continental margin				

Fig. 6.3. Illustrating how references of the SedFlux model are presented on its model page.

Applying semantic web technology, the CSDMS portal populates each model page with the publications that are associated with that model. Citations are added for model publication using Google Scholar, and updated throughout the year. Based on these citations per publication, CSDMS generates a citation ***h-index*** for each model within 24-hours.

Publication references are added by providing a Uniform Resource Locator (URL), a Digital Object Identifier (DOI), an International Standard Book Number (ISBN), a unique identifier number used in PubMed (PMID), or a PubMed Central reference number (PMCID). The CSDMS website automatically connects to a public API endpoint provided by the Citoid project to retrieve all necessary fields like authors, title, year of publications, journal, to properly cite a paper, and stores it locally in a database. The stored reference information is then linked back to the specified model or models. A unique number is used with each publication such that it is associated with Google Scholar to automatically retrieve the number of citations per publication.

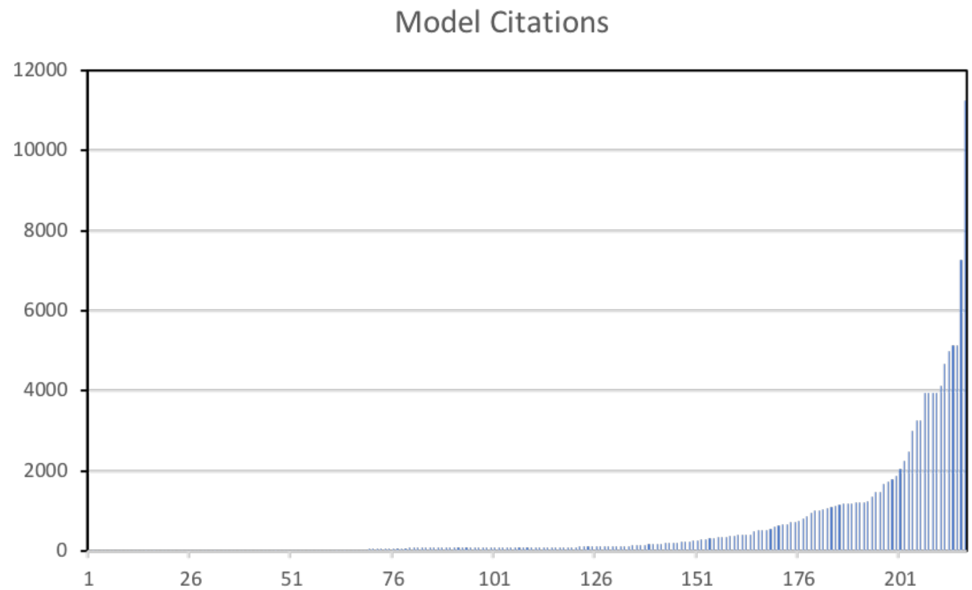


Figure 6.4. *Number of journal citations (y-axis) for each of CSDMS 222 registered models (x-axis). 38 models have each generated more than 1,000 citations, 5 models have each generated more than 5,000 citations.*

Digital Object Identifiers for models

DOI, or Digital Object Identifier is a unique string to identify an object in a digital environment. A DOI guaranties that an object can be traced by simply resolving a web address that is constructed by a DOI search engine combined by the unique identifier. The DOI contains metadata, including a URL that points to the specific object. Objects with a DOI are 5 times more likely to deliver active links to the digital content than objects without. With the adoption of GitHub, CSDMS assigns DOIs to any of the CSDMS maintained source code projects on GitHub in minutes by making use of an integrated service provided by Zenodo. Zenodo, based at CERN Data Centre, builds and operates a simple and innovative service that enables researchers, institutions and scientists to share multidisciplinary research results that are not part of the existing institutional or subject-based repositories of the research communities. Quoting from the website: "Zenodo enables researchers, institutions and scientists to:

- Easily share the long tail of small research results in a wide variety of formats including text, spreadsheets, audio, video, and images across all fields of science.
- Display their research results and get credited by making the research results citable and integrate them into existing reporting lines to funding agencies like the European Commission.
- Easily access and reuse shared research results."

Source code DOIs generated by Zenodo are searchable through standard DOI websites like e.g. http://dx.doi.org/. The following 10 models have been assigned a DOI over the last year:

Model	Developer	DOI
Barrier Inlet Environment (BRIE) Model	Jaap Nienhuis	10.5281/zenodo.1218142

CVPM	Gary Clow	10.5281/zenodo.1237889
FwDET	Sagy Cohen	10.5281/zenodo.1119066
GEOMBEST++	Rebecca Lauzon	10.5281/zenodo.1248198
GrainHill	Gregory Tucker	10.5281/zenodo.1306961
MRSAA	Li Zhang	10.5281/zenodo.893093
MarshMorpho2D	Giulio Mariotti	10.5281/zenodo.1218091
OTTER	Brian Yanites	10.5281/zenodo.1243079
OlaFlow	Pablo Higuera	10.5281/zenodo.1297012
SWEHR	Luke McGuire	10.5281/zenodo.824087

6.2 Data Repository

CSDMS offers the community the ability to share data resources. A new web form allows contributors to easily describe a data source and include an external link to the actual data. Smaller datasets can be hosted on the CSDMS server as well. The table below list the 91 datasets described, per domain as of July 2018. http://csdms.colorado.edu/wiki/Data_download

Data type	Databases	Data type	Databases
Topography	23	Oceanography	12
Climate	7	River discharge	11
Cryosphere	5	Surface properties	8
Human dimensions	4	Sea level	1
Hydrography	8	Substrates	4
Land cover	8		

CSDMS embraces the modeling challenge posed by the ongoing explosion of earth-surface data. To strengthen our bonds and enhance communications with the data community, CSDMS has joined the EarthCube Council of Data Facilities (https://earthcube.org/group/council-data-facilities). The CSDMS Model Repository is also now listed in the Coalition on Publishing Data in the Earth and Space Sciences (COPDESS) Directory of Repositories (https://copdessdirectory.osf.io/). CSDMS has also become a participating member of the Group on Earth Observations https://www.earthobservations.org/ an international effort that together is working to build a Global Earth Observation System of Systems (**GEOSS**). GEO is a partnership of more than 100 national governments and in excess of 100 Participating Organizations that envisions a future where decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations. GEO looks to CSDMS to help support model simulations as an effective means to address the world's sustainable development goals. CSDMS hopes that by combining forces with these organizations, we will have the opportunity to deepen our understanding of the dynamics of our planet's surface by confronting models with data.

6.3 Wiki, Analytics, Maintenance

Integration of Knowledge management system (Semantic Web)

CSDMS has integrated knowledge management systems or Semantic Web into the main community web portal. Web data can be easily queried, shared and reused across applications, webpages, and other community sites. The backend of its CSDMS website uses the latest version of Mediawiki; the system relies on the knowledge management systems extensions 'Semantic MediaWiki (SMW)' and 'Cargo' to enable Semantic Web functionality. Additional Semantic Web functionality is guaranteed by the extensions: Semantic Internal Objects, Semantic result Formats, Page Forms, and Maps.

Four CSDMS repositories and databases are converted to a Semantic Web structure: models, data, movie datasets and model reference papers. For each repository, a form is developed allowing members to fill in information by form-field. Once saved these form fields are displayed on an individual page just like a regular website, but they can also be queried; for example displaying how many members are located in each member country. This enriches the CSDMS website, and decreases the manual maintenance of webpages.

The CSDMS content management systems allow queries and displaying of data by external websites and databases using RESTful API technology, allowing direct, high-level access to the data contained in MediaWiki databases. Advantages of RESTful APIs are numerous, including data querries, client programs able to log in to the wiki, get data, and post changes automatically by making HTTP requests to the CSDMS web service.

API or Application Programming Interface allows applications to send and receive data to each other. This is done through a set of subroutine definitions, protocols, and tools. In practice, when using programmable APIs the request (or 'call') is simply a URL and the response is often in JSON format. CSDMS has enabled API functionality for its website and associated databases. The API of the CSDMS website provides direct, high-level access to the data contained in the MediaWiki databases. The CSDMS website API entry point is:

https://csdms.colorado.edu/mediawiki/api.php

Through this API an application can perform a set of actions, from reading website content of one of the underlying databases to creating user accounts, editing or removing pages, or uploading files. For many of these actions CSDMS requires a login and certain privileges, as we don't want to see, for example, pages being removed automatically. Letting an application reading information though might be very useful. For example, if another web host would like to copy information of a model (model metadata), they can simply use an API to automatically extract data from the CSDMS website, and embedded in their web portal. So if CSDMS makes changes, these get automatically updated on other portals as well.

To extend functionality CSDMS has implemented two additional web databases: Cargo and Semantic MediaWiki (SMW). Each has their own API parameters and actions. The SMW and Cargo API modules allow to select and retrieve annotated information stored on the CSDMS wiki. The databases that use the SMW database can be queried using the askargs statement. The Cargo build databases use the cargoquery statement.

CSDMS has built and maintains four web databases that can be accessed by using the API. These are: Model metadata, Model related publications, Data repository, and Model movies. So for example, you are only interested in numerical models that are written by a certain developer, say Greg Tucker. Then you would structure an API to something like:

https://csdms.colorado.edu/mediawiki/api.php?action=askargs&conditions=Model:%2B%7CLast_name::Tucker&parameters=limit%3D3&format=json

A full description on how to use the CSDMS website APIs, with a set of examples, a full description of the parameters, and what they represent can be found under 'Service', 'Web API', at: https://csdms.colorado.edu/wiki/Web_APIs.

The CSDMS community portal

Web portals are like the world of fashion—they change over time to please visitors by keeping up with the latest functionality and change their look and feel over time. The CSDMS portal has been updated significantly three times in ten years. The 2017 update accommodates the uniqueness of desktop computers, laptops, smartphones and tablet devices. The design process involved our team's technical, educational and logistics experts, to ensure web functionality and available resources in different focus areas. The CSDMS portal frontend is based on the popular Bootstrap 3 software, with MySQL databases for quantitative analysis, data manipulation, and advanced search functionality as backend. The main CSDMS landing page informs the community with: highlights of the latest relevant modeling science, a prominent twitter feed display on the portal, and other community features. Specific meeting events are given a prominent place on the front portal page. CSDMS complies with the University of Colorado regulations for updating software packages to guarantee performance and minimize the security risk that comes with open access platforms.

The CSDMS community portal web forms can among others be used for posting: a) job opportunities related to numerical modeling positions for students and early to mid-career scientists and for opportunities in the private sector, and b) upcoming conferences, meetings and short courses, c) model metadata that describe a model and has pointers to source code. A form has also be developed and used for participants registration for the CSDMS annual meetings. Developed web forms make it easy for community members to post their own advertisements or meetings when desired. The CSDMS annual meeting material is available through the web as well, including information for those who could not attend, including plenary presentations available through the CSDMS YouTube channel.

The CSDMS website search engine is CirrusSearch that which uses functionality of Elastic Search. The new search engine features: i) faster updates to the search index, ii) expanding templates, allowing content from a template to be reflected in search results, and iii) suggestions 'Did you mean' when you misspell a word or use an uncommon phrase. For improvement of webpage experience we are in the process of capturing visitors search queries, to better understand what information visitors are looking for, such that future updates of the website take make frequent search keywords more upfront visible.

CSDMS has experimented with discussion platforms. Discussion forums enable: 1) archiving of comments to a forum, 2) new users are provided access to these previous comments, and 3) flexible organization of posts, providing the ability to track threads that are 'dead' or are more active. Forums are tested and implemented to facilitate the working groups before, during and after annual meetings, e.g.: http://csdms.colorado.edu/wiki/Coastal_WG_Discussion (Fig. 6.4). The forum functionality within the CSDMS web portal is however very limited and it is decided to include user-friendly platform named 'Discourse'. Discourse provides the user a quick overview of all discussion categories, how many responses a discussion has, and the number of views (also for CSDMS an indication of what topic is important for the community). The Discourse discussion platform will be set up before the end of calendar year 2018.

Figure 6.4 *Forum example to support the Coastal Work Group in defining their long term coastal goals for the upcoming Five-Year Strategic Plan.*

The entire CSDMS website is publically accessible including material stored in our various repositories. To add content to the CSDMS web portal requires a login. Logins are monitored to minimalize the impact of misuse or spam content on CSDMS platforms. CSDMS has enabled OAuth (open standard for authorization). OAuth provides client applications a secure delegated access to server resources on behalf of a resource owner without sharing credentials. Using this makes it possible to use the website login for other CSDMS tools.

The CSDMS website upon a Google search, automatically appears at the top in the search results. In 2018 CSDMS posted 285 related job opportunities; 85 upcoming symposia, conferences and workshops; and 364 CSDMS tweets (https://twitter.com/CSDMS). On twitter CSDMS has 622 followers. On average the tweets sent out over 2017-2018 have 591 impressions, the measure of the total number of views of a conversation.

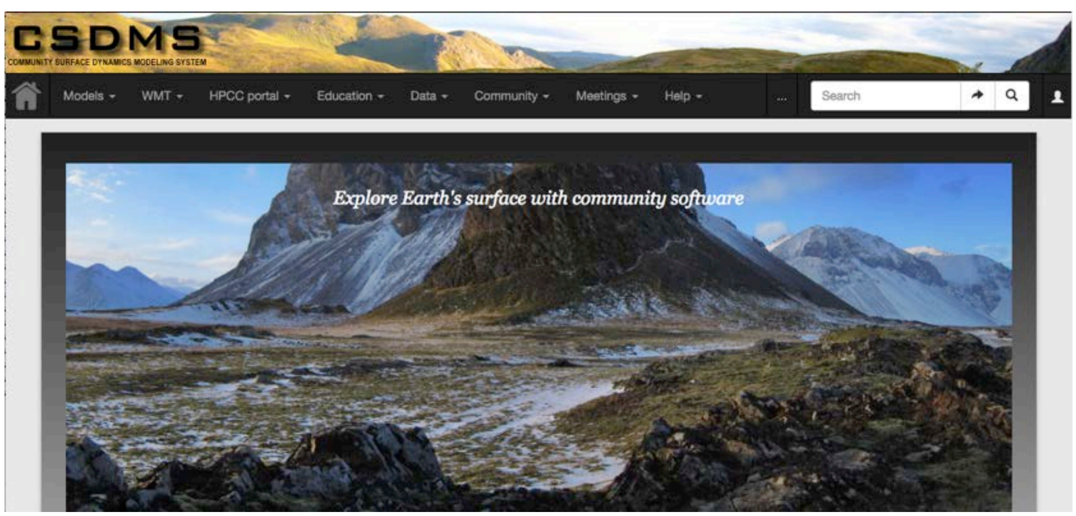


Figure 6.5. *New CSDMS web portal skin based on Twitter Bootstrap 3 web design framework.*

Improving Working Group and Focus Research Group Portal

Much of CSDMS content is ordered by category (models, education, products, services), and few repositories are sub-categorized by its science domain in Working Groups or Focus Research Groups. To improve each of the group portals, CSDMS web portal has integrated Semantic Web Tools. These make it possible to dynamically provide content on demand at specific locations (for example at the various landing pages of each WG or FRG). Web content is now prepared such that items of intrest like upcoming events, position opportunities, models, or members can all be called in a page per science domain. This should make each community portal more dynamic and attractive for domain scientists, and will make group activities more visible. The next step before the end of this funding year is to design and implement the science domains.

Web analytics

The CSDMS portal relies on 'Google Analytics' software to monitor web traffic. The CSDMS portal page is now viewed 471 times per day, and since January 2010, has received 1,409,044 views. Most web visitors are from the United States (48.3%), followed by India (28%) and China (3.9%) respectively. Most users accessed the CSDMS website using a desktop (92.1%) followed by mobile devises (6.7%) and tablets (1.2%). Mobile and tablet devises are now able to access the CSDMS Web Portal due to the new bootstrap frontend. For comparison, during the 2010 – 2011 monitoring period, 98.8% of the users used an operating system associated with laptops and PCs.

The most popular pages based on last year's page views are the front web page (http://csdms.colorado.edu; 17.5%), modeling related positions advertisement (https://csdms.colorado.edu/wiki/Jobs; 4.2%) the overall model repository page (http://csdms.colorado.edu/wiki/Model_download_portal; 3.2%), and the hydrological model domain website (2.1%). The annual meeting registration page generated 2% of page views. 45% of last year's web views go to the top ten pages. The core open-source web portal software CSDMS uses (MediaWiki) makes it possible for all community members to participate, collaborate, modify content, and share models and tools, findings, events, educational material and more, by simply using a web browser. The software itself provides the capability to keep track of some basic statistics:

Content Pages	3,112
Total Pages	16,528
Upload Files	4,699

Web maintenance

CSDMS cyber infrastructure builds upon the open software package Mediawiki (http://www.mediawiki.org) and numerous third-party extensions (53 extension as of July 2018) to extend cyber infrastructure capability and to provide the latest cyber tools to CSDMS web visitors to guaranty the easiest experience to interact through the web. Every year the core software (mediawiki) is significantly upgraded along with most third party software extensions, to guaranty performance, security, and to incorporate new features. The University of Colorado (CU) requires upgrading cyber infrastructure to the latest versions when a security upgrade becomes available, to reduce possible cyber attacks directed to CU.

6.4 CSDMS YouTube Channel

The CSDMS YouTube channel currently hosts 286 movies, distributed over the following 8 channels:

Channel	Number of movies
Annual meeting material	134

Terrestrial animations	36
Environmental animations	11
Coastal animations	39
Marine animations	14
Real events	35
CSDMS tutorials	5
Laboratory movies	12

The movies hosted on the CSDMS channel were visited 55.4K times last year, a total of 50-days of continuously streaming CSDMS content. The CSDMS YouTube movies are integrated into the CSDMS website, and can also be viewed through the CMSDS movie portal: http://csdms.colorado.edu/wiki/Movies_portal or through YouTube: https://www.youtube.com/user/CSDMSmovie/videos

Last year, most visitors were from the United States (44%), followed by Denmark (9.7%) and the United Kingdom (6.5%). The top 5 movies: Global circulation (61%), Laurentide Ice Sheet (10%), Sand Ripples (4.4%), Modeling Coastal Sediment Transport (4.4%) and World dams since 1800 (2.3%). Movies were shared 287 times with other people, and 300 people subscribed to the CSDMS channel (a 20% increase over previous year).

Top 10 most viewed CSDMS YouTube movies:

Global circulation	24.5K	http://www.youtube.com/watch?v=qh011eAYjAA
Laurentide Ice Sheet	8.4K	http://www.youtube.com/watch?v=wbsURVgoRD0
World dams since 1800	2.7K	http://www.youtube.com/watch?v=OR5IFcSsaxY
Sand Ripples	2.5K	http://www.youtube.com/watch?v=rSzGOCo4JEk
Jökulhlaup over Sandur Iceland	1.9K	https://www.youtube.com/watch?v=gKRFtm5Z8DM
Bedload Transport	1.4K	https://www.youtube.com/watch?v=is-qcxrKKBI
Barrier Island	1.1K	http://www.youtube.com/watch?v=VCX_SzPydsw
Delta formation	937	http://www.youtube.com/watch?v=eVTxzuaB00M
Coastal sed. transport	526	https://www.youtube.com/watch?v=PYp42uNLyIo
Arctic coastal erosion '10	497	https://www.youtube.com/watch?v=14Zk4YeEB4Y

Chapter 7: CSDMS Educational Mission

7.1 Developing a QSD Educational Toolbox

The Quantitative Surface Dynamics Toolbox involves the learning progression, from: 1) working with model output data and theory (equations); to 2) quantitative numerical modeling for inexperienced modelers; and to 3) more advanced numerical modeling on a high performance computing system. This approach aligns with the Next Generation Science Standards for K1-12: http://www.nextgenscience.org/next-generation-science-standards. A core idea of the NGS standards is the notion of learning as a developmental progression. Pedagogical research shows the importance of hands-on activities in learning. Students show more learning gains when they work with inquiry-based modules and receive instantaneous feedback (Fogleman et al., 2011).

CSDMS modeling exercises focus on sediment transport for geology, geography, oceanography, hydrology and environmental engineering students. Students learn to build a model from a concept, while using first principles like conservation of mass. Exercises were developed in collaboration with Prof. Greg Tucker and Prof. Bob Anderson (CU) and contain modeling assignments and codes: http://csdms.colorado.edu/wiki/Labs_Sediment_Transport_Mechanics.

The CSDMS website has introduced wiki-based modeling labs for advanced undergraduates and graduate students. The labs contain notes and figures, and marked-up question sections. Introductory labs build up modeling skills, and subsequent labs focus on model-parameter exploration and processes. Each lab is associated with downloadable introductory presentations with the goal to deepen understanding of physical process and earth system behavior. References are incorporated to further advance insight. The wiki functionality is interactive and allows learners to improve upon the documentation and to generate dynamic content.

Science practice condemns just manipulating models (black-box syndrome) without having knowledge of a model's internal workings, or model engine, or process routines (Schwarz et al., 2009). It is of crucial importance to understand the level of process simplification within a model engine and how theory is approximated by a numerical schema. Without such transparency, analysis of model output is of much less value. Any component in the CSDMS Web Modeling Tool is documented in detail on the CSDMS wiki (Figure 7.1 and 7.2), including: 1) an extensive model description, 2) notes on the input parameters, 3) key process equations for the model, 4) notes on coupling ports and 5) essential references to the model provided by the original model development team.

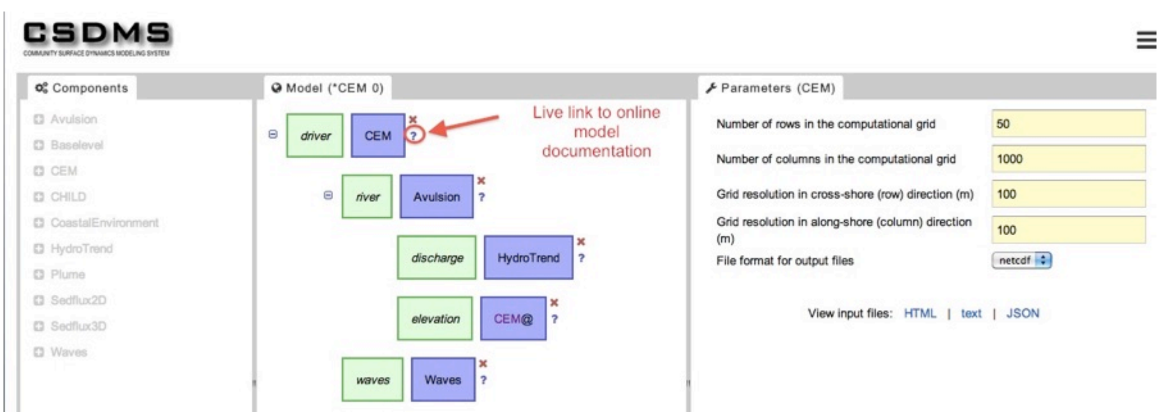
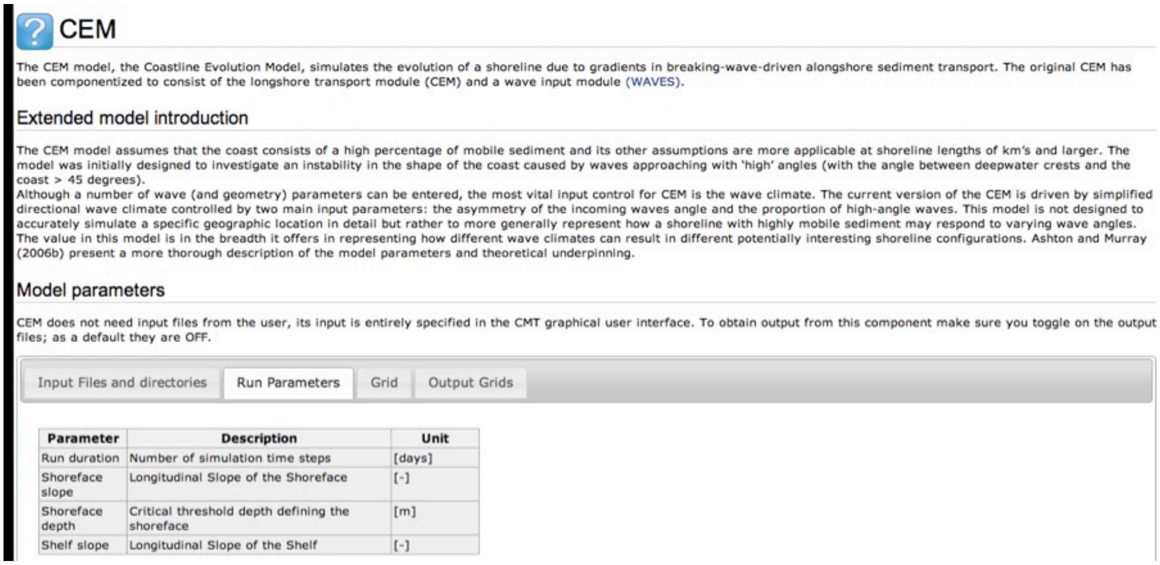


Figure 7.1 Components in WMT have easy live links to online detailed documentation maintained on the CSDMS wiki.



CEM

The CEM model, the Coastline Evolution Model, simulates the evolution of a shoreline due to gradients in breaking-wave-driven alongshore sediment transport. The original CEM has been componentized to consist of the longshore transport module (CEM) and a wave input module (WAVES).

Extended model introduction

The CEM model assumes that the coast consists of a high percentage of mobile sediment and its other assumptions are more applicable at shoreline lengths of km's and larger. The model was initially designed to investigate an instability in the shape of the coast caused by waves approaching with 'high' angles (with the angle between deepwater crests and the coast > 45 degrees).
Although a number of wave (and geometry) parameters can be entered, the most vital input control for CEM is the wave climate. The current version of the CEM is driven by simplified directional wave climate controlled by two main input parameters: the asymmetry of the incoming waves angle and the proportion of high-angle waves. This model is not designed to accurately simulate a specific geographic location in detail but rather to more generally represent how a shoreline with highly mobile sediment may respond to varying wave angles. The value in this model is in the breadth it offers in representing how different wave climates can result in different potentially interesting shoreline configurations. Ashton and Murray (2006b) present a more thorough description of the model parameters and theoretical underpinning.

Model parameters

CEM does not need input files from the user, its input is entirely specified in the CMT graphical user interface. To obtain output from this component make sure you toggle on the output files; as a default they are OFF.

Input Files and directories | Run Parameters | Grid | Output Grids

Parameter	Description	Unit
Run duration	Number of simulation time steps	[days]
Shoreface slope	Longitudinal Slope of the Shoreface	[-]
Shoreface depth	Critical threshold depth defining the shoreface	[m]
Shelf slope	Longitudinal Slope of the Shelf	[-]

Figure 7.2 *A detailed model description associated with the CEM-Coastline Evolution Model*

Complexity in teaching resources in the CSDMS 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. For example, there are many real-event movies on river sediment transport and hillslope processes. There are over 15 model animations categorized in the terrestrial category relevant for landscape evolution, including model animations of CHILD. All these resources are hosted in a database structure searchable by cross-cutting theme and intended level. At a basic level, there are stand-alone quantitative assignments, such as on flow routing in rasterized grids, a key concept in any of the landscape evolution modeling. Educators who subsequently want to expose their students to a more hands-on modeling experience and built efficacy in scenario modeling can use WILSIM to explore landscape evolution general principles and/or theoretical concepts. WILSIM is entirely web-based and requires no installation of local software beyond basic web browser functionality.

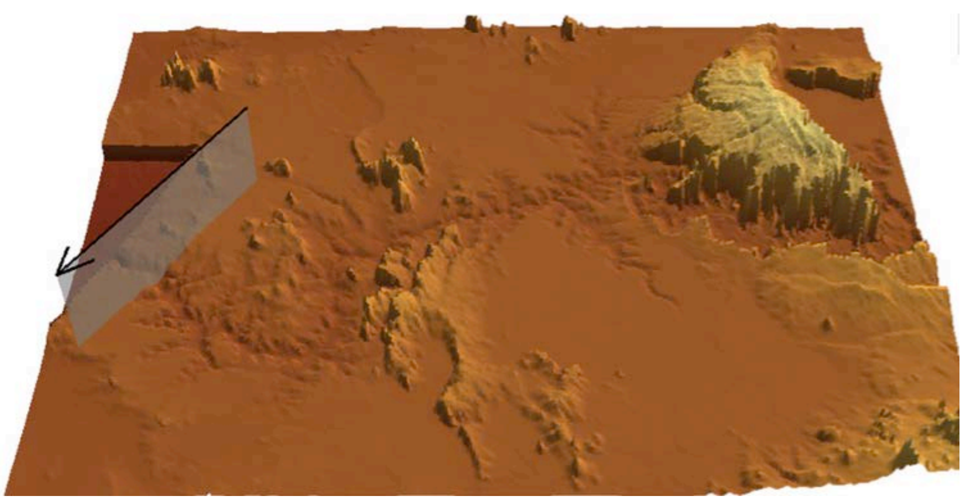


Figure 7.3 *Landscape Evolution WILSIM simulation of the Grand Canyon Region (developer Wei Luo). WILSIM is web-based and requires no installation of software a big plus for courses with large participation.*

At the most advanced level, three modeling labs explore hillslope processes and river sediment transport with CHILD through the CSDMS WMT. Each lab has a duration of approximately 4 hours, are well-documented and integrated into the Model Help system. The labs run on the CSDMS High Performance Computing Clusters (HPCC), and teach skills in working with common but advanced file formats, such as NetCDF, and provide valuable exposure on HPCC use.

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 (Chapter 3), and tight integration between the WMT and model theory, metadata, and help pages as an online resource (Fig 7.4).

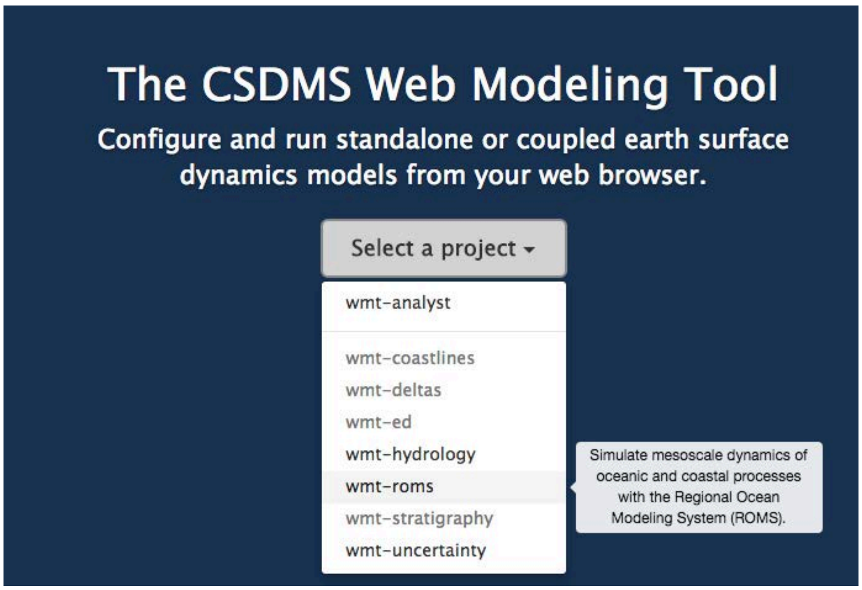


Figure 7.4 *CSDMS Web Modeling Tool is organized in dedicated projects to facilitate disciplinary labs in for example hydrology and coastal processes, https://csdms.colorado.edu/wmt/*

CSDMS has developed new framework functionality to allow model sensitivity testing and uncertainty quantification by incorporating the Dakota Tools (explained in Chapter 3). Our community needs have guided use of this functionality. Our Dakota Tools lab has been used within the framework of a Sediment Transport Modeling class at the University of Colorado. These lesson materials on uncertainty & sensitivity in modeling are then translated to dedicated online labs, for a second exposure to graduate students (~40 students in August 2016).

The CSDMS quantitative toolbox design decisions are evaluated by the CSDMS EKT working group, with the CSDMS Executive Committee offering insight on design strategies and comparison to other educational portals; i.e. Coursera and Khan academy, and domain-specific portals such as SERC and COMET. CSDMS prioritizes common open-source practices and standards and the skill building designed to emphasize these practices.

To better assess learning with modeling labs, CSDMS has adopted techniques from Martin et al., 2003; Libarkin and Stevenson, 2005; Arthur and Marchitto, 2011. These include concept inventories to determine beforehand what concepts students already know, and what concepts student are confused about or have not previously encountered. We designed the first concept inventory for the Regional Ocean Modeling (ROMS-Lite) WMT Labs. The assessment consists of 11 multiple choice questions as casted with VIMS faculty partners. These questions are both topical and fundamental (in this specific case they include continuity, velocity, momentum loss, units, plumes, waves, sediment settling, shear stress). A PDF of survey is posted online with the lab for the instructor to use pre and post course. This concept inventory was used in collaboration with faculty volunteers at VIMS and University of Virginia with students, and will be improved/refined based on initial feedback. We plan to develop a web form: 'Take Our Quiz' (see the earlier design figure for the mini-courses).

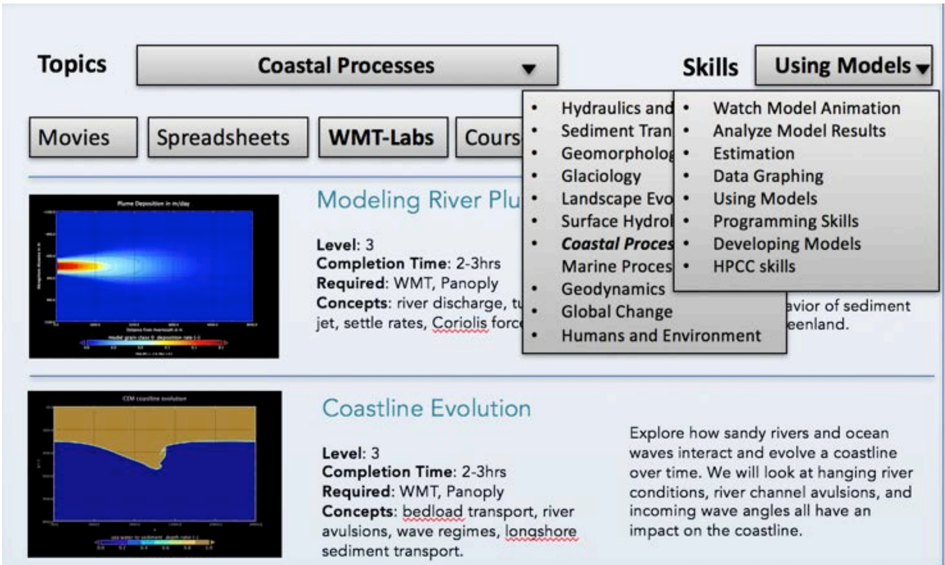


Figure 7.5. Example of designed prototype for mini-courses in the EKT repository

7.2 Online Educational Support

The educational repository contains 200+ animations and documented movies, 50 hands-on modeling labs with lecture notes and several e-textbooks. Beyond individual web visits, CSDMS receives requests of documentary filmmakers to incorporate movies or animations into their films and textbooks. Examples include: 1) the documentary Damocracy, 2) the California Regional Office of American Rivers for the Wild and Scenic Film festival, and 3) the Avian-Cetacean Press for incorporation of a barrier island migration animation into their textbook on hiking the Carolina Coast), among many others.

The CSDMS Integration Facility supports the efforts of other research teams to develop new labs able to exploit the latest developments of WMT. Examples include permafrost process modeling with focus on predicting the occurrence of permafrost, understanding active layer dynamics, and coupling of climate data with permafrost thermal models (Fig. 7.6). Recent labs have also focused on delta and river processes such as PyDelta-RCM – the Python reduced complexity model, and the floodwater river dynamics prediction model, ANUGA-SED.

The EKT working group has also explored the use of i-Python notebooks to foster the progression of students from model user to model developer. First prototypes of i-Python notebook exercises have been designed in parallel with the permafrost labs as well.

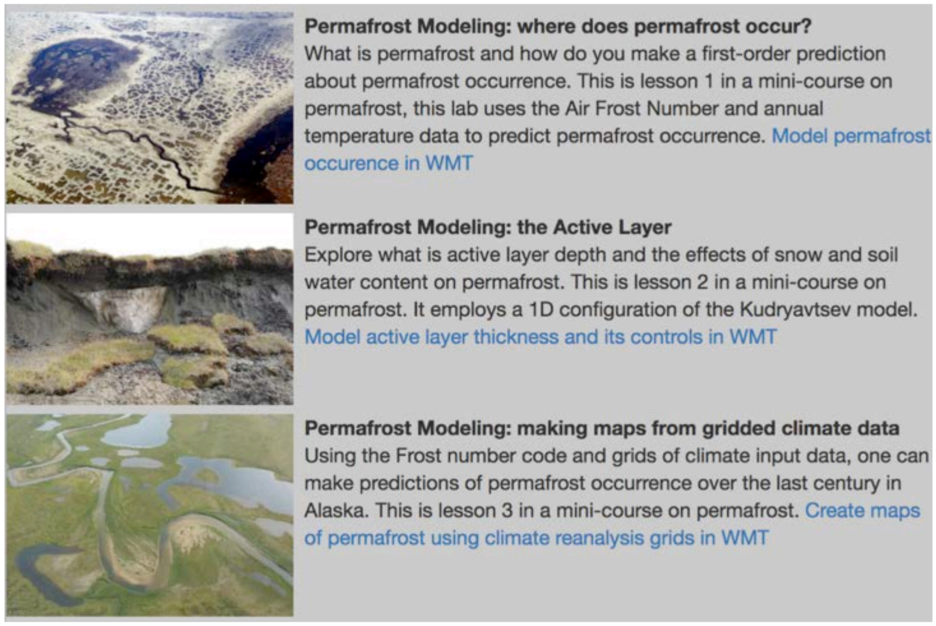


Figure 7.6. Mini-course on permafrost process modeling in Educational Repository

7.3 Online Keynote Lectures

There are 81 lectures that have been presented as keynote talks during CSDMS Annual Meetings, most posted online, in the section on 'Past Meetings'. Since the CSDMS Annual Meetings are themed, the keynote presentations offer a choreographed set of lectures.

Geoprocesses, Geohazards - CSDMS 2018 (PREEVENTS)

1. Greg Tucker — Introduction to the Natural Hazards Modeling WS
2. Justin Lawrence — NSF Update on PREEVENTS Program
3. Susan Cutter — Social Vulnerability & Community Resilience to Natural Hazards
4. David George — Modeling Earth-surface Flow Hazards with D-Claw
5. Paul Bates — Modeling Flood Risk in the Continental US
6. Julio Hoffiman — ImageQuilting.jl: A Code for Generating 3-D Stratigraphy from Flume Data
7. Rachel Glade — Modeling Blocky Hillslope Evolution in Layered Landscapes
8. Mike Willis — Private Eyes are Watching You
9. Phaedra Upton — Earthquake-induced Landslides & Landscape Dynamics: 2016 Kaikoura EQ
10. Chris Jenkins — Scale and Process Jumps in a Multimodel Project on Hurricane Impacts at Seabed
11. Jenny Suckale — Multiphase Instabilities and Extreme Events in Different Natural Systems
12. Robert Weiss — Simulating the Tsunami Hazard: Quantitative Predictions
13. Jannis Hoch — GLOFRIM - A Globally Applicable Framework for Integrated Hydrologic Modeling
14. Joannes Westerink — Storm Surge Model ADCIRC for Risk Assessment
15. Joel Johnson — Using Tsunami Sediment Transport Experiments to Imp Paleohydraulic Invrs Models
16. Terry Idol — Disasters: Increasing Interoperability for User-driven State of the Art Data & Models

CSDMS 2017: Modeling Coupled Earth and Human Systems - The Dynamic Duo

17.	Michael Barton	CoMSES Net
18.	J Syvitski & G Tucker	CSDMS - Looking back and forward
19.	Marco Janssen	Two Different Modeling Cultures
20.	Julia Moriarty	Coupling Sediment Transport and Biogeochemical Processes:
21.	Zachary Flaming	EF5: A hydrological model for prediction, reanalysis
22.	Scott Hagen	Assessing the impact of climate change on the coastal zone
23.	Michael Young	Improving soil models by connecting scientific disciplines
24.	Kim de Mutsert	Modeling a coastal environment with human elements
25.	G Tucker & E Hutton	PyMT Demo
26.	John Gilligan	Connecting human & natural systems: agent-based simulations
27.	Moira Zellner	Participatory complex systems modeling for planning
28.	Harrison Gray	Quantifying Fluvial Sediment Transport Rates
29.	David Gochis	WRF-Hydro/NOAA NWM: different processes & scales
30.	Brian Walsh	Integrated Assessment Models for Decision Making
31.	Robert Nicholls	Deltas as Coupled Socio-Ecological Systems

CSDMS 2016: Capturing Climate Change

32.	W Kim	Collaboration between Experimentalists and Modelers
33.	Jean Braun	Model Links Between Mantle Convection, Tectonics, Erosion & Climate
34.	A Damsgaard	Numerical Modeling of Ice Mechanics and Fluid Dynamics
35.	B Otto-Bliesner	Climate Dynamics of Tropical Africa: Paleoclimate perspectives
36.	Enrique Curchitser	Regional and Global Ramifications of Boundary Current Upwelling
37.	J-F Lamarque	Modeling the Couplings Across the Earth Surface in CESM
38.	Zhen Chen	Turbulence-Resolving Eulerian 2-Phase Model for Transport
39.	Jordan Adams	2-D Hydrodynamic Model in the Landlab Modeling Framework
40.	Mark Rounsevell	Integrative assessment modeling
41.	Zach Tessler	Estimating Contemporary and Future Flood Risk in Deltas
42.	N Lovenduski	Ocean Carbon Uptake and Acidification: Can We Predict the Future?
43.	Jon Pelletier	Modeling the Impact of Veg Changes on Erosion & the Landscape
44.	Don Deangelis	Ecological Applications of Agent Based Models

CSDMS 2015, Models meet Data, Data meet Models

45.	Brian Fath-	Insights from Ecological Modelling and Systems Ecology
46.	Raleigh Hood-	Modeling the Chesapeake Bay
47.	J-A Olive-	Modes of extensional faulting controlled by surface processes
48.	E Meselhe-	Coastal Eco-System Integrated Compartment Model (ICM)
49.	Kyle Straub-	Autogenic signal shredding vs. preservation in the stratigraphic record
50.	Phaedra Upton-	Models meet Data, Earth Surface meet Geodynamics
51.	Nick Cohn-	Development of a coupled nearshore and aeolian dune model
52.	Jen Glaubius-	Coupled Human and Natural Systems for Landscape Evolution
53.	Randy LeVeque-	The GeoClaw Software
54.	Stefano Nativi-	GEOSS and its Common Infrastructure
55.	Mary Hill-	Testing model analysis frameworks
56.	F Hoffman-	International Land Model Benchmarking Project
57.	Lejo Flores-	Critical Zone Observatory

CSDMS 2014, Uncertainty and Sensitivity in Surface Dynamics Modeling

58.	Tom Hsu-	Wave-driven sediment transport through 3D turbulence resolving sims
59.	J McElwaine-	The Dynamics of Granular Flows
60.	A Voinov-	Exploring climate mitigation: new challenges for model integration
61.	Peter Koons-	Unifying Tectonics and Surface Processes in Geodynamics
62.	Elowyn Yager-	Predictions of bedload transport in vegetated channels: uncertainties
63.	David Pyles-	Testing the efficacy and uncertainty of outcrop- and model-based studies
64.	Eric Larour-	Quantifications of uncertainty in polar ice-sheet projections using ISSM
65.	M van der Wegen-	Estuarine morphodynamics: better be certain about uncertainty
66.	R Caldwell-	Numerical modeling of sediment properties on deltaic morphology

67. M Perignon- Iinfluence of floodplain vegetation on large floods
68. Attila Lazar- Coupling terrestrial and marine biophysical processes with livelihoods
69. R Slingerland- The FESD Delta Dynamics Modeling Collaboratory
70. A Nicholas- Modeling the evolution of large river floodplains
71. Ajay Limaye- Vector-based method for coupling meander - landscape evolution models

CSDMS 2013, CSDMS 2.0: Moving Forward

72. Chris Duffy- Modeling The Isotopic "Age" of Water with PIHM
73. Katy Barnhart- Modeling Coastal Erosion in Ice-Rich Permafrost Bluffs, Alaska
74. J Atkinson- A Coupled ADCIRC and SWAN model of Hurricane Surge and Waves
75. M Schmeeckle- Turbulence- and Particle-Resolving Numerical Modeling of Transport
76. C Harris- Linking Sediment Transport Processes and Biogeochemistry with
77. Wonsuck Kim- Building a Network for Sediment Experimentalists and Modelers
78. Michael Eldred- DAKOTA: Object-Oriented Framework for Iterative Analysis
79. J Nienhuis- Quantifying First-order Controls on Wave Influenced Deltas
80. Mauro Werder- Modeling channelized and distributed subglacial drainage in 2D
81. Louis Moresi- Underworld: A high-performance, modular long-term tectonics code

7.4 Hands-on Clinics

An important part of CSDMS involves educating our community on disciplinary modeling efforts, and education of code developers by teaching protocols for better transfer of codes, advocating for code transparency, best-coding practices and version control. Post-meeting evaluation shows that the model clinics are one of the highlights of the CSDMS Annual Meeting — well organized and of appropriate length. Below we provide a list of 2 to 4 hr clinics offered at the annual meetings.

CSDMS 2018: Clinics

1. Mark Piper BMI Live!
2. Guy Schumann LISFLOOD-FP Clinic: Intro to Flood Hazard Modeling
3. Sed Exp Network SEN – Wrangling your research data
4. Doug Edmonds Introduction to using Google Earth Engine
5. Irina Overeem Permafrost Toolbox
6. Margaux Mouchene Landlab with Hydroshare
7. Chris Sherwood How to Make Digital Elevation Models using Drone Imagery
8. Cam Wobus Physical and Socio-Economic Data for Natural Disasters
9. S. Roberts & M. Perignon Hydrodynamic Modeling using ANUGA
10. Katy Barnhart Model Sensitivity Analysis and Optimization Dakota/Landlab
11. Ethan Gutmann Climate Model Output: Downscaling for Region Applications
12. Chris Jenkins Forum on Artificial Intelligence & Machine Learning

CSDMS 2017: Clinics

13. Irina Overeem & M Piper Bringing CSDMS Models into the Classroom
14. Mariela Perignon ANUGA - OS model of river flood morphodynamics
15. Jean-Arthur Olive Coupled geodynamics-surface process modeling with SiStER
16. Tatiana Filatova Spatial agent models: interacting actors in environmental models
17. I Overeem et al Permafrost: software toolbox to explore frozen grounds
18. Nicole Gasparini Modeling Earth-Surface Dynamics with Landlab 1.0
19. Allen Lee Good enough practices for reproducible scientific computation
20. Raleigh Martin The Sediment Experimentalist Network (SEN) Knowledge Base
21. Reed Maxwell Integrated Simulation of Watershed Systems using ParFlow
22. Kim de Mutsert Introduction to EcoPath with Ecosim
23. M Piper & E Hutton BMI: Live!
24. Katy Barnhart Model sensitivity analysis & optimization: Dakota and Landlab

CSDMS 2016: Clinics

13. I Overeem & M Piper — Using TopoFlow in the classroom
14. Eric White — Ecosystem Integrated Compartment Model (ICM): Framework
15. Mary Hill — MODFLOW: Applications for environmental modeling
16. S Peckham & A Pope — Best Practices for Publishing Your Research Products
17. W Kim, et al — SEN: Take only measurements. Leave only data
18. E Hutton & M Piper — BMI: Live!
19. C Harris, et al — Regional Ocean Modeling System (ROMS): Web-based model
20. Z Zhou, X Liu & T Hsu — Modeling coastal processes using OpenFOAM
21. G Tucker, et al — Modeling Earth-Surface Dynamics with LandLab
22. Monte Lunacek — Interactive Data Analysis with Python (PANDAS)
23. Randy LeVeque — GeoClaw Software for Depth Average Flow

CSDMS 2015: Clinics

24. M Piper & E Hutton — WMT and the Dakota iterative systems analysis toolkit
25. Chris Duffy — National Data and Distributed Models for Catchments
26. Z Cheng & Tian-Jian Hsu — Modeling Coastal Sediment Transport Using OpenFOAM®
27. S Roy & P Upton — Exploring fault slip on fluvial incision using CHILD and Matlab
28. B Murray & A Ashton — Coastline Evolution Model (CEM)
29. E Hutton & M Piper — Wrapping Existing Models with the Basic Modeling Interface
30. Jon Goodall — Integrated Modeling Concepts
31. I Overeem & M Piper — Bringing CSDMS Models into the Classroom
32. Greg Tucker — Landlab library for coupling 2D surface-process models
33. J Pollak & J Goodall — Data Access & Publication - the CUAHSI Water Data Center

CSDMS 2014: Clinics

34. A Khosronejad- SAFL Virtual StreamLab (VSL3D): High Resolution Simulations
35. Tucker & Hobley- Creative computing with Landlab: 2D surface-dynamics models
36. E Choi- SNAC: for long-term lithospheric deformation modeling
37. C Harris- Regional Ocean Modeling System (ROMS)
38. C Jenkins- Carbonate Models Clinic - carbo* suite
39. Swiler & Stephens Dakota: for Sensitivity Analysis, Uncertainty Quantification
40. Piper & Overeem WMT: The CSDMS Web Modeling Tool
41. S Peckham- Basic Model Interface and CSDMS Standard Names
42. Monte Lunacek- Interactive Data Analysis with Python
43. Joshua Watts- Agent-Based Modeling Research: Topics, Tools, and Methods

CSDMS 2013: Clinics

44. Gary Clow- Weather Research & Forecasting (WRF) System, a High-Res Atm Model
45. E Meiburg et al- TURBINS using PETSc
46. Xiaofeng Liu- Modeling of Earth Surface Dynamics using OpenFOAM®
47. S Peckham- Basic Model Interface and CSDMS Standard Names
48. Irina Overeem- CMT clinic
49. Mary Hill- Toward Transparent, Refutable Hydrologic Models in Kansas or Oz
50. H Mitasova- Modeling and analysis of evolving landscapes in GRASS GIS
51. Ad Reniers- Dune erosion and overwash with XBeach
52. Hari Rajaram- Basic intro to numerical methods for scientific computing
53. Hauser & Lunacek- Python for Matlab users clinic
54. Burgess & Jenkins- Three carbonate sedimentation models for CSDMS

We note that these clinics are well-received and well-evaluated by participants. As an example, the clinic on 'Bringing Models into the Classroom was attended by 89% academics and 11% government affiliates, with about 33% being at the stage of their career that they were actively teaching. Participants indicated their domains of study spanned all earth surface processes domains, and overwhelmingly responded that they expect to use the tools and learned skills.

All clinics, with one exception, received marks over 3.5 on a scale of 1-4 from participants. We have shared the evaluation results with the clinic leaders, and an overall summary survey is listed as an appendix to this report. In general, these clinics are perceived as a highlight of the CSDMS Annual meeting.

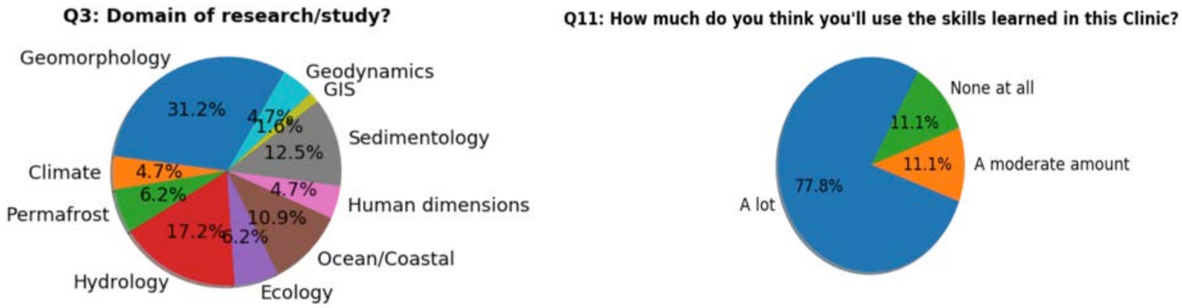


Figure 7.7. Evaluation results from one of the clinics at the Annual Meeting 2017

7.5 Bootcamps & software carpentry

Day-long courses have been offered nearly every year of CSDMS2.0

1. 2017 & 2018 CSDMS Software Carpentry (M Perignon & M Piper)
2. 2017 & 2018 Essentials for HPCC model code (CU Research Computing)
3. 2017 & 2018 BMIathon Workshop (E Hutton, M Piper)
4. 2016 & 2018 GeoClaw (R LeVesque)
5. 2016 Landlab/Anuga (Hobley & Hutton)
6. 2015 Software Carpentry (M Perignon & M Piper)
7. 2014 Software Carpentry (SC Team)

CSDMS regularly organizes software-carpentry bootcamps to promote software best practices within our community. CSDMS Integration Facility staff teach two 1-day programming bootcamps each year; one associated with the Annual Meeting, another for participants of the NCED-Summer Institute at the University of Minnesota. These bootcamps are designed after the Software Carpentry principles, hands-on exercises on Unix shell scripting, Github software sharing practices, and basic Python programming. The audience of the bootcamps varies from students wanting to get first exposure to skills needed for their research, to advanced scientist and faculty who are seeking an update to their own traditional programming skills. For more advanced modelers, a 1-day intensive skills clinic on High Performance Computing techniques is regularly offered at the Annual Meeting of CSDMS by Thomas Hauser Director of the University of Colorado Supercomputing Center.

In 2017 and 2018, CSDMS invited meeting participants to participate in a post-meeting 1-day Hackathon. The hackathon had participants bring their own codes and perhaps their initial attempts at wrapping the codes to become fully functional components, and to review their code with CSDMS software engineers (Eric Hutton and Mark Piper). The hackathon participants received pre-meeting instructions and were invited to share their codes beforehand, to allow for a more efficient interaction. The clinic appears to be a highly efficient way of boosting individual members' efforts to make use of CSDMS cyberinfrastructure tools for their own research objectives.

7.6 Summer Institute on Earth-Surface Dynamics (NCED/CSDMS)

Every year, Dr. Irina Overeem, CSDMS Deputy Director, has offered CSDMS clinics at the NCED Summer Institute on Earth System Dynamics. Course participants, are graduate students and postdoctoral fellows from universities across the US, and some from abroad.

2014: A 2-day clinic *Modeling of complex landscapes and sedimentary systems: using the CSDMS modelling framework*. U of Minnesota, Minneapolis. ~30 participants. An entrance into the CSDMS Web Modeling Tool (WMT) students will build and run coupled surface dynamics models, from a web browser, on a desktop, laptop or tablet computer. The earth-dynamic models explored and coupled will be *HydroTrend, Sedflux and CHILD*. The clinic increases efficacy with a high-performance computing system, and quantitative numerical modeling, and addresses in discussions and experiments complexity and predictability of landscape evolution and sedimentary systems.

2015: A 1-day clinic *Modeling River-Coastal Processes,* Tulane University, New Orleans, ~40 participants. Entrance to surface dynamics modeling using a number of numerical surface process models and hydrological models available through Community Surface Dynamics Modeling System. Graduate level for students of earth sciences, oceanography and engineering graduate students. The course introduces participants to the use of these software tools for their own research and teaching purposes. Students independently design and run simulations for research questions on sediment supply, coastline evolution and marine stratigraphic processes. Students learned basic skills of operating within a High Performance Computing System.

2017: 10-day clinic *Investigating scale in earth-surface systems to better inform predictions. S*hort courses are targeted to help students build programming and data-analysis skills for their independent research. The 'Programming Bootcamp' is a 1-day immersion in modern programming skills with an introduction to a unix-based supercomputing environment, Python, and best practices for open source code development (GitHub). The second course is with focus on modeling coastal and deltaic processes with CSDMS coupled component and the Regional Ocean Modeling System. A demonstration of the use of sensitivity modeling with CSDMS capability of the use of Dakota Tools is designed to be of use for the participants own research projects.

7.7 CSDMS Earth Surface Modeling Courses & Materials

- '*Source to Sink Modeling' at Nanjing University, Nanjing, China, October 2014 (14 participants, 4 days, instructors Albert Kettner and Irina Overeem).* This course follows a source-to-sink domain progression: from hillslopes to rivers to landscape evolution to coastal processes and marine stratigraphy.

    1. Get started with CMT: modeling runoff processes with TOPOFLOW
    2. River sediment supply modeling with HydroTrend
    3. Landscape Evolution Modeling with ERODE
    4. Landscape evolution modeling with CHILD
    5. Plume modeling
    6. Modeling stratigraphy in 2-D cross-sections with SedFlux
    7. Design an independent modeling study on a unique problem with a relevant model or coupled models.

    - **Coastal and shallow marine sediment transport modeling with 'ROMS-Lite** *(Irina Overeem, Courtney Harris & Julia Moriarty)* 2016 CSDMS Annual Meeting, Boulder
        1. Shallow marine sediment transport and waves
        2. Interactions of River Plume with waves
        3. Numerical modeling and the Boundary conditions

- **'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). A 1-day Teacher training workshop, course material is shared online. Resources are intended for advanced K12 students but are comprehensive enough to be used in introductory earth sciences classes or classes for non-majors.

7.8 Science-on-a-Sphere Animations

The CSDMS EKT mission includes a K-12 component as the entry tier to the Quantitative Dynamics Modeling Toolbox. Science on a Sphere (SOS)® is a spherical display system ~6 feet in diameter that shows "movies" of animated Earth system dynamics, developed by NOAA. There are few earth surface process and modeling datasets in the SOS archive. CSDMS developed a series of animations, lesson material and running exhibit 'fact slides' for 8 Science-on-a-Sphere (SOS) model/data based-animations, in close cooperation with the education and outreach team of the Fiske Planetarium at the University of Colorado and NOAA SOS technicians. CSDMS submissions to the Science on a Sphere are actively being displayed at museums and science discovery centers worldwide. The top hit of the CSDMS contributed datasets is the Wave Heights dataset, which has seen 9,289 plays (since November 2015 submission). We report only on sites monitored by the SOS system. Timelines of the monitored datasets show most use of the datasets occurs in the initial months after submission, with clustered peaks of intense usage in the subsequent months.

Animation Name	**No of Plays**
Wave Heights 2012	9289 https://sos.noaa.gov/datasets/wave-heights-2012/
Dams and Reservoirs 1800-2010	8482 https://sos.noaa.gov/datasets/dams-and-reservoirs-1800-2010/
Wave Power, 2012	6839 https://sos.noaa.gov/datasets/wave-power-2012/
Wave Heights during Hurricane Sandy	2288 https://sos.noaa.gov/datasets/wave-heights-hurricane-sandy-2012/
Wave Heights during Hurricane Katrina	2189 https://sos.noaa.gov/datasets/wave-heights-hurricane-katrina-2005/
Flood Events 2000-2009	1877 https://sos.noaa.gov/datasets/flood-events-2000-2009/
River Daily Discharge	1595 https://sos.noaa.gov/datasets/rivers-daily-discharge-2010/
Dams and Reservoirs Mississippi	922 https://sos.noaa.gov/datasets/dams-and-reservoirs-mississippi-river-1800-2010/
Dams and Reservoirs Yangtze	870 https://sos.noaa.gov/datasets/dams-and-reservoirs-yangtze-1800-2010/

7.9 Student Modeler Award Winners

Each year the CSDMS organization requests nominations of near-completion graduate students. A committee of 5 evaluates *pdfs* of papers and *drafts* of thesis. The Student Modeler Award is announced through the community portal and physically awarded at the Annual meeting banquet. The recipient receives a prize, a keynote presentation slot, and travel expenses covered to visit and work with the CSDMS software engineers. The selection is based an analysis of code, open source availability of code, adherence to best practices, the science problem solved, modeling strategy and complexity. Submissions range from specialty fields of geosciences, engineering, oceanography, ecohydrology, human-landscape interactions, among other many more. Listed below by year of receipt of award

2013 Awardee Surendra Adhikara (JPL) for numerical modeling study of valley glaciers. Adhikari formulated a new hierarchy of dynamical models that describes distinct physical processes of deformational flow. Together these models provide an intuitive tool for studying the mechanics of glaciers and help to improve sea level rise estimates.

2014 Awardee Ajay Limaye (CalTech) for his submission, *A vector-based method for bank-material tracking in coupled models of meandering and landscape evolution*.

2015 Awardee Jean-Arthur Olive (MIT) for his submission, *Modes of extensional faulting controlled by surface processes*, which investigates the feedbacks between surface processes and tectonics in an extensional setting by coupling a 2-D geodynamical model with a landscape evolution law.

2016 Awardee Anders Damsgaard (Aarhus U, Denmark) 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. 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.

2017 Awardee Julia Moriarty (VIMS) for her submission *The Roles of Resuspension, Diffusion and Biogeochemical Processes on Oxygen Dynamics Offshore of the Rhone River, France.* Her research focuses on developing and implementing a coupled hydrodynamic-sediment transport-biogeochemistry model, a novel and significant contribution to the geoscience modeling community. The ingenuity of her approach lies in the coupling of sediment transport and water column biogeochemistry.

2018 Awardee Julio Hoffiman Mendes (Caltech) for his submission *ImageQuilting.jl: A Code for Generating 3D Stratigraphy from Data Collected in Flume Experiments.* He developed fast algorithms that analyze and create surface and subsurface patterns. His paper describing the 'quilting techniques' was published in Computers and Geosciences in 2017.

7.10 Knowledge Transfer to Industry Partners and Government Agencies

CSDMS IF Staff has outreach to industry and governmental agencies across dozens of meetings (see Chapter 9). Presentations on the CSDMS community, software protocols and modeling framework services, and educational resources are shared with our partners. Their collaboration and support of CSDMS efforts occurs on various levels - from financial support to in-kind support and participation of representatives on the various committees and working groups operating within CSDMS. Our US lab partners include:

- Argonne National Laboratory (ANL)
- Idaho National Laboratory (INL)
- National Aeronautics and Space Administration (NASA)
- National Center for Atmospheric Research (NCAR)
- National Forest Service (NFS)
- National Park Service (NPS)
- National Oceanic and Atmospheric Administration (NOAA)
- National Oceanographic Partnership Program (NOPP)
- National Science Foundation (NSF)
- National Weather Service (NWRFC)
- Naval Research Laboratory (NRL)
- U.S. Agricultural Research Service (USDA)
- U.S. Army Corps of Engineers (ACE)
- U.S. Army Research Office (ARO)

U.S. Bureau of Ocean Energy Management (BOEMRE-ESP)
U.S. Geological Survey (USGS)
U.S. Nuclear Regulatory Commission (NRC)
U.S. Office of Naval Research (ONR)

Whereas the transfer of ideas is harder to measure; CSDMS concepts have been straightforwardly adapted by the World Bank in their large coastal engineering RFPs. CSDMS tools to generate GeoTIFFs and shapefiles of relevant GIS based datasets for delta modeling, can be used as model input for simulations within WMT. CSDMS connections to the US Army Corps of Engineers Coastal and Hydraulics Laboratory, have exchanged ideas to contribute tools for state-of-the-art numerical solvers for moving boundary problems. In 2016 we entered discussion with Statoil who have plans to advance model physical properties to further advance 3D space and deep time storage of subsurface materials both for industry and science needs.

The CSDMS team has intentionally sparked new connections to the Polar research community. CSDMS tools and cyberinfrastructure ideas have been presented at the US Department of Energy meeting for building cyberinfrastructure for environmental system science in April 2017. Other initiatives included teleconferences with the Permafrost Carbon Network, the Interagency Arctic Research Policy Committee (IARPC) and a keynote on CSDMS tools and services at the Forum for Arctic Modeling & Observational Synthesis (FAMOS) workshop, November 2016.

Most concretely, we presented the Web Model Tool and the development on 'PermaToolBox' at the International Permafrost Association, June 2016, Germany and more recently in Japan, July 2017. New CSDMS model components that are now online available include the 1D Frost model, the 2D Frost Model-GEO, the 1D and 2D Kudrayatsev model. This domain of Arctic surface process modeling has sparked the development of prototypes of a CSDMS data component; a dataset that can be coupled to CSDMS components. The example dataset is derived from the CRU climate data reanalysis for Alaska. The NSF Polar cyberinfrastructure award supports this targeted interaction with the permafrost field research community.

The CSDMS web-modeling tool has been presented in a stakeholder workshop aimed at exploring interest of coastal managers in predictive tools. We presented 'WMT-Deltas' in a Stakeholder Workshop of Belmont Forum-DELTAS: "Catalyzing Action Towards Sustainability of Deltaic Systems with an Integrated Modeling Framework for Risk Assessment", Sept 12-16th, at CUNY, New York. This included presentation of the new CSDMS model component for reduced complexity modeling of deltas; PyDeltaRC. The component generated interest from Bangladesh engineers and Water Development Board officials as a tool to assess the effects of sediment nourishing in tidal polders. This resulted in a small research effort in collaboration with the University of Texas, Austin for 2017-2018

A new CSDMS data component; Indian Rivers Linkages data is presented in the CSDMS data repository and has been shared with stakeholders in India and Bangladesh. A paper analyzing, documenting the data and code is in review in a CSDMS-led Special Issue on 'Deltas in the Antropocene' is currently being worked on with Elementa (a collection of 8 manuscripts are in advanced stages of revision).

7.11 Diversity Efforts

Diversity at the CSDMS Annual Meeting

CSDMS does not recorde data on diversity from their members, or from meeting attendees, a deliberate decision stemming from the fact that member profiles and meeting registration are generated through our wiki web platform. A wiki is editable by community members, and by definition is a totally open web environment, which suits the CSDMS efforts that rely on community input and editing of web resources and documents. However, it would mean that any sensitive information on members personal diversity metrics is not fully protected and thus deemed inappropriate to archive.

CSDMS does work to build and leverage a diverse and inclusive community of earth surface process modelers. 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). These numbers are likely lower in fields of earth surface process modeling and the analysis of "big data," increasingly using 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 2017 CSDMS Annual Meeting, 34% of attendees were women, at all career levels: students, PDF's, assistant professors, and full professors or senior scientists: 1) 98-male; 50-female; 2-non binary; Academic: 49-graduate students; 12-post-doctoral fellows; 12-assistant professors; 32-associate to full professors; 11-research scientists; Non-academic institutions: 17-Government Agency; 3-Industry; 9-Non-profit Research; 1-Other. At our 2018 PREEVENTS meeting, 34% of attendees were women, at all career levels: students, PDF's, assistant professors, and full professors or senior scientists: 1) 86-male; 45-female; Academic: 112; Government 16 and Industry 3. Total on-site participants career stage: 38-graduate students; 14-post-doctoral fellows; 25-early; 36-mid: 17-late. Ethnicity - Caucasian (105), Asian (12), African descent (2), Hispanic/Latino (7), Middle Eastern/India (5), American Indian (0), Pacific Islander (0).

Engaging a diverse student population in the CSDMS Annual Meeting

CSDMS reaches out through platforms aimed at non-traditional students to encourage students from all walks of life to participate in the CSDMS Annual Meetings. In 2017 and 2018, CSDMS awarded 5 student scholarships per year to underrepresented students with the explicit goal to increase diversity in the field of surface dynamics modeling. We explicitly call for students to submit applications for a stipend and send these announcements to mailing lists explicitly targeting minority students across the US. These include: 1) NSF Alliances for Graduate Education and the Professoriate (AGEP), Institute for Broadening participation: in 2017, CSDMS became an official sponsoring member of the institute of Broadening Participation. 2) AGEP listserv, especially for underrepresented groups at CU Boulder; 3) UNAVCO RESESS and UCAR SOARS program lists. We also distribute outreach information to faculty having a strong involvement with minority communities in our community, requesting them to personally invite students from their outreach programs. Stipends allowed these students to attend the entire annual meeting 2017 and the PREEVENTS meeting in 2018, and present on their research.

Diversity and representation in CSDMS leadership

Bell and Karsten (2004) found that only 13% of employed PhD geoscientist were women, with slight improvements over the last 10 years to 17-23% (Rhodes, 2010). Many of the CSDMS Working Groups and Focus Research Group chairs, and thus its executive committee are women (30%), with greater diversity counting using other measures. The CSDMS2.0 steering committee was chaired by and features 33% women. Leadership visibility is an important way to move the diversity dial.

NSF Advisory Committee for Geosciences 2014. Dynamic Earth: GEO Imperatives & Frontiers 2015–2020

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.

8.0 CSDMS Computational Support & Resources

8.1 CSDMS HPCC (*Beach – decommissioned 2018*)

During the working life of *Beach* 669 CSDMS members had an account on the CSDMS High-Performance Computing Cluster, *beach*. To obtain an account on beach users had to 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) was an SGI Altix XE1300 with 88 compute nodes (704 cores, 3.0 GHz Harpertown processors ≈ 8 Tflops). 64 nodes had 16 GB of memory each; 16 nodes had 32 GB of memory each. Internode communication used a non-blocking InfiniBand fabric. Each compute node had 250 GB of local temporary storage and could access 72TB (raw) of RAID storage through NFS. Beach provided GNU and Intel compilers as well as their MPI counterparts (mvapich2, mpich2, and openmpi). Beach was supported by the CU ITS Managed Services (UnixOps) under contract to CSDMS. CPU Utilization rates on Beach averaged 70%.

Table 8.1: Top 10 Beach users since 2015. *In the last year beach has seen jobs submitted from 91 users for a total of 112 processor years.*

Investigator	**Institution**	**Processor Days**
Jim McElwaine	U Cambridge, UK	35927
Jennifer Glaubius	U Kansas, USA	1217
Frances Dunn	U Southampton, UK	890
Omer Yetemen	U Washington, USA	682
Charles Shobe	U Colorado, USA	534
Katherine Ratliff	Duke U, USA	418
Mariela Perignon	U Colorado, USA	404
Theodore Barnhart	U Colorado, USA	375
Gaetano Achille	Osserv. Astronomico di Teramo, Italy	199
Katherine Barnhart	U Colorado, USA	114

8.2 CSDMS-supported HPCC (*Janus - decommissioned*)

The larger *Janus* supercomputing cluster (Syvitski is Co-PI) consisted 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 were connected using a non-blocking quad-data rate InfiniBand interconnect, and 1 PB of parallel temporary disk storage. Beach was connected to the Janus cluster through a private 10 Gb/s network. *Janus* was disassembled and has been replaced by S*ummit*.

8.3 CSDMS-supported HPCC (*Summit*)

The largest CU supercomputing cluster *Summit* (Syvitski/Tucker are Co-PIs) consists of a highly flexible and experimental architecture (see comparison table below). The architecture offers far fewer (405 CPU and 10 GPU) nodes, with more (24) cores per node and clock frequencies that range from 2.5 to 3.3 GHz. 380 of the nodes offer 5GB/c of RAM and 25 nodes offer 42 GB/c. Memory bandwidth has increased to 100 GB/s using the latest Omni-Path system. The file system is now GPFS that is extremely good at parallel transfers and small file operations. CU Research Computing manages *Summit*. Peak TFLOPS is nearly 3 times the speed of Janus. The HPCC is now available for jobs that have been successfully vetted by CU Research Computing managers.

Table 8.2. Comparison of three CU HPCCs: Beach, Janus and Summit.

Feature	Beach (decomshnd)	Janus (decomshnd)	Summit (active)	Blanca (active)
CPU nodes	88	1368	380; 5; 20	
GPU nodes	0	0	10	
CPU cores/node	8	12	24	28
Clock frequency	3.0 GHz	2.8 - 3.2 GHz	2.5 - 3.3 GHz	2.4 GHz
RAM/core	2-4 GB/c	2 GB/c	5 GB/c; 42GB/c	128 GB
Memory bandwidth	32 GB/s	32 GB/s	68 GB/s	10 Gb/s
Interconnect type	QDR InfiniBand	QDR InfiniBand	Omni-Path	
Bandwidth	21 Gb/s	40 Gb/s	100 Gb/s	
Filesystem	NFS	Lustre— optimized for large parallel transfers	GPFS— Good at parallel transfers & small file operations	
Storage	72 TB	1000 TB	1000+ TB	1000+ TB
Peak TFLOPS	8	153	290; 7; 53 39 Total >400	

8.4 CSDMS-supported HPCC (Blanca)

The CSDMS HPCC *Beach* was decommissioned in March 2018. In Spring 2018, the CSDMS IF successfully migrated users and software to a new cluster, *Blanca*, operated by CU's Research Computing division. *Blanca* is co-housed with *Summit*, and shares login nodes and filesystems, but it operates as a "condo cluster", where CSDMS has paid for priority on a set dedicated compute nodes. All CSDMS members can obtain an account and run jobs on *Blanca*. The CSDMS IF staff have successfully installed and operationalized the software for the CSDMS Modeling Framework (CMF) on *Blanca*. The CSDMS Web Modeling Tool (WMT) can use this instance of the CMF installed on *Blanca*.

8.5 CSDMS-supported HPCC Project Examples

1) **A Geo-Semantic Framework for Integrating Long-Tail Data and Models** *Peishi Jiang, University of Illinois at Urbana-Champaign* http://goo.gl/3zjUww

Development of 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. 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).

(2) 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.

(3) Chesapeake Bay FVCOM-ICM *Blake Clark, UMCES* Funded by NASA http://goo.gl/Q8K12r

Model the coastal ocean carbon cycle, particularly with respect to marsh-estuary dynamics in Chesapeake Bay, using FVCOM for 3d hydrodynamics and coupled offline to ICM for a carbon based biogeochemical model. The model developed here will be adapted for use in a broad range of coastal systems.

(4) 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

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. 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 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.

(5) 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.

(6) 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

We model the sediment discharge, into coastal basins to evaluate the condition of sand beaches along the Mexican littoral.

(7) Examining the landscape of the lower Chanduy Valley, Ecuador *Chris Blair* http://goo.gl/IxECyf

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. The project seeks to identify changes to the physical and social environment of the Chanduy Valley from a landscape archaeology prospective. Drone data will be analyzed in the CHILD landscape model in the CSDMS web modeling tool (WMT) utilizing a high performance computing cluster.

(8) Interannual variability and Glacier Modeling *Leif Anderson, University of Colorado* National Science Foundation (NSF) grant DGE- 1144083 (GRFP) http://goo.gl/qcN9bi

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. Methods: 1 and 2D Matlab-based numerical glacier models 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.

Anderson, Leif S., Gerard H. Roe, and Robert S. Anderson. "The effects of interannual climate variability on the moraine record." Geology 42.1 (2014): 55-58.

Rowan, A. V., Brocklehurst, S. H., Schultz, D. M., Plummer, M. A., Anderson, L. S., & Glasser, N. F. (2014). Late Quaternary glacier sensitivity to temperature and precipitation distribution in the Southern Alps of New Zealand. Journal of Geophysical Research: Earth Surface.

(9) 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

(10) 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.

(11) Improving Representations of Snow-Vegetation Interactions *Adrian Harpold* NSF EAR Postdoctoral Fellow (EAR#1144894) http://goo.gl/zcPpwJ

Applying LiDAR-derived vegetation datasets to verify and improve snow-vegetation interactions in land surface models.

(12) Landscape Evolution Modeling of Terrain Modified by Agricultural Terracing

Jennifer Glaubius, University of Kansas http://goo.gl/bX0k8O

(13) 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 with the erosion model Fastscape (Braun and Willet, 2013) coupled with a thermal module that can predict cooling ages for different thermocrhonometers. The model is run as an inversion to decipher which set(s) of model parameters best predict the observed data. Used models: Fastscape, PLEM, and Pecube

(14) 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

(15) 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.

(16) Multiscale stratigraphic and statistical characterization of fluvial systems *Jesse Pisel, Colorado School of Mines, 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.

(17) NCEP data read *Taylor Winchell, University of Colorado* http://goo.gl/76HIWH Funding: NSF GRFP

Project will 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

(18) Quantitative analysis of deepwater depositional systems *Ningjie Hu, University of Texas at Austin* http://goo.gl/dTylO8

Employ the modeling tools in CSDMS to delineate the evolution of and controls on deepwater depositional systems. This study will use Sedflux-2D and 3D

(19) River plumes in Ecuadorian coast *Willington Renteria, Secretaria Techica del Mar, Ecuador* http://goo.gl/odCSAz Funding by Secretaria del Mar, Ecuadorian Government

Modeling the effect of river plumes in ecosystems along the Ecuadorian coast. The interaction between the Humboldt current and the river plumes is poorly understood, the focus of this project is try to quantify this interaction.

(20) Simulation of Granular Flows *Jim McElwaine, University of Cambridge* Funded by University of Cambridge http://goo.gl/KCxvSX

Granular flow interaction with ambient fluid is critical, for 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. 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.

(21) Spatial Distribution of Solar Radiation as a Driver of Hillslope Asymmetry Across Latitudes *Omer Yeteman, University of Washington* NSF-EAR 0963858, NSF-ACI 1148305.

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:

- Yetemen, O., E. Istanbulluoglu, J.H. Flores-Cervantes, E.R. Vivoni, and R.L. Bras (2015), Ecohydrologic role of solar radiation on landscape evolution, Water Resour Res., 51, doi:10.1002/2014WR016169.

(22) Teaching basics of modeling in earth systems *Sarah Harbert, University of Washington* Funded by U of Minnesota Office of Equity and Diversityhttp://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.

(23) 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

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 and runoff at Como Creek, a snowmelt dominated catchment on the Colorado Front Range. 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.

(24) Understanding sediment delivery to deltas under environmental changes using WBMsed and HydroTrend*Frances Dunn, University of Southampton*Funded by U 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.

(25) 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).

(26) Vortex pairs interaction with density interface *Christina Schmitt, University of California, Santa Barbara* http://goo.gl/CRZfN3 https://sites.google.com/site/ucsbcfdlab/

The dynamics of vortex flows on a boundary surface of fluids with different densities is the focus of this project. When a vortex pair approaches to the interface, counter-rotating vorticity develops at 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.

(27) Teaching WMT course at University of Florida *John M. Jaeger, University of Florida*

(28) Teaching WMT course at Utah State University *Patrick Belmont, University of Florida*

(29) Bootcamp at the University of Colorado, day before annual meeting *Mariela Perignon, Mark Piper, University of Colorado* http://goo.gl/n6Xhy5 20 Participants attended.

(30) Three-day WMT modeling introduction during NCED summer course *Irina Overeem, University of Colorado* Approximately 40 participants attended.

(31) 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 ~56 participants attended these clinics.

A total of 64 projects are described on http://csdms.colorado.edu/wiki/HPCC_projects

9.0 CSDMS Staff Participation in Conferences / Meetings

Nov-12	World Within Reach: From Science to Policy	Vienna Austria	(Syvitski)
Dec-12	Frontiers in Computational Physics	Boulder, CO	(CSDMS Staff)
Dec-12	AGU Annual Meeting	San Francisco, CA	(CSDMS Staff)
Dec-12	Gilbert Club – Earth & Planetary Science	Berkley, CA	(Kettner)
Dec-12	EarthCube Experimentalist Workshop	Austin, TX	(Kettner)
Jan-13	NSF EarthCube: Digital Crust/GEO Domain	Fort Collins, CO	(Peckham)
Jan-13	NSF EarthCube Critical Zone Workshop	Newark, DE	(Peckham, Syvitski)
Feb-13	NSF EarthCube: Earth System Model Coupling	Irvine, CA	(Peckham)
Feb-13	Workshop: Coupling Tech. for Earth System Models	Boulder, CO	(Peckham)
Feb-13	PAGES Open Science Meeting,	Goa India	(Syvitski)
Feb-13	ASLO Aquatic Sciences Meeting	New Orleans	(Syvitski)
Mar-13	Reduced-Complexity Modeling Workshop	Boulder CO	(Overeem)
Mar-13	CSDMS 2.0 Moving Forward	Boulder, CO	(CSDMS Staff)
Mar-13	CSM Van Tuyl Lecture: Arctic Coastal Erosion	Golden, CO	(Overeem)
Mar-13	Global Flood Monitoring & Modeling	College Park, MD	(Brakenridge)
Mar-13	Flood Observatory Services For the World Bank	Washington DC	(Brakenridge)
Apr-13	NSF EarthCube: Modeling Workshop for Geo	Boulder, CO	(Peckham)
Apr-13	EarthCube BioGeoChemistry & Fluvial Sediment.	Boulder, CO	(Kettner)
Apr-13	Intl Working Group for Satellite Emergency Resp.	Torino, Italy	(Brakenridge)
Apr-13	Progress in Global Flood Detection System	Ispra, Italy	(Brakenridge)
Apr-13	14th Swiss Global Change Day	Bern Switzerland	(Syvitski)
May-13	Water in the Anthropocene	Bonn, Germany	(Syvitski)
Jul-13	10th Int'l Conference on Fluvial Sedimentology	Leeds, UK	(Syvitski)
Jul-13	IAHS - IAPSO - IASPEI Joint Assembly	Gothenburg, Sweden	(Syvitski)
Aug-13	Stratodynamics—EarthCube Experimentalist Wshp	Nagasaki, Japan	(Kettner)
Sep-13	Xiamen University Advisory Committee Meeting	Xiamen, China	(Syvitski)
Sep-13	CARIAA Advisory Committee	London, UK	(Syvitski)
Oct-13	GSA Annual Meeting	Denver, CO	(CSDMS Staff)
Nov-13	1st Int'l Workshop on Coastal Subsidence	New Orleans, LA	(Syvitski & Higgins)
Dec-13	AGU Annual Meeting	San Francisco, CA	(CSDMS Staff)
Dec-13	Gilbert Club – Earth & Planetary Science	Berkley, CA	(Kettner)
Jan-14	IGBP and IHDP Anthropocene Synthesis Wshp	Washington D.C.	(Syvitski)
Jan-14	Future Earth Global Environmental Change Projects	Washington D.C.	(Syvitski)
Jan-14	Rivers of the Anthropocene	Indianapolis, IN	(Syvitski)
Mar-14	EarthCube Stakeholder Assembly Workshop	Washington D.C.	(Syvitski)
Mar-14	44th International Arctic Workshop	Boulder, CO	(CSDMS Staff)
Mar-14	UNAVCO Science Workshop	Broomfield, CO	(Syvitski)
Apr-14	AAPG International Meeting	Houston, TX	(Overeem)
May-14	CSDMS Annual Meeting	Boulder, CO	(CSDMS Staff)
May-14	CSDMS Software Bootcamp	Boulder, CO	(CSDMS Staff)
May-14	Chesapeake Modeling Symposium	Annapolis, MD	(Syvitski)

Jun-14	7th Intl Congress on Environmental Modelling	San Diego, CA	(Syvitski)
Jun-14	Arctic COLORS Workshop	Greenbelt, MD	(Syvitski)
Jun-14	FESD Annual Meeting	Minneapolis, MN	(Syvitski & Xing)
Jul-14	Global Energy and Water Cycle	The Hague, Netherlands	(Syvitski)
Aug-14	BOEM Gulf of Mexico Sediment Models	Reston, VA	(Syvitski)
Aug-14	DOE Iowa National Lab, visit (Mark Byden)	Boulder, CO	(CSDMS staff)
Aug-14	GeoRAMA Film Producer Nicolas Koutsikas	Boulder, CO	(Syvitski)
Aug-14	NCED SIESD, University of Minn.	Minneapolis, MN	(Overeem)
Sep-14	NSF HQ, CSDMS presentation & meetings	Washington D.C.	(Syv. & Hutton)
Sep-14	CSDMS Nati'l Ocean Partnership Program HQ	Washington D.C.	(Syvitski)
Sep-14	CSDMS Interagency Meeting	Washington D.C.	(Syvitski)
Sep-14	NSF & Boise U, Roadmap for CMG++	Boise, ID	(Syvitski)
Sep-14	DeltaRes, Delft University, The Netherlands	Delft, NL	(Overeem)
Sep-14	Deltas in Times of Climate Change	Rotterdam, NL	(Overeem)
Oct-14	Latitudinal Controls On Strat Models & Concepts	Banff, Canada	(Syvitski)
Oct-14	Southeastern U Research Association, SURA HQ	Washington D.C.	(Syvitski)
Oct-14	ICS Anthropocene Working Group	Berlin, Germany	(Syvitski)
Oct-14	IGBP & the Royal Swedish Academy	Stockholm, SW	(Syvitski)
Oct-14	CSDMS S2S Modeling Course	Nanjing, China	(Kettner/Overeem)
Nov-14	EuroCSDMS Meeting	Vienna, Austria	(Syvitski)
Nov-14	Floodplain Dynamics, UIUC	Champagne, IL	(Syvitski)
Nov-14	WSSSPE2	New Orleans, LA	(Hutton)
Nov-14	Supercomputing 2014	New Orleans, LA	(Hutton)
Nov-14	ROMS Course design, VIMS	Gloucester Pnt, VA	(Overeem)
Dec-14	American Geophysical Union	San Francisco, CA	(CSDMS staff)
Jan-15	Marine Environmental Sciences	Xiamen, China	(Syvitski)
Jan-15	Terrestrial Hydrology in CESM, Lawrence NCAR	Boulder, CO	(Overeem)
Mar-15	The Anthropocene, U Nebraska	Lincoln, NB	(Syvitski)
Mar-15	Building Capacity in the Social Sciences (NSF)	Washington D.C.	(Syvitski)
Mar-15	GEOSS Stakeholders & Technology	Norfolk, VA	(Syvitski)
Apr-15	IDRC/DFID Deltas and Basins	London, UK	(Syvitski)
Apr-15	Earth System Science (IGBP & IIASA)	Vienna, Austria	(Syvitski)
Apr-15	UCAR Software Engineering Assembly	Boulder, CO	(Hutton, Piper)
May-15	GeoRAMA Floods	Boulder, CO	(Syvitski)
May-15	NCAR- The Anthropocene	Boulder, CO	(Syvitski)
May-15	2015 CSDMS Annual Meeting	Boulder, CO	(CSDMS staff)
Jun-15	36th IAHR World Congress "Deltas"	Den Hague, Neth	(Syvitski)
Jun-15	Future Deltas, U Utrecht	Utrecht, Neth	(Syvitski)
Jun-15	DELTARES, Delft3D & EuroCSDMS	Delft, Netherlands	(Syvitski)
Jul-15	UNAVCO HQ, Subsidence	Boulder, CO	(Syvitski)
Jul-15	NREL: Food, Water, Energy	Denver, CO	(Syvitski)
Jul-15	INQUA Congress: Deltas & the Anthropocene	Nagoya, Japan	(Syvitski)
Aug-15	River Coastal & Estuarine Morphodynamics (RCEM)	Iquitos, Peru	(Syvitski)

Aug-15	Boulder Creek CZO Annual Sci Day	Bolder, CO	(Tucker)
Aug-15	Rivers and Vegetation Dynamics Teacher WS	Boulder, CO	(Overeem,Tucker, Perign
Aug-15	NCED Summer Institute 2015	New Orleans, LA	(Overeem)
Sep-15	3rd Workshop Sustainable Software for Science	Boulder, CO	(Tucker)
Sep-15	EarthLab Meeting CU Boulder, Grand Challenges	Boulder, CO	(Overeem)
Sep-15	Colorado Geomorphology Org Meeting	Denver, CO	(Overeem,Kettner)
Oct-15	John R Mather Visiting Scholar Lecture	Newark, DE	(Syvitski)
Oct-15	Slingfest: Sediment from Mountain to Sea	State College, PA	(Tucker)
Oct-15	Science discovery, Boulder Public Library	Boulder, CO	(Overeem,Higgins)
Nov-15	Coastal & Estuarine Research Fed Meeting	Portland, OR	(Syvitski)
Nov-15	Arctic Observing Open Science Meeting	Seattle, WA	(Overeem)
Dec-15	GRIOS-Greenland Ice-Ocean Observing WS	San Fransisco,CA	(Overeem)
Dec-15	Belmont Forum DELTAS Meeting	San Fransisco,CA	(Overeem,Higgins)
Dec-15	AGU Fall Meeting	San Fransisco, CA	(CSDMSStaff)
Jan-16	CSDMS Interagency WG Meeting	Washington, D.C.	(Syvitski,Tucker)
Jan-16	ONE-Delta Conference	Nashville, TN	(Overeem,Perignon)
Feb-16	SI2 Principle Investigator's Meeting	Arlington, VA	(Tucker)
Feb-16	AGU 2016 Ocean Sciences Meeting	New Orleans, LA	(Syvitski)
Feb-16	Louisiana State University Lecture & Meetings	Baton Rouge, LA	(Syvitski,Piper)
Mar-16	International Soil Modeling Consortium Meeting	Austin, TX	(Overeem)
Mar-16	Ambiguous Geographies Symposium	Indianapolis, IN	(Rogers)
Apr-16	Entanglements Lecture Series:	Indianapolis, IN	(Syvitski,Rogers)
Apr-16	Ostrom Workshop Lecture	Bloomington, IN	(Syvitski,Rogers)
Apr-16	Anthropocene Working Group Meeting	Oslo, Norway	(Syvitski)
Apr-16	Forward Modeling of Sedimentary Systems	Trondheim, Nway	(Syvitski)
Apr-16	Statoil Meeting	Trondheim, Nway	(Syvitski)
May-16	International Society for Ecological Modeling	Baltimore, MD	(Syvitski, Tucker)
May-16	Japan Geoscience Union Meeting 2016	Tokyo, Japan	(Overeem)
May-16	CSDMS 2016 Annual Meeting	Boulder, CO	(CSDMS Staff)
May-16	Linking Earth System & Social System Modeling	Boulder, CO	(Syvitski, Kettner, Rogers)
May-17	2nd Intl Workshop on Coastal Subsidence	Venice, Italy	(Syvitski, Higgins)
Jun-16	AAPG/SEPM 2016 Annual Conference	Calgary, Alberta	(Syvitski)
Jun-16	24th Biennial American Quanternist As. Meeting	Santa Fe, NM	(Syvitski)
Jun-16	FESD Annual Meeting	Baton Rouge, LA	(Perignon)
Jul-16	Newcastle University Jeffery Lecture	Newcastle, ENG	(Syvitski)
16-Jul	International Society for Systems Science	Boulder, CO	(Syvitski)
16-Aug	LSU Center for Coastal Resilience Symposium	Baton Rouge, LA	(Syvitski, Piper)
16-Aug	NCED Summer Institute	Minneapolis, MN	(Overeem, Perignon)
16-Sep	Prevegitation River Systems	Online Conference	(Syvitski)
16-Sep	Geological Society America Annual Meeting	Denver, CO	(Jenkins, Kettner, Brakenridge, Tucker)
16-Sep	LDEO Greenland Icesheet Mass Balance WS	Palisades, NY	(Overeem)
16-Sep	Belmont Forum Synthesis Meeting	New York, NY	(Overeem)

16-Sep	Binghampton Symposium, Colo State U	Fort Collins, CO	(Tucker)
16-Sep	Future Earth Cluster Workshop	Kyoto, Japan	(Syvitski)
16-Sep	ASU Aspect WS	Tempe, AZ	(Tucker)
16-Oct	CZO/LTER Meeting	Boulder, CO	(Tucker)
16-Nov	5th FAMOS Annual Meeting	Woods Hole, MA	(Overeem)
16-Nov	ESPA Deltas and the SDGs	London, UK	(Syvitski)
16-Nov	Budapest Water Summit Sci-Tech Forum	Budapest, Hungary	(Syvitski)
16-Nov	SGF Sorce to Sink Conference, U Rennes	Rennes, France	(Hutton)
16-Dec	5th GEOSS Sci and Tech Stakeholder WS	Berkeley, CA	(Syvitski)
16-Dec	AGU Fall Meeting	San Francisco, CA	(IF Staff)
17-Jan	Denver American History Association 2017	Denver, CO	(Syvitski)
17-Feb	Pages – GloSS Conference	Louvain, Belgium	(Kettner)
17-Feb	NSF SI2 PI Meeting	Arlington, VA	(Tucker)
17-Feb	USC School of Earth, Ocean & Environment	Columbia, SC	(Syvitski)
17-Mar	Tulane University, Schl Science & Engineering	New Orleans, LA	(Overeem)
17-Mar	UC Riverside, Envirn Sci Graduate Program	Riverside, CA	(Syvitski)
17-Mar	Linking Earth Sys & Socio Economic Models	Potsdam, Germany	(Syvitski)
17-Mar	Landlab Annual Meeting	Boulder, CO	(Tucker, Hutton)
17-Mar	U Victoria, Pacific Inst for Climate Solutions	Victoria, Canada	(Syvitski)
17-Mar	Rutgers University, Dept Earth & Planetry Sci	N Brunswick, NJ	(Overeem)
17-Apr	European Geosciences Union Gen Assembly	Vienna, Austria	(Kettner)
17-Apr	World's Large Rivers Conference	New Delhi, India	(Kettner)
17-Apr	Science Gateways Com. Institute Bootcamp	Indianapolis, IN	(Tucker, Hutton, McCready)
17-May	2017 CSDMS Annual Meeting	Boulder, CO	(IF Staff & Tucker)
17-May	CSDMS ExCom & Steering Com Meetings	Boulder, CO	(Tucker & IF Staff)
17-May	Coastal SEES Annual Project Meeting	Boulder, CO	(Overeem)
17-Jun	CZO All Hands Meeting	Arlington, VA	(Tucker)
17-Jun	CUAHSI Hydrology CyberInfrastructure WS	Cambridge, MA	(Hutton)
17-Jun	US Flood Inund Map Repos, GFP	Tuscaloosa, AL	(Kettner, Brakenridge)
17-Jul	11th Int. Conf. on Fluvial Sedimentology	Calgary, Canada	(Overeem, Kettner)
17-Jul	CUAHSI Conference on HydroInformatics	Tuscaloosa, AL	(Tucker)
17-Jul	Institute for Water Modeling	Dhaka, Bangladesh	(Overeem)
17-Aug	Int. WS Open Geographical Modeling & Simulation	Nanjing, China	(Kettner)
17-Oct	NSIDC Cryosphere & Polar Processes Seminar	Boulder, CO	(Overeem)
17-Oct	Deltares International Software Days	Delft, Netherlands	(Overeem)
17-Oct	Permafrost Carbon Working Group Meeting	New Orleans, LA	(Overeem)
17-Dec	AGU Fall Meeting	New Orleans, LA	(Tucker, Overeem, Kettne
18-Jan	STAC Chesapeake Bay Modeling Visioning WS	Sheperdstown, WV	(Hutton)
18-Jan	Algorithms, Combinatorics & Information	Pitea, Sweden	(Tucker)
18-Mar	Los Alamos National Laboratory	Los Alamos, NM	(Overeem)
18-Mar	Socio-Env Systems Modeling Actionable Sci-SESYNC	Annapolis, MD	(Kettner)

18-Mar	NSF Science Technology Center WS	Baton Rouge, LA	(Tucker)
18-Mar	Applied Tools for Monitoring Water Dis & Floods	Medellin, Colombia	(Kettner)
18-Apr	UCAR Software Engineering Assembly	Boulder, CO	(Hutton, Piper)
18-Apr	Stanford University GeoSci Graduate Program	Palo Alto, CA	(Syvitski)
18-Apr	NCAR Arctic System Change Workshop	Boulder, CO	(Wang)
18-Apr	NSF SI2 Principal Investigator Meeting	Alexandria, VA	(Tucker)
18-May	River Corridors Synthesis Meeting - USGS	Fort Collins, CO	(Wang)
18-May	NSF Panel Review	Alexandria, VA	(Piper)
18-Jun	9th Int. Congress Environmental Modeling & Software	Fort Collins, CO	(Hutton, Tucker)

10.0: CSDMS Revenue & Expenditures (2013-2018)

CSDMS received $5.7M from NSF during the period 2013 to 2018. CSDMS Integration Facility staff received significant additional ($3.3M) from other sources (Fig. 10.1). The largest portion of CSDMS funding is for salaries (CSDMS staff and students), followed by indirect cost recovery by the University of Colorado for administering and supporting the Integration Facility (Fig. 10.2). The University of Colorado returns a significant portion of these indirect costs in the form of salary support for the Director and by underwriting CSDMS HPCC costs.

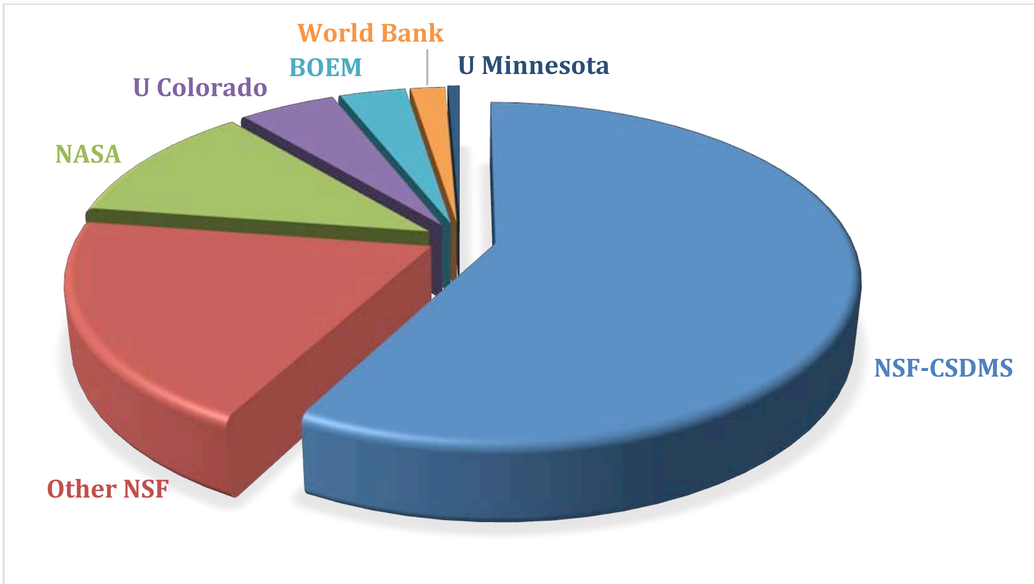


Fig. 10.1 Pie Chart of the 2013-2018 $9M funding received by CSDMS (all sources).

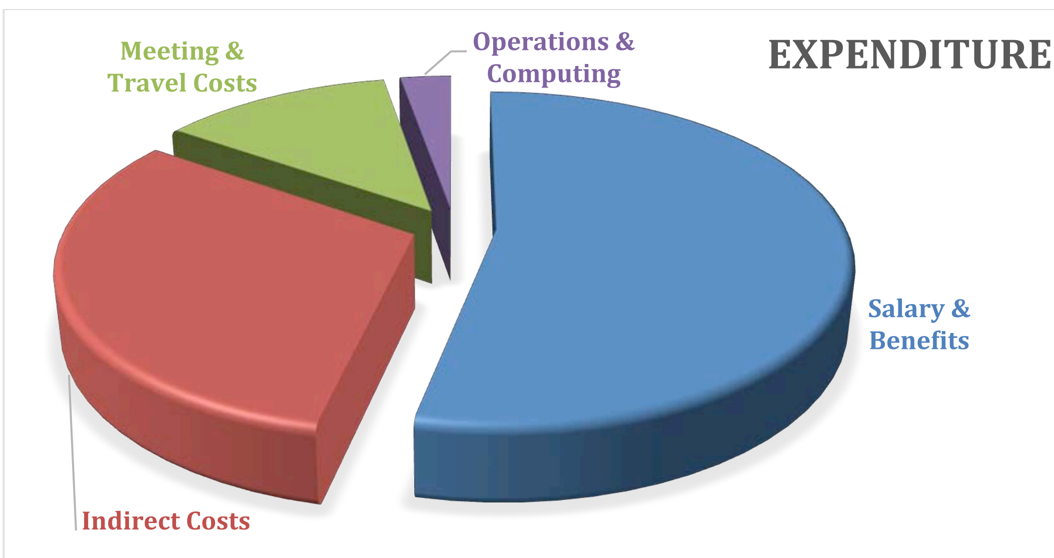


Fig. 10.2 Pie Chart of the CSDMS 2013-2018 expenditures (NSF-CSDMS sources).

Most CSDMS staff have their annual salaries only partially funded through the NSF-CSDMS Continuing Grant. Secondary grants complete the salaries and are listed below by agency subject topics:

NASA: Threatened River Delta Systems
Accelerating Changes in Arctic River Discharge
Permafrost Benchmark System to Evaluate Permafrost Models

BOEM: Shelf-Slope Sediment Exchange, Numerical Models for Extreme Events

NSF: Governance in Community Earth Science
A Delta Dynamics Collaboratory
River plumes as indicators of Greenland Ice Sheet Melt
Software Reuse Venture Fund
Towards a Tiered Permafrost Modeling Cyberinfrastructure
Impacts of Vegetation and Climate Change on Dryland Rivers
Tectonics in the Western Anatolia - sequence stratigraphic modeling
PREEVENTS: A Transdisciplinary Approach to Next-gen Natural Hazards Modeling
CoastalSEES Collaborative Research: Multi-scale Modeling & Observations Ganges-Bramaputra Delta
NCED-NSF PDF Fellowship Program

U. Colorado: Salary support for the CSDMS Integration Facility

NSF-Belmont: Sustainability of deltaic systems with an integrated modeling framework

World Bank: Improving access, query and visualization of flood info for African regions

U. Minnesota: Predicting highly regulated deltas: the Colorado

Chapter 11 CSDMS IF Publications

Published July 2012 to July 2018:

Adams, J. M., Gasparini, N. M., Hobley, D. E., **Tucker, G. E., Hutton, E. W**., Nudurupati, S. S., and Istanbulluoglu, E. (2017) The Landlab OverlandFlow component: a Python library for computing shallow- water flow across watersheds. *Geoscientific Model Development*, v. 10, p. 1645–1663, doi:10.5194/gmd-10- 1645-2017.

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Appendix A

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

1. Context
Aim: To bring together researchers from diverse disciplinary backgrounds to advance global-scale coupled social and biogeophysical modeling. The workshop was used to develop a research plan and timetable for integrating human systems models with Earth system models, and to initiate a dialogue between researchers with the cross-and trans-disciplinary skills for implementing a joint modeling effort that will improve understanding of the bi-directional connections between human activities and global environmental change.

Purpose: To assess the intellectual, informatics, and material resources needed to develop global models of human system dynamics that can be coupled to Earth system dynamics models for the purpose of understanding interactions and feedbacks within coupled human-natural systems. Coupled social system and Earth system models will help us better understand, anticipate, and prepare for the consequences of change arising from both social and natural drivers, including climate, land cover shifts, and policy modifications.

Outcomes: A three-year research plan and timetable for identifying the most tractable components for modeling of the coupled Human-Earth system that can be scaled from the local to the global. The workshop supported further development of a US national center for advanced social informatics and analytics, and established a distributed interdisciplinary scientific network with the expertise needed to build integrated Human-Earth System Models (HESMs) for carrying this initiative forward. These efforts are outlined in this white paper.

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.

2. Background
Global population is expected 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 within the same timeframe (1). The demand for water, food, and energy needed to sustain this population growth is also expected to increase. For example, demand for food crops is predicted to rise 60-110% by 2050 (2,3), fueling a projected 50% increase in water consumption (4). Simultaneously, production of bioenergy will require dedicated crops or crop area, creating additional pressure on water resources and land availability for food growth. Extreme weather events related to climate change will also impact the availability and quality of water resources (5), agricultural production and irrigation needs (6), and ecosystem health, resulting in total economic losses of 5-20% of GDP by 2100 (7). These losses could be reduced significantly if global mean temperature rise is constrained to 2°C above pre-industrial levels (8). However, unpredictable social calamities such as the collapse of states or major pandemics may occur in conjunction with erratic climate change, thus offsetting any gains made from stabilization of global temperature. In anticipation of these 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); while 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 modeling tools in support of achieving these goals?

The Earth system, comprised of linked processes between the atmosphere, geosphere, and biosphere, is increasingly dominated by human action. At the same time, Earth system processes continue to significantly impact human life and well being (10). This creates an urgent need for tighter coupling between social simulation models representing human behavior and Earth system models (ESMs) that focus on biogeophysical processes (11). Advances in ESM science is giving us invaluable insights into Earth system dynamics and helping us better plan for future conditions. However, existing models typically consider humans as exogenous to the Earth system. This precludes few, if any, feedbacks based on human decisions and activities that might amplify or dampen environmental changes from being effectively represented in computational models. For example, 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 global-scale models of human activity focus on economic markets, resource extraction, agriculture, energy production/consumption, etc., and portray biophysical phenomena as externalities or boundary conditions.

Just as we recognize that Earth system processes such as climate change or ocean circulation have effects on human societies, and social response to these dynamics impact 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) that couple 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). Accomplishing this goal requires that social, natural, and computational scientists work together, learn one another's disciplinary languages, and integrate methods from these different disciplines.

Fortunately, 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 is considered. There is not yet explicit consideration of the feedbacks of human actions back to the climate system, or how those feedbacks would, in turn, affect weather hazards. The NSF-wide Food Energy Water Nexus initiative is a 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 of 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. An international network of researchers with cross- and trans-disciplinary skills are needed to implement this ambitious project. The workshop facilitated the process of establishing such a scientific community and developing a next-generation modeling effort to better represent the complex interactions of human activities and environmental change. Participants in this workshop included leading representatives from computational social science communities and Earth system modeling communities in the US and internationally. This involved collaboration among national laboratories, research centers, and university programs that have a common interest in the human dimensions of the Earth system (see list of participants in Appendix 2).

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 Pacific Northwest, Oakridge, and Lawrence Berkeley National Laboratories. However, the primary missions and scientific expertise of these centers focus on the biophysical components of the Earth system, and social scientists comprise a relatively small number of employees. 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 new 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.

3. Content

Approach: Workshop participants identified a set of seven interdisciplinary scientific research issues and key questions through facilitation. Breakout groups for each of these issues were asked to address four questions to guide discussion and planning: 1) what is the scope of the scientific questions most relevant to the issue? 2) What are the methods needed to address those questions? 3) What opportunities are currently available to take the set of issues forward; what new work is needed; what funding mechanisms could support this work? The outcomes of the breakout group discussions are presented below and summarized in the subsequent section.

A. Motivation and Purpose of Linking Models. The primary purpose of developing a linked modeling community includes answering and generating questions (i.e., new realizations and discovery) and testing hypotheses in order to create HESMs that are more accurate and useful. This would serve to broaden, rather than steer, the conversation and requires 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 to advance research and modeling of human science; human processes are complex, and must be treated as such.

Another motivation for linking social systems and earth systems models is to inform and prioritize the information needed for effective decision-making. The water crisis in Flint, Michigan provides a current and realistic example of this: a HESM could have been used to identify the risks associated with switching the water supply from Lake Huron to the Flint River through testing various policy scenarios and engineering solutions. With better models, both problems and solutions become more visible as a guide to decision-making.

We recognize that efforts to integrate human systems and biophysical models will require people from diverse disciplines to confront one another's ideas, processes, capabilities, and epistemologies. There are benefits to developing a single HESM modeling community, mainly because people contribute to it collectively and the community is self-sustaining and supportive. However, 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 systems models. Therefore, we need to ask ourselves whether the purpose of developing new, coupled human-natural systems models is to converge the science or diverge the science.

B. Land and Water Issues. Modeling the human dimensions of 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 have significantly impacted terrestrial and aquatic systems, realistically modeling many of these systems requires consideration of the human component.

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 (e.g., 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 (e.g., weather, soil, moisture, etc.), and physical models of landscape evolution (e.g., soil conditions, hydrology) and climate that can affect crop productivity. Some models in each general class can 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.

Important methodological issues that need to be overcome pertain to 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 up-scaling, 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, mismatches in spatial and temporal scale are equally important here. Also, water users encompass a wide range of social and economic heterogeneity, 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, sustainable management of this critical resource will require 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 produce 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 human-natural 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 ground work 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.

C. Challenges and Opportunities for Coupling Human and Earth System Models. 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, and potentials 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' 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 need to be scientific, professional, and policy incentives for all 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 have written a joint paper outlining challenges and potential returns of integrated modeling of human and Earth systems (Robinson, D.T., Vittorio, A.D., Alexander, P., Arneth, A., Barton, C.M., Brown, D.G., Kettner, A.J., Lemmen, C., O'Neill, B.C., Janssen, M., Pugh, T.A.M., Rabin, S.S., Rounsevell, M., Syvitski, J.P.M., Ullah, I., and Verburg, P.H., 2018. Modelling feedbacks between human and natural processes in the land system. Earth System Dynamics, 9, 895-914. https://doi.org/10.5194/esd-9-895-2018).

D. Extreme Events and Migration. Extreme events (either social or biophysical) can trigger major Land Use Change (LUC) decisions and affect the vulnerability and resilience of societies. Past extreme events triggered by climate change or other natural or social stresses have been demonstrated to have had considerable consequences for human and biophysical systems. An initial goal in modeling extremes could be to explore the effects of biophysical and social extreme events on agricultural responses to climate variability. In doing this, consideration of 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 understanding 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, etc.? 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 (specifically for migration): There is much current work on migration, but creating models of migration comes with many questions. For example, how can the modeling community 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 consequence 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 many 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.

E. Decisions, Behaviors, and Institutional Change. 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 (i.e., 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 it 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 microclimates? 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, i.e., 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 model 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.

F. Multi-scalar Impact Assessment Methods. 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.

G. Model Evaluation. We identified a long-term goal of introducing a new generation of models that reproduce human systems at least as well as we currently are able to reproduce vegetation dynamics and earth surface processes. 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 (e.g., 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 social system models work properly/as expected through validation and verification, and that we accredit models that do so. 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 human systems modeling is in its infancy, the modeling community should encourage best practices in model evaluation, just as is done in the biophysical systems modeling community.

4. Summary

A number of lessons learned emerged from the workshop discussions, including:

1. It is important to understand more about the role of the heterogeneity of decision-making actors and the role of behavioral mechanisms that underpin 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 dynamics, cooperation and communication, competition, and social learning.
3. Keystone actors can sometimes be very important in understanding human-environment systems. Other times they have limited impact. Can we understand the contexts that lead to these differences?
4. How can studies of the past (e.g., land use change) benefit, but also support, modeling of Earth system change in the future?
5. There is a need to endogenize institutions within social system models, especially as one up-scales models from the local to global.
6. Inconsistency in baseline input data, including thematic definitions, is an important limitation to modeling. This underscores the need for quantitative meta-analyses of human systems case studies of phenomena such as power, learning, and decision-making by and among individuals, institutions, and governance structures.
7. There needs to be open discussion among human and earth systems scientists around issues of complexity and its representation versus simplicity in models, and when it is and is not useful to couple models with different modeling approaches.
8. Understanding the sensitivity of biophysical models to human processes such as land management, and vice versa, is critical in supporting the development of the next generation of coupled human-environment models.

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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
Lunch and depart (from 12h30)

Annex 2: Participant list & contact details

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