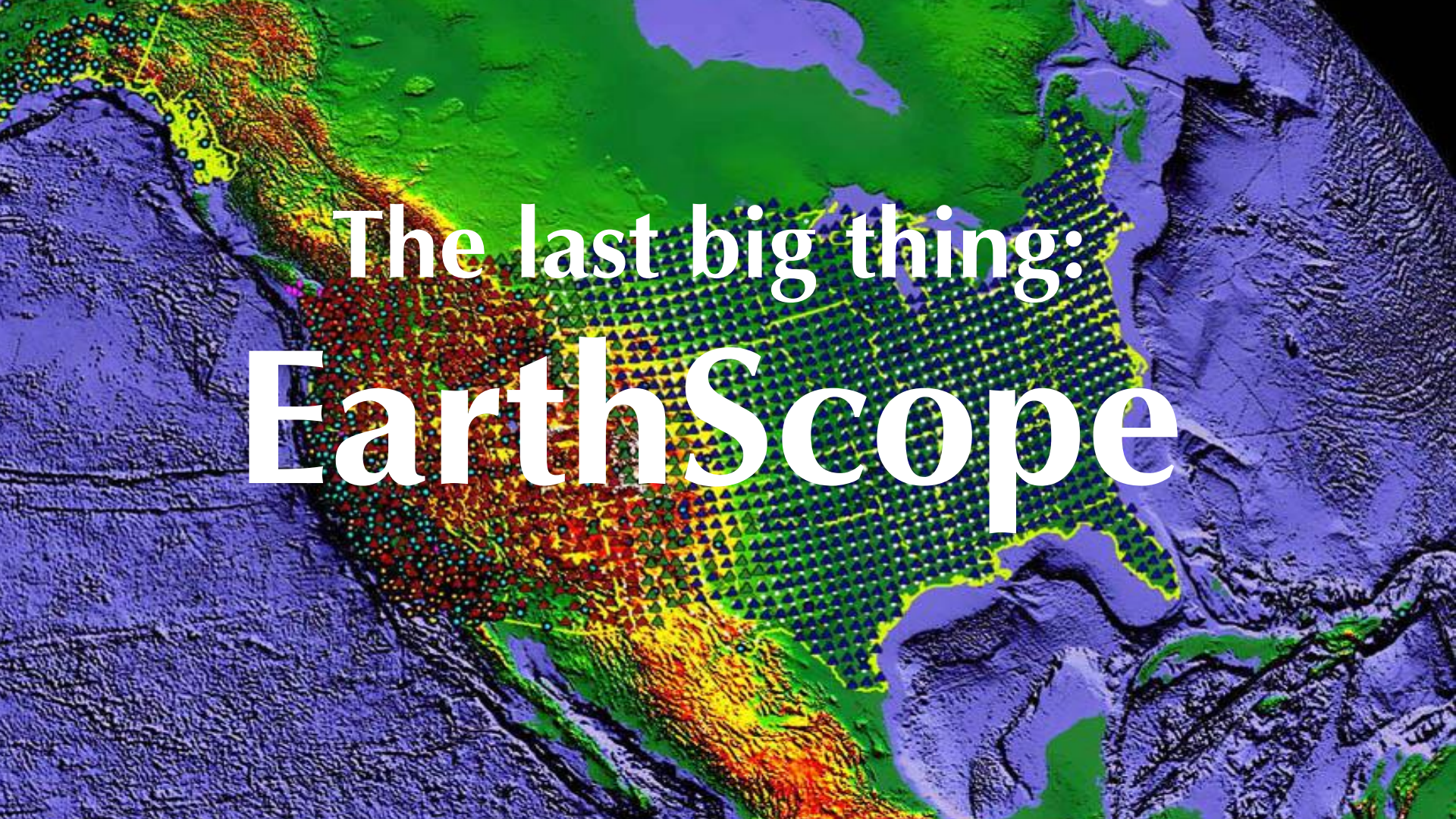
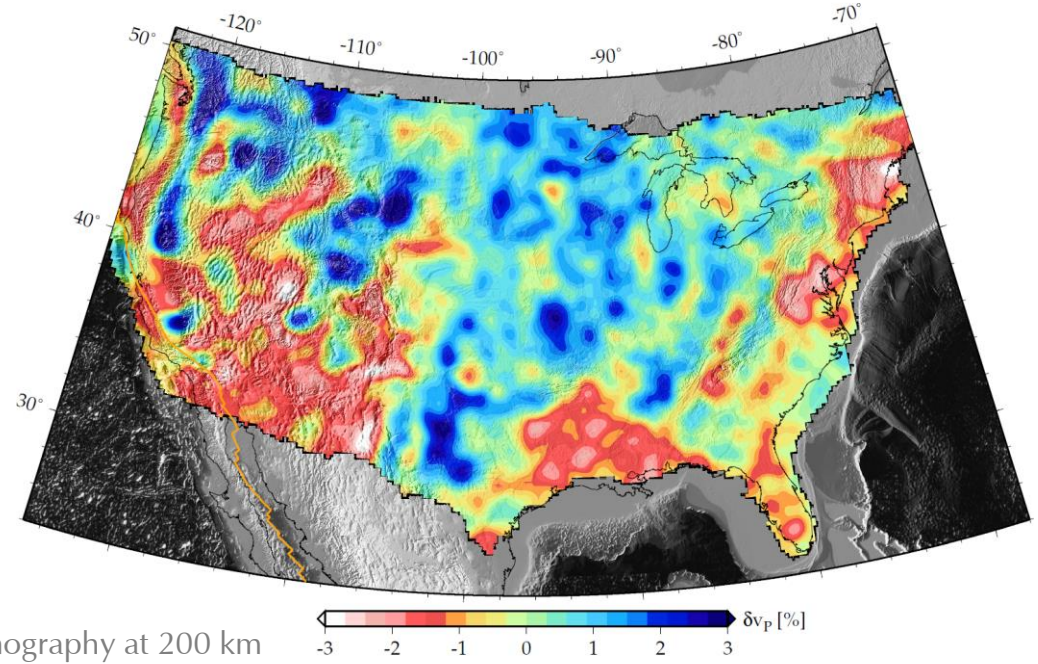
Modeling Collaboratory for Subduction Zone Science

Thorsten Becker (UT Austin)
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

NSF SZ4D Briefing
December 21, 2020

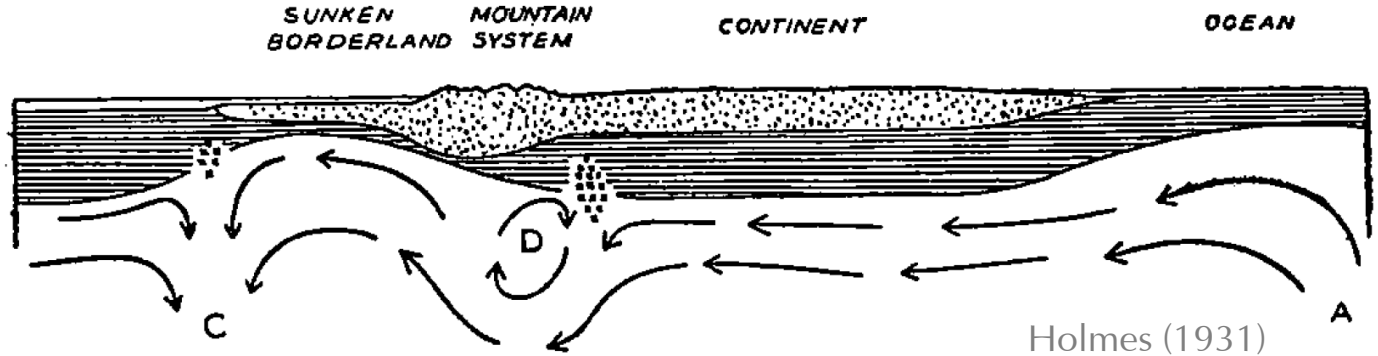
MCS RCN


The last big thing:
EarthScope

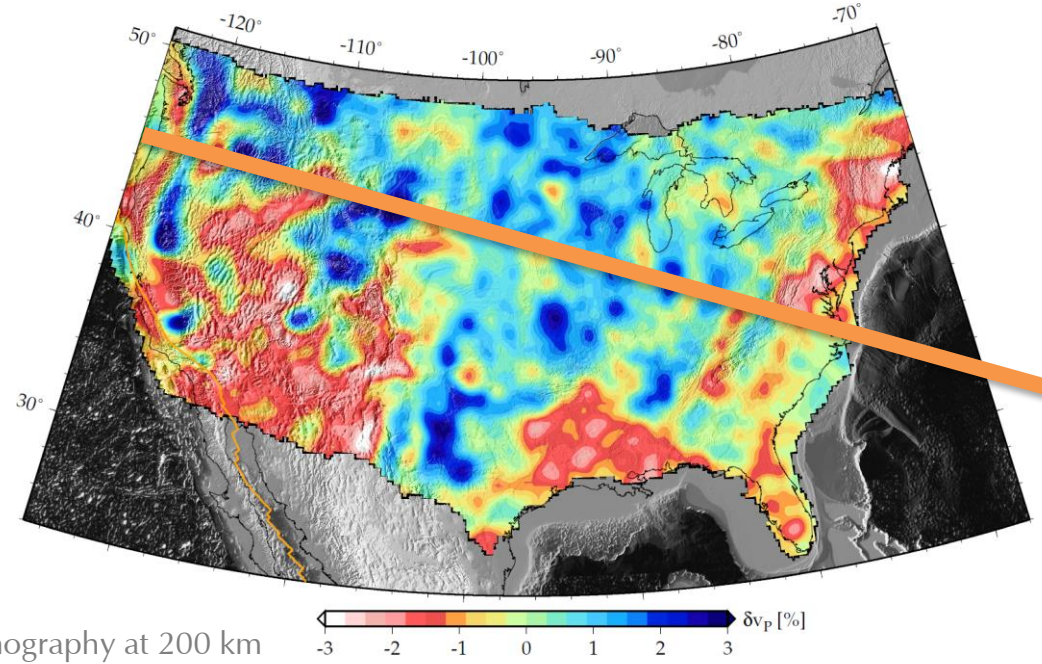


Tomography at 200 km
Schmandt and Liu (2014)

- Huge advance in imaging
- Major surprises
- Remaining challenges with quantitative integration for continental dynamics and inter-disciplinary systems science

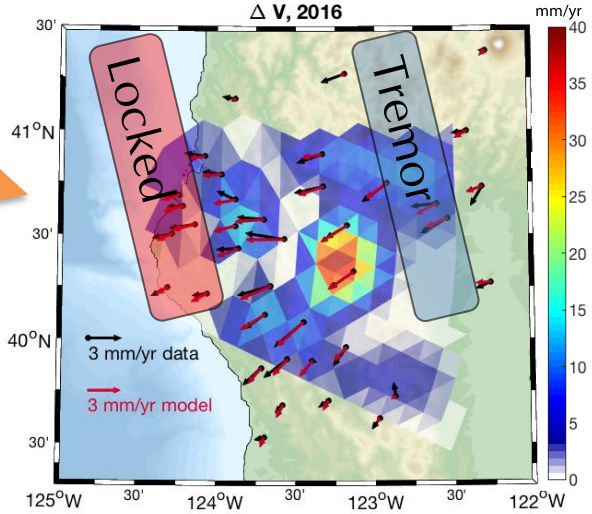


Holmes (1931)



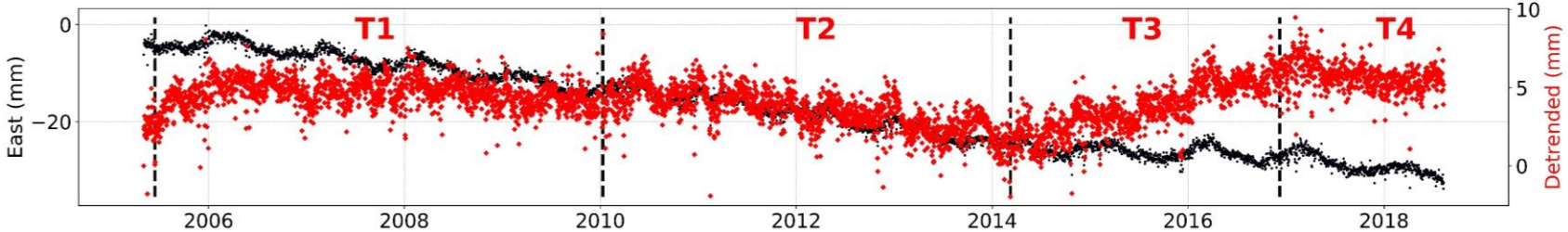
Tomography at 200 km
Schmandt and Liu (2014)

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



Materna et al. (2019)

GPS record of relative motion deviates from tectonic locking



Opinion

New Opportunities to Study Earthquake Precursors

Matthew E. Pritchard[*1], Richard M. Allen[2], Thorsten W. Becker[3], Mark D. Behn[4], Emily E. Brodsky[5], Roland Bürgmann[2], Cindy Ebinger[6], Jeff T. Freymueller[7], Matt Gerstenberger[8], Bruce Haines[9], Yoshihiro Kaneko[8], Steve D. Jacobsen[10], Nate Lindsey[11], Jeff J. McGuire[12], Morgan Page[13], Sergio Ruiz[14], Maya Tolstoy[15], Laura Wallace[3,8], William R. Walter[16], William Wilcock[17], and Harold Vincent[18]

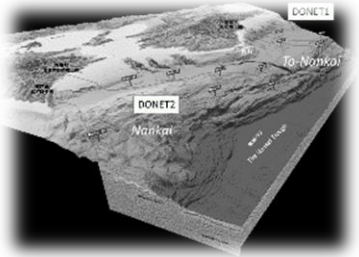
Pritchard et al. (2020), cf. 2019 COSEG Workshop at NASEM

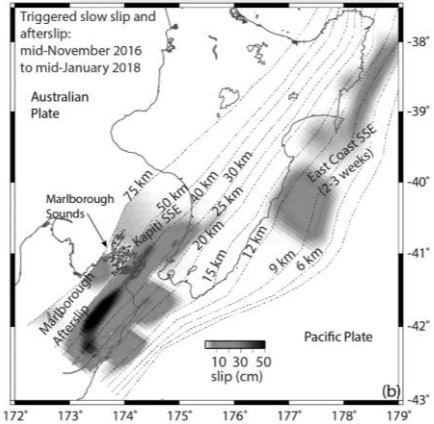
- How to link tectonic system transients to event probabilities?
- How to quantify uncertainties and unknowns?
- **How to build physics-based, predictive geodynamic models?**

Modeling Collaboratory for Subduction (MCS): Science

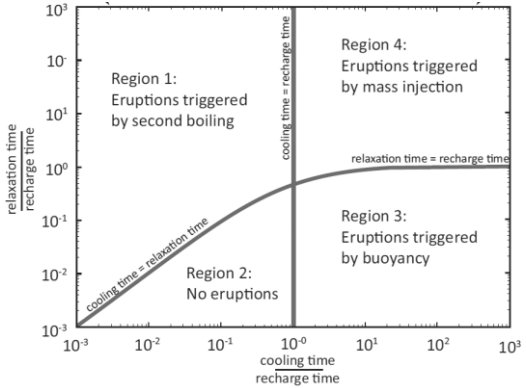
Understanding the physics of volcanic and earthquake systems

- 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)

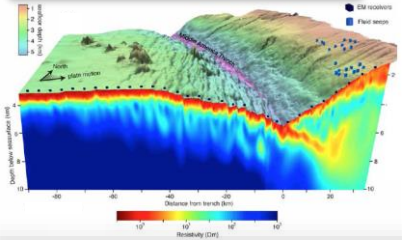
Modeling Collaboratory for Subduction (MCS): Approach

Science Driven Community and Model Building

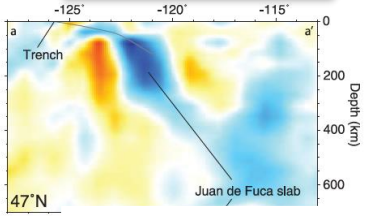
- Modeling framework for data integration and systems modeling
- Open, reproducible, international collaboration
- Geoscience and STEM capacity building
- Example for next generation computational geoscience effort

geological constraints

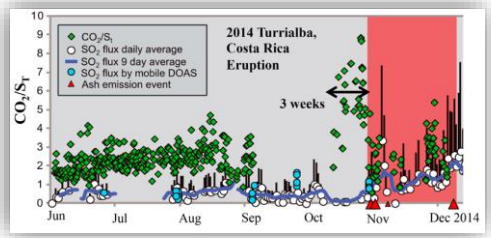
active source and MT

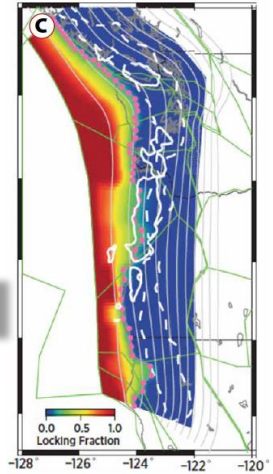


passive source

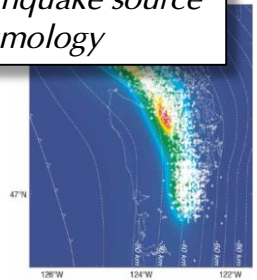


geomorphological constraints

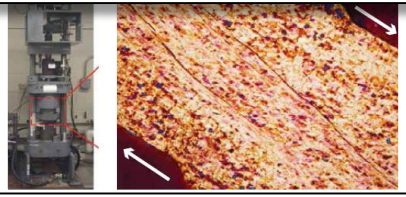




earthquake source seismology



Volcano and earthquake precursors



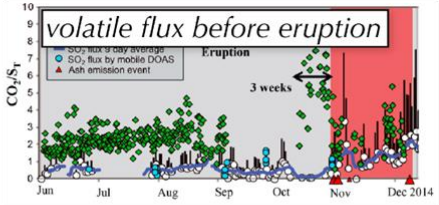
rock mechanics experiments

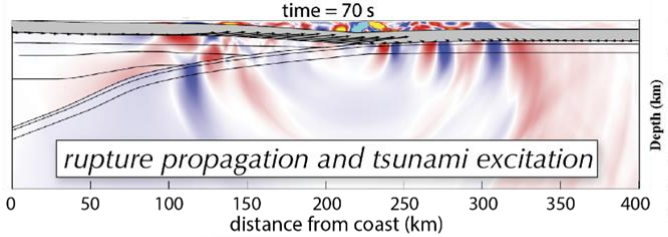
On- and off-shore geodesy

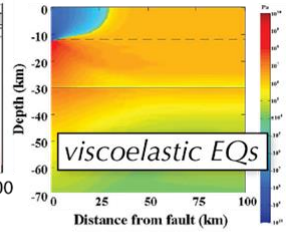
Gomberg et al. (2010); Naif et al. (2015); Chadwell et al. (2015); Schmalzle et al. (2014); Hawley et al. (2016); Tong & Lavier (2017); Proctor & Hirth (2015); W. Behr (pers. comm.), Kristen Cook

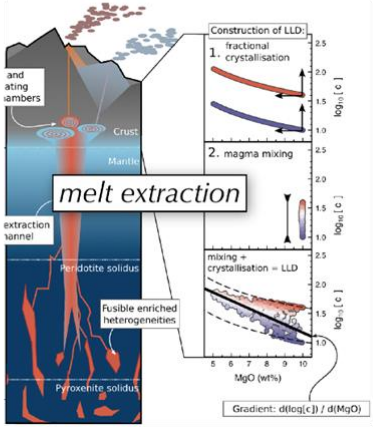
MCS: Modeling

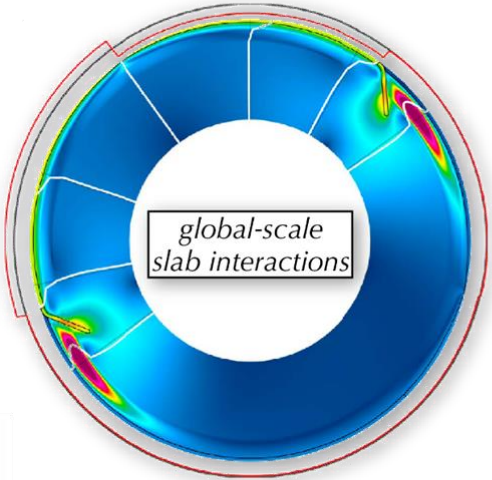
- **Understanding the dynamics of earthquakes and volcanoes in a societally relevant hazards context**
- Integrating multi-scale, multi-physics processes
- Assimilating multi-disciplinary, spatio-temporally heterogeneous data
- **Quantifying uncertainties & unknowns and designing the best experiments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

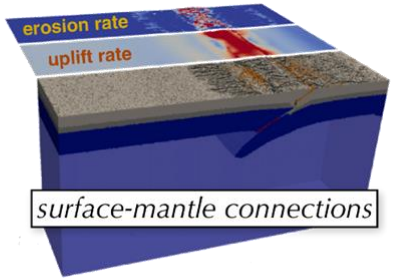


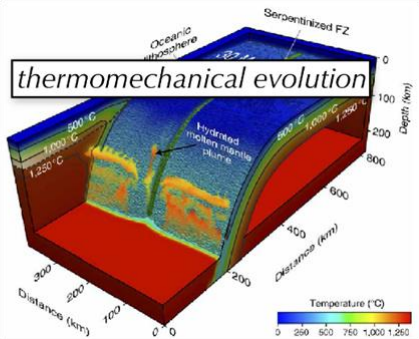


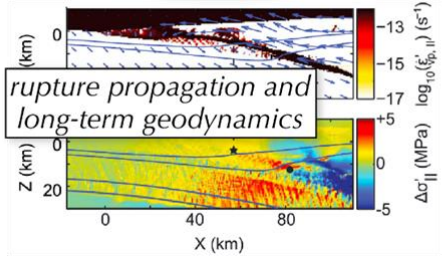


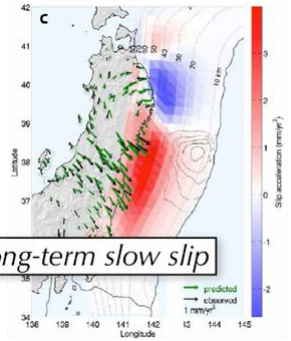










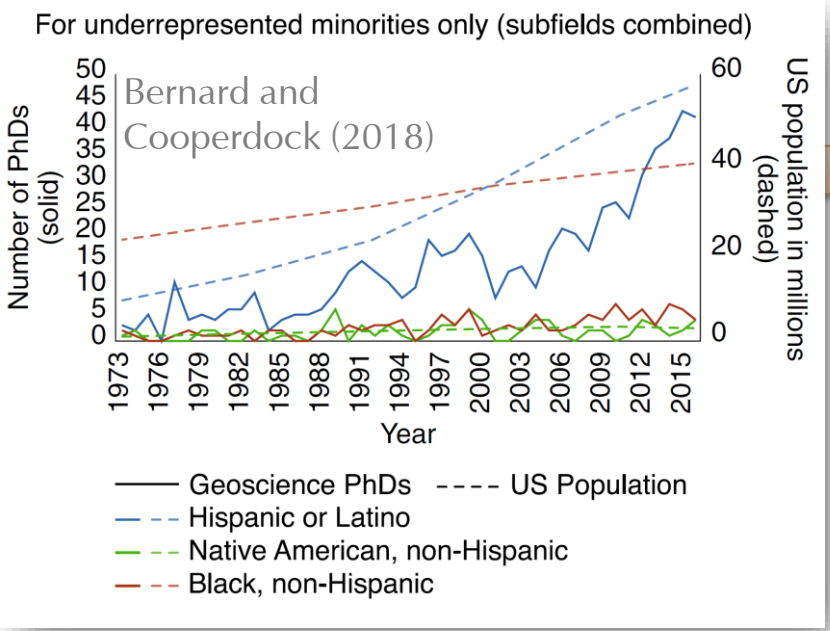


Mavrommatis et al. (2014); deMoor et al. (2016); Ueda et al. (2015)van Dinther et al. (2014); Allison & Dunham (2017); McCormack & Hesse (2017); Kozdon & Dunham (2014); Manea et al. (2014) Wilson et al. (2014); Gerault et al. (2012)

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)

Computational geoscience training as a complementary pathway for enhancing diversity

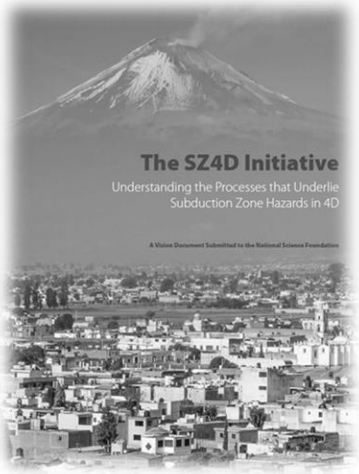


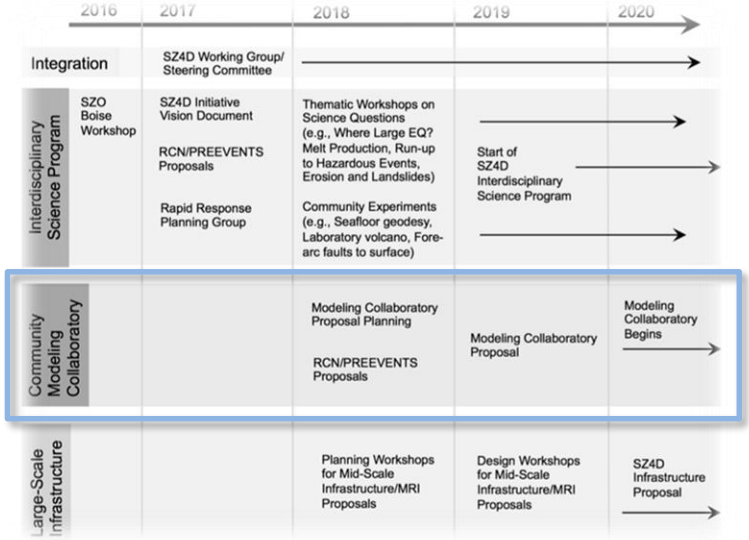
SCEC USEIt (2016), USC

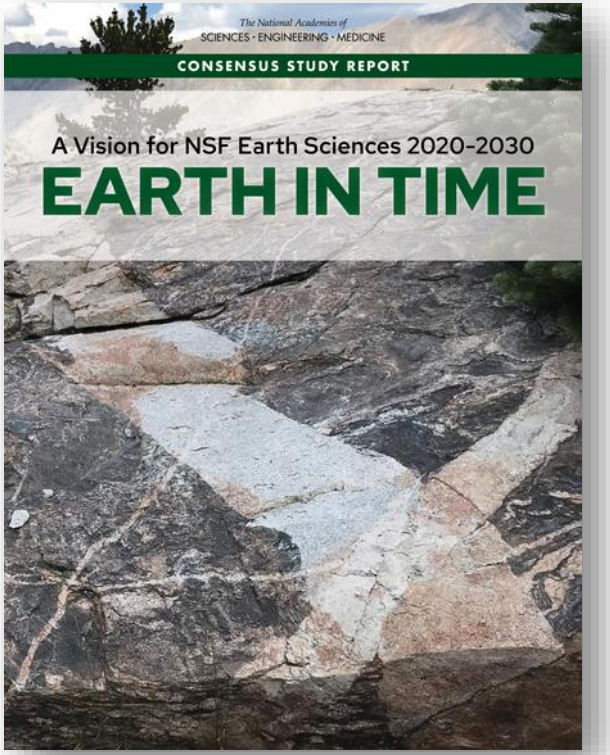
- Inclusive, scalable entry point for K12 science education underserved communities
- More students play computer games than go camping

MCS: Example science deliverables

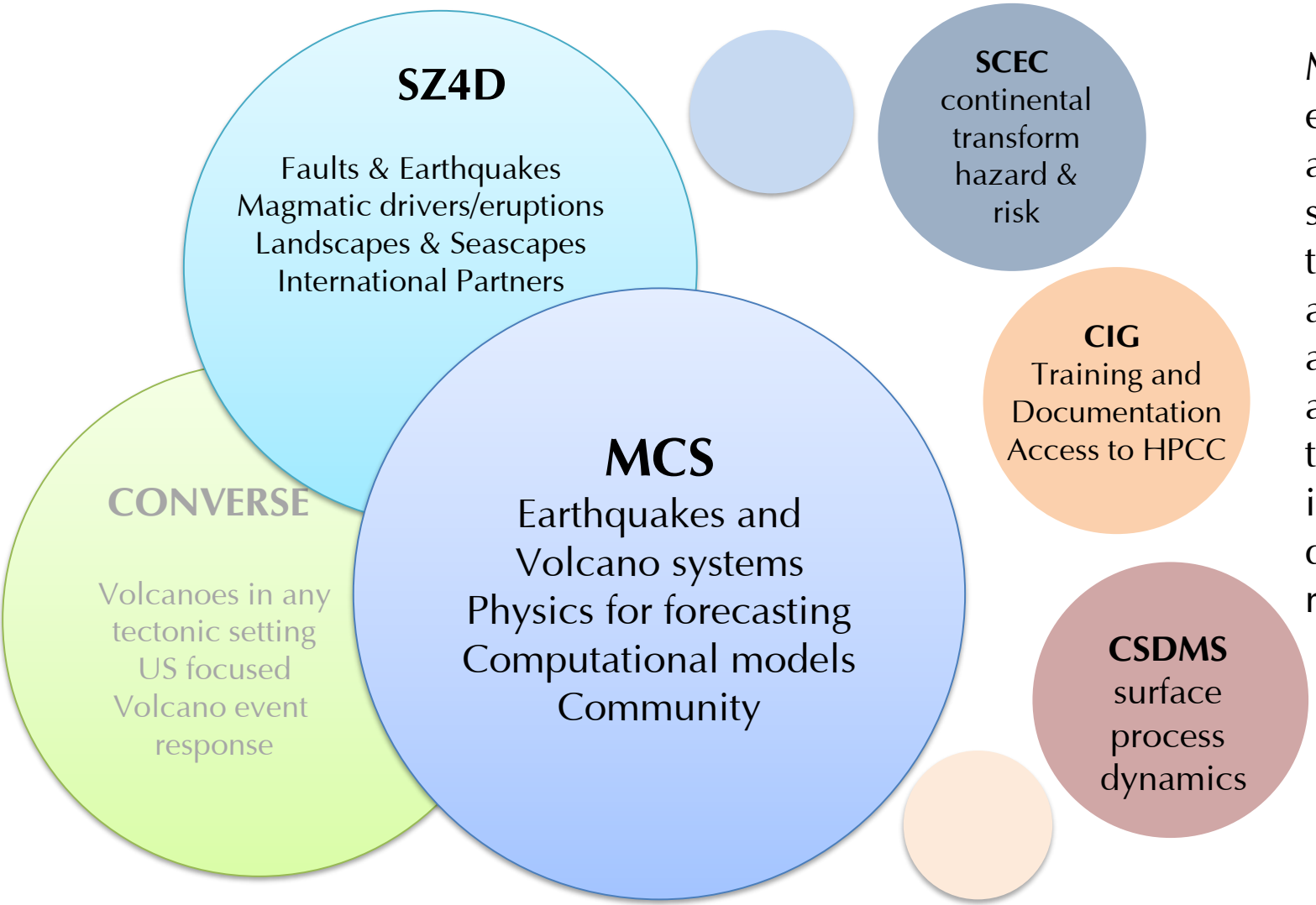
- Links between the style of **volcanic eruptions and thermo-mechanical structure of the crust and melt generation** within the mantle wedge
- Links between **long term evolution** of arcs (e.g plutons) and **short term hazards and monitoring** (active volcanoes)
- **Nature of asperities** (stationary 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)



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

Modeling Collaboratory for Subduction RCN

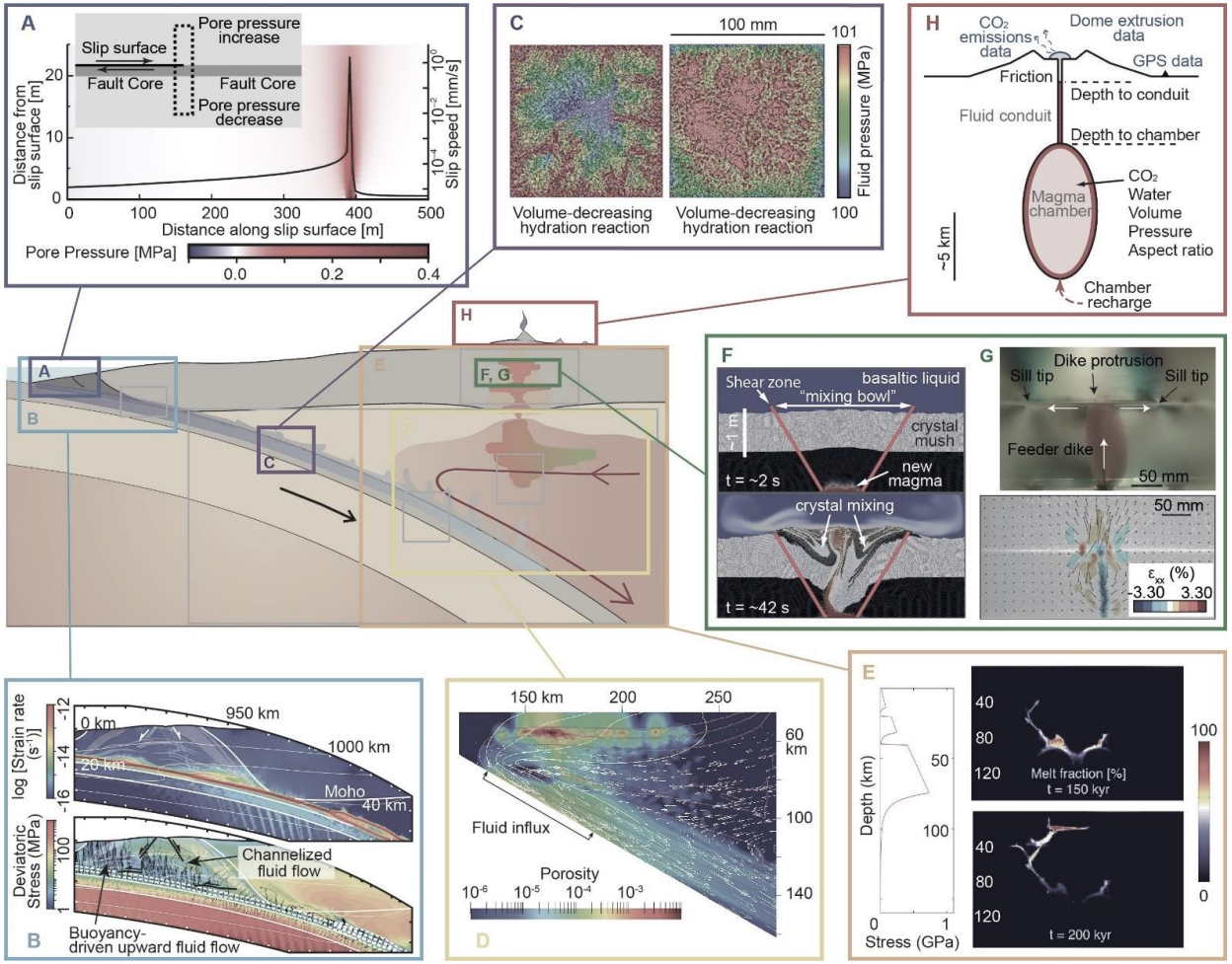
MCS RCN

NSF

@sz4d_mcs contact@sz4dmcs.org

sz4dmcs.org, Fall 2018 – Fall 2021

- Fluids
- Megathrust
- Volcanoes



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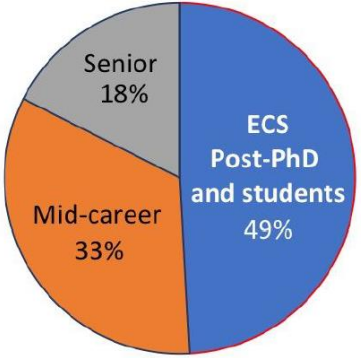


Modeling Collaboratory for Subduction RCN
Fluid Migration Workshop Report

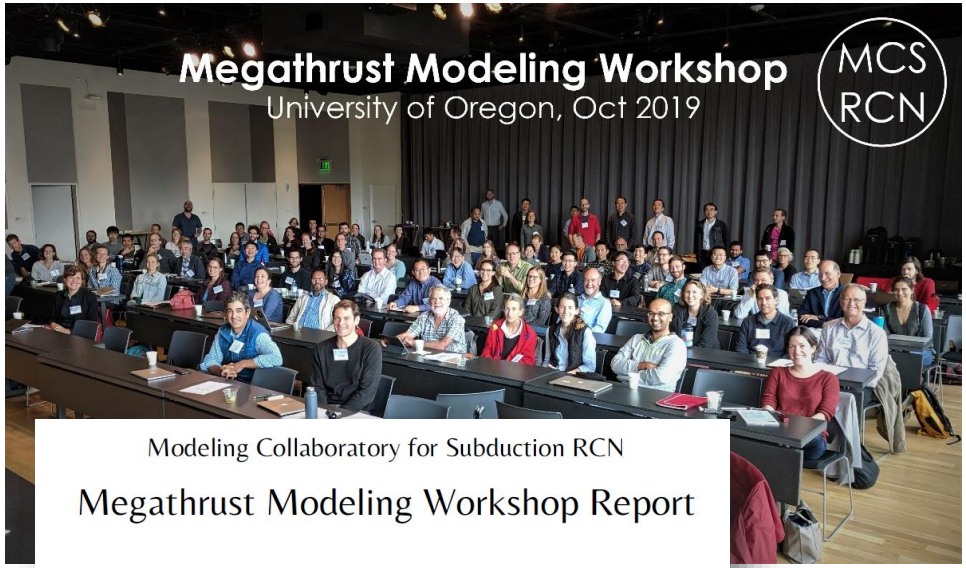
Fluids Report (download here)

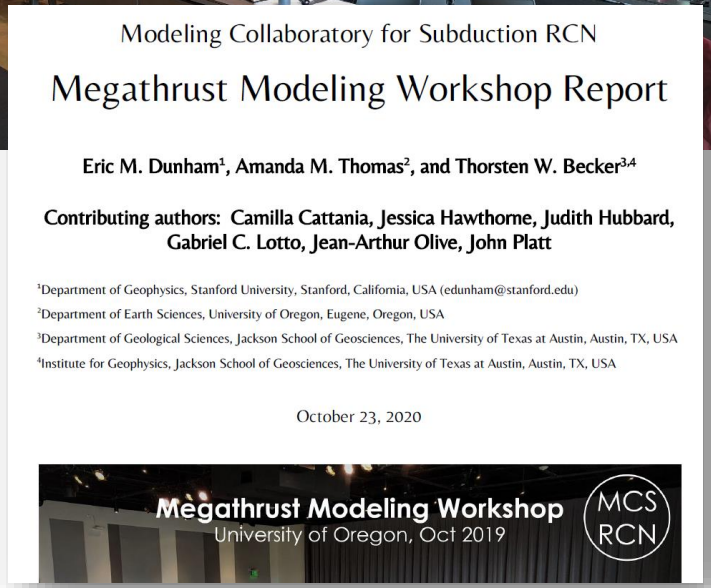
- Need better understanding of processes that control fluid migration
- Community modeling resources should include approaches for model validation
- Cross-disciplinary training and knowledge exchange
- Research would benefit from a multidisciplinary modeling collaboratory

s.org/fluids-workshop

Wada and Karlstrom (2020)

MCS RCN





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

Megathrust Modeling Workshop
University of Oregon, Oct 2019
MCS RCN

Dunham, Thomas, et al. (*EarthArXiv*, doi:10.31223/X5730M, 2020)

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

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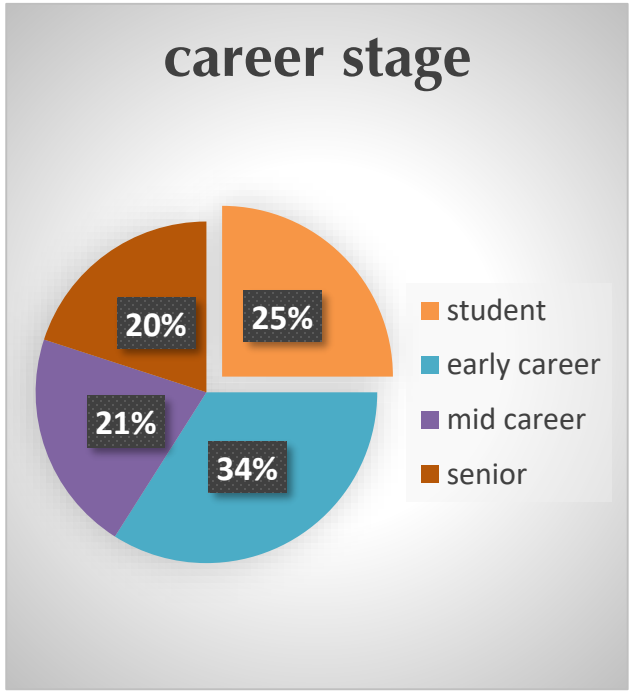
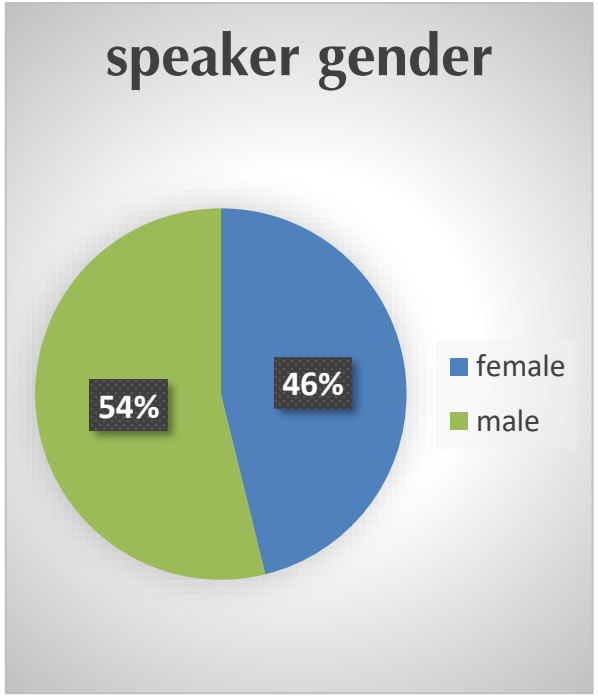
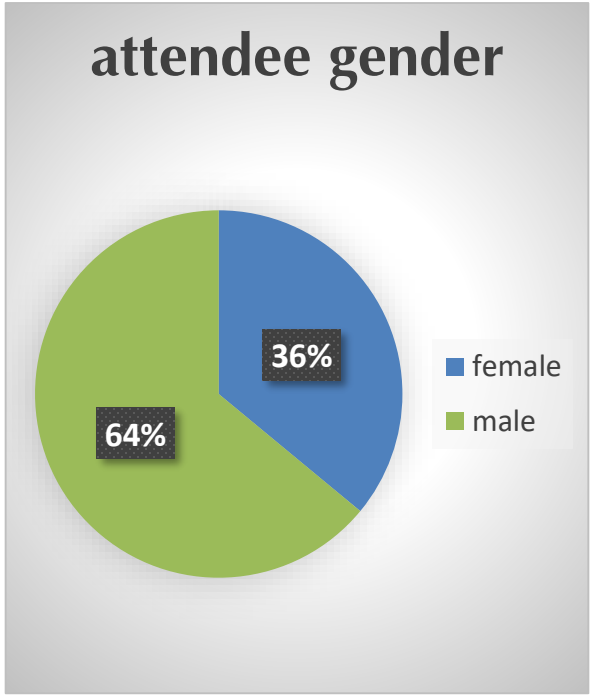
MCS RCN Megathrust Workshop (09/2019)

107 people in person + 123 virtual

57 institutions, 24 countries







www.sz4dmcs.org/megathrust-workshop

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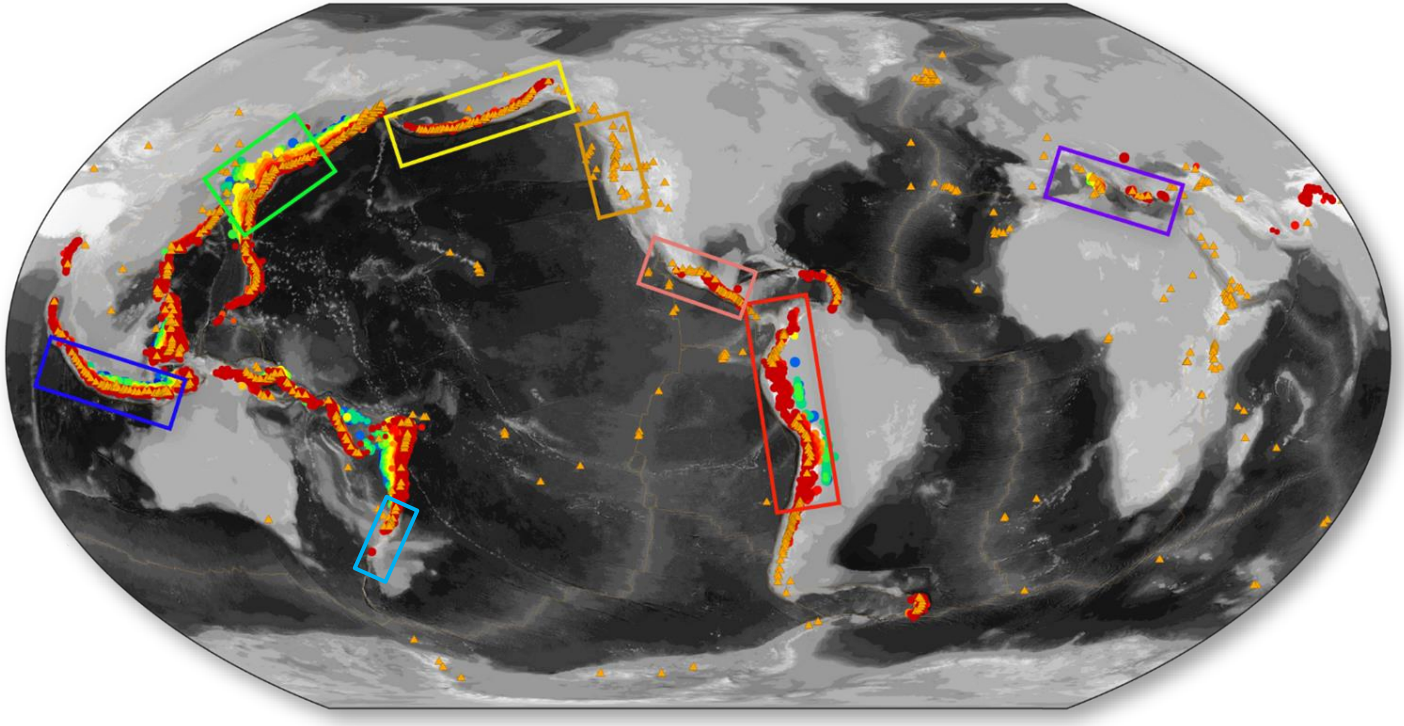
Modeling Collaboratory for Subduction: Global scientific exchange

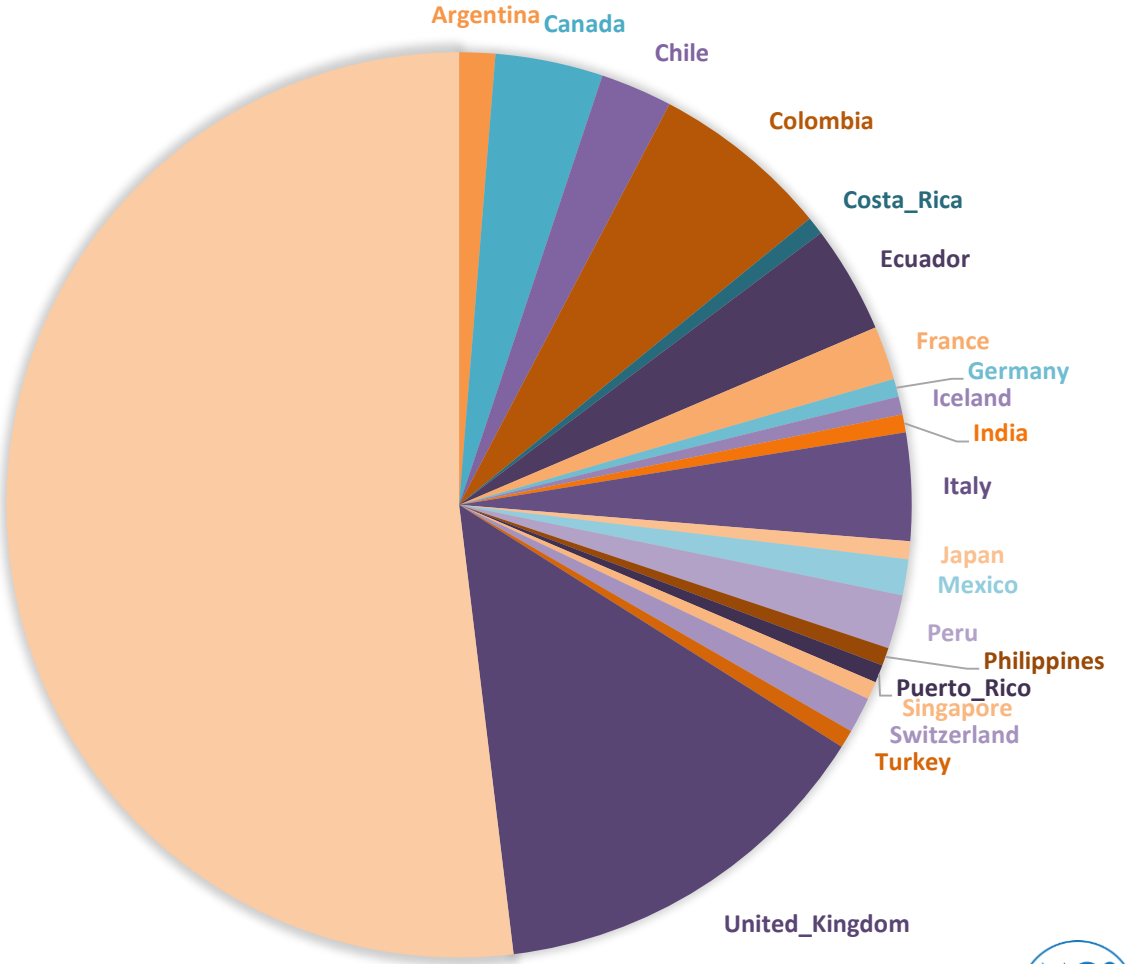
- apply and test modeling framework across different:
  - tectonic settings
  - stages of seismic and volcanic cycle
- Integrate with a network of global observatories
- **drive community support for open science – research and training**



(example observatories, completed to various degrees)

Volcanic Eruption Plume Webinar #2 (09/2020)

156 participants



MCS RCN Activities Timeline

Workshop 1: Fluid and Melt Transport

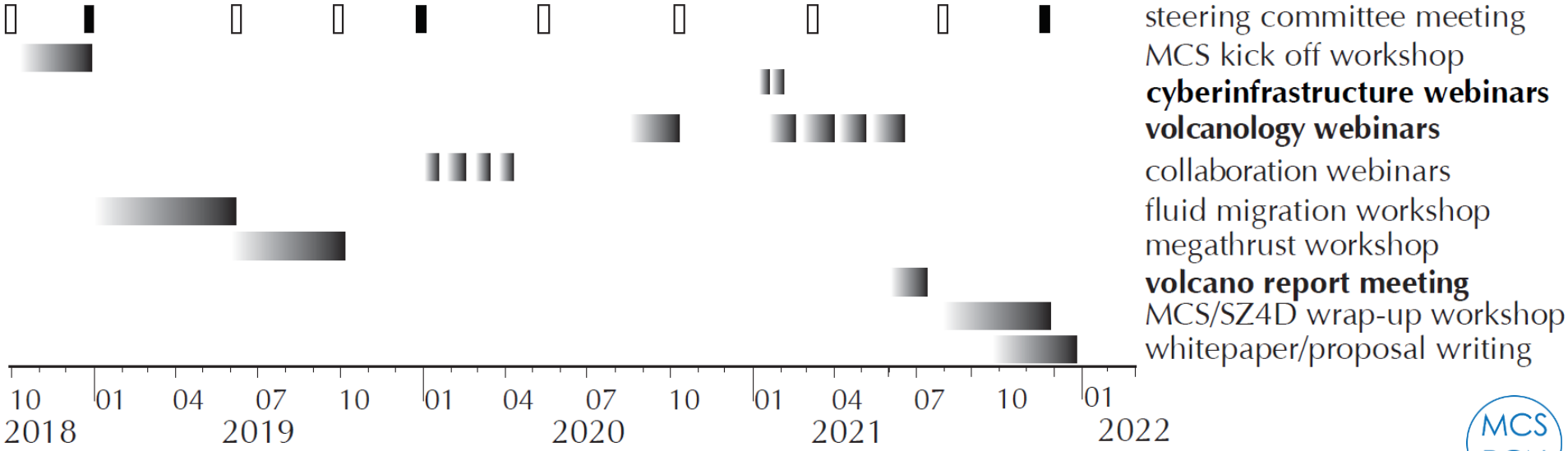
- Fluid migration & fracture formation in magma systems
- Lithosphere-scale magma transport
- Microscopic and short-time-scale processes

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?



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Questions and comments?

MCS RCN

@sz4d_mcs contact@sz4dmcs.org

Volcanic Systems Modeling Workshop

Jan - May 2021
online, via Zoom

Register Here

Meeting Format (updated Dec 2C

Dates: ***26 January - 8 May, 2021, various dates (see below)***
Location: **online via Zoom webinar (register here)**

The workshop will be divided into five science-centered ***themes***. Each theme will be successive Tuesdays in conjunction with the International Volcanology Seminar, and ***meeting***. Webinars will be recorded and available for anyone to view at their leisure and provide input on any aspect of the volcanic systems virtual workshops ***asynchro***

Each webinar will be comprised of two science talks plus time for science questions, guided by specific questions focused on the MCS (within the context of the given the community an opportunity for active contribution to the MCS.

For each theme the working group meeting will be a few days after the second webi scientist interested and willing to commit to active participation, with some working themes, and others participating in select themes only. The objective of the working community input provided under each theme into a written report. The combined tl single final MCS Volcanic Systems report.

In summary:

- 5 *themes*, each comprised of 2 *webinars* + 1 *working group meeting* + *asynch*
- 1 summary report per theme.
- 1 *final working group meeting* to produce a final integrated MCS Volcanic Sy

By agreeing to participate in a MCS event, participants agree to abide by

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, Pritchard, Jackson, Bergantz.

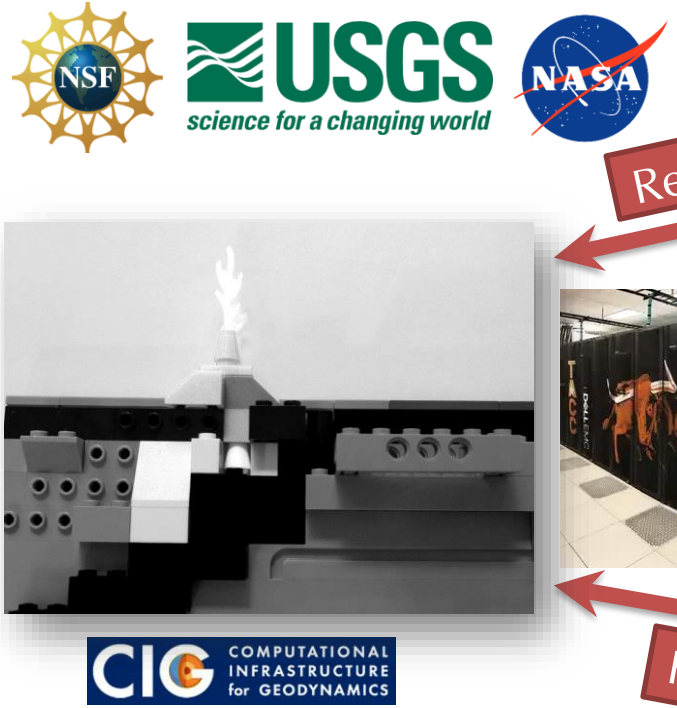
2. **Magma storage**
   - Needs and opportunities for modeling the evolution of magma chambers, their architecture and dynamics. Internal mechanisms that drive chambers toward eruption include recharge, differentiation, rejuvenation, and volatile accumulation. Opportunities and needs for modeling 'essential' 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*: Huber, Ghiorso, Hooft, 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' Michieli Vitturi, Rivalta, Roman, Myers

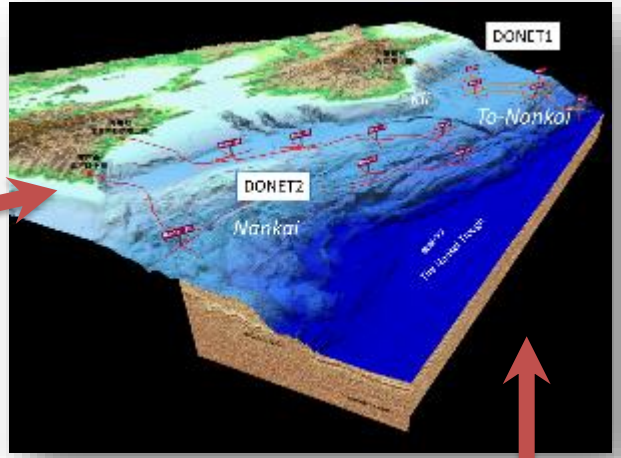
4. **Eruption Plumes**
   - Overview of eruption plume modeling, fluid dynamics of volcanic plumes, model intercomparison, eruption source parameters derived from tephra deposits, and operational plume modeling. These webinars took place in September 2020 and are available here. Speakers were Costa,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

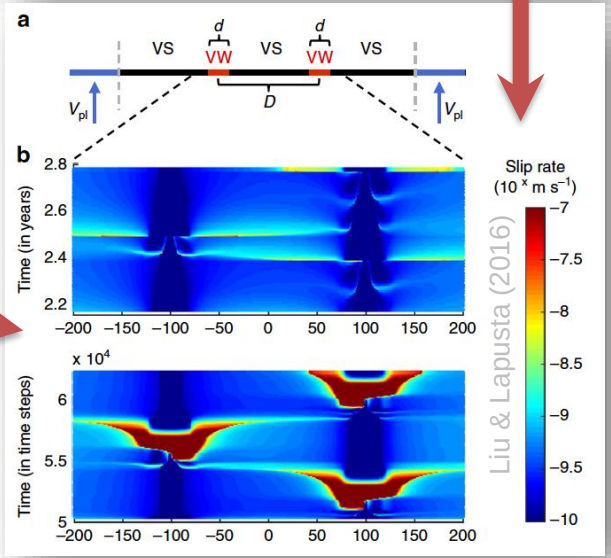
5. **Integrative volcano modeling and forecasting**
   - Linking magma storage, transport, and eruption modeling. Integrating observations with models of volcanic systems with the goal to advance understanding and forecasting. Opportunities and needs for coupling models between disciplines and problems, 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 Mével, Bato

MCS connections and partnerships

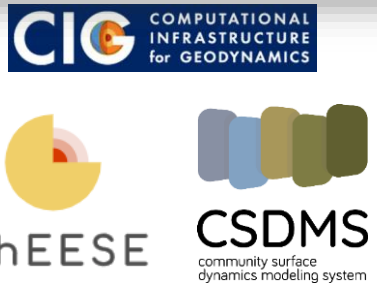


Regional data assimilation





Fundamental physics



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

MCS RCN

VOLCANOLOGY WEBINAR 1 ATTENDANCE

Volcanic Plume Eruption
Webinar #1
191 participants