Seismology education and public-outreach resources for a spectrum of audiences, as provided by the IRIS Consortium

J. Taber[1], M. Hubenthal[1], T. Bravo[1], P. Dorr[1], J. Johnson[2], P. McQuillian[3], D. F. Sumy[1], R. Welti[1]

Abstract

The Incorporated Research Institutions for Seismology's (IRIS) Education and Public Outreach (EPO) program is committed to advancing awareness and understanding of seismology and geophysics while also inspiring careers in the earth sciences. To achieve this mission, the IRIS EPO program combines the content expertise of the consortium membership with the educational and outreach expertise of IRIS staff members to create programs, products, and services that target a range of audiences, including students and teachers in grades six through 12, undergraduate and graduate students, faculty, researchers, and the general public. Since 1998, the IRIS EPO program has produced a portfolio of freely available products and services and offers a rich repository for anyone who teaches seismology-related topics and/or communicates seismology research to the general public.

Introduction

The Incorporated Research Institutions for Seismology (IRIS) is a nonprofit consortium of more than 120 research universities and institutions dedicated to monitoring the earth and exploring its interior through the collection and distribution of data broadly related to seismology. IRIS is funded primarily through cooperative agreements with the National Science Foundation (NSF) Division of Earth Sciences and draws on the rich seismological expertise of IRIS Consortium members to govern the IRIS facility.

IRIS staff members support the seismological community and other geoscientists by developing programs to increase access to seismic instrumentation and data and provide seismology education and outreach materials for audiences ranging from grade six through geophysics professionals and the public. The inclusion of an education and public-outreach program within a research consortium allows the integration of current seismological research with best educational practices and helps convey why this research is relevant to society.

Although the researchers served by the consortium naturally have a close connection with undergraduate and graduate students, it is important to also engage students in geoscience activities in middle and high school so that they become aware of the discipline and to provide the general public with the ongoing results of scientific research. Such work is primarily undertaken by IRIS Education and Public Outreach (EPO), although some professional training opportunities are provided by IRIS Data Services and Instrumentation Services.

IRIS EPO is committed to advancing awareness and understanding of seismology and geophysics while inspiring careers in the earth sciences. To achieve this mission, the IRIS EPO program combines the content expertise of the consortium membership with the educational and outreach expertise of the IRIS staff to create programs, products, and services that target a range of audiences, including students and teachers in grades six through 12, college students and faculty members, researchers, and the public. All EPO programs and products are subject to a continuous evaluation and improvement effort that informs the program's decision-making process, allowing IRIS to effectively manage its resources and significantly enhance EPO activities over time.

The program's strategic plan includes a set of broad goals that underpins all its activities. These goals include increasing the quantity and enhancing the quality of seismology education; expanding opportunities for the public to understand and appreciate seismology; providing education and outreach products and services for members of the IRIS community and other geophysics professionals; and supporting development of the earth-science workforce and increasing its diversity.

These goals allow IRIS EPO to maintain successful programs and priorities that include the engagement of a diverse audience in all activities. This is accomplished through three key diversity approaches. First, IRIS EPO partners with existing programs and organizations that are specifically designed to serve underrepresented groups, such as the Society for Advancement of Chicanos and Native Americans in Science (SACNAS) and UNAVCO's Research Experience in Solid Earth Science for Students (RESESS) program for underrepresented minorities. Next, specialized programming to target a diverse audience is developed when necessary. For example, IRIS EPO has developed the IRIS/UNAVCO minority recruitment lecture series, which enlists dynamic, early-career alumni of the IRIS and/or RESESS Internship Programs to deliver cutting-edge presentations on seismological research with explicit connections to core physics content. The lecture series targets physics students at predominately minority-serving undergraduate intuitions. Finally, where possible, we are mindful of including underrepresented groups within existing activities, such as facilitating professional-development workshops for teachers in school systems with large minority populations.

The following sections describe IRIS EPO activities, with sections arranged by audience from the undergraduate level, to grades six through 12 and the general public and finally to graduate and professional training. The activities are presented to show the diverse range of resources available to the geoscience community, university faculty members, teachers, and the general public.

Undergraduate

IRIS EPO focuses on two key ways to support development of the earth-science workforce and increase its diversity. The first is an undergraduate internship program; the second engages students in short-term field experiments.

[1]Incorporated Research Institutions for Seismology.
[2]Earth Sciences Animated.
[3]Liberty Science Center.

http://dx.doi.org/10.1190/tle34101178.1.

Summer internships for undergraduates in seismology. A summer internship can give students who are considering continuing their education in geophysics a chance to "try on" the role of a graduate student. Providing this opportunity is a central element of the IRIS EPO program. The goal of the IRIS Research Experience for Undergraduates (REU) is to encourage more students from a diverse range of personal and professional backgrounds to choose careers in earth science.

The IRIS internship program uses modern cyberinfrastructure to connect as many as 15 intern/mentor pairs working at nationally distributed institutions into a single cohort. Fundamental elements of the internship program include (1) a weeklong orientation in which interns learn seismology and data-processing techniques (Figure 1); (2) social media to encourage group interactions and enable peer learning and collaboration within the cohort; (3) a transition to independent research through carefully structured experiences to conduct fieldwork with modern seismological equipment and produce research products; (4) faculty mentorship and an alumni mentor who provides experienced, consistent support throughout the entire process and beyond; and (5) attendance at a professional conference to present research results, reconnect with the cohort, and integrate into the alumni network.

This internship model capitalizes on the consortium's distributed yet extensive resources and potential mentor pool, which are more substantial than any individual institution could furnish. As a result, the program is uniquely able to provide undergraduate students with research opportunities across the full spectrum of specialties within seismology (Hubenthal and Judge, 2013).

Follow-up surveys of program alumni in 2011 and 2014 found that of the 110 respondents who had completed their undergraduate degrees, 83% are pursuing an advanced degree in the geosciences or are working in a geoscience field (Figure 2). For those in geoscience careers, 53% are employed in the energy or natural-resources sectors. In addition, we find that more than 80% of our alumni who either earn a Ph.D. or are employed in a geoscience career report that the program was influential or very influential in their career development.

Field experiences for undergraduates. Because of the limited extent of earth-science education in most middle and high schools, students often discover geophysics almost by chance and late in their undergraduate careers. By then, it can be too late for students to change their majors or earn appropriate credits for graduate school. To provide students with the opportunity to experience geophysics earlier in their academic careers, EPO is developing a program to engage students from outside the geoscience pipeline with an opportunity to explore seismology through participation in short-duration field experiments. This program will target underrepresented math or physics majors who might have an interest in seismology and/or community-college students who do not have the prerequisites to participate in a research internship and might not have taken a geoscience course or participated in fieldwork. The program will connect students with the numerous field efforts to collect seismological data that are conducted each summer by members of the IRIS Consortium or in cooperation with other scientists. A pilot of this approach has proven successful at engaging underrepresented minority nongeoscience students in field campaigns and encouraging them to pursue a seismology career.

Figure 1. Students learn how to use a hammer seismograph recording system during the internship program orientation week.

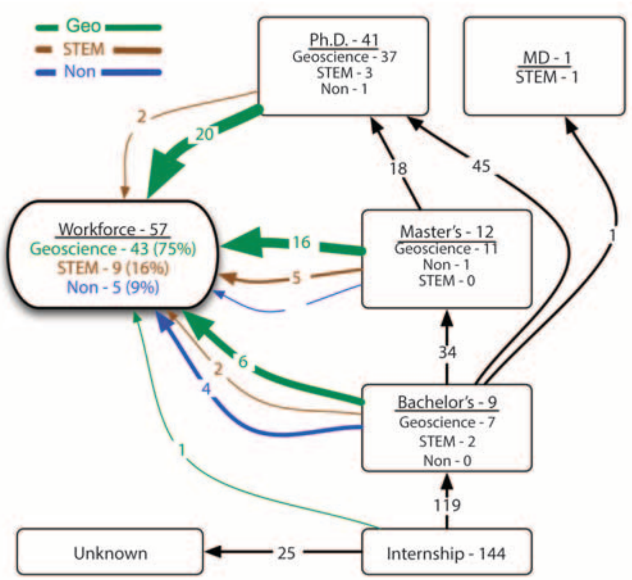

Figure 2. IRIS internship alumni career paths. From 1998 to 2013, the IRIS Undergraduate Internship Program facilitated opportunities for 144 undergraduates. Solid lines indicate pathways, labeled with the number of interns who completed that pathway. Boxes indicate the number of interns in that stage of their careers (e.g., 45 alumni completed undergraduate degrees and enrolled directly in a Ph.D. program, whereas nine alumni are earning their bachelor's degrees).

This new effort also builds on the success of student involvement in identifying sites for EarthScope's Transportable Array (TA), an array of 400 broadband seismographs installed across the contiguous United States and parts of southern Canada in a uniform grid with 70-km station spacing for a two-year deployment period (Abbott and Cook, 2012; Witze, 2013). From 2004 to 2014, the TA occupied nearly 1700 locations. The TA partnered with colleges and universities in the regions where sites were to be identified, and 135 students (mostly undergraduates) from more than 50 institutions identified ~ 1375 of these sites over eight summers. An IRIS-led workshop introduced students to the project, defined criteria for a good TA site, reviewed how to prepare the required report for each site, and provided an opportunity for students to practice speaking to the general public about the project. Afterward, the student teams spent nine weeks in their assigned region looking for sites. For many students, the involvement in a major research project had a significant impact on their career path and personal growth.

Middle school to undergraduate

To increase the quantity and enhance the quality of seismology education, IRIS EPO employs a two-pronged approach. IRIS EPO creates a spectrum of high-quality educational resources for educators and enables their use by making them easily accessible online and by providing instructors with the support (virtual or in person) necessary to effectively use the resources.

Curriculum. To capture student interest in the classroom, IRIS EPO has created a collection of curriculum materials designed using best educational practices and involving students in the use of real data. At the undergraduate level, a suite of six inquiry-based laboratory activities was designed around the seismological grand challenges in understanding earth's dynamic systems report (Lay, 2009). These activities, developed in collaboration with the College of New Jersey, make the grand challenges of modern seismology accessible to undergraduates in 100- and 200-level courses. Topics range from episodic tremor and slip to ice quakes in Greenland to the relationship between fluid injection and earthquakes. A separate set of lectures and exercises that focuses on petroleum-industry-related topics is also in the collection (Schroeder, 2015). These lectures and exercises are designed to introduce students to the basics of seismic processing and interpretation.

IRIS has developed nearly two dozen activities geared toward middle and high school classrooms. These materials cover a wide range of seismological topics, including elastic-rebound theory, faulting and folding, seismic wave propagation, and the discovery of earth's interior. They make use of actual data and/or require students to collect their own data. Lessons are constructed using the 5E-learning cycle, which promotes hands-on/minds-on engagement with seismology content (Bybee et al., 2006). Efforts are under way to align these resources with the Next Generation Science Standards, which are significantly raising the profile of earth sciences (NGSS Lead States, 2013). In the near future, IRIS EPO plans to combine individual lessons to form pedagogically sound learning sequences. This approach adds value to each individual piece by scaffolding student learning of individual concepts.

Professional development for college faculty and teachers in grades six through 12. To expand the use of curriculum resources, IRIS offers a variety of professional-development opportunities for instructors at the undergraduate, high school, and middle school levels. Each workshop is designed to improve instructors' seismology content knowledge and pedagogy to enable instructors to easily use IRIS resources in the classroom. Professional-development opportunities range from one-hour sessions at regional and national conferences or informal educator conferences to multiday, highly customized workshops designed to meet the needs of a specific educational institution. Since 1998, more than 1200 teachers and college faculty members have attended one-day or longer IRIS-led workshops. One year after participating in an IRIS professional-development workshop, teachers in grades six through 12 report increased confidence in teaching seismology content, and 76% report they spend more time teaching seismology to their students. Such increases in time spent have been shown to correlate with improved student learning.

Animations, videos, and visualizations. Seismology topics can be difficult to convey through text or images alone, which has led to IRIS EPO developing a suite of more than 100 animations to illustrate fundamental seismology concepts. These clips range from a few seconds to several minutes in length and cover both basic seismology-related topics and more complex concepts, such as focal mechanisms (Figure 3). As a result of the concise format and their dynamic nature, IRIS animations have engaged more than 1.8 million students, instructors, and members of the general public through our YouTube channel alone.

Among the most unique and publicly accessible products from EarthScope's TA have been the "Ground Motion Visualization" (GMV) movies (Figure 4). These visualizations, now generated automatically by IRIS Data Services after moderate and large earthquakes (http://ds.iris.edu/spud/gmv), show the propagation of body and surface waves across the TA from both local and global earthquakes. Students also can use GMVs to explore the heterogeneity of the North American continent and for simple determinations of seismic velocities. Because GMVs were generated as the TA moved across the United States, it is possible to find a local example for almost any school in the conterminous United States. The TA is being deployed in Alaska and northwestern Canada, so GMVs will soon be available there as well.

IRIS also hosts a collection of video clips and lectures designed to enhance earth-science teachers' comprehension of new science content and to support their classroom instruction of earthquake science. Most of the animations and videos also have classroom-ready activities that promote active learning of key seismology topics.

Recent earthquake "teachable moments." Newsworthy earthquakes can capture the attention and imagination of students. In the classroom, this increased attention manifests as a "teachable moment" or an unplanned opportunity to increase students'

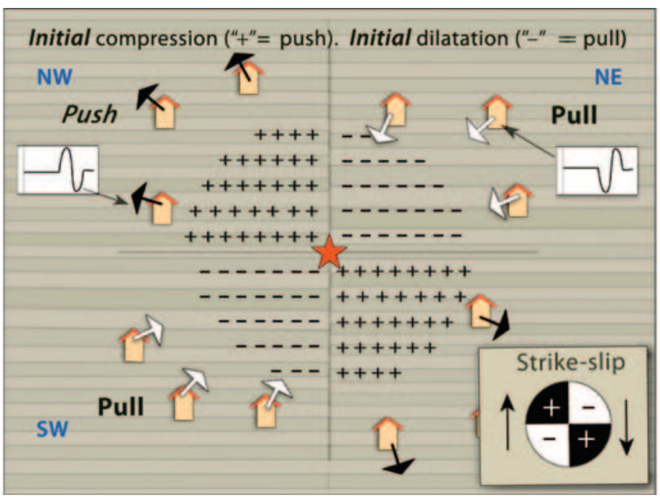

Figure 3. Snapshot from the focal-mechanism animation developed primarily for undergraduates (http://www.iris.edu/hq/inclass/animation/focal_mechanisms_explained).

understanding of both a specific event and seismology concepts more broadly. However, many instructors lack the time and/or background knowledge to quickly synthesize available Web materials into a coherent presentation. IRIS EPO, in collaboration with the University of Portland, fulfills this need by producing a rapid-response resource following large newsworthy earthquakes (magnitude 7.0 and above). IRIS Teachable Moments provide interpreted U. S. Geological Survey tectonic maps and summaries, animations, visualizations, and other event-specific information necessary for educators to explore the unique storyline of a newsworthy earthquake with their students. Each Teachable Moment is prepared in both English and Spanish within 24 hours of the event. Presentations are designed to allow instructors to tailor the slide set to their audience, which results in wide use in middle school through college classrooms. The slide sets are also popular with geoscience faculty members as a source of background information when answering media inquiries and as quick summaries for policy makers.

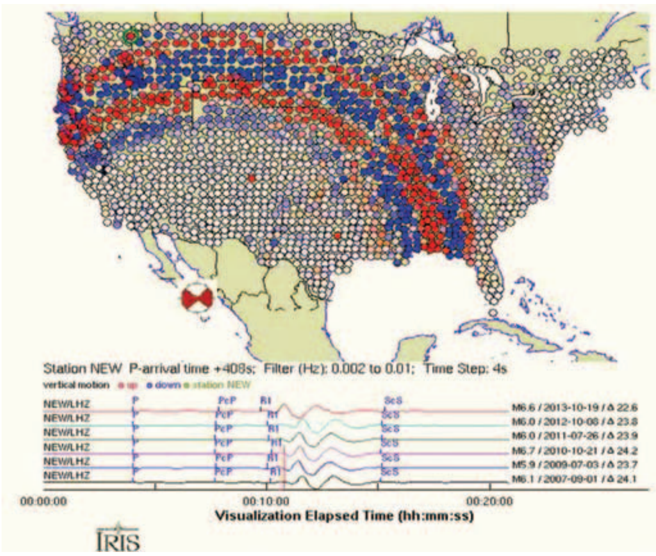

Figure 4. Snapshot from a composite visualization of the ground motions from six earthquakes of similar magnitude and the same focal mechanism that occurred near Baja California (http://ds.iris.edu/ds/newsletter/vol15/no2/super-ground-motion-visualizations-sgmvs/). The ground motions from each earthquake have been normalized to the same peak amplitude, and the event start times have been synchronized.

Seismographs in schools. The use of data in the classroom can enhance student engagement, and earthquakes are particularly effective at capturing student attention. Seismic observations also allow students and teachers to make direct measurements from their location that can reveal earth's interior structure and dynamics. To enable the use of seismic data in middle school through college classrooms, IRIS EPO has developed the infrastructure to provide easy access to data, robust ways for students to collect their own data, intuitive analysis tools, and educational activities that leverage seismic data.

Currently, IRIS EPO supports the use of data at three levels of involvement: (1) high-sensitivity sensors in classrooms to record global earthquakes; (2) USB and other MEMS accelerometers to teach the basics of ground motion recording via the Quake-Catcher Network (Cochran et al., 2009); and (3) easy access to data in the IRIS archive via the Web. The Seismographs in Schools Web site serves teachers across the country and around the world using seismic instruments or real-time seismic data in grades five through 16 classrooms by providing tools to share seismic data in real time. The Web site also has classroom activities and technical-support documents for seismic instruments. The site design encourages local and regional network operators to provide support to classroom teachers in their areas.

IRIS also provides a cross-platform program (jAmaseis) that allows middle school and older students to view and locally store data from educational and high-dynamic-range seismographs. The jAmaseis program also enables data from a local seismometer to be shared in near real time with other schools and to display near-real-time data feeds from the IRIS Data Management Center from stations around the world. Using this data, students can locate earthquakes that they have recorded (Figure 5). More than 420 users of educational seismographs from 37 states and 18 countries have registered their stations in the Seismographs in Schools database.

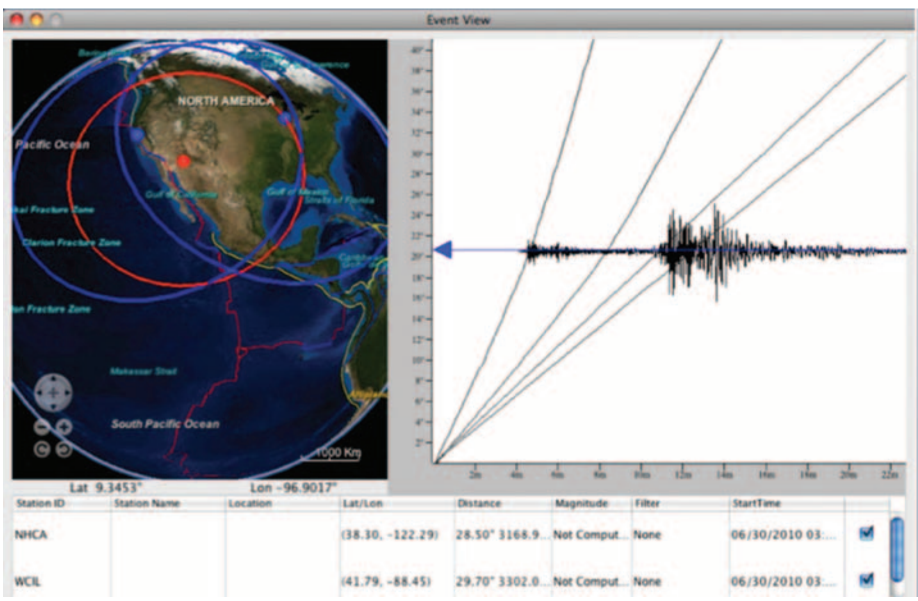

Figure 5. Students can use jAmaseis software to record data from any global sensor available via IRIS Data Services or from their own educational seismograph and then can calculate earthquake locations using that data (http://www.iris.edu/hq/inclass/software-web-app/_jamaseis).

Web-based seismicity browsers. Exploring recent and/or historical seismicity is one of the most common earthquake-related interests of students and the general public. For example, the Seismic Monitor, which provides a quick look at recent global seismicity, accounts for the majority of traffic on the IRIS Web site. For more in-depth exploration, the IRIS Earthquake Browser allows users to examine global, regional, and local seismicity via a Google Maps–based interface. The catalog contains instrumentally located events going back 50 years as well as today's earthquakes. Users can customize their searches for specific time, space, and magnitude ranges, which are immediately displayed on the map (Figure 6a) and are viewable in an integrated pseudo-3D viewer (Figure 6b). The 3D viewer is particularly effective in helping students to understand the geometry of subduction zones because students can easily manipulate the viewing angle. Instructors also can select particular views and sets of earthquake parameters and then share those links with students so that all students can focus their explorations on the same regions.

Informal education

IRIS EPO has developed two core programs to expand opportunities for the public to understand and appreciate seismology.

Public displays for museums and other venues. Informal science venues are an important mechanism for scientific outreach to the general public, and the display of real-time seismic data offers the opportunity to capitalize on visitors' enthusiasm for current information. IRIS has developed two types of museum displays as an outgrowth of our efforts in creating large custom museum displays for such venues as the Smithsonian Institution Museum of Natural History and the American Museum of Natural History. The first, the Earthquake Channel, is a widescreen real-time seismicity wall display that cycles through regions selected by the venue. This display, which shows the latest seismicity, is intended for use in venues with large numbers of short-term visitors, such as museums, and in university department or corporate lobbies where the same people come by frequently. The display software is freely available and simply requires hardware and an Internet connection.

The second type of display, the Active Earth Monitor (AEM), is a touch screen (Figure 7) that encourages the exploration of a set of seismic and geodetic stories and near-real-time data organized around a regional or topical theme. Current content sets include general seismicity, Cascadia, basin and range, New Madrid, Alaska, and EarthScope topics. Venues can select complete content sets or they can customize their content by adding and subtracting content pages as desired. All content sets are provided free of charge and are accessed via a Web browser interface with no additional software needs. AEMs are installed in locations ranging from visitor centers in national parks to small museums, schools, and departmental lobbies in universities, and even an earthquake-themed highway rest area near New Madrid, Missouri. Content sets have been developed in collaboration with UNAVCO, the EarthScope National Office, the University of Memphis, and the University of Alaska–Fairbanks, among others.

IRIS/SSA lectureship. There is a strong demand from science museums and science cafés to provide local communities with direct contact with distinguished scientists. To help meet this need, IRIS and the Seismological Society of America have collaborated annually to provide two speakers to convey both the excitement and the complexities of seismology to a general audience. To expand the number of viewers, most lectures also are recorded and placed online. The impact of the Distinguished Lectureship Program is increased further by arranging additional

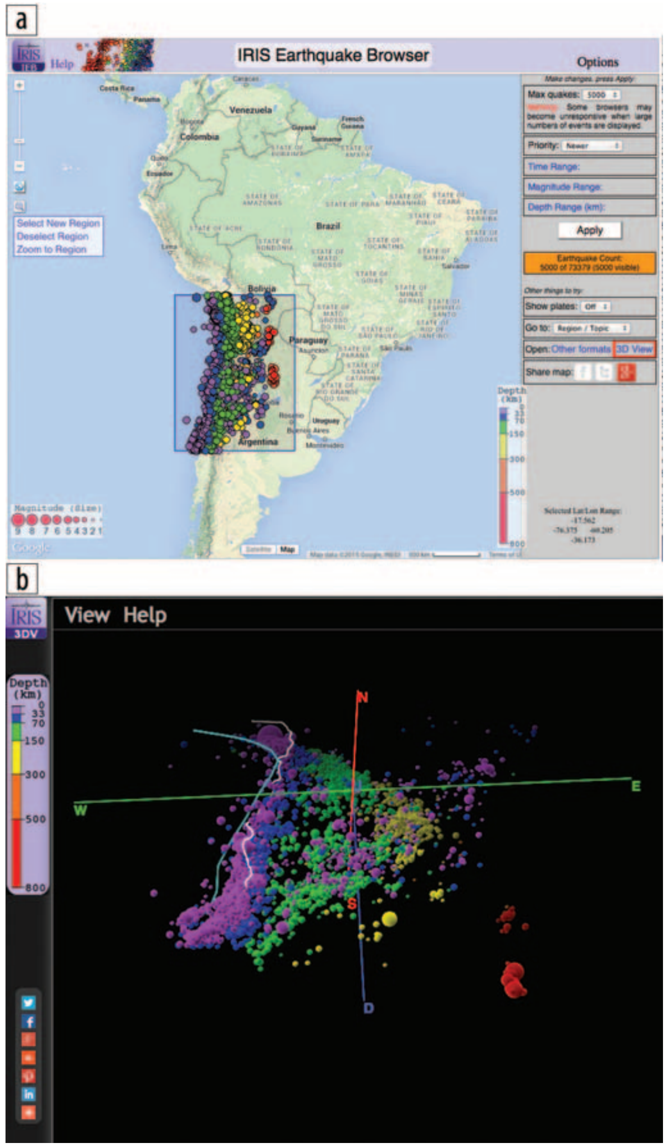

Figure 6. IRIS Earthquake Browser in (a) map and (b) 3D view (http://www.iris.edu/ieb).

Figure 7. Students explore the Active Earth Monitor kiosk.

events in conjunction with the public lectures, such as radio interviews, teacher workshops, and technical talks at nearby universities and professional society meetings. Since the inception of the program in 2003, 25 IRIS/SSA Distinguished Lecturers have given more than 130 presentations to public audiences. The 2016 lectureship topics are "Human-induced Earthquakes" and "From Plate Tectonics to Deep Earth Dynamics: A Seismological Journey inside the Earth."

Graduate and professional training

IRIS also provides specialized products and services for members of the IRIS community and other geophysics professionals.

Multiple divisions of IRIS provide training and mentoring at the graduate to professional level. For example, in an effort to help lower the barriers that hinder early-career scientists, researchers, and educators from thriving in a diverse range of career paths, IRIS organizes practical resources and professional-development opportunities for early-career investigators as they complete graduate school, navigate postdoctoral and other temporary research positions, apply to permanent jobs in academia, industry, and government/nonprofit sectors, and/or apply for tenure (Colella et al., 2015). One aspect of this support is a series of webinars spanning technical software tutorials, proper presentation of scientific lectures, how to navigate federal funding agencies, and best-research-based teaching practices.

IRIS also provides training at the graduate level through the USArray data-processing short course, which has been held in most years from 2009 to 2015. The course alternates between introductory and advanced graduate levels. The primary goal of the introductory short course is to provide training in the foundations of seismic data processing for the next generation of young scientists. Students are taught the basics of command-line coding, a variety of seismic data access methods, and simple software tools for processing, analysis, and visualizing waveform data. The advanced course challenges senior graduate students and postdoctoral researchers to develop new ways to analyze seismic array data.

The IRIS PASSCAL Program provides students and researchers training in the use of IRIS portable seismographs and the processing of the data recorded by those instruments. IRIS Data Services conducts metadata workshops designed for seismologists and network operators to help them store, process, and disseminate their data. IRIS also has led capacity-building workshops around the world, building on the successful Advanced Studies Institutes conducted in Santo Domingo in 2013 and in Bogotá in 2014. An online data-processing library is planned that will consist of software and sample data sets used in the short courses and the Advanced Studies Institutes so that the materials will be available to a wider audience.

Summary

The unique collaboration between the membership of the IRIS Consortium and the IRIS staff has resulted in the development of a substantial suite of highly specialized educational and public-outreach resources. These resources are designed to achieve the following four goals:

1) increase the quantity and enhance the quality of seismology education
2) expand opportunities for the public to understand and appreciate seismology
3) provide education and outreach products and services for members of the IRIS community and other geophysics professionals
4) support development of the earth-science workforce and increase its diversity

This set of resources creates a rich repository for those who teach seismology-related topics and/or communicate seismology research to the general public. All IRIS resources are freely available to anyone, regardless of membership in the IRIS Consortium. Resources can be accessed from http://www.iris.edu. TLE

Acknowledgments

Primary funding for the IRIS activities described above is provided via NSF awards EAR-1261681 and EAR-1156739.

Corresponding author: taber@iris.edu

References

Abbott, L., T. Cook, 2012, USArray: Geoscientists' "earth telescope" illuminating what lies beneath our feet: EARTH Magazine, **57**, no. 11, 40–47.

Bybee, R. W., J. A. Taylor, A. Gardner, P. Van Scotter, J. C. Powell, A. Westbrook, and N. Landes, 2006, The BSCS 5E instructional model: Origins, effectiveness, and applications: Biological Sciences Curriculum Study.

Cochran, E. S., J. F. Lawrence, C. Christensen, and R. S. Jakka, 2009, The Quake-Catcher Network: Citizen science expanding seismic horizons: Seismological Research Letters, **80**, no. 1, 26–30, http://dx.doi.org/10.1785/gssrl.80.1.26.

Colella, H. V., D. L. Schutt, D. F. Sumy, A. M. Frassetto, 2015, Helping early-career researchers succeed: Eos, Transaction, American Geophysical Union **96**, 8 September 2015, http://dx.doi.org/10.1029/2015EO034965.

Hubenthal, M., and J. Judge, 2013, Taking research experiences for undergraduates online: Eos, Transactions, American Geophysical Union, **94**, no. 17, 157–158, http://dx.doi.org/10.1002/2013EO170001.

Lay, T., ed., 2009, Seismological grand challenges in understanding earth's dynamic systems: Report to the National Science Foundation: IRIS Consortium.

NGSS Lead States, 2013, Next Generation Science Standards: For states, by states: National Academies Press.

Schroeder, F. W., 2015, Petroleum geoscience online short course, http://www.iris.edu/hq/inclass/lesson/focus_of_the_petroleum_industry, under development, accessed 16 September 2015.

Witze, A., 2013, US seismic array eyes its final frontier: Nature, **503**, no. 7474, 16–17, http://dx.doi.org/10.1038/503016a.