Resource from animation found at: <http://www.iris.edu/hq/inclass/search>

**Narration from the animation:**

**Earthquake Early Warning: Pacific Northwest subduction zone**

Data gathered during the 2011 Tohoku earthquake taught us much about mega thrust earthquakes. 6 The largest magnitude earthquakes that affect both Japan, and the Pacific Northwest occur along the shallow portions of the offshore subduction-zone plate boundaries.

With over 4,000 modern seismograph stations deployed across the country, Japan implemented an earthquake early-warning plan to issue alerts about impending ground shaking and tsunamis. First-arriving P waves locate the epicenter and estimate the magnitude, then trigger an alert to nearby population centers via sirens, automated phone messages, TV, and radio before the slower, damaging S waves arrive. This works well for strong magnitude 6 and major magnitude 7 earthquakes.

But the March 2011 magnitude 9 Tohoku earthquake revealed limitations of the seismic early warning system and taught us how GPS can improve warnings for great earthquakes of magnitude 8 or 9.

During that earthquake, P-waves from the initial rupture located the epicenter and estimated a magnitude. Early warnings indicated that shaking, produced by slower but larger S waves, would hit Sendai in just 8 seconds and Tokyo in 80 seconds These arrival times were accurate but the intensity and duration of ground shaking were 130 times greater than expected because the system vastly underestimated the magnitude. Here’s why:

In its simplest form, an early warning system assumes the earthquake results from sudden slip on a small area of a fault surface. But for earthquakes greater than magnitude 7, the small patch at the epicenter is just the starting point for a rupture that spreads over a huge area as it tears the fault and radiates immense seismic energy from all parts of the rupturing fault area. The magnitude 9 Tohoku earthquake ripped a fault area three hundred miles long, releasing seismic energy over an interval of nearly 3 minutes.

Let’s show how GPS can enhance earthquake early warning by using a simplified cross section of the Tohuku earthquake. As S-waves traveled past the nearest GPS stations, the ground moved more than 14 feet toward the epicenter in 45 seconds. At the same time near the Japan Trench, the ocean floor uplifted 23 feet generating the tragic tsunami that rushed onshore minutes after ground shaking ended.

At 95 seconds, GPS revealed large ground motions that indicated a Great subduction-zone earthquake was rupturing offshore and a tsunami was certain to follow. This data could have given coastal communities a far-more-urgent tsunami alert, and Tokyo an additional minute to prepare for the shaking that would be much stronger than initially calculated.

Can an Earthquake early warning system be developed for Cascadia subduction zone earthquakes? Indeed it can. With a coordinated effort by seismologists and geodesists, a better earthquake and tsunami early warning system is possible.

To understand the components of early earthquake warnings let’s watch an animation of a hypothetical magnitude 9 Cascadia subduction-zone earthquake. 9 The epicenter is offshore of Port Orford, a scenario to give optimal warning times for Portland and Seattle. The earthquake generates seismic waves as it ruptures northwards.

10 seconds after the P waves hit the coast, the seismic network locates the hypocenter and determines the magnitude as seven or larger, it cannot say how much larger. As S-waves arrive, the Port Orford GPS station lurches seaward indicating significant ground displacement. Knowing they might have little time after shaking stops to reach high ground, residents evacuate immediately.

20 seconds after initiation, rupture moves past Cape Blanco. S-waves produce strong ground movement and the Cape Blanco GPS station lurches 10 meters indicating that the Port Orford station wasn’t an

data point, but that this earthquake is greater than M8.5! Tsunami warnings are issued for coastal communities and broadcast throughout the Pacific Ocean.

Coastal towns farther north, like Coos Bay Oregon, have about 20 seconds warning which allows people to “drop, cover, and hold-on”; get away from dangerous machines or chemicals; and shut down gas and electric supply lines.

Region-wide emergency alerts are issued indicating when strong ground shaking will arrive. Portland is warned that damaging S-waves will arrive in 80 seconds. Seattle has a 2 minutes and 20 second warning.

One minute after the earthquake rupture began, P waves arrive in Portland. As the rupture and S waves reach Newport, we will see that GPS station lurch southwest indicating the earthquake will approach magnitude nine. Strong shaking affects the inland valleys east of the ongoing rupture as it generates more seismic waves.

Two minutes after initiation, Seattle feels the initial P-waves jolt. The S-waves, generated by the rupture offshore west of Portland, begin producing the most violent ground shaking in Portland. Shaking lasting up to five minutes will damage older unreinforced buildings.

This animation shows that Portland and Seattle could have several minutes warning before the strongest shaking hits.

With a minute of warning, additional precautions include: stopping rail and road traffic, closing bridges and tunnels; halting airport takeoffs and landings; opening elevator doors at the nearest floor; stopping surgeries, and getting emergency personnel and equipment ready to respond.

At 3 minutes, S-waves arrive in Seattle as the rupture passes north of Astoria where GPS stations move southwest by 5 meters confirming a magnitude of 9.

Rupture has progressed north to offshore Vancouver Island with violent ground shaking continuing in Seattle for several more minutes. We know that a rupture like the one depicted here— along the entire length of the Cascadia subduction zone—last occurred on January 26, 1700. A similar scenario could occur with an epicenter initiating anywhere along the subduction-zone boundary.

In addition to a joint seismic and GPS network, an early warning system requires public education, as well as an integrated plan with civil-protection authorities and telecommunications groups to make such a system effective for saving lives.