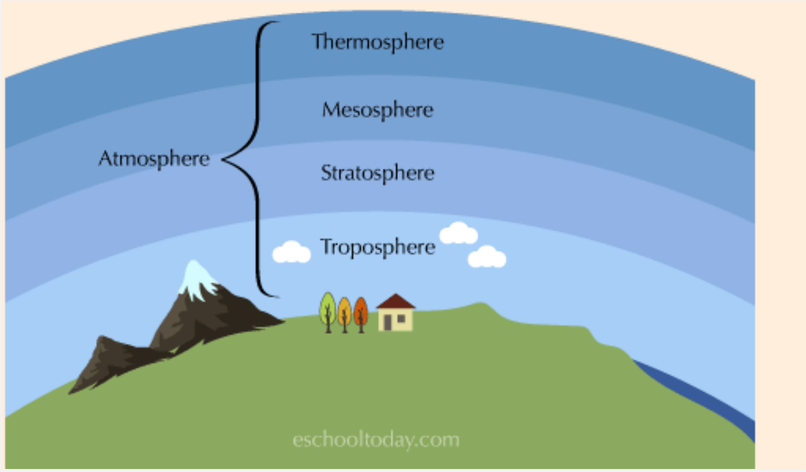
CSDMS Overview and Update

Greg Tucker, CSDMS Executive Director

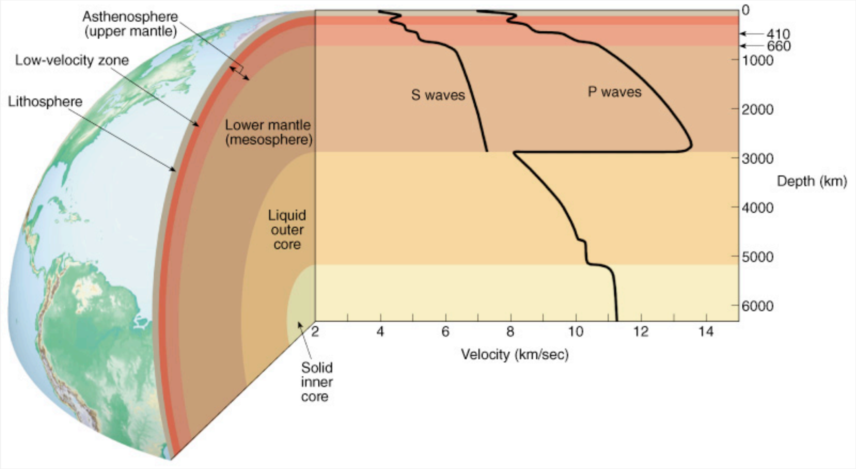
CSDMS Interagency Working Group Meeting,
Alexandria, VA, November 2019

NSF Geoscience Modeling Facilities



CESM
Community Earth System Model
(NCAR)
1983

CSDMS
Community Surface Dynamics
Modeling System
2007

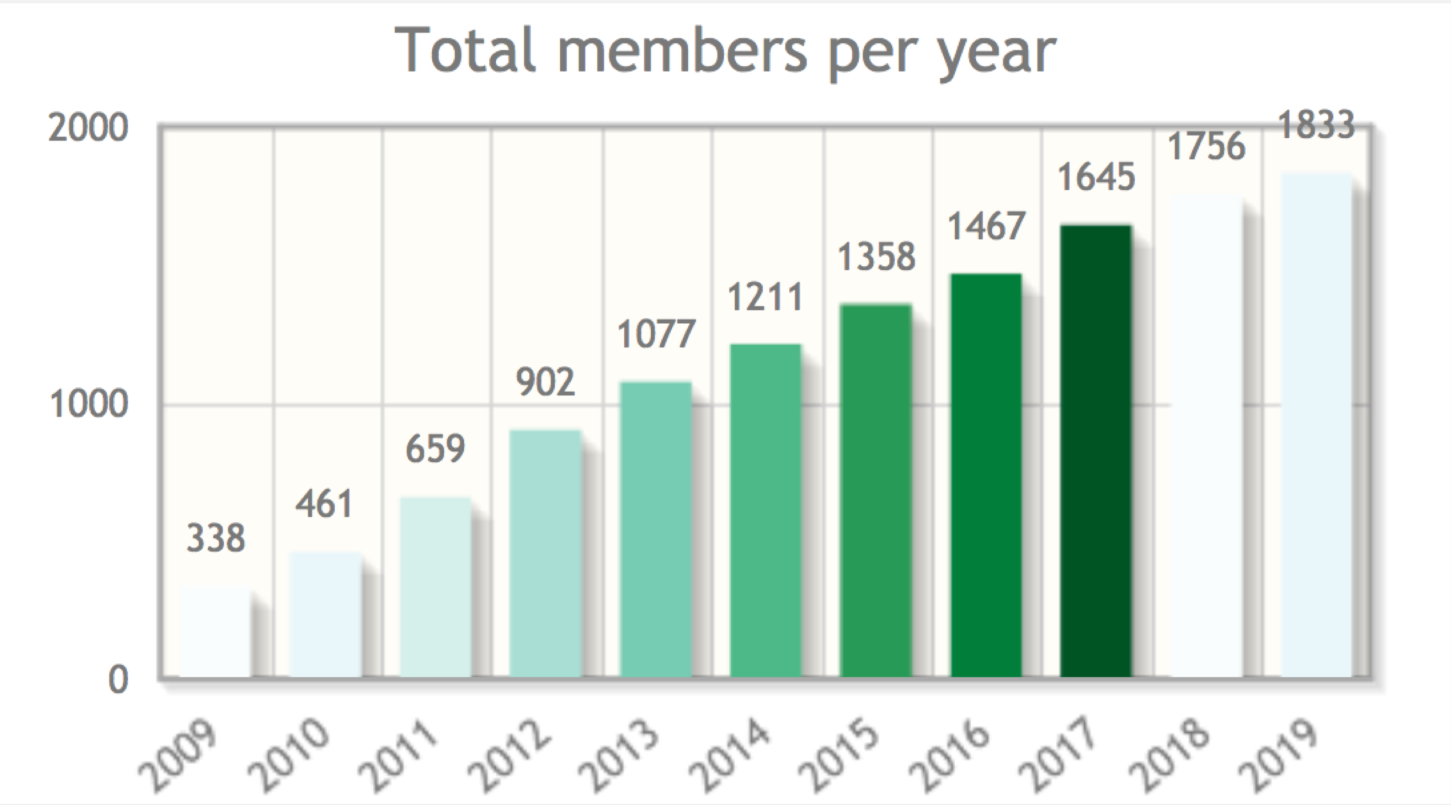


CIG
Computational Infrastructure
for Geodynamics
2005

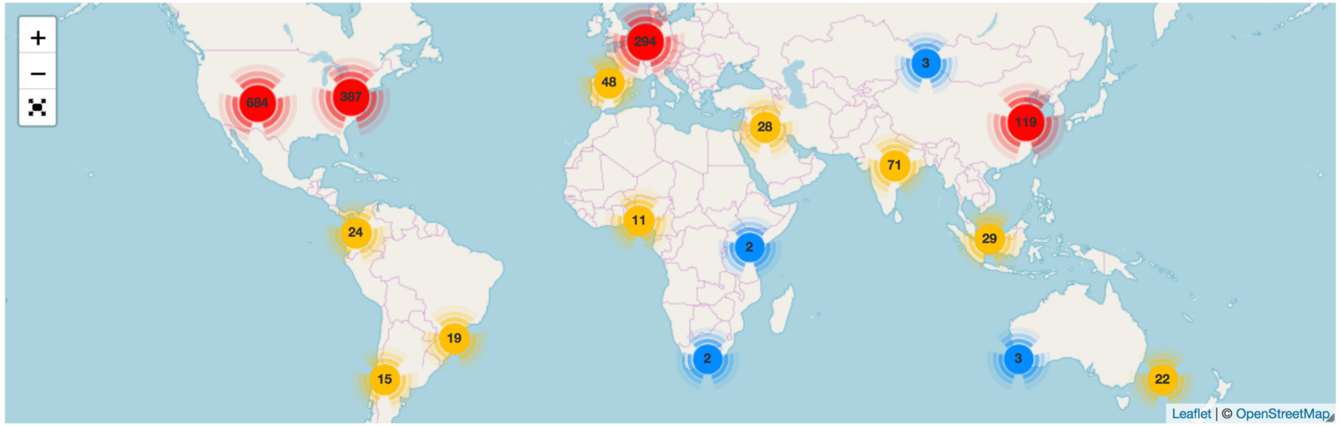
"CSDMS is envisioned as a modeling environment containing a community-built, freely available suite of integrated, ever-improving software modules aimed at predicting the erosion, transport, and accumulation of sediment and solutes in landscapes and sedimentary basins over a broad range of time and space scales."

- Science Plan vision document, 2004

CSDMS Community



Where are CSDMS Members



70 countries

641 institutions (222 US academic, 38 US government/NGO)

Federal Agencies – Total 76

USGS: 26

National Labs – 20 total

- Argonne: 1
- Brookhaven: 1
- Sandia: 4
- Lawrence Berkeley: 2
- JPL: 2
- Oak Ridge: 2
- Idaho National Lab: 1
- Los Alamos: 4
- Pacific Northwest: 3

Army Corps of Engineers: 6

NOAA: 5

NSF: 5

US Bureau of Reclamation: 3

EPA: 2

NASA: 2

BOEM: 1

Naval Research Lab: 1

National Geospatial-Intelligence Agency: 1

National Weather Service: 1

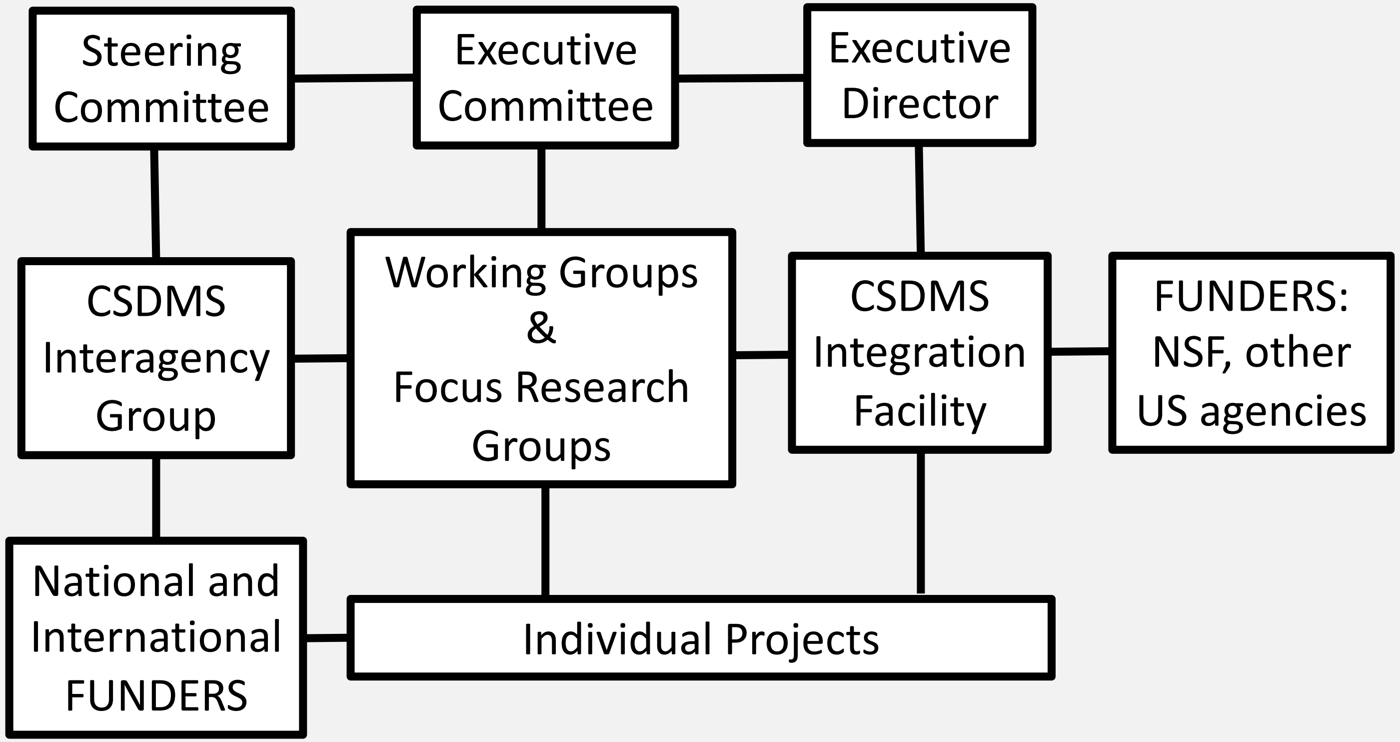
Office of Naval Research: 1

US Naval Academy: 1

US Nuclear Regulatory Commission: 1

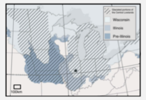
State and Local Agencies – Total 6

CSDMS Organization and Management

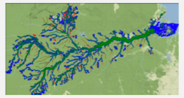


Groups	Members
All members	*1833*
Working groups (WG)	
Terrestrial	896
Coastal	678
Marine	427
Education and Knowledge Transfer (EKT)	298
Cyberinformatics and Numerics	269
Focus Research Groups (FRG)	
Hydrology	698
Geodynamics	249
Human Dimensions	149
Carbonates and Biogenics	132
Ecosystem Dynamics	155
Critical Zone	138
Chesapeake	96
Initiatives	
Coastal Vulnerability	173
Continental Margin	96
Artificial Intelligence & Machine Learning	55

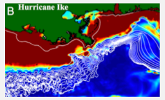
Examples of community research questions*



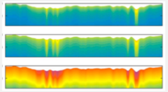
How do drainage networks form after glaciation?



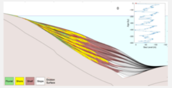
Can we better predict flood inundation?



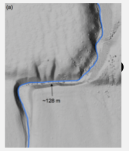
How do hurricanes trigger deep-sea turbidity currents?



How will permafrost melt impact Arctic slopes?

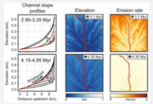


How are climate and sea level cycles reflected in marine stratigraphy?

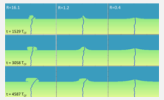


When does stream offset accurately record fault slip?

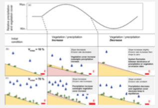
How can we efficiently predict debris-flow timing?



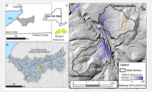
Can sediment provenance reveal environmental signals in stratigraphy?



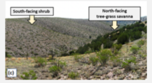
How will sea-level rise impact coastal deltas?



How do cycles in climate and vegetation influence landscape evolution?



Can we forecast erosion at hazardous waste sites?



Can changes in grazing and wildfire regime trigger woody plant encroachment?

** addressed using CSDMS technology*

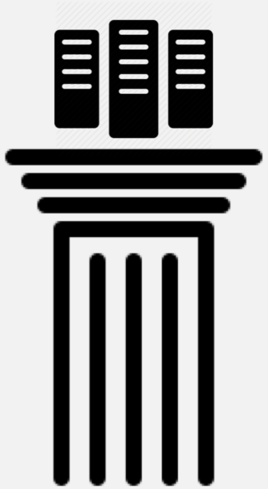
CSDMS
community surface
dynamics modeling system

CSDMS supports computational modeling in earth-surface science by engaging ***community***, providing ***computing*** resources, and promoting ***education***

share resources, collaborate

COMMUNITY
SUPPORT

create, run, test, analyze, and apply models

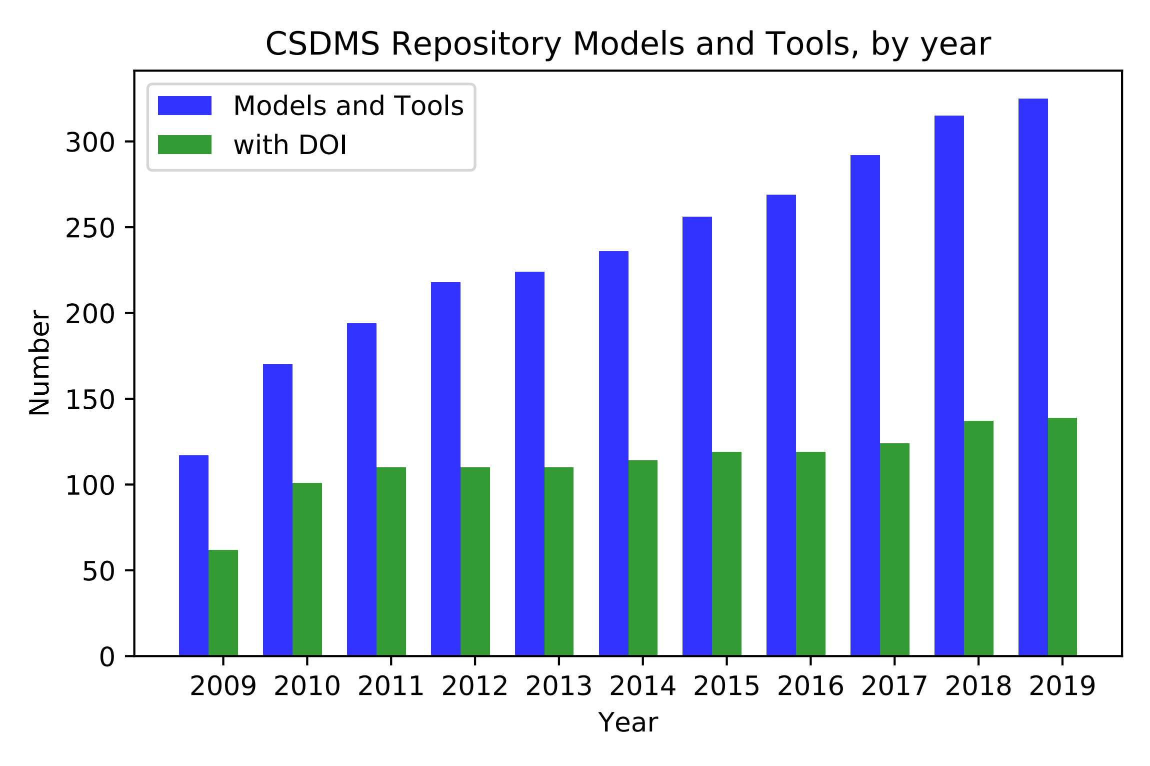


COMPUTING
RESOURCES

learn and teach

EDUCATION
OPPORTUNITIES

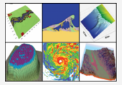
CSDMS Model Repository



- Community **open catalog & archive** for modeling software and tools
- Full **metadata** for each program
- Contributors can obtain Digital Object Identifier (DOI) to make product citable
- CSDMS tracks h-index for programs based on bibliography

235 Models
90 Tools

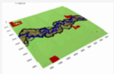
All models



Number of models: *229*, Number of tools: *89*, WMT compliant: *35*, PyMT compliant: *8*

Type: All of the models mentioned below

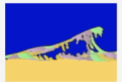
Terrestrial models



Number of models: *105*, Number of tools: *78*, WMT compliant: *10*, PyMT compliant: *5*

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.

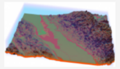
Coastal models



Number of models: *70*, Number of tools: *9*, WMT compliant: *10*, PyMT compliant: *2*

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

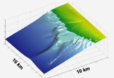
Hydrological models



Number of models: *76*, Number of tools: *51*, WMT compliant: *25*, PyMT compliant: *3*

Type: Hydrologic models, stream avulsion models, flow routing models, groundwater models, fluvial sediment transport models, etc.

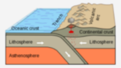
Marine models



Number of models: *53*, Number of tools: *8*, WMT compliant: *4*, PyMT compliant: *1*

Type: Basin circulation models, gravity flow models, wave models, stratigraphy models, etc.

Geodynamic models



Number of models: *16*, Number of tools: *1*, WMT compliant: *1*, PyMT compliant: *1*

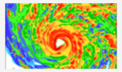
Type: Fault, lithospheric flexure, lithosphere deflection, Mantle Evolution Model, etc.

Ecosystem models

Number of models: *1*, Number of tools: *1*, WMT compliant: *1*, PyMT compliant: *0*

Type: Ecosystem models

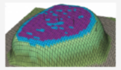
Climate models



Number of models: *14*, Number of tools: *6*, WMT compliant: *4*, PyMT compliant: *1*

Type: Climate models, weather models

Carbonates and Biogenics models



Number of models: *1*, Number of tools: *0*, WMT compliant: *0*, PyMT compliant: *0*

Type: Carbonate cyclicity model

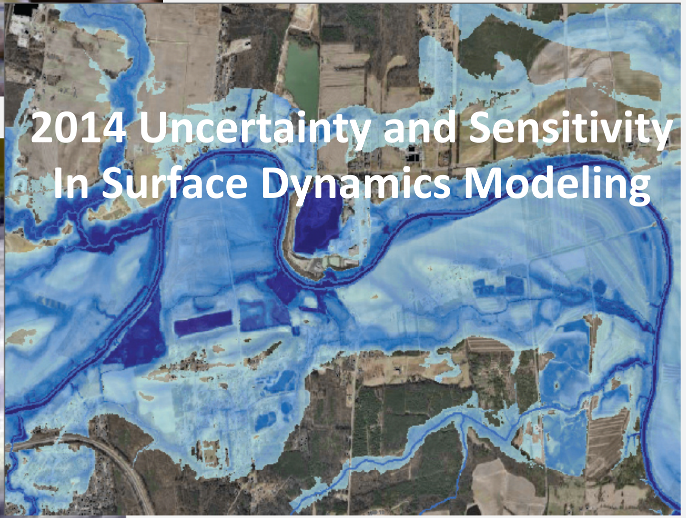
Landlab components and models

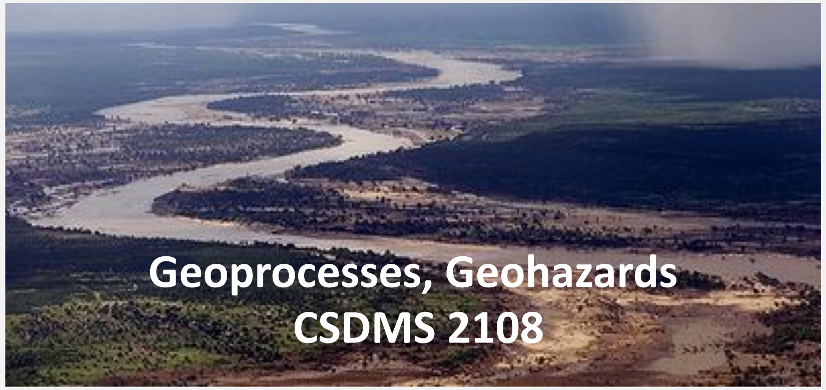
Number of models: *8*, Number of tools: *1*, WMT compliant: *2*, PyMT compliant: *0*

Type: Earth surface processes models

COMMUNITY

Annual Meetings





COMMUNITY

Workshops

2014

- ***Workshop: The Art and Science of Reduced-Complexity Modeling in the Environmental Sciences*** – 45 participants, co-organized with NCED

2016

- ***Linking Earth system Dynamics and Social System Modeling WS*** – 35 participants, Human Dimensions FRG

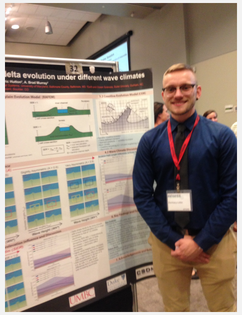
2018

- ***Coupled Tectonic and Earth Surface Processes WS*** **–** 150 participants, Geodynamics FRG
- ***NASA Flood Risk WS*** – 79 participants, NASA

COMMUNITY

Diversity, Equity, and Inclusion

- Student scholarships to attend annual meeting
- Panels on Diversity, Equity, and Inclusion
- Clinic, 2020 Annual Meeting
- Outreach to MSIs
- Individual mentoring (RESESS, RECCS)



Panel discussion
Annual meeting May 2019

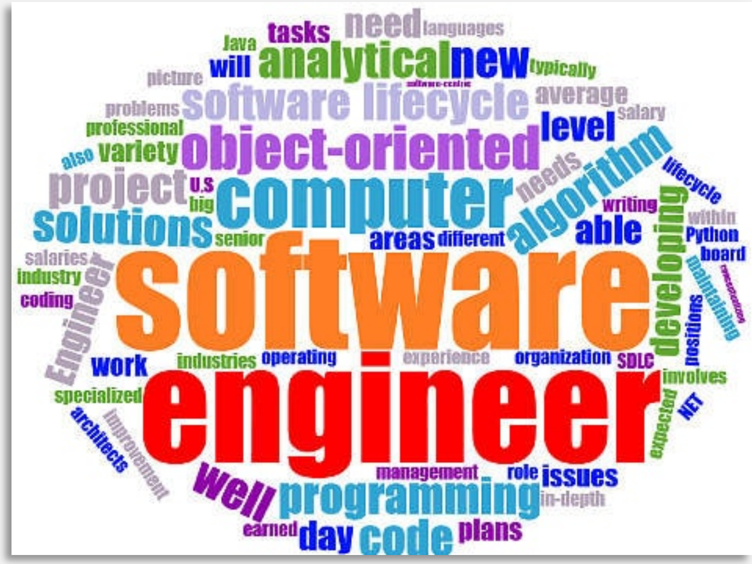
COMMUNITY

Member support functions

PROPOSAL SUPPORT

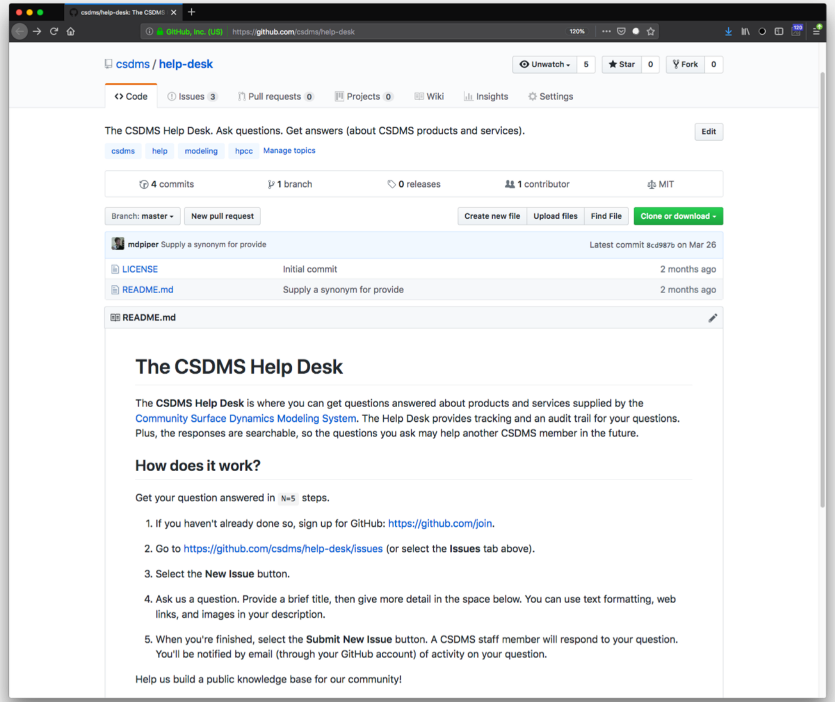
- Letters for funding agencies
- Help with Broader Impacts
- Data management
- 40 LOCs in 2018/2019

PROJECT SUPPORT



- Collaboration
- Site visits
- Research Software Engineer consulting

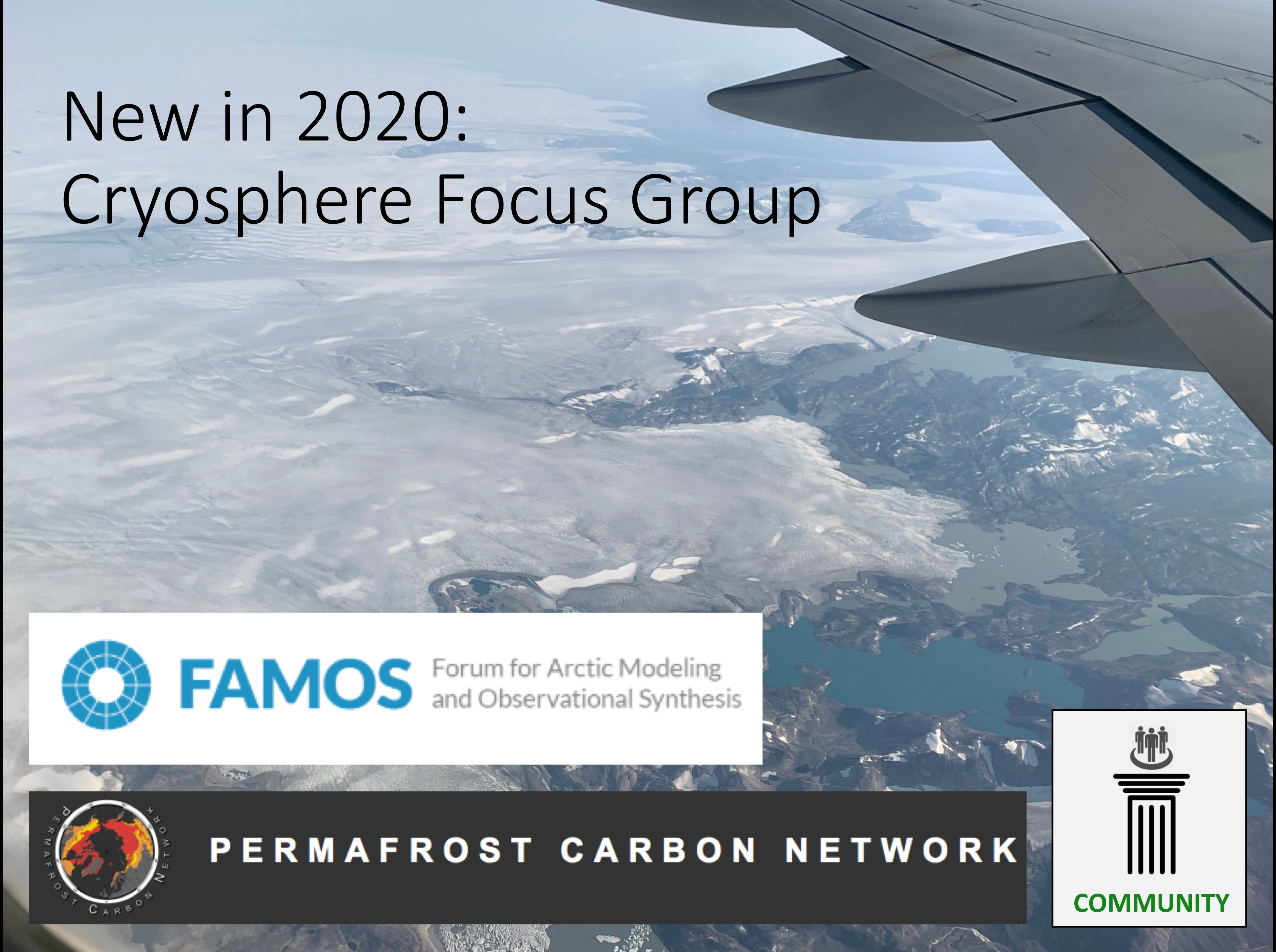
ONLINE SUPPORT



- User Help Desk

COMMUNITY

New in 2020:
Cryosphere Focus Group



Bridge to High-Performance Computing

Blanca:	*RAM/core*
64 x 2.1 GHz cores	192 GiB
Summit:	
9,960 x 3.3GHz cores,	5-42 GB

COMPUTING

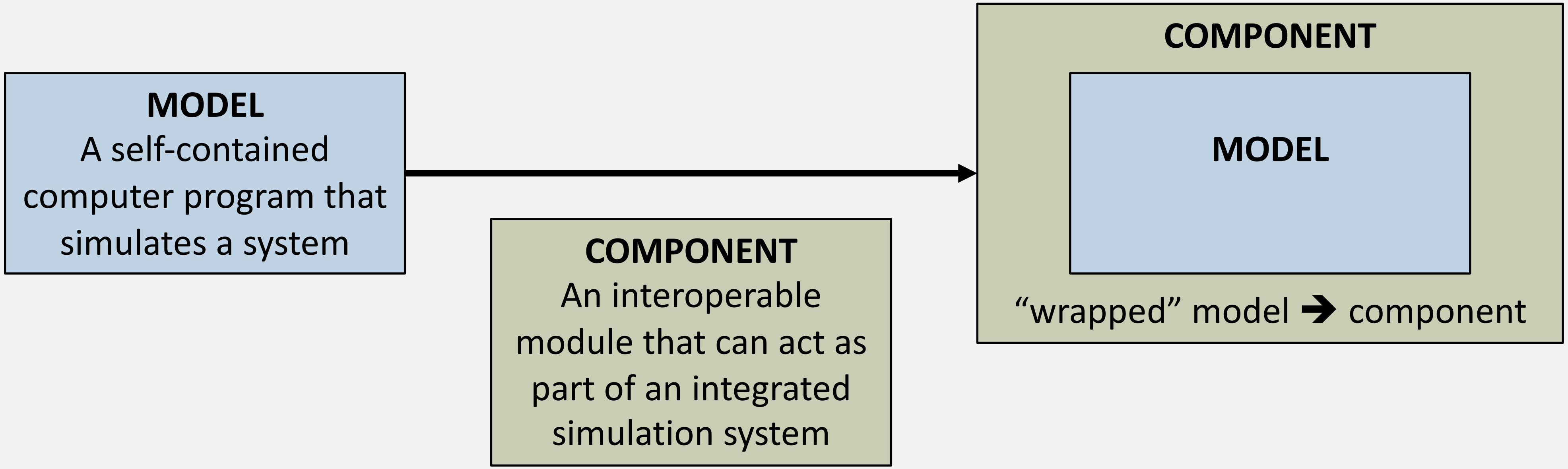
Software Cyberinfrastructure: CSDMS Modeling Framework

> ***"CSDMS is envisioned as a modeling environment containing a community-built, freely available suite of integrated, ever-improving software modules aimed at predicting the erosion, transport, and accumulation of sediment and solutes in landscapes and sedimentary basins over a broad range of time and space scales."***
>
> \- ***Science Plan, 2004***

1. Interface standard (BMI)
2. Language interoperability (Babelizer)
3. Model-building toolkit (Landlab)
4. Execution and coupling framework (PyMT)

COMPUTING

Software Cyberinfrastructure: CSDMS Modeling Framework



COMPUTING

Standards for models: *Basic Model Interface* (BMI)

COMPUTING

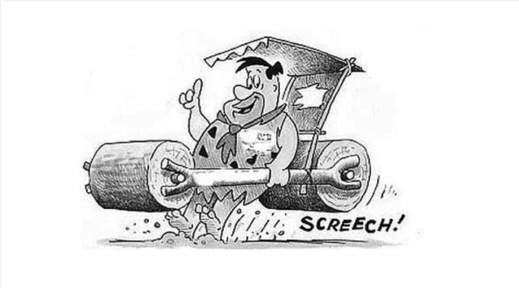
BMI specifies a common set of functions, such as:

`initialize()`

`get_value()`

`update()`

`set_value()`



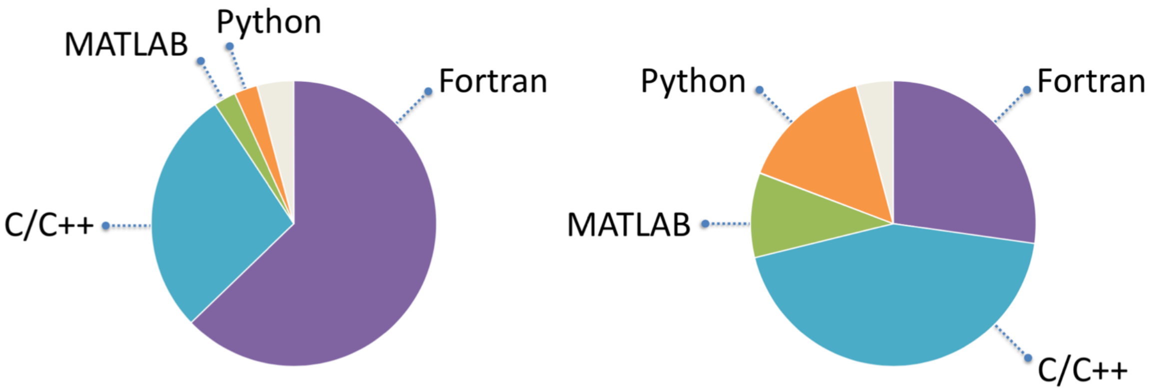
`finalize()`

COMPUTING

Language interoperability

The CSDMS Model Repository

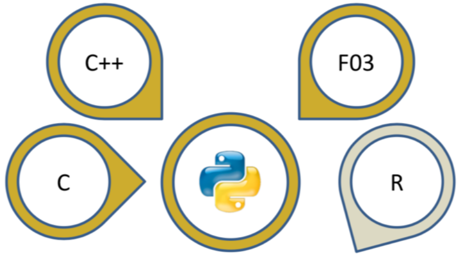
Over 300 community-contributed Earth-system models.



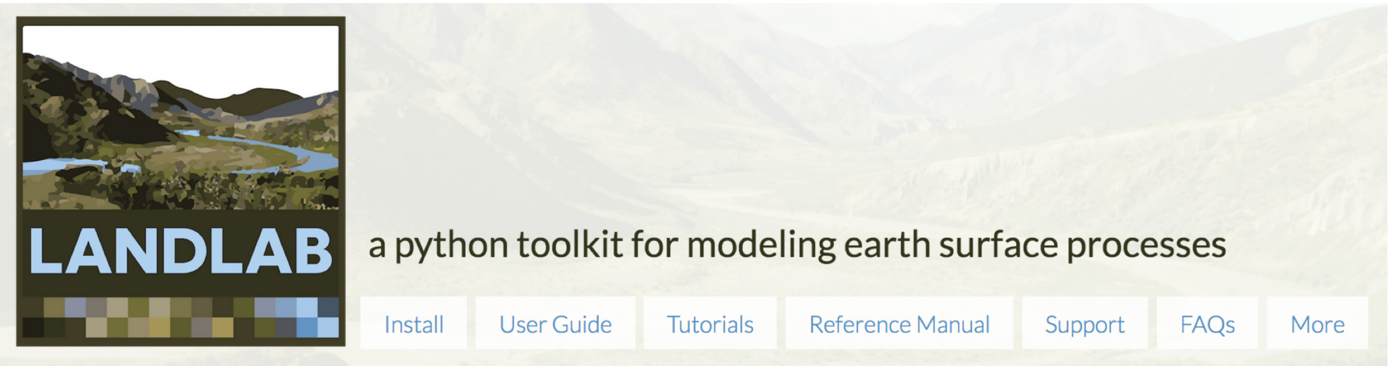
Fraction of Earth-system models as contributed to the CSDMS model repository as measured by lines of code (left) and number of models (right).

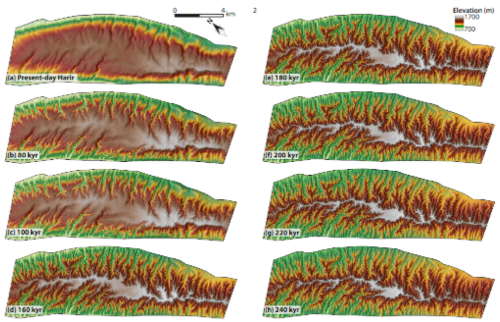
Language Interoperability: *The Babelizer*

Inter-language communication between models.

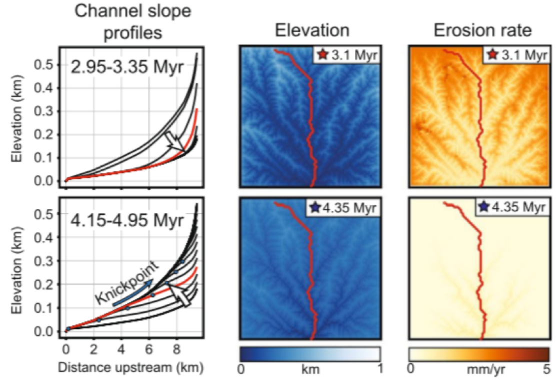


The CSDMS *Babelizer* automatically generates the necessary code to wrap shared libraries that expose a Basic Model Interface so that they can be imported into a Python environment. Currently, the Babelizer supports libraries written in *C*, *C++*, *FORTRAN* (and *Python*, obvs). We will look to add addition languages (like *R*) as needs arise.

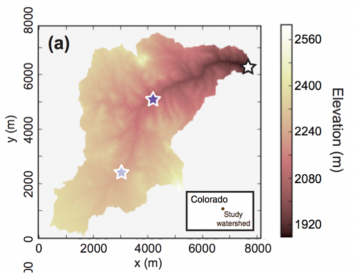


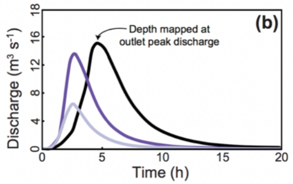


Evolution of anticlines (Zebari et al., 2019)

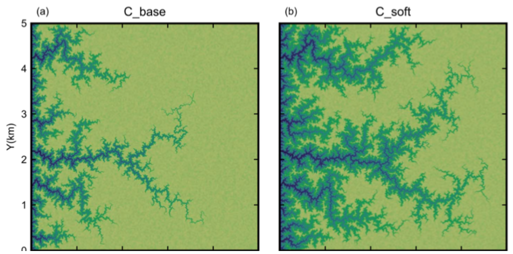


Sediment provenance as a signal of climate and tectonics in sedimentary basins (Sharman et al., 2019)

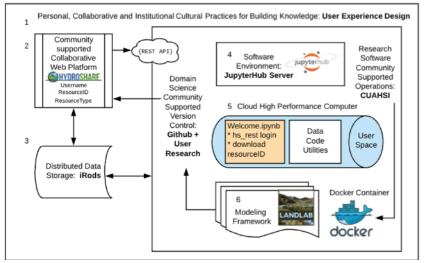




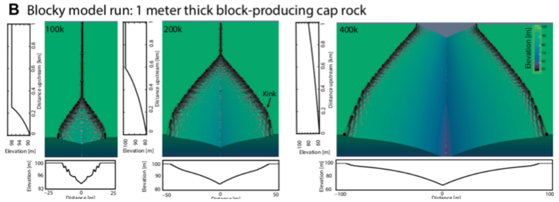
Rainfall-runoff (Adams et al., 2017)



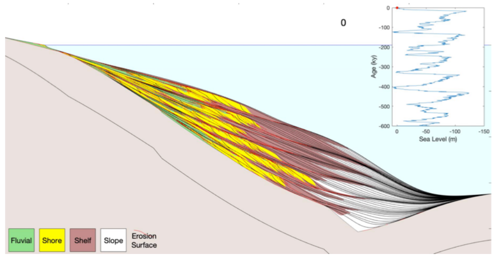
Post-glacial drainage nets (Lai & Anders, 2017)



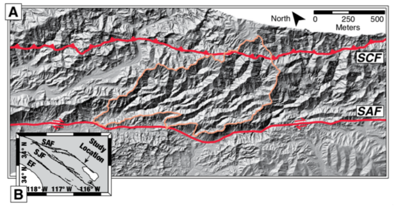
Hydrology education (Bandaragoda et al., 2019)



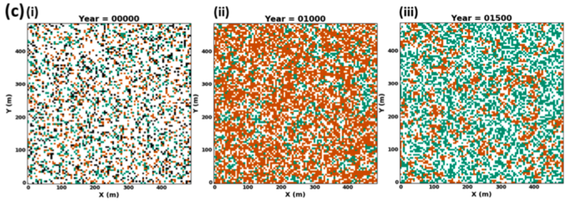
Influence of boulders on hillslope and channel evolution (Glade et al., 2019)



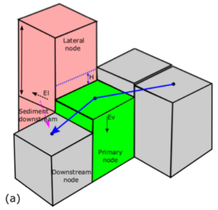
Basin stratigraphy (Steckler et al., in prep)



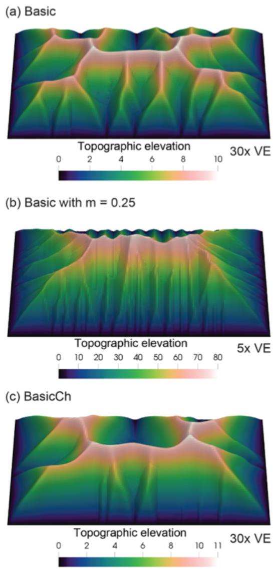
Tectonic shear (Gray et al., 2017)

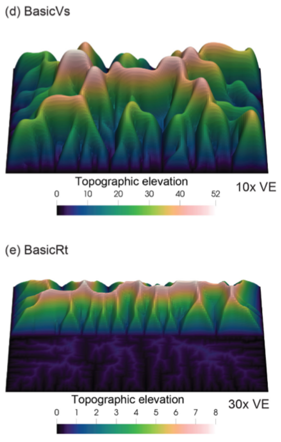


Vegetation dynamics (Nudurupati et al., in prep.)

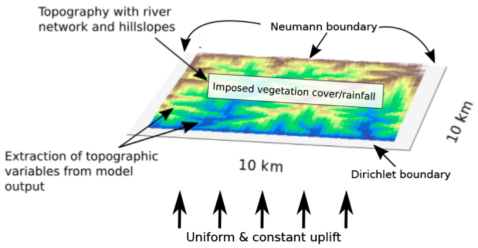


Valley widening (Langston et al., 2018)

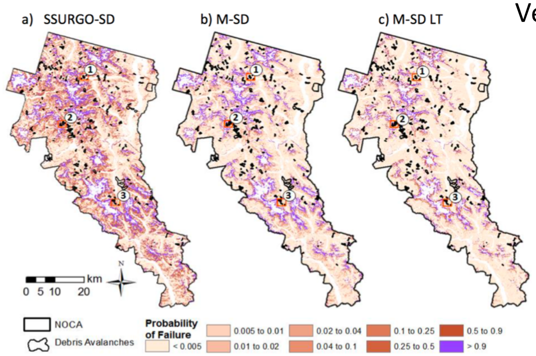




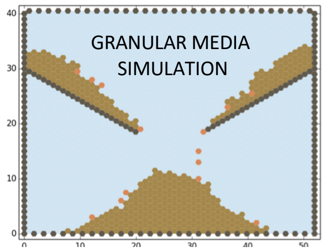
Landform evolution (Barnhart et al., 2019)



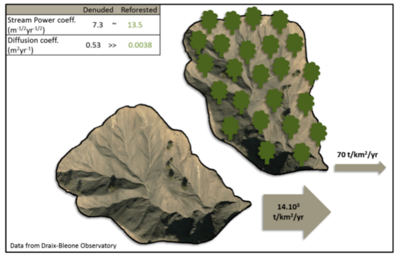
Vegetation & erosion (Schmid et al., 2018)



Landslide probability (Strauch et al., 2018)



Cellular automata (Tucker et al., 2016)



Sediment yield (Carriere et al., 2019)

pymt

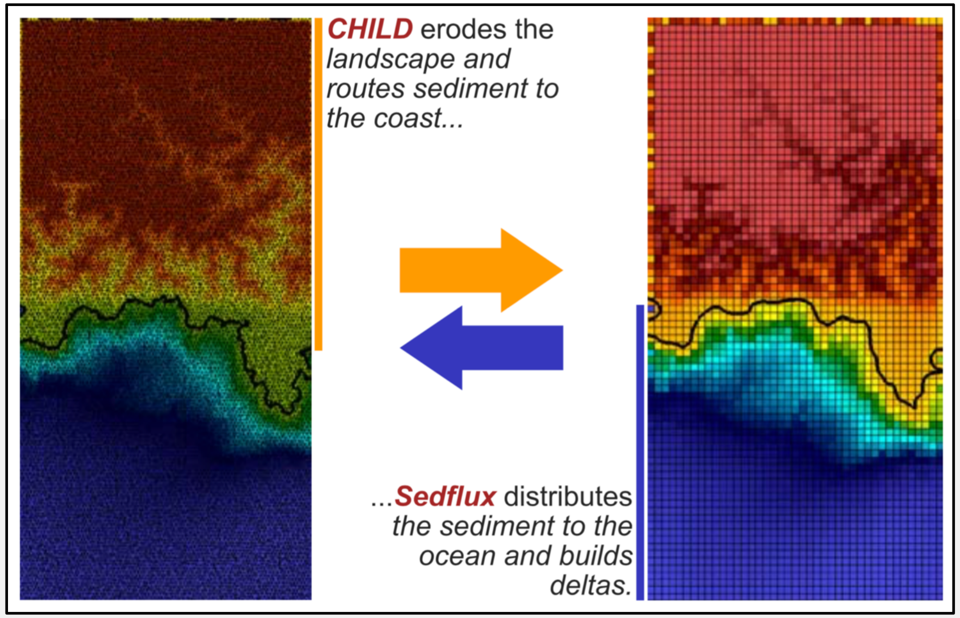
a Python toolkit for coupling and running Earth surface models

Install Quickstart User Guide Examples Reference Manual Source

```
[8]: model.initialize(config_file, dir=initdir)

[9]: model.set_value("channel_exit_water_flow__speed", 1.2)
     model.set_value("channel_exit_x-section__mean_of_width", 400.)
     model.set_value("channel_exit_x-section__mean_of_depth", 4.)
     model.set_value("channel_exit_water_sediment~suspended__mass_conc

[9]: array([ 0.01])
```

Here we update the model for 10 time steps, printing the model time after each step.

```
[10]: for t in range(10):
          model.update()
          print(model.get_current_time())

      365.00000000036493
      730.0000000010949
      1095.00000000219
      1460.00000000365
      1825.000000005475
      2190.000000007665
      2555.00000001022
      2920.00000001314
      3285.0000000164246
      3650.0000000200744
```



current
pymt models:

Avulsion
CEM
Child
ECSimpleSnow
FaSTMECH
FrostNumber
GIPL
Hydrotrend
Ku
Plume
Sedflux3D
Subside
Waves

https://csdms.github.io/pymt/

pymt

a Python toolkit for coupling and running Earth surface models

Install   Quickstart   User Guide   Examples   Reference Manual   Source

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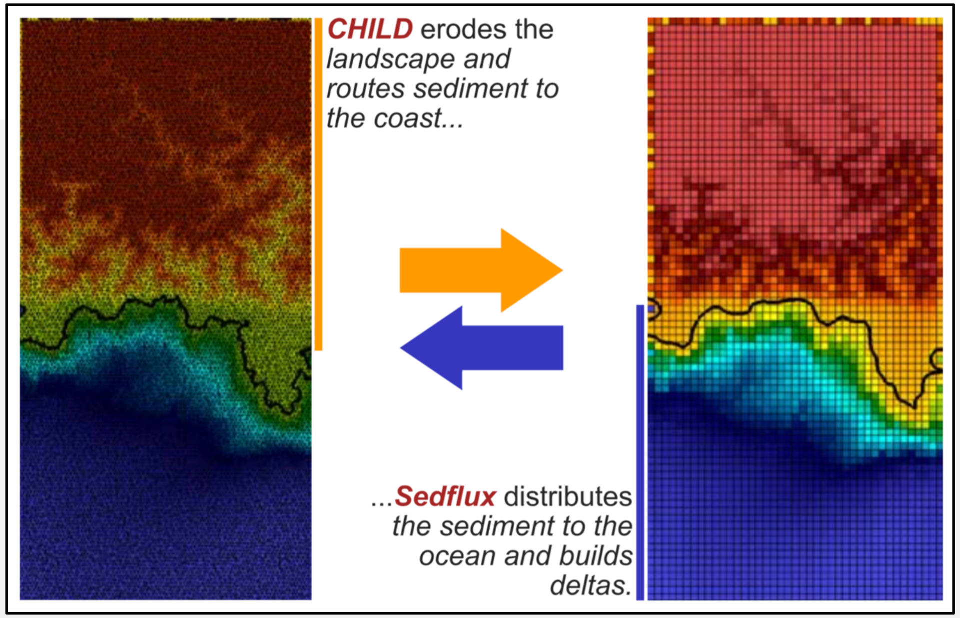


current
pymt components:

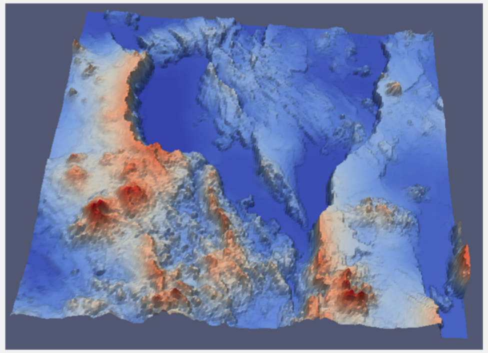
Avulsion
CEM
Child
ECSimpleSnow
FrostNumber
GIPL
Hydrotrend
Ku
Plume
Sedflux3D
Subside
Waves

Landlab process components can act as **pymt** components:

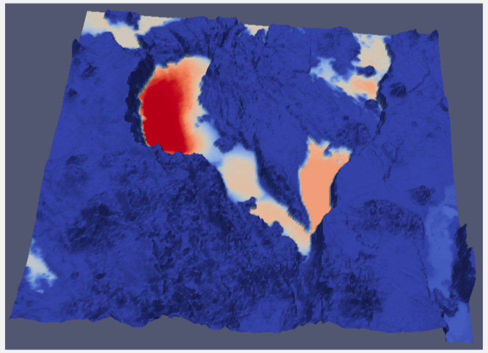
DepthDependentDiffuser
ErosionDeposition
Flexure
FlowDirector
FlowAccumulator
LandslideProbablity
LinearDiffuser
NormalFault
OverlandFlow
PotentialET
PrecipitationDistribution
Radiation
SoilMoisture
StreamPowerEroder
SPACE
TaylorNonLinearDiffuser
TransportLengthDiffuser
VegetationDynamics

Why modular, standardized, shared software?

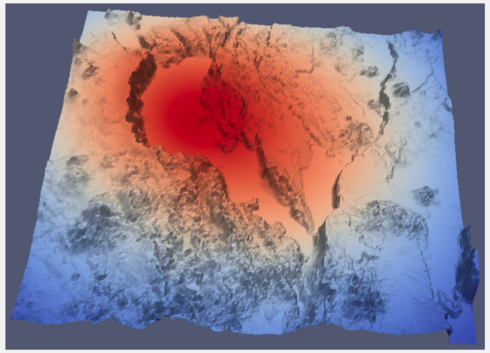
TOPOGRAPHY

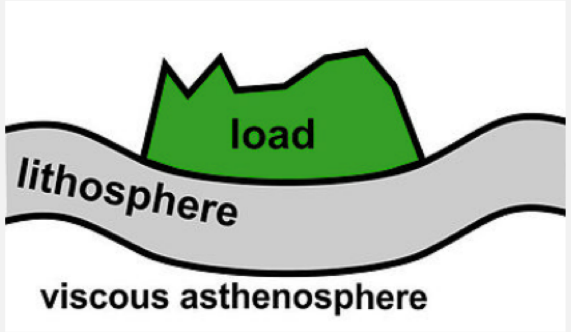


WATER DEPTH



ISOSTATIC REBOUND



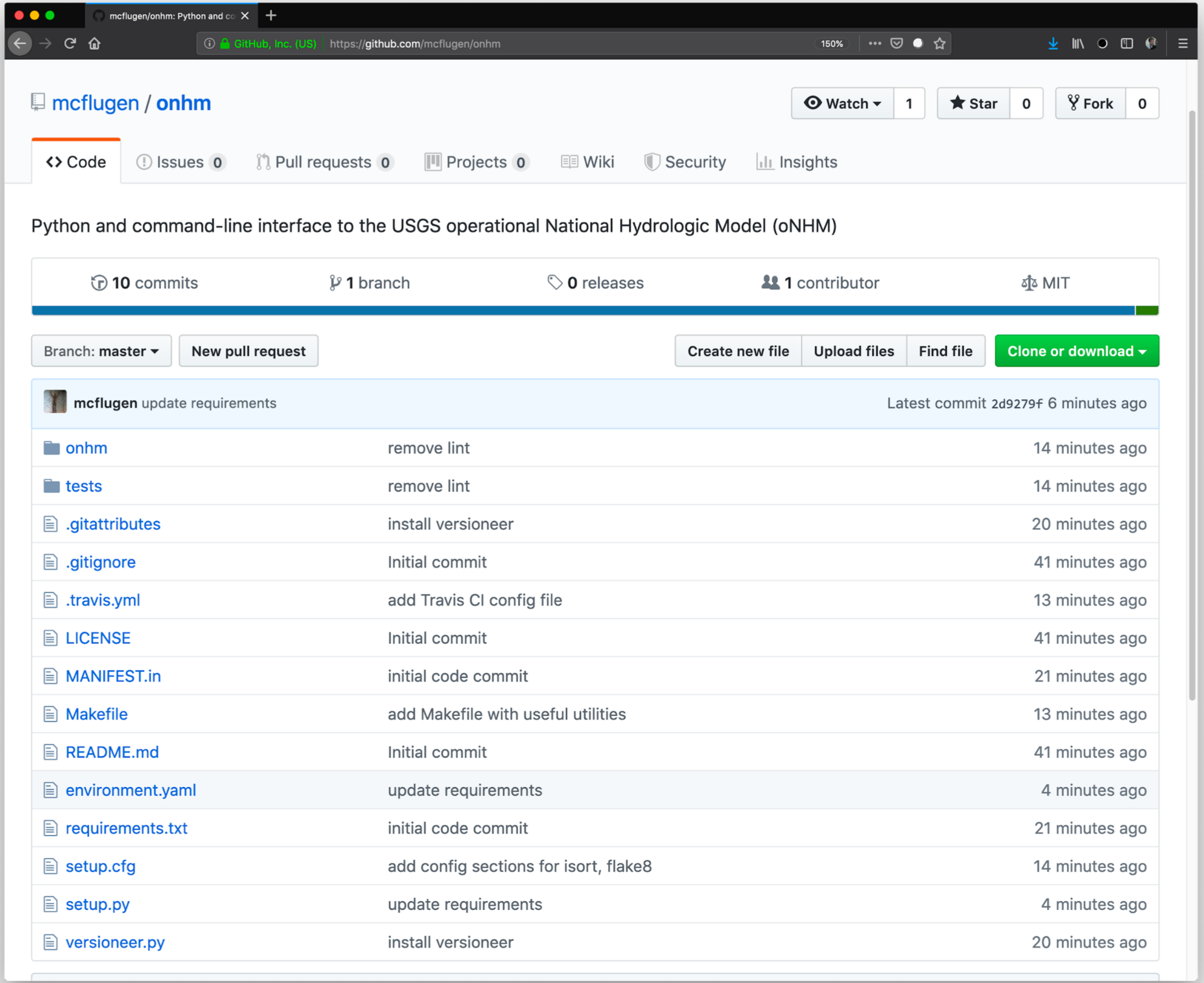


2D ELASTIC FLEXURE COMPONENT

With plug-and-play, solved problems (models) take hours, not weeks, to apply

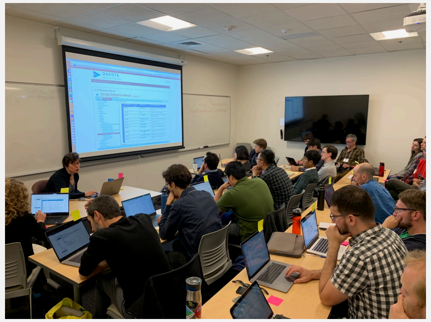
New: Data Components

- Goal: Implement BMI for datasets
- First: oNHM (USGS)
- More to come



https://github.com/mcflugen/onhm

Education: Workshops and Clinics



Examples of recent topics:

- Intro to Python, git, and shell
- FAIR principles for models
- Model calibration with Dakota
- Neural nets for landcover classification
- Pangeo: scalable geo-Python tools
- ADCIRC storm-surge modeling
- Delft3D for morphodynamics
- Sensitivity analysis with Salib
- Interactive sed/strat teaching tools
- BMI Live!
- CUAHSI services for models & data
- Tectonic modeling with DES3D

Studies show that scientists…

- Spend as much as 30% of research time on software
- Are mostly self-taught
- Are mostly unaware of tools and practices that would save time and improve reliability

(e.g., Hannay et al., 2009; Merali, 2010; Prabhu et al., 2011; Pinto et al., 2018; Kellogg et al., 2019)

SCIENTIFIC PUBLISHING (Miller, 2006 Science)

A Scientist's Nightmare: Software Problem Leads to Five Retractions

EDUCATION

CSDMS

Webinars series

2019/10/14	**Caers**, Jeff	Bayesian Evidential Learning: a protocol for uncertainty quantification in Earth systems
2019/09/30	**Gasparini**, Nicole	Building capacity to deepen the critical zone: expanding boundaries and exploring gradients through data-model synergy
2019/05/07	**LeVeque**, Randy	The GeoClaw software and tsunami modeling
2019/04/24	**Hsu**, Leslie	Do I have to make my models FAIR? Current practices in making models and data Findable, Accessible, Interoperable, and Reusable
2019/03/20	**Hutton**, Eric	The CSDMS Python Modeling Toolkit (PyMT)
2018/11/12	**Piper**, Mark	CSDMS Basic Model Interface (BMI)
2018/10/09	**Overeem**, Irina	Using CSDMS in the Classroom
2018/09/14	**Tucker**, Greg	Landlab Toolkit overview

EDUCATION

CSDMS

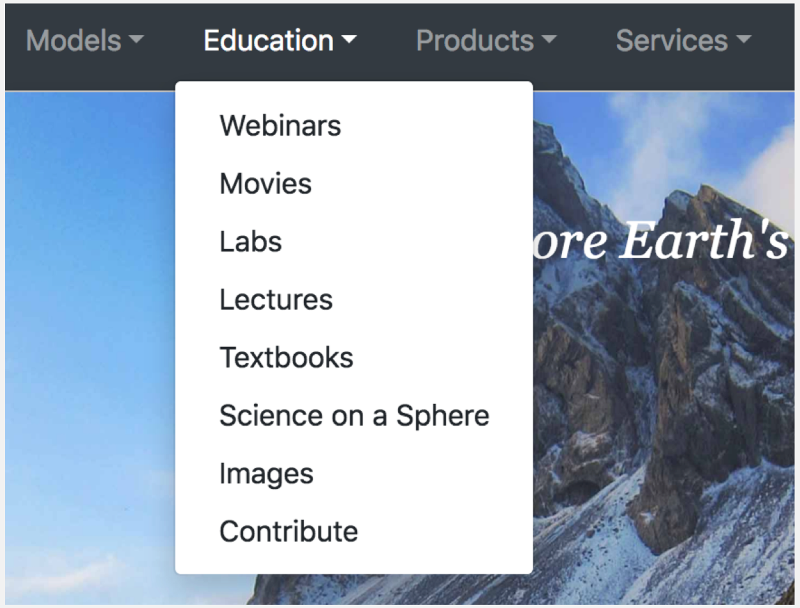
Webinars series

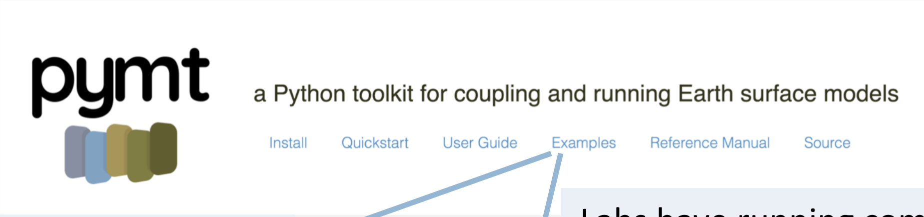
Date	Time	Presenter	Title
2019/11/12	10:00 am MST	**Buscombe**, Dan	Continuous Streamflow and Nearshore Wave Monitoring from Time-lapse Cameras using Deep Neural Networks
2019/11/18	09:00 am MST	**Harris**, Courtney	Cohesive and mixed sediment-transport processes in ROMS

EDUCATION

Other online resources

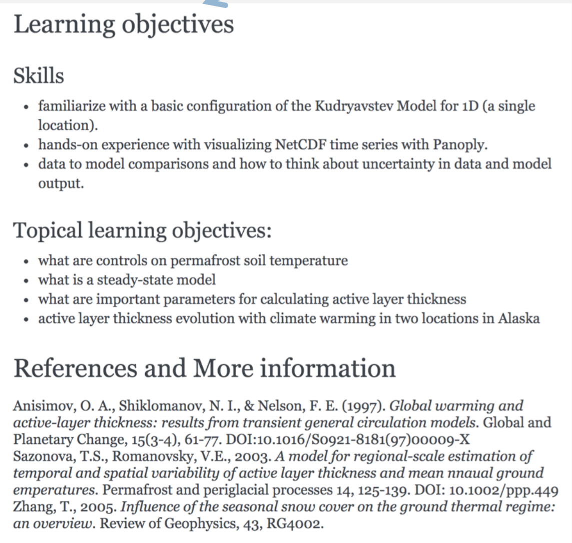
- Documentation & tutorials
- Workshop materials
- Education Repository:





Labs have learning objectives and point to background theory

Labs have running components with visualized output, and questions for further exploration



Learning objectives

Skills

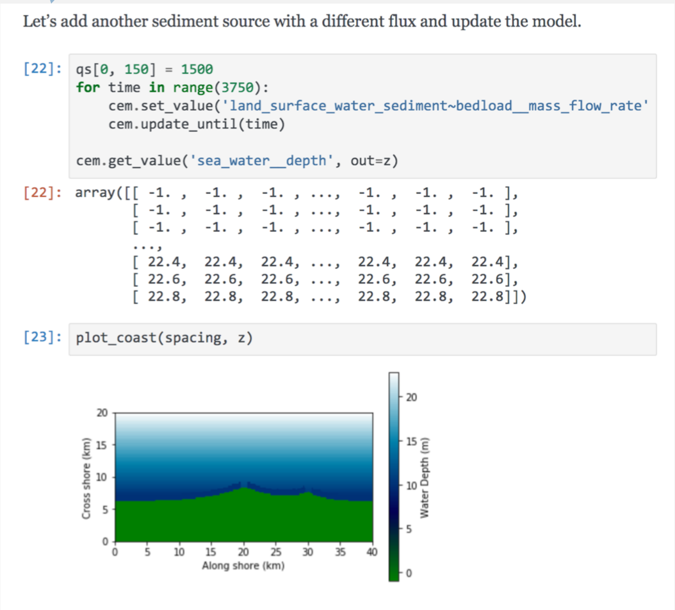
- familiarize with a basic configuration of the Kudryavstev Model for 1D (a single location).
- hands-on experience with visualizing NetCDF time series with Panoply.
- data to model comparisons and how to think about uncertainty in data and model output.

Topical learning objectives:

- what are controls on permafrost soil temperature
- what is a steady-state model
- what are important parameters for calculating active layer thickness
- active layer thickness evolution with climate warming in two locations in Alaska

References and More information

Anisimov, O. A., Shiklomanov, N. I., & Nelson, F. E. (1997). *Global warming and active-layer thickness: results from transient general circulation models.* Global and Planetary Change, 15(3-4), 61-77. DOI:10.1016/S0921-8181(97)00009-X
Sazonova, T.S., Romanovsky, V.E., 2003. *A model for regional-scale estimation of temporal and spatial variability of active layer thickness and mean nnaual ground emperatures.* Permafrost and periglacial processes 14, 125-139. DOI: 10.1002/ppp.449
Zhang, T., 2005. *Influence of the seasonal snow cover on the ground thermal regime: an overview.* Review of Geophysics, 43, RG4002.



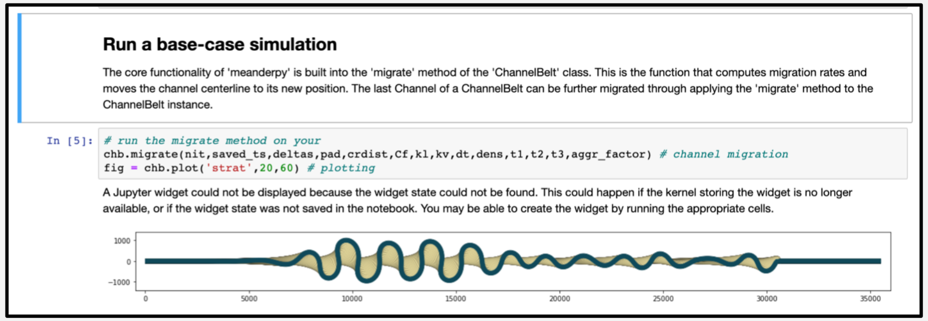
Let's add another sediment source with a different flux and update the model.

```
[22]: qs[0, 150] = 1500
      for time in range(3750):
          cem.set_value('land_surface_water_sediment~bedload__mass_flow_rate'
          cem.update_until(time)

      cem.get_value('sea_water__depth', out=z)
```

```
[22]: array([[ -1. ,  -1. ,  -1. , ...,  -1. ,  -1. ,  -1. ],
             [ -1. ,  -1. ,  -1. , ...,  -1. ,  -1. ,  -1. ],
             [ -1. ,  -1. ,  -1. , ...,  -1. ,  -1. ,  -1. ],
             ...,
             [ 22.4,  22.4,  22.4, ...,  22.4,  22.4,  22.4],
             [ 22.6,  22.6,  22.6, ...,  22.6,  22.6,  22.6],
             [ 22.8,  22.8,  22.8, ...,  22.8,  22.8,  22.8]])
```

```
[23]: plot_coast(spacing, z)
```

Run a base-case simulation

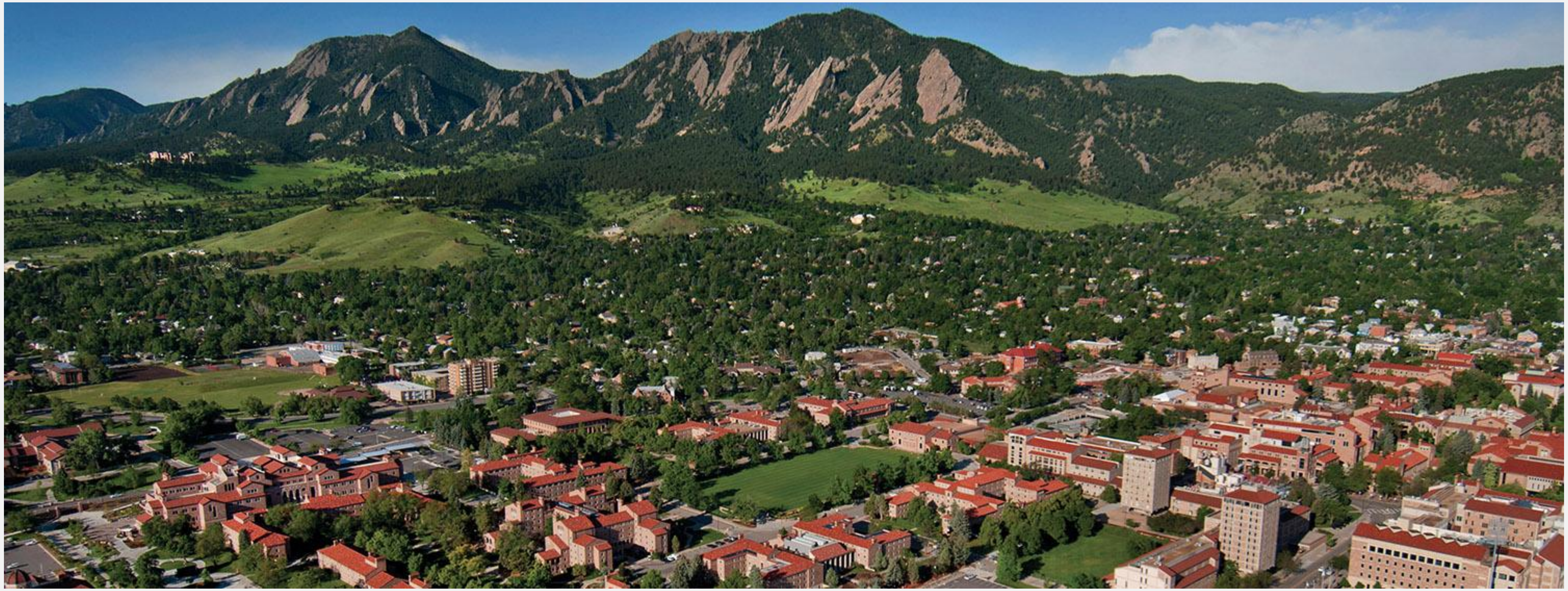
The core functionality of 'meanderpy' is built into the 'migrate' method of the 'ChannelBelt' class. This is the function that computes migration rates and moves the channel centerline to its new position. The last Channel of a ChannelBelt can be further migrated through applying the 'migrate' method to the ChannelBelt instance.

```
In [5]: # run the migrate method on your
        chb.migrate(nit,saved_ts,deltas,pad,crdist,Cf,kl,kv,dt,dens,t1,t2,t3,aggr_factor) # channel migration
        fig = chb.plot('strat',20,60) # plotting
```

A Jupyter widget could not be displayed because the widget state could not be found. This could happen if the kernel storing the widget is no longer available, or if the widget state was not saved in the notebook. You may be able to create the widget by running the appropriate cells.

EDUCATION

Earth Surface Processes Cybertraining Institute (ESP-In) 2020 and 2021

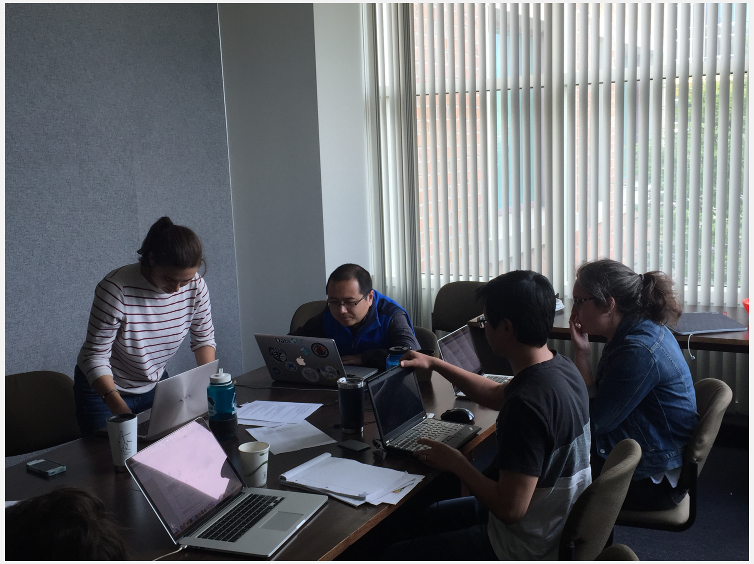


Organizing Team: Irina Overeem, Nicole Gasparini, Leilani Arthurs, Mark Piper, Benjamin Campforts, Lynn McCready, CSDMS

NSF-CISE 2-year CyberTraining-Pilot

ESP-IN 2020

- 10-day Cyberinfrastructure in Earth Surface Processes Institute
- Stipends for 20 US graduate students, PDFs and early career faculty selected to come from diverse disciplinary backgrounds with explicit slots reserved for underrepresented minorities.
- Goal: gain direct experience in converting their research codes into open-source distributed software. ESPIn would help train a new generation of computationally savvy, integrative scientists, while accomplishing major community science priorities.



Working on authentic modeling problems, using pymt and CSDMS tools.
Small teams will work on earth surface processes research questions

"Just-in-Time Teaching"
Modules on programming, best coding practices, HPC, numerical techniques

Weekend field excursion on local earth surface Processes and Front Range geology,
Explicit activities for networking and professional development.

CSDMS

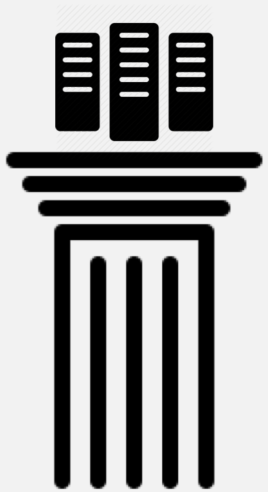
community surface
dynamics modeling system

CSDMS supports computational modeling in earth-surface science by engaging ***community***, providing ***computing*** resources, and promoting ***education***

share resources, collaborate

COMMUNITY
SUPPORT

create, run, test, analyze, and apply models



COMPUTING
RESOURCES

learn and teach

EDUCATION
OPPORTUNITIES