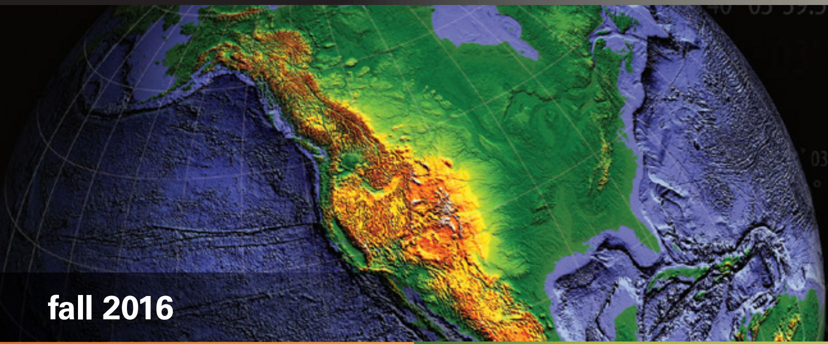

inSights
the EarthScope newsletter

fall 2016

EarthScope News

inSights moving to email format

Over the years, the EarthScope National Office has delivered quarterly updates as printed and electronic newsletters. inSights is making its final move, to an emailed format. Look for the Winter 2016 issue in your Inbox! Make sure your email is current in our mailing list.

EarthScope at AGU

If you are attending the annual AGU meeting this December in San Francisco, be sure to check out the recent EarthScope science that will be presented there. For a comprehensive list of EarthScope-related presentations, visit http://www.earthscope.org/events/agu-meeting-2016. And be sure to visit us in the exhibit hall at booth #519, between UNAVCO and IRIS.

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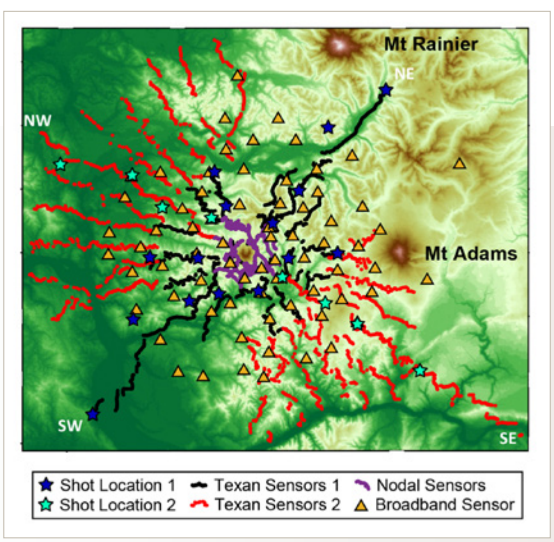
The Multi-Chambered Heart of Mount St. Helens

Enhancing earthquake detection and imaging beneath the volcano

by Gail McCormick

The most active volcano in Cascadia has a lot going on downstairs. Earthquakes are common under Mount St. Helens, but they don't all originate from tectonic forces, which are the most common culprit for earthquakes globally. Generating and moving melt under a volcano can also cause earthquakes, motivating scientists to resolve the links between earthquakes and magmatic processes. To do so, researchers at Mount St. Helens are working to gain a better understanding of the volcano's innards. From this pursuit was born the iMUSH project—imaging Magma Under St. Helens—a collaborative effort funded by the NSF GeoPRISMS, EarthScope, and Geophysics programs. The project has enhanced the image resolution of subvolcanic structures by temporarily tapping a deployment of nearly 6,000 seismometers in an area that is normally monitored by about 15.

"A lot of people would have a cartoon of a volcano in their mind that has a balloon of liquid magma downstairs. Probably not too many volcanoes look like that," says Dr. Brandon Schmandt, Assistant Professor of Geophysics at the University of New Mexico (UNM) and a member of the interdisciplinary team investigating the plumbing system beneath St. Helens. He joined a team of seismologists from University of Washington, Rice University, Cornell University, and the Cascades Volcano Observatory who designed the seismology portion of the project. (See the iMUSH and USArray support websites for more information).



This shaded-relief map of Mount St. Helens and surrounding peaks shows how seismic instruments were arrayed across her flanks for the iMUSH experiment. The instruments include broadband seismographs, geophones with mini seismic recorders called "Texans" (deployed in two phases), and cable-free geophones, or nodes. The stars, labeled as shot locations, are the sites of the controlled, small-scale explosions.

Understanding the Mount St. Helens plumbing system has long been an objective of geologists. With enhanced imagery made possible through the considerable increase in seismometers near the volcano, they are starting to see that magma may occupy multiple chambers at various depths.

The instrument array of the iMUSH project captured seismic waves reflecting and refracting off of subterranean rocks, in a manner similar to a CAT scan. In addition to enhancing the subvolcanic imagery, the large number of recording stations greatly boosted their power to detect tiny tremors that previously slipped under the radar of the pre-existing smaller network, enabling the iMUSH team and their colleagues to better determine when and where earthquakes are occurring under Mount St. Helens.

Magmatic structure and small earthquakes provide complementary information that may help iMUSH researchers be able to better link the earthquakes to magma transport and eruptive activity. "We might be able to better identify if changes in earthquake

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The Multi-Chambered Heart of Mount St. Helens

Enhancing earthquake detection and imaging beneath the volcano

activity are related to magma movement or if they're just related to tectonic stresses jostling things around," says Schmandt.

The temporary array placed around the mountain includes 70 broadband seismic stations (provided by IRIS) that just finished a two-year recording gig, 904 smaller seismometers (from the company NodalSeismic) that recorded for two weeks in summer 2014, and about 5,000 other small seismometers (also IRIS provisioned) that focused on recording controlled explosions. The 904 seismometers that recorded continuously for two weeks were all within 15 km of the volcano where nine long-term seismometers normally operate as part of the Pacific Northwest Seismic Network. These units, called nodes or cable-free seismometers, were originally developed by the oil and gas industry to find subsurface oil and gas. Deployment of the nodes by a team from UNM was a late add-on to the iMUSH experiment in summer 2014.

Schmandt describes the nodes as cylinders six inches tall by five inches wide. "They're the size of a big soup can," he says. The nodes are self-contained and include a battery, a GPS clock, internal memory, and a geophone that measures ground movement. They're completely cable free, which, when combined with their small size, means they can be deployed rapidly and in great numbers even in the wilderness.

"Generally the passive, or natural-source, seismology community has worked with many, many fewer stations," says Schmandt, "which have a much bulkier setup with an external power system and a solar panel." A power system allows the larger broadband stations to record for a few years with proper maintenance and to record across a larger-frequency range than the nodes, but their more entailed deployment is limiting. "If we just have to stick a soup can in the ground, we can install a lot more."

The trade-off with deploying many instruments is usually time. Large numbers of smaller-sized instruments make for short-term experiments, typically only recording for 24 hours. In 2014, the 904 nodes around Mount St. Helens recorded continuously for two weeks, roughly the extent of their battery life. Although two weeks seems like a short period, it greatly boosted the earthquake monitoring array over that time and provided the largest continuous seismic dataset for an active volcano.

A node seismometer stands in front of Mount St. Helens; it is pinned to the ground beneath it with a stake. (photo credit: Brian Haug)

Identifying Earthquakes

Continuous seismic monitoring using nodes has only recently been adopted by the research community, and Schmandt and colleagues demonstrated their ability to monitor earthquakes in the shallow crust. They used a method called "reverse-time imaging" to automatically detect small earthquakes, or microseismicity, with the dense array.

"The previous network would have detected about 50 earthquakes," says Schmandt. "At this point using our array, we've boosted that to something more like 1,000." Among these, about 200 were used by Dr. Xiaofeng Meng, a postdoctoral seismologist at University of Washington, as templates to detect more than 800 additional earthquakes with the node array. The depth and frequency of the earthquakes was surprising—the bulk were shallow, occurring at an average rate of four per hour during the two-week period, much more frequently than previously recorded. The reverse-time imaging results from Schmandt and Dr. Steve Hansen, a UNM postdoctoral seismologist, appeared in a recent issue of Geophysical Research Letters.

"The exact number of earthquakes is not so important," says Schmandt, "but the big increase gives a chance to see whether the locations of earthquakes are steady or if they evolve over time." Investigating where earthquakes occur gives insight into why they occur if we have good images of the subsurface structure. Analyzing a greater number of earthquakes increases the ability to accurately identify trends in where they occur.

Most earthquakes are created by slip on a fault, but this is not always the case at volcanoes, explains Schmandt. "We get a rather complicated set of different types of seismic signals that come from volcanoes," he says. "A lot of them do look like fault-slip signals, but many of them don't." For example, movement of magma or opening and closing of cracks in the crust should produce signals that differ from earthquakes along faults, possibly explaining the complexity of earthquakes in volcanic fields.

Using the nodes, Margaret Glasgow, a graduate student at UNM, detected some unusual earthquakes that otherwise would have gone unnoticed. These start quiet and gradually become loud, have only low-frequency signals, and last longer than other earthquakes. Such long-period, low-frequency earthquakes have been observed in the past during times of volcanic activity, but in this study they were detected under Mount St. Helens during a quiescent period, and in some cases multiple times a day.

"This brings up the questions, 'Are these happening all the time? Are these the same areas that would produce them later on in a more active phase?'" Schmandt hopes that continued monitoring, analysis, and imaging will help reveal connections between these unusual earthquakes and volcanic activity.

Under the Mountain

While enhanced monitoring of volcano-related earthquakes is helping to resolve the structure under the volcano and provide a link between the quakes and underground adjustments, to really characterize the structure

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The Multi-Chambered Heart of Mount St. Helens

Enhancing earthquake detection and imaging beneath the volcano

beneath the volcano, Dr. Eric Kiser of University of Arizona and other iMUSH researchers are using seismic tomography. With this method, they create 2D and 3D images underneath Mount St. Helens from the surface to the crust–mantle boundary.

Called tomographic imaging, this approach measures seismic waves from two sources—a series of controlled small-scale explosions that generate seismic waves for the purpose of the imaging, otherwise known as active-source seismology, and waves from earthquakes or ambient noise in the earth, or passive-source seismology. The controlled explosions are set off in specially drilled wells, and can only be felt by humans on the surface within about 50 m of the site. The seismic waves refract and reflect in subsurface formations and are picked up by instruments on the surface. The resulting images show variations in the speed of seismic waves, allowing scientists to make inferences about properties of the materials that the waves passed through, such as temperature, composition, and presence of melt.

The iMUSH team set off 23 controlled explosions whose seismic waves were picked up by a temporary array of about 2500 instruments, including the 904 nodes. Hansen, the UNM postdoctoral seismologist, and others discovered a sharp transition in reflectivity at the Moho—where the earth's mantle meets the crust—just beneath Mount St. Helens. They believe this is due to a shift in the composition of material in the uppermost mantle that is driven by dehydration of the subducting plate and changes in temperature suggesting that mantle melts originate east of Mount St. Helens. This matches up with recent imaging of the area by Kiser, who identified multiple magma reservoir beneath Mount St. Helens with seismic tomography. The upper-crust reservoir is directly beneath the volcano, but another potential reservoir southeast of the volcano lies at about 20-40 km deep, in the lower crust. A number of low-frequency earthquakes have occurred on the boundaries of the lower-crustal reservoir, which Kiser suspects may mark magma movement from this reservoir. His findings were published in a recent issue of Geology.

Moving Forward

iMUSH researchers have already produced a number of 2D images and are working on 3D images using both active and passive sources to create a comprehensive map of the area. The 3D images would enhance monitoring efforts and analysis of seismic activity at Mount St. Helens.

"We could put earthquakes in context," says Schmandt. "We won't just say that they happened somewhere near Mount St. Helens deep underground. If they're right on the edge of a magma reservoir that we image, that's something that we might want to pay attention to more than if they're far from the magma plumbing system."

The iMUSH project and the impressive but temporary increase in imaging power may also guide future monitoring practices. Instead of nine or 900 recording stations, Schmandt hopes to determine the optimal number and arrangement of instruments needed to adequately identify earthquake sources. "Is it just 25?" he asks. "Where would we put them? In what arrangement? What frequency range would they need to cover if we wanted to identify these strange low-frequency sources that might be related to fluid movement? These are the kinds of things we want to keep track of between volcanic events."

Schmandt remarks that even if the network at Mount St. Helens remains unchanged moving forward, the 3D models emerging from the project will be a significant step forward, allowing scientists to put earthquakes in a much more refined structural context than previously. ■

The iMUSH seismology principal investigators include University of Washington's Ken Creager, Heidi Houston, and John Vidale; Alan Levander of Rice University; Geoff Abers from Cornell University; Seth Mora of the U.S. Geological Survey Cascades Volcano Observatory; and University of New Mexico's Brandon Schmandt.

Watching a Volcano Breathe

Plate Boundary Observatory monitoring networks on Mount St. Helens

by Beth Bartel and Elisabeth Nadin

Mount St. Helens was studded with thousands of instruments for the relatively short-term objectives of the iMUSH project, but her restless nature requires long-term monitoring as well. The iMUSH team also incorporated a four-station borehole geophysics network that is part of EarthScope's Plate Boundary Observatory (PBO). Borehole seismometers and strainmeters record many small earthquakes and are poised to record any sudden movements related to magma migration. The iMUSH team used data from the seismometers, which often yield the cleanest, quietest, clearest seismic signals because they are installed in holes around 750 ft deep.

Along with the eight tiltmeters and 17 continuous GPS stations on and around the volcano that are also part of PBO, the borehole instruments monitor volcano deformation that is likely linked to eruptions. Maintaining continuous data for these instruments is challenging, yet critical for researchers as well as for partners at the U.S. Geological Survey charged with monitoring the volcano's activity. The GPS stations, for example, have recorded the slow inflation of the volcano since the end of its 2004–2008 eruption.

PBO instruments plug away through the snowy winters, facing snowpacks and snowdrifts that sometimes reach a crushing thickness of 30 ft. Heavy rime ice can distort GPS signals. They collect data year-round thanks to large battery banks and well-anchored fiberglass huts designed to resist snow damage.

For more on how UNAVCO keeps PBO stations running on Mount St. Helens, check out this short video: Instrumenting Mount St. Helens: Plate Boundary Observatory Lessons Learned. ■

Instruments near the summit of Mount St. Helens capture its every move. (photo credit: Beth Bartel, UNAVCO)

Driving the Dempster

The Transportable Array deploys along a remote Canadian "highway"

by Andy Frassetto

In summer 2016, instruments of the Transportable Array (TA) were deployed along the Dempster Highway, which traverses vast wilderness in the Yukon and Northwest Territories of Canada. The Yukon is a region larger than the state of California, with a population of around 35,000 people and a few major roads providing direct access to only a small part. The Dempster is one of these, an engineering feat that traverses 736 km of gravel berm built over two decades to serve Canada's economic interests along the Arctic Ocean. The road overlies permafrost in many places, requiring constant maintenance, and is subject to periodic closures due to washouts and avalanches. Near its northern extent, summer ferry crossings and winter ice roads substitute for bridges.

The remoteness of this stretch of road is the exact reason that Jeremy Miner and Andy Frassetto from IRIS, along with Jim Coates and Astrid Grawehr of Darkside Drilling made their way northward from Whitehorse, Yukon in two pickup trucks, a flatbed, and a drill rig on August 21. En route to the active gold rush town of Dawson City, Jeremy and Andy upgraded a communications relay at TA.M30M, and the next day the group drilled and installed new station TA.K29M. Embarking on the Dempster the following morning, they installed two new, complete stations TA.G30M and TA.F31M north of the Arctic Circle. The team installed a new borehole sensor at Eagle Plains (TA.EPYK), which has operated a TA seismometer since October 2012. TA.F31M is located within the First Nation village of Tsiigehtchic, a friendly community located at the intersection of two rivers. During the TA crew's visit, the locals were enjoying a period of unusually warm late-summer weather while Andy, Jeremy, Jim, and Astrid battled lingering swarms of black flies.

Driving the Dempster Highway is an unparalleled experience—stretches of it are wide straightaways through the wilderness, where the crew spotted bears and foxes. The 2000-mile expanse took the IRIS team eight days to cover for three new station installs and upgraded equipment at two more. For an up-to-date map of installation progress in the North, visit http://www.usarray.org/alaska ■

The Dempster Highway winds southward in the distance from station TA.G30M, situated north of the Arctic Circle.

Fall Creek, Oregon

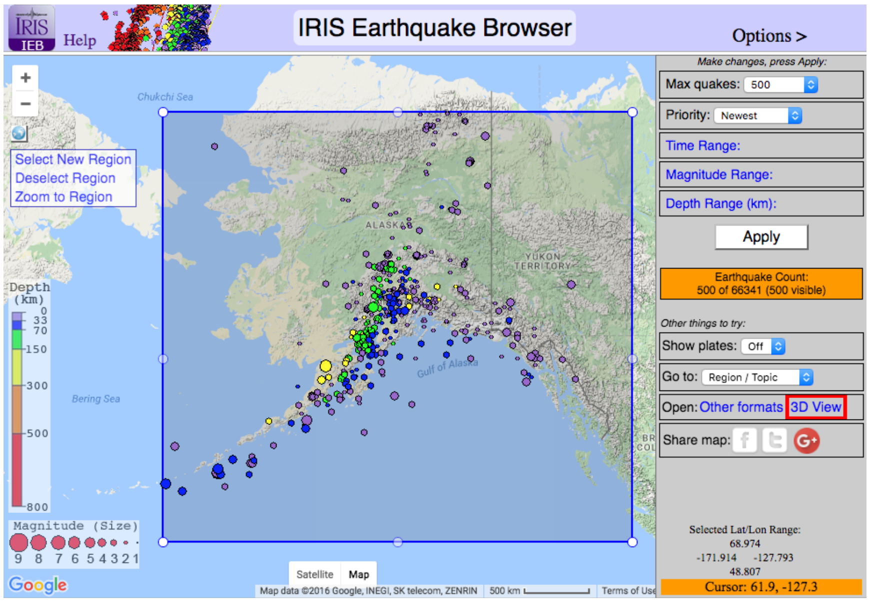
Borehole strainmeter B030 records slip around the world

by Beth Bartel

Borehole strainmeters in the EarthScope Plate Boundary Observatory measure the shifting and compressing Earth, and are so sensitive they can measure changes in their shape of less than the width of a hydrogen atom. Station B030, in Fall Creek, Oregon, southeast of Eugene, has recorded the waves of many large earthquakes, including the 2011 Tohoku earthquake. Closer to home, it records the regional "silent earthquakes" produced by slow-slip events every 19 months or so. In these events, slip down deep along the subduction-zone interface shows up as a temporary change in the strain field at ~550 ft below the surface, where this instrument lives. Station B030 was installed to better understand how slow-slip events impact the seismic hazard in central Oregon. Some of the rock down its borehole is vesicular, or air-bubble-filled basalt, in which quartz crystals and other minerals grow into the voids. Perhaps most interestingly, station B030 is near an air-conditioned chicken coop! ■

Education Corner

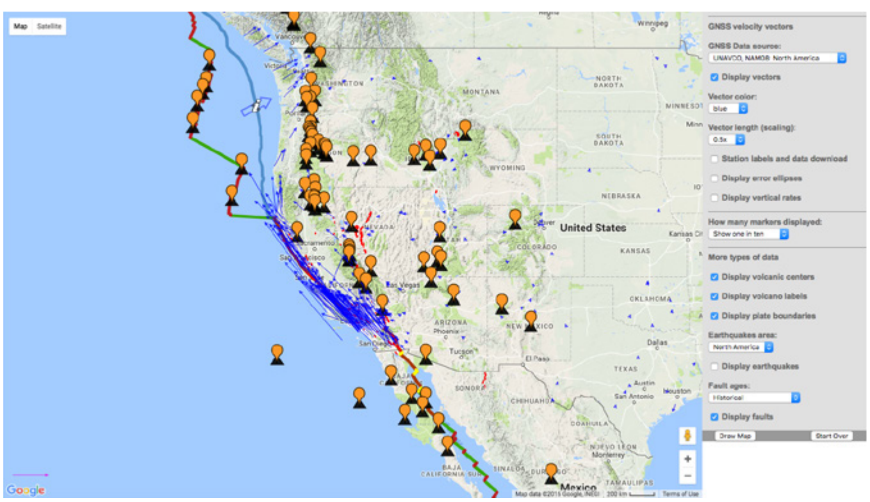
For every InSights issue, we feature two of the dozens of tools, modules, and activities that utilize EarthScope data to benefit a wide variety of users. We intend to reach K–12 and university educators, as well as informal programs like museums. This issue focuses on the data tools available to the public through the UNAVCO and IRIS websites.



IRIS:
Earthquake Browser

This interactive map provides information on millions of earthquakes all over the globe. Explore recent and historical global seismicity in the context of tectonic plate boundaries, displaying up to 5,000 quakes at a time. Users can filter the earthquake catalog by magnitude, depth, location, and/or date of occurrence, and even rotate and zoom through hypocenters with the 3D viewer. All selected data can be exported to a spreadsheet for use in other programs. ■

VIEW ONLINE



UNAVCO:
GPS Velocity Viewer

Use the GPS velocity viewer to map the velocity vectors of GPS stations in UNAVCO's network throughout the U.S. The tool shows how fast and in what direction the ground moves in a particular location, at a variety of scales. Add overlays of other geophysical information such as the locations of earthquakes, volcanoes, faults, and plate boundaries. The velocity viewer is a global map, putting at the user's fingertips GPS and seismic data on ground movement and deformation beyond the boundaries of North America. ■

VIEW ONLINE

EarthScope News

continued from front

Synthesis updates

The first synthesis workshops are underway. There is still time to participate in the following upcoming events:

1) Structural and Tectonic Evolution of the Southern Margin of North America

http://www.earthscope.org/science/about-synthesis-workshops/southern-exposure-an-earthscope-synthesis-workshop

Application deadline December 2.

2) Evolution of the Southern Appalachian Lithosphere

http://www.earthscope.org/science/about-synthesis-workshops/earthscope-synthesis-workshop-on-the-evolution-of-the-southern-appalachian

Application deadline January 27.

Upcoming Speaker Series Visits

The EarthScope speaker series has begun! Scientists will be crisscrossing the country to deliver EarthScope science to your doorstep. Please visit our speaker series web page for a list of who will be in your area, as well as an interactive map showing their target destinations.

http://www.earthscope.org/resources/speaker-series/2016-2017-speaker-series

VESS: Visualizing EarthScope Science

The world of science is one of wonder, no more evident than when a new image reveals the inner workings of a hidden world. The EarthScope National Office is launching an initiative to capture the public's interest in the visual world of Earth science, similar to the Vizzies challenge offered by the National Science Foundation and Popular Science.

VESS, or Visualizing EarthScope Science, aims to celebrate the most stunning and stimulating imagery conveying the discoveries of EarthScope scientists. If you have been imagining and drafting your EarthScope results in an aesthetic form, now is the time to share them!

Submit to one or more of the following three categories:

- Photography
- Motion—short animations, sonifications, or video clips of <5 min
- Illustrations—2D data visualizations, graphics, cartoons, drawings, etc.

VESS is open to the entire EarthScope research community, including faculty, postdocs, and graduate and undergraduate students who use EarthScope data in their research. Submissions will be rated by aesthetic appeal, with winners determined by public vote.

The EarthScope National Office and its partner in this endeavor, UNAVCO, will showcase the winning entries at the EarthScope National Meeting in May 2017. Prizes will be awarded at the meeting (your presence is not required to win). The winning entries will be highlighted on our website, in our summer newsletter, through social media by ESNO and its partners, and at the EarthScope booth at forthcoming GSA and AGU meetings.

Official guidelines for the VESS will be posted on December 12, 2016. Visit us at the EarthScope booth at AGU for more information, or sign up for EarthScope updates at http://eepurl.com/ca5eUz. We look forward to seeing your science!

EarthScope National Meeting

It's official! The next EarthScope National Meeting will be held in May 2017 in Anchorage, Alaska.

May 15: Workshops | May 16–18: Meeting | May 18 afternoon: Field trip

inSights the EarthScope newsletter

inSights the EarthScope newsletter is published four times a year by EarthScope (www.earthscope.org)

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EarthScope facilities are funded by the National Science Foundation and are being operated and maintained as a collaborative effort by UNAVCO Inc. and the Incorporated Research Institutions for Seismology with contributions from the US Geological Survey and several other national and international organizations. The EarthScope National Office at the University of Alaska Fairbanks (UAF) is supported by Grant No. EAR-1464674. This material is based upon work supported by the National Science Foundation under Grants No. EAR 1445937, EAR 1520875, EAR-1144455, EAR-1545750, EAR-1444275, EAR-1144568. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. UAF is an AA/EO employer and educational institution.