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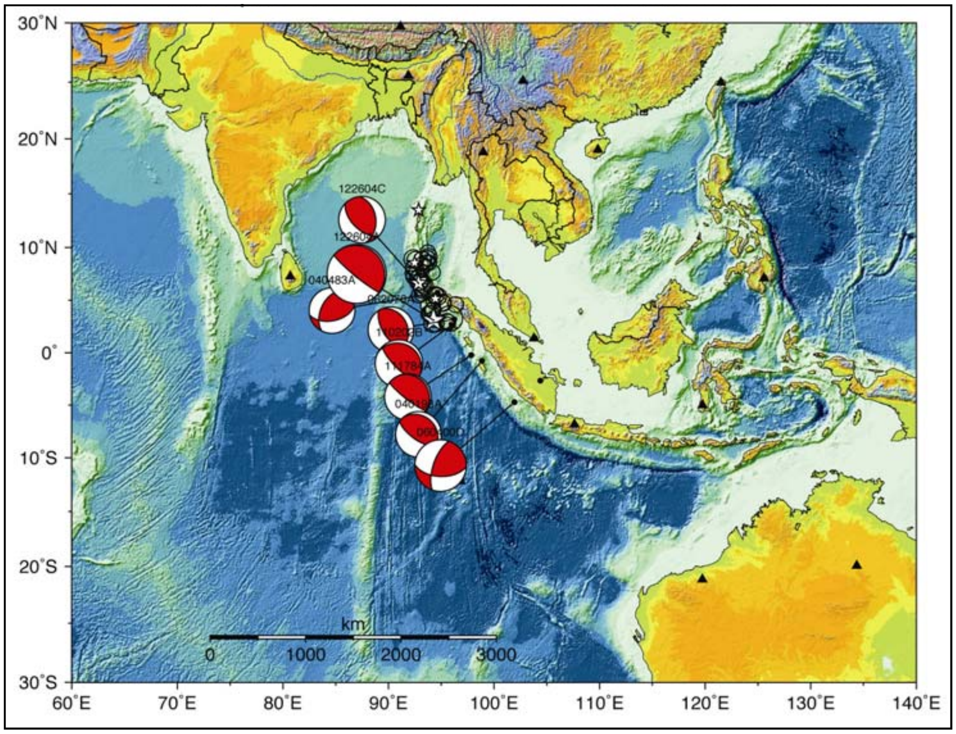
The Earth Scientist



The 2004 Sumatra Earthquake

Epicenters of the December 26, 2004, northern Sumatra earthquake and its large aftershocks are plotted as stars. The Harvard CMT (Centroid Moment Tensor) solutions are plotted as beach-balls, which indicate the mode of earthquake faulting (see <geology.about.com/library/bl/blbeachball.htm>). The main shock was a predominantly thrust faulting along the fault plane gently dipping (10 degrees) to the northeast. Epicenters of the 45 large aftershocks Dec. 26-29 determined by the National Earthquake Information Center/US Geological Survey, Golden, Colorado are plotted with circles.

Six additional large earthquakes (Mw > 7) that occurred along the Sumatran subduction zone between 1976 and 2003 are plotted. Most of the mechanisms indicate thrust faulting due to convergent plate motion between the Indo-Australian and South-east Asian plates, but there are some events that show substantial strike-slip faulting mechanisms reflecting right lateral component of plate motion due to highly oblique relative motion between the Indo-Australian and South-east Asian plates. The Sumatran plate boundary trends NW, whereas the relative plate motion vector has a N10E orientation (about 50-60 mm/year; see Natawidjaja et al., 2004, JGR B04306).

Credit: Won-Young Kim, Lamont-Doherty Earth Observatory

IRIS

This issue of The Earth Scientist is a cooperative venture between NESTA—the National Earth Science Teachers Association and IRIS—the Incorporated Research Institutions for Seismology. NESTA greatly appreciates the generous support of IRIS in helping to produce and publish this special issue on seismology.

INSIDE THIS ISSUE...

FROM THE PRESIDENT

The recent tsunami in the Indian Ocean has helped to bring to the forefront the importance and potential impact of seismic activity. This issue of The Earth Scientist is dedicated to Seismology. Many of us are "blessed" to be teaching in a geographic location which experiences seismic activity. Our students are all too familiar with the unannounced shaking caused by shifts within the Earth's crust. It is fairly easy to engage our students in discussions and activities regarding seismic activity, because they want to know what's going on, it affects them.

Then again, some of us teach in geographic areas in which we have whole classes of students who have never experienced the shaking which accompanies crustal movement. These students have no idea what the big fuss is all about. Here, motivation for the study of seismology is more difficult to generate. Nonetheless, it is important for the students to gain knowledge of earthquake activity, for today's society is highly mobile, and although the students may currently live in an area that is relatively free of P and S waves, they are likely to live in a more active region at some point, after they have left the nest.

As you peruse the journal, we hope that you will take the featured activities, tailor them to your classroom, and thereby pique the interest of your students, regardless of their backgrounds.

Tom Ervin

FROM THE EXECUTIVE ADVISOR

Colleagues.

We have been fortunate to have support from several organizations in pulling together our events at NSTA in Dallas and IRIS in particular for the contributions to this issue. Thanks again to Mike Smith for his work in putting the issue together. I would also like to add a note of thanks to Michael Hubenthal at IRIS for his help in coordinating articles. For those of you who have been involved in publication of a newsletter know what a job it is. Help Mike and support NESTA by contributing to the journal. It is your journal—and your association. Both can only be as strong as you make them.

NESTA has regretfully accepted the resignation of President Elect Thomas McGuire. Thomas's other commitments made in impossible for him to devote the time needed to effectively carry out the duties of his office. In his place, President Tom Ervin has appointed Parker Pennington IV from Michigan as his replacement. Parker has served as NESTA Regional Director and has been active in the Michigan Earth Science Teachers Association, the parent organization of NESTA. Parker will serve out Thomas's term and assume the presidency in 2006.

It seems that almost on a monthly basis I receive a plea for help from a teacher whose state or school is cutting back on Earth science as a middle or high school course. There have been many conferences and organizations battling this trend for several years now. The No Child Left Behind act and its emphasis on reading and mathematics at the expense of other subjects has put more pressure on science departments. Don't be afraid to step up to the plate. Both AGI and AGU have active programs to help. Don't hesitate to contact them for assistance. If you don't stick up for Earth science in your state, who will?

Once again kudos to Mike and Cara for getting The Earth Scientist back on track and published. With our renewed publication and expanded efforts at NSTA meetings, NESTA can continue to grow. Have you recruited a member lately?

M. Frank Ireton, Ph.D.

Guest Editor's Corner

The Incorporated Research Institutions for Seismology Education and Outreach (IRIS E&O) program is committed to using seismology and the unique resources of the IRIS Consortium to make significant and lasting contributions to science education, science literacy, and the general public's understanding of the Earth. The IRIS staff and membership strive to achieve this mission through the continued development and dissemination of a well-rounded suite of educational activities designed to impact a spectrum of learners, ranging from 5th grade students to educators and adults. These powerful learning experiences transpire in a variety of educational settings ranging from the excitement and awe of an interactive museum exhibit hall[1], to a major public lecture[2], or an in-depth exploration of the Earth's interior as part of a professional development workshop.

Professional development experiences like the IRIS One-Day Earthquake Workshop for Teachers[2] have been one of the most effective and popular components of the IRIS E&O Program. Because many educators do not have access to regional and national conferences where IRIS workshops are held, IRIS and the National Earth Science Teachers Association (NESTA) are pleased to partner to develop this special seismology focused issue of The Earth Scientist. Through this issue, NESTA and IRIS seek to deliver the same high caliber of professional development found in an IRIS workshop directly to your classroom. Specifically we strive to;

- increase your knowledge of seismology/geophysics related content,
- provide high-quality, scientifically accurate activities and tools to deliver content to students, and;
- connect you to IRIS-supported research and E&O individuals.

This issue features a variety of invited articles from authors within the seismological research community. One article explores how, through the support of the National Science Foundation, the IRIS Consortium is revolutionizing the field of observational seismology. Other articles discuss the causes of the Sumatra "Great Quake", research on measuring the magnitude of this event, and impacts on the US Tsunami Warning System.

To help you merge this new content into your classroom, we also feature invited pieces that emphasize content specific pedagogy. Seismologists and seismology educators share tips, tools and related activities to help you use the content of seismology to involve your students in the process of science. Articles detail ways to access seismological data through the IRIS website and places to download free data analysis tools, and also present activities designed to engage your students in the analysis of seismological data.

This issue also features a special insert of the newest IRIS poster "Sumatran – Andaman Islands Earthquake", which highlights data collected from the IRIS Global Seismic Network. As the first recipients of this beautiful poster, NESTA members will be equipped to help students learn about the worldwide ground movement associated with a huge event and the speed and paths waves take as they travel through and around our earth.

We hope that this issue provides you with a variety of new resources to use in your regular instruction and also equips you to for the next teachable moment associated with an earthquake. If you are attending this or future NSTA meetings, please be sure to stop to talk with us at either at the IRIS booth or at the NESTA Share-A-Thon.

Michael Hubenthal

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[1] www.amnh.org/rose/hope/earthquake

[2] www.iris.edu/about/ENO

The IRIS Consortium – Twenty Years of Supporting Facilities for Seismological Research

David Simpson

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The faint rumblings from distant earthquakes can be unraveled to determine where an earthquake happened, its size and the type of faulting that produced it. Tracking the much stronger motions from nearby earthquakes can help the understanding of how different ground conditions can influence earthquake damage to buildings and other critical structures in large cities. By combining the observations of many earthquakes or explosions at different stations, it is possible to map internal variations in the structure and composition of the Earth's interior. These fundamental results from seismology, which use data from remote sensors all over the world, are combined with other Earth science information to help guide scientists in exploring a variety of fundamental and applied topics, including the history and evolution of our planet, exploration for oil, minerals and water, mitigation of earthquake risk, development of safer cities and monitoring of nuclear test ban treaties.

Twenty years ago, all branches of science were being revolutionized by advances in digital electronics and communications technology, as well as new hardware and software for data storage. Just as the entertainment industry was being revolutionized by the transition from AM to FM broadcast and analog to digital recording, new digital recording systems were being developed for seismology that allowed us to sense and record ground vibrations with much higher fidelity than was possible in the past. Low power electronics and efficient batteries and solar panels made it possible to install self-contained seismographs to operate unattended in remote areas and relay their data back to a central recording system. Once captured in digital form, the massive quantities of data from this new generation of instruments could be indexed and placed in mass data storage archives from which they could be freely and openly retrieved by multiple users via search mechanisms that were much more effective than sorting and analyzing old paper records.

In this era of expanding opportunities, the National Science Foundation challenged the US seismology research community in 1982 to join together to define and prioritize its needs for seismic instrumentation and data management. Scientists and engineers from the leading research universities and government agencies came together to establish the specifications for sensors, recording systems, formats, data collection and distribution systems that formed the basis of a major funding proposal to NSF in 1984. The proposal was submitted by a newly-formed consortium – the Incorporated Research Institutions for Seismology – that initially consisted of 26 of the major US research universities.

Twenty years later, IRIS has grown from its 26 original members to a consortium of 105 Members, two US Affiliates, more than 40 International Affiliates and eight Educational Affiliates. With funding from the National Science Foundation, and through cooperation with the US Geological Survey and many international partners, the Consortium has established core programs to develop and maintain the basic research tools that have become an essential part of the fabric of domestic and international programs in seismology and the Earth Sciences:

1. Global Seismographic Network (GSN): A permanent worldwide network of over 130 broadband seismological observatories that constantly monitor global earthquake activity.
2. Program for the Array Seismic Studies of the Continental Lithosphere (PASSCAL): A program of portable instruments and arrays for use by individual scientists for high-resolution experiments in focused areas,
3. Data Management System (DMS): A data system for collecting, archiving and distributing data from IRIS facilities, as well as a number of other national and international networks and agencies.

4. **Education and Outreach Program (E&O):** A program designed to integrate research and education by making our data and science accessible to non-seismologists through a variety of innovative programs.

Over the past two years, the IRIS core programs have been expanded under USArray, a key component of EarthScope, an ambitious new project to merge a variety of geophysical technologies to create a continent-scale observatory to study the structure and evolution of North America.

The GSN and PASSCAL are complementary programs and the primary tools for acquisition of new data. The GSN permits a large-scale look at the geology under the continents and oceans, whereas PASSCAL allows for a much more focused investigation. The DMS and E&O are also complementary programs and the primary means of distributing data for research and education. By combining and distributing data from different sources, the DMS allows individual investigators to assemble data products tailored to their research objectives. The DMS also serves as a forum to coordinate international cooperation, set data and software standards, and promote data exchange.

As these core facilities have grown, so has the demand from the seismological community for the services and products that they provide. IRIS facilities, products and services are now essential for the progress of a large proportion of seismological research funded by the NSF, USGS, DoD, and other US government agencies with programs in the Earth sciences and nuclear monitoring. IRIS facilities and data are also making new styles of scientific investigation possible. A constant goal of IRIS is to improve operation and efficiency of the existing core IRIS facilities.

From the beginning, IRIS facilities and products have also been used for educational purposes. Educators use seismograms or earthquake data obtained from the DMS in the classroom, construct public displays of “live” seismological data from the GSN, and introduce students to field work and research through participation in PASSCAL deployments. Following the advice of reviewers of the 1996 IRIS proposal, and recognizing the opportunity that IRIS has to facilitate the use of many types of seismological data for educators, in 1998 IRIS established the Education and Outreach (E&O) Program to better address this the need for educational materials and services. The E&O Program integrates seismological data with educational programs and public outreach, making IRIS data available and usable, not only for research seismologists, but also for educational institutions and the interested public. The E&O Program also plays an important role in translating scientific results on Earth structure and dynamics into terms meaningful and accessible to the general public.

As the Consortium has grown since 1984, IRIS has become much more than an instrument facility; it has become a primary focal point for university-based seismological activities. The fundamental problems of Earth science require synthesis of information and activities of other fields, organizations, and institutions. Therefore, IRIS strives to coordinate, cooperate, and work with a variety of activities within the Earth sciences and thus maximize the impact of its contributions on the larger global and societal problems it is helping to solve.

Sample IRIS Resources for Earth Science Teachers

- The Sumatran-Andaman Earthquake of 2004 — www.iris.iris.edu/sumatra/
- Earthquake Maps, Lists, and Other Resources — www.iris.edu/quakes/quakes.htm
- Seismology “One-Pagers” (also in Spanish!) — www.iris.edu/edu/onepagers.htm
- Seismology Lessons and Exercises — www.iris.edu/edu/lessons.htm
- Seismology Posters — www.iris.edu/about/publications.htm#p
- Mega-quakes and the Series “10.5” — www.iris.edu/edu/megaquakes.htm

NATIONAL EARTH SCIENCE TEACHERS ASSOCIATION

The 2004 Sumatra Earthquake and Indian Ocean Tsunami: What Happened and Why

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On December 26, 2004 the world saw yet again how strains built up over hundreds of years by slow and almost imperceptible motions of tectonic plates are released with devastating effect. A giant earthquake beneath the Indonesian island of Sumatra generated a massive sea wave that crossed the Indian Ocean in a few hours, wreaking destruction along seacoasts and causing at least 300,000 deaths.

Geological Cause

The geologic causes of this event can be traced back over 120 million years ago, when the southern supercontinent of Gondwanaland broke up. The subcontinent of India separated from Antarctica and started its steady motion northward. 50 million years ago it collided with Asia, raising the Himalayas and forming the Tibetan plateau. The plate collision continues today as the Indian plate moves northward, forcing pieces of China and southeast Asia eastward.

Part of the plate boundary extends along the trench on the west coast of Sumatra. Here, an oceanic part of the Indian plate subducts beneath the Burma plate (Figure 1). The Burma plate is a small sliver or microplate between the Indian plate and the Sunda plate that contains much of southeast Asia. The east-dipping Indian plate can be identified by earthquakes that occur within it, down to a depth of about 300 km. However, most of the time little seems to be happening along the great thrust fault, sometimes called a mega-thrust fault that forms the plate boundary interface.

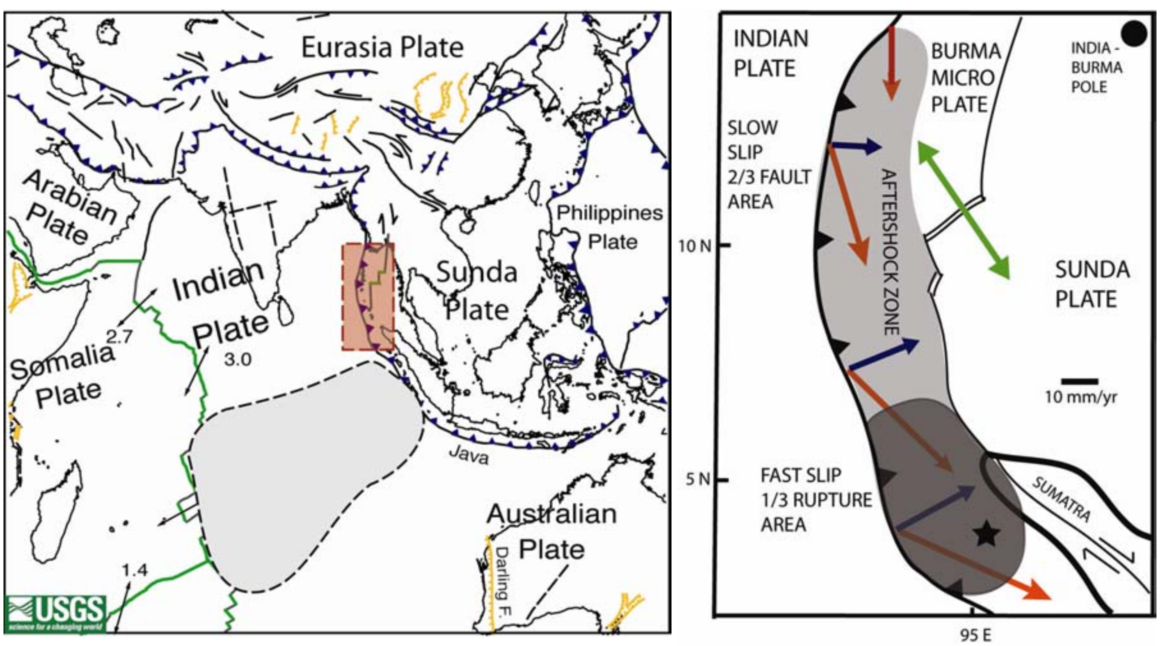

Fig. 1a. Approximate plate tectonic boundaries in the region of the Sumatra earthquake. Dashed region is broad boundary zone between India and Australia. The box shows the area of the map in Figure 1b. Fig. 1b. Schematic illustration of the regional tectonics and slip process in the earthquake. Studies based on high frequency seismic waves find that fast slip was concentrated on the southern part of the aftershock zone (dark grey) whereas the normal mode study (discussed below) shows a much larger possible area of slow slip (light grey). Star denotes epicenter where rupture started. The earthquake resulted from the Indian plate subducting beneath the Burma microplate due to motions about the rotation pole. Total (red arrows) and orthogonal (blue arrows) convergence between the plates is shown.

In reality, a lot is going on. Every year, about 20 mm of convergence occurs between the Indian and Burma plates. However, the mega-thrust fault is locked, so strain builds up on it (Figure 2). Eventually the accumulated strain exceeds the frictional strength of the fault, and it slips in a great earthquake like December's.

Such plate boundary thrust fault earthquakes can be very large – by far the largest that occur.

A huge area of the plate interface slips, generating seismic waves that can do great damage near the earthquake. Moreover, because this typically occurs at an underwater trench, the overriding plate that had been dragged down since the last earthquake rebounds and displaces a great volume of water, causing a tsunami that can have devastating effects far away.

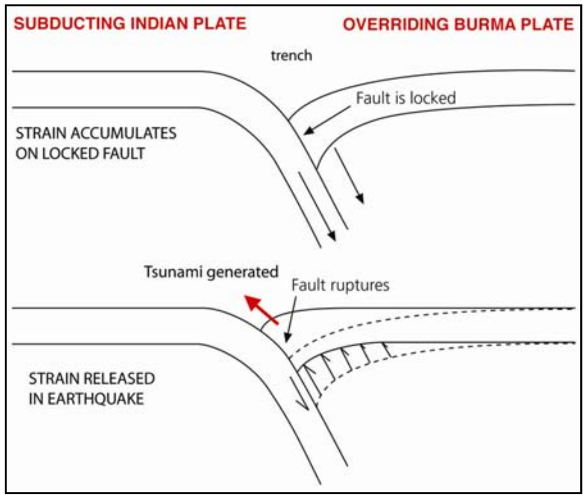

Fig. 2. Illustration of the cycle of strain accumulation and release that causes great thrust fault earthquakes at a subduction zone.

Measuring Earthquake Size

The huge size of this earthquake has consequences for the fault rupture process and generation of the tsunami. To understand this issue requires understanding the concept of earthquake magnitude, a measure of earthquake size based on the amplitude of the resulting waves recorded on a seismogram. The earliest magnitude scale, introduced by Charles Richter in 1935 for Southern California earthquakes, is the local or "Richter" magnitude. This scale has been replaced by other magnitude scales that use seismic waves of different periods. These give more information, because an earthquake radiates different amounts of seismic energy at different periods.

To see why different measurements yield different magnitudes, consider the spectrum of the earthquake source, or how much energy is radiated at different periods. Figure 3 shows the logarithm of amplitude of the radiated waves versus the logarithm of the wave frequency (1 over the period). Ideally the plot is flat at low frequency (long period) and then decays for frequencies above (periods shorter than) "corner" frequencies proportional to 1 over the times needed for the rupture to propagate along the length of the fault and for slip to be completed at a point on the rupture. The larger the earthquake, the more the corner frequencies move to the left.

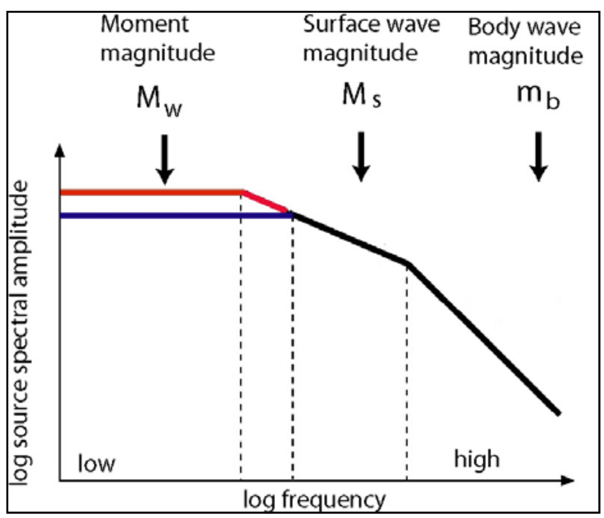

Fig. 3. Illustration of earthquake spectra showing corner frequencies (dashed vertical lines) and different magnitude determinations. The earthquake whose spectrum is shown in red has larger moment magnitude than the one with spectrum shown in blue, even though they have the same surface and body wave magnitudes, as shown by the black part of the spectra that are the same for both earthquakes.

Typically three different magnitudes are used, each of which measures the seismic energy radiated at a different period. The body wave magnitude mb is determined from the amplitude of waves that travel through the earth's interior, with a period of 1 second. Similarly, the surface wave magnitude Ms is determined from the amplitude of waves that travel along the earth's surface, with a period of 20 seconds. A problem with both these magnitudes is that they saturate or remain constant once earthquakes exceed a certain size. This happens because the added energy release in the very large earthquakes is all at longer periods than are measured by the 20 sec period surface waves. No matter how big an earthquake is, its body and surface wave magnitudes do not get above about 6.5 and 8.4, respectively. Hence for very large earthquakes these magnitude measurements underestimate the earthquake's size. This issue is crucial for tsunami warning, as we will see.

To surmount this difficulty, we use the seismic moment that can be calculated by measuring the energy in the longest periods of the seismogram. The seismic moment also relates directly to the physical properties of the fault, so the moment can be determined either from seismograms or from the fault dimensions. In terms of the fault dimensions, the seismic moment is found by

Mo = [fault rigidity] X [fault area] X [fault slip]

The rigidity is the strength of the fault and is an approximate value determined from lab experiments. The moment magnitude Mw is calculated from the seismic moment using the relation Mw = (log Mo / 1.5) - 10.73. The constants in the equation have been chosen so that the moment magnitude scale correlates with the other magnitudes when they do not saturate.

Size of the Sumatra Earthquake from the Earth's Normal Modes

The Sumatra earthquake was a gigantic event. The aftershock zone extended 1200 km northward along the trench. Studies using body waves show that rupture started at the epicenter at the south end of this zone and propagated northward, with most of the rapid slip on the southern third of the rupture. Initial estimates based on surface waves with periods less than 300 s found a seismic moment of 4 x 1029 dyn-cm, corresponding to Mw = 9.0.

Additional insight into the size of the event comes from the earth's longest period normal modes. These are vibrations in which the earth rings like a bell (or more precisely rattles like a garbage can at many frequencies) for days and even weeks after a gigantic earthquake. Analysis of long seismograms shows distinct energy peaks whose height reflects the earthquake's seismic moment. The modes are standing seismic waves on a spherical earth analogous to standing waves on a string that add up to form traveling waves. The longest period modes occur in groups or multiplets consisting of singlets or peaks that are split - have distinct periods or frequencies - because the standing waves are affected by the rotation and shape of the earth. Seismic waves traveling in the direction of the rotation travel faster than those going the other way and the effect varies with latitude since a piece of the earth at the equator is traveling faster than a piece near the poles. In addition, waves traveling across the poles travel a shorter distance than ones traveling around the equator because of the shape of the earth.

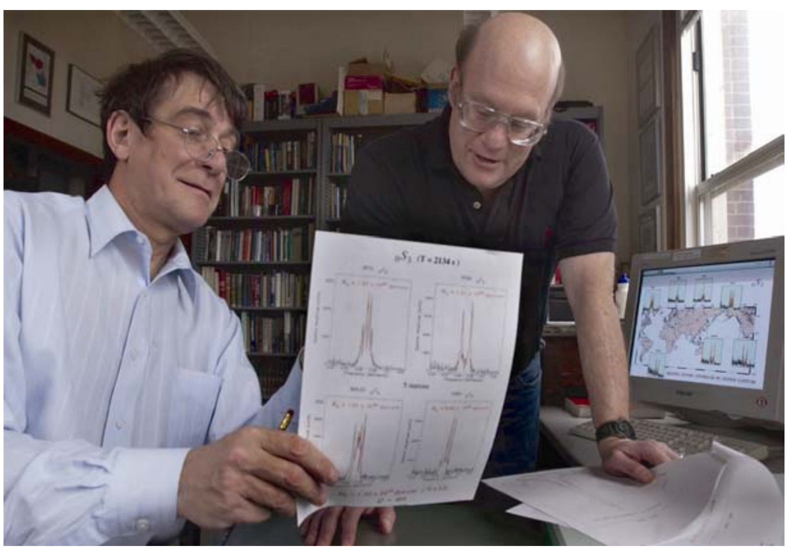

Fig. 4. The authors discussing data from the Sumatra earthquake.

The Sumatra earthquake excited the earth's normal modes beautifully. We analyzed them using techniques we developed with Robert Geller (now at the University of Tokyo) as graduate students almost 30 years ago. However, because such gigantic earthquakes are rare, these methods had been essentially unused until records of the Sumatra earthquake became available on modern digital seismometers of the Global Seismographic Network operated by IRIS. Hence immediately after the earthquake, we exhumed computer programs (some so old that they were originally on punch cards) and set to work (Figure 4). The computer programs calculate numerical seismograms, based on a model of how an earthquake will generate normal modes in the earth. Comparing the seismograms from seismic stations around the world and the modeling results are done in terms of the relative energy at different frequencies, called the frequency spectra (Figure 5).

Matching the amplitudes of the peaks shows that the earthquake had seismic moment of 1 x 1030 dyn-cm, or moment magnitude Mw = 9.3, approximately 2.5 times larger than shown by the

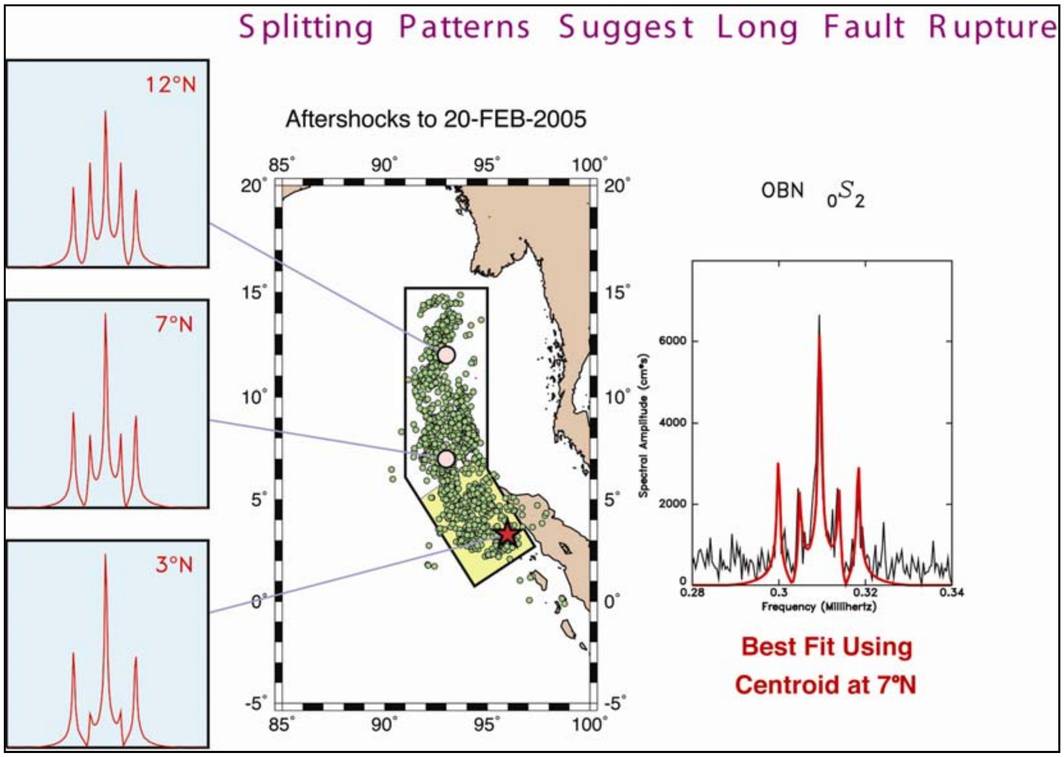

Fig. 5. Comparison of data (black) and model (red) at different seismic stations for the earth's longest period mode, which has a period of 52 minutes. Note the similarity of the peaks for stations with similar latitude (compare BFO and YSS) and the different shapes of the peaks for stations to the north and south. The pattern of the peaks depends only on the latitude of the seismometer because it reflects the earth's rotation and ellipticity, which are symmetric about the North Pole.

surface waves. This difference arises because the earthquake is so large that even the 300 second surface waves used in the initial Mw calculation did not record the very long period energy.

This larger magnitude likely reflects slow slip along the entire rupture zone suggested by aftershocks. The larger moment as calculated from the seismograms can be fit to the moment calculated using the fault dimension equation by 11 m of slip on a fault 1200 km long and 200 km wide (down-dip dimension). A larger rupture area is consistent with the fact that relative amplitudes of modes are better fit by a source with average position (known as the centroid) at 7°N than by one at the epicenter (Figure 6). Thus while the epicenter of the earthquake as determined from high frequency waves is at the south end of the fault rupture (the star in Figure 6), the centroid indicated by the normal modes is the center of the aftershock zone.

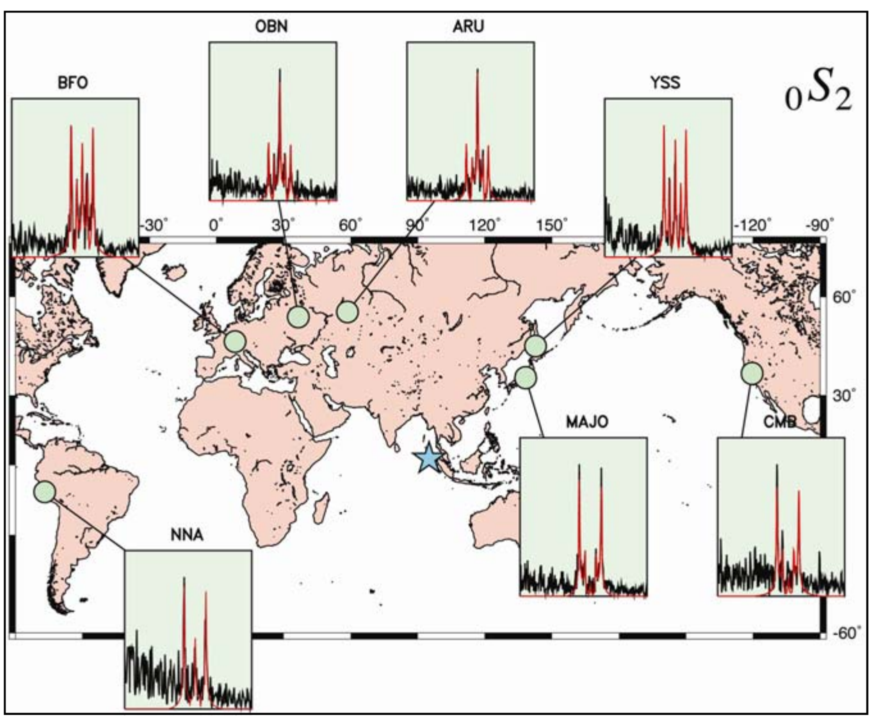

Fig. 6. Comparison of the peaks of the fundamental mode (black line) at seismic station OBN to theoretically predicted values (red lines) for different latitudes of the earthquake centroid.

Implications of Magnitude 9.3

The Sumatra earthquake appears to be the second largest earthquake (after the 1960 Chilean earthquake) recorded since the invention of the seismometer in the late 1800s. Its size is illustrated in Figure 7 where its fault area is compared to some California earthquakes. Relative to the 1906 San Francisco earthquake (known locally as "the big one") the Sumatra earthquake had about three times the slip on a fault three times longer along strike and about 20 times wider (down dip). This difference illustrates the general principle that the largest earthquakes are at subduction zones because of their geometry. The San Francisco earthquake ruptured a long segment of the San Andreas transform fault, which dips vertically, so the down-dip width is controlled by the fact that rocks deeper than about 20 km are weak due to high temperatures and so slide rather than accumulate elastic strain for future earthquakes. In contrast, subduction zone earthquakes on the shallow-dipping plate interfaces have much larger rupture areas at depths shallow enough for strain to build up. Moreover, larger fault dimensions give rise to greater slip, so the combined effects of larger fault area and more slip yield the largest earthquakes.

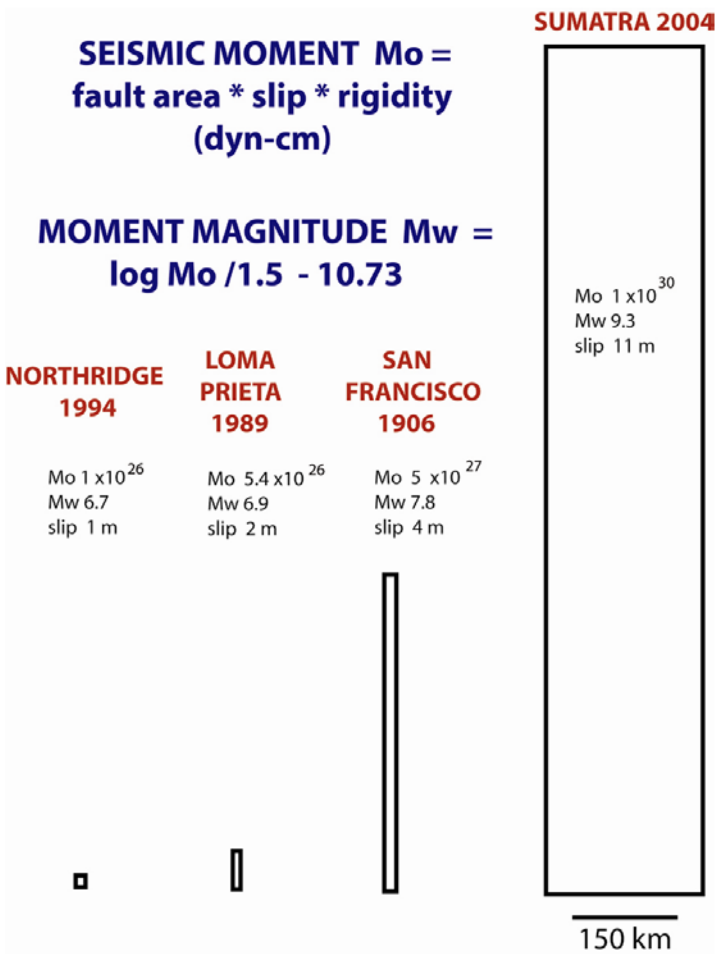

Fig. 7. Comparison of fault areas, seismic moment, slip, and magnitude for the Sumatra earthquake and some California earthquakes.

For the same reason, great subduction zone earthquakes cause the largest tsunamis. In the case of Sumatra, the long rupture played a key role in generating the devastating tsunami. In particular, the large tsunami amplitudes in Sri Lanka and India result from rupture on the northern, north-trending, segment because tsunami amplitudes are largest perpendicular to the fault. This effect is shown by comparison of snapshots from two tsunami animations (Figure 8).

Tectonic and Hazard Implications

The normal mode analysis indicates that a much larger fault ruptured than found by the earlier body and surface wave analysis, and that there was a very slow rupture in the northern segment. This view is consistent with the regional tectonics. Although the plate geometry and motions are not precisely known, Figure 1b shows estimates of India's motion with respect to Burma. Plate motions between two plates are described by rotations about a pole. Since the pole is nearby, the convergence direction varies along the rupture zone and motion becomes strike-slip at the north end of the rupture, presumably explaining why rupture ceased. The thrust faulting in earthquake reflects the arc-normal component of convergence.

If the entire aftershock zone slipped, strain accumulated from subduction of India beneath

Burma on the northern part of the rupture has also been released. This leaves no immediate danger of a large tsunami being generated by slip on this segment of the plate boundary, since such earthquakes should be at least 400 years apart. However, the danger of a large tsunami resulting from a great earthquake on segments to the south, or a local tsunami due to a large aftershock, remains.

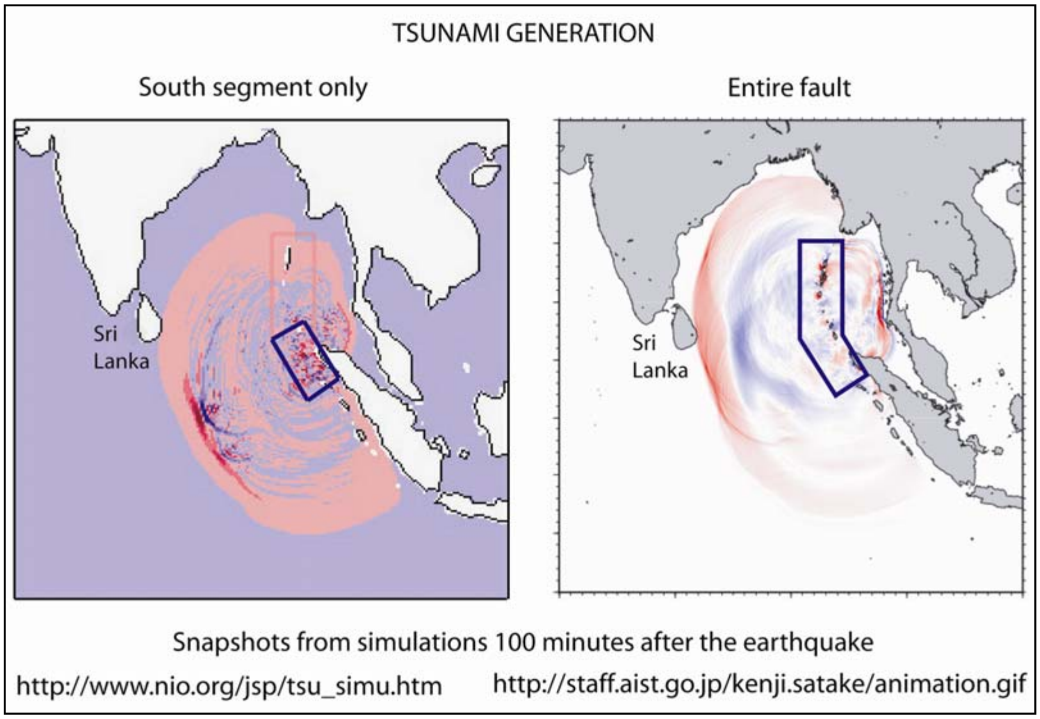

Fig. 8. Comparison of predicted tsunami amplitudes assuming the entire fault ruptured or only the southern segment did. The largest tsunami waves would have missed Sri Lanka if only the southern segment of the fault had ruptured.

Finally, the Sumatra earthquake illustrates the challenge in tsunami warning, namely rapidly determining whether a large earthquake will generate a destructive oceanwide tsunami. The problem is that this must be done quite rapidly, because the water wave travels across the ocean at jet plane speeds. For example, the December tsunami hit Sri Lanka only two hours after the earthquake. Seismic waves from earthquakes travel much faster, giving a very short time window for seismologists to locate the earthquake, decide if a major tsunami will result, and start the warning process. Because false alarms would be enormously expensive and destroy the credibility of the warning system, a difficult decision must be made quickly. The problem is that the tsunami is generated by the long period part of the slip, so – as shown in Figure 3 - the body and surface wave magnitudes do not show whether an earthquake is large enough to generate a major oceanwide tsunami. However surface and body wave magnitudes are much quicker and easier to determine and thus had been used as the basis for tsunami estimates. As a result, algorithms are now being developed to more rapidly assess the seismic moment and decide if a warning should be issued. These approaches together with sea floor sensors that detect the tsunami are the key elements in warning systems.

NATIONAL EARTH SCIENCE TEACHERS ASSOCIATION

Tsunami Preparedness in the United States

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The Tsunami Warning System (TWS) in the United States has evolved into a multi-faceted program reliant on many different aspects of emergency management, and scientific observation and analysis for effective implimentation. Preparation and planning prior to an event are critical for the system to function properly during an emergency. Pre-event analysis of a community's tsunami hazard potential, development of evacuation routes and shelters, public education campaigns, development of response plans, and installation of local warning notification systems are just some of the groundwork which must be laid in advance. Emergency management personel and the public must be aware of the tsunami phenomena, and must be able to properly respond to either nature's warning signs or broadcast warnings of the TWS.

The U.S. TWS is composed of a strong partnership between several state and federal agencies. Through participation in the NOAA National Tsunami Hazard Mitigation Program (NTHMP), this partnership supplies tsunami warning guidance, hazard assessment, and mitiga-tion activities; allowing an integrated response to a potentially tsunamigenic earthquake.

Hazard Assessment

Understanding a community's tsunami threat is an important aspect of preparedness. Without a clear understanding of what areas are at risk and which areas are unlikely to flood, it is impossible to develop effective emergency response plans and education programs. Risk is evaluated by constructing inundation maps through tsunami models generated by scenario earthquakes and landslides. As inundation maps for communities are completed, they are presented to both state and local emergency managers who then use the information for planning and exercising evacuation routes and safe zones for visitors, tourists, and local residents. The NTHMP has been the driving force behind creating and upgrading inundation maps throughout western coastal communities.

Fig. 1. Inundation map for Kodiak, Alaska produced by the Alaska Earthquake Information Center in partnership with the Alaska Div. of Homeland Security and Emergency Mgmt. and the Alaska Div. Geological and Geophysical Surveys www.aeic.alaska.edu/tsunami/index.html

Mitigation and Response

Arguably the most important aspect of a tsunami warning system is the mech-anism for disseminating warning information to the people and businesses on the shorelines. It has been recognized that tsunami hazard mitigation requires a long-term sustained effort that must become an institutionalized part of continuing public education, emergency management and responsible planning decisions in coastal communities. Tsunami edu-cation materials, inundation maps, community evacuation maps and signs, and numerous other mitigation-related products are being developed as part of the NTHMP program. These materials are brought to communities by a team of scientists and statewide emergency planners on a routine schedule to establish the infrastructure for education and outreach with respect to tsunami hazards and warnings.

The National Weather Service's (NWS) TsunamiReady Program

The NWS TsunamiReady Program (www.stormready.noaa.gov/tsunamiready.htm) sets forth criteria for communities to follow to be as prepared as possible. This program ties together several different aspects of the NTHMP hazard assessment and mitigation efforts as well as warning dissemination originating at the tsunami warning centers. To date, fifteen communities throughout Alaska, Washington, Oregon, California, and Hawaii have been designated TsunamiReady.

Fig. 2. The community of Kodiak, Alaska receiving the TsunamiReady recognition.

Warning Guidance

Tsunami warning centers, similar to warning centers responsible for other natural hazards, gather observational data, process the data, and disseminate bulletins to recipients. Observational data recorded at the centers consists of sesmic data and sea level data. Seismic data are provided by many agencies, such as NTHMP-funded regional networks, the USGS National Seismic Network, the IRIS Global Seismic Network, and other networks such as the Alaska Earthquake Information Center, the Pacific Geosciences Center, the California Institute of Technology, and the UC-Berkeley network. Each tsunami warning center also maintains their own network of critical sites. Initial tsunami warnings are based solely on seismic data so that warnings are received by coastal populations prior to the tsunami wave arrival. After a large magnitude earthquake, a watch is issued for any community that is at a distance away that the tsunami would take more than 3 hours to arrive. If the existence of the tsunami is verified, the watch becomes a warning as the wave reaches the 3-hour distance. On the other hand, a watch can be cancelled without issuing a warning if the tsunami can be shown to not exist sea level observations. Warnings trigger activity such as evacuations that can be quite costly, and so are not issued lightly.

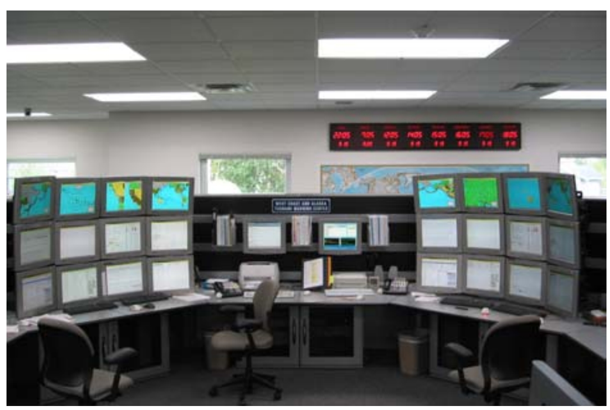

Fig. 3. Operations room at the West Coast/Alaska Tsunami Warning Center.

Tsunami bulletins are issued through standard NWS channels, such as the NOAA Weather Radio, NOAA Weather Wire, the FAA NADIN2 system, FEMA's National Warning System, and other means. Warning bulletin content includes earthquake information, evaluation guidance, tsunami arrival times, observed tsunami heights, and when it can be ascertained, expected impact information.

Once a warning has been issued, analysis of sea level data begins. Data are obtained from a Pacific-wide network of coastal tide gages operated by the National Ocean Service and other agencies, and from a network of six deep ocean pressure sensors initially installed with NTHMP funding. Based on observed sea level data, pre-computed models, historic tsunami information, and further seismic processing warnings are canceled, restricted or expanded.

U.S Tsunami Warning Program History

The U.S. tsunami warning program began after a tsunami unexpectedly inundated Hawaii in 1946. This tsunami, generated south of the eastern Aleutian Islands in Alaska, lead to the development of what is now called the Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii. In 1964, the damage and casualties inflicted by the Gulf of Alaska tsunami alerted officials to the need for a regional system in Alaska. The system, which originally consisted of three observatories, has evolved into the West Coast/Alaska Tsunami Warning Center located in Palmer, Alaska.

The U.S. Tsunami Warning System today still consists of two warning centers: the PTWC which has responsibility for Hawaii and international coordination throughout the Pacific, and the WC/ATWC which issues bulletins to Alaska, British Columbia, and the U.S. west coast. In 1997 NOAA, in conjunction with the USGS, FEMA, and state agencies, embarked on a broader approach to addressing the tsunami hazard, by establishing the National Tsunami Hazards Mitigation Program. The NTHMP was formed to improve hazard assessment, tsunami mitigation, and warning guidance through a state/federal partnership in support of the two warning centers.

As a result of the 2004 Sumatra earthquake and Indian Ocean tsunami, the U.S. tsunami-warning program is again undergoing a major change. Each facet of the NTHMP hazard assessment and mitigation activities will be expanded, and improvements will be made to warning center capabilities. With direction and oversight from congress, the tsunami warning system will be expanding its coverage to the U.S. east coast, Gulf of Mexico, and Caribbean Sea. The integrated approach developed over the years in the Pacific will serve as a guide for expansion in these other areas.

As a result of the 2004 Sumatra earthquake and Indian Ocean tsunami, the U.S. tsunami-warning program is again undergoing a major change.

NATIONAL EARTH SCIENCE TEACHERS ASSOCIATION

Seismic Wave Demonstrations Using the Slinky

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Seismic Waves

Because of the elastic properties of Earth materials (rocks) and the presence of the Earth's surface, four main types of seismic waves propagate within the Earth. Compressional (P) and Shear (S) waves propagate through the Earth's interior and are known as body waves. Love and Rayleigh waves propagate primarily at and near the Earth's surface and are called surface waves. Wave propagation and particle motion characteristics for the P, S, Rayleigh and Love waves are illustrated in Bolt (1993, p. 27 and 37; 1999, p. 22) and in Shearer (1999, p. 32 and 152). A table summarizing the detailed characteristics of the P, S Rayleigh and Love waves is contained in the document www.eas.purdue.edu/~braile/edumod/slinky/slinky.pdf and the web page www.eas.purdue.edu/~braile/edumod/waves/WaveDemo.htm. Effective animations of P and S waves are contained in the Nova video "Earthquake" (1990; about 13 minutes into the program), and of P, S, Rayleigh and Love waves in the Discovery Channel video "Living with Violent Earth: We Live on Somewhat Shaky Ground" (1989, about 3 minutes into the program) and at www.eas.purdue.edu/~braile/edumod/waves/WaveDemo.htm.

Slinky Demonstrations of P and S Waves

The P and S waves have distinctive particle motions and travel at different speeds. P and S waves can be demonstrated effectively with a slinky (the original metal slinky works best; (www.slinkytoys.com/main.htm). For the P or compressional wave, have two people hold the ends of the slinky about 3-4 meters apart. One person should cup his or her hand over the end (the last 3-4 coils) of the slinky and, when the slinky is nearly at rest, hit that hand with the fist of the other hand. The compressional disturbance that is transmitted to the slinky will propagate along the slinky to the other person. Note that the motion of each coil is either compressional or extensional with the movement parallel to the direction of propagation. Because the other person is holding the slinky firmly, the P wave will reflect at that end and travel back along the slinky. The propagation and reflection will continue until the wave energy dies out. The propagation of the P wave by the slinky is illustrated in Figure 1.

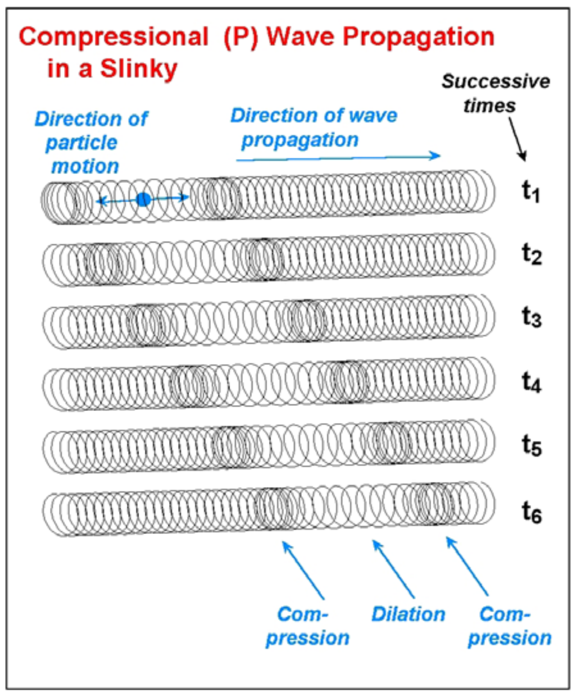

Fig. 1. Compressional (P) wave propagation in a slinky. A disturbance at one end results in a compression of the coils followed by dilation (extension), and then another compression. With time (successive times are shown by the diagrams of the slinky at times t_1 through t_6), the disturbance propagates along the slinky. After the energy passes, the coils of the slinky return to their original, undisturbed position. The direction of particle motion is in the direction of propagation.

Demonstrating the S or Shear wave is performed in a similar fashion except that the person who creates the shear disturbance does so by moving his or her hand quickly up and then down. This motion generates a motion of the coils that is perpendicular to the direction of propagation, which is along the slinky. Note that the particle motion is not only perpendicular to the direction of motion but also in the vertical plane. One can also produce Shear waves with the slinky in which the motion is in the horizontal plane by the person creating the source moving his or her hand quickly left and then right. The propagation of the S wave by the slinky is illustrated in Figure 2. Notice that, although the motion of the disturbance was purely perpendicular to the direction of propagation (no motion in the disturbing source was directed along the slinky), the disturbance still propagates away from the source, along the slinky. The reason for this phenomenon (a good challenge question for students) is because the material is elastic and the individual coils are connected (like the individual particles of a

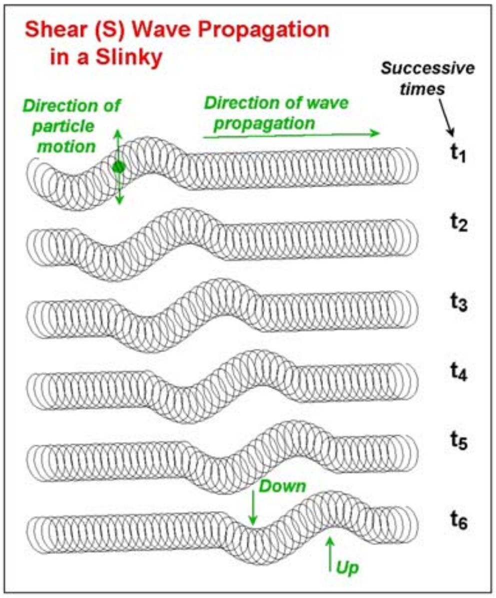

Fig. 2. Shear (S) wave propagation in a slinky. A disturbance at one end results in an up motion of the coils followed by a down motion of the coils. With time (successive times are shown by the diagrams of the slinky at times t_1 through t_6), the disturbance propagates along the slinky. After the energy passes, the coils of the slinky return to their original, undisturbed position. The direction of particle motion is perpendicular (for example, up and down or side to side) to the direction of propagation.

solid), and thus transmit their motion (disturbance or deformation) to the adjacent coils. As this process continues, the shear disturbance travels along the entire slinky (elastic medium).

P and S waves can also be generated in the slinky by an additional method that reinforces the concept of elasticity and the elastic rebound theory which explains the generation of earthquakes by plate tectonic movements (Bolt, 1993, p. 74-77; 1999, p. 113-116). In this method, for the P wave, one person should slowly gather a few of the end coils of the slinky into his or her hand. This process stores elastic energy in the coils of the slinky that are compressed (as compared to the other coils in the stretched slinky) similar to the storage of elastic energy in rocks adjacent to a fault that are deformed by plate motions prior to slip along a fault plane in the elastic rebound process. When a few coils have been compressed, release them suddenly (holding on to the end coil of the slinky) and a compressional wave disturbance will propagate along the slinky. This method helps illustrate the concept of the elastic properties of the slinky and the storage of energy in the elastic rebound process. However, the compressional wave that it generates is not as simple or visible as the wave produced by using a blow of one's fist, so it is suggested that this method be demonstrated after the previously described method using the fist.

Similarly, using this "elastic rebound" method for the S waves, one person holding the end of the stretched slinky should use their other hand to grab one of the coils about 10-12 coils away from the end of the slinky. Slowly pull on this coil in a direction perpendicular to the direction defined by the stretched slinky. This process applies a shearing displacement to this end of the slinky and stores elastic energy (strain) in the slinky similar to the storage of strain energy in rocks adjacent to a fault or plate boundary by plate tectonic movements. After the coil has been displaced about 10 cm or so, release it suddenly (similar to the sudden slip along a fault plane in the elastic rebound process) and an S wave disturbance will propagate along the slinky away from the source.

Surface Waves

The Love wave is easy to demonstrate with a slinky or a double length slinky. Stretch the slinky out on the floor or on a tabletop and have one person at each end hold on to the end of the slinky. Generate the Love wave motion by quickly moving one end of the slinky to the left and then to the right. The horizontal shearing motion will propagate along the slinky. Below the surface, the Love wave motion is the same except that the amplitudes decrease with depth. Using the slinky for the Rayleigh wave is more difficult. With a regular slinky suspended between two people, one person can generate the motion of the Rayleigh wave by rapidly moving his or her hand in a circular or elliptical motion. The motion should be up, back (toward the person generating the motion), down, and then forward (away from the person), coming back to the original location and forming an ellipse or circle with the motion of the hand. This complex pattern will propagate along the slinky but will look very similar to an S wave. Rayleigh wave motion also decreases with depth below the surface. Excellent illustrations of the wave motion of Love and Rayleigh waves can also be found in Bolt (1993, p. 37) or in the seismic wave animations available at www.eas.purdue.edu/~braile/edumod/waves/WaveDemo.htm. Further details on the characteristics and propagation of Love and Rayleigh waves can be found in Bolt (1993, p. 37-41).

Illustration of Energy Carried by the Waves

The fact that the seismic waves that propagate along the slinky transmit energy can be illustrated effectively by using a slinky in which one end (the end opposite the source) has a small wood block attached. The wood block has a cardboard model "building" attached to it as shown in Figures 3. As P- or S-wave energy that propagates along the slinky is transmitted to the wood block, the building vibrates. This model is a good demonstration of what happens when a seismic wave in the Earth reaches the surface and causes vibrations that are transmitted to houses and other buildings. By generating P, S-vertical and S-horizontal waves that transmit vibration to the model building, one can even observe differences in the reaction of the building to the different directions of motion of the propagating wave.

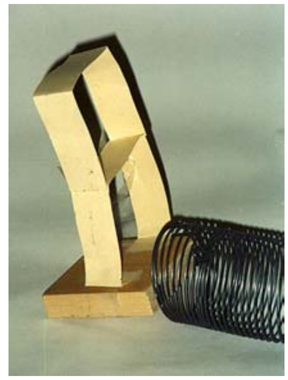

Fig. 3. Photograph of slinky attached to a small wood block and cardboard "house." The slinky could also be attached to the bottom of the wood block to illustrate P- and S-waves propagating upwards and shaking the building. The slinky is attached to the wood block using screws and washers using the same method illustrated in Figures 4-6.

Wave Propagation in All Directions

An additional demonstration with P and S waves can be performed with the 5-slinky model. By attaching 5 slinkys to a wood block as shown in Figure 4, five people can hold the ends of the 5 slinkys (stretched out in different directions to about 3-4 m each). One person holds the wood block and can generate P or S waves (or even a combination of both) by hitting the wood block with a closed fist or causing the block to move quickly up and then down or left and then right. The purpose of this demonstration is to show that the waves propagate in all directions in the Earth from the source (not just in the direction of a single slinky).

When the slinkys are stretched out to different positions (five people hold the end of one slinky each) and a P or S wave is generated at the wood block, the waves propagate out in all directions. The five slinky model can also be used to show that the travel times to different locations (such as to seismograph stations) will be different. To demonstrate this effect, wrap a small piece of tape around a coil near the middle one of the slinkys. Have the person holding that slinky compress all of the coils from the outer end to the coil with the tape so that only one half of the slinky is extended. Also, attach an additional (sixth) slinky, using plastic electrical tape, to the end of one of the slinkys. Have the person holding this double slinky stand farther away from the wood block so that the double slinky is fully extended. When a P or S wave is generated at the wood block, the waves that travel along the slinky will arrive at the end of the half slinky first, then at approximately the same time at the three regular slinkys, and finally, last at the double length slinky

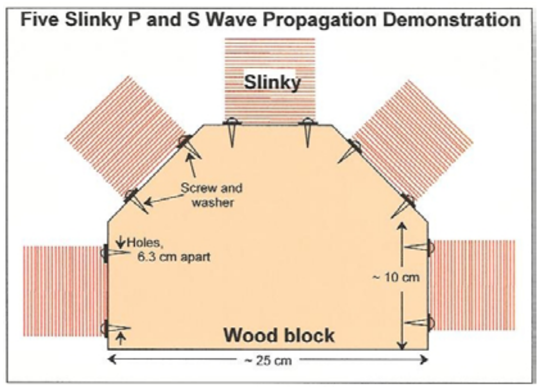

Fig. 4. Diagram showing how five slinkys can be attached to the edge of a wood block. Photographs of the five slinky model are shown in Figures 5 and 6.

Attaching an additional slinky (with small pieces of plastic electrical tape) to one of the five slinkys attached to the wood block makes one slinky into a double length slinky which can be stretched out to 6-8 m. For one of the other four slinkys, have the person holding it collapse about half of the coils and hold them in his or her hands, forming a half slinky, stretched out about 1½ - 2 m. Now when a source is created at the wood block, one can see that the waves take different amounts of time to travel the different distances to the ends of the various slinkys. An effective way to demonstrate the different arrival times is to have the person holding each slinky call out the word "now" when the wave arrives at their location (if the people holding the slinkys close their eyes and call out when they feel the wave arrive, their responses may be more accurate). The difference in arrival times for the different dis-

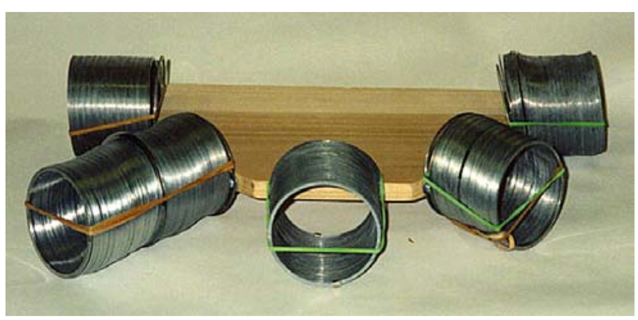

Figure 5. Photograph of the five slinky model.

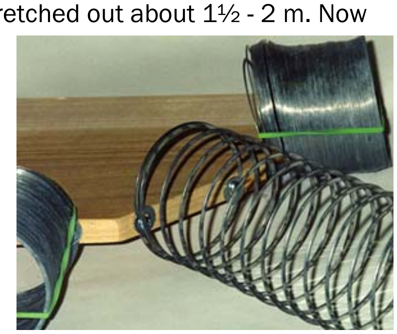

Fig. 6. Close-up view of five slinky model showing attachment of slinky using screws and washers (holes are 6.3 cm apart, screws are #6, ½" long, washers are 3/16").

tances will be obvious from the sequence of the call of "now." This variation in travel time is similar to what is observed for an earthquake whose waves travel to various seismograph stations that are different distances from the source (epicenter). Although these two demonstrations with the five slinky model represent fairly simple concepts, we have found the demonstrations to be very effective with all age groups. In fact, the five slinky demonstrations are often identified as "favorite activities" of participants.

Human Wave Demonstration – P and S Waves in Solids and Liquids

This demonstration involves a class or group in simulating seismic wave propagation in solids and liquids. If you have 20 or more people in the group, half can perform the demo while the other half watches; then switch places. The concepts that are involved in this demonstration are very dramatically illustrated to the participants. Once they have done the human wave activity, they should always remember the properties of P and S waves propagating in both solids and liquids. Have about 10 people stand at the front of the room, side by side, with their feet about shoulder width apart. Instruct the group to not be too rigid or too limp when pushed from the side. They should give with the force that they will feel from the person next to them, but not fall over, and then return to their upright position. In other words, they should be "elastic". Have a "spotter" at the end of the line in case the last person begins to fall. (It is important to stress these instructions to the participants so that the demonstration will work effectively and so that participants do not fall over as the wave propagates down the line of people.)

Fig. 7. Human P Wave.

To represent wave propagation in a solid, have each person put their arms over the shoulders of the person next to them ("chorus line style"; the "molecules" or "particles" of the solid are tightly bonded). Push on the person at the end of the line and the deformation (leaning to the side and then straightening up) will propagate down the line of people approximating a P wave. Note that the propagation down the line took some time (there is a velocity for the wave propagation) and that although each person was briefly subjected to a deformation or disturbance, the individuals did not move from their original locations. Also, the motion of each person as the wave passed was in the direction of propagation and that, as the wave passed, the people moved closer together temporarily (compression), and then apart (dilation or extension) to return to their original positions (Fig. 7).

Fig. 8. Human S Wave.

For the S wave in a solid, make the first person at the end of the line bend forward at the waist and then stand up straight. The transverse or shear motion will propagate down the line of people. Again, the wave takes some time to propagate and each person ends up in the same location where they started even though a wave has passed. Also, note that the shear motion of each particle is perpendicular to the direction of propagation. One of the observers can time the P and S wave propagation in the human wave using a stopwatch. Because the shear wave motion is more complicated in the human wave, the S wave will have a slower velocity (greater travel time from source to the end of the line of people), similar to seismic waves in a solid.

Next, to represent wave propagation in a liquid, have the people stand shoulder-to-shoulder, without their arms around each other. Push on the shoulder of the end person and a P wave will propagate down the line. The P wave will have the same characteristics in the liquid as described previously for the solid. Now, make the person at the end of the line bend forward at the waist – a transverse or shear disturbance. However, because the "molecules" of the liquid are more loosely bound, the shearing motion will not propagate through the liquid (along the line of people). The disturbance does not propagate to the next person because the liquid does not support the shearing motion. (Compare pressing your hand down on the surface of a solid such as a table top and on the surface of water and moving your hand parallel to the surface. There will be considerable resistance to moving your hand on the solid. One could even push the entire table horizontally by this shearing motion. However, there will be virtually no resistance to moving your hand along the surface of the water.) Only the first person in the line – the one that is bent over at the waist – should move because the people are not connected. If the next person bends, "sympathetically", not because of the wave propagating, ask that person if he or she felt, rather than just saw, the wave disturbance, then repeat the demonstration for S waves in a liquid.

Exploration and Assessment

After demonstrating seismic waves with the slinky, have students use the slinky to explore wave propagation and generation of different wave types and wave characteristics. One can also use slinky activities for authentic assessment by asking students to show their understanding by performing the demonstrations in class.

Connections to *National Science Education Standards*

The seismic wave demonstrations described here are related to the following NSES standards: Teaching Standards: inquiry-based (A, B); opportunity for assessment (C). Professional Development Standards: opportunity for learning new Earth science content (A, C); suggestions for effective teaching strategies (B). Assessment Standards: authentic assessment (C). Content Standards: Science as Inquiry – practice inquiry and fundamental science skills (grades 5-8 and 9-12, A); Physical Science – properties of matter, motion, transfer of energy (grades 5-8, B), structure of matter, motion, interactions of energy and matter (grades 9-12, B); Earth and Space Science – relate to energy in the Earth system (grades 9-12, D).

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Acknowledgements

This description of seismic waves and the slinky is excerpted from "Seismic Waves and the Slinky: A Guide for Teachers" available at: www.eas.purdue.edu/~braile/edumod/slinky/slinky.pdf. A 4-page slinky document is also available at: www.eas.purdue.edu/~braile/edumod/slinky/slinky4.doc. Developed in cooperation with the IRIS Consortium (Incorporated Research Institutions for Seismology, (www.iris.edu). This development was partially supported by the National Science Foundation.

Watch Earthquakes As They Occur

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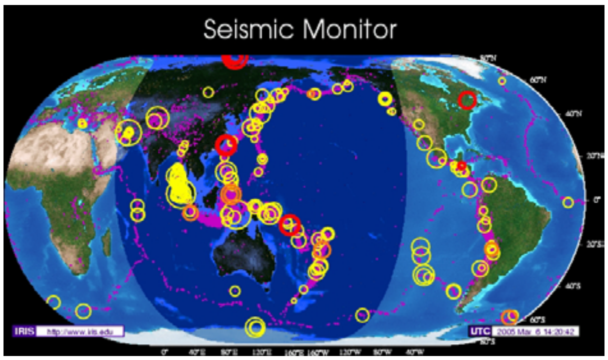
The seismic monitor (www.iris.edu/seismon) is a free, interactive web-based display of global seismicity. This tool allows teachers and students to easily monitor earthquakes in near real-time, view records of ground motion, learn about earthquakes, and visit seismic stations around the world.

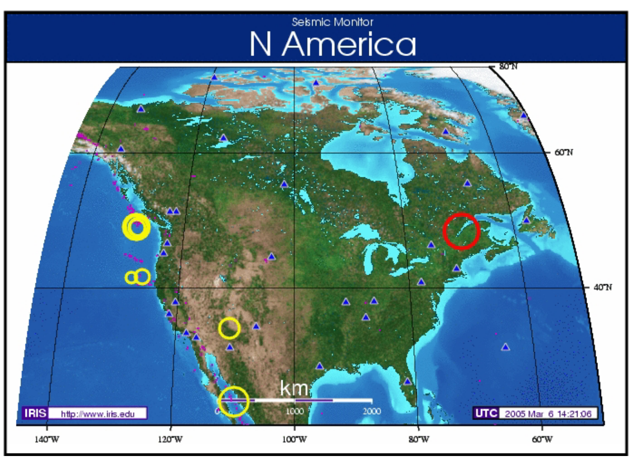


Global View

Monitor Current Earthquakes: Red circles mark earthquakes that have occurred within the last 24 hours. Earthquakes that have occurred in the past 25-48 hours are orange and those that have occurred between 49 hours and two weeks ago are yellow. After two weeks the earthquakes are noted as purple dots, which remain on the screen for five years. The size of the circle is proportional to the magnitude of the earthquake. Moving the mouse over each earthquake on the screen shows the magnitude, latitude and longitude for each earthquake.

View Global Topography and Seismicity: The global view shows the relationship between topography and seismicity. Notice how many of the large features of the Earth (like mountain ranges) coincide with earthquake zones. The distribution of seismicity during the past five years illustrates how earthquakes define the boundaries of Earth's tectonic plates. The shadow in the image illustrates the day/night and seasonal changes.

Plot Recent Activity: View the "Last 30 Days of Earthquakes" to generate a data table for global events of magnitude 4 or greater; event date, latitude, longitude, depth and magnitude and region. Students can discover the major plate boundaries themselves by using the information contained in this table to plot these events on a map. Further details of the plates can them be revealed when compare their results to the larger data set of Seismic Monitor.



Zoom View

Zoom into an area of the world by clicking on the region you wish to look at, and then use these fun tools!

Get Earthquake Data: For any earthquake that has occurred in the past two weeks click on the circle (from the zoom view) and get a list of earthquakes in that area. Clicking on the date of the earthquake will take you to a list of seismic stations. To see a seismogram of the earthquake click on a station name and it will be displayed.

Visit Seismic Stations: Each of the blue triangles represents a seismic observatory. Click on the blue triangle to visit the station. At each station you can get information on the geology of the area, the type of seismometer being used, and contact information. Some stations have a photo available.

- **Search For Earthquake Information:** To get local information, news, and photos of earthquakes and seismology, check the GOOGLE™ box when in the zoom view and click on an area of interest.

Acknowledgements: This description is adapted from the IRIS one-pager #1 available online at (www.iris.edu/edu/resources.htm).

Student-centered Experiments with Earthquake Occurrence Data

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An ever-growing catalog of earthquake locations, dates, times and magnitudes is available and easily accessed through Alan Jones' free Windows program Seismic/Eruption (Jones, et al., 2003; www.geol.binghamton.edu/faculty/jones). This program plots earthquake locations through time on a map of the world or on maps of various geographical areas (Figure 1). There are a number of teaching activities designed using Seismic/Eruption (e.g. Braile and Braile, 2001) which can help students see for themselves which areas of the Earth are more or less seismically active, where plate boundaries occur, typical depths of earthquakes, and sense that large earthquakes do not occur as often as smaller earthquakes. The activity presented in this paper allows the students to select their own region of interest and to interrogate the earthquake catalog to obtain quantitative data on the rate of occurrence of earthquakes of various magnitudes within their chosen region.

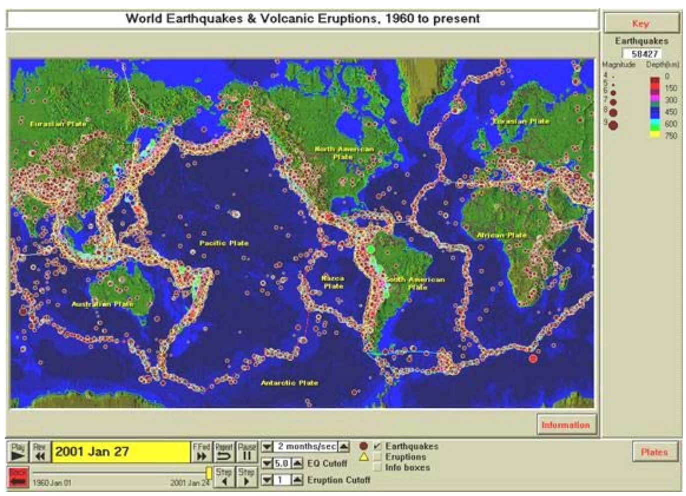

Fig. 1. Seismic/Eruption's World map showing earthquakes as circles plotted through time. The size of the circle indicates the magnitude, while the color indicates the depth of the earthquake.

After a suitable introductory activity or demonstration of Seismic/Eruption, students working individually or in small groups select a seismically active region of the world. Using a tool called “Make Your Own Map” (under the Map heading on the menu bar), they drag the mouse to create a zoomed view of their area of interest. Using the “Map menu” students should note of the latitude and longitude boundaries they have chosen. Next the time limits for the earthquake data they will analyze must be selected. The earthquake catalog in Seismic/Eruption begins in 1960 corresponding to the establishment of the World-wide Standard Seismograph Network. This global network, which later became the IRIS Global Seismic Network, greatly increased the accuracy and completeness of the catalog. If the student’s computer has an Internet connection, the catalog contained in Seismic/Eruption can be updated (under the Options menu) so that the end of the catalog is essentially today. This functionality allows students’ data sets to include earthquakes recently in the news. Within the time frame (1960 - present) students select starting and ending dates from the Control menu, and note the number of years selected. Reasonable choices may be 10 years, or 20 years, or even 45 years (the entire catalog to date).

Now the students are ready to “play” the earthquake data set for their chosen region and time window using the audio-style controls in Seismic/Eruption (Figure 2). By observing earthquakes occurring in accelerated time, students may draw preliminary estimates of how many large earthquakes will occur within their region and how many small earthquakes will occur. They may even attempt to predict when the next earthquake of a certain magnitude will plot on their map based on plotting “rhythms”. To find out if their estimates and predictions are correct, students will run the program several times selecting each time a minimum magnitude threshold to plot.

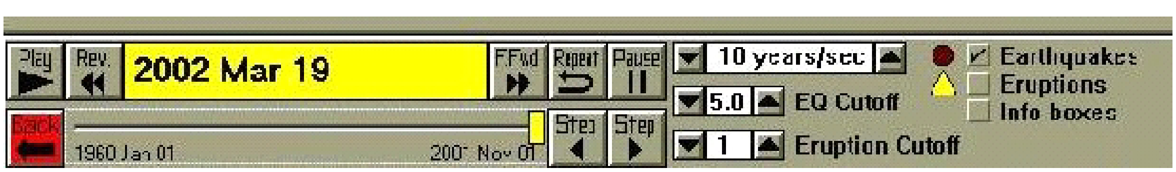

Fig. 2. A close-up view of Seismic/Eruption's controls.

For example, to determine the number of earthquakes with magnitude greater or equal to 8.0, students increase the “EQ Cutoff” value to 8.0. They should increase the speed with which the data set is plotted to 10 years/sec (the “Fast” setting should be avoided for this experiment). Seismic/Eruption also displays and counts volcanic eruptions; and can be disabled for this experiment by clicking to remove the check mark next to Eruptions. Students then click the Repeat button to replay the earthquake data set using these settings. The total number of earthquakes displayed on the map is printed in the upper right corner of the screen (see Figure 1), and students should make note of this number in a table. Next, they decrease the magnitude threshold to 7.5, click repeat to replay the data set, and collect the total number of earthquakes for this magnitude or larger. This procedure is repeated for smaller magnitude thresholds in 0.5 magnitude increments down to, say, 3.5. Finally the students divide their total number of earthquakes by the number of years in the time window they selected to obtain the number per year of earthquakes with magnitudes larger or equal to certain values.

An example of this exploration, Table 1 shows the results obtained for a region that includes Indonesia and the Philippines (latitudes from 12^{0}S to 12^{0}N, longitudes from 90^{0}E to 130^{0}E), for a period of 40 years beginning 1/1/1960 and ending 1/1/2000. Following data collection, the number of earthquakes per year is plotted on semi-log graph paper to create a Gutenberg-Richter plot Figure 3, which allows students to explore the data set. The data for the example region are plotted as red dots. Ordinary graph paper may be used for this, or a blank Gutenberg-Richter plot may be downloaded from (www.geol.binghamton.edu/faculty/barker/labs.html). Also shown for illustration, are similar results obtained from a region including California and Nevada for a period of 10 years (green dots) and a region around Italy for a period of 40 years (blue dots).

Table 1. Example Earthquake Occurrence Data for Indonesia and the Philippines.

Magnitude	Number	Number per Year
8.0	4	0.1
7.5	18	0.5
7.0	63	1.6
6.5	179	4.5
6.0	508	12.7
5.5	2019	50.5
5.0	5203	130
4.5	8457	211
4.0	8457	211
3.5	8457	211

By examining the plots and data tables, students can draw a number of conclusions. For example, by connecting points on the plot, they will see a linearly decreasing trend. Large earthquakes occur less often than smaller earthquakes. In fact for most regions of the world, for each increase of one magnitude unit, the number of earthquakes per year is smaller by a factor of 10. Students working on a regional scale can deduce this global scale trend by comparing their results with those of other students who have chosen a different region of the world (for example, comparing the different colors of data in Figure 3). Students may also notice a departure from this trend of decreasing number with increasing magnitude. In particular, for small magnitudes, the number may not change at all. Students should be encouraged to speculate on the reason for this. For most of the world, the earthquake catalog used by Seismic/Eruption does not include earthquakes smaller than magnitude 4.5. Therefore, the number of earthquakes with magnitude greater than 4.0 is the same as the number with magnitude greater than 4.5 simply because there are no earthquakes in the catalog for the selected region with magnitudes between 4.0 and 4.5. Other regions, particularly within the U.S. the catalog used by Seismic/Eruption includes smaller magnitudes. Though smaller events are included, there still may be a departure from the linear trend at small magnitudes, because small earthquakes are difficult to detect. Incompleteness of the catalog may also be the cause of the departure from a linear trend at large magnitudes. The time between large magnitude earthquakes may be longer than the time window we have selected, or may be longer than the entire earthquake catalog used by Seismic/Eruption.

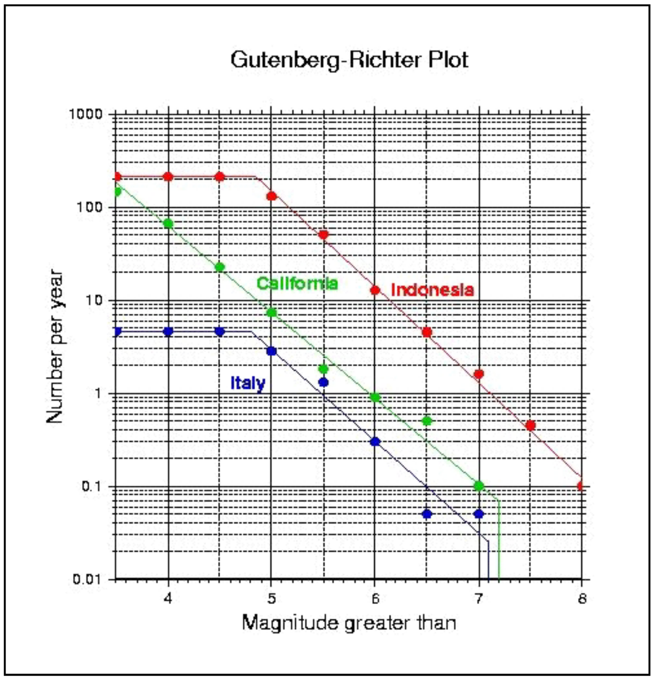

Fig. 3. Gutenberg-Richter plot of earthquake occurrence for the example data set including the region of Indonesia and the Philippines (red) and for other data sets from the California-Nevada region (green) and a region including Italy (blue). Students' plots will typically include only the data set from their chosen region, but others may be plotted for comparison.

Students may draw additional conclusions regarding the rate of earthquake occurrence within their area of interest, assuming that earthquakes are, on average, equally distributed through time. Thus in the example data (Figure 3), Indonesia and the Philippines, potentially damaging earthquakes of magnitude 6.5 or greater occur at a rate of 4.5 earthquakes per year. Therefore a damaging earthquake can be expected about every 80 days in this region. For California and Nevada, the trend suggests that magnitude 6.5 or greater earthquakes occur at a rate of about 0.3 earthquakes per year, or one earthquake approximately every 3 years. For Italy, the trend is for 0.1 earthquakes per year with magnitude 6.5 or greater, or one every 10 years. The actual data values collected for magnitude 6.5 or greater for California and Italy are greater than and less than the trend, respectively. The reasons for this difference could be discussed with students. Perhaps a different time window for the same region would produce slightly different results. Finally, although the time window for Indonesia did not include the 2004 M_W 9.3 Sumatra earthquake, we can extrapolate our data trend to estimate the expected rate of occurrence of earthquakes with magnitude greater than 9.0. If the trend is appropriate for earthquakes of that size, our data indicate we could expect approximately 0.015 earthquakes per year, or one magnitude 9.0 or greater earthquake every 67 years somewhere within the region of Indonesia and the Philippines. Our example data suggest that such an earthquake would be expected once every 1,000 years in the California and Nevada region or once every 3,000 years in Italy. This could (and should) lead to a discussion of whether such an extrapolation is reasonable (see Stein and Okal, this issue). Students could also test the assumption that earthquakes are evenly distributed through time by observing when earthquakes of a given magnitude threshold occur within their chosen region.

Allowing students to interrogate the most accurate, complete and up-to-date earthquake catalog about a region of their own choosing provides “ownership” of the experiment. Perhaps they will choose an area with a recent newsworthy earthquake such as the 2004 Sumatra event. Or perhaps they will choose their family's ancestral region. Or perhaps they will choose a geographical area they are studying in another class. After some simple data processing, graphing and analysis, they can pose questions and obtain answers about the occurrence of earthquakes in their chosen region.

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NATIONAL EARTH SCIENCE TEACHERS ASSOCIATION

In the News: EarthScope

Gayle Levy and John Taber
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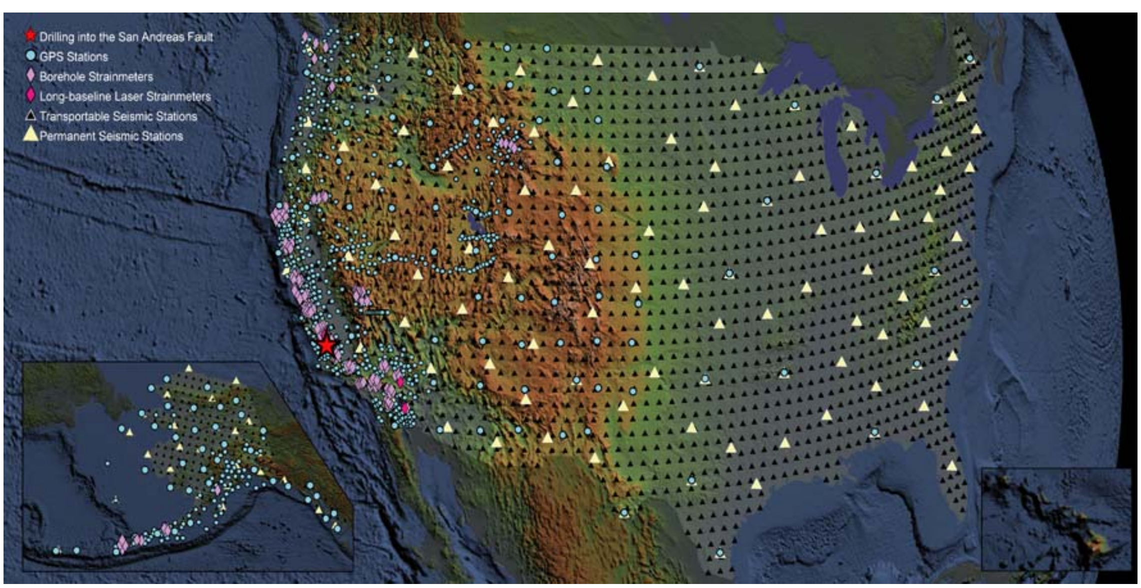
EarthScope is a national science initiative to explore the structure and evolution of the North American continent and to understand the physical processes controlling earthquakes and volcanoes. EarthScope is funded by the National Science Foundation (NSF) and will be developed over the next five years in partnership with the US Geological Survey. Once complete, EarthScope is anticipated by NSF to be operating for an additional 15 years. This project is the largest systematic survey of the North American continent funded by Congress since the Lewis and Clark expedition 200 years ago. To meet the project's scientific goals, EarthScope will install thousands of seismic and GPS stations across the country and drill a 3.2 km borehole into the San Andreas Fault. All of the data collected from EarthScope will be freely and openly available to the scientific community, the educational community and the public, providing an unparalleled source of data for the next generation of Earth scientists and educators.

The EarthScope project consists of three smaller projects, USArray, San Andreas Fault Observatory at Depth (SAFOD), and Plate Boundary Observatory (PBO). The monitoring of local, regional and global earthquakes is a vital part of learning about the geology below the North American continent as well as deeper Earth structure. To do this 400 seismometers will be set out in an array, starting with the West coast of the United States and moving East. The seismometers will be spaced on a grid about 70 kilometers apart. This spacing of the seismometers gives the scientists a good resolution to measure what is going on under crust of the Earth. The arrays of seismometers will stay on the West coast for 18 -24 months and then begin moving Eastward in a "leapfrog" fashion with the western-most instruments moved to the eastern edge of the array. After moving across the continental U.S. in about 8 years, the seismometers will go to Alaska for 18-24 months.

The other two EarthScope projects are focused mainly on the western half of the United States. The PBO project uses global positioning systems (GPS) and strainmeters to detect small movements in the Earth's crust in real time. Strainmeters are highly sensitive instruments designed to measure small changes in strain due to a variety of stresses in the Earth, including slow plate tectonic deformation, the Earth's tides, changes in atmospheric pressure and groundwater levels, thermoelastic effects, earthquakes, magmatic intrusions, and volcanic eruptions. This equipment is being placed in a broad region near the boundary between the Pacific and North American plates and will help scientists determine how volcanoes form, what causes earthquakes and how the

To meet the project's scientific goals, EarthScope will install thousands of stations across the country and drill a 3.2km borehole into the San Andreas Fault over the next five years. In addition, EarthScope will purchase 2,500 campaign GPS and seismic instruments, which will be available for temporary deployments and individual research experiments. Most of the stations will transmit data in real-time to data collection centers for an additional 15 years. All of the data from EarthScope will be freely and openly available to the scientific community, the educational community, and the public.



North American continent is deforming, as it is moving.

The goal of the SAFOD program is to drill a borehole through the San Andreas Fault Zone to install instruments directly in the area of earthquake generation. This project hopes to answer some of the fundamental questions about the physical and chemical processes that control faulting and earthquakes. Drilling of the borehole began on June 11, 2004, and although drilling stopped at the end of the summer, it will resume again next spring. When complete, the borehole will be 3.2 kilometers deep and stretch 1.8 kilometers to the side to cut across the fault.

Overall, the EarthScope program will give a much clearer picture into the geology under the North American continent. The information collected from this large-scale project will help scientists all over the world.

EarthScope In The Schools

The USArray outreach program incorporates the seismic data being collected with local schools and communities where the seismic stations will be located. Recently, a USArray instrument was placed at Wishkah school in Washington State. To accompany the USArray instrument installed on the school grounds, IRIS provided a simple, stand alone, AS-1 seismometer for the science teacher at the school to run in the classroom. This pair allows the teachers and students to make a connection between the sensor in their schoolyard with the instrument in their classroom. At the conclusion of the USArray instruments' rotation at the site, the AS-1 seismometer will remain with the school as a legacy for the school community.

Lynn Simmons, right, a geophysicist at the University of Washington with the U.S. Department of the Interior and the U.S. Geological Survey, talks to Don Hay's science class at Wishkah Valley School about the new seismic equipment. Photo credit: Kathy Quigg/The Daily World

As the USArray seismic stations pass through your state, you will be able to take advantage of the IRIS and EarthScope resources for incorporating the seismic data into the classroom. The seismic data from the USArray experiment is already available online and free of charge through the main IRIS data center (www.iris.edu/cgi-bin/wilberII_page1.pl). Step-by-step instructions for downloading data are available at www.eas.purdue.edu/~braile/edumod/as1lessons/UsingAmaSeis/UsingAmaSeis.htm#Downloading_5. A simplified data access interface designed for students will be available soon, along with classroom activities. Please check the IRIS and USArray Web sites in the coming months for more information.

Michael Flanagan, left, a student at the University of Washington, and Robert Busby, chief of operations, transportable array, with IRIS.

Photo credit: Kathy Quigg/The Daily World

Using the *Seismic Waves* Program in Schools

Alan Jones
SUNY Binghamton

Most people do not realize that when an earthquake occurs any place in the world, waves propagate from the earthquake and, if the earthquake is large enough, can be recorded on a seismograph on the opposite side of the Earth. A teacher or student can fetch and install the free Windows® program ***Seismic Waves*** at <www.geol.binghamton.edu/faculty/jones> to illustrate how this happens.

The program uses real data from earthquakes to show what records from seismographs look like as they are received. At the same time that the seismogram is displaying on one window, a second window shows waves traveling through the Earth reaching stations. A third window shows the waves traveling over the surface of three-dimensional (3D) Earth to these stations (see Figure 1). The location of each wave front was computed using a modified version of the tau-p program written by Ray Buland (Buland, 1979). The location of the P, PP, S, and SS arrivals at the surface are computed using the Jeffrey-Bullen tables.

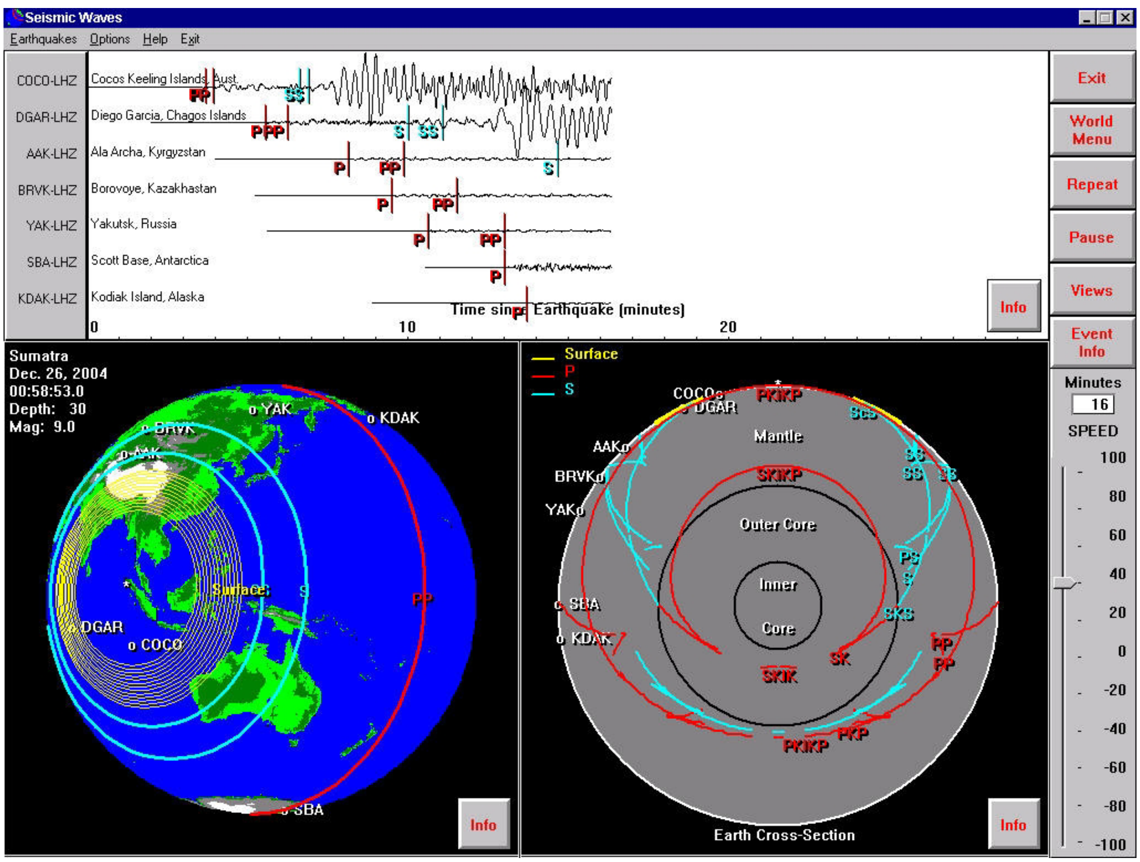


Fig. 1. Screenshot from the Seismic Waves program.

The program is very flexible. For example, you can display just the major phases for elementary classes, or leave the more complex phases in for high school and college classes.

When you install *Seismic Waves*, you will see that there are data from several major earthquakes of the last decade. New earthquakes can be added from the IRIS web site <www.iris.washington.edu> using *Wilbur II*. *Wilbur II* allows you to select an event and then select stations and wave forms from each station. These seismograms are downloaded to your computer in SAC binary form, which the *Seismic Waves* program can use.

For classrooms that participate in the IRIS ***Seismographs In Schools Program***

<www.iris.edu/edu/AS1.htm>, another way to bring new earthquakes into the program is to use the feature in ***AmaSeis*** to produce wave forms for *Seismic Waves*. By doing this, the students can see their seismogram as it is arrives at their station with respect to world-wide wave propagation.

How the Program is Used

While it is exciting to see action on the three windows at the same time, when beginning to use the program, one can also display either the cross-sectional view or just the Earth 3D view. This is recommended when the program is used in a classroom setting on a projection screen. One could start with the cross-sectional view and run the waves at a slow speed. (The speed numbers on the scale at the right are relative to real time. For example, a speed of 40 shows the waves propagating 40 times faster than they actually do.) One can watch the P and S waves leave the hypocenter and propagate into the Earth. The first point one makes is to observe that the S wave does not propagate into the liquid outer core as an S wave but, instead, converts to a P wave and, in addition, generates reflected P and S waves. Also, note the generation of the PP waves as the P wave bounces from the surface.

Next, show just the 3D view which illustrates the arrival of the P, PP, S, and SS waves as they arrive at the surface. In addition, the 3D view shows the widening band of surface waves as they spread over the Earth. You might want to ask students why there are no surface waves from the deep 1994 Bolivia earthquake. (Answer: deep earthquakes do not generate surface waves.)

As you run the program, you can slow the animation down, pause at any time, and even run it backwards to illustrate a point again. This should generate questions from the students as they comprehend what goes on in the Earth after an earthquake.

When running the 2004 Sumatra-Andaman event, stop the animation at 15 minutes and point out to the students that at this point, the seismic waves have not yet reached the United States, but that both the Pacific Tsunami Warning System and the U. S. Geological Survey had just issued their warnings of a magnitude 8.0 earthquake based on seismic stations in southeast Asia. Several hours later both organizations increased this to magnitude 9.0.

Preparing Students for the *Seismic Waves* Program

Before using the *Seismic Waves* program with students, it's helpful to introduce concepts of wave propagation using some of the seismic wave activities available at the Purdue web site <www.eas.purdue.edu/~braile>. Useful reference information on seismic waves and earthquakes is contained in Bolt (1993, 2003). A set of demonstrations and activities called, "Seismic Waves and the Slinky: A Guide For Teachers" is available at <www.eas.purude.edu/~braile/edumod/slinky/slinky.htm>. The demonstrations and activities available at the site include: descriptions of waves and seismic waves; instructions for demonstrations of waves in water, elastic wave propagation using a slinky and the human wave demonstration; an experiment for demonstrating elasticity; activities to illustrate energy carried by waves, wave velocity and attenuation, and wave propagation in all directions; and notes to teachers with suggestions for using the seismic wave activities and how the activities correlate to national education standards.

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Shake Up Your Community With The IRIS Seismographs in Schools Program

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The IRIS Seismographs in Schools program (www.iris.edu/edu/AS1.htm) annually disseminates 25 simple stand-alone seismographs to educators across the United States, through funding from the National Science Foundation. The seismographs are capable of recording local earthquakes and larger earthquakes worldwide. The AS-1 seismograph used by the program is relatively inexpensive ($550) and is effective for educational purposes because of its simplicity and ease of management and operation. Its open design makes it a convenient tool for educators to illustrate the principles and mechanics of seismometry and to monitor events from their classroom. AS1 seismographs are capable of recording local earthquakes with a magnitude 4 or greater and teleseismic events (earthquakes from a long distance away) with a magnitude 6 or 6.5 or greater. This sensitivity is sufficient to record at least one earthquake a month at any school in the United States. Since the program's inception in 2000, over 100 AS-1 seismographs have been placed in schools and science centers across the US. Additional instruments have been seeded in educational programs in the Virgin Islands, Costa Rica, Turkey, France and New Zealand.

Data recorded by the AS-1 can be viewed locally on a Windows computer using the free Amaseis software provided with the instrument or downloaded from the web. This software, written for IRIS by Alan Jones, can be used to analyze data collected in the classroom, data downloaded from the IRIS website or data from other Seismographs In School classrooms. Records can be used by teachers and students to determine the distance the earthquake was from their station, the magnitude of the earthquake, and if combined with data from other schools, to locate the epicenter of the earthquake.

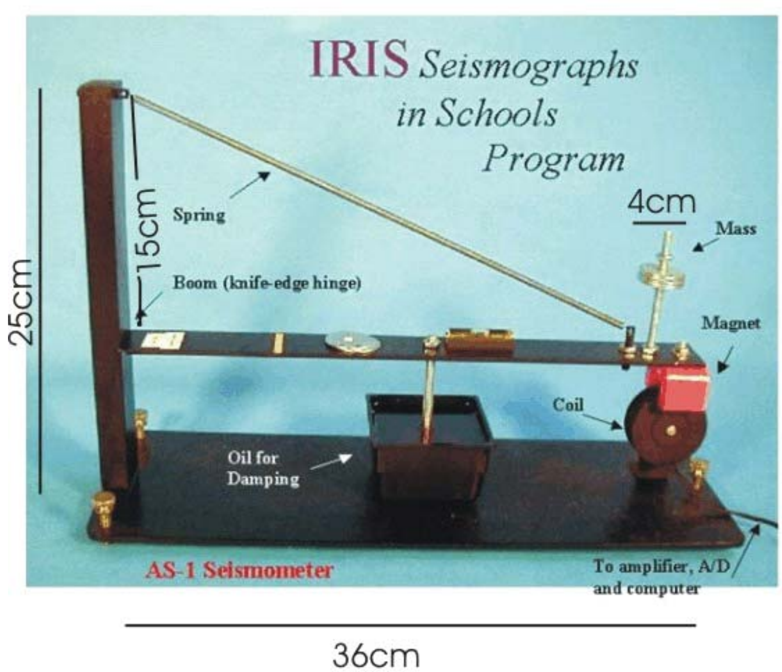

Fig. 1. AS-1 Seismograph use in the IRIS Seismograph in Schools Program

Students get a sense of ownership of the seismograph if they help to set it up and then make "important" calculations such as magnitude and locating the epicenter when an earthquake is recorded in their classroom. A comparison of magnitudes recorded by AS1s and the official USGS magnitudes shows that the AS-1 measures magnitude with surprising accuracy given the instruments low cost. These activities are not only aligned with the Earth science standards, but also enable students to learn more about earthquakes, geography and math.

To facilitate data sharing among classroom users, Science Education Solutions has developed www.SpiNet.com. This site allows teachers to register their seismograph station and upload and download data files for events they have recorded. Because data is uploaded manually, students can help upload the data and are more engaged in the process. Currently, there are 22 stations registered on SpiNet with as many as 6 stations reporting data per earthquake. It is a free service and is an effective way for teachers to see what other seismographs in their area or across the country are recording.

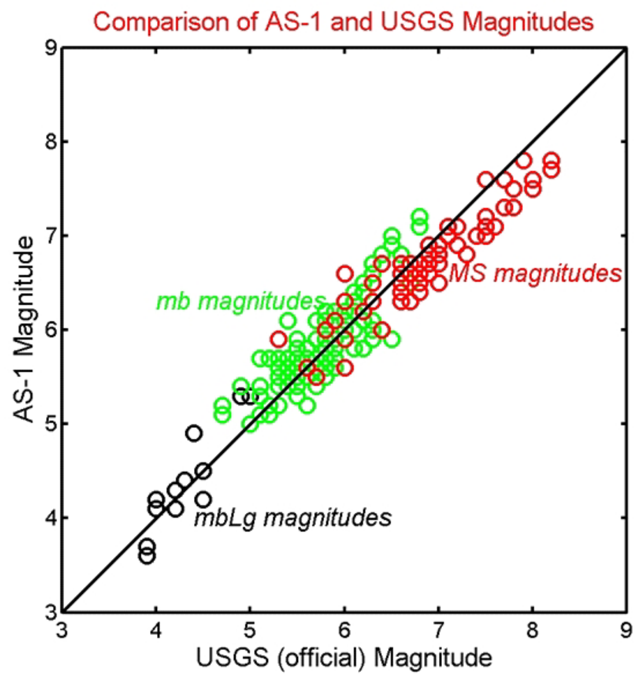

Fig. 2. Comparing actual and AS-1/AmaSeis magnitudes (September, 2003). The AS-1 magnitude calculations result in accurate magnitude determinations. Standard deviations of the differences between AS-1 (single station) and USGS (average of many stations) magnitudes are similar to other (standard seismograph) single station uncertainties. Credit: Larry Braile, Purdue University

Teachers can also serve screenshots of their seismogram recordings over the Web in near-real time. An image of the last 24 hours of seismic data is uploaded automatically and refreshed every 10 minutes. Teachers can use this page to see what the seismographs at other schools look like, or see if other local schools have recorded the same earthquake. This can easily be linked to the school's Web page, local chamber of commerce page or even a local news station page. A community of these school seismographs can be seen at www.jclahr.com/science/psn/as1/heli/allas1.php. Many schools have received local press coverage of their recordings of newsworthy earthquakes.

To ensure that teachers are able to easily incorporate the AS-1 into their Earth science and physics instruction the IRIS Education and Outreach program provides technical support and training sessions. To help troubleshoot and share ideas a community listserve serve is maintained, and IRIS staff are available by email or phone for support and inquiries. A Seismographs in Schools workshop is held annually and subsidized for program participants. Through this workshop educators are introduced to the community, learn to maintain their instrument, and explore and share activities for use in the classroom. This workshop is usually held in conjunction with regional NSTA meetings so that attendees may participate in both.

Seismologist In the Schools

John Lahr, a retired seismologist from the United States Geological Survey, visits schools with AS-1s whenever he is passing through that area of the country. While there he confirms the system set up, calibrates it, makes the teacher feel more comfortable using it, and talks with classes. Learning seismology is a hurdle for some teachers, but learning the technology is also a challenge. This is why Dr. Lahr's efforts are greatly appreciated, not only by the teachers he visits, but also by IRIS. His contributions help make the Seismographs in Schools program a successful one.

John Lahr, a retired USGS seismologist examines seismic data with students in a classroom participating in the Seismographs In Schools program.

NATIONAL EARTH SCIENCE TEACHERS ASSOCIATION

THE SUMATRA EARTHQUAKE AND TSUNAMI OF DECEMBER 2004: A COMPREHENSIVE INQUIRY-BASED EXERCISE FOR HIGH SCHOOL EARTH SCIENCE CLASSES

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Introduction

The incredible media coverage of the earthquake and tsunami of December 26, 2004, provided the world with images provoking both incredible sadness at the tragic loss of life, and awe at the destructive energy released from a convulsion of Earth's crust. Earth scientists everywhere were immediately eager to study the earthquake that rattled the entire planet and generated the tsunami that destroyed so much on the rim of the Indian Ocean basin. As earth science teachers, we viewed the event as a teachable moment ripe with possibilities.

The relationship between the underlying geologic processes and the day-to-day lives of people was made instantly, obviously, and painfully clear. Here was an opportunity for our students to see firsthand the importance of earth scientists' efforts to understand and perhaps eventually predict the workings of the earth system. The misfortune of beachgoers who followed the receding sea before the arrival of the waves, and the story of the young girl who had learned the significance of such a recession (and saved many lives by warning others to leave the beach) drove home the value of personal understanding and preparedness. The irony of the instantaneous appearance of images and videos of the destruction juxtaposed with the lack of warning to people who might have had hours to prepare, illustrated the fact that technology is limited by how effectively it is employed. Armed with actual data related to a real, familiar event, we were prepared to introduce our students to the concepts in seismology and plate tectonics, through thoughtful and careful analysis.

Creating the Activity

Shortly after the quake, we downloaded a number of maps and original seismograms using the Global Earthquake Explorer[1] (GEE) , and found that working out the epicenter location and origin time from the seismograms yielded remarkably accurate results. From there on, we each worked in tandem, developing additional activities and supporting materials (web links, images, and our own web pages) that would introduce or reinforce understandings of the geologic principles involved and the connection between that science, technology and the lives of everyday people. In a steady stream of emails each built upon the other's ideas, this comprehensive classroom exercise achieved its present form. The activity consists of the following sections;

Part 1 — Students analyze actual seismograms, calculate P and S wave travel time differences, and determine the corresponding epicenter distances. This information is recorded in a table on the student exercise. Using the data, students then plot the epicenter distances on a map and triangulate the epicenter location, and finally work backwards to determine the origin time of the quake. Students that are careful every step of the way will be rewarded with a very accurate, pinpoint location of the epicenter on their maps, and origin times within a few seconds of the actual time. Questions accompanying Part 1 lead students to examination the nature of the plate boundary east of Indonesia, including the study of maps and cross sections, web resources provided by the USGS, as well as original material developed for this exercise.

Part 2 — Skills and concepts developed in Part 1 are reinforced as students analyze additional seismograms and plot the epicenter location on a larger scale map.

Part 3 — Students study the nature of tsunamis, and determine the location of the advancing waves over a period of several hours.

Part 4 — Students determine the average velocity of seismic waves that have traveled various distances, and are asked to reflect on the reasons for the observed discrepancy. This final activity provides an excellent anticipatory set for teachers wishing to further explore the nature of the earth's interior and the how this revealed through the interpretation of seismic wave propagation.

Part 5 — Contains a number of concluding questions regarding the human impact of the event. Students view video clips and still images, and are asked to review their data and explore ways in which various locations might have been spared some of the enormous loss of life.

Our downloadable exercise[2] includes seismograms, maps, seismic wave travel time charts, and a world tectonic map customized for the Indian Ocean basin.

Reflecting on the Activity

To date, hundreds of students have used this lab. If anecdotal reports from teachers are accurate, the results have been outstanding. Teachers have noted the enthusiasm with which students have approached the lab, and are happy with the concepts the students retain. The breadth of the lab provides several "kick off" points for additional discussions and study of plate tectonics; the examination of the distance volcanoes are from the surface expression of the plate boundary, the depth to which a plate must dive before magma is generated, and earthquakes produced by the rising magma.

Plotting tsunami travel times, watching associated videos, and discussing who had a chance to get out of the ay (and even what "out of the way" means) brought the relationship between day-to-day human activity and the abstract idea of subducting plates into clear focus for our students. Taking it a step farther, we've been able to discuss the similarities and differences in the Pacific Northwest of the US, illustrating images from the Earth Science Picture of the Day[4], a recent article regarding hazards in the Pacific Northwest[3] and personal photos and anecdotes.

For years, high school earth science students have used artificial or doctored seismograms to plot earthquakes that as far as they're concerned may or may not have ever happened. These 'quakes' have no real connection to their lives, and as such the activity often devolves into the mere acquisition of a skill. What has impressed us with our activity is how students who work carefully can so accurately plot the position and calculate the origin time of a very real and current earthquake using real, un-doctored data and a simple travel time graph that has been part of the NYS Earth science reference tables for 35 years.

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[1] www.seis.sc.edu/gee/

[2] *Where to find additional teacher notes, materials, and the downloadable activity*

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[3] Krajick, Kevin. (2005) Future Shocks, *Smithsonian 35*(12)

[4] www.epod.usra.edu

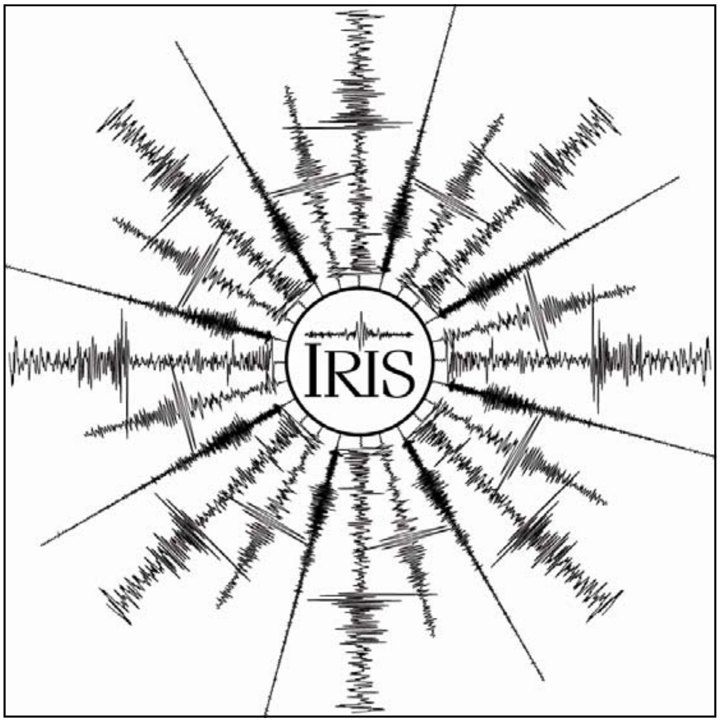
Workshop Announcement—Science Research in the High School

13-17 June 2005 Fairbanks, Alaska

Secondary teachers of science, technology, engineering, and mathematics are invited to attend a 4.5-day training workshop, "Science Research in the High School", on 13-17 June 2005 in Fairbanks, Alaska. This goal of the workshop is to provide teachers with the tools necessary to get their students involved in original scientific research through the Alaska Statewide High School Science Symposium (ASHSSS).

The ASHSSS, a University of Alaska outreach program, supports secondary students conducting scientific research outside the classroom and provides the guidance of a mentor. This workshop will familiarize teachers with more recent technology and show them how to help their students participate in the ASHSSS. The workshop is sponsored jointly by the Universities of Alaska Fairbanks and New York at Albany with funding provided by NSF. Participants will be provided with:- all workshop materials;- room and board costs at UAF during the 4.5-day workshop;- three seminar hours of transferable graduate credit at UNY at Albany;- travel costs to get from home site to UAF; and- a $600 USD stipend! Participants will pre-prepare articles and presentations with guidance before coming to the workshop and, as a result, will be ready to "hit the ground running." An NSF stipulation requires that the school or district of each teacher and/or participant assist with costs not to exceed $500. Funds needed to accommodate 25 teacher/participant's for this cost to school districts have been requested from UAF's Vice Chancellor for Outreach. To pre-register, visit www.albany.edu/scienceresearch/training.html. For further information, please contact Dr. Gary Laursen, UAF Department of Biology and Wildlife Phone: 907-474-6295E-mail: ffgal@uaf.edu

www.nestanet.org **www.iris.edu/**



Seismograms from three earthquakes recorded at IRIS GSN stations around the world make up the snowflake (left).

One of the largest earthquakes of the year shook northeast India on January 26, 2001. The magnitude 7.7 earthquake was felt throughout northern India, in Pakistan, Bangladesh, and western Nepal. The earthquake was triggered by stress due to the Indian tectonic plate pushing northward into the Eurasian plate. IRIS GSN station WMQ near Urumqi in China recorded the earthquake at about 2,800 km distance from the epicenter.

The IRIS GSN station GRFO near Graefenberg in Germany recorded a mining induced earthquake near the border between France and Germany on June 21, 2001. Eyewitnesses described this event as explosion-like. The magnitude 4.2 earthquake caused damage to houses on both sides of the border.

The magnitude 7.0 earthquake south of the Mariana Islands on October 12, 2001 was recorded at IRIS GSN station RCBR near Riachuelo in Brazil at a distance of about 20,000 km (173 degrees). Near the antipodal distance, several branches of P-waves traversing the outer core and P-waves reflected once at the Earth's surface dominate this seismogram.

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