Magnitude 9.1 NEAR THE EAST COAST OF HONSHU, JAPAN
Friday, March 11, 2011 at 05:46:24 UTC

Ten years ago, on March 11, 2011, a devastating magnitude 9.1 earthquake occurred 130 km (80 miles) east of Sendai, Honshu, Japan and 373 km (231 miles) northeast of Tokyo, Japan at a depth of 24.4 km (15 miles).

In this March 15, 2011 photo, a survivor of the earthquake and tsunami rides his bicycle through the leveled city of Minamisanriku, in northeastern Japan, four days after the tsunami.

(AP Photo/David Guttenfelder)

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This M 9.1 earthquake and the tsunami that followed caused 15,899 deaths and 6,157 injuries, with 2,529 still missing. 130,927 people were displaced from their homes. 332,395 buildings, 2,126 roads, 56 bridges and 26 railways were destroyed or damaged. The vast majority of fatalities and damage was due to the tsunami and were concentrated on the Pacific coast of northern Honshu.

Electricity, gas and water supplies, telecommunications, and railway service were disrupted. The tsunami disabled the power supply and cooling of three Fukushima Daiichi reactors, causing a nuclear accident. The region experienced liquefaction, landslides, and a dam failure.

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An aerial combination photo shows Okawa Elementary School after the tsunami hit (top, March 15, 2011) and (bottom, September 28, 2020) in Ishinomaki, Miyagi Prefecture.

Seventy-eight students and ten teachers of the elementary school were killed in the tsunami.

The Yomiuri Shimbun via AP Images

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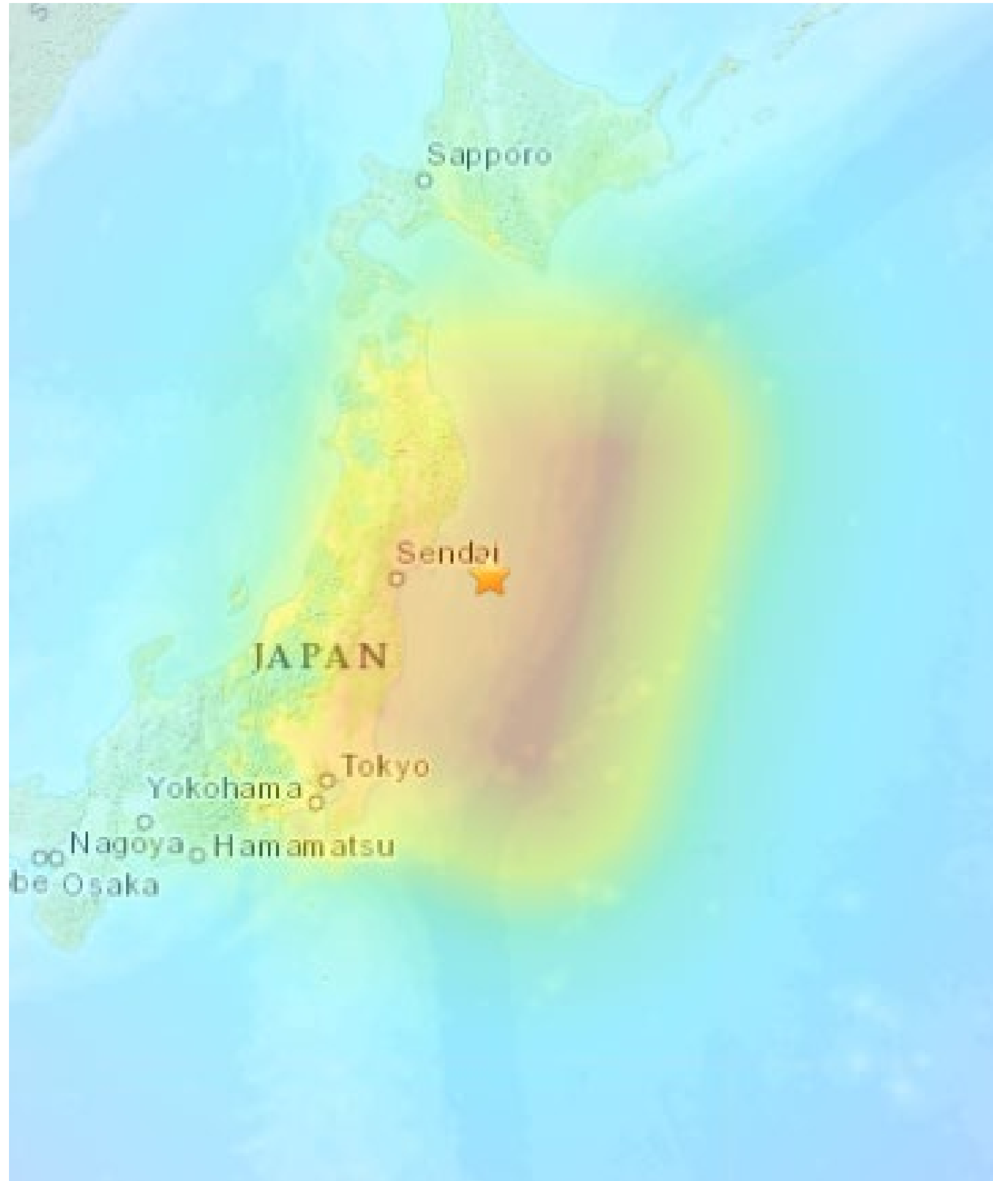
The Modified-Mercalli Intensity (MMI) scale is a ten-stage scale, from I to X, that indicates the severity of ground shaking.

Intensity is based on observed effects and is variable over the area affected by an earthquake. Intensity is dependent on earthquake size, depth, distance, and local conditions.

MMI	Perceived Shaking
X	Extreme
IX	Violent
VIII	Severe
VII	Very Strong
VI	Strong
V	Moderate
IV	Light
II-III	Weak
I	Not Felt



USGS estimated shaking intensity from M 9.1 Earthquake

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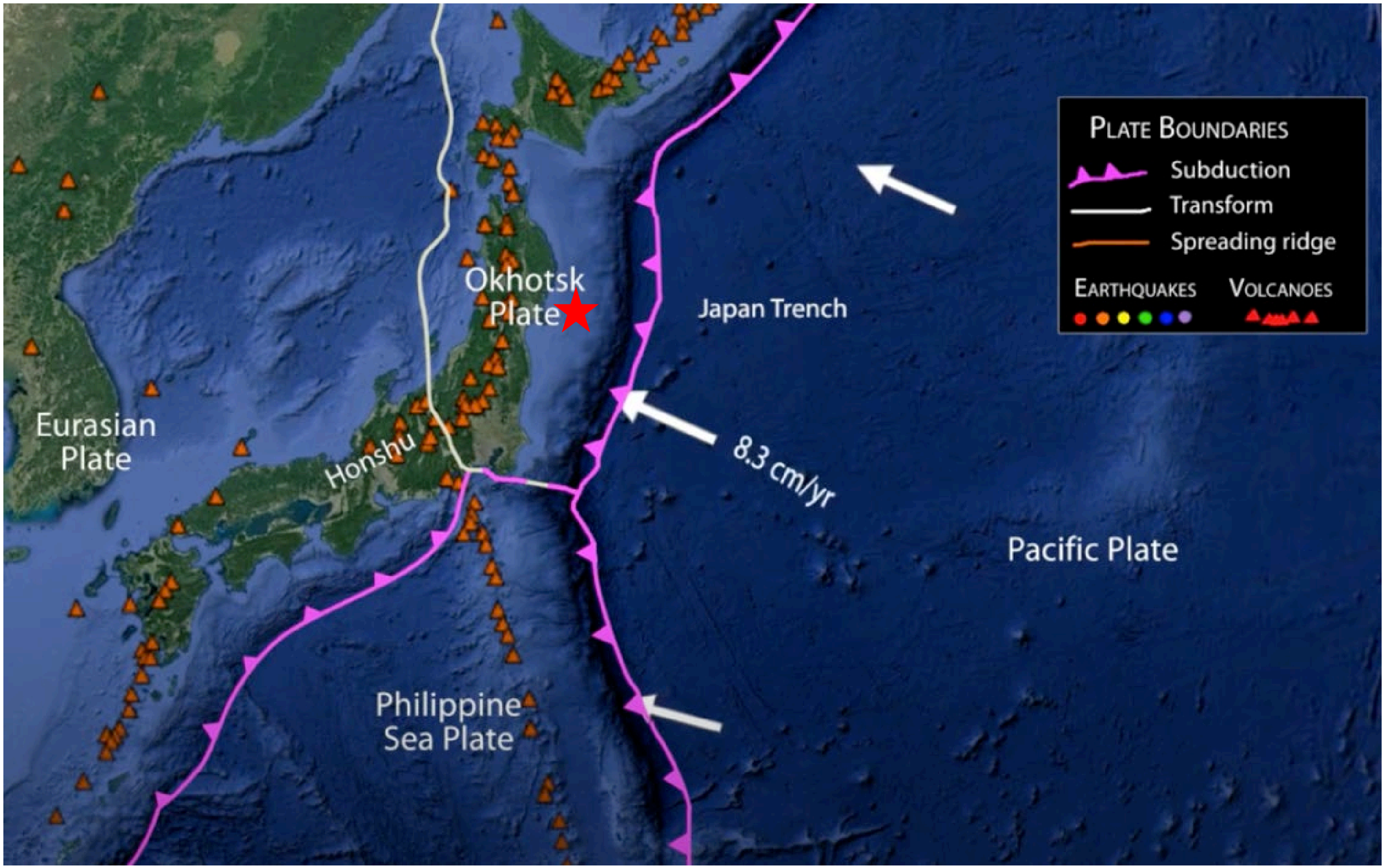

In Northern Honshu, the Pacific Plate subducts beneath the Okhotsk Plate at a rate of 8.3 cm/year. The epicenter of the magnitude 9.1 earthquake is shown by the red star.

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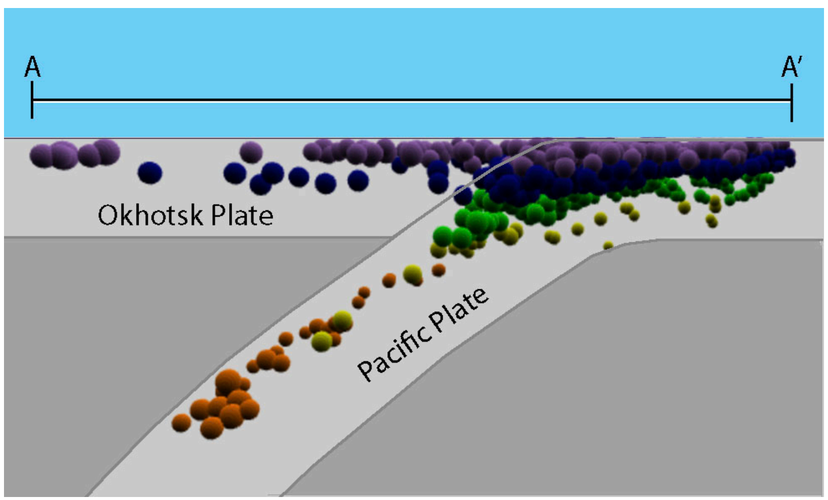
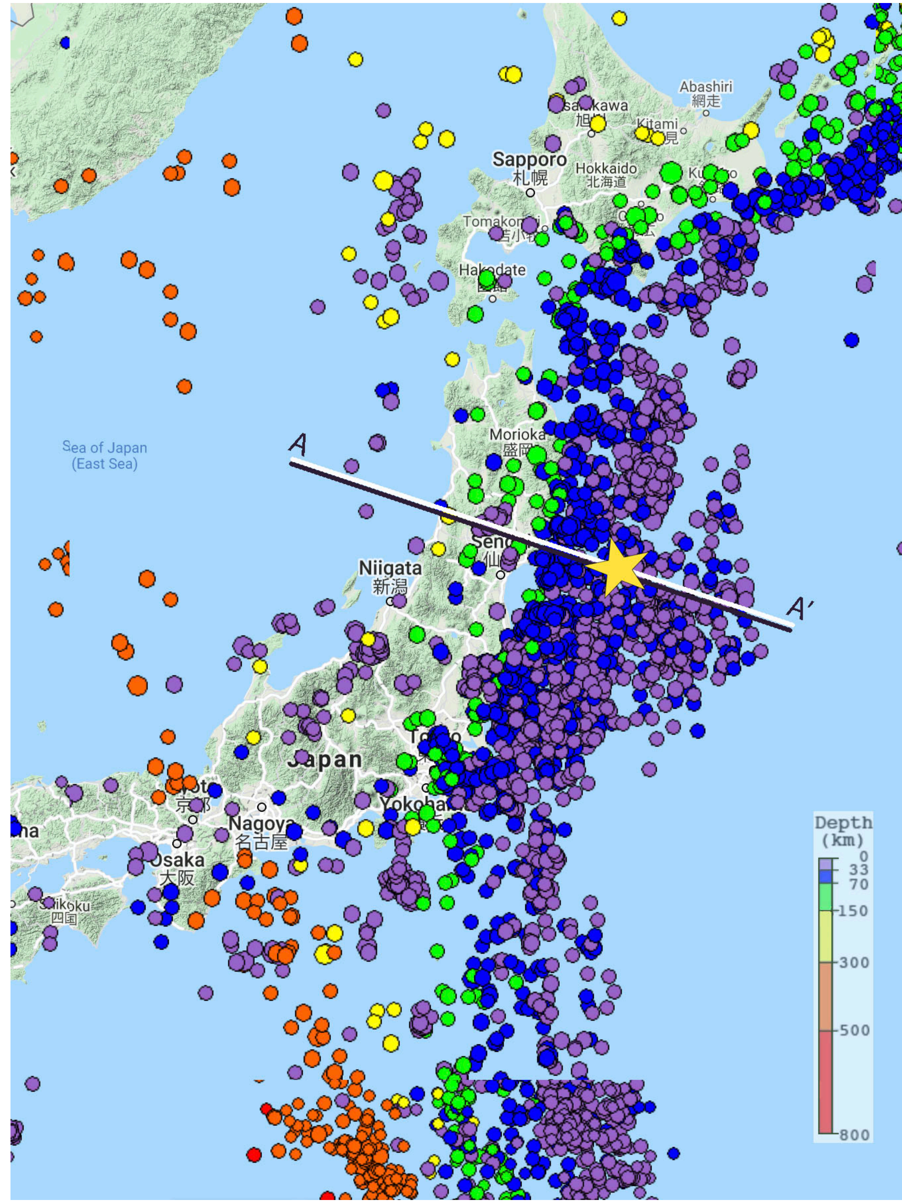
The map on the right shows historic earthquake activity > M 5 near the epicenter (star) from 1990 to present.

As shown on the cross section, earthquakes are shallow (purple) at the Japan Trench and increase in depth towards the west as the Pacific Plate dives deeper beneath Japan.



Seismicity Cross Section showing the megathrust plate boundary dipping beneath northern Honshu.



Images created with the IRIS Earthquake Browser

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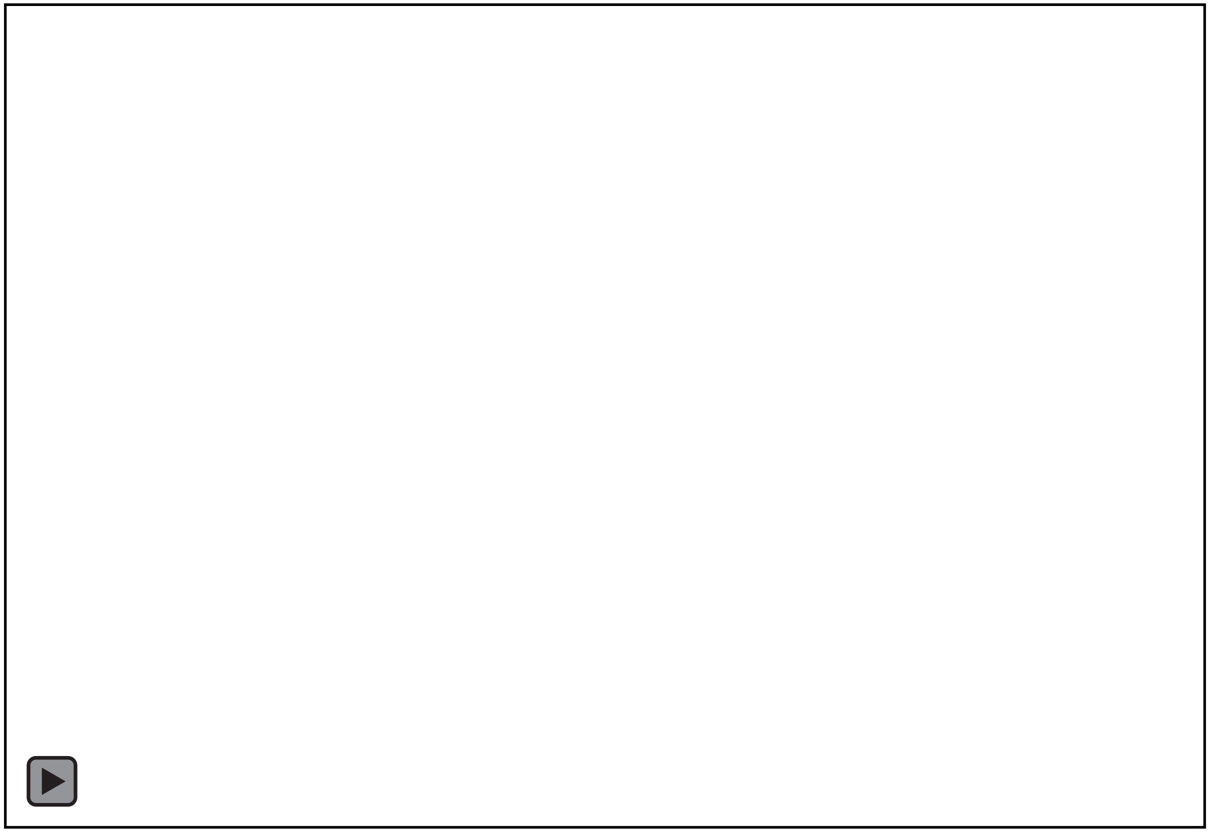
Animating 21 years of regional seismicity greater than magnitude 5. The red star highlights a recent 2021 aftershock, the black star highlights the M 9.1 2011 earthquake.

This earthquake was preceded by a series of large foreshocks over the prior two days, beginning on March 9th with an M 7.2 event approximately 40 km from the M 9.1.

In the 10 years that followed, aftershocks have continued and now number in the thousands.



Animation created with the IRIS Earthquake Browser

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An animation exploring the tectonic setting of Japan.

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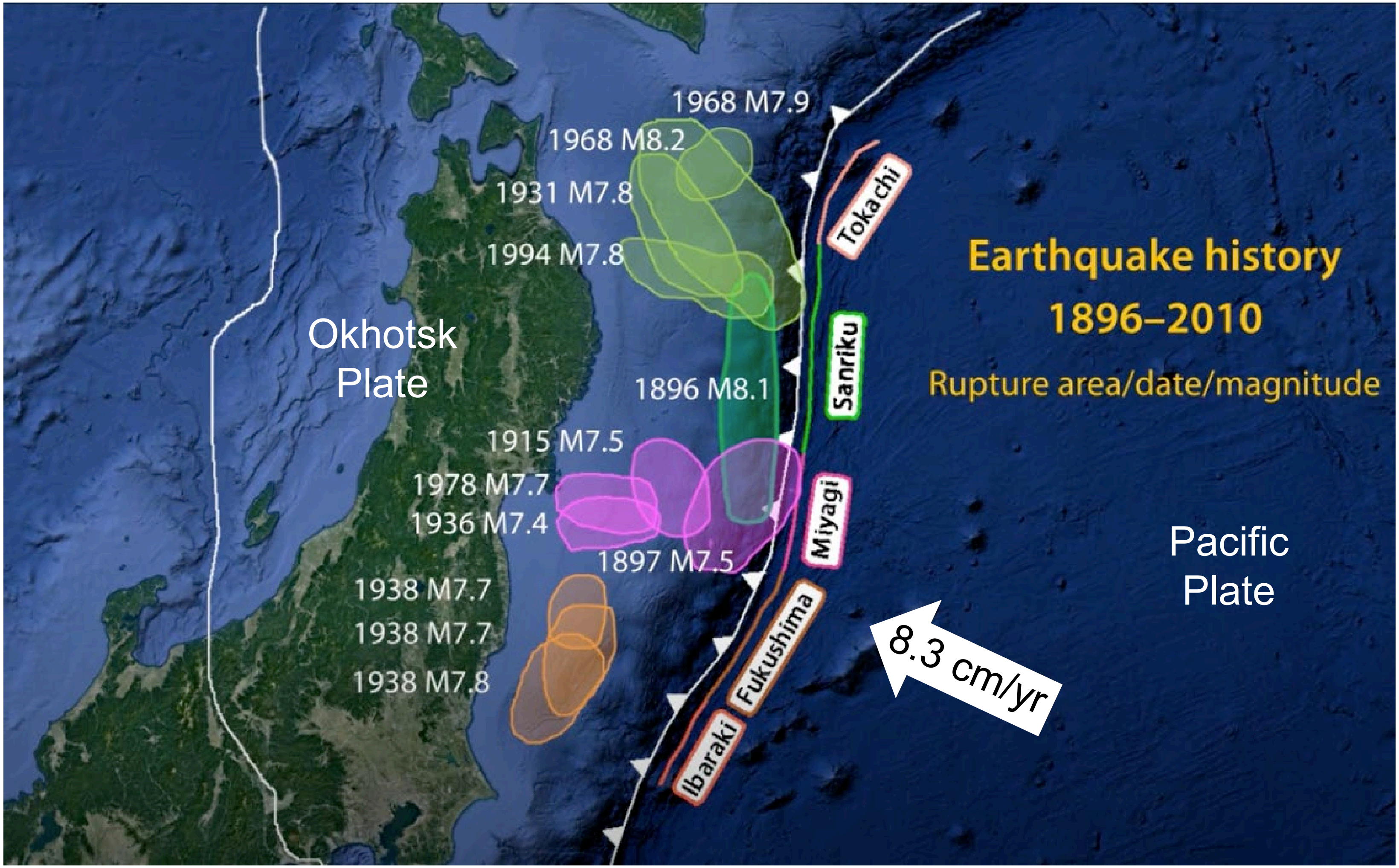

On this map, the year, magnitude, and rupture area are shown for magnitude 7.4 and larger earthquakes on the Pacific – Okhotsk subduction plate boundary from 1896 to 2010, just prior to the 2011 magnitude 9.1 earthquake.

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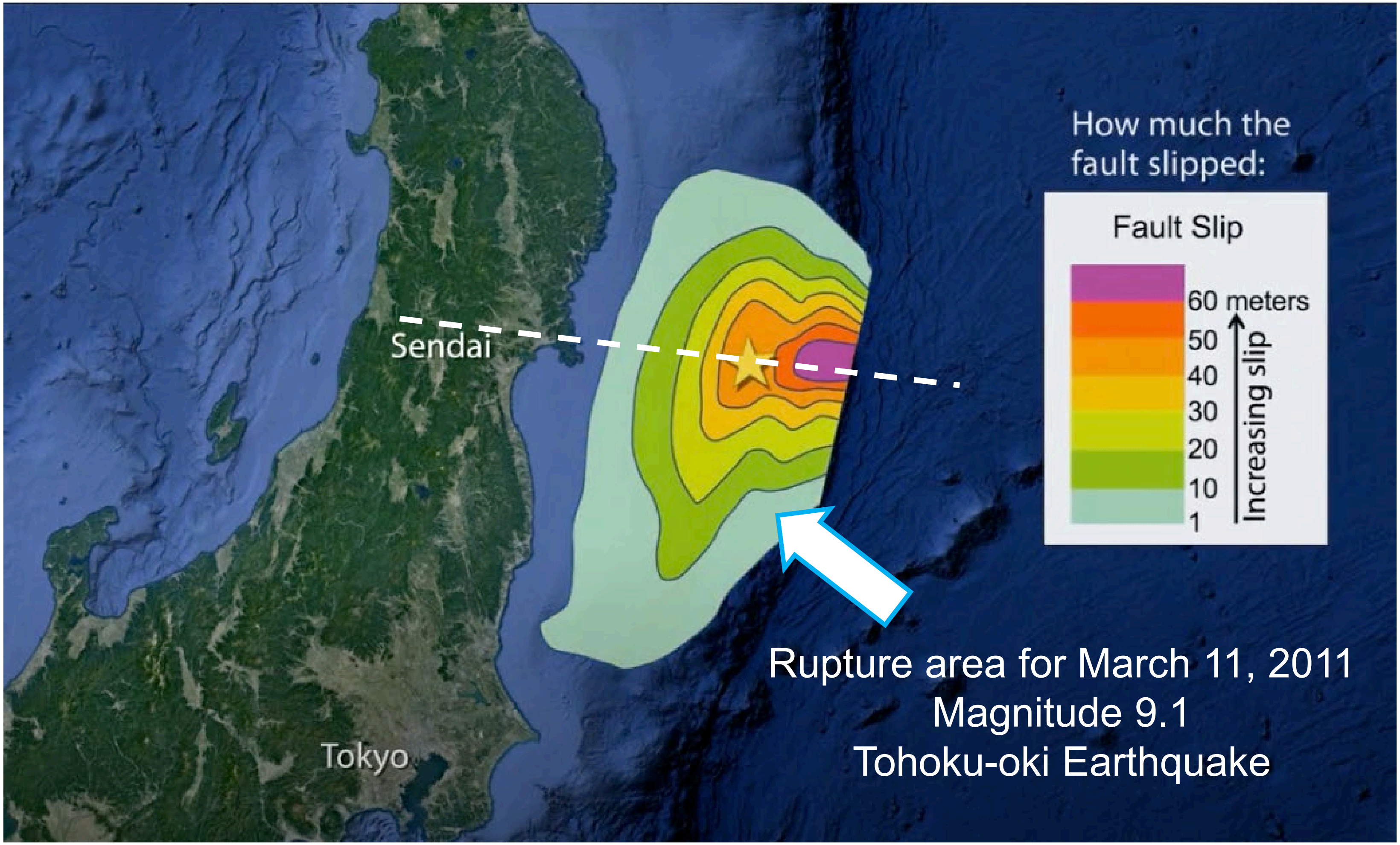

The M 9.1 Tohoku-oki earthquake ruptured a 500-km-long by 200-km-wide area of the Pacific – Okhotsk megathrust plate boundary. Fault slip reached over 60 meters near the Japan Trench. This great earthquake, the largest in Japan's history, and the resulting tsunami took almost 20,000 lives and caused approximately $200 billion in damage (2011 dollars). A cross section along the dashed line is shown on the next slide.

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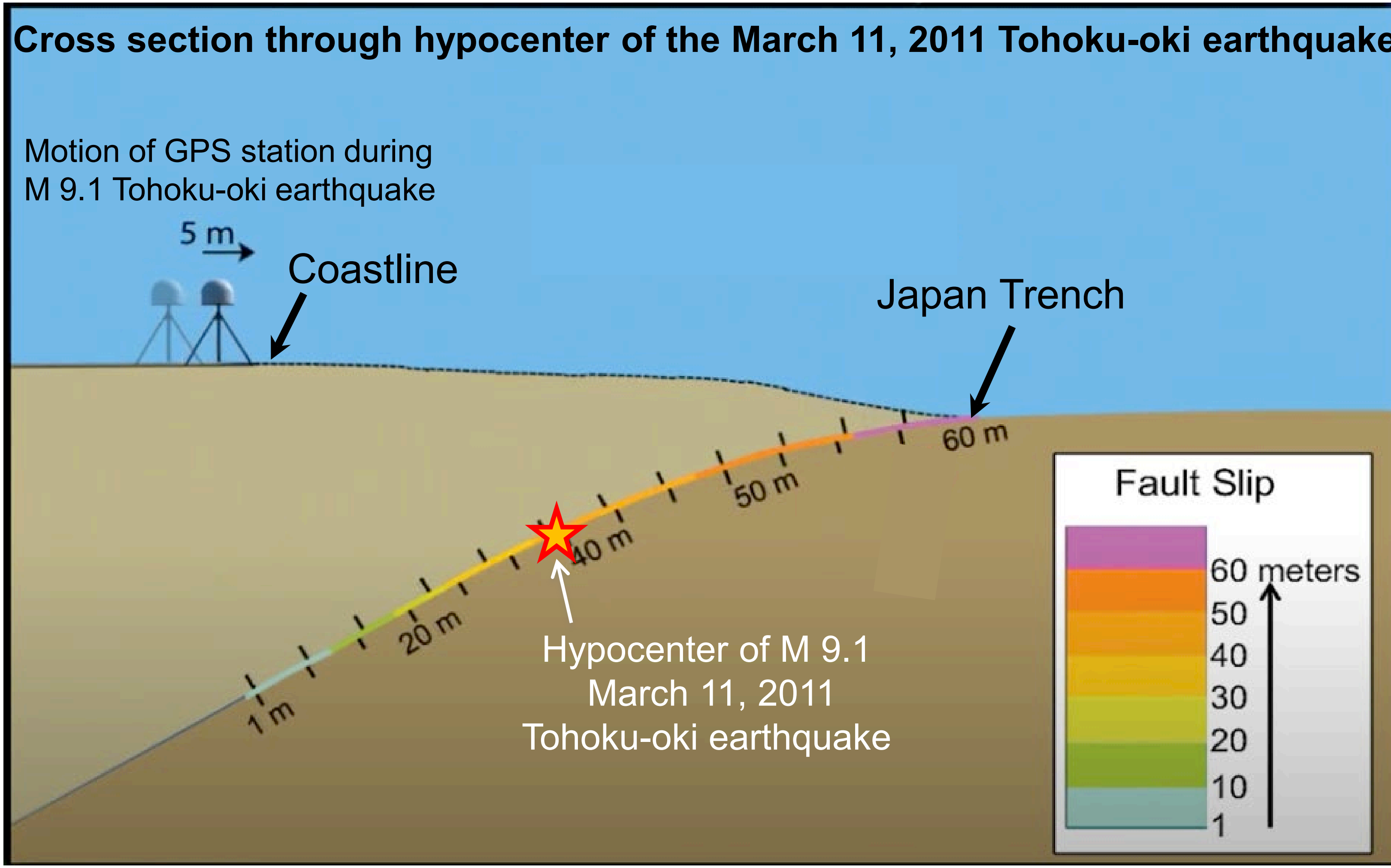

Fault slip during the M 9.1 Tohoku-oki earthquake is shown on this cross section through the hypocenter at ~25 km depth. Fault slip was 40 meters at the hypocenter and increased to over 60 meters at the Japan Trench. Fault slip decreased downdip from the hypocenter to about 1 meter at ~50 km depth.

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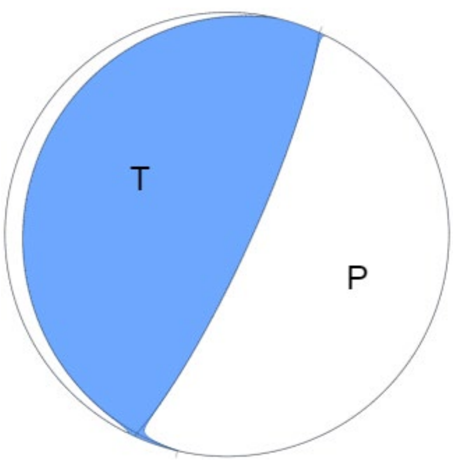
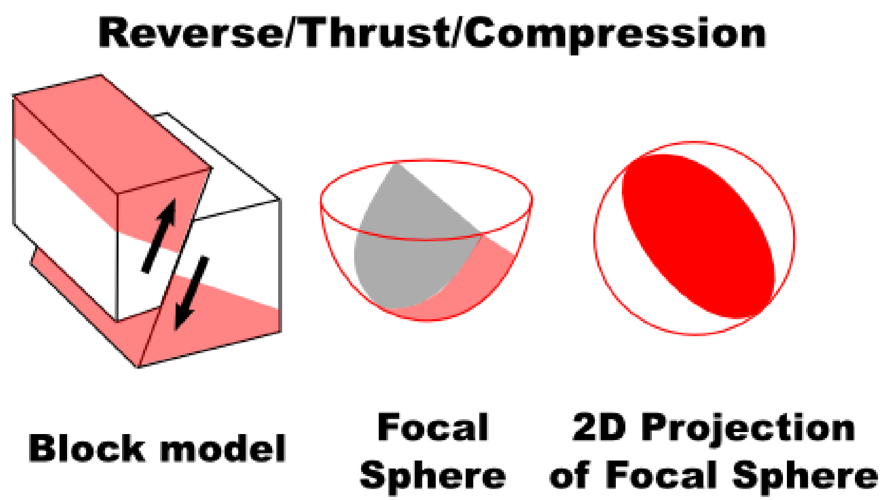
The focal mechanism is how seismologists plot the 3-D stress orientations of an earthquake. Because an earthquake occurs as slip on a fault, it generates primary (P) waves in quadrants where the first pulse is compressional (shaded) and quadrants where the first pulse is extensional (white). The orientation of these quadrants calculated from recorded seismic waves determines the type of fault that produced the earthquake.



USGS W-phase Moment Tensor Solution

The tension axis (T) reflects the minimum compressive stress direction. The pressure axis (P) reflects the maximum compressive stress direction.

In this case, the earthquake location and focal mechanism indicate it was due to thrust faulting on the plate boundary between the subducting Pacific Plate and the overriding Okhotsk Plate.



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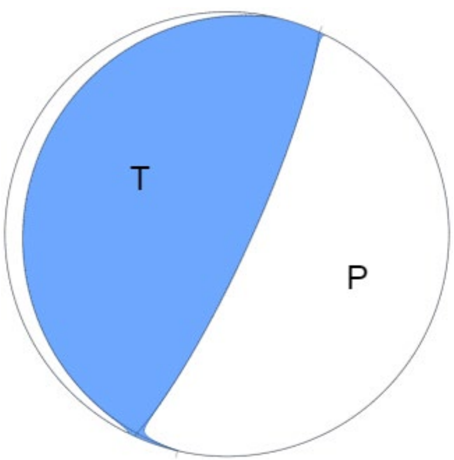
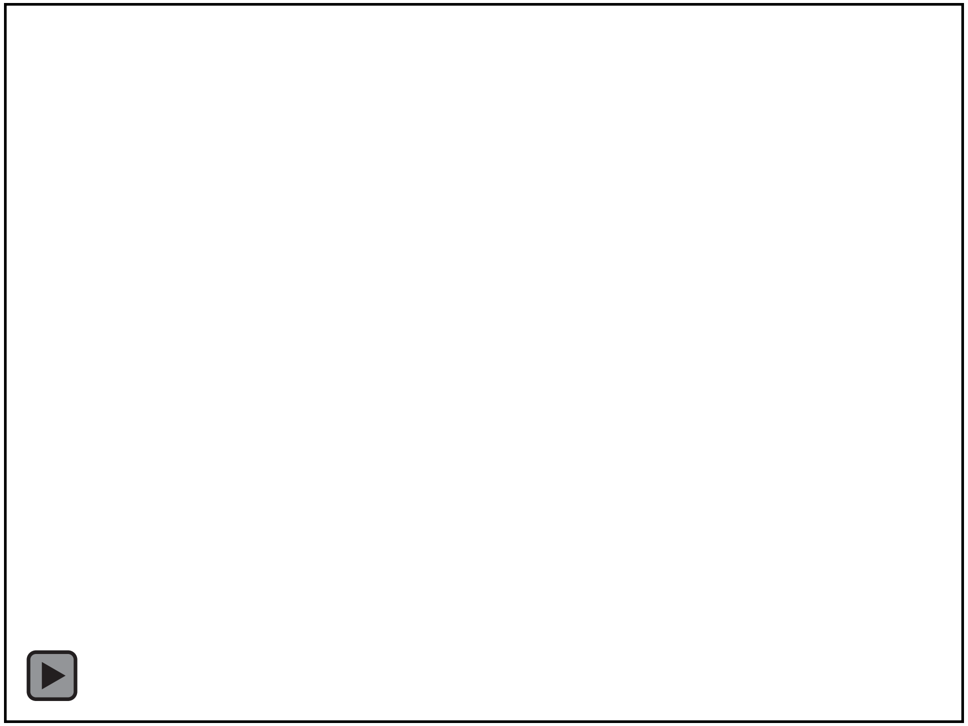
This animation explores the motion of a reverse fault, and how reverse faults are represented in a focal mechanism.

Remember, this was the focal mechanism solution for this earthquake. It was estimated by an analysis of observed seismic waveforms, recorded after the earthquake, observing the pattern of "first motions", that is, whether the first arriving P waves push up or down.



USGS W-phase Moment Tensor Solution



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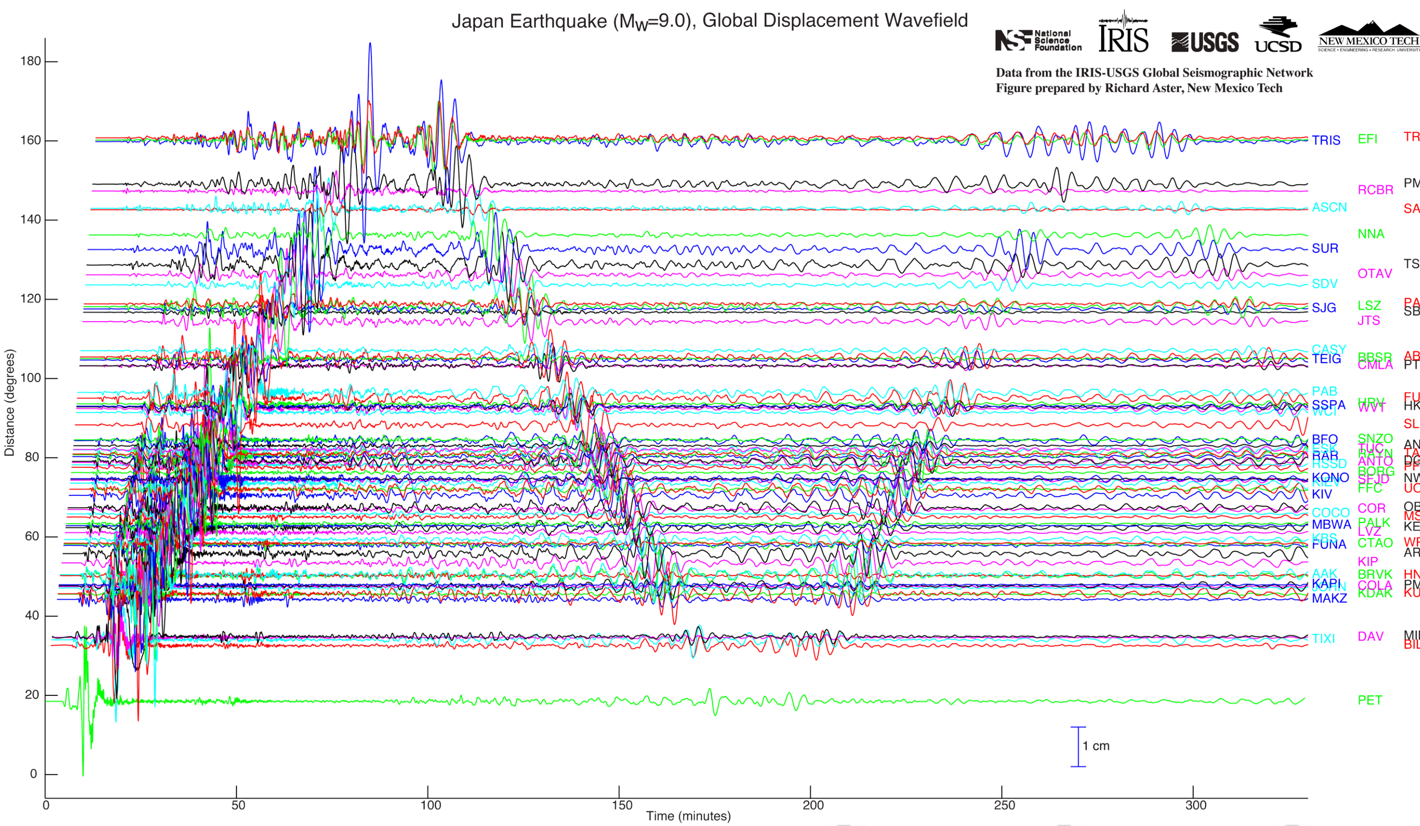
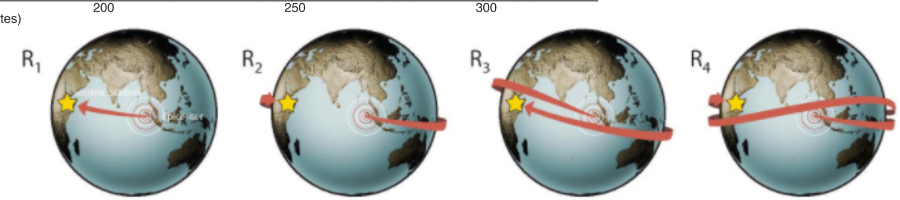
This assembly of seismograms displays the vertical movement of the Earth's surface due to seismic waves generated by the earthquake. The seismograms are plotted with respect to time since the start of the earthquake on the horizontal axis and are sorted vertically according to distance from the epicenter in degrees.





Paths of earthquake surface waves as they travel multiple times around the Earth

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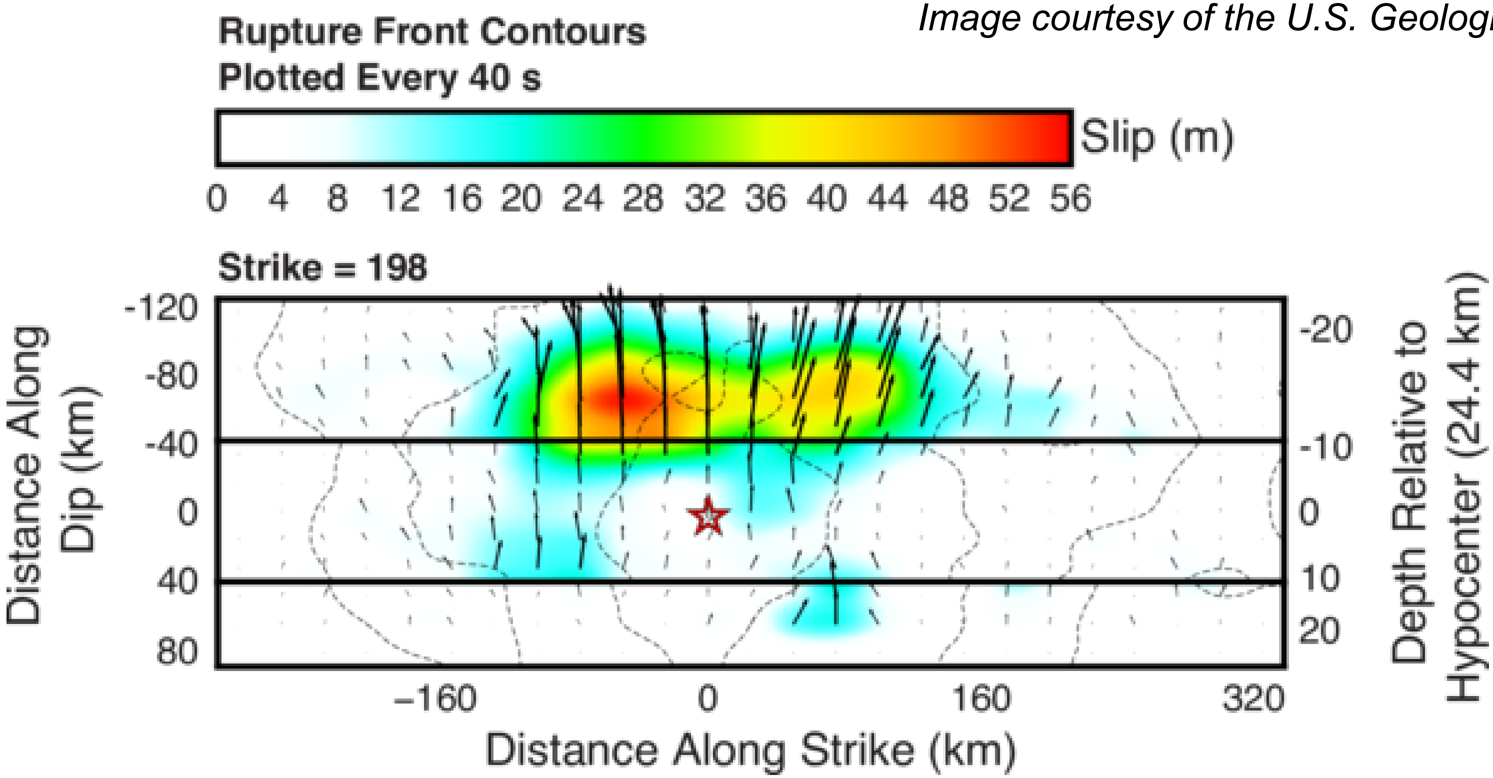
This “map” of the slip on the fault surface of the M 9.1 Japan earthquake shows how fault displacement propagated outward from an initial point (or focus) about 24 km beneath the Earth’s surface. The rupture extended over 500 km along the length of the fault, and from the Earth’s surface to depths of over 50 km.

Image courtesy of the U.S. Geological Survey



Distribution of fault slip on the megathrust rupture zone. The hypocenter is shown by the red star. Distances of fault slip are color coded and the direction of the hanging wall motion relative to the footwall is indicated by black arrows. Dashed contours show the perimeter of the rupture zone moving outward from the hypocenter at 40-second intervals.

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Superimposing the slip distribution on a map allows visualization of the size of the rupture from this earthquake.

The gray circles are aftershock locations, sized by magnitude.

The slip wasn't uniform across the fault. After an earthquake, the stress on the fault changes. Aftershocks occur due to these stress changes and they often occur on or near the main fault.

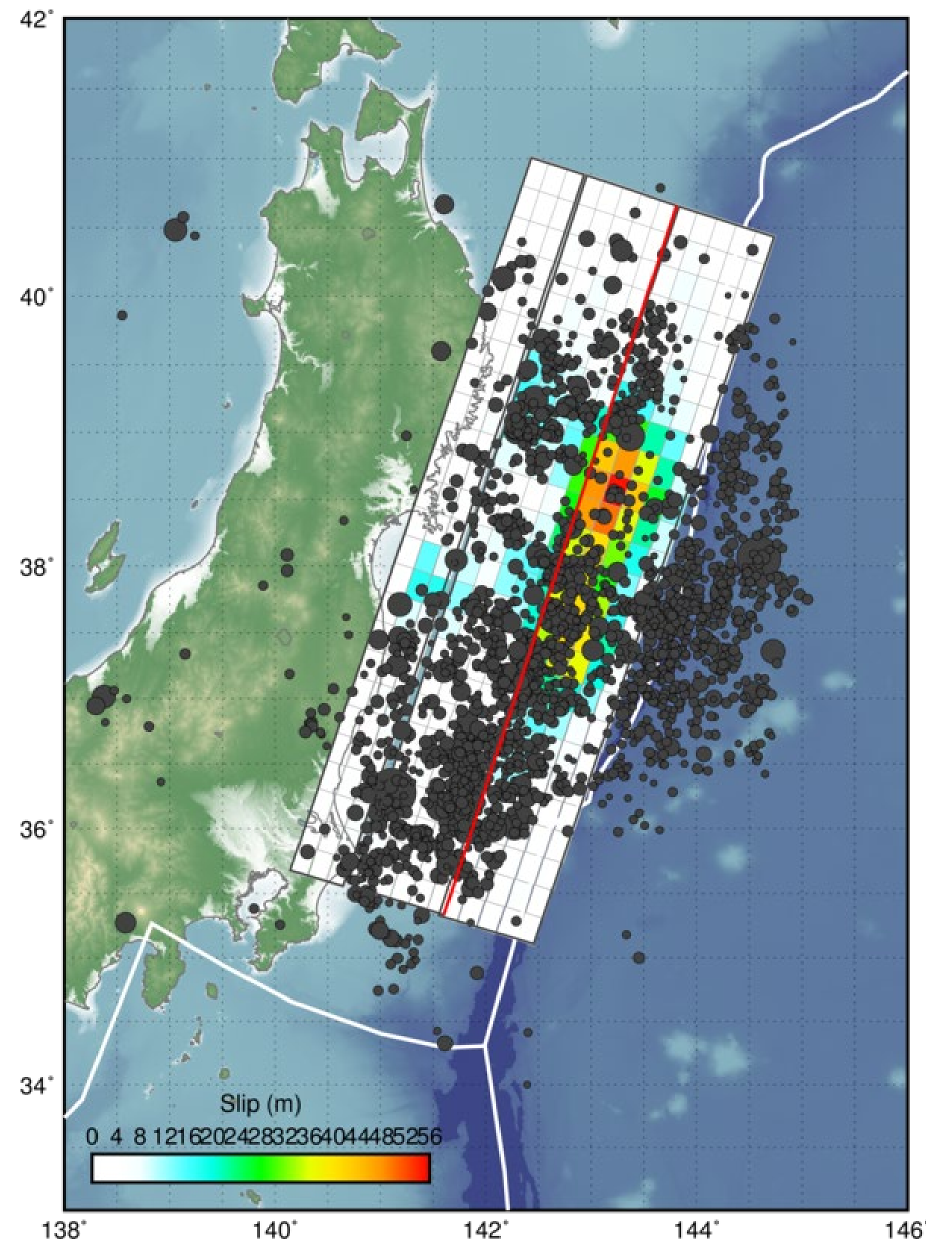

Image courtesy of the U.S. Geological Survey

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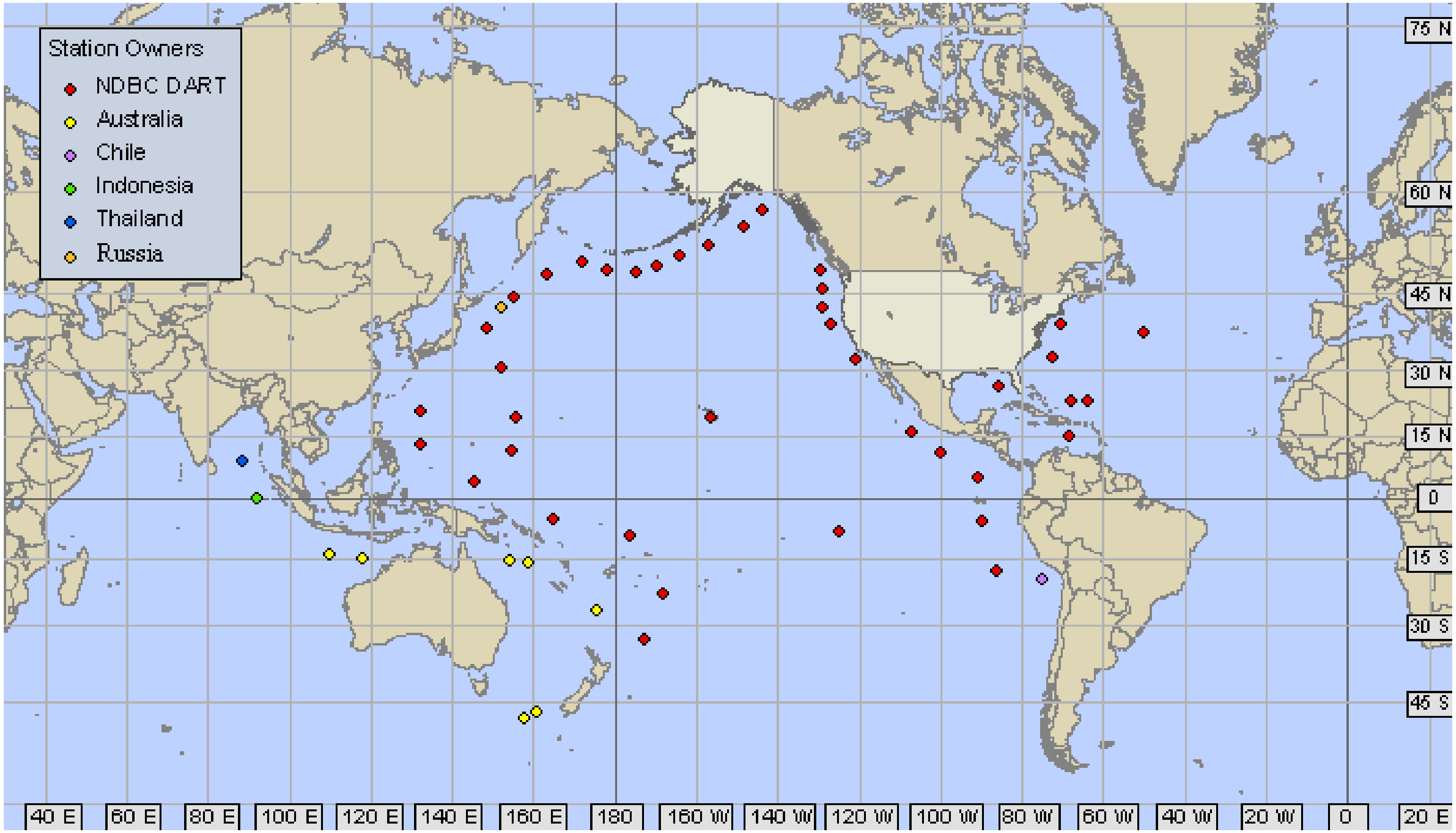

Locations of NOAA's National Data Buoy Center (NDBC) DART stations comprising the operational network.

Tsunami monitoring systems have been strategically deployed near regions with a history of tsunami generation. Measurement of wave heights as they propagate into the open ocean are used to forecast tsunami arrival times and heights on distant shorelines.

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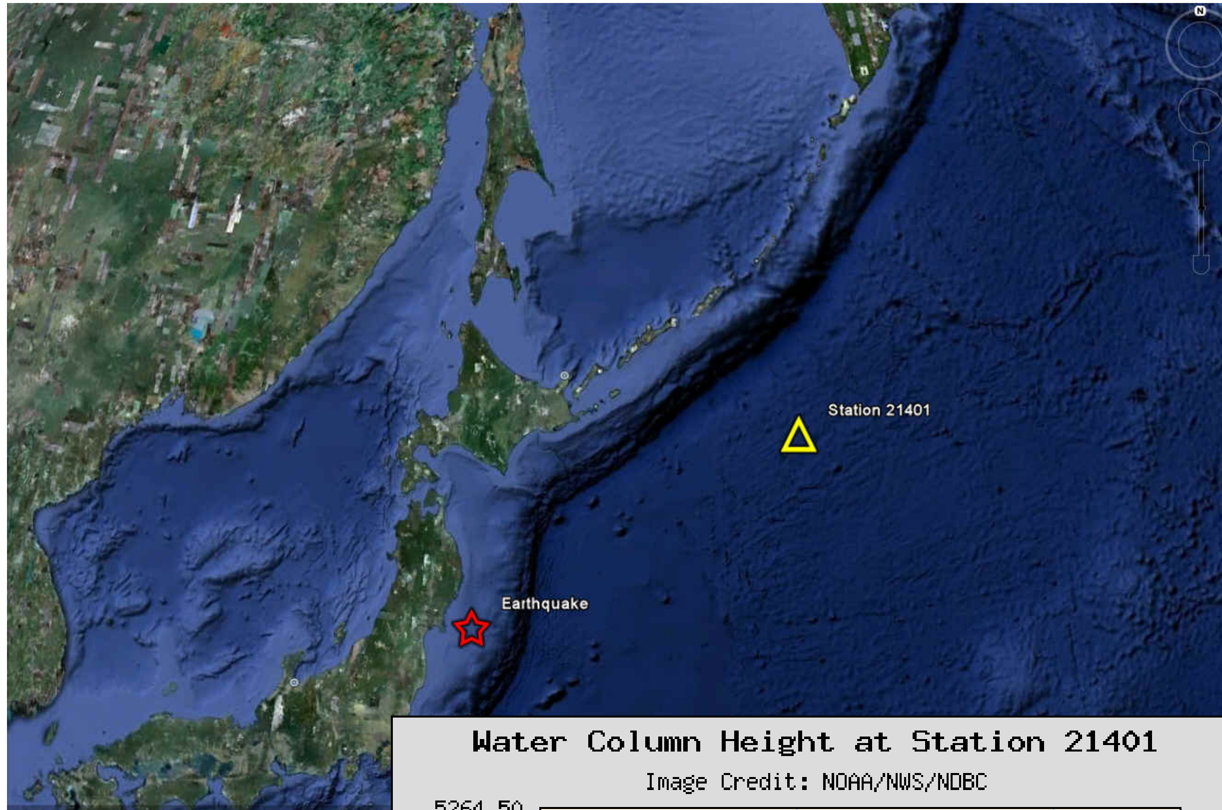
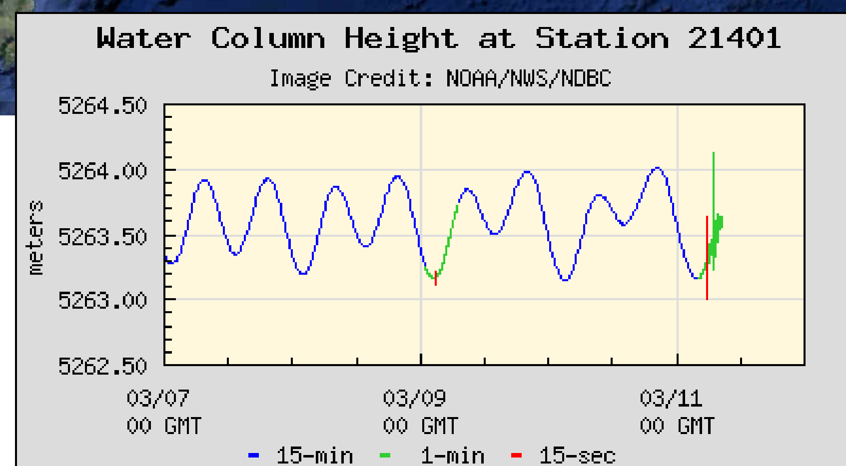
Shallow great earthquakes in subduction zones often cause tsunamis because they offset the ocean floor. The March 11, 2011 M 9.1 earthquake generated a massive tsunami because it uplifted the ocean floor as much as 10 meters.

Nearby DART measurements allowed warnings of tsunami arrival times and wave heights around the Pacific Ocean.





The water column height change that triggered the system. Blue oscillations are tides while the green lines show the tsunami waves passing the DART station.

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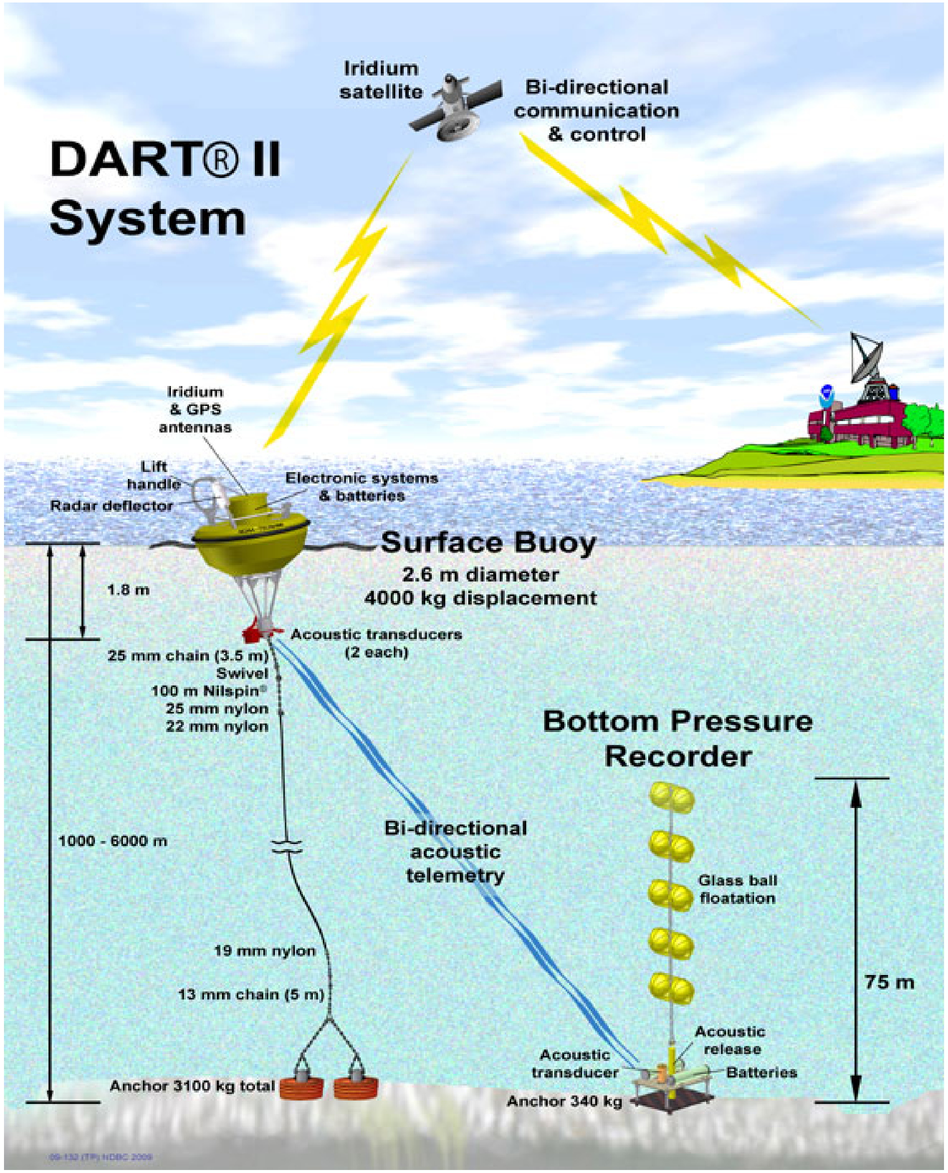

The DART II® system consists of a seafloor bottom pressure recording (BPR) system capable of detecting tsunamis as small as 1 cm, and a moored surface buoy for real-time communications.

DART II has two-way communications between the BPR and the Tsunami Warning Center (TWC) using the Iridium commercial satellite communications system. The two-way communications allow the TWCs to set stations in event mode in anticipation of possible tsunamis or retrieve the high-resolution (15-s intervals) data in one-hour blocks for detailed analysis.

DART II systems transmit standard mode data, containing twenty-four estimated sea-level height observations at 15-minute intervals, once very six hours.

NOAA

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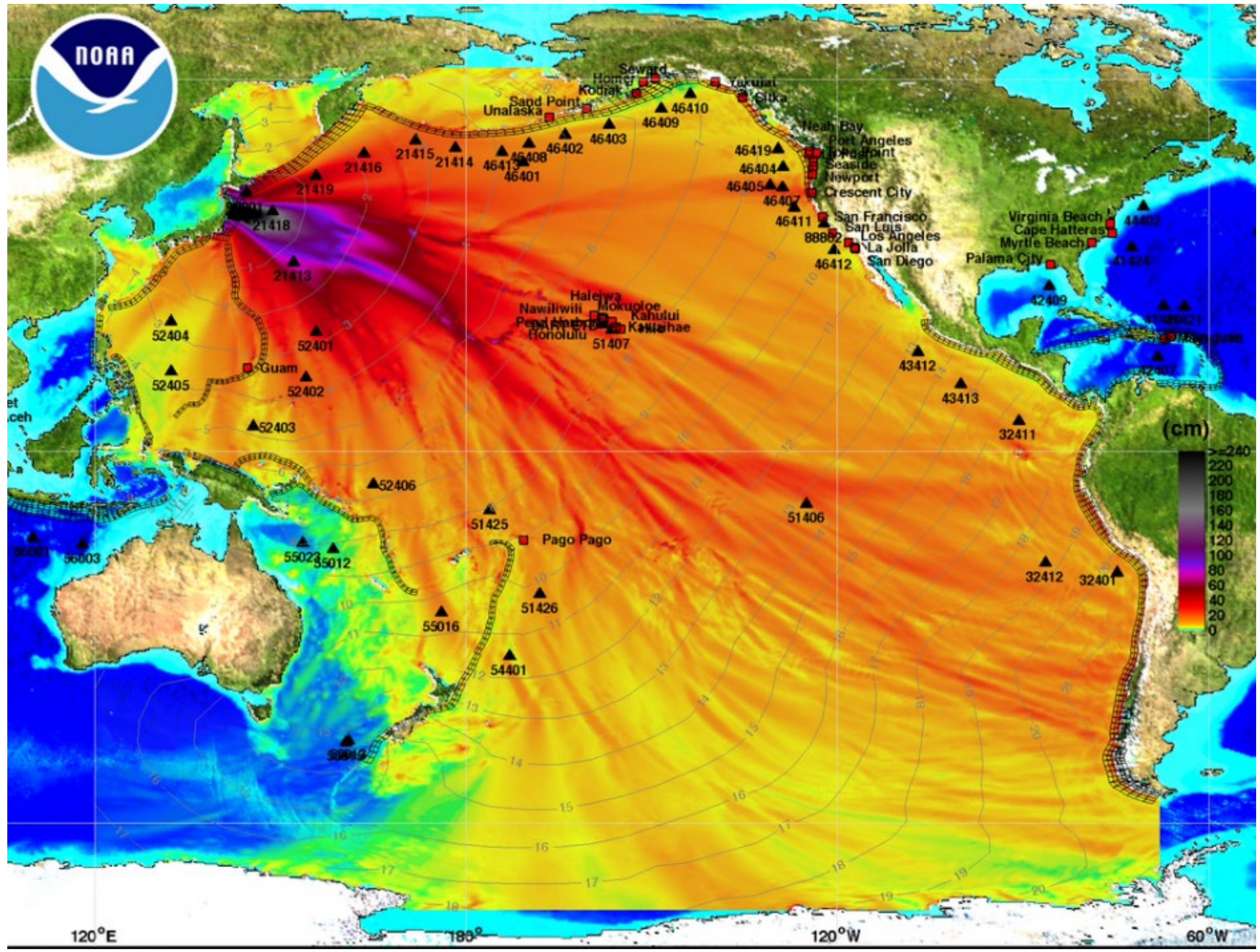
Image courtesy of NOAA

A Pacific wide tsunami warning was issued following this earthquake. The contour lines on this map show tsunami travel time in hours and the colors indicate wave height in centimeters. See wave height legend on top of South America.

Ocean floor bathymetry affects the wave height because a tsunami moves the seawater all the way to the floor of the ocean.



In the open ocean, tsunami waves can travel at speeds up to 800 km per hour (500 miles per hour), as fast as a jet plane.

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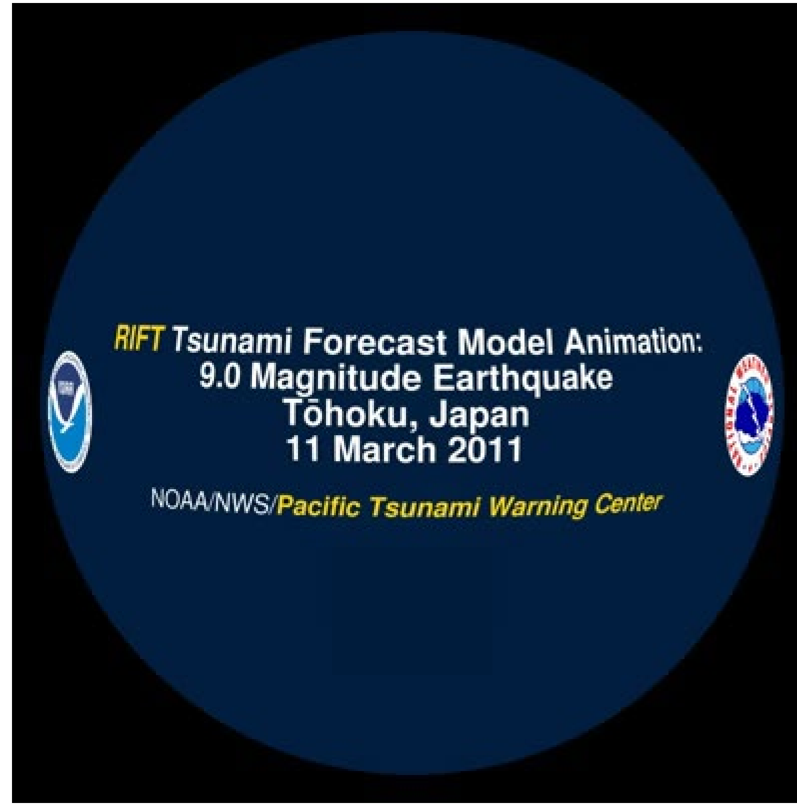
Japan
The tsunami destroyed or severely damaged many coastal towns in Japan. The tsunami killed over 17,000 people, all but two of whom were in Japan.

Indonesia
One person was killed and several houses were destroyed at Jayapura, Indonesia by the tsunami (wave height 2 m).

US
One person was killed south of Crescent City, California (wave height 247 cm). Several houses, boats and docks were destroyed or damaged in Santa Cruz, California; Brookings, Oregon; Hale`iwa, Kailua Kona and Kealakekua, Hawaii.

South America
Buildings were damaged in the Galapagos Islands, Ecuador (wave height 208 cm). Several houses were destroyed in Peru. Several buildings and boats were destroyed in Chile.



Coastline Hazard Color Scheme
blue-green - no hazard
yellow-orange - low hazard
red - significant hazard
dark red - severe hazard

NOAA

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The March 11, 2011 earthquake and tsunami was a tragedy. Research since this earthquake has shown that combining GPS and seismometer observations can determine fault slip during magnitude 8 or 9 subduction zone earthquakes within two minutes from the beginning of the earthquake. Such accurate and rapid fault slip determinations are particularly important for tsunami warnings. The combination of GPS and seismometer observations is an emerging new discipline called “seismogeodesy”.

These are two short clips from a longer animation that explores lessons learned from the 2011 Japan earthquake and tsunami.

https://www.iris.edu/hq/inclass/animation/762

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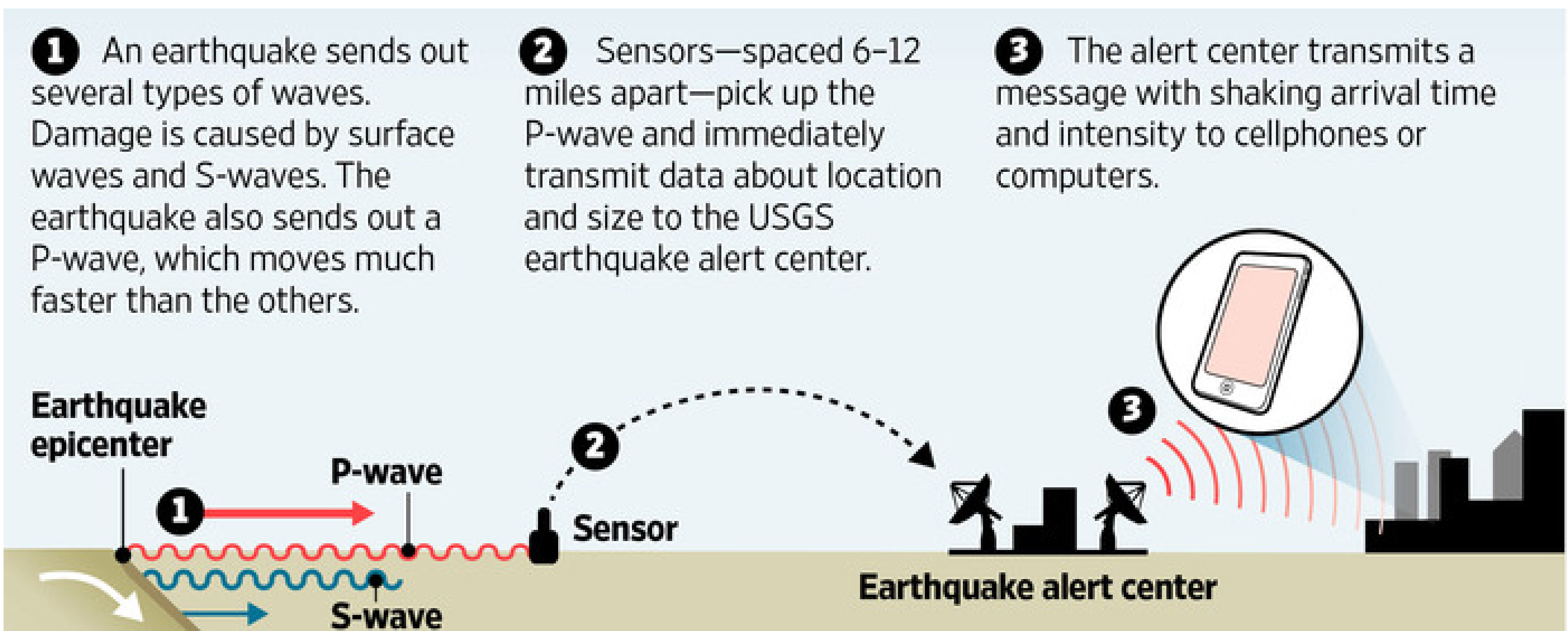
The ShakeAlert® Earthquake Early Warning (EEW) system, now operating in California and Oregon (March 11!), and to begin in Washington in May, is an advancement for protecting life and critical infrastructure. EEW is not earthquake prediction. Seismometers in the field detect an earthquake that has already begun and data from it is sent to a ShakeAlert Processing Center.

ShakeAlert quickly estimates the earthquake location, size, and expected shaking. If the earthquake fits the right profile the USGS issues a ShakeAlert Message which is used by distribution partners to develop and deliver alerts to people and automated systems.



Source: Interior Department

THE WALL STREET JOURNAL.

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With this animation, explore how the ShakeAlert system works and how even a few seconds of warning can help people and automated systems prepare for earthquake shaking.

Learn more about ShakeAlert at https://www.ShakeAlert.org
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IRIS Teachable Moments

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What do you do if you feel shaking or get a ShakeAlert powered alert? You may only have a few seconds warning before the shaking starts. Use that time to protect yourself!

DROP where you are onto your hands and knees.

- This position protects you from being knocked down and also allows you to stay low and crawl to shelter if nearby.

COVER your head and neck with one arm and hand

- If a sturdy table or desk is nearby, crawl underneath it for shelter
- If no shelter is nearby, crawl next to an interior wall (away from windows)
- Stay on your knees; bend over to protect vital organs

HOLD ON until shaking stops

- Under shelter: hold on to your shelter with one hand; be ready to move with it if it shifts
- No shelter: hold on to your head and neck with both arms and hands.

Teachable Moments are a service of

The Incorporated Research Institutions for Seismology
Education & Public Outreach
and
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