USArray Seismic Wave Visualizations: Teacher Information

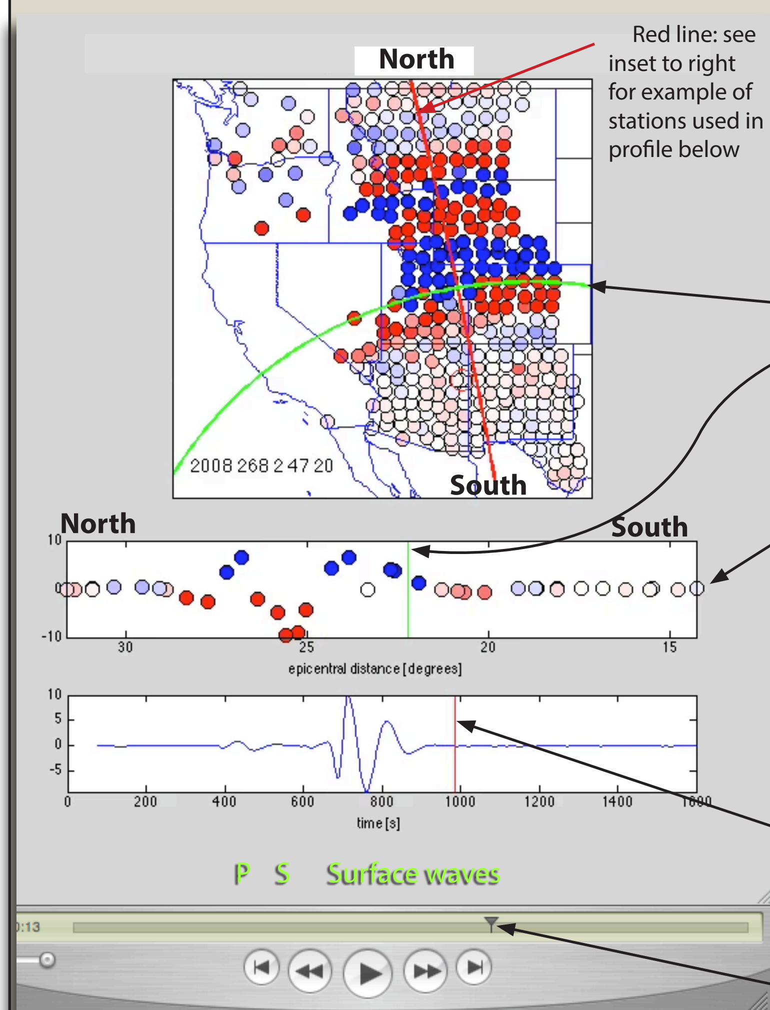
As earthquake waves travel along the surface of the Earth, they cause the ground to move. The ground motions can be captured and displayed as a movie, providing a visual demonstration of these often indiscernible movements.

Overview

These animations show how the ground responds when seismic waves from worldwide earthquakes sweep across more than 400 sensitive seismograph stations of USArray (www.usarray.org/), the seismologic component of EarthScope. (See Page 4 for description of EarthScope's continental project.) Each animation has a map of the active USArray grid at the time of the earthquake. These animations are a creative use of the data being received by this unusually dense array of monitoring stations that were deployed as a means to "image" the roots of our continent.

The instructions that follow provide a step-wise teachers' guide to USArray visualizations. These visualizations are especially effective for contrasting the speeds of travel of P, S, and surface waves. Part I is a tutorial developed by IRIS (Incorporated Research Institutes for Seismology) to introduce USArray animations. It is critical to go through this tutorial before advancing to the Part II classroom demonstration.

USArray Wave Animation Basics



Red line: see inset to right for example of stations used in profile below

Color Key

Seismometer: no motion

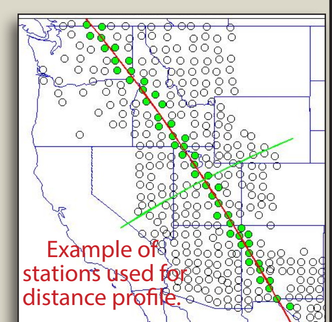
Downward ground motion

Upward ground motion

The color changes as waves of differing amplitude cross the circle. Darker equals the increased amplitude (height) recorded by each seismometer.

Green arc marks the radial distance from the earthquake that is depicted by the distance graph. Red line on map shows location of distance profile (middle graph left; example below right).

Notice that individual circles don't move to the left or right, but rise and turn blue when the seismometer senses vertical movement up and sink and turn red when movement is downward.



Red line moves across the seismogram to show time elapsed since the earthquake occurred at time = zero. Y axis = vertical displacement.

Drag toggle bar to slow/stop the action.

PART I: Introduction to the Animations

The IRIS tutorial on USArray animations provides an excellent introduction to the kinds of animations that have been developed to display seismic waves from a distant earthquake sweeping across the dense array of seismometers. The tutorial is available from:
www.iris.edu/hq/programs/epo/visualizations/tutorial

The most important sections of the tutorial are:

1. Introduction;
2. USArray Tutorial;
3. Tutorial #2: The Family of Stations;
4. Tutorial #3: 3-D; and
5. Global Window: Tutorial #5 The Big Picture. It is important to spend some time studying each tutorial section so you are familiar with the methods used to display the ground motions detected by the USArray seismometers.

Once you have completed the IRIS online tutorial, you are ready for Part III that will explain how to use the seismic waves from an earthquake in the Mariana Islands as a classroom demonstration.

Visualizing P, S, and Surface Waves Classroom Demonstration

The basics: Seismic waves from a magnitude 7.4 earthquake in the Mariana Islands are shown sweeping across the USArray seismometers in the second animation of Tutorial #5. This animation is "Animation of Mariana Island Earthquake". This earthquake occurred on September 28, 2007 when the array was located across the western US including the Pacific Northwest. The animation shows a global view of the earthquake epicenter in the Mariana Islands of the western Pacific Ocean with P, S, and surface waves traveling in all directions away from the epicenter. P waves are color coded ("go go") green while S waves are colored red and surface waves are shown in yellow. The animation zooms in on the western US location of USArray seismometers as P, S, and surface waves sweep across the array. The speeds of travel of these waves are visibly distinguishable from one another with P waves travelling faster than S waves that in turn travel faster than surface waves. Showing this animation to your Earth Science class after introducing types of seismic waves can visually reinforce fundamentals of kinds and velocities of seismic waves.

Further study: To get more out of this animation, you can examine the travel times for P, S, and surface waves from the earthquake to USArray and also determine the times required for these waves to cross the array. Time is shown on the bottom left corner of the lower panel of the animation. The format for the time stamp is YYYY DDD HH MM SS with time in Greenwich Mean Time. The origin time for the Mariana Islands earthquake at 13:38:58 on September 28, 2007 translates to 2007 271 13 38 58, the time stamp on the first frame of the animation. When showing the QuickTime animation, you can start and stop the animation using the center "play / pause" control button at the bottom of the QuickTime window. When you want to examine details of timing (e.g. exactly when does the first S wave arrive in the northwest corner of USArray?), you can use the fast-forward (right double arrow) and rewind (left double arrow) control buttons. Tapping briskly on the fast-forward (rewind) button will move the animation forward (backward) one frame at a time. Using these methods, the times of arrival of P, S, and surface waves from the Mariana Islands earthquake at the USArray station nearest the earthquake in northwest Washington (Forks, WA station about 8400 km from the earthquake) and farthest from the earthquake in southeast Arizona (Douglas, AZ station about 10,300 km from the earthquake) have been determined and are listed in the table below. You can turn this classroom demonstration into an inquiry lesson by giving students the "mariana_globe.mov" QuickTime movie and having them determine the arrival times. (Watch out! Without question, K-12 students are much faster at these computer skills than are their teachers.)

Some observations and insights: As listed in Table 1, arrival times of seismic waves from the Mariana Islands earthquake in northwest Washington are: P = 11 minutes and 15 seconds; S = 20 minutes and 35 seconds; surface waves = 37 minutes and 35 seconds.

The time required for waves to cross USArray are: P = 1 minute and 30 seconds; S = 2 minutes Arrival times in southeast Arizona are: P = 12 minutes and 45 seconds; S = 23 minutes and 25 seconds; surface waves = 46 minutes and 20 seconds. The time required for waves to cross USArray are: P = 1 minute and 30 seconds; S = 2 minutes and 50 seconds; surface waves = 8 minutes and 45 seconds. These arrival times and times required for P, S, and surface waves to cross USArray nicely demonstrate the relative speeds of these different types of seismic waves. While textbooks describe how P waves are faster than S waves that in turn are faster than surface waves, this animation of seismic waves generated by the Mariana Islands earthquake visually reinforces these observed seismic wave velocities.

Table 1: Travel time for P, S, and Surface waves to travel from the Mariana Islands to Washington and Arizona through the USArray.

Observation	**Time** (GMT)	**Travel Time** (HH MM SS)
Earthquake occurs in Mariana Islands	13 38 58	00 00 00
1st P wave arrives in northwest WA	13 50 13	00 11 15
1st P wave leaves southeast AZ	13 51 43	00 12 45
Time for P wave to cross USArray		00 01 30
1st S wave arrives in northwest WA	13 59 33	00 20 35
1st S wave leaves southeast AZ	14 02 23	00 23 25
Time for S wave to cross USArray		00 02 50
1st surface wave arrives in northwest WA	14 16 33	00 37 35
1st surface wave leaves southeast AZ	14 25 18	00 46 20
Time for surface wave to cross USArray		00 08 45
	15 51 38	02 12 40

Even after the P, S, and surface waves from the Mariana Islands earthquake have swept across USArray, there is still more information to be gathered from careful analysis of this "mariana_globe.mov" QuickTime movie. After the surface waves leave USArray, there are other waves that continue to be detected by the seismometers. These include P and S waves that have reflected and refracted at Earth's internal boundaries such as the boundary between the mantle and outer core and between the inner and outer core. At about 70 minutes (4200 seconds) after the earthquake, some well-defined waves start traversing from southeast to northwest across USArray. These are P waves then S waves that have travelled the long way around the Earth from the Mariana Islands to USArray. At about 2 hours and 13 minutes after the earthquake, a yellow line travelling from southeast to northwest arrives in southeast Arizona. This is the surface wave that travelled the long way (29,600 km!) around the Earth from the Mariana Islands to USArray.

Figure 1, below, shows the paths of surface waves that can travel multiple times around the Earth. It is astonishing that seismic waves that have travelled all the way around planet Earth can still be detected by sensitive seismometers. Great earthquakes, like the Sumatra 2004 M9.2 earthquake, generated seismic waves that were detectable after several passages around the globe. In fact, great earthquakes cause the Earth vibrate like a bell in "free oscillations" that can go on for several days after the earthquake.

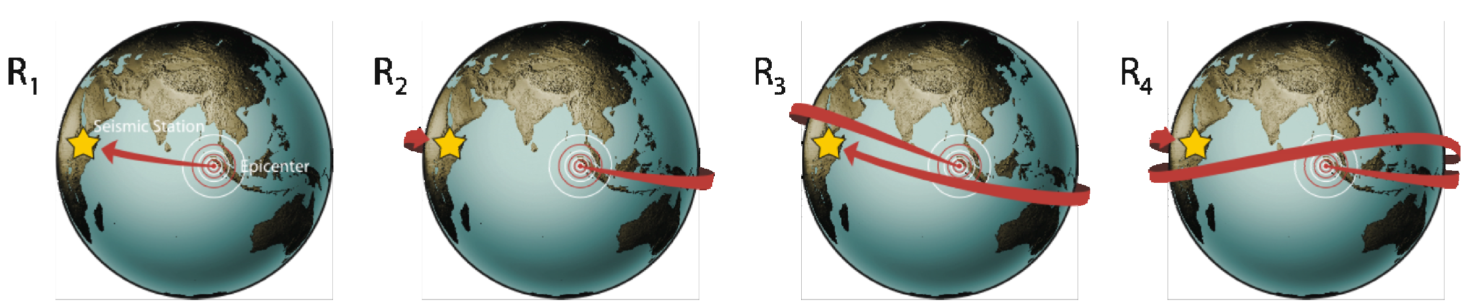


Figure 1: *Paths of earthquake surface waves as they travel four times around the Earth. Image from IRIS (www.iris.edu) Active Earth Index Pages*

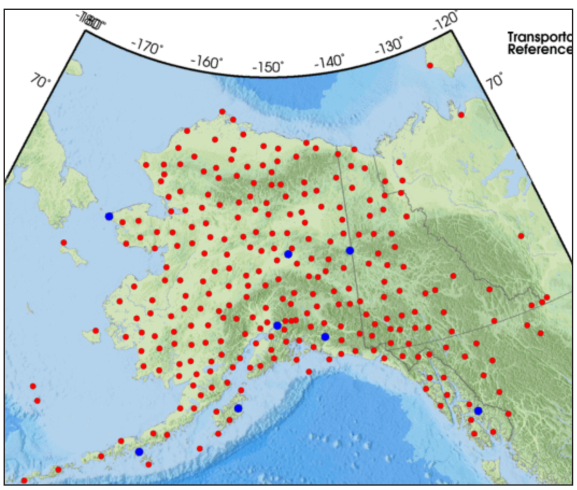
EarthScope & USArray

EarthScope is a ten-year series of geophysical experiments to explore the making of the North American continent. EarthScope is funded by the National Science Foundation and involves three major components:

1. **USArray,** (http://www.usarray.org/) a continental-scale array of seismometers to provide a coherent three-dimensional image of the North American continental crust, the underlying mantle portion of the North American plate, and the deeper Earth. Four hundred seismometers spaced about 70 km apart are deployed in a grid across a region of the US for 18 months. The array began in California in 2004, was located across the western US from 2007 to 2008, and is now, 2018, situated in Hawaii. When completed, nearly 2000 locations will have been occupied during this program. Seismologists are now analyzing the records of 1000s of worldwide earthquakes to develop a seismic-wave "cat scan" of the continental crust and the deeper Earth beneath the western US.

2. **PBO** (Plate Boundary Observatory; www.unavco.org/projects/major-projects/pbo/pbo.html), arrays of strain meters and GPS receivers to measure real-time deformation on a plate boundary scale. Permanent arrays of high-precision GPS receivers have been deployed in California and across the Pacific Northwest. Data from these receivers can be used to determine their location to within an error ellipse the size of a grain of rice! PBO can measure the deformation of the Pacific Northwest caused by the accumulation of elastic energy along the Cascadia subduction zone. These observations will provide constraints on models of earthquakes and volcanic behavior.

3. **SAFOD** (San Andreas Fault Observatory at Depth; https://earthquake.usgs.gov/research/parkfield/safod_pbo.php), borehole observatory to directly measure the physical conditions under which plate boundary earthquakes occur. This drill hole has penetrated the San Andreas Fault in the depth range of 3 to 4 km below Earth's surface. Samples of rocks along and adjacent to the fault have been collected for study and instruments are monitoring the behavior of this important plate boundary fault to provide insight into processes that occur before, during, and after earthquakes.



Above: USArray seismic stations in Alaska in 2018.

Right: Installation plan for the deployment of USArray stations from 2004–2013.