Modeling Collaboratory for Subduction Zone Science

Thorsten Becker, Kyle Anderson, Mark Behn, Magali Billen, Chuck Connor, Eric Dunham, Alison Duvall, Alice Gabriel, Helge Gonnermann, Kaj Johnson, Leif Karlstrom, Gabriel Lotto, Amanda Thomas, Ikuko Wada

MCS-RCN Townhall
May 13, 2021 - 2 pm Central

@sz4d_mcs contact@sz4dmcs.org
Modeling Collaboratory for Subduction (MCS): Science Goals
Understanding the physics of subduction zone systems

Key science issues:

- **Nature of asperities** (stationary vs. dynamic), with implications for earthquake and tsunami hazard assessment
- Links between **geodetically determined plate boundary coupling and future earthquake ruptures**
- Linking crustal magma transport and storage, thermo-mechanical structure, and volcanic activity: **Melt production to eruption**
- Capture **long term evolution** of arcs (e.g. plutons) and **short term hazards and monitoring** (active volcanoes)
- Feedbacks between **magmatic and surface processes** in controlling subduction margin tectonics and **megathrust cycle**
Volcano forecasting example

- How to link volcanic system state and long-term subduction margin evolution to event probabilities?
- How to quantify uncertainties and unknowns in diverse multiscale data, e.g., crystal clocks, seismicity, gas emissions?
- How to build physics-based, predictive volcano systems models?
MCS: A digital subduction zone for SZ4D

- Science-driven and enabling computational infrastructure and large-scale community effort is needed to advance systems levels understanding
Digital twins in climate science

Bauer et al. (2021)
Uncertainty about subduction physics requires validation of fundamental models.

Solid Earth systems dynamics is not climate science:
- major remaining questions regarding physics
- adjoints and data assimilation incompletely explored
- important role for modeling-based exploration of emergent dynamics

Wada and Karlstrom (2020)
MCS: Connections for science and communities

Regional data assimilation

Fundamental physics

Liu & Lapusta (2016)
MCS: Modular Community Systems Science

- Inclusive and equitable community building, observationalists and modelers
- International collaboration
- Science focused, distributed, open, FAIR, and sustainable model and code-development
- Data integration using verified building blocks
- Regional laboratories for validation
- Capacity building and access to leading-edge computing

reassembly encouraged
Computational geoscience training as a complementary pathway for enhancing diversity in the geosciences

- Inclusive, scalable entry point for K12 science education underserved communities
- More students play computer games than go camping?
Building Equity and Capacity in Geoscience (BECG)
Other integrative efforts within SZ4D

- **Charge to BECG:** Identify the correct set of activities that are strategically useful and maximize the specific assets of SZ4D
- **Intrinsic Goal:** Transform the mindset of our community to embrace education, outreach, capacity building, diversity, equity, inclusion, and social justice as critical for successful science

- Connects to the MCS ideas about modular community systems science
Building Equity and Capacity in Geoscience Research Targets

- Leverage international efforts into sustainable capacity building partnerships that avoid colonial attitude
- Use SZ geohazards to inform and address social justice and equity issues
- Educational efforts that are more inclusive with measurable student learning outcomes
- A more distributed model of outreach through science communication training for the SZ4D community
- Identify and develop evidenced-based best practices for interdisciplinary collaboration
MCS RCN Activities

Workshop 1: Fluid and Melt Transport
- Fluid migration & fracture formation in magma systems
- Lithosphere-scale magma transport
- Microscopic and short-time-scale processes

Workshop 2: Megathrust Modeling
- Sequences of earthquakes & aseismic slip
- Dynamic rupture and tsunamis
- Geodynamics and surface processes

Workshop 3: Volcano Modeling
- Location, timing, and magnitudes of volcanic eruptions on an arc scale
- How does the lithosphere influence magma transport?

Community Network for Volcanic Eruption Response (CONVERSE)
MCS RCN and Surface Processes

- Landscape evolution plays a key role in fault loading and magmatic systems
- Insights into mass wasting processes to link dynamic wave propagation with landslide hazard estimate
- Joint workshop with Landscape and Seascapes group @ SZ4D postponed to Fall 2021, integrative links with earthquake and volcano activities of SZ4D as well.
Fluid transport in subduction zones:

Role of the MCS

➢ Need better understanding of processes that control fluid migration at huge range of scales - a grand challenge
➢ Community modeling resources should include approaches for model validation
➢ Cross-disciplinary training and knowledge exchange
➢ Fluid transport is a unifying framework for subduction systems, including all groups within SZ4D. Perhaps a common research framework, e.g., controls on magnitude and frequency of eruption and earthquake hazards
Understanding the physics of megathrust systems:
Role of the MCS

Megathrust Report (download here)

Vision for MCS as community-building organization:

➢ International and open collaboration, engaging with partner organizations in US (e.g., USGS) and abroad
➢ Focus groups, organized along multiple axes:
  ○ Regional laboratories and case histories
  ○ Processes
  ○ Links with SZ4D through community model building, and data interpretation efforts
➢ Integration of modeling efforts with observations and lab experiments for hypothesis testing
Understanding the physics of volcanic systems:

Role of the MCS

- Grants for model development and collaboration
- Modeling Collaboratory Network
  - Workshops, summer schools
  - Interdisciplinary collaboration
- Development of open-source, well-documented, interoperable models
  - Supporting/enable the development of reusable model building blocks
  - Supporting/enabling model verification, validation, and benchmarking
  - Computational support infrastructure

Rosen (2016)
MCS: Physical models to understand hazard

Credits: AP, Global Volcanism Program, University of Washington, Wilcock et al. (2016)
MCS Design Objectives

Sustained Computational Geoscience Community Support and Model Development

- Natural laboratory focus groups
- Subduction zone science integration
- Process focus groups
- Training and Outreach
- Code and Cookbook development
- Workflows and Access to Computing
MCS as a subduction zone science hub for SZ4D

Natural laboratory focus groups

Process focus groups

Digital twins

Building capacity

ChEESE

CIG

CZ Net

CIDER

CAGE

SAGE

Earthquake Centers

SZ4D observatories

Building equity

MCS Subduction zone science integration
MCS Design Objectives

Verification
Are we building the system right?

Validation
Are we building the right system?

Uncertainty Quantification

Optimal Experimental Design
<table>
<thead>
<tr>
<th>Coordination &amp; communication</th>
<th>Database and workflow support</th>
<th>Applied math support</th>
<th>Statistics and data science support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Documentation and cookbook support</td>
<td>Hardware support (parallelization, GPU, architecture)</td>
<td>Workshops and hackathon support</td>
<td>Post-doc and grad student program</td>
</tr>
<tr>
<td>Code development grants</td>
<td>Outreach activities</td>
<td>HPCC allocations</td>
<td>Cloud compute allocations</td>
</tr>
</tbody>
</table>
Example MCS Code Lego Kits 
driven by community input

- Thermo-petrological magma dynamics (host rock + dike)
- Visco-elastic earthquake cycle with fluid transport
- Global, 3-D, thermal convection with two phase flow
- New framework for multi-physics, multi-scale (Julia, FEniCS)

- Complex physico-chemical fluid framework
- Coupled tectonics-surface processes
- Python/Jupyter notebook cookbooks and teaching modules
MCS Implementation Straw-Man

Must have:
- Workshops and collaboration between observationalists and modelers
- Structural and code database
- Program manager/coordinator
- Community driven science committee

High priority:
- Programmers at center and on loan to community
- Subawards for code development outside SZ4D program
- Compute allocations
- Post-doc program
Community impact of MCS

- New, large-scale, science-driven and science-enabling computational infrastructure needed to advance systems levels problems
- Integrative science to complement and optimize new observational and laboratory efforts
- Computational geoscience for physics based hazard assessment
- Training and enhancing diversity in the geosciences
- Generating new opportunities for interdisciplinary research
- Leveraging and democratization of computational science advances
Questions for the community and breakouts

1. Which suggested MCS activities are the highest priority?
2. Is the suggested MCS structure well aligned with those priorities?
3. Which MCS tools, codes, and repositories would the most useful?
4. Is the MCS well aligned to ensure observations, including from SZ4D, are best integrated into models?

Slides for breakout discussions here