Modeling Collaboratory for Subduction RCN
Status, Recap and MCS Implementation

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

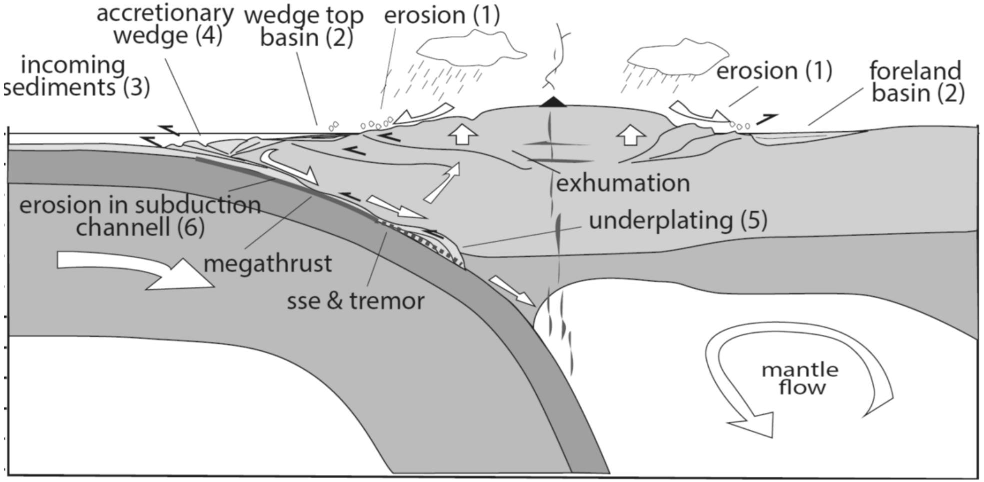
MCS-SZ4D Modeling Landscapes and Seascapes Workshop
October 19, 2021 – updated November 13, 2021

@sz4d_mcs   contact@sz4dmcs.org

MCS RCN

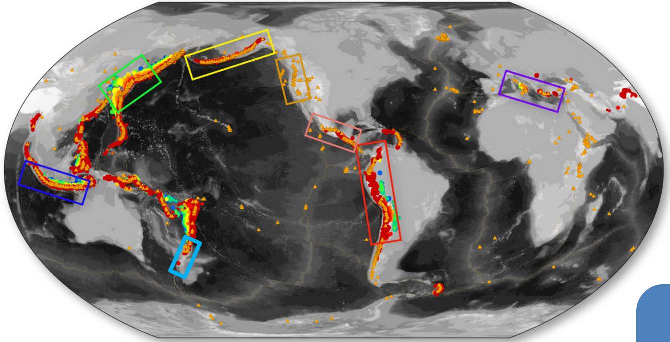
Modeling Collaboratory for Subduction (MCS)

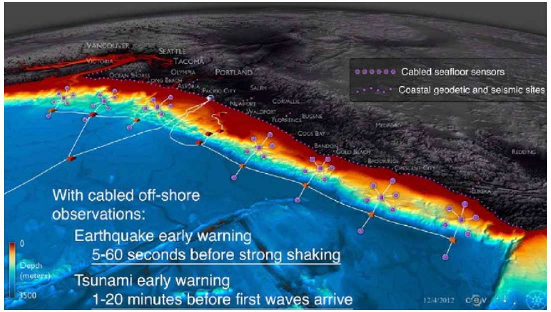
Science Questions

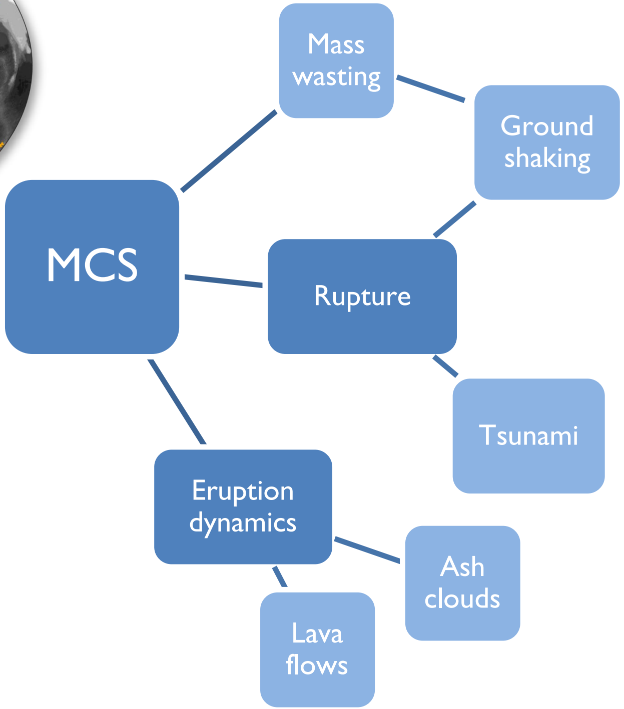


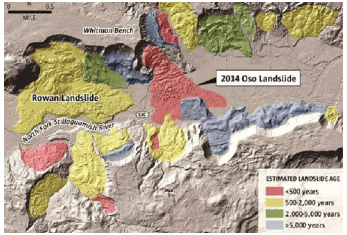
- How do we construct models that link subduction zone state and margin evolution to the character and probability of events?
- How can we best integrate observational constraints into models, while simultaneously using models to define optimal observational strategies (e.g., to reduce uncertainties)?
- How can we build physics-based, predictive models for volcano, earthquake, and geomorphic systems that couple across time and space?
- How can we build a diverse and equitable community of scholars?

MCS: Physical models to understand hazard



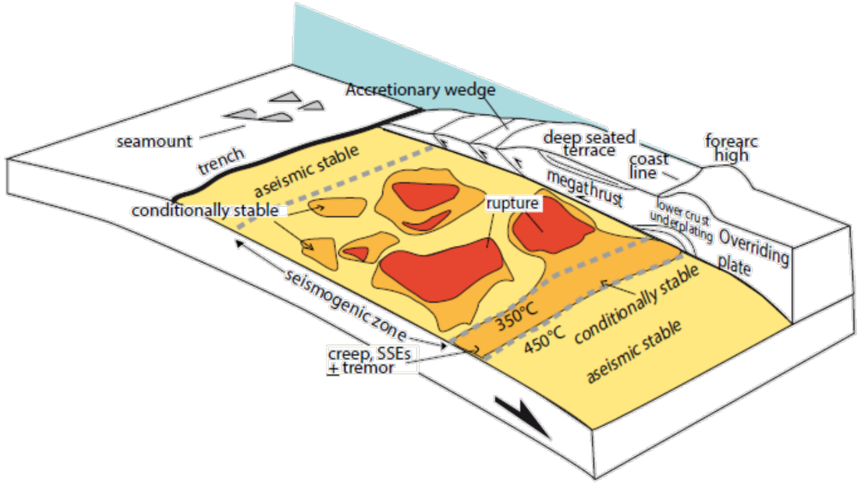


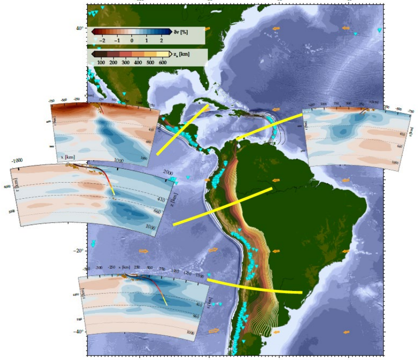




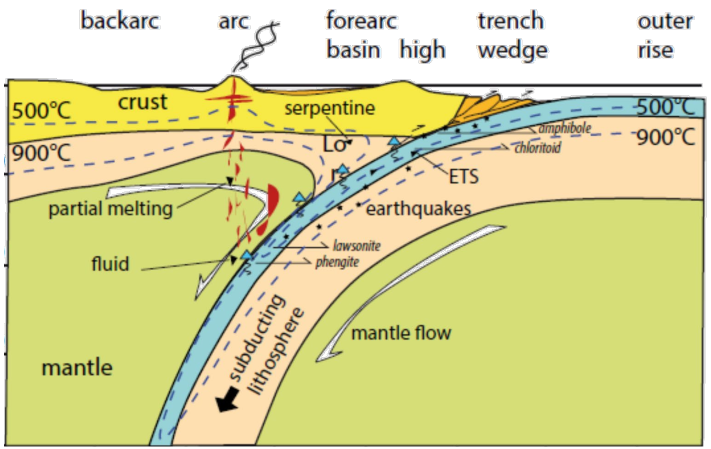
Credits: AP, Global Volcanism Program, University of Washington, Wilcock et al. (2016)

Uncertainty about physics requires validation

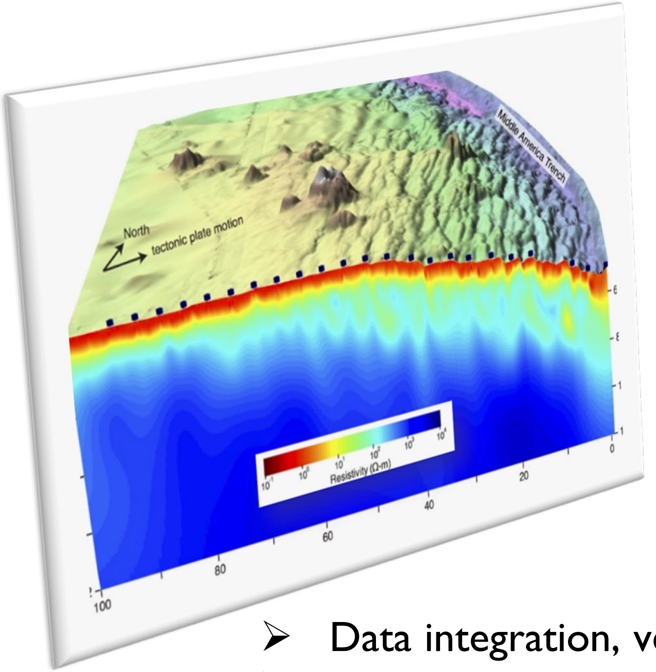




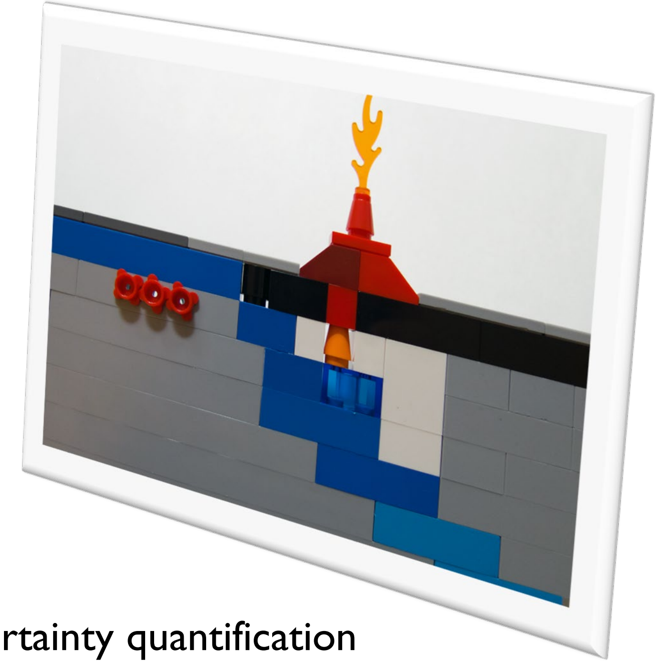
- major remaining questions regarding physics
- important role for modeling-based exploration of emergent dynamics
- huge potential for integration of laboratory and field data
- adjoints and data assimilation incompletely explored
- **potential of connecting and integrating insights from natural laboratories**



Modeling Collaboratory for Subduction



digital twins

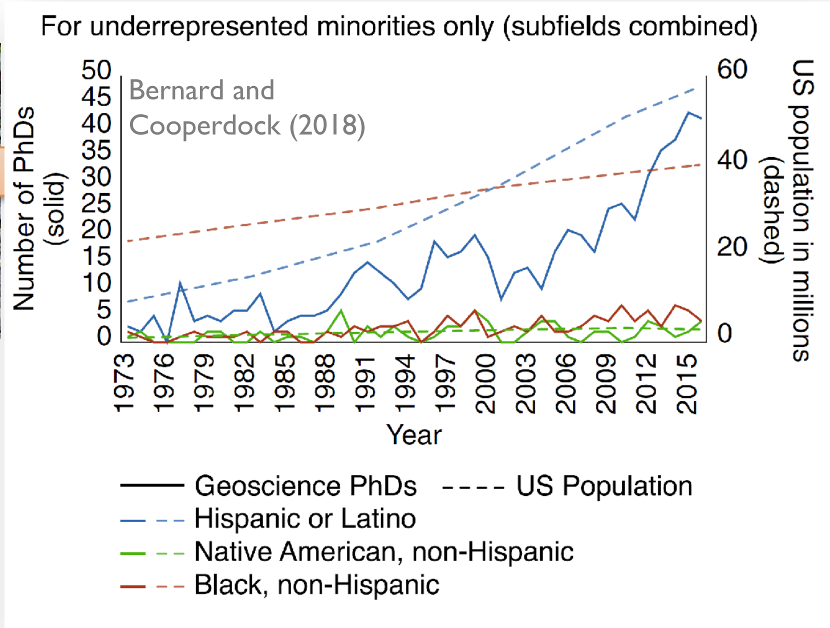


- Data integration, verification, validation, and uncertainty quantification
- Next generation, sustained code development for cross-scale, multi-physics
- Science-driven and science-enabling computational infrastructure
- Large-scale **community and capacity building effort**

Naif et al. (2015)

Computational geoscience training as a complementary pathway for enhancing diversity in the geosciences – links with SZ4D BECG

AAPG Explorer



SCEC USEIt (2016), USC

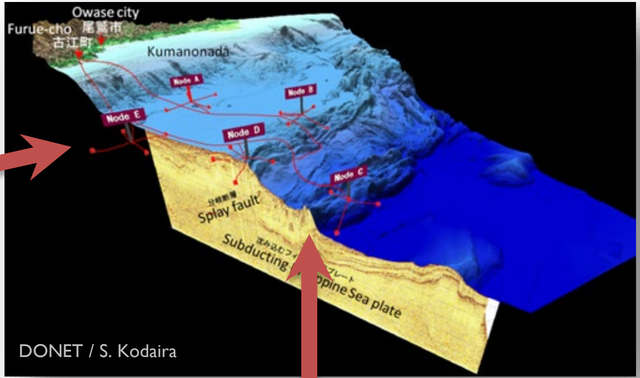
SZ4D draft report (2021)

- Inclusive, scalable entry point for K12 science education underserved communities
- More students play computer games than go camping?

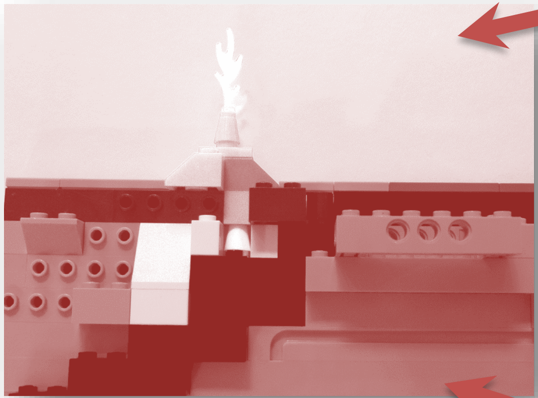
MCS: Modular **Community** Systems Science

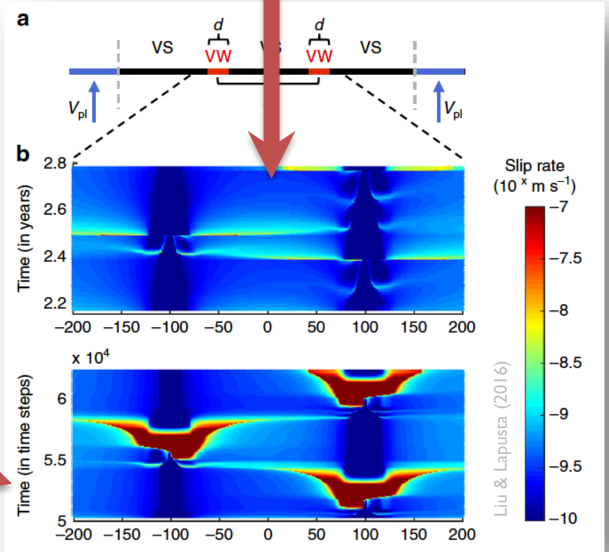
- **Science focused,** striving for a transformative advance of interdisciplinary research questions based on a collaborative effort
- **Inclusive and equitable community building** for observational and model science
- International collaboration
- Distributed, open, FAIR, and sustainable model and code-development
- Data integration using verified building blocks
- Regional laboratories for validation
- **Capacity building** and access to leading-edge computing

MCS: Transformative subduction zone science through sustained community, code, and model development



Regional data assimilation





Fundamental physics

CIG COMPUTATIONAL INFRASTRUCTURE for GEODYNAMICS

ChEESE

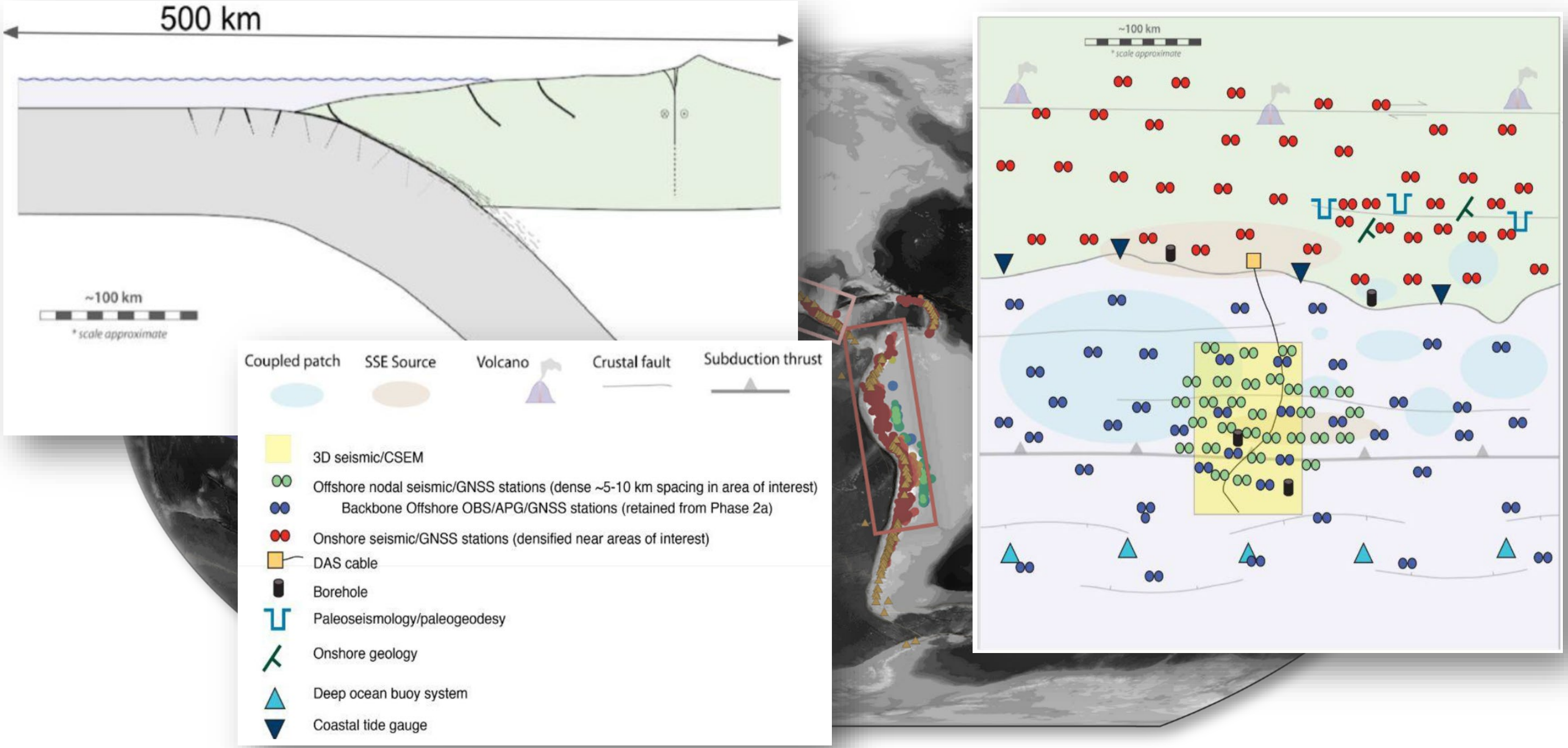
CSDMS community surface dynamics modeling system

NSF

USGS science for a changing world

NASA

Synergy with SZ4D instrumentation



Phase 2b observational scenario from SZ4D draft report (2021)

Modeling Collaboratory for Subduction RCN

MCS RCN

NSF

sz4dmcs.org, Fall 2018 – Summer 2022

MCS RCN Planning and Collaboration Process

Fluid and Melt Transport Workshop

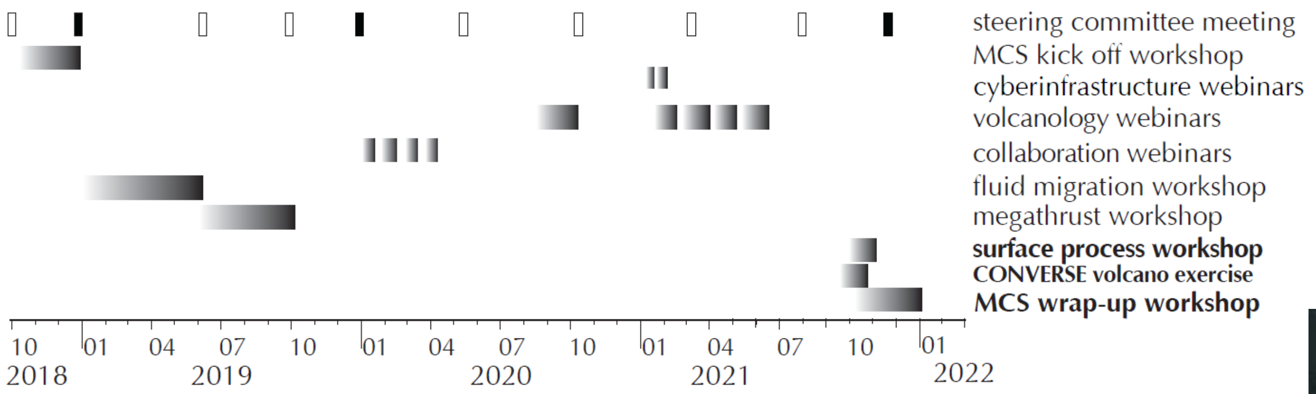
- Fluid migration & fracture formation in magma systems
- Lithosphere-scale magma transport
- Microscopic and short-time-scale processes

Megathrust Modeling Workshop

- Sequences of earthquakes & aseismic slip
- Dynamic rupture and tsunamis
- Geodynamics and surface processes

Volcano Modeling Workshop

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



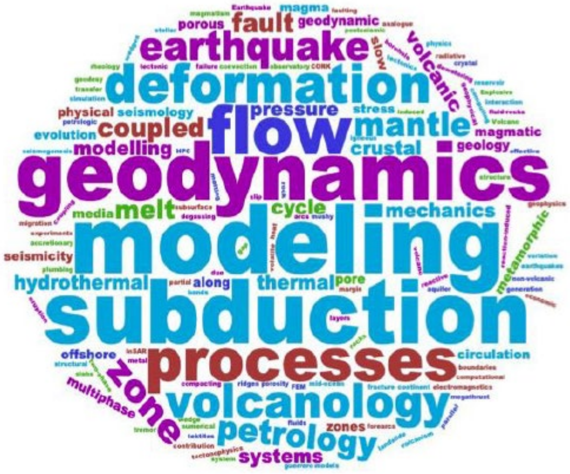
- Volcano modeling exercise with CONVERSE, Oct. 8-10
- ***MCS-SZ4D Landscapes and Seascapes integration and implementation workshop*** Oct. 18-19
- MCS RCN planning: Dec. 1-3
- MCS RCN wrap-up: Jan 2022

MCS RCN

https://www.sz4dmcs.org/

MCS RCN Fluid and melt transport workshop

- May 2019 in Twin Cities, Minnesota
- Organized by Ikuko Wada and Leif Karlstrom
- Early Career Scientist session
- Attended by 56 people in person, 90 via Zoom, 18% students, 30% early career
- All material available at sz4dmcs.org

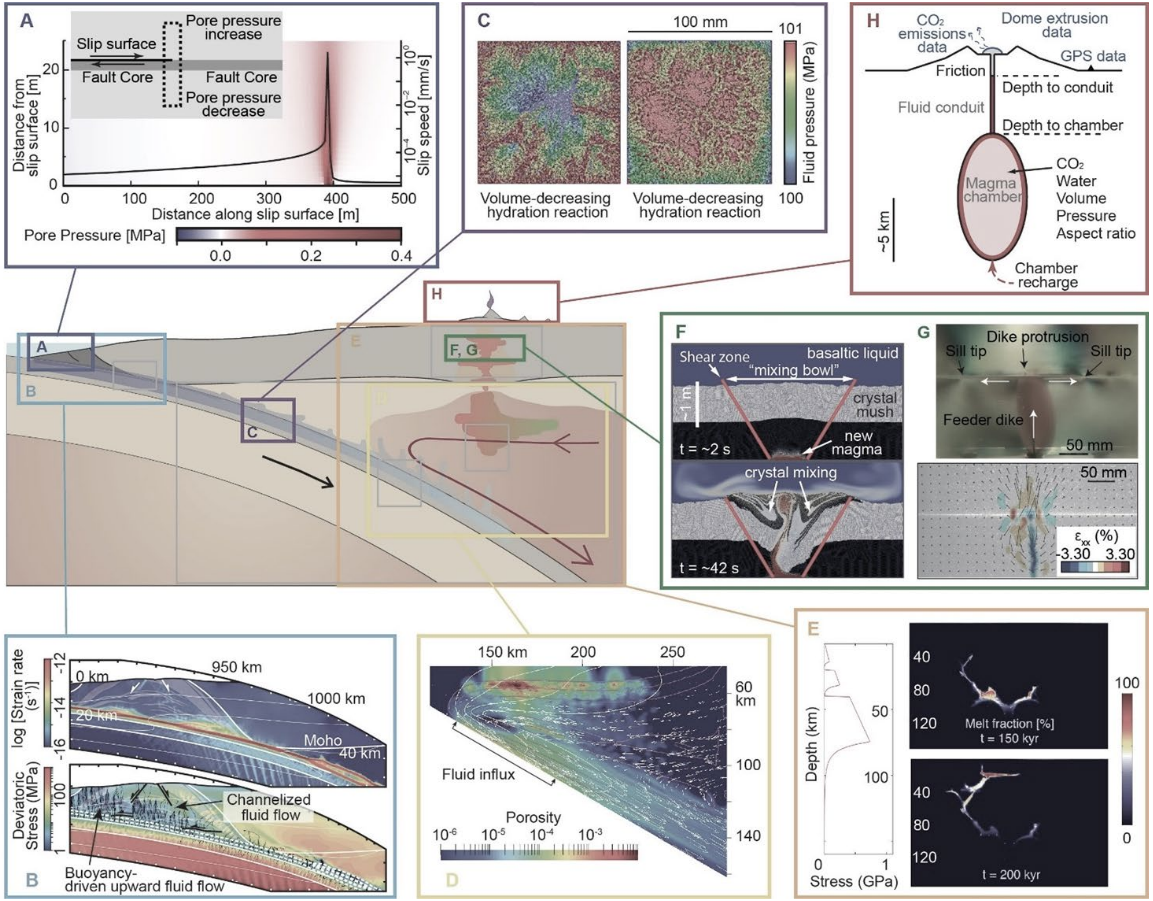


MCS RCN

Fluid and melt transport workshop: Science questions

MCS
RCN

1. How do fluids affect spatio-temporal variations in seismic and aseismic tectonic activities?
2. How do fluids affect the spatio-temporal variations in magma ascent?
3. How are fluid-related processes linked to the thermal-chemical-mechanical structure and dynamics of the subduction system?



Wada and Karlstrom (2020)

MCS RCN Fluid and melt transport workshop

- need a better understanding of processes that control fluid migration
- Current research would benefit from a multidisciplinary MCS that identifies and resolves related challenges that exist across subduction zone science.
- Interfacing scientists across disciplines to develop models is as important at this stage as interfacing models.
- Community modeling resources should include approaches for model validation (and uncertainty quantification) through observations and minimum/standard sets of benchmarking exercises.
- Cross-disciplinary training and knowledge exchange for students and practicing research scientists alike would be an important function of an MCS

Modeling Collaboratory for Subduction RCN
Fluid Migration Workshop Report

May 29 – June 1, 2019
University of Minnesota – Twin Cities

Workshop Writing Committee:

Ikuko Wada and Leif Karlstrom
Diane Arcay
Luca Caricchi
Patrick Fulton
Taras Gerya
Kayla Iacovino
Tobias Keller
Rachel Lauer
Gabriel Lotto
Laurent Montesi
Tianhaozhe Sun
Hans Vrijmoed
Jessica Warren

Published online November 2019 – https://www.sz4dmcs.org/fluids-workshop

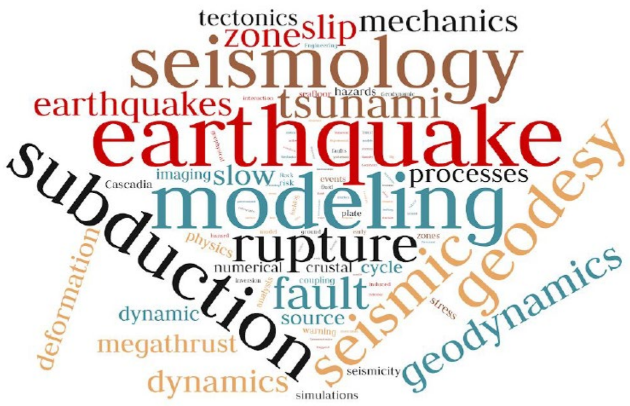
Fluids Workshop Report by Wada, Karlstrom, et al. (2019) download link.

MCS RCN Megathrust workshop

- October 2019 in Eugene OR
- Organized by Amanda Thomas and Eric Dunham
- Early career session
- Attended by 107 people, 25% students, 34% early career
- All material available at sz4dmcs.org

Report by Dunham, Thomas, et al. (2020) available for download here

MCS RCN Megathrust workshop: Science questions



1. What are asperities and how do they relate to past and future earthquakes?
2. What is the nature of deformation, structure, and rupture behavior in the toe of the subduction zone and how do these relate to tsunamigenesis?
3. How do different parts of the megathrust interact across space and time?
4. What processes are responsible for deformation below the seismogenic zone?
5. What is the state of stress and pore pressure in and around the megathrust?
6. What is the role of structure, geology, geometry, and rheology in controlling slip behavior?

Report by Dunham, Thomas, et al. (2020) available for download here

MCS RCN

MCS RCN Megathrust workshop

Recommendations for the MCS 1/2:

- developing **sustained, international, distributed, and open collaborations** to facilitate comparative analysis, verification, exchange of ideas and knowledge, and joint model development;
- **organizing focus groups dedicated to regional laboratories, and case histories of significant earthquakes**;
- organizing **focus groups for subsets of megathrust processes**, to document the current state of knowledge, provide guidance for code and workflow development, and provide science focus;
- **integration of modeling efforts with observations and experiments** in a manner that includes transparency of assumptions, data resolution, and joint development of falsifiable hypotheses, in conjunction with the regional laboratories;


Modeling Collaboratory for Subduction RCN

Megathrust Modeling Workshop Report

Eric M. Dunham[1], Amanda M. Thomas[2], and Thorsten W. Becker[3,4]

Contributing authors: Camilla Cattania, Jessica Hawthorne, Judith Hubbard, Gabriel C. Lotto, Jean-Arthur Olive, John Platt

[1]Department of Geophysics, Stanford University, Stanford, California, USA (edunham@stanford.edu)
[2]Department of Earth Sciences, University of Oregon, Eugene, Oregon, USA
[3]Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX, USA
[4]Institute for Geophysics, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX, USA

October 23, 2020

Report by Dunham, Thomas, et al. (2020) available for download here

MCS RCN Megathrust workshop

Recommendations for the MCS 2/2:

- thorough **code benchmarking, verification, and validation exercises**; and
- the **immediate development of three specific models** that would benefit the community:

1. a viscoelastic earthquake sequence model with fluid transport;
2. a global, 3-D, thermo-mechanical mantle circulation model with two-phase flow;
3. a flexible modeling framework for multi-physics, multi-scale modeling including rupture, earthquake cycle, and tectonic time scales.

Modeling Collaboratory for Subduction RCN

Megathrust Modeling Workshop Report

Eric M. Dunham[1], Amanda M. Thomas[2], and Thorsten W. Becker[3,4]

Contributing authors: Camilla Cattania, Jessica Hawthorne, Judith Hubbard, Gabriel C. Lotto, Jean-Arthur Olive, John Platt

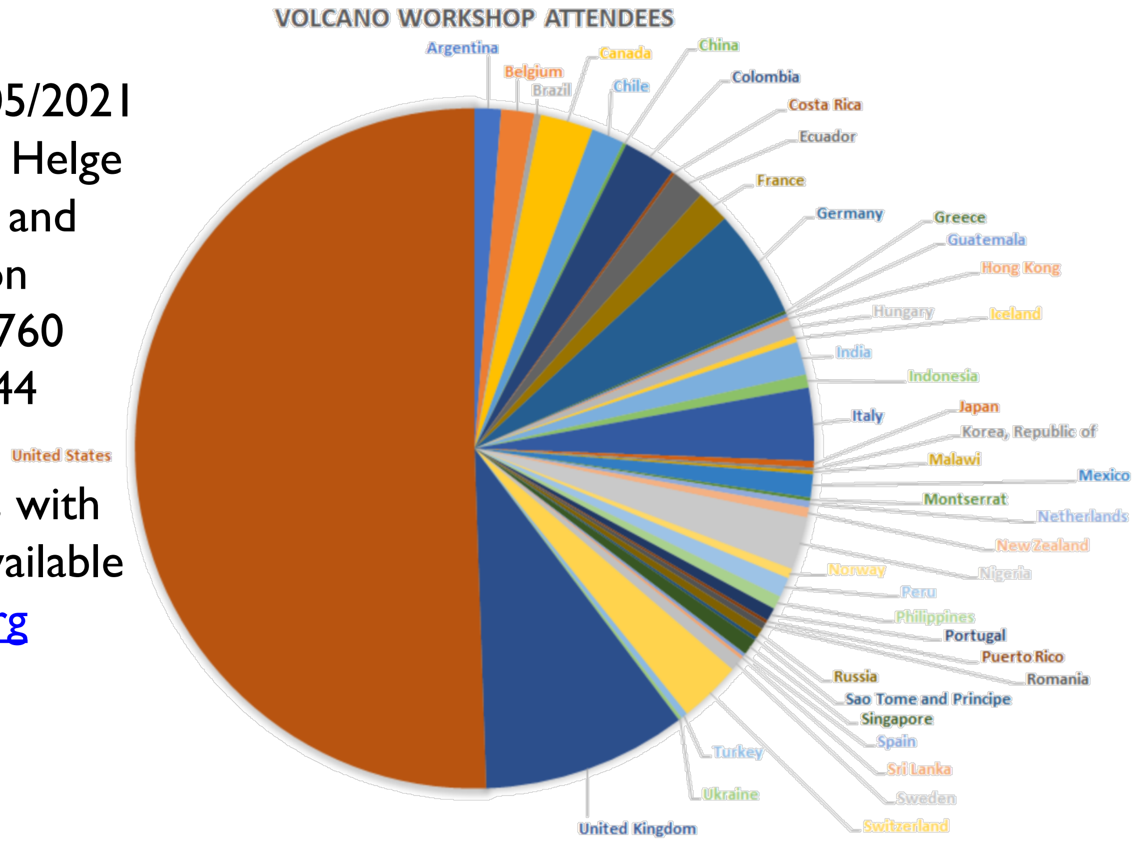
[1]Department of Geophysics, Stanford University, Stanford, California, USA (edunham@stanford.edu)
[2]Department of Earth Sciences, University of Oregon, Eugene, Oregon, USA
[3]Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX, USA
[4]Institute for Geophysics, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX, USA

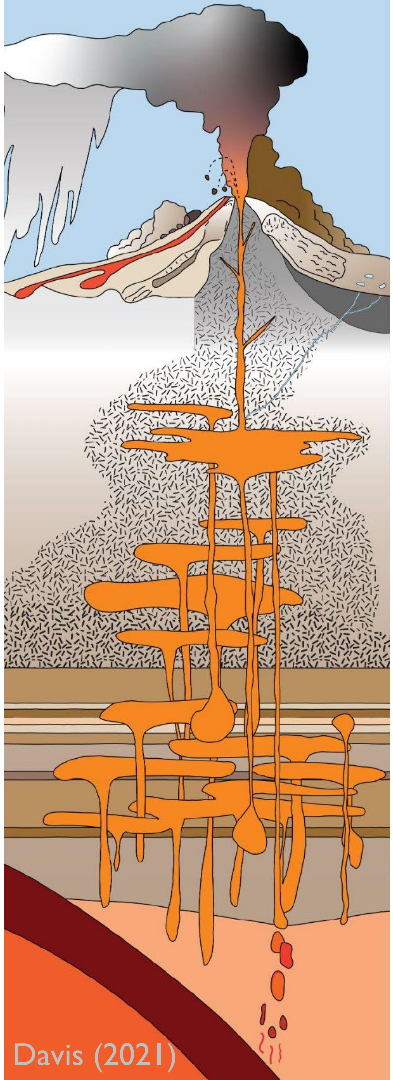
October 23, 2020

Report by Dunham, Thomas, et al. (2020) available for download here

MCS RCN Volcanic Systems Workshop

- Virtual 01 – 05/2021
- Organized by Helge Gönnermann and Kyle Anderson
- Attended by 760 people from 44 countries
- Five webinars with all material available at sz4dmcs.org





MCS RCN

Report available here (Gönnermann, Anderson, et al. 2021)

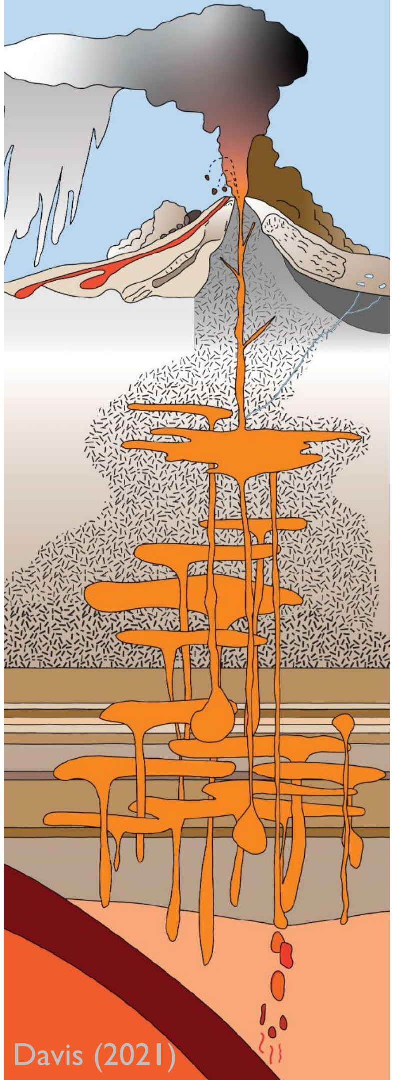
MCS RCN Volcanic Systems Workshop: Science questions

- How do large-scale subduction parameters control magma production and delivery within the crust?
- How can we better understand and anticipate magma pathways to the surface?

  - requires the development of quantitative models to interpret diverse observations including real-time monitoring data
  - enhanced support for the development and dissemination of system models and associated methodologies will enable advances in ways not currently possible
  - transformative potential of diverse groups of scientists working together on common problems

MCS RCN

Report available here (Gönnermann, Anderson, et al. 2021)

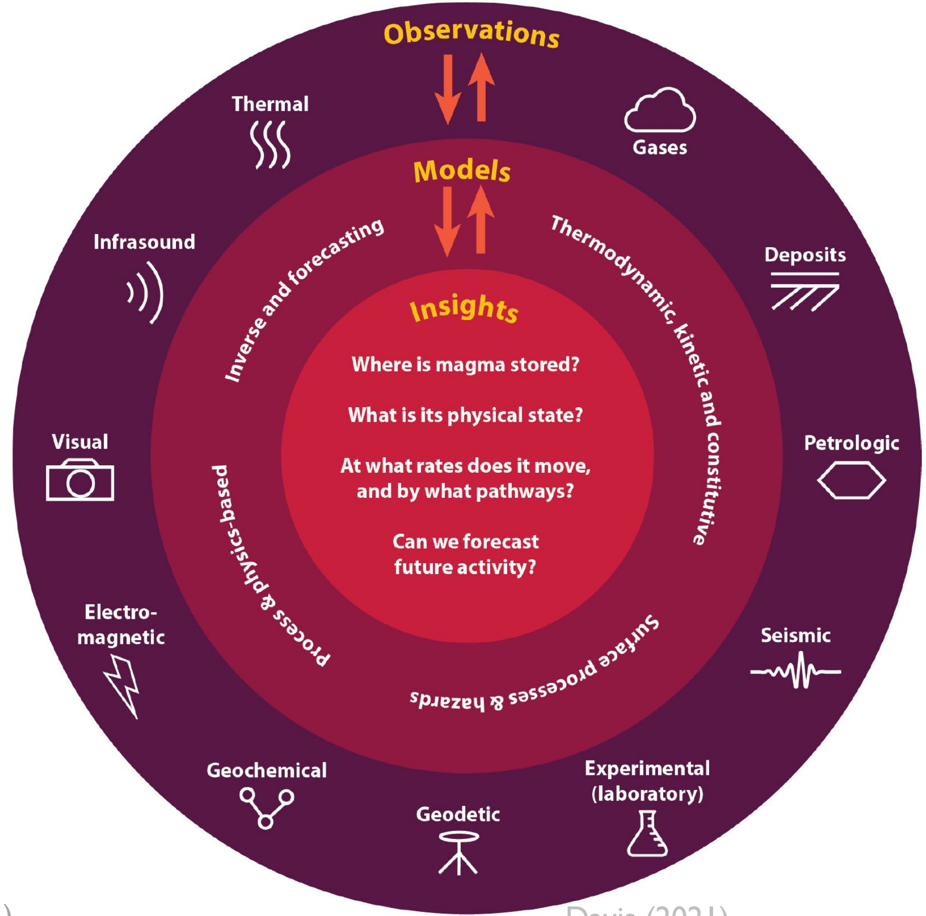


MCS RCN Volcanic Systems Workshop

MCS RCN

The MCS can foster and enhance

- flexible development of subsystem and integrative system models
- the development of public, open-source modeling codes
- code verification, validation, and benchmarking
- interdisciplinary collaboration
- modeling efforts within the CONVERSE initiative
- science community and preparing future scientists



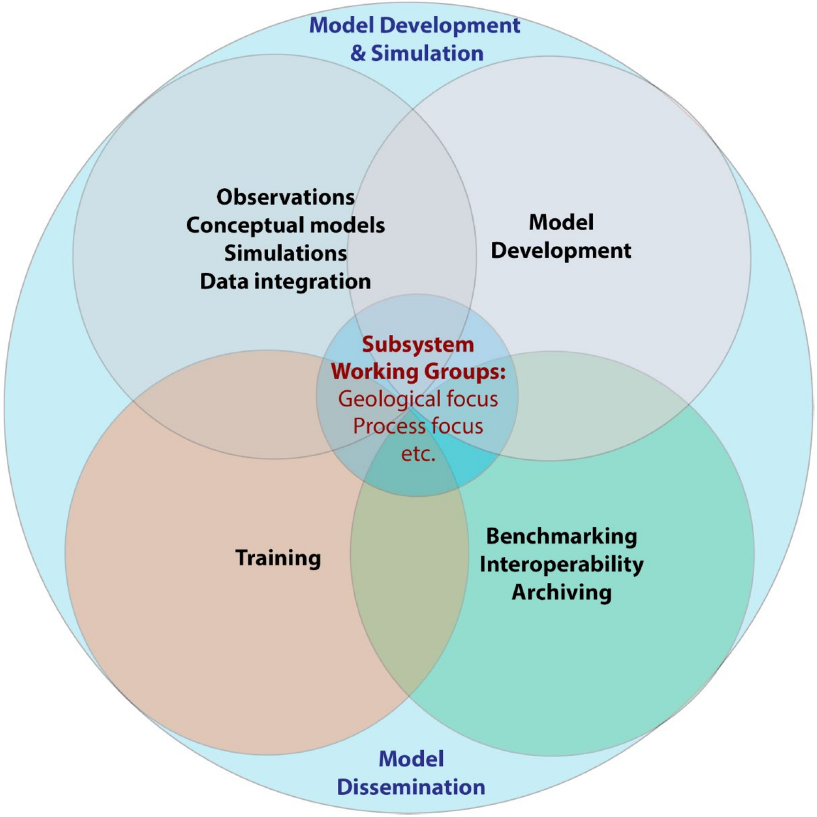
Davis (2021)

Report available here (Gönnermann, Anderson, et al. 2021)

MCS RCN Volcanic Systems Workshop

MCS RCN

- Need for community working groups (Powell Center, or SCEC as analogs)
- Programmatic funding (grants)
- Models are not merely tools, understanding of natural processes and developing models thereof are intimately intertwined.
- The modeling process matters, as opposed to creating a toolbox full of models that will be obsolete a few years down the road.
- Need for sustained funding for model development and simulation.



Report available here (Gönnermann, Anderson, et al. 2021)

Goals for the MCS

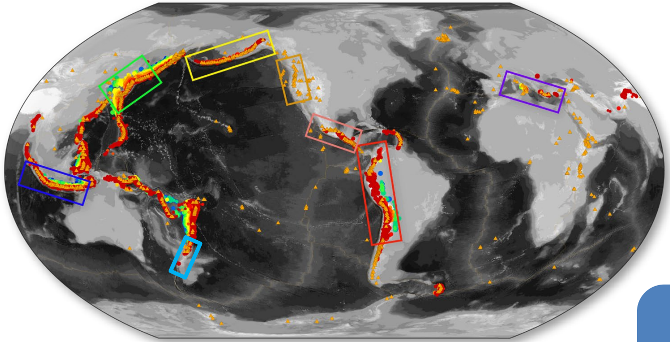
The objective of the MCS is to create new kinds of physics-based models for subduction zones and apply them to understand fundamental processes, guide instrument deployment, interpret observations, and assess hazards.

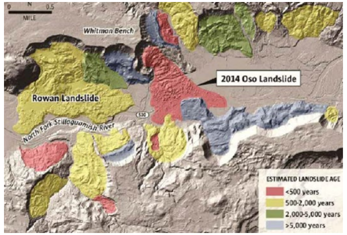
Guiding Questions:

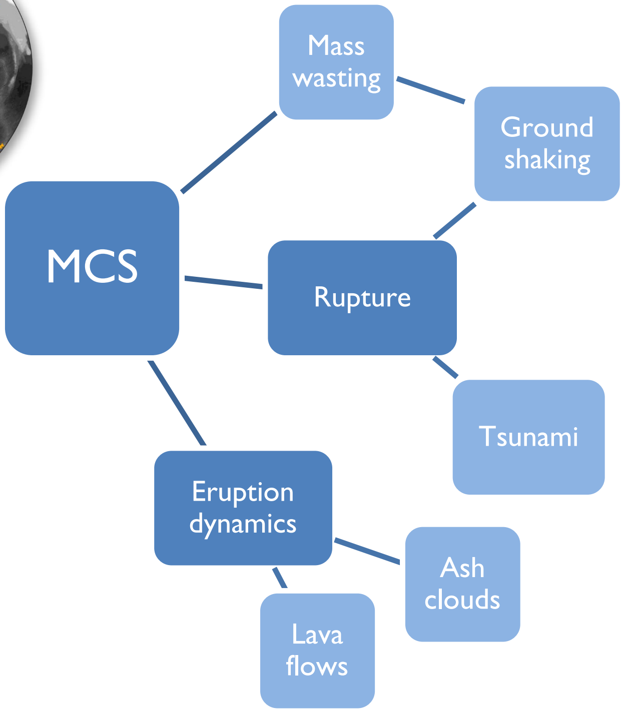
- How do we construct models that link subduction zone state and long-term margin evolution to the character and probability of event occurrence?
- How can we best integrate observational constraints into models, while simultaneously using models to define optimal observational strategies (e.g., to reduce uncertainties)?
- How can we build physics-based, predictive models for volcano, earthquake, and geomorphic systems that couple across time and space?
- How do we build a diverse and equitable community of scholars?

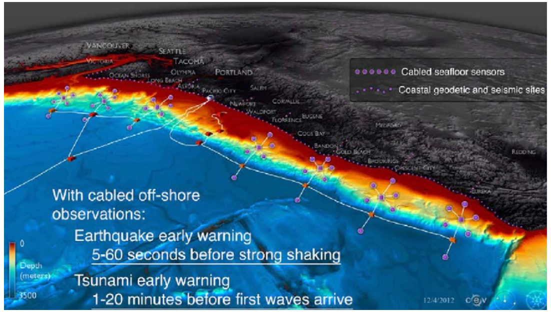
MCS RCN

MCS: **Physical models to understand hazard**









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

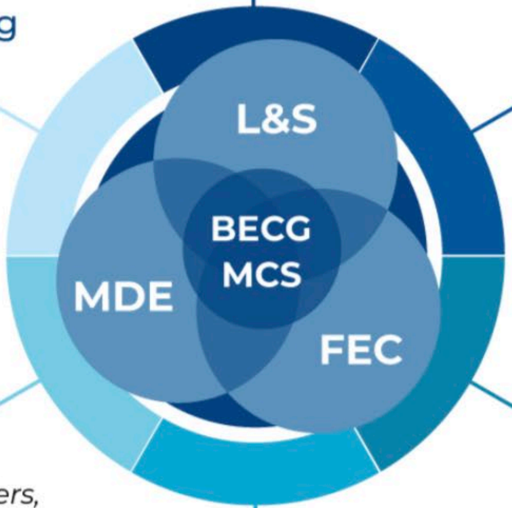
MCS RCN

1. Forecasting & Prediction

An integrative understanding of the subduction zone system is key for providing robust forecasts of subduction hazards.

6. Triggering & Cascading Hazards

Subduction hazards are often not isolated events, but cascading, requiring a system-scale approach.



2. Mass & Energy Balance

Understanding the subduction zone mass and energy budget requires an interdisciplinary approach to inform the energy available for geohazards.

3. Rheology & Stress

Rheology provides ways to estimate stress, which is essential for assessing hazard potential in the subduction zone system.

5. Climate Variability

Climate variability drives changes in sea level, glaciers, and sediment transport affecting geohazards along the entire subduction zone system.

4. Fluid Migration

Fluid migration plays a critical role in each region of the subduction zone factory, from hydration of the mantle wedge to erosion of the landscape.

From SZ4D integration chapter

MCS RCN

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 RCN

MCS Implementation Straw-Man

From draft MCS-SZ4D integration report

Must have components for an MCS:

- Support for workshops, hackathons, and training for continued collaboration between observationalists, experimentalists, and modelers
- Repositories for models (time-independent geological and geophysical data) for SZ4D and other natural laboratories, as well as for primary and derived data product workflow
- Repositories for code documentation, cookbooks, and teaching material
- A dedicated program manager/coordinator
- A community-sourced and engaged science planning committee made up of modelers and observationalists

MCS RCN

MCS Implementation Straw-Man

From draft MCS-SZ4D integration report

Components required for transformative advance:

- Support for multiple programmers (e.g., with HPC, applied math, visualization, database focus) at a central facility.
  - Work on goals defined by long-term MCS science plan
  - Made available to the community through a competitive grant process
- Subawards for distributed, but coordinated code development
  - PI-driven awards through NSF panel (outside SZ4D science program?)
- Compute allocations, portals, and cloud workflow system
- Post-doc program, reside with PIs, connection with center
- Support for competitive and inclusive graduate fellowships, with a focus on entraining new and underrepresented members to the geoscience community from diverse backgrounds

MCS RCN

MCS Components

- Coordination & communication
- Database and workflow support
- Applied math support
- Statistics and data science support
- Documentation and cookbook support
- Hardware support (parallelization, GPU, architecture)
- Workshops and hackathon support
- Post-doc and grad student program
- Code development grants to PIs
- Outreach activities
- HPCC allocations
- Cloud compute allocations

MCS Implementation Straw-Man

From draft MCS-SZ4D integration report

3-Tiered Structure:

1. **MCS Office** – facilitating community engagement throughout workshops, hackathons, postdoc and graduate fellowship programs, and DEI initiatives.
2. **Facility** – housing a community code development team led by a group of computational scientists.
3. **Competitive grant process** – supporting PI-driven science by allowing individual researchers to both leverage the computational resources of the MCS and contribute to the development of new community codes.

Total Resources Envisioned: $3m - $5m/year effort, with ~75% for distributed and community embedded resources

MCS RCN