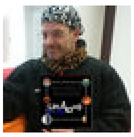
A huge volcano explosion: the Volcano Island of Hunga Tonga Ha‘apai {S:-20.536° || W:-175.382°}

Volcano Island Hunga Tonga Ha‘apai -{S:-20.536° || W:-175.382°}-

Recovery data from RG-proj.



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A huge volcano explosion: the Volcano Island of Hunga Tonga Ha‘apai {S:-20.536° || W:-175.382°} Volcano Island Hunga Tonga Ha‘apai -{S:-20.536° || W:-175.382°}-

https://www.researchgate.net/figure/1_fig362_346931099
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-------Hunga Tonga-Hunga Ha‘apai Erupts. NASA Earth Observatory Jan.2022.
A powerful volcanic eruption has obliterated a small, uninhabited South Pacific island known as Hunga Tonga-Hunga Ha‘apai. Damage assessments are still ongoing, but preliminary reports indicate that some communities in the island nation of Tonga have been severely damaged by volcanic ash and significant tsunami waves.
The volcano had sporadically erupted multiple times since 2009. The most recent activity began in late December 2021 as a series of Surtseyan eruptions built up and reshaped the island, while sending bursts of tephra and volcanic gases spewing from the vent. Relatively powerful blasts shook Hunga Tonga-Hunga Ha‘apai on January 13, but it was an even more intense series of explosions early on January 15 that generated atmospheric shock waves, sonic booms, and tsunami waves that traveled the world.
Several Earth-observing satellites collected data during and after the eruption. Scientists affiliated with NASA’s Disasters program are now gathering imagery and data, and they are sharing it with colleagues around the world, including disaster response agencies.
The sheer power of the eruption was quickly apparent in satellite imagery. As shown in the animation above, a vast plume of material created what volcanologists call an umbrella cloud with crescent-shaped bow shock waves and a vast number of lightning strikes.
“The umbrella cloud was about 500 kilometers (300 miles) in diameter at its maximum extent,” said Michigan Tech volcanologist Simon Carn. “That is comparable to Pinatubo and one of the largest of the satellite era. However, the

involvement of water in the Tonga eruption may have increased the explosivity compared to a purely magmatic eruption like Pinatubo."

NOAA's Geostationary Operational Environmental Satellite 17 (GOES-17) captured the images for the animation above. The natural-color views from the satellite's Advanced Baseline Imager were acquired between 5 and 8 p.m. local time (04:00 to 07:00 Universal Time) as the volcanic plume expanded upward and outward over the South Pacific. (NASA builds and launches the GOES series of satellites for NOAA.).

The second image, based on data collected on January 16 by the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission, shows material from the eruption rising to an altitude of 31 kilometers (19 miles). Other CALIPSO data collected on January 15 indicates that a small amount of ash and gas may have reached as high as 39.7 kilometers (24.7 miles).

"This is by far the highest volcanic plume we've ever measured with CALIPSO," said Jason Tackett, a researcher at NASA's Langley Research Center. CALIPSO was launched in 2006 by NASA and France's National Centre for Space Studies (CNES).

The eruption was powerful enough to inject volcanic material into the stratosphere, which generally begins above 15 kilometers (9 miles) in this part of the world. Scientists watch closely when volcanic materials reach this relatively dry layer of the atmosphere because particles linger much longer and travel much farther than if they remain in the lower, wetter troposphere. If enough volcanic material reaches the stratosphere, it can start to exert a cooling influence on global temperatures.

Despite the extreme height of the January 15 plume, scientists do not expect it to have much impact on climate. Satellite observations indicate the eruption injected about 0.4 teragrams of sulfur dioxide into the upper atmosphere, but the threshold for climate impacts is about 5 teragrams. "It is not unlike a dozen other eruptions that have occurred in the past 20 years in terms of likely impacts on climate," explained Brian Toon, an atmospheric scientist at the University of Colorado. "It is possible the impacts will be observable in very closely studied data (when the effects of La Niña and El Niño are removed), but the impacts will be too small to be felt by the average person."

Why this eruption was so violent is not clear yet. "With something this explosive, it is typically a consequence of a large volume of seawater coming into contact with a large reservoir of magma in a confined geologic setting," explained Daniel Slayback, a NASA scientist who visited Hunga Tonga-Hunga Ha'apai in 2019 to study how erosion was affecting the youngest parts of the island. Understanding erosion processes around volcanic features on Earth provides insights into how related processes may have played out in other parts of the solar system, including

Mars.

Preliminary imagery from commercial satellites and European and Canadian radar imagers suggest that little of Hunga Tonga-Hunga Ha‘apai still stands above the water line. The volcanic island first rose from the sea in January 2015. Eruptive activity built up ash around a new volcanic cone and connected the older, more lava-based islands of Hunga Tonga and Hunga Ha‘apai to create Hunga Tonga-Hunga Ha‘apai.

Signs of the island’s recent demise were easy for satellites to spot in the seas. The trio of natural-color images above shows how sediment, ash, pumice, and possibly continuing emissions from the volcano discolored the water in the days after the event. The images were acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA’s Aqua satellite.

The geologic record suggests Hunga Tonga may have produced large explosive eruptions like this in the past. “I just didn't expect to see one happen quite so soon,” said Slayback. “It was a beautiful little island with a thriving ecosystem of grasses, tropical birds, and other wildlife.”

https://earthobservatory.nasa.gov/images/149347/hunga-tonga-hunga-haapai-erupts

-------Massive eruption of Tongan volcano provides an explosion of data on atmospheric waves. PHYS, May.2022.

The Hunga volcano ushered in 2022 with a bang, devastating the island nation of Tonga and sending aid agencies, and Earth scientists, into a flurry of activity. It had been nearly 140 years since an eruption of this scale shook the Earth.

UC Santa Barbara's Robin Matoza led a team of 76 scientists, from 17 nations, to characterize the eruption's atmospheric waves, the strongest recorded from a volcano since the 1883 Krakatau eruption. The team's work, compiled in an unusually short amount of time, details the size of the waves originating from the eruption, which the authors found were on par with those from Krakatau. The data also provides exceptional resolution of the evolving wavefield compared to what was available from the historic event.

The paper, published in the journal Science, is the first comprehensive account of the eruption's atmospheric waves.

Early evidence suggests that an eruption Jan. 14 sunk the volcano's main vent below sea level, priming the massive explosion the following day. The Jan. 15 eruption generated a variety of different atmospheric waves, including booms heard 6,200 miles away in Alaska. It also created a pulse that caused the unusual occurrence of a tsunami-like disturbance an hour before the actual seismically driven tsunami began.

"This atmospheric waves event was unprecedented in the modern geophysical record," said lead author Matoza, an associate professor at UC Santa Barbara's Department of Earth Science.

The Hunga volcanic eruption has provided unprecedented insight into the behavior of a variety of atmospheric wave types. "The atmospheric waves were recorded globally across a wide frequency band," said co-author David Fee at the University of Alaska Fairbanks Geophysical Institute. "And by studying this remarkable dataset we will better understand acoustic and atmospheric wave generation, propagation and recording.

"This has implications for monitoring nuclear explosions, volcanoes, earthquakes and a variety of other phenomena," Fee continued. "Our hope is that we will be better able to monitor volcanic eruptions and tsunamis by understanding the atmospheric waves from this eruption."

The researchers were most interested in the behavior of an atmospheric wave known as a Lamb wave, which is the dominant pressure wave produced by the eruption. These are longitudinal pressure waves, much like sound waves, but of particularly low frequency. Such low frequency, in fact, that the effects of gravity must be taken into account. Lamb waves are associated with the largest atmospheric explosions, such as large eruptions and nuclear detonations, though

the wave characteristics differ between these two sources. They can last from minutes to several hours.
After the eruption, the waves traveled along Earth's surface and circled the planet in one direction four times and in the opposite direction three times, the authors recorded. This was the same as scientists observed in the 1883 Krakatau eruption. The Lamb wave also reached into Earth's ionosphere, rising at 700 mph to an altitude of about 280 miles.
"Lamb waves are rare. We have very few high-quality observations of them," Fee said. "By understanding the Lamb wave, we can better understand the source and eruption. It is linked to the tsunami and volcanic plume generation and is also likely related to the higher-frequency infrasound and acoustic waves from the eruption."
The Lamb wave consisted of at least two pulses near the volcano. The first had a 7- to 10-minute pressure increase followed by a second and larger compression and subsequent long pressure decrease.
A major difference between the accounts of Hunga's Lamb waves versus Krakatau's is the amount and quality of data scientists were able to gather. "We have more than a century of advances in instrumentation technology and global sensor density," Matoza said. "So the 2022 Hunga event provided an unparalleled global dataset for an explosion event of this size."
Scientists noted other findings about atmospheric waves associated with the eruption, including remarkable long-range infrasound—sounds too low in frequency to be heard by humans. Infrasound arrived after the Lamb wave and was followed by audible sounds in some regions.
Audible sounds reached Alaska, about 6,200 miles from the volcano, where they were heard around the state as repeated booms. "I heard the sounds," Fee recalled, "but at the time definitely did not think it was from a volcanic eruption in the South Pacific."
The scientists believe the sounds heard in Alaska couldn't have originated in Hunga. While there's still much to learn, it's clear that standard sound models cannot explain how audible sounds propagated over such extreme distances. "We interpreted that they were generated somewhere along the path by nonlinear effects," Matoza explained.
"There is a long list of possible follow-up studies examining the many different aspects of these signals in more detail," he said. "As a community, we will be working further on this event for years."
https://phys.org/news/2022-05-massive-eruption-tongan-volcano-explosion.html

-------Tonga's volcano sent tons of water into the stratosphere. That could warm the Earth. NPR, Aug.2022.

The violent eruption of Tonga's Hunga Tonga-Hunga Ha'apai volcano injected an unprecedented amount of water directly into the stratosphere — and the vapor will stay there for years, likely affecting the Earth's climate patterns, NASA scientists say.

The massive amount of water vapor is roughly 10% of the normal amount of vapor found in the stratosphere, equaling more than 58,000 Olympic-size swimming pools.

"We've never seen anything like it," said atmospheric scientist Luis Millán, who works at NASA's Jet Propulsion Laboratory. Millán led a study of the water the volcano sent into the sky; the team's research was published in Geophysical Research Letters.

The volcano sent vapor and gases to a record height

The Jan. 15 eruption came from a volcano that's more than 12 miles wide, with a caldera sitting roughly 500 feet below sea level. One day earlier, Tongan officials reported the volcano was in a continuous eruption, sending a 3-mile-wide plume of steam and ash into the sky. Then the big blast came, sending ash, gases and vapor as high as 35 miles — a record in the satellite era — into the atmosphere.

Drone aircraft and other video from that day show the dramatic scale of the blast, as the volcano launched an incredibly wide plume into the sky. The intense eruption sent a pressure wave circling around the Earth and caused a sonic boom heard as far away as Alaska.

The huge amount of water will likely raise temperatures

Earlier large volcanic eruptions have affected climate, but they usually cool temperatures, because they send light-scattering aerosols into the stratosphere. Those aerosols act as a sort of massive layer of sunscreen. But since water vapor traps heat, the Tongan eruption could temporarily raise temperatures a bit, the researchers said.

It normally takes around 2-3 years for sulfate aerosols from volcanoes to fall out of the stratosphere. But the water from the Jan. 15 eruption could take 5-10 years to fully dissipate.

Given that timeframe and the extraordinary amount of water involved, Hunga Tonga-Hunga Ha'apai "may be the first volcanic eruption observed to impact climate not through surface cooling caused by volcanic sulfate aerosols, but rather through surface warming," the researchers said in their paper.

NASA says the data for the study came from the Microwave Limb Sounder (MLS) instrument on its Aura satellite, which measures water vapor, ozone, aerosols and gases in Earth's atmosphere.

The volcano interrupted the 'heartbeat' of water in the stratosphere

The Jan. 15 eruption emphatically disrupted annual water patterns in the stratosphere (which also holds most of the atmosphere's ozone).

The normal mechanism by which water rises into the stratosphere is so reliable that researchers refer to it as a sort of tape recorder, marking annual temperature cycles through alternating bands of dry and moist air rising from the tropics.

January is normally the middle of the dry period in that seasonal cycle — but then the Tongan volcano erupted in the South Pacific Ocean, suddenly injecting a huge amount of water high in the atmosphere.

"By short-circuiting the pathway through the cold point, [Hunga Tonga-Hunga Ha'apai] has disrupted this 'heartbeat' signal" in the planet's normal atmospheric water pattern, the researchers said.

They recommend closely monitoring the water from the volcanic eruption, both to predict its impact in the near term and to better understand how future eruptions might affect the planet's climate.

https://www.npr.org/2022/08/03/1115378385/tonga-volcano-stratosphere-water-warming

-------NASA Mission Finds Tonga Volcanic Eruption Effects Reached Space. NASA May 2022.
When the Hunga Tonga-Hunga Haʻapai volcano erupted on Jan. 15, 2022, it sent atmospheric shock waves, sonic booms, and tsunami waves around the world. Now, scientists are finding the volcano's effects also reached space.
Analyzing data from NASA's Ionospheric Connection Explorer, or ICON, mission and ESA's (the European Space Agency) Swarm satellites, scientists found that in the hours after the eruption, hurricane-speed winds and unusual electric currents formed in the ionosphere – Earth's electrified upper atmospheric layer at the edge of space.
"The volcano created one of the largest disturbances in space we've seen in the modern era," said Brian Harding, a physicist at University of California, Berkeley, and lead author on a new paper discussing the findings. "It is allowing us to test the poorly understood connection between the lower atmosphere and space."
ICON launched in 2019 to identify how Earth's weather interacts with weather from space – a relatively new idea supplanting previous assumptions that only forces from the Sun and space could create weather at the edge of the ionosphere. In January 2022, as the spacecraft passed over South America, it observed one such earthly disturbance in the ionosphere triggered by the South Pacific volcano.
"These results are an exciting look at how events on Earth can affect weather in space, in addition to space weather affecting Earth," said Jim Spann, space weather lead for NASA's Heliophysics Division at NASA Headquarters in Washington, D.C. "Understanding space weather holistically will ultimately help us mitigate its effects on society."
When the volcano erupted, it pushed a giant plume of gases, water vapor, and dust into the sky. The explosion also created large pressure disturbances in the atmosphere, leading to strong winds. As the winds expanded upwards into thinner atmospheric layers, they began moving faster. Upon reaching the ionosphere and the edge of space, ICON clocked the windspeeds at up to 450 mph – making them the strongest winds below 120 miles altitude measured by the mission since its launch.
In the ionosphere, the extreme winds also affected electric currents. Particles in the ionosphere regularly form an east-flowing electric current – called the equatorial electrojet – powered by winds in the lower atmosphere. After the eruption, the equatorial electrojet surged to five times its normal peak power and dramatically flipped direction, flowing westward for a short period.
"It's very surprising to see the electrojet be greatly reversed by something that happened on Earth's surface," said Joanne Wu, a physicist at University of California, Berkeley, and co-author on the new study. "This is something we've only

previously seen with strong geomagnetic storms, which are a form of weather in space caused by particles and radiation from the Sun."

The new research, published in the journal Geophysical Research Letters, is adding to scientists' understanding of how the ionosphere is affected by events on the ground as well as from space. A strong equatorial electrojet is associated with redistribution of material in the ionosphere, which can disrupt GPS and radio signals that are transmitted through the region.

Understanding how this complex area of our atmosphere reacts in the face of strong forces from below and above is a key part of NASA research. NASA's upcoming Geospace Dynamics Constellation, or GDC, mission will use a fleet of small satellites, much like weather sensors on the ground, to track the electrical currents and atmospheric winds coursing through the area. By better understanding what affects electrical currents in the ionosphere, scientists can be more prepared to predict severe problems caused by such disturbances.

https://www.nasa.gov/feature/goddard/2022/sun/nasa-mission-finds-tonga-volcanic-eruption-effects-reached-space

►► VIDEO►►
https://youtu.be/Y4NpOIdV8To

►► NASA DATA►►
https://earthobservatory.nasa.gov/images/event/85016/undersea-eruption-near-tonga

►► ANIMATED GIF►►
https://media.nature.com/lw800/magazine-assets/d41586-022-00394-y/d41586-022-00394-y_20117580.gif

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https://goo.gl/maps/9GVQtrbGxoatEqeT7

-------Atmospheric waves and global seismoacoustic observations of the January 2022 Hunga eruption, Tonga. Science, 2022. DOI:10.1126/science.abo7063. PMID:35549311.

Going on the lamb.-- The Hunga Tonga undersea volcanic eruption was one of the most powerful recorded, with audible sound detected more than 10,000 kilometers from the source. Matoza et al. present infrasound and seismic recordings, along with other geophysical observations, that help to describe this event. An atmospheric lamb wave, characteristic of energetic atmospheric events, circled the planet four times and was similar to the 1883 Krakatau eruption. Kubota et al. detail how this lamb wave contributed to the global tsunami waves arriving much earlier than expected. The eruption also generated long-range infrasounds and ionospheric interations, along with a global tsunami. This set of observations will be helpful for disentangling the event and understanding the propagation of waves through the atmosphere and ocean (see the Perspective by Brodsky and Lay).

Abstract.-- The 15 January 2022 climactic eruption of Hunga volcano, Tonga, produced an explosion in the atmosphere of a size that has not been documented in the modern geophysical record. The event generated a broad range of atmospheric waves observed globally by various ground-based and spaceborne instrumentation networks. Most prominent was the surface-guided Lamb wave (≲0.01 hertz), which we observed propagating for four (plus three antipodal) passages around Earth over 6 days. As measured by the Lamb wave amplitudes, the climactic Hunga explosion was comparable in size to that of the 1883 Krakatau eruption. The Hunga eruption produced remarkable globally detected infrasound (0.01 to 20 hertz), long-range (~10,000 kilometers) audible sound, and ionospheric perturbations. Seismometers worldwide recorded pure seismic and air-to-ground coupled waves. Air-to-sea coupling likely contributed to fast-arriving tsunamis. Here, we highlight exceptional observations of the atmospheric waves.

https://doi.org/10.1126/science.abo7063

-------Why the Tongan eruption will go down in the history of volcanology. Nature, 602, Feb.2022. DOI:10.1038/d41586-022-00394-y.
The 15 January blast sent shock waves around the globe and defied scientific expectations. Researchers are now scrambling to work out why. The eruption that devastated Tonga on 15 January lasted just 11 hours, but it will take years for scientists to work out exactly what happened during the cataclysmic explosion — and what it means for future volcanic risks.
The volcano, named Hunga Tonga–Hunga Ha‘apai, sent a plume of ash soaring into the upper atmosphere and triggered a tsunami that destroyed homes on Tonga's nearby islands. Reverberations from the eruption circled the globe multiple times.
The extraordinary power of the blast, captured by a range of sophisticated Earth-observing satellites, is challenging ideas about the physics of eruptions. Researchers are finding it hard to explain why the volcano sent a cloud to such heights, yet emitted less ash than would be expected for an eruption of such magnitude. And the shock waves that rippled through the atmosphere and oceans are unlike anything seen in the modern scientific era.
The eruption of Hunga Tonga–Hunga Ha‘apai is forcing scientists to rethink their ideas on the hazards posed by the many submarine volcanoes that lurk beneath the waves of the Pacific Ocean.
"It just basically rips the Band-Aid on our lack of understanding of what's happening under water," says Nico Fournier, a volcanologist at GNS Science in Taupo, New Zealand.
Fresh danger
The eruption, which happened just 65 kilometres from the Tongan capital of Nuku‘alofa, has been a disaster for the more than 100,000 people living in Tonga. They are working to clear away the thick layer of ash that blanketed everything, to establish clean drinking-water supplies and to recover from the crop damage, estimated to equate to nearly 39 million Tongan pa‘anga (US$17 million). At least three people have died in Tonga as a result of the eruption. The crisis is being compounded by COVID-19, with Tongans facing their first wave of cases, which started after relief ships arrived from other countries.
But earthquakes continue to shake the region, and the volcanic danger might not be over. Preliminary studies of ash from the 15 January eruption suggest that it was fed by a fresh batch of magma rising from inside Earth. Hunga Tonga–Hunga Ha‘apai could remain active for some time, with uncertain effects on the people of Tonga.
Geoscientists have limited ability to provide people in the region with a good sense of the future risks. "It's a really difficult situation of wishing volcanology could give

more to the local people," says Janine Krippner, a volcanologist with the Smithsonian Institution's Global Volcanism Program in Washington DC, who is based in New Zealand. "But right now, that's not the case."

Most of Hunga Tonga–Hunga Ha'apai lies under water. It rises more than 2,000 metres from the sea floor and is part of the Tonga–Kermadec volcanic arc. This string of mostly underwater volcanoes sits above a massive geological collision zone, where the western edge of the Pacific plate of Earth's crust dives beneath the Indo–Australian plate. The edge of the Pacific plate heats up as it sinks into the planet's depths, and molten rock rises to feed the volcanoes of the Tonga–Kermadec arc. Geological evidence shows that large eruptions have convulsed Hunga Tonga–Hunga Ha'apai about once every millennium, with huge blasts that occurred in around AD 200 and AD 1100. The past century has brought smaller ones, in 1937 and 1988. By that point, the top of the volcano was peeking out above the waves in the form of two small islands, named Hunga Tonga and Hunga Ha'apai. Then, in 2009, the volcano began spitting ash and steam in an eruption at Hunga Ha'apai. In December 2014 and January 2015, another eruption formed new land that connected the two islands, forming a single landmass1,2. Several research teams visited the new island soon after it formed and gathered samples of volcanic ash and rock. Geochemical analysis of that material, described in a paper in Lithos3, found that the 2009 and 2014–15 eruptions involved molten rock that had not risen recently from the great depths of Earth's mantle. Instead, it had spent some time at a geological way station, a magma chamber located 5–8 kilometres deep in Earth's crust. While sitting there, the magma had gone through some tell-tale chemical changes, almost like wine ageing in a barrel, before ultimately erupting onto the surface. The magma that erupted this January was different. Shane Cronin, a volcanologist at the University of Auckland in New Zealand, and his colleagues have analysed ash from the eruption that military relief workers scooped up near the airport on Tonga's largest island. Chemical analysis shows that it differs from that of the 2014–15 eruptions. Cronin says that the fresh magma rose quickly, without spending much time undergoing chemical changes in the buried magma chamber. Geologist Taaniela Kula and his colleagues at the Tonga Geological Services in Nuku'alofa have been collecting ash samples from islands across Tonga that Cronin and others are analysing. By studying ash from different islands, including noting how thickly and how widely it is distributed, researchers will be able to build up a better picture of how the eruption unfolded. Surprisingly, there seems to have been relatively little ash emitted, given the size of the blast. That might be a result of the environment in which Hunga Tonga–Hunga Ha'apai erupted: under water, but at a relatively shallow depth.

The water factor.-- Volcanoes in deep water rarely erupt through the ocean surface in big blasts, because the pressure of the overlying water prevents gas bubbles from forming and growing with explosive force. But the volcanic vent that erupted at Hunga Tonga–Hunga Ha'apai on 15 January was just tens to 250 metres deep. That's shallow enough that the water didn't suppress the power of the blast, but deep enough for the erupting magma to encounter a lot of water.

Water can fuel explosive eruptions by flash-heating to form steam, which expands quickly. In this way, it efficiently transforms thermal energy from magma into the kinetic energy of an eruption, says Michael Manga, a geoscientist at the University of California, Berkeley. "Some of the most powerful eruptions have been through water," he says.

Another important factor is how much volcanic gas is mixed into the magma before it erupts. A gas-rich upwelling of magma might have fed the 15 January eruption by providing a large number of bubbles to fuel the explosion, says Raymond Cas, a volcanologist and emeritus professor at Monash University in Melbourne, Australia.

The eruption of Hunga Tonga–Hunga Ha'apai is unusual in that it combined features not usually seen together, says Cas. Volcanologists know of other examples of eruptions that occurred under water, or under snow and ice, and thus incorporated water. Scientists have also seen extremely high eruption plumes that towered into the atmosphere. But Hunga Tonga–Hunga Ha'apai is a unique example of both things happening together. It might ultimately come to serve as the prototype of a newly recognized type of eruption style, he says.

Most submarine eruptions don't produce particularly high plumes. For instance, in 2012 the massive deep-sea eruption of Havre volcano, north of New Zealand, produced mainly a huge floating collection of lightweight pumice stones4. That eruption occurred at a depth of more than 900 metres. "We have relatively few cases where we see large plumes that breach the ocean surface," says Kristen Fauria, a volcano scientist at Vanderbilt University in Nashville, Tennessee.

Yet the Hunga Tonga–Hunga Ha'apai eruption plume soared to a height of at least 30 kilometres, well into the upper atmosphere, or stratosphere. That's so high that researchers have been scrambling to understand what long-term impact it might have. High-resolution satellite imagery is allowing them to track how ash, gas and certain chemical species are drifting through the atmosphere — in much more detail than they could in 1991, when Mount Pinatubo in the Philippines erupted even more powerfully than Hunga Tonga–Hunga Ha'apai. "We have never seen anything like this," says Anja Schmidt, a volcanologist at the German Aerospace Center in Oberpfaffenhofen.

The Tonga volcano didn't emit enough sulfur dioxide to change global climate, as eruptions from some other volcanoes have. It expelled an estimated 400,000 tonnes of SO_2, whereas the 1991 eruption of Pinatubo ejected nearly 20 million tonnes. That blast temporarily cooled the planet by nearly 0.5 °C, as the sulfur formed sulfate particles that reflected some of the Sun's radiation back into space.

One possible explanation for the discrepancy is that much of the SO_2 from Hunga Tonga–Hunga Ha'apai might have 'fallen out' of the plume at low altitudes, before the plume got too high. But Hunga Tonga–Hunga Ha'apai did throw ash high into the stratosphere, and researchers will be looking for signs of any impact on climate, Schmidt says. They will also be watching to see whether the volcanic material causes any destruction of stratospheric ozone, and whether the atmospheric waves the eruption unleashed affect atmospheric circulation patterns in the coming months.

Early findings could come from balloon experiments lofted into the Tongan eruption plume. Several research teams have already launched balloons carrying instruments from the island of La Réunion in the Indian Ocean. One such effort, led by the US National Oceanic and Atmospheric Administration, was able to measure volcanic particles up to a height of 28 kilometres as the plume drifted over La Réunion, says team member Elizabeth Asher, an atmospheric scientist at the Cooperative Institute for Research in Environmental Sciences in Boulder, Colorado. That's so high that she expects to see the eruption's atmospheric effects to linger for longer than they would after less-powerful eruptions.

Ripple effects.-- Another aspect that could reshape volcanology is the way in which Hunga Tonga–Hunga Ha'apai unleashed a rich variety of waves that rippled through the oceans and the atmosphere. The reverberations it sent around the world are reminiscent of those seen after the 1883 eruption of Krakatau in Indonesia, says Alan Robock, a climate scientist at Rutgers University in New Brunswick, New Jersey. The eruption last month triggered pressure waves and gravity waves in the atmosphere and tsunami waves all around the Pacific Ocean — even in distant ocean basins. GPS satellites also detected disturbances in the ionosphere, the layer of the atmosphere that lies above the stratosphere, starting at a height of 80–90 kilometres.

"There are huge pieces of this puzzle that we haven't quite managed to pull together," says Fournier.

The challenge now is to gather enough data to complete the puzzle. Volcanologists would normally monitor an active volcano using seismometers to study earthquakes in the surrounding area. There are currently no active seismometers in Tonga, so the large quakes that have been happening around Hunga Tonga–Hunga Ha'apai since the 15 January eruption have not been tracked in much detail. The data that exist, however, suggest that the quakes are generated by fresh magma rising into the crust to refill the reservoir that was emptied by the

large eruption, says Cronin.
Another priority is to survey the sea floor around the volcano to see which parts of its underwater structure have blown up or otherwise changed since previous surveys. Satellite radar imagery suggests that the top part of the volcano has subsided by at least 10 metres, Cronin says. But it is too dangerous to approach the volcano to do a scientific survey just yet.
Some early data might come from relief ships that have been travelling to and around Tonga, such as the one tasked with repairing the submarine cable that connects Tonga to Fiji. This was severed during the eruption, cutting off international communications. The cable might have been buried by a landslide coming off the side of the volcano, or cut in several places.
Foremost in everyone’s minds is what Hunga Tonga–Hunga Ha‘apai might do next. A group of international experts is providing information to the Tonga Geological Services to help the Tongan government to assess the risk and decide what to do. The researchers are weighing up three possible scenarios: the eruption could end, it could continue at a low level or there could be another massive blast. “All these scenarios are still live,” says Cronin.
Regardless of what the immediate future holds for this particular volcano, the eruption has volcanologists rethinking the hazards of submarine volcanoes more broadly, says Schmidt. “It’s a stark reminder that these kinds of volcanoes exist, that they pose a hazard, and that they are understudied.”
https://doi.org/10.1038/d41586-022-00394-y

-------The Hunga Tonga-Hunga Ha'apai Hydration of the Stratosphere. Geophysical Research Letters, 49, Jul.2022. DOI:10.1029/2022GL099381.

Abstract.-- Following the 15 January 2022 Hunga Tonga-Hunga Ha'apai eruption, several trace gases measured by the Aura Microwave Limb Sounder (MLS) displayed anomalous stratospheric values. Trajectories and radiance simulations confirm that the H2O, SO2, and HCl enhancements were injected by the eruption. In comparison with those from previous eruptions, the SO2 and HCl mass injections were unexceptional, although they reached higher altitudes. In contrast, the H2O injection was unprecedented in both magnitude (far exceeding any previous values in the 17-year MLS record) and altitude (penetrating into the mesosphere). We estimate the mass of H2O injected into the stratosphere to be 146 ± 5Tg, or ~10% of the stratospheric burden. It may take several years for the H2O plume to dissipate. This eruption could impact climate not through surface cooling due to sulfate aerosols, but rather through surface warming due to the radiative forcing from the excess stratospheric H2O.

Key Points.-- Following the Hunga Tonga-Hunga Ha'apai eruption, the Aura Microwave Limb Sounder measured enhancements of stratospheric H2O, SO2, and HCl. The mass of SO2 and HCl injected is comparable to that from prior eruptions, whereas the magnitude of the H2O injection is unprecedented. Excess stratospheric H2O will persist for years, could affect stratospheric chemistry and dynamics, and may lead to surface warming.

Plain Language Summary.-- The violent Hunga Tonga-Hunga Ha'apai eruption on 15 January 2022 not only injected ash into the stratosphere but also large amounts of water vapor, breaking all records for direct injection of water vapor, by a volcano or otherwise, in the satellite era. This is not surprising since the Hunga Tonga-Hunga Ha'apai caldera was formerly situated 150 m below sea level. The massive blast injected water vapor up to altitudes as high as 53 km. Using measurements from the Microwave Limb Sounder on NASA's Aura satellite, we estimate that the excess water vapor is equivalent to around 10% of the amount of water vapor typically residing in the stratosphere. Unlike previous strong eruptions, this event may not cool the surface, but rather it could potentially warm the surface due to the excess water vapor. .... In summary, MLS measurements indicate that an exceptional amount of H2O was injected directly into the stratosphere by the HT-HH eruption. We estimate that the magnitude of the injection constituted at least 10% of the total stratospheric H2O burden. On the day of the eruption, the H2O plume reached ~53 km altitude. The H2O injection bypassed the cold point tropopause, disrupted the H2O tape recorder signal, set a new record for H2O injection height in the 17-year MLS record, and could alter stratospheric chemistry and dynamics as the long-lived H2O plume propagates through the stratosphere in

the BDC. Unlike previous strong eruptions in the satellite era, HT-HH could impact climate not through surface cooling due to sulfate aerosols, but rather through surface warming due to the excess stratospheric H2O forcing. Given the potential high-impact consequences of the HT-HH H2O injection, it is critical to continue monitoring volcanic gases from this eruption and future ones to better quantify their varying roles in climate.
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-------Global fast-traveling tsunamis driven by atmospheric Lamb waves on the 2022 Tonga eruption, Science (2022). DOI:10.1126/science.abo4364.

Going on the lamb.-- The Hunga Tonga undersea volcanic eruption was one of the most powerful recorded, with audible sound detected more than 10,000 kilometers from the source. Matoza et al. present infrasound and seismic recordings, along with other geophysical observations, that help to describe this event. An atmospheric lamb wave, characteristic of energetic atmospheric events, circled the planet four times and was similar to the 1883 Krakatau eruption. Kubota et al. detail how this lamb wave contributed to the global tsunami waves arriving much earlier than expected. The eruption also generated long-range infrasounds and ionospheric interations, along with a global tsunami. This set of observations will be helpful for disentangling the event and understanding the propagation of waves through the atmosphere and ocean (see the Perspective by Brodsky and Lay).

Abstract.-- On 15 January 2022, the Hunga Tonga-Hunga Ha‘apai volcano erupted, producing tsunamis worldwide including first waves which arrived more than 2 hours earlier than what is expected for conventional tsunamis. We investigated the generation and propagation mechanisms of the tsunami “forerunner,” and our simulation found that fast-moving atmospheric Lamb waves drove the leading sea height rise whereas the scattering of the leading waves related to bathymetric variations in the Pacific Ocean produced subsequent long-lasting tsunamis. Tsunamis arriving later than the conventionally expected travel time are composed of various waves generated from both moving and static sources, which makes the tsunami, due to this eruption, much more complex and longer-lasting than ordinary earthquake-induced tsunamis.

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