

Study suggests heavy snowfall and rain may contribute to some earthquakes

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When scientists look for an earthquake's cause, their search often starts underground. As centuries of seismic studies have made clear, it's the collision of tectonic plates and the movement of subsurface faults and

fissures that primarily trigger a temblor.

But MIT scientists have now found that certain [weather events](#) may also play a role in setting off some quakes.

In a study appearing in *Science Advances*, the [researchers report](#) that episodes of heavy snowfall and rain likely contributed to a swarm of earthquakes over the past several years in northern Japan. The study is the first to show that [climate conditions](#) could initiate some quakes.

"We see that snowfall and other environmental loading at the surface impacts the stress state underground, and the timing of intense precipitation events is well-correlated with the start of this earthquake swarm," says study author William Frank, an assistant professor in MIT's Department of Earth, Atmospheric and Planetary Sciences (EAPS). "So, climate obviously has an impact on the response of the solid earth, and part of that response is earthquakes."

The new study focuses on a series of ongoing earthquakes in Japan's Noto Peninsula. The team discovered that seismic activity in the region is surprisingly synchronized with certain changes in underground pressure, and that those changes are influenced by seasonal patterns of snowfall and precipitation. The scientists suspect that this new connection between quakes and climate may not be unique to Japan and could play a role in shaking up other parts of the world.

Looking to the future, they predict that the climate's influence on earthquakes could be more pronounced with global warming.

"If we're going into a climate that's changing, with more extreme precipitation events, and we expect a redistribution of water in the atmosphere, oceans, and continents, that will change how the Earth's crust is loaded," Frank adds. "That will have an impact for sure, and it's a

link we could further explore."

The study's lead author is former MIT research associate Qing-Yu Wang (now at Grenoble Alpes University), and also includes EAPS postdoc Xin Cui, Yang Lu of the University of Vienna, Takashi Hirose of Tohoku University, and Kazushige Obara of the University of Tokyo.

Seismic speed

Since late 2020, hundreds of small earthquakes have shaken up Japan's Noto Peninsula—a finger of land that curves north from the country's main island into the Sea of Japan. Unlike a typical earthquake sequence, which begins as a main shock that gives way to a series of aftershocks before dying out, Noto's seismic activity is an "earthquake swarm"—a pattern of multiple, ongoing quakes with no obvious main shock, or seismic trigger.

The MIT team, along with their colleagues in Japan, aimed to spot any patterns in the swarm that would explain the persistent quakes. They started by looking through the Japanese Meteorological Agency's catalog of earthquakes that provides data on [seismic activity](#) throughout the country over time. They focused on quakes in the Noto Peninsula over the last 11 years, during which the region has experienced episodic earthquake activity, including the most recent swarm.

With seismic data from the catalog, the team counted the number of seismic events that occurred in the region over time, and found that the timing of quakes prior to 2020 appeared sporadic and unrelated, compared to late 2020, when earthquakes grew more intense and clustered in time, signaling the start of the swarm, with quakes that are correlated in some way.

The scientists then looked to a second dataset of seismic measurements

taken by monitoring stations over the same 11-year period. Each station continuously records any displacement, or local shaking that occurs. The shaking from one station to another can give scientists an idea of how fast a seismic wave travels between stations. This "seismic velocity" is related to the structure of the Earth through which the seismic wave is traveling. Wang used the station measurements to calculate the seismic velocity between every station in and around Noto over the last 11 years.

The researchers generated an evolving picture of seismic velocity beneath the Noto Peninsula and observed a surprising pattern: In 2020, around when the earthquake swarm is thought to have begun, changes in seismic velocity appeared to be synchronized with the seasons.

"We then had to explain why we were observing this seasonal variation," Frank says.

Snow pressure

The team wondered whether environmental changes from season to season could influence the underlying structure of the Earth in a way that would set off an earthquake swarm. Specifically, they looked at how seasonal precipitation would affect the underground "pore fluid pressure"—the amount of pressure that fluids in the Earth's cracks and fissures exert within the bedrock.

"When it rains or snows, that adds weight, which increases pore pressure, which allows seismic waves to travel through slower," Frank explains.

"When all that weight is removed, through evaporation or runoff, all of a sudden, that pore pressure decreases and seismic waves are faster."

Wang and Cui developed a hydromechanical model of the Noto Peninsula to simulate the underlying pore pressure over the last 11 years in response to seasonal changes in precipitation. They fed into the model

meteorological data from this same period, including measurements of daily snow, rainfall, and sea-level changes.

From their model, they were able to track changes in excess pore pressure beneath the Noto Peninsula, before and during the earthquake swarm. They then compared this timeline of evolving pore pressure with their evolving picture of seismic velocity.

"We had seismic velocity observations, and we had the model of excess pore pressure, and when we overlapped them, we saw they just fit extremely well," Frank says.

In particular, they found that when they included snowfall data, and especially, extreme snowfall events, the fit between the model and observations was stronger than if they only considered rainfall and other events. In other words, the ongoing earthquake swarm that Noto residents have been experiencing can be explained in part by seasonal precipitation, and particularly, heavy snowfall events.

"We can see that the timing of these earthquakes lines up extremely well with multiple times where we see intense snowfall," Frank says. "It's well-correlated with earthquake activity. And we think there's a physical link between the two."

The researchers suspect that heavy snowfall and similar extreme precipitation could play a role in earthquakes elsewhere, though they emphasize that the primary trigger will always originate underground.

"When we first want to understand how earthquakes work, we look to plate tectonics, because that is and will always be the number one reason why an earthquake happens," Frank says. "But, what are the other things that could affect when and how an [earthquake](#) happens? That's when you start to go to second-order controlling factors, and the climate is

obviously one of those."

More information: Qing-Yu Wang, Untangling the environmental and tectonic drivers of the Noto earthquake swarm in Japan, *Science Advances* (2024). DOI: [10.1126/sciadv.ado1469](https://doi.org/10.1126/sciadv.ado1469).
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