Modeling Collaboratory for Subduction Zone Science

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The last big thing: EarthScope
➤ Huge advance in imaging
➤ Major surprises
➤ Remaining challenges with quantitative integration for continental dynamics and inter-disciplinary systems science
Materna et al. (2019)

- Spectrum of plate boundary slip
- Loading transients at subduction plate boundaries

GPS record of relative motion deviates from tectonic locking

Tomography at 200 km
Schmandt and Liu (2014)
New Opportunities to Study Earthquake Precursors

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Pritchard et al. (2020), cf. 2019 COSEG Workshop at NASEM

- How to link tectonic system transients to event probabilities?
- How to quantify uncertainties and unknowns?
- How to build physics-based, predictive geodynamic models?
Modeling Collaboratory for Subduction (MCS): Science

Understanding the physics of volcanic and earthquake systems

- What is the constitutive law controlling fault slip?
- How are faults loaded and what are asperities?
- What controls the location, timing, and magnitudes of volcanic eruptions?
- How do fluids transport and fracture network interactions affect the magma plumbing system and seismicity?
- How can we model three phase transport and solid-fluid interactions?
- How do subduction zone earthquakes and volcanoes interact with mass transport and topography?

Slow slip and afterslip triggered by the M7.8 2016 Kaikōura on Hikurangi (Wallace et al., 2017, 2018)

Degruyter and Huber (2014)
Modeling Collaboratory for Subduction (MCS): Approach

Science Driven Community and Model Building

- Modeling framework for data integration and systems modeling
- Open, reproducible, international collaboration
- Geoscience and STEM capacity building
- Example for next generation computational geoscience effort

- Geological constraints
- Active source and MT
- Passive source
- Geomorphological constraints
- Earthquake source seismology
- Volcano and earthquake precursors
- Rock mechanics experiments
- On- and off-shore geodesy
MCS: Modeling

- Understanding the dynamics of earthquakes and volcanoes in a societally relevant hazards context
- Integrating multi-scale, multi-physics processes
- Assimilating multi-disciplinary, spatio-temporally heterogeneous data
- Quantifying uncertainties & unknowns and designing the best experiments to reduce them
MCS: Modular Community Systems Science

- Inclusive community building
- International collaboration
- Science focused, distributed code-development
- Data integration using fundamental building blocks and assembled, regional solutions
- Training and access to leading edge computing (super computers and cloud computing)
Inclusive, scalable entry point for K12 science education underserved communities

More students play computer games than go camping
MCS: Example science deliverables

- Links between the style of **volcanic eruptions and thermo-mechanical structure of the crust and melt generation** within the mantle wedge
- Links between **long term evolution** of arcs (e.g. plutons) and **short term hazards and monitoring** (active volcanoes)
- **Nature of asperities** (stationary vs. dynamic), with implications for earthquake and tsunami hazard assessment
- **Spectrum of slip behavior** (hazardous earthquakes vs. slow slip) throughout the earthquake cycle
- Links between **geodetically determined locking and future earthquake ruptures**
“(...) the science priority questions will require advanced computational capabilities and new methods of data integration to enable (...) better constraints on Earth’s dynamical evolution”, “(...) driving a deep integration of data and models that can inform and guide each other.” (NASEM, 2020)
Volcanoes in any tectonic setting
US focused Volcano event response

MCS focused on earthquake and volcano systems, but tools and approaches are general, and apply to transforms, intraplate deformation, rifting, etc…

SV4D
Faults & Earthquakes
Magmatic drivers/eruptions
Landscapes & Seascapes
International Partners

SCEC
continental transform hazard & risk

CIG
Training and Documentation
Access to HPCC

CSDMS
surface process dynamics

CONVERSE
Volcanoes in any tectonic setting
US focused Volcano event response

MCS
Earthquakes and Volcano systems
Physics for forecasting
Computational models
Community
- Fluids
- Megathrust
- Volcanoes
Fluids Report *(download here)*

- Need better understanding of processes that control fluid migration
- Community modeling resources should include approaches for model validation
- Cross-disciplinary training and knowledge exchange
- Research would benefit from a multidisciplinary modeling collaboratory
Megathrust Report (download here)

- international and open collaboration
- focus groups
  - regional laboratories and case histories
  - process
- integration of modeling efforts with observations and lab experiments for hypothesis testing
- code benchmarking, verification, and validation
- immediate development of
  1. visco-elastic cycle model with fluids
  2. global mantle circulation model with two phase flow
  3. community code framework for multi-scale, multi-physics

Dunham, Thomas, et al. (EarthArXiv, doi:10.31223/X5730M, 2020)
MCS RCN Megathrust Workshop (09/2019)
107 people in person + 123 virtual
57 institutions, 24 countries

career stage

- student: 20%
- early career: 25%
- mid career: 21%
- senior: 34%

speaker gender

- female: 54%
- male: 46%

attendee gender

- female: 64%
- male: 36%

www.sz4dmcs.org/megathrust-workshop
Modeling Collaboratory for Subduction: Global scientific exchange

- apply and test modeling framework across different:
  - tectonic settings
  - stages of seismic and volcanic cycle
- Integrate with a network of global observatories
- drive community support for open science – research and training

(example observatories, completed to various degrees)
Volcanic Eruption Plume
Webinar #2 (09/2020)

156 participants
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?
Questions and comments?
Science Centered Themes

1. Crustal-scale magma transport
   - Needs and opportunities for modeling crustal-scale magma transport processes: multiphase (melt, solid, volatiles) mass transport, differentiation and assimilation, energetics. Integration of observational and experimental endeavors, including plutonic systems, to inform models.
   - Tentative dates:
     - Webinar: Tu 26 & Th 28 January, 12:00-1:30 (CT).
     - Speakers: Sisson, Fritchard, Jackson, Bergantz.

2. Magma storage
   - Needs and opportunities for modeling the evolution of magma chambers, their architecture and dynamics. Internal mechanisms that drive chambers toward eruption include recharge, differentiation, rejuvenation, and volatile accumulation. Opportunities and needs for modeling essential magma chamber processes and integration with diverse observations. Reactive multiphase (melt, crystals, volatiles) transport and integration with thermodynamic models. Coupling with rock mechanics, volcano-tectonics, and magma and magma chamber deformation. Integration of internal and external mechanisms by which eruptions are initiated.
   - Tentative dates:
     - Webinar: Tu 23 & Th 25 February, 12:00-1:30 (CT).
     - Speakers: Hübner, Ghiorso, Hoofit, Ruprecht

3. Eruptive magma ascent
   - The state of the art in magma ascent/eruption modeling, remaining challenges and opportunities. Coupling to magma storage and eruption initiation mechanisms. Opportunities and challenges for integrating diverse observations, both precursory and syneruptive, within process-based models. Needs and opportunities for the MCS to support rapid response efforts to emerging events through the CONVERSE initiative.
   - Tentative dates:
     - Webinar: Tu 23 & Th 25 March, 12:00-1:30 (CT).
     - Speakers: de Micheli Vitturi, Rivalta, Roman, Myers

4. Eruption Plumes
   - Overview of eruption plume modeling, fluid dynamics of volcanic plumes, model intercomparison, eruption source parameters derived from tephra deposits, and operational plume modeling. These webinars took place in September 2020 and are available here. Speakers were Costa, Dufek, Mastin and Bonadonna. A report will be forthcoming.

5. Integrative volcano modeling and forecasting
   - Linking magma storage, transport, and eruption modeling. Integrating observations with models of volcanic systems with the goal to advance understanding and forecasting. Opportunities and needs for coupling models between disciplines and problems, including the incorporation of volcano system models into their broader subduction zone tectonic context. This theme may touch on aspects of any of the preceding webinars, as well as topics not yet considered.
   - Tentative dates:
     - Webinar: Tu 4 & Th 6 May, 12:00-1:30 (CT).
     - Speakers: Segall, Poland, Le Mée, Bato
MCS connections and partnerships

Regional data assimilation

Fundamental physics

Liu & Lapusta (2016)
Ongoing MCS RCN activities

- Joint MCS-CIG-CSDMS Cyberinfrastructure/Computational Earth Science webinars (January 2021)
- Volcano (magma system and eruption modeling) webinars (Spring 2021)
- Volcano systems workshop (Summer 2021)
- Joint surface process with SZ4D
Volcanic Plume Eruption Webinar #1
191 participants