UC SANTA BARBARA

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Tonga Eruption

On January 15, the volcano Hunga Tonga-Hunga Ha'apai devastated the nation of Tonga. The eruption triggered tsunamis as far afield as the Caribbean and generated atmospheric waves that travelled around the globe several times. Meanwhile, the volcano's plume shot gas and ash through the stratosphere into the lower mesosphere.

Just two months after the eruption, geologists have put together a preliminary account of how it unfolded. UC Santa Barbara's Melissa Scruggs and emeritus Professor Frank Spera were part of an international team of researchers that published the first holistic account of the event in the journal Earthquake Research Advances. The authors think that an eruption the day before may have primed the volcano for the violent explosion by sinking its main vent below the ocean's surface. This enabled molten rock to vaporize a large volume of seawater, intensifying the volcanic eruption the very next day.

"This is definitely, without a doubt, the largest eruption since Mt. Pinatubo in 1991," said corresponding author Scruggs, who studies magma mixing and eruption triggering mechanisms, and recently completed her doctorate at UC Santa Barbara. She compared January's event to the 1883 eruption of Krakatoa, which was heard 3,000 miles away.

Hunga Tonga-Hunga Ha'apai (HTHH) is a stratovolcano: a large, cone-shaped mountain that is prone to periodic violent eruptions, but which usually experiences milder activity. It's one of many along the Tofua Volcanic Arc, a line of volcanoes fed

by magma from the Pacific Plate diving beneath the Indo-Australian Plate. Heat and pressure cook the rocks of the descending plate, driving out water and other volatiles. That same water decreases the melting temperature of the rock above, leading to a chain of volcanoes about 100 kilometers from the plate boundary.

A submerged danger

The islands of Hunga Tonga and Hunga Ha'apai — after which the volcano is named — are merely the two highest points along the rim of the caldera, or central crater. Or they were, until the eruption blew most of the islands sky high.

Scruggs first heard about the eruption as she scrolled through her Twitter feed while getting ready for bed. "I saw a GIF of the satellite eruption, and my heart just stopped," she said, pausing to find her words. She immediately knew that the event would cause massive devastation. "The scariest part was that the entire country was cut off, and we didn't know what had happened."

Bathymetry Hunga Tonga-Hunga Ha'apai by vizualism

She was already messaging other volcanologists as the events unfolded, trying to understand the images that satellites had so clearly captured. "We really just set out to try to understand what happened," Scruggs said. "So, we gathered all the information that we could, anything that was available within the first few weeks." The authors drew on whatever resources they could find to quickly characterize this eruption, including publicly available data, videos and even tweets.

Using a variety of data sets, the team calculated that the January 15 event began at 5:02 p.m. local time (0402 ±1 UTC). The U.S. Geological Survey recorded a seismic event around 13 minutes later at the vent location. The first two hours of the eruption were particularly violent, with activity fading after about 12 hours.

But eruption activity had actually started all the way back on December 20, 2021. And before that, the volcano had erupted in 2009 and again in 2014 and 2015. Scruggs believes these earlier episodes are key to understanding the violence behind HTHH's recent eruption, perhaps related to changes in the magma plumbing system at depth or the chemistry of the magma over time.

Hunga Tonga and Hunga Ha'apai used to be separate islands until they were united by eruptions from the volcano's main vent, which created a land bridge. "This island

was just born in 2015," said Scruggs. "And now it's gone. Were it not for the satellite era, we would not have even known it ever existed."

On January 14, 2022 an explosion from the main vent razed this connection, sinking the vent beneath the ocean's surface. "Had that land bridge not been taken out, the January 15 eruption might have behaved just like the day before because it would not have had that excess seawater," Scruggs remarked.

A staggering explosion

Same volcano, one day's difference: On Friday the vent was above the water, and by Saturday it was below. "That made all of the difference in the world," Scruggs said.



Top: Hunga Tonga and Hunga Ha'apai were separate islands that grew together over the course of seven years.

Bottom: The eruption on Jan. 14, 2022 sunk the main vent below sea level, enabling the eruption the following day to all but obliterate the islands.

Dates: Nov. 16, 2021; Jan. 7, 2022; Jan. 15, 2022; and Jan. 18, 2022.

Photo Credit: PLANET LABS PBC

The team believes that the seawater played a large part in the violence and force behind the Jan. 15 eruption. Much like a bottle rocket, an eruption of this scale takes the right ratio of water and gas to provide the force to send it skyward.

And it took off like a rocket, too. “It went halfway to space,” Scruggs exclaimed. The ash plume shot 58 kilometers into the atmosphere, past the stratosphere and into the lower mesosphere. This is more than twice the height reached by the plume from Mt. Saint Helens in 1980. It was the tallest volcanic plume ever recorded.

A truly staggering amount of lightning also accompanied the eruption. The authors suspect that vaporizing seawater caused the lava to fragment into microscopic ash particles, which were joined by tiny ice crystals once the steam froze in the upper atmosphere. The motion, temperature change and size of the particles generated incredible amounts of static charge separation that flashed above the eruption. For the first two hours of the eruption, about 80% of all lightning strikes on Earth split the sky above Hunga Tonga-Hunga Ha’apai.

The authors estimate around 1.9 km^3 of material, weighing 2,900 teragrams, erupted from HTHH on Jan. 15. “But the volume of the eruption was not the big deal,” said Spera, a coauthor on the paper and Scruggs’ doctoral advisor. “What was special is how the energy of the eruption coupled to the atmosphere and oceans: A lot of the energy went into moving air and water on a global scale.”

Shockwave from Hunga Tonga GOES 17

The shockwave from Hunga Tonga-Hunga Ha’apai traveled around the world.

Photo Credit: Tim Schmit, NOAA/NESDIS/ASPB

The shockwave traveling through the ocean triggered tsunamis throughout the Pacific, and beyond. What’s more, the wave arrived faster than tsunami warning models predicted because the models aren’t calibrated for volcanic eruptions — they're based on equations that describe tsunamis generated by earthquakes.

A second tsunami followed the atmospheric pressure wave. This shockwave even triggered a meteo-tsunami in the Caribbean, which has no direct connection to the South Pacific. Scruggs called it unprecedented: “Basically the whole ocean just kind of sloshed around for five days after the eruption,” she added.

Plenty of work to do

Scientists are still piecing together what happened at the volcano, so they have yet to develop a complete understanding of the tsunami wave. However, it’s an important task needed to update tsunami travel forecast systems so they account for this type of mechanism. Otherwise, warnings could be incorrect the next time a volcano like HTHH erupts, potentially costing more lives.

Indeed, the event highlights the danger posed by unmonitored submarine volcanoes. Despite the devastation, the people of Tonga were relatively well prepared for the Jan. 15 eruption. The government had issued warnings based on the previous day’s activity, and the nation had plans in place for eruptions and tsunamis.

HTHH has experienced similarly violent eruptions in the past. A recent paper by researchers at the University of Otago, New Zealand revealed that a large eruption destroyed the caldera at the summit of the undersea volcano about 1,000 years ago. And similar volcanoes could well erupt in the same manner. Consider Kick ‘em Jenny, another submarine volcano whose main vent is a mere 150 meters underwater. It’s located just 8 km north of the island of Grenada. “Imagine if something like the Tonga eruption happened in the Caribbean,” Scruggs said.

The researchers worked quickly with only publicly available data. They plan to revisit all their findings as more information and samples become available and as more researchers publish their own findings on this groundbreaking eruption. Their

primary goal was to provide a point of departure for future work on the topic.

Scruggs is particularly keen on learning about the ash collected from this eruption. Volcanic rock provides a wealth of information to a trained geologist. Examining the material could shed light on the type of magma that erupted, how much of it there was and perhaps even how much seawater was involved in the eruption.

“There’s so many questions that have been raised,” said Scruggs. “Things we didn’t even think were possible have now been recorded.”

The UC Santa Barbara researchers will lead a special invited session on the Hunga Tonga-Hunga Ha’apai eruption at the Geological Society of America’s 2022 annual meeting in Denver this October. “It will be exciting to see what scores of other earth scientists can discover about this unique volcano,” Spera said. “We are just at the beginning.”

About UC Santa Barbara

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