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Hawaii's Active Volcanoes: Federal Role in Research, Monitoring, and Warning

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SUMMARY

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August 12, 2025

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Hawaii's Active Volcanoes: Federal Role in Research, Monitoring, and Warning

Hawaii has six active volcanoes, five of which the U.S. Geological Survey (USGS) considers threatening to people and property. Hawaii's volcanoes formed the Hawaiian island chain from a hotspot plume over millions of years, and all of the islands are composed of one or more shield volcanoes. On the island of Hawai'i, Kīlauea volcano is among the most active volcanoes in the world. It sits on the flank of Mauna Loa volcano, which is also among the world's most active and largest volcanoes. Some of the greatest risks from Hawaii's volcanoes include lava flows, volcanic bombs, volcanic gases, and volcanic ash. Hawaii also faces risks from earthquakes, landslides, and tsunamis, some of which may be generated by volcanic activity.

Congress has directed federal agencies such as the USGS and the National Oceanic and Atmospheric Administration (NOAA) to research, monitor, and warn about volcanic hazards affecting the United States. In 2019, Congress passed legislation that authorized a National Volcano Early Warning and Monitoring System (NVEWS; Section 5001 of P.L. 116-9, 43 U.S.C. 31k). The law directed the USGS to establish NVEWS to monitor volcanoes, warn U.S. citizens of volcanic activity, and protect citizens from "undue and avoidable harm." In 2020, the USGS submitted a five-year plan for establishing and managing NVEWS, and from 2021 to 2024 the agency submitted annual reports charting the progress of NVEWS. In 2024, the USGS published its *Volcano Science Center Response Plan for Significant Volcanic Events*. In 2022, Congress amended NVEWS to direct cooperation and coordination between USGS's NVEWS and NOAA's activities to monitor and warn about volcanic activity impacting the atmosphere and ocean, especially NOAA's Volcanic Ash Advisory Centers (VAACs) (P.L. 117-263). In 2025, NOAA submitted an implementation plan to modernize NVEWS in collaboration with the USGS.

The USGS Hawaiian Volcano Observatory (HVO) studies, monitors, forecasts, warns about, and seeks to reduce risks from volcanic hazards in Hawaii. With partners, HVO also monitors and informs about earthquakes as the lead for the Hawaii Integrated Seismic Network. In addition, HVO, NOAA's Washington Volcanic Ash Advisory Center (WVAAC, located in College Park, MD, outside of Washington, DC), and other partners study, monitor, forecast, and warn about volcanic gas and ash hazards in the atmosphere to reduce risks to people, property, vessels, and aircraft. The Hawaii Interagency Vog Information Dashboard warns about volcanic gases and volcanic smog (i.e., *vog*).

Considerations for Congress

Congress may consider continued oversight of the USGS Volcano Hazards Program (VHP) and, more specifically, of NVEWS. Congress may consider VHP's plans, progress, and priorities; annual and any potential supplemental appropriations for VHP; potential reauthorization of appropriations for NVEWS (authorized appropriations expired in FY2023) and amendments to NVEWS. Since the establishment of NVEWS, the USGS generally has divided VHP's activities into volcano threat assessments, operational support, the Volcano Disaster Assistance Program, and NVEWS activities. Most of the research, monitoring, and warning conducted by HVO is supported by NVEWS. Congress provided supplemental appropriations for new HVO facilities and the repair or replacement of monitoring equipment after the damaging 2018 Kīlauea eruption. Congress may consider how HVO is being modernized and unified with other observatories and whether HVO is able to monitor volcanoes in its area of responsibility (i.e., Hawaii and American Samoa) to help prevent undue harm, a primary objective of NVEWS.

The 119th Congress may consider the future of authorizations and appropriations for various federal agencies to research, monitor, and warn about volcanic hazards affecting the United States. S. 1052, introduced on March 13, 2025, would reauthorize appropriations for the USGS of $75 million until FY2033. It also would extend the period of authorization of sums necessary for NOAA to carry out its NVEWS activities to FY2034. S. 1052 would amend NVEWS by adding "infrasound arrays, visible and infrared cameras and advanced digital telemetry networks" to the emerging technologies the USGS should apply to modernize the system. Another measure, H.R. 3176, introduced on May 5, 2025, would reauthorize NVEWS appropriations of $55 million to the Secretary of the Interior for FY2026 to FY2030. Congress may continue to evaluate the efficiency and effectiveness of NVEWS activities in maintaining the nation's preparedness and reducing volcanic hazards' impacts on lives, property, aviation, maritime activities, and the economy.

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Introduction

The United States has 170 potentially active volcanoes, and the U.S. Geological Survey (USGS) considers 161 of these volcanoes threatening.[1] According to the Smithsonian Institution's Global Volcanism Program, the United States has the most active volcanoes of any country.[2] Hawaii has six active volcanoes, five of which the USGS considers to be threatening (see "Primer on Hawaii's Active Volcanoes and Hazards"). People and property close to Hawaii's active volcanoes face the greatest risks from lava flows, fire fountains, volcanic ejecta or bombs, volcanic gases, and volcanic ash (**Appendix B**).[3] Volcanic gases and ash from Hawaii's active volcanoes may harm human health and the environment and may damage property, maritime activities, and aviation.

Hawaii's active volcanoes typically have a low volcanic explosivity index (VEI) of 0 for nonexplosive or 1 for small explosivity, so that volcanic ash from Hawaii's volcanoes generally is not a significant hazard beyond the eruption site.[4] *Vog*, volcanic smog created by sulfur dioxide and other volcanic gases, poses a more significant risk to human health and the environment beyond an eruption site in Hawaii (**Appendix B**). In addition to these volcanic hazards, Hawaii may experience earthquakes, landslides, and tsunamis, some of which may be caused by the growth and activity of the state's volcanoes.[5] Hawaii's active volcanoes have added risks from volcanic activity that intersects with the Pacific Ocean, such as laze plumes (**Appendix B**) and tsunamis.[6]

[1] A 2018 U.S. Geological Survey (USGS) threat assessment considered active volcanoes that may pose a threat to people or property. The USGS considered *active volcanoes* to include volcanoes that have erupted within the past approximately 11,000 years plus "three notably large and long-lived caldera systems (Yellowstone, Wyoming; Valles, New Mexico; and Long Valley, California)." The three large caldera systems have not erupted in the past 11,000 years but may erupt in the future. John W. Ewert et al., *2018 Update to the U.S. Geological Survey National Volcanic Threat Assessment*, USGS, Scientific Investigations Report 2018-5140, 2018, https://doi.org/10.3133/sir20185140 (hereinafter USGS, *Volcanic Threat Assessment*, 2018).

[2] The Smithsonian Institution's Global Volcanism Program defines *active volcanoes* as volcanoes that have erupted in the past 12,000 years. The other top-five nations with the most active volcanoes include Japan (120), Russia (115), Indonesia (108), and Chile (91). Smithsonian Institution Global Volcanism Program, "Which Countries Have the Most Volcanoes?," https://volcano.si.edu/faq/index.cfm?question=countries.

[3] Of these risks, volcanic ash eruptions are rarer events at Hawaii's active volcanoes and may catch people by surprise. USGS, "Questions About Volcanic Ash and Other Tephra from Kīlauea," https://www.usgs.gov/observatories/hawaiian-volcano-observatory/questions-about-volcanic-ash-and-other-tephra-kilauea.

[4] The *volcanic explosivity index* (VEI) provides a relative measure of the amount of erupted ash and may be useful for assessing the relative risks of ash and ashfall to people, property, and aviation. VEI does not measure the amount of erupted lava and is not useful for assessing the risks of lava flows or other ground-based hazards. USGS, "The Volcanic Explosivity Index: A Tool for Comparing the Sizes of Explosive Volcanic Eruptions," https://www.usgs.gov/observatories/yvo/news/volcanic-explosivity-index-a-tool-comparing-sizes-explosive-volcanic. Large to very large explosive eruptions (VEI of 4 to 8) may have global impacts on climate; modern technologies, such as satellites, telecommunications, power infrastructure, and aviation; and other aspects of modern society with global interdependencies. Such impacts are not discussed in this report. For an overview, see Chris Newhall et al., *Anticipating Future Volcanic Explosivity Index (VEI) 7 Eruptions and Their Chilling Impacts*, Geosphere 2018, vol. 14, no. 2 (February 28. 2018), pp. 572-603, https://doi.org/10.1130/GES01513.1 (hereinafter Newhall, *Anticipating Future Eruptions*). Alaska's volcanoes typically have a VEI of 2 to 3, with some eruptions having a VEI from 4 to 6. Eruptions with a VEI of 5 to 8 are not common in the global record of volcanic eruptions. See CRS Report R48529, *Alaska's Active Volcanoes: Federal Role in Research, Monitoring, and Warning*, by Linda R. Rowan.

[5] USGS, Hawaiian Volcano Observatory (HVO), "Hazards," https://www.usgs.gov/observatories/hvo/science/hazards.

[6] A *laze plume* forms when hot lava hits the ocean and consists of hydrochloric acid, steam, and fine volcanic glass particles.

Research, monitoring, and warning about volcanoes may reduce the risk from volcanic, earthquake, landslide, and tsunami hazards. It also may identify where hazards from volcanic activity may threaten people and property. Additional information may help authorities take protective actions to reduce risks. These actions may include evacuations; shelter-in-place orders; land, air, or water restricted areas; closures; suspensions or changes to operations; property relocation; and, where possible, the removal of ashfall deposits to prevent further damage to people, property, or infrastructure.

Congress has directed federal agencies such as the USGS and the National Oceanic and Atmospheric Administration (NOAA) to research, monitor, and warn about volcanic hazards affecting the United States and other countries. The mission of the USGS Volcano Hazards Program (VHP) is to enhance safety and minimize disruption from volcanic eruptions, and NOAA's Volcanic Ash Advisory Centers (VAACs) keep the aviation community informed of volcanic hazards.[7] In 2019, Congress passed the John D. Dingell Jr. Conservation, Management, and Recreation Act (P.L. 116-9), which authorized the establishment of the National Volcano Early Warning and Monitoring System (NVEWS).[8] The objectives of NVEWS are to organize, modernize, and unify the monitoring systems of volcano observatories and to monitor U.S. volcanoes at a level commensurate with their threat. The Volcano Science Center (VSC) within VHP oversees the five U.S. observatories (Alaska, California, Cascades, Hawaiian, and Yellowstone), and VSC is leading the effort to establish and manage NVEWS.[9]

In 2022, Congress passed the James M. Inhofe National Defense Authorization Act for Fiscal Year 2023 (P.L. 117-263), in which Title CV, Section 10501, amended NVEWS to strengthen the monitoring and warning systems of U.S. volcano observatories by integrating relevant capacities of NOAA, including the VAACs.

This report focuses on the USGS's and NOAA's roles in research, monitoring, and warning for Hawaii's active volcanoes and how these efforts may meet the objectives of NVEWS. The primary USGS and NOAA-led organizations include the following:

- The USGS Hawaiian Volcano Observatory (HVO) is responsible for volcano and earthquake monitoring in Hawaii and volcano monitoring in American Samoa.[10]
- HVO leads the Hawaii Integrated Seismic Network (HISN) for earthquake monitoring, and HISN is part of the U.S. Advanced National Seismic System (ANSS). Partners in HISN include the NOAA Pacific Tsunami Warning Center, USGS National Strong-Motion Project, EarthScope Consortium (formerly Incorporated Research Institutions for Seismology), and Infrasound Laboratory University of Hawai'i.[11]

[7] USGS, "Volcano Hazards Program," https://www.usgs.gov/programs/VHP/what-we-do-volcano-hazards-program; National Oceanic and Atmospheric Administration (NOAA), "Volcano Ash Advisory Centers (VAAC)," https://www.ospo.noaa.gov/products/atmosphere/vaac/other-vaacs.html.

[8] Title V, §5001, of the John D. Dingell Jr. Conservation, Management, and Recreation Act (P.L. 116-9) authorized the National Volcano Early Warning and Monitoring System (NVEWS). For more information, see CRS In Focus IF11987, *The National Volcano Early Warning and Monitoring System*, by Linda R. Rowan.

[9] P.L. 116-9, the John D. Dingell Jr. Conservation, Management, and Recreation Act, directed the USGS to unify and modernize the volcano observatories. The USGS chose the Volcano Science Center, which oversees the five observatories, to lead the implementation of NVEWS. USGS, "Volcano Hazards Program," https://www.usgs.gov/vhp; USGS, "Volcano Science Center," https://www.usgs.gov/centers/volcano-science-center.

[10] USGS, "Hawaiian Volcano Observatory," https://www.usgs.gov/observatories/hvo.

[11] USGS, "Monitoring Earthquakes in Hawaii," https://volcanoes.usgs.gov/observatories/hvo/hvo_monitoring_earthquakes.html; NOAA, "U.S. Tsunami Warning System," https://www.tsunami.gov/; USGS, (continued...)

- NOAA Washington VAAC is responsible for warning aviation of volcanic hazards from Hawaii's active volcanoes and from other U.S. volcanoes, except those in Alaska and the Northern Mariana Islands.[12]
- The Hawaii Interagency Vog Information Dashboard—a partnership between the USGS, NOAA, the U.S. Department of Agriculture, the National Park Service (NPS), state agencies, and universities—researches, monitors, and warns about vog hazards.[13]

Congress may continue to consider whether NVEWS enables HVO to monitor Hawaii's active volcanoes at levels commensurate with their threats to meet the system's objective "to monitor, warn, and protect citizens of the United States from undue and avoidable harm from volcanic activity."[14] Congress also may consider how to address specific volcanic hazards, such as volcanic ash, that may have a regional-to-global impact. For example, modernizing and unifying volcano observatory monitoring systems could enable the USGS and NOAA to integrate and improve volcanic ash and gas models, forecasts, and warnings.

Primer on Hawaii's Active Volcanoes and Hazards

Hawaii has six active volcanoes, five of which the USGS considers threatening to people and property (**Figure 1**).[15] The five threatening volcanoes are Kīlauea and Mauna Loa (very high threat), Hualālai (high threat), and Haleakalā and Mauna Kea (moderate threat). The submarine volcano Kama'ehuakanaloa (also known as the Lō'ihi seamount), which lies offshore just south of the Kīlauea volcano, is active but was not ranked by the USGS in its 2018 assessment of threatening volcanoes in the United States.[16]

"National Strong Ground Motion Project," https://earthquake.usgs.gov/monitoring/nsmp/; University of Hawaii, "Infrasound Laboratory University of Hawaii," https://www.isla.hawaii.edu/; EarthScope Consortium, "SAGE," https://www.iris.edu/hq/.

[12] NOAA, "Washington Volcanic Ash Advisory Center," https://www.ospo.noaa.gov/products/atmosphere/vaac/. For more about monitoring Alaska volcanoes, see CRS Report R48529, *Alaska's Active Volcanoes: Federal Role in Research, Monitoring, and Warning*, by Linda R. Rowan.

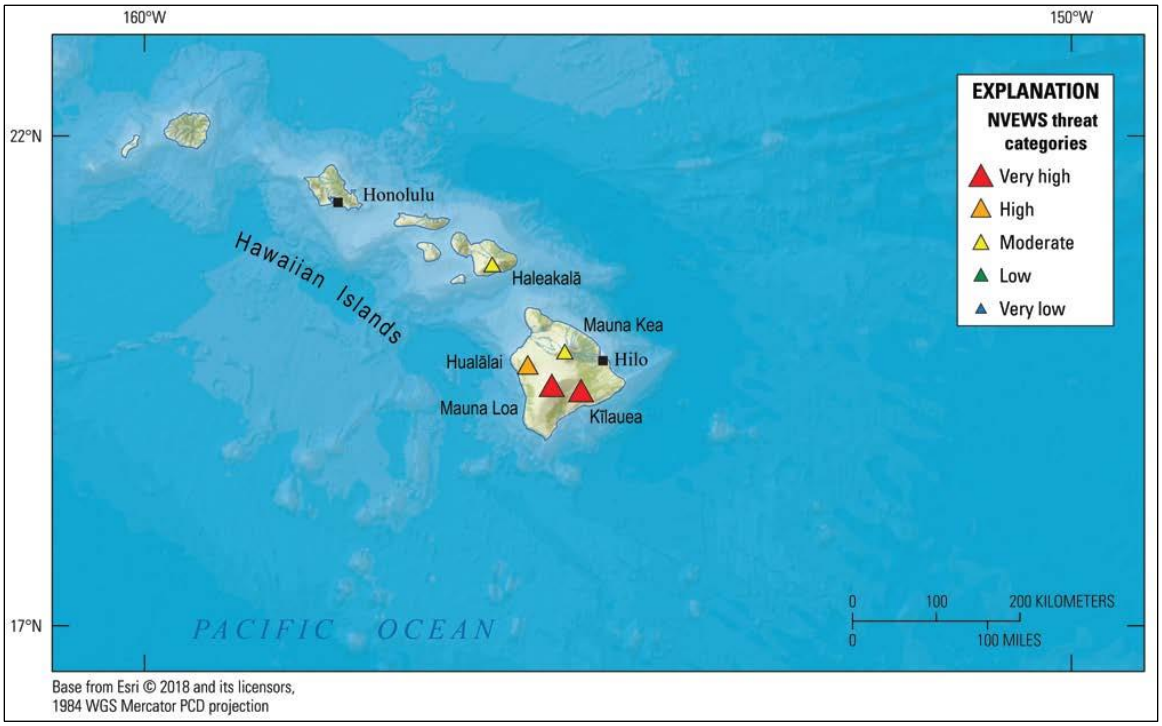
[13] International Volcanic Health Hazard Network (IVHHN), "Hawaii Interagency Vog Information Dashboard," https://vog.ivhhn.org/.

[14] 43 U.S.C. 31k.

[15] According to HVO, Hawaii has six volcanoes that have been active (i.e., had eruptive episodes) within the past 11,000 years. USGS, "Hawaiian Volcano Observatory," https://www.usgs.gov/observatories/hvo. See also footnote 1.

[16] USGS, "Kama'ehuakanaloa," https://www.usgs.gov/volcanoes/kama%E2%80%98ehuakanaloa. A *submarine volcano* (also known as a *seamount*) is completely underwater and forms on the seafloor.

Figure 1. USGS Threat Assessment of Five Active Volcanoes in Hawaii



Source: John W. Ewert et al., *2018 Update to the U.S. Geological Survey National Volcanic Threat Assessment*, U.S. Geological Survey (USGS), Scientific Investigations Report 2018-5140, 2018, https://doi.org/10.3133/sir20185140. Map from USGS and Esri.

Notes: Triangles with different colors and sizes denote the location and threat level of five volcanoes in Hawaii (see legend). The USGS uses 24 volcanic hazard factors, including the potential exposure of people and property, to determine each volcano's threat level.

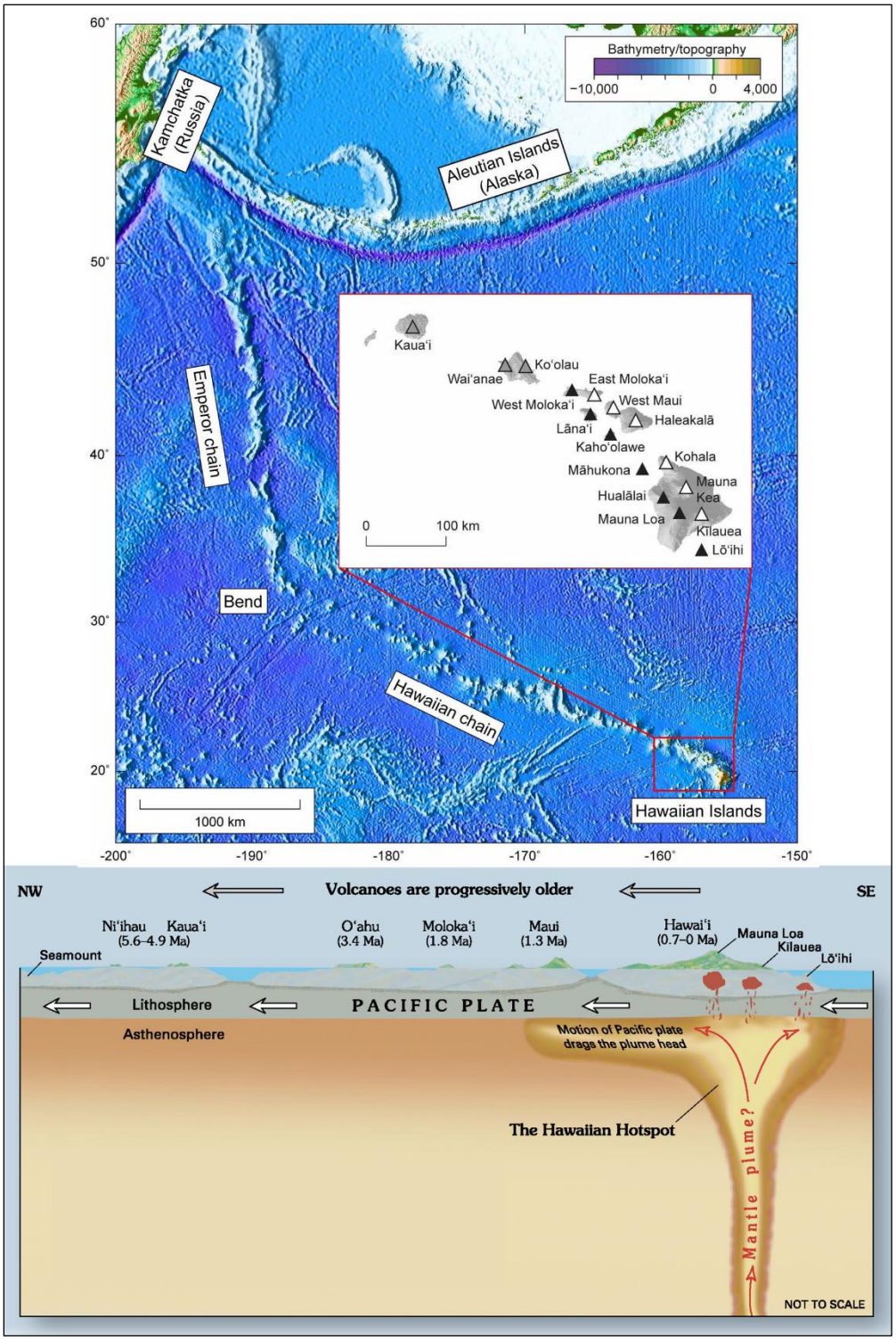
The Hawaiian Islands are of volcanic origin, and each island comprises one or more volcanoes (**Figure 2**).[17] The island of Hawai'i has four threatening volcanoes (Mauna Kea, Hualālai, Mauna Loa, and Kīlauea), and these are the youngest and most active volcanoes of the Hawaiian chain.[18] The island of Maui has one active and threatening volcano, Haleakalā, which last erupted about 400 years ago and has had at least 10 documented eruptions in the past 1,000 years. The volcanoes formed over time from the Hawaiian hot spot plume, or a plume of hot material, rising from deep within the Earth. Heat from the Hawaiian hot spot partially melts mantle rock at depths starting about 200-400 kilometers (125-250 miles) below Earth's surface. This melting produces magma that rises upward through the overlying Pacific plate. As the plate moves west-northwest, each volcano that formed on the plate moves with it and stops growing as it moves away from the hot spot plume.[19] The age and orientation of the volcano island chain record the Pacific plate's direction and rate of movement over time.

[17] USGS, "Evolution of Hawaiian Volcanoes," https://www.usgs.gov/observatories/hvo/evolution-hawaiian-volcanoes.

[18] USGS, "Active Volcanoes of Hawaii," https://www.usgs.gov/observatories/hvo/active-volcanoes-hawaii.

[19] The Pacific plate is moving to the west-northwest at a speed of between 7 and 11 centimeters (cm), or approximately 3-4 inches, a year. Pacific Northwest Seismic Network, "Plate Tectonics," https://pnsn.org/outreach/about-earthquakes/plate-tectonics.

Figure 2. Emperor-Hawaiian Chain and Hot Spot Plume Model



Sources: Top panel: U.S. Geological Survey (USGS), Hawaiian Volcano Observatory, "Volcano Watch—Exploring the Deep Source of Hawaiian Volcanoes," https://www.usgs.gov/observatories/hvo/news/volcano-watch-exploring-deep-source-hawaiian-volcanoes. Bottom panel: USGS, "Geologic Investigations Map I-2800: This Dynamic Planet," https://pubs.usgs.gov/imap/2800/.

Notes: Bathymetry, which is the measurement of the depth of water or the underwater equivalent of topography, and topography in map legend given in meters. Ma = millions of years ago. The Emperor chain consists of extinct volcanoes that are below the water surface, called *seamounts*. The Hawaiian chain consists of seamounts and *subaerial volcanoes* (i.e., volcanoes that exist on land rather than underwater). Most of the subaerial volcanoes are part of the Hawaiian Islands. In the upper panel, the triangles denote the approximate location of each volcano, and the different shades of white, gray, and black denote slightly different chemical compositions of the lava. The lower panel is a schematic cross section of the Hawaiian hot spot plume, showing the rise of hot material from deep in the Earth and the formation of volcanoes on the Pacific plate. The Pacific plate moves, and a new volcano begins to form over the hot spot in an assembly-line-like fashion. The plume and plate motion form the chain of seamounts and volcanoes seen on the map in the upper panel.

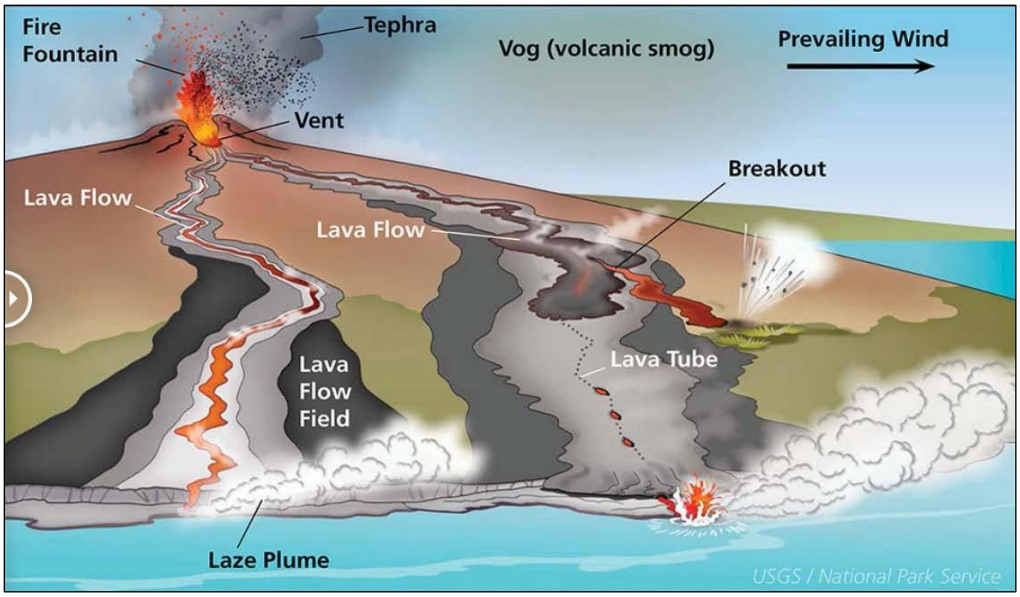
Hawaiian Volcanic Risks

Hawaii's volcanoes are categorized as *shield volcanoes*, and people and property near a shield volcano face the greatest risks from lava flows, volcanic bombs, and volcanic gases (**Figure 3** and **Appendix B**). A shield volcano forms a broad shield-shaped (i.e., greater width than height) mountain over time from successive effusive eruptions of lava, mostly basalt, composed of mostly low-silica magmas (**Appendix B**).[20] As a shield volcano grows, it may accommodate its growth (i.e., adding mass, spreading, and widening) by forming *rift zones* (or *fissures*), which are zones of weakness where magma may flow and may erupt to the surface through fissures, cracks, vents, craters, cones, fumaroles, and other openings (**Figure 4** and **Appendix B**). Most eruptive activity starts at the summit or along the rift zones of a shield volcano. Mauna Loa and Kīlauea, the two most active Hawaiian volcanoes, feature two major rift zones each branching away from the summit of the volcano (**Figure 4**).[21]

[20] Low-silica magmas (silica is silicon dioxide, which in crystal form is the mineral quartz) tend to have less gas and be less explosive than high-silica magmas. Low-silica lavas tend to flow slowly away from an eruptive center and form low-silica rocks, such as basalts and andesites upon cooling (**Appendix B**). National Park Service (NPS), "Shield Volcanoes," https://www.nps.gov/articles/000/shield-volcanoes.htm; USGS, "How Big Are the Hawaiian Volcanoes?" https://www.usgs.gov/faqs/how-big-are-hawaiian-volcanoes.

[21] Kīlauea's two rift zones are oriented parallel to its mobile southern flank, because Kīlauea is growing and is buttressed against Mauna Loa on its northern flank. NPS, "Shield Volcanoes," https://www.nps.gov/articles/000/shield-volcanoes.htm.

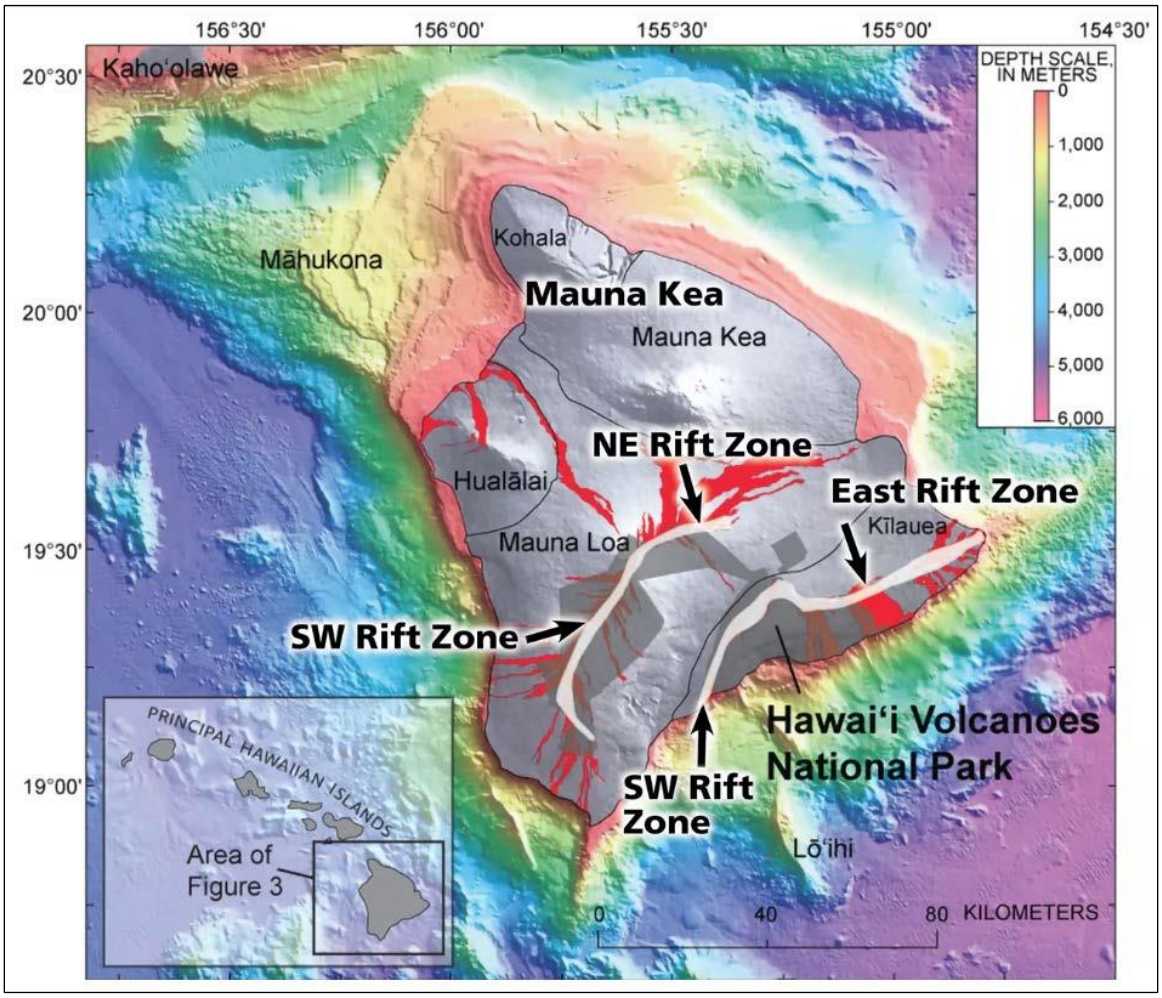
Figure 3. Schematic of Volcanic Hazards from Hawaii's Shield Volcanoes



Source: National Park Service/U.S. Geological Survey, "Shield Volcanoes," https://www.nps.gov/articles/000/shield-volcanoes.htm.

Notes: A fully formed shield volcano has gentle slopes, is much wider than it is tall, and resembles the shape of a shield. The schematic shows volcanic hazards, including hazards created when volcanic activity meets ocean water. See **Appendix B** for a description of these hazards. Not shown are other hazards from earthquakes, landslides, and tsunamis that are related to volcanic activity and volcanic growth.

Figure 4.Volcanoes on the Island of Hawai'i



Source: National Park Service, "Shield Volcanoes," at https://www.nps.gov/articles/000/shield-volcanoes.htm.

Notes: Map showing the topography (gray shaded relief) and bathymetry (colors, see legend) as well as the five subaerial volcanoes and one submarine volcano (labeled) that comprise the island of Hawai'i. The red and orange shaded regions on the island are individual lava flows from Kīlauea, Mauna Loa, or Hualālai volcanoes. The approximate location of the rift zones (labeled) of Mauna Loa and Kīlauea are traced by white bands on the map. Most eruptive activity starts at the summit or along the rift zones. Hawai'i Volcanoes National Park is shown by the dark gray shaded area. The park includes the summits and parts of the rift zones of Mauna Loa and Kīlauea. SW = southwest; NE = northeast. Thin black lines denote the boundaries of each volcano. See also U.S. Geological Survey, "Hawaii's Volcanoes Revealed," https://pubs.usgs.gov/imap/2809/.

In addition to these volcanic hazards, growing and active volcanoes may cause earthquakes, landslides, and tsunamis, which may pose a risk to people and property.[22] **Figure 5** shows historic earthquakes with a magnitude 6 or greater on the island of Hawai'i during the 19th and 20th centuries.[23] **Figure 6** shows the USGS-estimated seismic hazard for Hawaii with the estimated

[22] HVO, "Hazards," https://www.usgs.gov/observatories/hvo/science/hazards. Earthquakes, landslides, and tsunamis in Hawaii may have other sources besides volcanic activity in Hawaii. For example, severe weather may cause a landslide, and an earthquake in Alaska may cause a tsunami in Hawaii. Earthquakes in Hawaii may be volcanic (i.e., related to magma, fluid, or gas movement) or tectonic (i.e., related to ground movement along faults or landslides).

[23] Magnitude refers to the size of an earthquake and is expressed in whole numbers and decimal fractions. There are (continued...)

exposed population density.[24] **Figure 7** shows some submarine landslides around Hawaii caused by eruptions, earthquakes, or erosion.[25] Some of these landslides may generate tsunamis. Hawaii's active volcanoes have added risks from volcanic activity that intersects with the Pacific Ocean, such as laze plumes and tsunamis (**Figure 9** and **Appendix B**). In Kīlauea's recorded history, most of the fatalities and injuries were related to a 1790 explosive eruption from Halema'uma'u crater and an 1868 earthquake that generated landslides and tsunamis.[26]

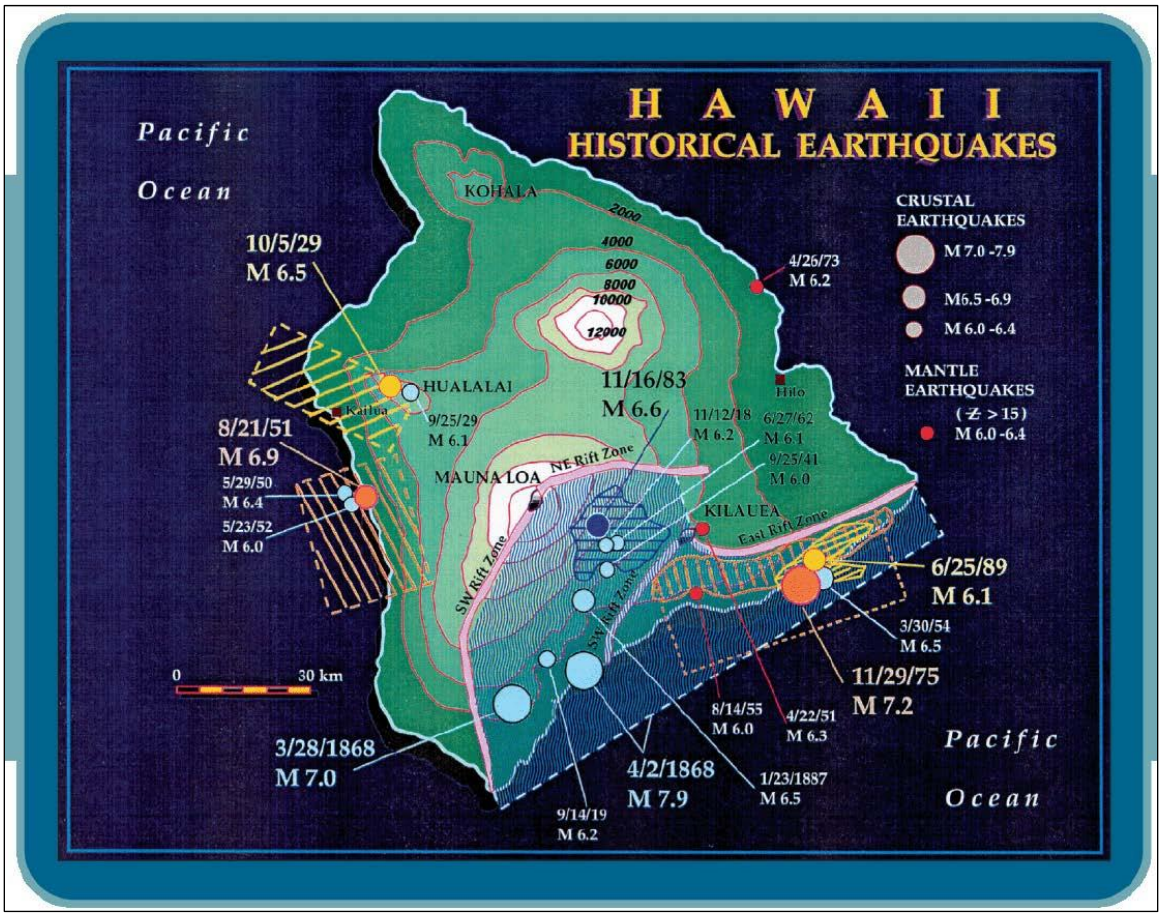
different magnitude scales. USGS, "Earthquake Magnitude, Energy Release, and Shaking Intensity," https://www.usgs.gov/programs/earthquake-hazards/earthquake-magnitude-energy-release-and-shaking-intensity.

[24] For more information about the USGS Earthquake Hazards Program that is responsible for U.S. Seismic Hazard Assessments, see CRS Report R43141, *The National Earthquake Hazards Reduction Program (NEHRP): Overview and Issues for Congress*, by Linda R. Rowan.

[25] For more information about the USGS Landslide Hazards Program, which supports landslide research and monitoring in the United States, see CRS Report R47588, *Landslides: Federal Role in Research, Assessment, and Response*, by Linda R. Rowan.

[26] USGS, HVO, "Volcano Watch: Kīlauea: Nation's Most Deadly Volcano," https://www.usgs.gov/news/volcano-watch-kilauea-nations-most-deadly-volcano; USGS, HVO, "Volcano Watch: The Threat of Tsunamis," https://www.usgs.gov/news/volcano-watch-threat-tsunami; USGS, HVO, "Volcano Watch: Volcano Slides Are Often the Cause of Large Earthquakes," https://www.usgs.gov/news/volcano-watch-volcano-slides-are-often-cause-strong-earthquakes.

Figure 5. Earthquakes on the Island of Hawai'i with a Magnitude of 6+ During the 19th and 20st Centuries

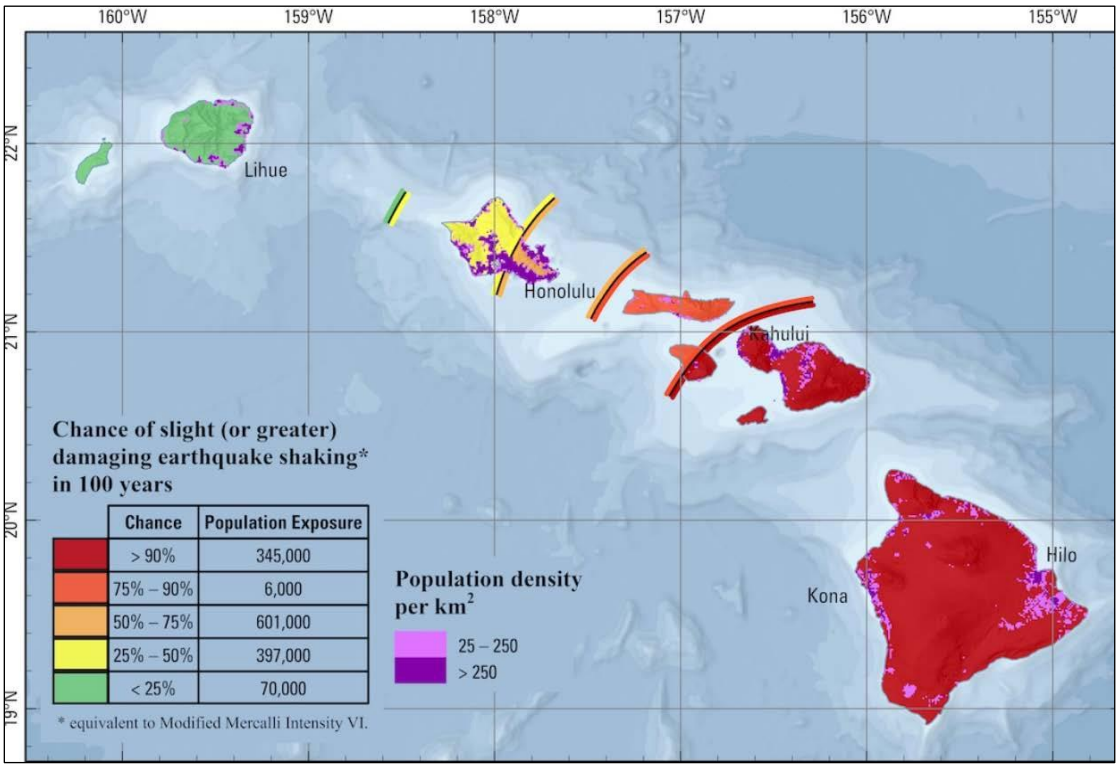


Source: County of Hawai'i, *Earthquake Hazards and Estimates in the County of Hawaii*, February 2005, https://www.nehrp.gov/pdf/earthquake_hazards_hawaii.pdf.

Notes: Map shows earthquakes of magnitude (M) 6.0 or larger in the 19th and 20th centuries. Dates given in month/day/year format. All double-digit years are in the 20th century. Magnitudes and earthquake locations are estimated for events that occurred before a seismic network was deployed to record earthquakes. Magnitudes and locations for events observed by a seismic network are calculated based on the type of seismic instruments in use at the time. Shaded areas show the extent of the rupture for select earthquakes. See Fred W. Klein et al., "Seismic Hazard in Hawaii: High Rate of Large Earthquakes and Probabilistic Ground-Motion Maps," *Bulletin of the Seismological Society of America*, vol. 91, no. 3 (June 2001), pp. 479-498 for more information about magnitude estimates and calculations. In the 21st century, damaging ground shaking has occurred from two M 6.7+ earthquakes, one in 2006 and one in 2018; an M 5.2 earthquake on July 5, 2021; and an M 6.2 earthquake on October 10, 2021. These 21st-century earthquakes were associated with Kīlauea volcanic activity and volcanic growth. Data on 21st-century earthquakes from the U.S. Geological Survey, "ANSS Comprehensive Earthquake Catalog (ComCat)," https://earthquake.usgs.gov/data/comcat/.

Figure 6. USGS Seismic Hazard Model for Hawaii

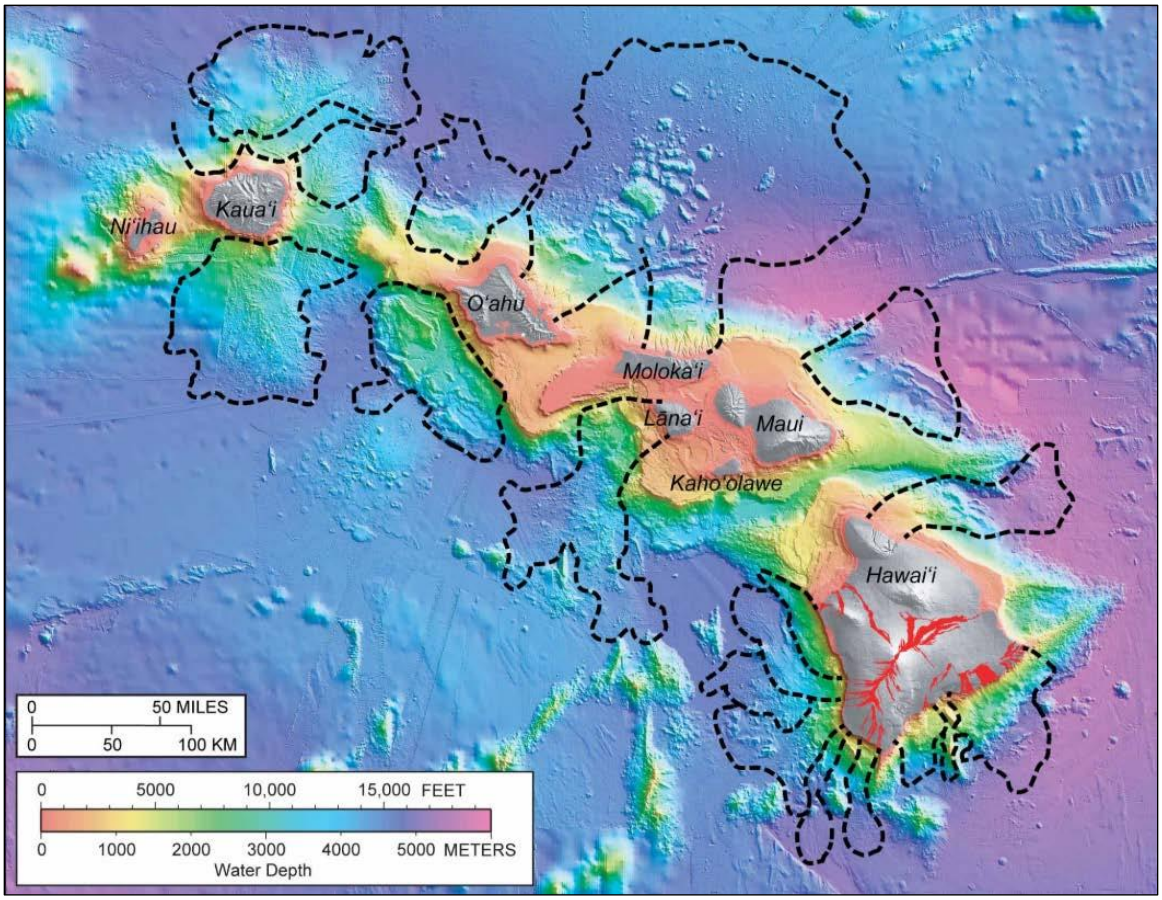
(2021)



Source: Mark D. Petersen et al., "2021 U.S. National Seismic Hazard Model for the State of Hawaii," *Earthquake Spectra*, vol. 38, no. 2 (May 2022), pp. 865-916, https://doi.org/10.1177/87552930211052061.

Notes: Modified Mercalli Intensity VI is strong shaking that is felt by all and causes slight damage. The shaking may be more intense, ranging from very strong (VII) to extreme (X). See USGS, "Modified Mercalli Intensity Scale," https://www.usgs.gov/programs/earthquake-hazards/modified-mercalli-intensity-scale. The population density is given in number of people per square kilometer (km^2).

Figure 7. Some Submarine Landslides in Hawaii



Source: U.S. Geological Survey (USGS), "Black Dashed Lines Delineate 17 Distinct Landslides," https://www.usgs.gov/media/images/black-dashed-lines-delineate-17-distinct-landslides.

Notes: Black dashed lines delineate 17 distinct submarine landslides around Hawaii over the last several million years. Bathymetry of the seafloor shown by colors ranging from pink to purple indicates the water depth around the islands (see legend); shades of gray show land topography above sea level. Red areas on the island of Hawai'i indicate lava flows from eruptions within the past 200 years. See USGS, "Evolution of Hawaiian Volcanoes," https://www.usgs.gov/observatories/hvo/evolution-hawaiian-volcanoes for more details about these landslides.

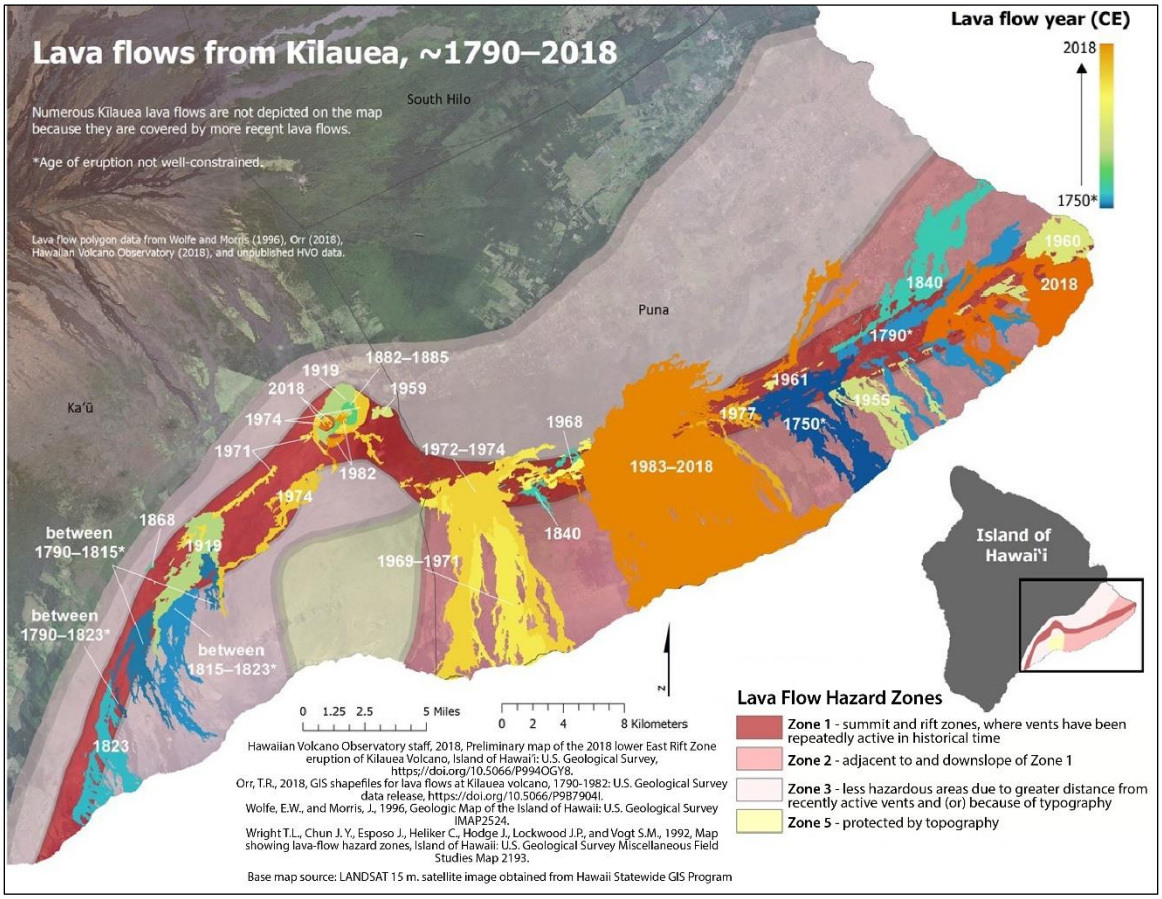
Kīlauea Volcano

Kīlauea is among the most active volcanoes in the world.[27] Since 1952, Kīlauea has erupted dozens of times. From 1983 to 2018, eruptive activity was nearly continuous along the volcano's East Rift Zone (ERZ; **Figure 8**).[28] At the summit, Halema'uma'u crater within the summit caldera hosted an active lava pond and vigorous gas plume from 2008 to 2018. In 2018, the 35 years of continuous activity on the ERZ ended. Additional eruptions and volcanic activity at Kīlauea have occurred over short (hours to days) to long (days to weeks) periods since 2018. Since December 23, 2024, eruptive episodes have been intermittently active within Halema'uma'u crater.

[27] USGS, "Kīlauea," https://www.usgs.gov/volcanoes/kilauea.

[28] Also see **Figure 4** and **Appendix B**.

Figure 8. Lava Flows from Kīlauea Volcano, 1750 to 2018



Source: National Park Service (NPS), "Shield Volcanoes," at https://www.nps.gov/articles/000/shield-volcanoes.htm.

Notes: NPS modified the map and figure using data from the U.S. Geological Survey (USGS), as listed on the figure. Lava flow hazard zones are from the USGS, "Map Showing Lava-Flow Hazard Zones, Island of Hawaii," https://pubs.usgs.gov/mf/1992/2193/. The hazard flow zones are approximate and gradational, not distinct as displayed on the map.

The most recent damaging volcanic event was the 2018 Kīlauea eruption (**Figure 9** and **Figure 10**).[29] From May through August 2018, large lava flows covered land southeast of the Hawai'i Volcanoes National Park (HAVO) on the easternmost part of the ERZ, destroying more than 700 homes and devastating residential areas in the Puna District (**Appendix C** lists some damage and economic losses tabulated by the County of Hawai'i).[30] There were no fatalities. Twenty-three people were injured on a boat that was hit by a volcanic bomb during the 2018 Kīlauea eruption (**Figure 9**), and a volcanic bomb from a lava flow from fissure 17 (**Figure 10**) reportedly caused

[29] USGS, "2018 Lower East Rift Zone Eruption and Summit Collapse at Kīlauea," https://www.usgs.gov/volcanoes/kilauea/science/2018-lower-east-rift-zone-eruption-and-summit-collapse-kilauea.

[30] Hawaii Volcanoes National Park, "Kīlauea Eruption," https://www.nps.gov/havo/learn/nature/2018-eruption.htm. Hawaii County, "Kīlauea Eruption," https://recovery.hawaiicounty.gov/resources/2018-eruption#:~:text=Summary,of%20lava%20erupted%20through%20August. Elinor S. Meredith et al., "Damage Assessment for the 2018 Lower East Rift Zone Lava Flows of Kīlauea Volcano, Hawai'i," *Bulletin of Volcanology*, vol. 84, no. 65 (2022), https://doi.org/10.1007/s00445-022-01568-2; Kyle R. Anderson et al., "The 2018 Eruption of Kīlauea: Insights, Puzzles, and Opportunities for Volcano Science," *Annual Review of Earth and Planetary Sciences*, vol. 52 (2023), https://doi.org/10.1146/annurev-earth-031621-075925.

one injury in Leilani Estates.[31] In addition, the Puna Geothermal Venture's 38 megawatt Puna power plant, which is about 15 miles from Kīlauea's summit and supplied about 29% of the island's electricity before the eruption, was shut down and damaged by the volcanic event. On May 9, 2018, then-Governor David Ige issued an emergency declaration for the Puna power plant to remove 60,000 gallons of pentane, a highly flammable gas used in geothermal operations.[32] Operators had to shut down power generation by quenching 10 of 11 geothermal wells with water, and they plugged one well to prevent further damage and gas releases. Lava inundated part of the plant, covered and damaged two capped wellheads and other infrastructure, and eventually completely surrounded the plant. Repairs were required to reaccess the plant after the eruption.[33]

[31] Hawaii Department of Natural Resources, "07/16/18—Ocean Lava Explosion Injures 23 Passengers on Tour Boat; State and Federal Investigation Underway," https://dlnr.hawaii.gov/blog/2018/07/16/nr18-140/; Mark Strassman, "Man Says Lava Bomb from Hawaii Volcano 'Snapped' His Leg in Half," CBS News, May 23, 2018, https://www.cbsnews.com/news/hawaii-kilauea-volcano-lava-bomb-injury-darryl-clinton/.

[32] Hawai'i Groundwater and Geothermal Resources Center, "Gov. Ige: Pentane Will Be Removed from Puna Geothermal Venture," https://www.higp.hawaii.edu/hggrc/gov-ige-pentane-will-be-removed-from-puna-geothermal-venture/.

[33] Puna Geothermal Venture, "Community," at https://punageothermalproject.com/; Ormat, "Ormat Provides an Update on the Puna Power Plant in Hawaii Following the Kīlauea Volcanic Eruption," https://investor.ormat.com/news-events/news/news-details/2018/Ormat-Provides-an-Update-on-the-Puna-Power-Plant-in-Hawaii-Following-the-Kilauea-Volcanic-Eruption-05ac629ba/default.aspx; U.S. Energy Information Administration, "Volcanic Lava Flows Continue to Affect Geothermal Power Generation on Hawaii's Big Island," https://www.eia.gov/todayinenergy/detail.php?id=36672.

Figure 9. Volcanic Hazards from Kīlauea Eruptions

Sources: (a) U.S. Geological Survey (USGS), "Helicopter Overflight of Kīlauea's LERZ on May 19, 2018, around 8:1 ...", https://www.usgs.gov/media/images/helicopter-overflight-kilaueas-lerz-may-19-2018-around-81. (b) USGS, Hawaiian Volcano Observatory, "Volcano Watch—New Insights Gained from Kīlauea Volcano's 2018 Summit Collapses," https://www.usgs.gov/news/volcano-watch-new-insights-gained-kilauea-volcanos-2018-summit-collapses. (c) National Park Service, "September 2023 Summit Eruption," https://www.nps.gov/havo/learn/nature/september-2023-summit-eruption.htm. (d) Hawaii Department of Natural Resources, https://dlnr.hawaii.gov/blog/2018/07/16/nr18-140/.

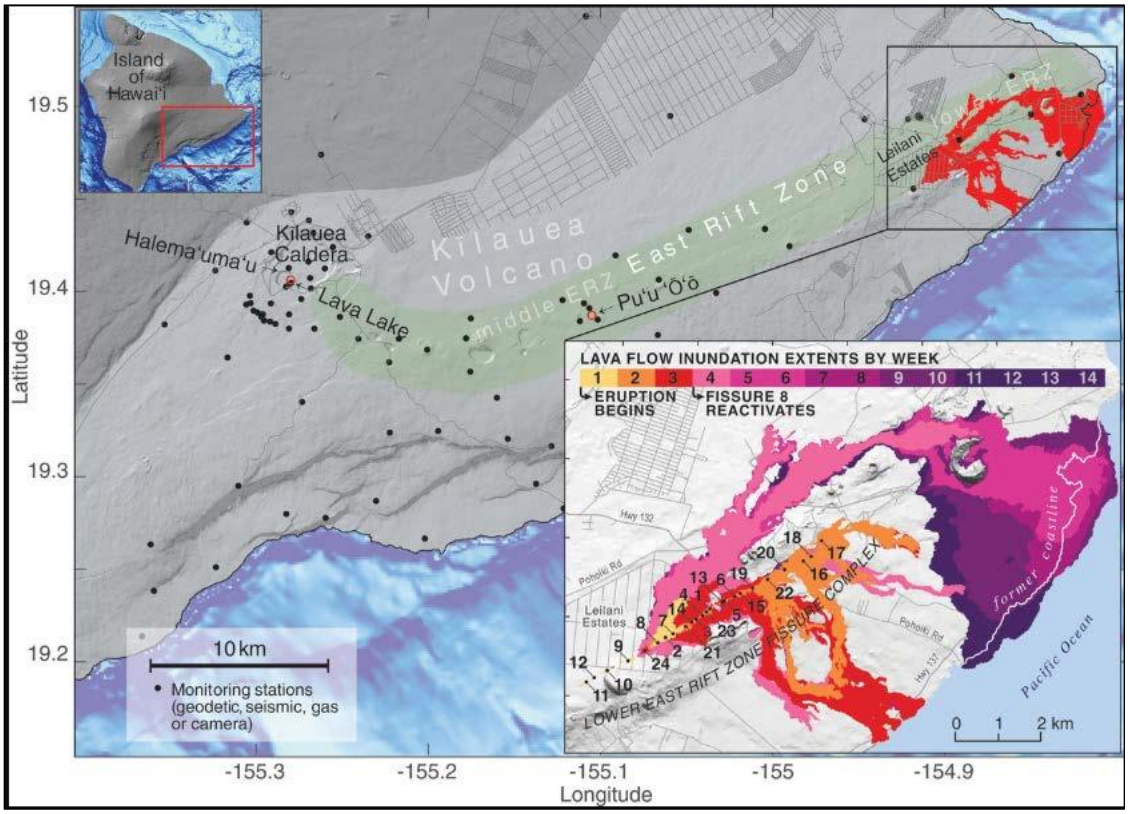
Notes: (a) Aerial photograph of lava flows emerging from the elongated fissure that damaged property and infrastructure in the Puna District. The flow direction in this photograph is from upper center to the lower left. Photograph taken during a helicopter overflight of Kīlauea Volcano's lower East Rift Zone on May 19, 2018,

around 8:18 am, Hawaii Standard Time (HST). (b) Photograph of ash that exploded from Halema'uma'u crater on May 27, 2018. (c) Aerial photograph of a volcanic gas-rich plume that created damaging volcanic smog (i.e., vog) moving away from the floor of Halema'uma'u crater, Kīlauea, on September 14, 2023. (d) Photograph shows some of the damage to the metal roof of a vessel caused by a volcanic bomb. Twenty-three people on a Lava Ocean Tours vessel were injured shortly after 6 a.m. HST on July 16, 2018, when a volcanic bomb crashed through the metal roof of the vessel near the coast of Kīlauea volcano. See **Appendix B** for descriptions of volcanic terms.

In addition to damage to communities near the volcanic activity, the 2018 eruption caused many changes to Kīlauea volcano that may impact natural resources and land management, visitors, and local communities. The summit area of Kīlauea was dramatically changed by tens of thousands of earthquakes, towering ash plumes (**Figure 9**), and a massive collapse of the summit caldera (**Figure 11**; note the Halema'uma'u crater is a smaller pit crater within the larger caldera, **Appendix B**). According to the USGS, 13.7 square miles of land were inundated by lava (lava thickness varies across the area, up to 30-80 feet thick in some places), 875 acres of new land were created at the coastline (**Figure 10**), about 30 miles of roads were covered by lava, about 1 billion cubic yards of lava erupted (enough to fill at least 320,000 Olympic-size swimming pools), and about 60,000 earthquakes were recorded from April 30 to August 4, 2018 (4,400 were magnitude 3 and higher, and the largest, at magnitude 6.9, occurred on May 4, 2018).[34]

[34] NPS/USGS, "Preliminary Summary of Kīlauea Volcano's 2018 Lower East Rift Zone Eruption and Summit Collapse," https://www.nps.gov/havo/planyourvisit/upload/PrelimSum_LERZ-Summit_2018_508.pdf; USGS, HVO, "Volcano Watch: The 2018 Eruption of Kīlauea Was Big on a Global Scale," https://www.usgs.gov/observatories/hvo/news/volcano-watch-2018-eruption-kilauea-was-big-global-scale.

Figure 10. 2018 Kīlauea Eruption: Map of Part of Volcano and Lava Flows



Source: Christina A. Neal et al., "The 2018 Rift Zone Eruption and Summit Collapse of Kīlauea Volcano," *Science*, vol. 363, no. 6425 (January 2019), pp. 367-374, https://www.science.org/doi/10.1126/science.aav7046.

Notes: The light gray lines are roads, and the white irregular line on the inset map denotes the former coastline before it was inundated with lava. The 2018 eruption created 875 acres of new land, as shown in the inset map. The numbers pointing to black dots on the inset map denote individual fissures where eruptive activity occurred.

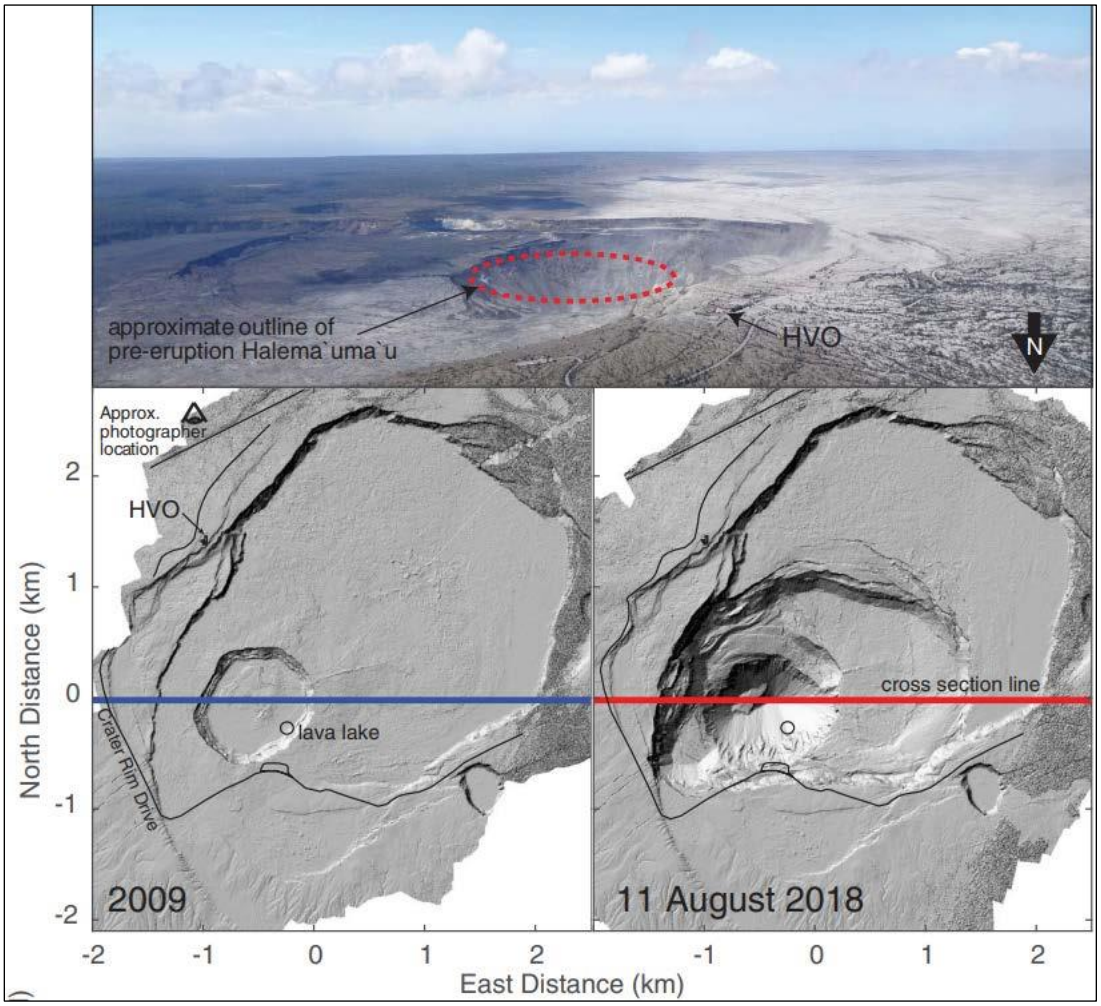
The 2018 eruptive events also damaged federal facilities. The USGS HVO facilities at the summit caldera of Kīlauea volcano were damaged beyond repair (**Figure 11**).[35] The USGS is building a new research facility at the University of Hawai'i at Hilo; constructing a new field station on Kīlauea summit in HAVO; and repairing, hardening, and adding monitoring instruments, communications, and power to its monitoring network on Kīlauea.[36] HAVO was closed to the public on May 11, 2018, and partially reopened on September 22, 2018. NPS is still repairing facilities and infrastructure damaged by the 2018 Kīlauea eruption within the park (**Figure 12**).[37]

[35] USGS, HVO, "Volcano Watch: HVO's Ongoing Recovery from the 2018 Kīlauea Eruption," https://www.usgs.gov/volcanoes/kilauea/news/volcano-watch-hvos-ongoing-recovery-2018-kilauea-eruption.

[36] USGS, "2019 Disaster Relief Act: USGS Recovery Activities," Fact Sheet 2019-3066, October 2019, https://pubs.usgs.gov/fs/2019/3066/fs20193066.pdf.

[37] NPS, "Recovery of Hawai'i Volcanoes National Park," at https://www.nps.gov/havo/recovery.htm.

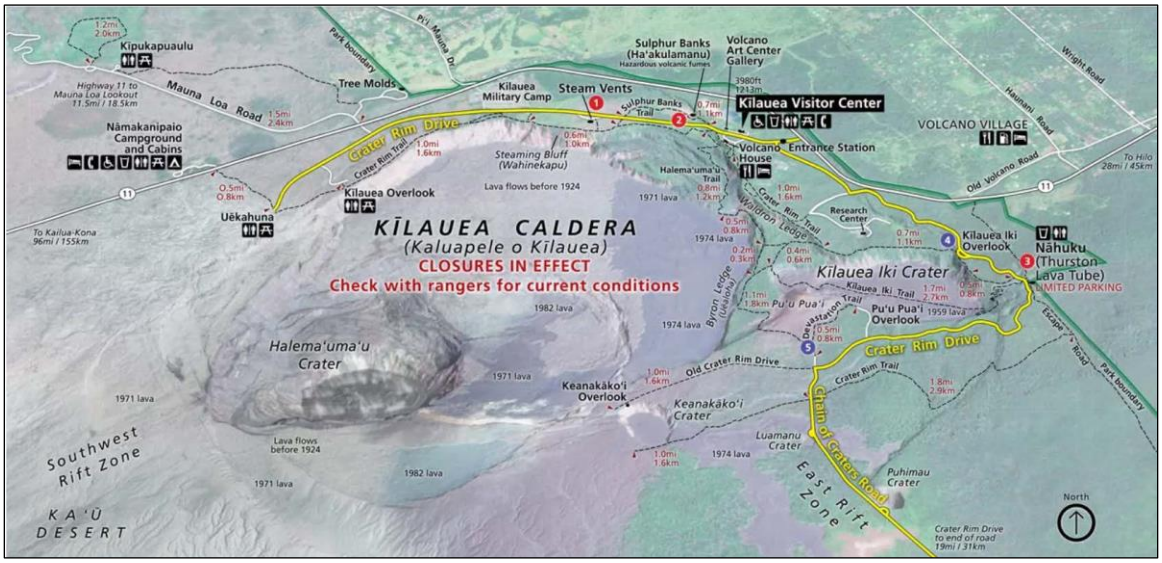
Figure 11. 2018 Summit Collapse at Kīlauea Volcano



Source: Christina A. Neal et al., "The 2018 Rift Zone Eruption and Summit Collapse of Kīlauea Volcano," *Science,* vol. 363, no. 6425 (January 2019), pp. 367-374, https://www.science.org/doi/10.1126/science.aav7046.

Notes: Top: Aerial photograph of the summit caldera was taken northwest of the caldera looking to the southeast after the collapse. Bottom: Light detection and ranging (lidar) images for digital elevation models of Kīlauea's summit from 2009 and from August 11, 2018, showing the collapse of the caldera. Black lines indicate roads; the locations of the Hawaiian Volcano Observatory (HVO) facilities and former lava lake are indicated. The red and blue lines correspond to the locations of cross sections for depth measurements. Along the red line, the crater deepened by as much as 500 meters (about 1,640 feet).

Figure 12. Hawai'i Volcanoes National Park, Kīlauea Summit Map



Source: National Park Service (NPS), "Recovery of Hawai'i Volcanoes National Park," at https://www.nps.gov/havo/recovery.htm.

Notes: Areas that remain closed indefinitely include 'Iliahi Trail (not shown on map) and Halema'uma'u Trail (partially shown on map) that use to traverse part of the caldera floor, Crater Rim Drive beyond Uēkahuna, and the Jaggar Museum (not shown on map). NPS may update park information as conditions change. U.S. Geological Survey, "Kīlauea Volcano Updates," https://www.usgs.gov/volcanoes/kilauea/volcano-updates. Accessed information and map on April 7, 2025.

Mauna Loa Volcano

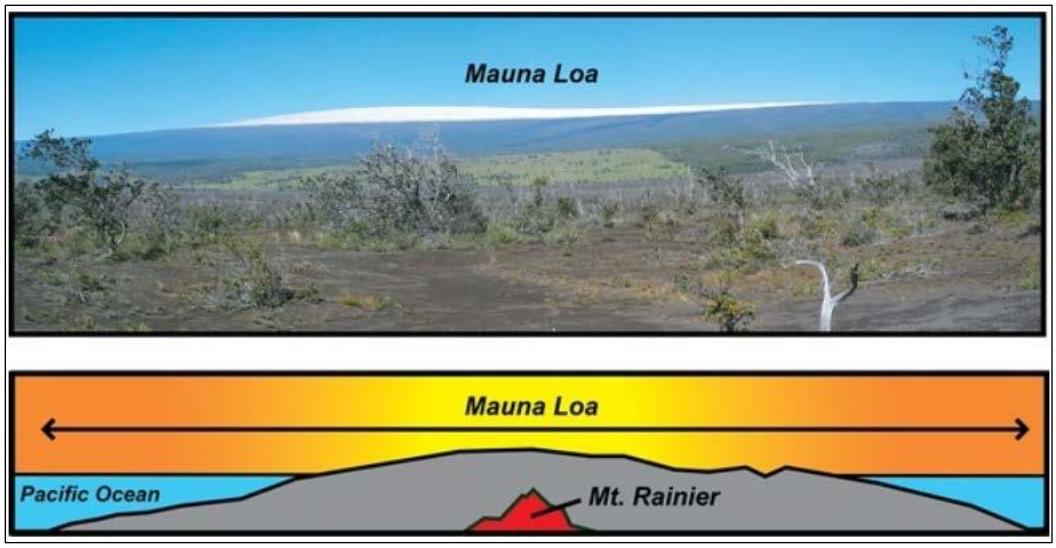
Mauna Loa is among the largest and most active volcanoes on Earth.[38] The volcanic mass rises 17 kilometers (about 10.5 miles) from the seafloor, and the subaerial part of the volcano is about 120 kilometers (about 74.5 miles) wide, covering roughly half the island of Hawai'i (**Figure 4** and **Figure 13**). Mauna Loa has erupted 34 times since 1843, and its volcanic hazards threaten people and property on the island of Hawai'i (**Figure 14**). The 2022 Mauna Loa eruption caused some damage, including to NOAA's Mauna Loa Observatory.[39] **Figure 14** shows the amount of time it may take lava flows to reach different populated areas, ranging from hours to weeks. According to the USGS, research, monitoring, and warning to identify volcanic hazards such as lava flows may help ensure timely response by authorities to reduce volcanic risks to people and property.[40]

[38] USGS, "Frequently Asked Questions About Mauna Loa Volcano," https://www.usgs.gov/volcanoes/mauna-loa/frequently-asked-questions-about-mauna-loa-volcano#.

[39] CRS Insight IN12059, *Mauna Loa Eruption*, by Linda R. Rowan; and USGS, "November 27–December 10, 2022 Eruption of Mauna Loa," at https://www.usgs.gov/volcanoes/mauna-loa/science/november-27-december-10-2022-eruption-mauna-loa. See also NOAA, "Global Monitoring Laboratory," https://gml.noaa.gov/obop/mlo/.

[40] USGS, *Island of Hawai'i Interagency Operations Plan for Volcanic Eruptions*, July 2024, https://www.usgs.gov/programs/VHP/coordination-plans (hereinafter, USGS, *Island of Hawai'i Interagency Plan*, 2024).

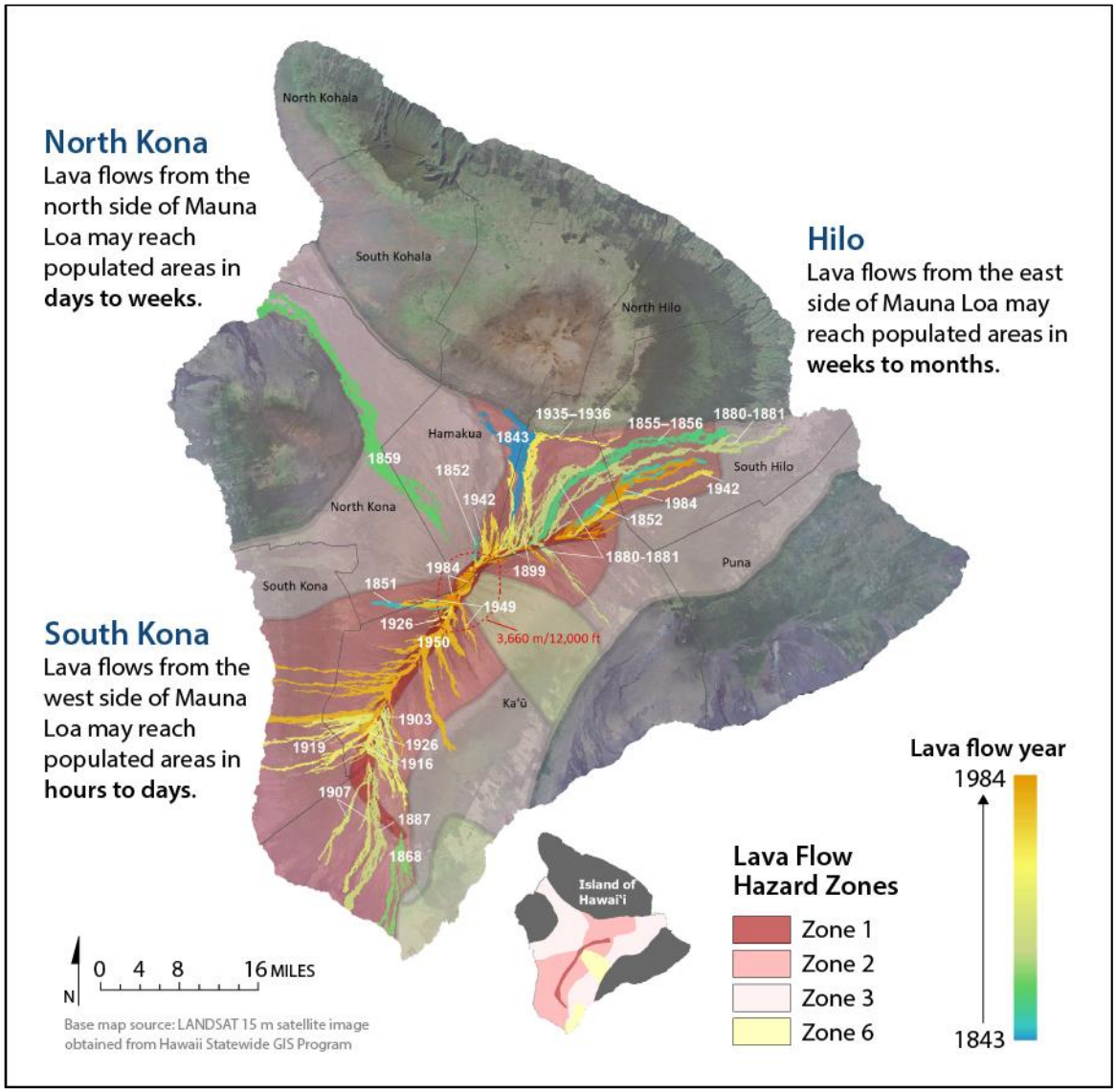
Figure 13. Mauna Loa Shield Volcano: Photograph and Graphic



Source: National Park Service, "Shield Volcanoes," at https://www.nps.gov/articles/000/shield-volcanoes.htm. Photograph by U. S. Geological Survey, "Snow Adorns the Upper 1.5 km (5,000 ft) of Mauna Loa Volcano," https://www.usgs.gov/media/images/snow-adorns-upper-15-km-5000-ft-mauna-loa-volcano. Graphic modified from Rebecca H. Ashton, "A Dynamic Landscape Formed by the Power of Volcanoes" (master's thesis, Oregon State University, 2003).

Notes: Shield volcanoes are much wider than they are tall. Mauna Loa rises 17 kilometers (about 10.5 miles) from the seafloor (the subaerial part of Mauna Loa rises about 13,680 feet above sea level). Mauna Loa's base on the seafloor is about 160 kilometers (100 miles) wide, and the subaerial part of the volcano is about 120 kilometers (about 74.5 miles) wide, covering about half of the island of Hawai'i. For comparison, Mount Rainier, the tallest stratovolcano in the contiguous United States, rises about 4.3 kilometers (2.7 miles or 14,410 feet) above sea level and is about 16 kilometers (10 miles) wide. See **Appendix B** for definitions of volcano types.

Figure 14. Mauna Loa Lava Flow Hazards



Source: U.S. Geological Survey, "Geology and History of Mauna Loa," https://www.usgs.gov/volcanoes/mauna-loa/science/geology-and-history-mauna-loa.

Notes: The lava flow hazard zones displayed on the figure and listed in the legend include Zone 1 (most hazardous)—the summit and rift zones, where lava and volcanic gases have repeatedly erupted; Zone 2 (hazardous)—slopes of the volcano adjacent to the summit and rift zones, where recorded lava flows have repeatedly flowed downslope; Zone 3 (less hazardous)—less likely to have lava flows because of greater distance from the summit and rift zones or because the topography does not allow easy downslope flow; and Zone 6 (no hazard)—protected from lava flows by topographic features or barriers. The dashed red circle around the summit is the 12,000-foot elevation contour. Historic lava flows from eruptions between 1843 and 1984 are displayed in colors, with blue-to-green shades being the oldest lava flows and yellow-to-orange shades being the youngest lava flows during the time period. See U.S. Geological Survey, "Frequently Asked Questions and Answers About Lava-Flow Hazards," https://www.usgs.gov/observatories/hvo/frequently-asked-questions-and-answers-about-lava-flow-hazards, for a complete lava flow hazard map for the island of Hawai'i that includes Zones 4 and 5, which cover other areas of the island but not Mauna Loa.

National Volcano Early Warning and Monitoring System

In 2019, Congress passed legislation that authorized a National Volcano Early Warning and Monitoring System (NVEWS; §5001 of P.L. 116-9; 43 U.S.C. 31k).[41] The law directed the USGS to establish NVEWS to monitor volcanoes, warn U.S. citizens of volcanic activity, and protect citizens from "undue and avoidable harm."[42] In addition, under the Robert T. Stafford Disaster Relief and Emergency Assistance Act (42 U.S.C. §5132), the USGS may provide alerts and other technical assistance about volcanoes using federal and other communication services to states and civilian populations in endangered areas. The 2019 law specifies that the system's objective is to monitor U.S. volcanoes at a level commensurate with the volcanic threats. NVEWS has two purposes: (1) organize, modernize, standardize, and stabilize the monitoring systems of the five U.S. volcano observatories, and (2) unify the monitoring systems of these observatories into a single interoperative system.[43]

The USGS has published various reports and plans about NVEWS. The agency submitted a five-year plan for establishing and managing NVEWS to Congress in 2020, annual reports to Congress charting the progress of NVEWS from 2021 to 2024, a recommended monitoring plan in 2024, and the *Volcano Science Center Response Plan for Significant Volcanic Events* in 2024.[44] Through these reports and plans, the USGS has detailed updates to monitoring systems; the establishment of a National Volcano Information System, which is expected to serve the dual purposes of a national volcano data center and a 24/7 volcano watch office; and efforts to establish advisory committees (pursuant to §5001 of P.L. 116-9).[45]

In 2022, Congress passed legislation that amended NVEWS to direct cooperation and coordination between the USGS's and NOAA's volcano monitoring (§10501 of P.L. 117-263). The law directed the Secretary of the Interior and the Secretary of Commerce to develop and execute a memorandum of understanding to establish cooperative support for NVEWS activities with NOAA.[46] The law also directed the Secretary of Commerce to submit cost estimates for

[41] For additional information about NVEWS see CRS In Focus IF11987, *The National Volcano Early Warning and Monitoring System*, by Linda R. Rowan.

[42] USGS, "National Volcano Early Warning System: Monitoring Volcanoes According to Their Threat," https://www.usgs.gov/programs/VHP/national-volcano-early-warning-system-monitoring-volcanoes-according-their-threat.

[43] 43 U.S.C. 31k.

[44] Peter F. Cervelli et al., *Five-Year Management Plan for Establishing and Operating NVEWS: The National Volcano Early Warning System*, USGS Open-File Report 2021–1092, 2021, https://doi.org/10.3133/ofr20211092 (hereinafter USGS, *NVEWS Plan*, 2021). See also Charlie Mandeville et al., *The Volcano Hazards Program—Strategic Science Plan for 2022–2026*, USGS, Circular 1492, 2022, https://doi.org/10.3133/cir1492; Ashton F. Flinders et al., *Recommended Capabilities and Instrumentation for Volcano Monitoring in the United States*, USGS, Scientific Investigations Report 2024-5062, 2024, https://doi.org/10.3133/sir20245062 (hereinafter USGS, *Recommended Monitoring*, 2024); and Seth C. Moran et al., *The U.S. Geological Survey Volcano Science Center Response Plan for Significant Volcanic Events*, USGS, Circular 1518, 2024, https://doi.org/10.3133/cir1518 (hereinafter USGS, *Response for Volcanic Event*, 2024).

[45] USGS, HVO, "Volcano Watch: A Focus on the National Volcano Information System," https://www.usgs.gov/observatories/hvo/news/volcano-watch-a-focus-national-volcano-information-service. Posted by the USGS on April 10, 2025. See also USGS, "National Volcano Early Warning System Advisory Committee," https://www.usgs.gov/programs/VHP/national-volcano-early-warning-system-advisory-committee-nvewsac.

[46] A memorandum of understanding between the USGS and NOAA already exists to collaborate on activities involving physical and biological sciences that the USGS can utilize as needed. Correspondence between CRS and USGS, March (continued...)

NVEWS activities at NOAA to the Secretary of the Interior to be incorporated into the NVEWS management plan. In 2025, NOAA submitted an implementation plan with cost estimates to Congress. The plan aims to focus on seven equal priorities to improve (1) the monitoring and forecasting of vog; (2) operational planning to warn about debris flows/lahars; (3) the quantification of airborne ash hazards for aviation; (4) the quantification of ashfall hazards; (5) near-real-time data sharing; (6) the forecasting of volcanogenic tsunamis and submarine eruptions; and (7) the efficacy of USGS and NOAA hazard information products.[47]

Federal Research, Monitoring, and Warning in Hawaii

The below section summarizes USGS's and NOAA's roles in researching, monitoring, and warning for Hawaii's active volcanoes.

Hawaiian Volcano Observatory

HVO researches, monitors, forecasts, warns about, and seeks to reduce risks from volcanic hazards in Hawaii and American Samoa (**Figure 15**).[48] HVO was founded in 1912 and was the first USGS volcano observatory in the United States.[49] The USGS Volcano Science Center (VSC) manages HVO. HVO also monitors, analyzes, and warns about earthquakes in Hawaii and maintains a seismic network, the Hawaii Integrated Seismic Network (HISN), that is part of the U.S. Advanced National Seismic System (ANSS).[50]

As needed, HVO may involve other USGS VSC staff from volcano observatories in Alaska (AVO), the Cascades (CVO), California (CalVO), and Yellowstone (YVO) or other USGS offices (**Figure 15**).[51] HVO communicates and collaborates with international agencies involved in volcanic hazards, including the International Civil Aviation Organization (ICAO) and the International Volcanic Health Hazard Network (IVHHN).[52] The USGS volcano observatories and NOAA's VAACs are contributing members of ICAO's International Airways Volcano Watch.[53]

31, 2025. See also "MOU GS21000543" in USGS, "List of Memorandums of Understanding (MOUs)," updated August 23, 2023, https://www.usgs.gov/media/files/list-memorandums-understanding-mous.

[47] Kenneth E. Graham et al., *Implementation Plan for the National Oceanic and Atmospheric Administration's Modernization of the National Volcano Early Warning and Monitoring System Pursuant to the National Defense Authorization of Fiscal Year 2023*, NOAA, 2025, pp. 1-19 (hereinafter NOAA, *Implementation Plan*, 2025). For more information about debris flows see CRS Report R47588, *Landslides: Federal Role in Research, Assessment, and Response*, by Linda R. Rowan and CRS Report R47618, *Post-Wildfire Debris Flows: Federal Role in Assessment and Warning*, by Linda R. Rowan and Eva Lipiec.

[48] HVO, "Hawaiian Volcano Observatory," https://www.usgs.gov/observatories/hvo. The Alaska Volcano Observatory (AVO) acts as the backup for HVO, the California Volcano Observatory, the Cascades Volcano Observatory, and the Yellowstone Volcano Observatory. In the event that AVO is unable to serve as a backup, the Cascades Volcano Observatory will assume this critical function. USGS, *Response for Volcanic Event*, 2024.

[49] NPS, "The Hawaiian Volcano Observatory," https://www.nps.gov/parkhistory/online_books/hawaii-notes/vol4-2-7m.htm.

[50] USGS, "Advanced National Seismic System," https://www.usgs.gov/programs/earthquake-hazards/anss-advanced-national-seismic-system.

[51] USGS, *Response for Volcanic Event*, 2024.

[52] International Civil Aviation Organization (ICAO), "ICAO," https://www.icao.int/Pages/default.aspx; and IVHHN, "Welcome to IVHHN," https://ivhhn.org/.

[53] ICAO, *Handbook on the International Airways Volcano Watch*, Doc 9766-AN/968, 2024 (hereinafter ICAO, (continued...)

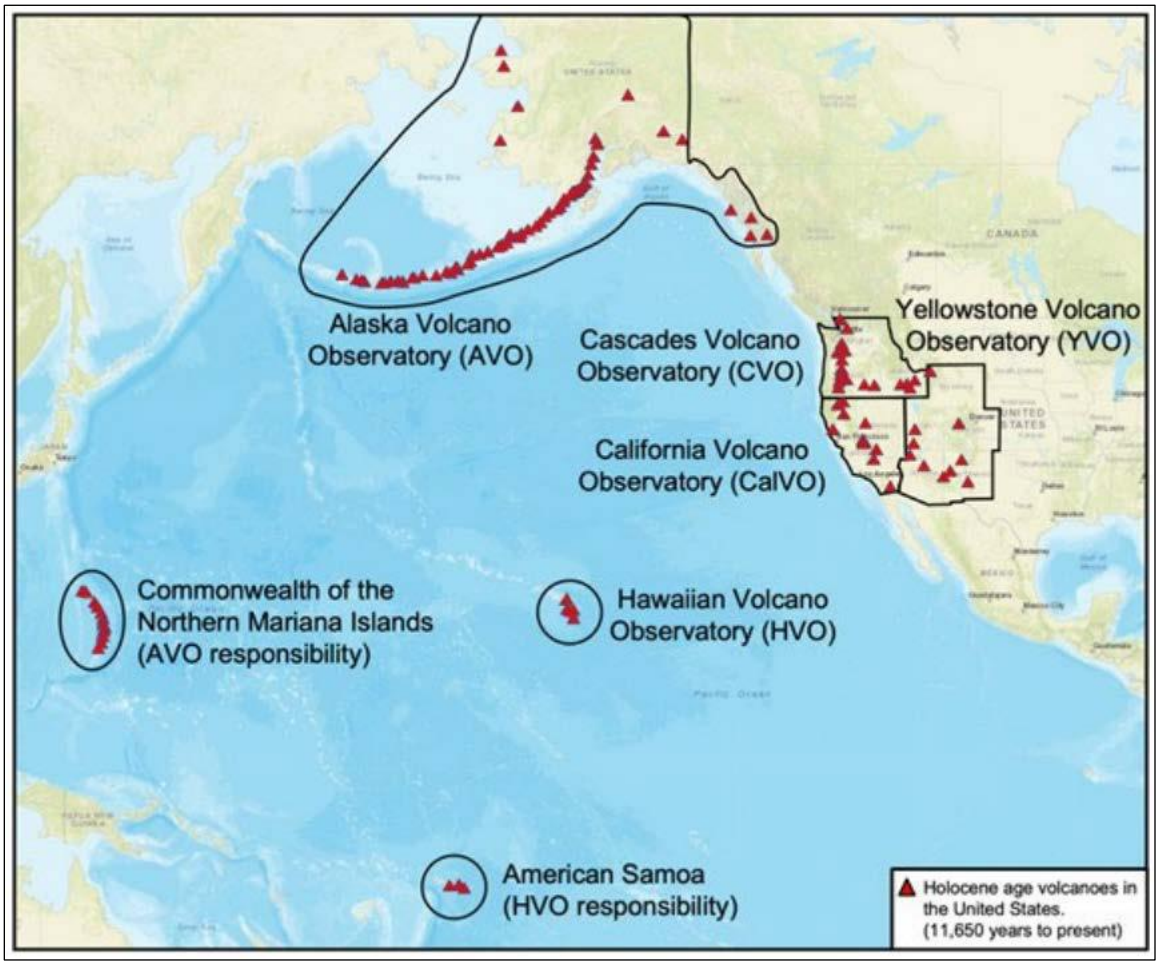
The USGS volcano observatories publish weekly reports on volcanic activity for U.S. volcanoes, and the Smithsonian Institution's Global Volcanism Program publishes weekly reports on volcanic activity for volcanoes outside the United States to cooperating organizations and the public.[54] In particular, HVO and the Washington VAAC provide information and warnings for Hawaii's active volcanoes to ICAO. HVO and NOAA provide information to the Hawaii Interagency Vog Information Dashboard in coordination with IVHHN.[55]

Handbook, 2024). See also Larry Mastin et al., "Progress in Protecting Air Travel from Volcanic Ash Clouds," *Bulletin of Volcanology*, vol. 84, no. 9 (2022), https://doi.org/10.1007/s00445-021-01511-x (hereinafter Mastin et al., *Progress in Protecting Air Travel*).

[54] Smithsonian Institution, "Global Volcanism Program," https://volcano.si.edu/. USGS, "USGS operates five U.S. Volcano Observatories," https://www.usgs.gov/programs/VHP/usgs-operates-five-us-volcano-observatories. ICAO relies on the U.S. Volcano Observatories for information about U.S. volcanoes and the Global Volcanism Program for information on volcanoes outside of the United States and its territories. ICAO also cooperates with other volcano observatories when there is significant volcanic activity that may require volcanic ash advisories. ICAO, *Handbook*, 2024.

[55] International Volcanic Health Hazard Network (IVHHN),"Hawaii Interagency Vog Information Dashboard," https://vog.ivhhn.org/.

Figure 15. U.S. Volcano Observatories and Areas of Responsibility



Source: Interagency Council for Advancing Meteorological Services, *National Volcanic Ash Operations Plan for Aviation, Second Release*, ICM-P35-2024, December 2024, https://www.icams-portal.gov/resources/icams/related_documents/2024_nvaopa.pdf.

Notes: The map depicts U.S. Geological Survey (USGS)-led volcano observatories and areas of responsibility. The black boundaries on the map indicate the geographical areas of responsibility assigned to each of the five USGS volcano observatories. The red triangles locate the 158 volcanoes within the United States and its Pacific territories that have been active during the Holocene Epoch (11,700 years ago to the present day), plus "three notably large and long-lived caldera systems (Yellowstone, Wyoming; Valles, New Mexico; and Long Valley, California)." John W. Ewert et al., *2018 Update to the U.S. Geological Survey National Volcanic Threat Assessment*, USGS, Scientific Investigations Report 2018-5140, 2018, https://doi.org/10.3133/sir20185140.

Research

HVO research is focused on understanding the processes, hazards, and risks of Hawaii's and American Samoa's volcanoes. HVO employs scientists and other specialists in geology, geophysics, seismology, volcanic gases, computer technology, geophysical instruments, and radio systems.[56] Kīlauea and Mauna Loa volcanoes on the island of Hawai'i are among the most active in the world, and this activity has led to a large number of observations and research to

[56] USGS, "About the Hawaiian Volcano Observatory," https://www.usgs.gov/observatories/hvo/about-hawaiian-volcano-observatory.

understand volcanic processes and volcanic hazards.[57] In addition, data collected from the large number of earthquakes on the island of Hawai'i are used for research to understand volcanic processes and earthquake mechanisms.[58]

Monitoring

HVO volcano monitoring (**Figure 16**) includes ground-based instruments to record and measure earthquakes, ground movement (e.g., tilting, uplift, subsidence, movement along a fault, landslide), lava movement, magma movement and magma volume below the surface, volcanic gases, sound waves in the atmosphere, and visual changes in volcanic activity.[59] HVO's monitoring networks consist of more than 100 monitoring sites with instruments, power, and communications. Instruments may include seismometers, accelerometers, tiltmeters, Global Navigation Satellite System (GNSS) receivers, gas instruments, infrasound, and cameras. Monitoring sites continuously transmit data to HVO, where the data are recorded, processed, and analyzed. Changes in volcanic activity are detected automatically, and HVO scientists are notified immediately for further observations and analysis and for warning.

Scientists and engineers may go into the field to directly sample gases, lavas, and other volcanic material for research, monitoring, and warning (**Figure 16**). Analyzing the chemical and physical properties of volcanic materials may help scientists define hazards and better understand volcanic processes. Scientists and specialists in the field also may survey the volcano to measure any changes and use cameras to measure volcanic activity.

Remote-sensing from instruments on aircraft (e.g., unoccupied aircraft systems, helicopters, planes) and satellites is used to detect, record, process, and analyze volcanic activity (**Figure 16**).[60] HVO uses Earth observations from satellites, which may include the USGS and National Aeronautics and Space Administration's (NASA's) Landsat Mission,[61] NASA's Earth Observing System,[62] NOAA's weather satellites,[63] and the European Space Agency's Sentinel Mission, among others.[64] HVO also uses weather data from NOAA and pilot observations.[65]

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[57] Smithsonian Institution, Global Volcanism Program, "Kīlauea," https://volcano.si.edu/volcano.cfm?vn=332010; Global Volcanism Program, "Mauna Loa," https://volcano.si.edu/volcano.cfm?vn=332020.

[58] See for example, John D. Wilding et al., "The Magmatic Web Beneath Hawaii," *Science*, vol. 379, no. 6631 (December 22, 2022), pp. 462-468, https://doi.org/10.1126/science.ade5755.

[59] USGS, "Volcano Monitoring by Hawaiian Volcano Observatory," https://www.usgs.gov/observatories/hvo/science/volcano-monitoring-hawaiian-volcano-observatory.

[60] For example, Ryan Lanclos, "Hawaii Volcano: Scientists, Emergency Responders Put Drones to Work," Esri, *Esri Blog*, August 8, 2018, at https://www.esri.com/about/newsroom/blog/hawaii-volcano-drones-responders.

[61] USGS, "Landsat Missions," https://www.usgs.gov/landsat-missions.

[62] NASA, "NASA's Earth Observing System," https://eospso.nasa.gov/content/nasas-earth-observing-system-project-science-office.

[63] NOAA, "Satellites," https://www.noaa.gov/satellites, and National Weather Service (NWS), "Satellites," https://www.weather.gov/about/satellites.

[64] The European Space Agency, "The Sentinel Missions," https://www.esa.int/Applications/Observing_the_Earth/Copernicus/The_Sentinel_missions. See also National Academies of Sciences, Engineering, and Medicine, *Volcanic Eruptions and Their Repose, Unrest, Precursors, and Timing*, 2017, pp. 1-122, https://doi.org/10.17226/24650, Table 1.2 Satellite-Borne Suite for Volcano Monitoring.

[65] A *Pilot Weather Report* (PIREP) is an inflight weather report submitted by an aircraft pilot or crew member. An *Aircraft Report* (AIREP) is also an inflight weather report provided by the pilot or derived from onboard sensors, such as wind and temperature. PIREPs are U.S.-only reports, whereas AIREPs are worldwide. In instances where volcanic ash is observed, pilots can report this information either in a PIREP or an AIREP. When volcanic ash details are communicated in a PIREP, the report is termed an *Urgent PIREP*; in an AIREP, it is referred to as a *Special AIREP*. (continued...)

The 2018 Kīlauea eruption destroyed instruments and monitoring infrastructure.[66] Congress provided supplemental appropriations in FY2019 to repair some of the volcano monitoring network and establish new HVO facilities (P.L. 116-20).[67] Using those funds, HVO has replaced some instruments and is hardening telemetry and adding new instruments.[68] HVO has installed new seismometers, higher-resolution GNSS receivers and tiltmeters, and higher-resolution image and thermal cameras. HVO has acquired new field instruments, including a gravimeter to measure magma movement, a laser rangefinder to measure the level of any lava lakes, and gas sensors to measure gas compositions and concentrations. The funding also allowed HVO to acquire high-resolution topographic maps using airborne light detection and ranging (lidar) to measure and analyze changes (see, for example, **Figure 11**).[69]

Pilots typically complete a *Volcanic Activity Report* (example of the form available at Federal Aviation Administration (FAA), Aeronautical Information Manual, https://www.faa.gov/air_traffic/publications/atpubs/aim_html/appendix_2.html) that may contain extra details about the physical characteristics of ash clouds after concluding flight operations or during flight debriefings. It also may function as a Special AIREP, with an additional section dedicated to describing the ash cloud. Interagency Council for Advancing Meteorological Services (ICAMS), *National Volcanic Ash Operations Plan for Aviation, Second Release*, ICM-P35-2024, December 2024, https://www.icams-portal.gov/resources/icams/related_documents/2024_nvaopa.pdf (hereinafter ICAMS, *National Volcanic Ash Operations*, 2024).

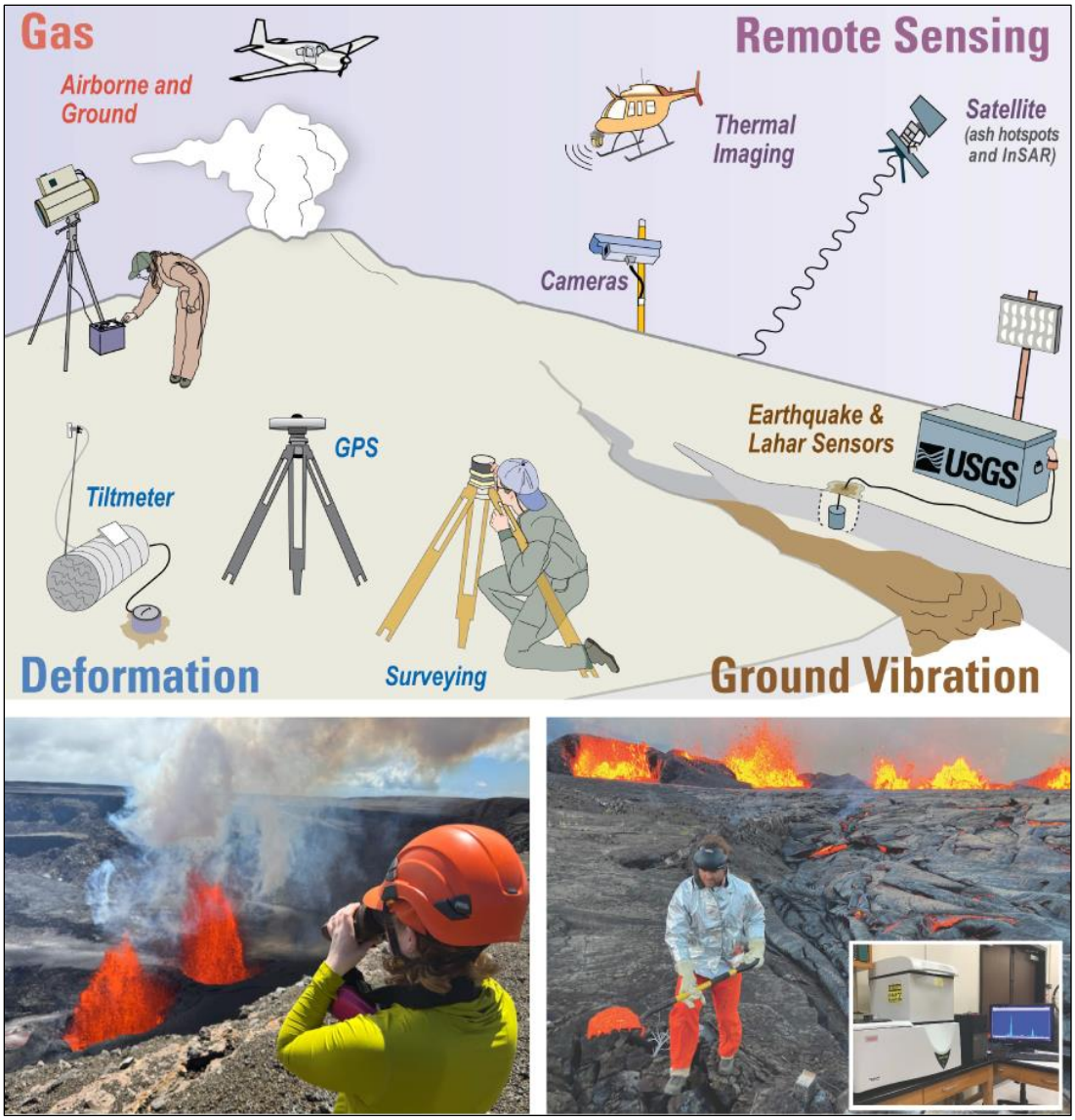
[66] USGS, HVO, "Volcano Watch: HVO's Ongoing Recovery from the 2018 Kīlauea Eruption," at https://www.usgs.gov/volcanoes/kilauea/news/volcano-watch-hvos-ongoing-recovery-2018-kilauea-eruption.

[67] USGS, "2019 Supplemental Appropriations Activities," https://www.usgs.gov/supplemental-appropriations-for-disaster-recovery-activities/2019-supplemental-appropriations.

[68] In addition to network restoration and hardening, instrument upgrades in the field and in the laboratory included new gravimeters, seismometers, Global Positioning System/Global Navigation Satellite System, multi-gas sensors, laser rangefinders, visual and thermal cameras, tephra/ash analyzers, optical and infrared microscopes, and unoccupied aircraft systems.

[69] For more information about lidar and related USGS topographic mapping programs, see CRS In Focus IF13079, *The 3D Elevation Program (3DEP) and Its Role in Mapping Hazards and Resources*, by Linda R. Rowan.

Figure 16. Volcano Monitoring



Source: U.S. Geological Survey (USGS) Volcano Hazards Program and the Hawaiian Volcano Observatory (HVO).

Notes: Top: USGS Infographic. USGS monitoring includes measurements of volcanic gases, ground movement (i.e., rise, fall, or sideways movement of the surface), or vibration (i.e., shaking) related to magma movement, earthquakes, flows or lahars, or landslides, as well as remote sensing (via camera, aircraft, and satellite imaging/measurements) of volcanic activities. Bottom left: A USGS geologist uses a handheld laser rangefinder to measure eruption features during the 13th episode of a 2025 Kīlauea summit eruption. USGS photograph taken on March 11, 2025, from the western rim of Halemaʻumaʻu by M. Patrick. Bottom right: A USGS geologist, wearing protective equipment, collected a molten sample of newly erupted material in Kīlauea caldera on September 11, 2023. The sample provided information on magma storage and transport before it was erupted onto the surface as lava. Access to this hazardous area is by permission from, and in coordination with, Hawaiʻi Volcanoes National Park. USGS photograph by M. Patrick. The inset shows an energy dispersive x-ray fluorescence instrument for analysis (box on the left in the image). The computer screen shows the spectral spikes for certain elements measured in the sample during the analysis. HVO and University of Hawaiʻi (UH), Hilo, partners use these compositional analyses to understand the eruption. UH-Hilo photograph by S. Lundblad.

Earthquake Monitoring and Reporting

HVO is unique among USGS volcano observatories in that it is responsible for earthquake monitoring and reporting.[70] HVO oversees the HISN, which comprises about 100 seismic sites on the islands (about 60 of which are on the island of Hawai'i). HVO studies and reports on earthquakes in various ways.[71] The seismic network automatically locates earthquakes, and the earthquake data is posted online in real time.[72] HVO seismic analysts review the data, may update the earthquake information, and post the information on the ANSS Comprehensive Earthquake Catalog (ComCat).[73] Earthquakes larger than magnitude 4 trigger a rapid response by HVO duty seismologists and others, who are responsible for manually reviewing the earthquake and issuing a news release within two hours.[74] In addition, the National Earthquake Information Center computes several enhanced earthquake information products, such as Did You Feel It, ShakeMap, PAGER, and other information, that USGS and its partners use for hazard analysis and decisionmaking.[75] Anyone can sign up with the USGS to receive earthquake alerts and may tailor the alerts for specific regions, specific magnitudes, or other parameters.[76] HVO typically reports earthquakes in volcanic activity warnings (see "Warnings" section below), because volcanic earthquakes may track magma and lava movements and tectonic earthquakes may alter volcanic activity. Hawaii is not part of the ShakeAlert earthquake early warning system operated by the USGS and partners in California, Oregon, and Washington.[77] A 2016 feasibility study of earthquake early warning in Hawaii considered implementation.[78]

Warnings

HVO provides warnings of volcanic activity using a warning system designed by the USGS VHP in coordination with HVO, ICAO, and the Federal Aviation Administration (FAA). The alert system has two parts: (1) ranked terms (normal, advisory, watch, and warning) to inform people on the ground about a volcano's status (**Figure 17**) and (2) ranked colors (green, yellow, orange, and red) to inform the aviation sector about airborne ash and gas hazards (**Figure 18**).

[70] USGS, "Monitoring Earthquakes in Hawaii," https://www.usgs.gov/observatories/hvo/science/monitoring-earthquakes-hawaii.

[71] USGS, "Monitoring Earthquakes in Hawaii," https://www.usgs.gov/observatories/hvo/science/monitoring-earthquakes-hawaii.

[72] Earthquake data is posted in two places online, HVO homepage and the USGS Earthquakes page. Users may need to adjust the maps on either website to see the most recent earthquakes on a Hawaiian volcano. USGS, "Hawaiian Volcano Observatory," https://www.usgs.gov/observatories/hvo; USGS, "Earthquake Map," https://earthquake.usgs.gov/earthquakes/map/?extent=7.63168,-178.1543&extent=45.95661,-106.43555.

[73] USGS, "ANSS Comprehensive Earthquake Catalog (ComCat) Documentation," https://earthquake.usgs.gov/data/comcat/.

[74] A *rapid response* means a duty seismologist intends to review the data within 20 minutes of receiving the data. HVO does not operate a 24-hour-a-day (24/7) service, but the National Earthquake Information Center (NEIC) does. An NEIC duty seismologist should provide a rapid response when HVO is closed.

[75] USGS, "National Earthquake Information Center," https://www.usgs.gov/programs/earthquake-hazards/national-earthquake-information-center-neic. See also USGS, "Earthquakes," https://www.usgs.gov/programs/earthquake-hazards/earthquakes. NEIC acts as the national operations center of the U.S. Advanced National Seismic System.

[76] USGS, "Real-Time Notifications, Feeds, and Web Services," https://earthquake.usgs.gov/earthquakes/feed/.

[77] CRS Report R47121, *The ShakeAlert Earthquake Early Warning System and the Federal Role*, by Linda R. Rowan.

[78] Weston A. Thelen et al., *Feasibility Study of Earthquake Early Warning (EEW) in Hawaii*, USGS, Open-File Report 2016-1172, 2016, https://doi.org/10.3133/ofr20161172.

Figure 17. USGS Alert-Level Terms for a Volcano

NORMAL	Volcano is in typical background, noneruptive state or, after a change from a higher level, volcanic activity has ceased and volcano has returned to noneruptive background state.
ADVISORY	Volcano is exhibiting signs of elevated unrest above known background level or, after a change from a higher level, volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
WATCH	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, **OR** eruption is underway but poses limited hazards.
WARNING	Hazardous eruption is imminent, underway, or suspected.

Source: U.S. Geological Survey, *Island of Hawai'i Interagency Plan for Volcanic Eruptions*, July 2024, https://www.usgs.gov/programs/VHP/coordination-plans.

Figure 18. USGS Aviation Color Codes for Volcanic Activity

GREEN	Volcano is in typical background, noneruptive state or, *after a change from a higher level,* volcanic activity has ceased and volcano has returned to noneruptive background state.
YELLOW	Volcano is exhibiting signs of elevated unrest above known background level or, *after a change from a higher level*, volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
ORANGE	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, **OR** eruption is underway with no or minor volcanic-ash emissions [ash-plume height specific, if possible].
RED	Hazardous eruption is imminent with significant emission of volcanic ash into the atmosphere likely OR Eruption is underway or suspected with significant emission of volcanic ash into the atmosphere [ash-plume height specific, if possible].

Source: U.S. Geological Survey, *Island of Hawai'i Interagency Plan for Volcanic Eruptions*, July 2024, https://www.usgs.gov/programs/VHP/coordination-plans.

HVO may issue a Volcano Activity Notice (VAN) and a Volcano Observatory Notice for Aviation (VONA).

- **Volcano Activity Notice.** A VAN is issued when a volcano's alert level changes (**Figure 17** and **Figure 18**)—that is, when there is significant volcanic activity or a significant ash resuspension event.[79]
- **Volcano Observatory Notice for Aviation**. VONA is a derivative product of the VAN that contains information in a format specifically intended for aviation users (e.g., pilots, dispatchers, air-traffic managers, meteorologists) of volcanic hazard information, with emphasis on ash emission. Its purpose is to communicate volcanic activity details to the aviation sector, specifically focusing on ash-plume information. The VONA includes an Aviation Color Code and is transmitted to Air Route Traffic Control Centers (ARTCCs), the Honolulu Meteorological Watch Office (MWO), and NOAA's Washington Volcanic Ash Advisory Center (WVAAC, located in College Park, MD, outside of Washington, DC).[80]

HVO may issue daily updates, weekly updates, information releases, and status reports about Hawaii's active volcanoes.[81] In addition to these reports, HVO provides access to webcams, photographs, videos, lava flow maps, hazards discussions, frequently asked questions, and information about recent earthquakes. Anyone can sign up to receive notifications about volcanic activity at U.S. monitored volcanoes through the USGS Volcano Notification Service.[82]

HVO follows USGS plans for distributing warnings and notices to federal, state, and local officials as described in the *Volcano Science Center Response Plan for Significant Volcanic Events* and in the *Island of Hawai'i Interagency Operation Plan for Volcanic Eruption* (hereinafter, IH plan).[83] HVO communicates with NOAA, FAA, the Department of Defense (DOD), and NPS—among other federal, state, and local agencies—to provide observational data and consistent interpretations and notifications of volcanic activity and hazards. HVO may coordinate as needed with appropriate federal agencies (e.g., U.S. Fish and Wildlife Service

[79] Significant volcanic activity includes elevated unrest above normal background levels or eruption (**Figure 17**). Ash from previous eruptions may be resuspended in the atmosphere by strong winds and may pose a threat to people and property. The ICAO added resuspension of ash as a type of volcanic event that may impact aviation and may be reported in a volcanic ash advisory. Resuspension of ash is more likely from stratovolcanoes with a higher VEI that deposit large volumes of ash around a volcano, such as stratovolcanoes in Alaska, California, Oregon, or Washington, rather than shield volcanoes, such as shield volcanoes in Hawaii. ICAO, *Handbook*, 2024.

[80] The Honolulu Meteorological Watch Office (MWO) falls under the purview of the Honolulu Weather Forecast Office (WFO). NOAA, "NWS Forecast Office Honolulu, HI," https://www.weather.gov/hfo. The United States has three MWOs: Anchorage, AK; Honolulu, HI; and Kansas City, MO. The ICAO designates MWOs to maintain a continuous watch over weather conditions that affect flight operations and to issue warnings and forecasts for the aviation community. The Honolulu MWO maintains a meteorological watch over the central and western Pacific Ocean. The Honolulu MWO is responsible for an ICAO flight information region (FIR) that covers a portion of the Oakland Oceanic FIR south of 30 N and west of 140 W (**Figure 19**). ICAO, *Handbook*, 2024; ICAMS, *National Volcanic Ash Operations*, 2024. See also NOAA, "Aviation Weather Services," https://www.weather.gov/media/aviation/Aviation%20trifold_without%20crop%20marks.pdf.

[81] USGS, "Volcano Updates," https://www.usgs.gov/programs/VHP/volcano-updates#hvo; and USGS, "Hawaiian Volcano Observatory," at https://www.usgs.gov/observatories/hvo.

[82] USGS, "Volcano Notification Service (VNS)," at https://volcanoes.usgs.gov/vns2/.

[83] USGS, *Response for Volcanic Event*, 2024; USGS, HVO, "Volcano Watch: Introducing Island of Hawai'i Interagency Operations Plan for Volcanic Eruptions," https://www.usgs.gov/observatories/hvo/news/volcano-watch-introducing-island-hawaii-interagency-operations-plan-1. The plan was completed in July 2024. USGS, *Island of Hawai'i Interagency Plan*, 2024.

[FWS], NPS, DOD), state agencies (e.g., state departments of natural resources), and private land managers who have jurisdiction over the land encompassing an active or restless volcano.[84]

A *volcanic event*—defined by the USGS as any instance of heightened volcanic unrest—may require a response scaled to the event's magnitude.[85] The USGS has developed plans to scale up or scale down a response depending on how threatening a volcanic event is or becomes over time. HVO issues a first response to significant changes in volcanic activity that are above normal baseline levels for each volcano through release of VANs and VONAs to the public and to federal, state, and local officials (**Figure 17** and **Figure 18**).[86] If a volcanic event becomes more threatening, then HVO may scale up its response by establishing an Observatory Volcanic Event Response Team, which monitors the volcano without interruption by establishing a 24/7 watch. If the volcanic event becomes even more significant, the VSC Director may establish a Center Volcanic Event Response Team.

The USGS plans also describe roles and responsibilities for USGS response team members and consider staffing increases (using personnel from other volcano observatories or other USGS programs) to respond to increasing levels of unrest. The plans follow the National Incident Management System developed by the Federal Emergency Management Agency (FEMA) to standardize command, control, and coordination of emergency responses in the United States.[87] In the event of a presidential emergency or major disaster declaration, HVO coordinates with FEMA, as FEMA takes a lead role in the command, control, and coordination of emergency response in these situations.[88]

Washington Volcanic Ash Advisory Center

NOAA's WVAAC (located in a suburb of Washington, DC), together with HVO, studies, monitors, forecasts, and warns about volcanic ash hazards in the atmosphere to reduce risks to people, property, and aviation.[89] WVAAC is one of nine VAACs organized by ICAO to monitor volcanic ash around the world (**Figure 19**).[90] A single VAAC at a time issues volcanic ash

[84] USGS, *Alaska Interagency Plan for Volcanic Ash Episodes*, 2022.

[85] A *volcanic event* may include a volcanic eruption (i.e., where magma reaches the surface), venting of gas or ash, earthquakes, landslides, or any other volcanic hazard that threatens harm and damage. Although much has been learned about volcanic activity—especially at Kīlauea, among the best-studied volcanoes in the world—no volcanic event can be precisely predicted and any volcanic event may change, so continued and sometimes enhanced monitoring is warranted throughout a volcanic event. USGS, *Response for Volcanic Event*, 2024, p. 5.

[86] The USGS's federal authority to monitor and warn about volcanic activity is codified in statute by legislation authorizing NVEWS (§5001 of P.L. 116-9; 43 U.S.C. 31k). The law directed the USGS to establish NVEWS to monitor volcanoes, warn U.S. citizens of volcanic activity, and protect citizens from "undue and avoidable harm." Under the Robert T. Stafford Disaster Relief and Emergency Assistance Act (42 U.S.C. §5132), the USGS has authority through the President to provide alerts about volcanoes using federal and other communication services to states and civilian populations in endangered areas.

[87] USGS, *Response for Volcanic Event*, 2024; Federal Emergency Management Agency (FEMA), "National Incident Management System," https://www.fema.gov/emergency-managers/nims.

[88] CRS Report R43784, *FEMA's Disaster Declaration Process: A Primer*, by Bruce R. Lindsay.

[89] NOAA, "Washington Volcanic Ash Advisory Center," https://www.ospo.noaa.gov/products/atmosphere/vaac/. The Washington Volcanic Ash Advisory Center (WVAAC) is organized within NOAA's Office of Satellite and Product Operations (OSPO) as part of the National Environmental Satellite Data and Information Service. OSPO has physical offices at NOAA's headquarters in Silver Spring, MD, WVAAC has offices in College Park, MD, and Command and Data Acquisition Stations at Wallops Island, VA, and Fairbanks, AK. The WVAAC is named after Washington, DC. The other U.S. VAAC is in Anchorage, AK. NOAA, "Office of Satellite and Product Operations," https://www.ospo.noaa.gov/.

[90] ICAO, "ICAO," https://www.icao.int/Pages/default.aspx; ICAO, *Manual on Volcanic Ash, Radioactive Material*, (continued...)

advisories (VAAs) for a continuous ash cloud, although two VAACs may issue simultaneous VAAs for different ash clouds from the same volcano. As ash nears and crosses VAAC boundaries, VAACs transfer responsibility of VAA issuance to the downstream VAAC.[91] The other U.S. VAAC is located in Anchorage, AK.[92] The WVAAC serves as the backup for the Anchorage VAAC. In addition, the U.S. Air Force 2nd Weather Squadron in the 557th Weather Wing operates a VAAC to monitor more than 1,500 volcanoes in a 24/7 operation to monitor eruptions that may impact DOD operations worldwide.[93] The 2nd Weather Squadron VAAC serves as a backup for the WVAAC.

Volcanic ash and gases may pose a serious risk for aircraft in flight or on the ground.[94] Ash clouds can damage aircraft in flight, such as by causing engine and avionic system failures.[95] Ash can make takeoff and landing of an aircraft treacherous and can damage aircraft on the ground, incurring costs for cleaning, repair, or even replacement. Compared with other types of volcanoes—such as stratovolcanoes in Alaska, California, Oregon, and Washington—Hawaiian shield volcanoes tend to have a low volcanic explosivity index (VEI) of between 0 and 1; as a result, Hawaiian eruptions pose less of a volcanic ash threat to aviation than eruptions from other types of volcanoes.[96] In addition, Hawaiian volcanic ash and gas eruptions generally are confined to the area and airspace near the eruptive vent, so only aviation near a vent may be impacted.[97] HVO, WVAAC, and the Honolulu MWO participate in international and national planning and activities to address volcanic ash and gas hazards for aviation within their areas of responsibility (**Figure 19**).[98]

and Toxic Chemical Clouds, 3rd ed., Doc 9691, AN954, 2015 (hereinafter ICAO, *Manual on Volcanic Ash*, 2015) and NOAA, *Implementation Plan*, 2025.

[91] ICAMS, *National Volcanic Ash Operations*, 2024.

[92] NWS, "Anchorage Volcanic Ash Advisory Center," https://www.weather.gov/vaac/.

[93] Air Force, "Renewal Ensures Wing, Volcanic Ash Advisory Center Partnership Endures," https://www.af.mil/News/Article-Display/Article/2540260/renewal-ensures-wing-volcanic-ash-advisory-center-partnership-endures/.

[94] FAA, Chapter 7-6-10, "Flight Operations in Volcanic Ash," in *Aeronautical Information Manual (AIM)*, September 2024, https://www.faa.gov/air_traffic/publications/atpubs/aim_html/chap7_section_6.html (hereinafter FAA, "Flight Operations in Volcanic Ash," 2024); ICAO, *Manual on Volcanic Ash*, 2015.

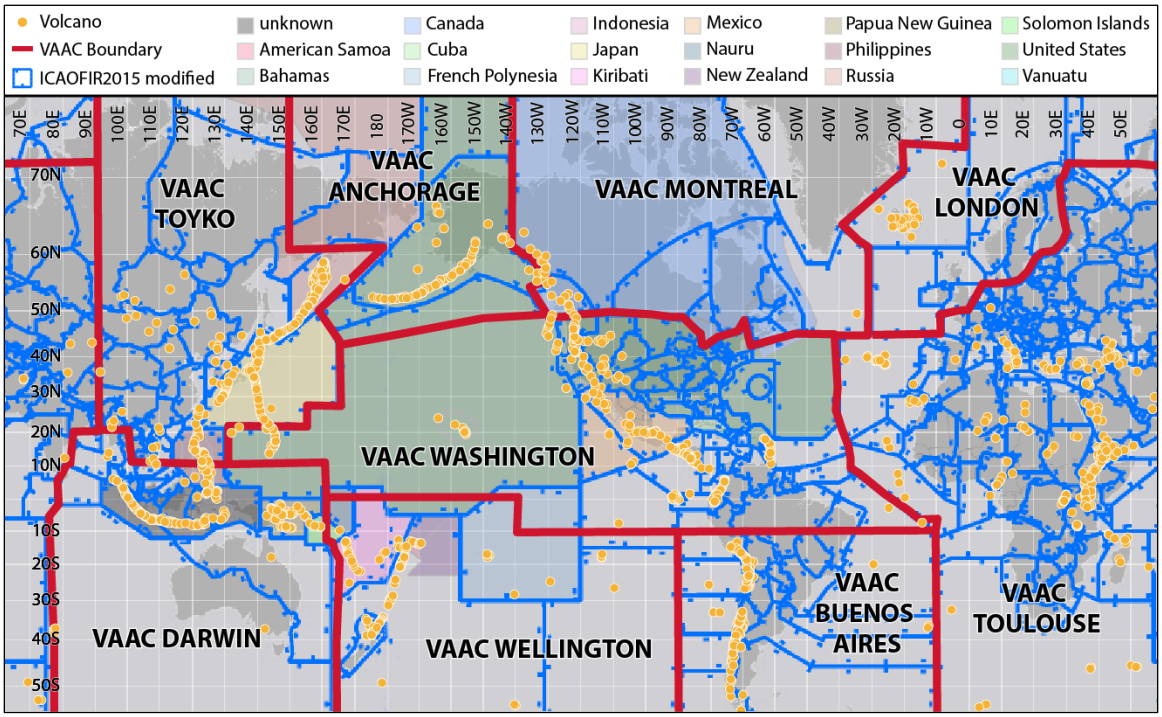
[95] Marianne Guffanti et al., *Encounters of Aircraft with Volcanic Ash Clouds: A Compilation of Known Incidents, 1953-2009*, USGS, Data Series 545, 2010; Uta Reichardt et al., "Volcanic Ash and Aviation: Recommendations to Improve Preparedness for Extreme Events," *Transportation Research Part A*, vol. 113 (2018), pp. 101-113, https://doi.org/10.1016/j.tra.2018.03.024 (hereinafter Reichardt et al., Volcanic Ash and Aviation, 2018).

[96] VEI describes the size of explosive volcanic eruptions based on magnitude and intensity. VEI is a partially logarithmic scale that ranges from a low explosivity of 0 to a high explosivity of 8. NPS, "Volcanic Explosivity Index (VEI)," https://www.nps.gov/subjects/volcanoes/volcanic-explosivity-index.htm. See Smithsonian Institution's Global Volcanism Program, "Kīlauea," https://volcano.si.edu/volcano.cfm?vn=332010, and Global Volcanism Program, "Mauna Loa," https://volcano.si.edu/volcano.cfm?vn=332020, for a list of past eruptions and their VEIs.

[97] Hawaii is remote and not densely populated; nonetheless, threats to people and property are significant because people live and work on active volcanic islands and people visit active volcanoes from the land, sea, and air. Research, monitoring, and warning support residents, workers, and visitors with access to active volcanic islands and help emergency responders and jurisdictional authorities prepare responses and take protective actions, such as restricting access, when there are volcanic threats. USGS, *Island of Hawai'i Interagency Plan*, 2024.

[98] ICAO, *Handbook*, 2024; and ICAMS, *National Volcanic Ash Operations*, 2024.

Figure 19. Volcanic Ash Advisory Centers: Areas of Responsibility



Source: Congressional Research Service based on International Civil Aviation Organization (ICAO) – global map from ICAO with an online map view available at https://store.icao.int/en/icao-volcanic-ash-advisory-centers-icao-regions#mz-expanded-view-49962856382.

Notes: The National Oceanic and Atmospheric Administration (NOAA) operates the Anchorage Volcanic Ash Advisory Center (VAAC) and the Washington VAAC (Washington, DC). These centers are responsible for observing, measuring, and modeling volcanic ash plume distribution in the atmosphere and providing volcanic ash advisories about volcanic hazards to aviation in the areas of responsibility shown on the map by thick red lines. ICAO flight information regions for local to regional areas are shown by blue lines. See also National Weather Service, "Anchorage Volcanic Ash Advisory Center," at https://www.weather.gov/vaac/, and NOAA, "Washington Volcanic Ash Advisory Center," at https://www.ospo.noaa.gov/products/atmosphere/vaac/. Airspace by country adjacent to the Anchorage and Washington VAACs shown by color shading, with each country identified in the legend. Volcanoes shown by yellow circles from NOAA, National Centers for Environmental Information, "Volcano Locations," https://www.ngdc.noaa.gov/hazel/view/hazards/volcano/loc-data.

Research

Research on volcanic ash hazards in the atmosphere includes observations and modeling and forecasting of ash and ash movement in the atmosphere. The USGS, NOAA, NASA, and National Science Foundation support much of this research at the federal level.[99] The Satellite Analysis Branch of the National Environmental Satellite, Data, and Information Service (NESDIS) and the NWS's National Centers for Environmental Prediction operate WVAAC.[100] The NWS operates the other NOAA VAAC, Anchorage VAAC.[101] NESDIS's mission is to provide secure, timely global environmental data from satellites and other sources with a component of data analysis and research. The NWS's mission is to provide weather, climate, and

[99] ICAMS, *National Volcanic Ash Operations*, 2024 and NOAA, *Implementation Plan*, 2025.

[100] NOAA, "National Environmental Satellite, Data, and Information Service," https://www.nesdis.noaa.gov/; NOAA, "Airlines, Observatories, and Others Keep Tabs on Volcanic Activity with VOLCAT," https://www.nesdis.noaa.gov/news/airlines-observatories-and-others-keep-tabs-volcanic-activity-volcat.

[101] NWS, "Anchorage Volcanic Ash Advisory Center," https://www.weather.gov/vaac/.

water data, forecasts, warnings, and other decision-support information.[102] Given the different missions of NESDIS and the NWS, it is not clear if the Anchorage VAAC and WVAAC are integrated in their approach to research for volcanic ash warnings or if the WVAAC is responsible for research and data analysis for volcanic ash warning products. The ICAO lists additional research and monitoring programs from NOAA, NASA, USGS, and other organizations that help support the VAACs' monitoring of ash and gas (**Appendix D**).[103]

Satellite Observations

Higher spatial- and temporal-resolution observations by satellites support research and have led to more accurate ash and gas detection and tracking to enhance forecast modeling and allow for more timely forecasts of ash and gas movement and dispersion, compared with past forecasts. Current geostationary satellites have roughly doubled the spatial resolution (0.5-3 kilometers; about 0.3-2 miles) and image repeat times (< 1 to 15 minutes) compared with satellites in orbit more than 10 years ago. Whereas satellites imaged the 1991 Pinatubo ash cloud once per hour and the 2010 Eyjafjallajökull ash cloud once every 15 minutes, 2021 eruptions at Soufrière, St. Vincent, were imaged once per minute. As of 2022, every VAAC may access high-quality images at least every 15 minutes and several volcanic arcs were routinely imaged every 2.5 or 5 minutes.[104]

The NESDIS Center for Satellite Application and Research is responsible for developing satellite products that support VAAC operations. The NESDIS Volcanic Cloud Analysis Toolkit, developed by the Cooperative Institute for Meteorological Satellite Studies, is a widely used suite of satellite-based products and services comprising, but not limited to, eruption alerts, automated ash detection and tracking, automated gas detection and tracking, ash cloud top height, ash loading, and imagery.[105]

Models

NOAA and the USGS have different models (HYSPLIT and Ash3d, respectively) to forecast ash movement, the size of ash clouds and plumes, and ash concentrations.[106] NOAA's VAACs use the HYSPLIT model to prepare VAAs and volcanic ash graphics (see "Warning"). P.L. 117-263 directs the U.S. volcano observatories to integrate relevant capacities of NOAA, including the VAACs, to observe and model volcanic activity in the atmosphere and ocean. NOAA and USGS models are adding quantitative ash concentrations to their probability forecasts, a feature the ICAO requires from VAACs by the next decade.[107]

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[99] NWS, "The National Weather Service," https://www.weather.gov/about/.

[103] ICAO, *Handbook*, 2024.

[104] Mastin et al., *Progress in Protecting Air Travel*.

[105] Cooperative Institute for Meteorological Satellite Studies (CIMSS), "Volcanic Cloud Monitoring—NOAA/CIMSS," https://volcano.ssec.wisc.edu/; CIMSS, "Cooperative Institute for Meteorological Satellite Studies," https://cimss.ssec.wisc.edu/. See also Michael J. Pavlonis et al., "Automated Detection of Explosive Volcanic Eruptions Using Satellite-Derived Cloud Vertical Growth Rates," *Earth and Space Science*, vol. 5 (2018), pp. 843-980, https://doi.org/10.1029/2018EA000410. See also NOAA, *Implementation Plan*, 2025, for a description of how NOAA uses and plans to use the Volcanic Ash Cloud Analysis Tool to modernize NVEWS.

[106] NOAA, "HYSPLIT Volcanic Ash Model," https://www.arl.noaa.gov/hysplit/volcanic-ash-model/ and USGS, "Ash3d," https://vsc-ash.wr.usgs.gov/ash3d-gui/#!/ .

[107] For example, Alice Crawford et al., "Evaluation and Bias Correction of Probabilistic Volcanic Ash Forecasts," *Atmospheric Chemistry and Physics*, vol. 22, no. 21 (2022), pp. 13967-13996, https://doi.org/10.5194/acp-22-13967-2022. See also ICAMS, *National Volcanic Ash Operations* and NOAA, *Implementation Plan*, 2025.

Quantitative Ash Concentration

The ICAO is asking VAACs to develop a quantitative volcanic ash product (QVA) that provides forecast probabilities of ash concentration at aircraft altitudes or quantifies the concentration of ash with height, enabling aircraft operators to move away from traditional criteria for visible (to the human eye) or discernable (by satellite) volcanic ash aloft.[108] NOAA intends to begin issuing QVAs by November 2025.[109] Since the 2010 Eyjafjallajökull eruption, the ICAO and the European Union Aviation Safety Agency have developed new procedures for aviation to deal with volcanic ash hazards in Europe. These procedures allow aircraft operators to consider flying through ash concentrations that pose a low risk to aircraft based on the operator's risk assessment.[110] Studies of the 2010 Eyjafjallajökull eruption in Iceland and others have led to advances in volcanic ash measurements, models, and forecasts.[111] In Western Europe and parts of the North Atlantic regions, the responsibility for volcanic ash avoidance or the decision to fly (or not to fly) into an area of known or forecast volcanic ash contamination was transferred from air traffic management to commercial aircraft operators.[112] Aircraft operators must have safety risk assessments that include decisions about flight operations in known or forecast volcanic ash.[113]

Monitoring

WVAAC uses observations, measurements, and forecasts from the USGS, NOAA, and other volcano observatories to forecast, advise, and monitor the movement of volcanic ash in WVAAC's assigned airspace (**Figure 19**). WVAAC is staffed 24/7 to provide guidance and support to Honolulu's MWO, other MWOs, and the aviation community.[114] Duty meteorologists or satellite analysts continuously monitor remote sensing data, pilot reports, and volcano observatories' VANs and VONAs. WVAAC is tasked with running ash dispersion models, determining the current and forecast area extent of the ash, and producing ash warnings. WVAAC can request a HYSPLIT model run whenever necessary by contacting the senior duty meteorologist and providing essential details, such as the eruption's start time, duration, and

[108] ICAMS, *National Volcanic Ash Operations*, 2024.

[109] NOAA, *Implementation Plan*, 2025. FAA issued letters to NOAA instructing both U.S. VAACs to be compliant with QVA product issuance by November 26, 2026. In addition, the NWS issued a notice about other changes in VAAs from NOAA's VAACs, such as providing information only in imperial measurements (i.e., feet) and removing the aviation color code. Kevin Stone, *Service Change Notice 25-43*, NWS, NOUS41 KWBC 211610 PNSWSH, May 21, 2025, https://www.weather.gov/media/notification/pdf_2025/scn25-43_vaa_changes.pdf.

[110] European Union Aviation Safety Agency (EASA), *Flight in Airspace with Contamination of Volcanic Ash*, Safety Information Bulletin (SIB) 2023-13, December 19, 2023, https://ad.easa.europa.eu/ad/2023-13 (hereinafter EASA, *Flight in Volcanic Ash*); ICAO, *Volcanic Ash Contingency Plan, European and North Atlantic Regions*, EUR Doc 019, NAT Doc 006, Part II, Edition 2.2.0, 2024 (hereinafter ICAO, *Volcanic Ash European and North Atlantic*); Reichardt et al., "Volcanic Ash and Aviation."

[111] The eruption released ash into the atmosphere for 39 days. Frances M. Beckett et al., "Atmospheric Dispersion Modelling at the London VAAC: A Review of Developments Since the 2010 Eyjafjallajökull Volcano Ash Cloud," *Atmosphere* vol. 11, no. 4 (2020), pp. 352-378, https://doi.org/10.3390/atmos11040352; Reichardt et al., "Volcanic Ash and Aviation"; Mastin et al., *Progress in Protecting Air Travel*.

[112] EASA, *Flight in Volcanic Ash*; ICAO, *Volcanic Ash European and North Atlantic*; Frances Beckett et al., "Conducting Volcanic Ash Cloud Exercises: Practising Forecast Evaluation Procedures and the Pull-Through of Scientific Advice to the London VAAC," *Bulletin of Volcanology*, vol. 86, no. 63 (2024), https://doi.org/10.1007/s00445-024-01717-9.

[113] EASA, *Flight in Volcanic Ash*; ICAO, *Volcanic Ash European and North Atlantic*.

[114] ICAMS, *National Volcanic Ash Operations*, 2024.

eruption height. For Hawaii's active volcanoes, WVAAC works closely with HVO and the Honolulu MWO. WVAAC also serves as a backup for the Anchorage VAAC and other VAACs.[115]

Warning

WVAAC may issue a VAA with a volcanic ash graphic.[116]

- **Volcanic Ash Advisory**. A VAA provides information about the presence or anticipated occurrence of volcanic ash that could impact the safety of aircraft operations. These advisories include details such as the volcano's identification, eruption time, observed position of the ash cloud, and forecast position of the ash. In cases where the ash cloud is crossing into another VAAC's area of responsibility, the VAA also includes hand-off information.
- **Volcanic Ash Graphic**. A volcanic ash graphic provides information from the VAA in a graphical format (**Figure 20**).[117]

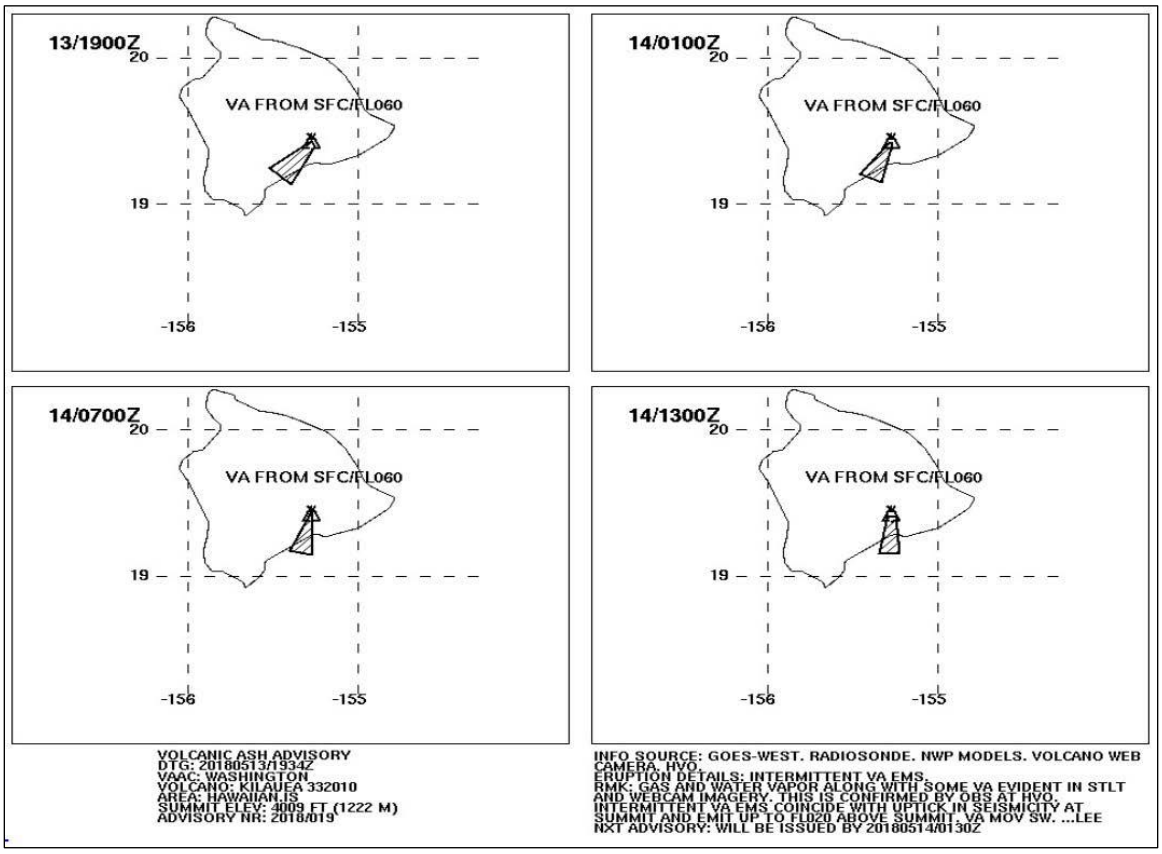
[115] ICAO, *Handbook*, 2024. See also CRS Report R48529, *Alaska's Active Volcanoes: Federal Role in Research, Monitoring, and Warning*, by Linda R. Rowan.

[116] ICAMS, *National Volcanic Ash Operations*, 2024.

[117] ICAO specified the format for consistency. ICAMS, *National Volcanic Ash Operations*, 2024.

Figure 20. Example of a Volcanic Ash Graphic from NOAA's Washington Volcanic Ash Advisory Center

(Kīlauea eruption on May 13, 2018)



Source: Volcanic Ash Advisory for Kīlauea Volcano, issued on May 13, 2018, National Oceanic and Atmospheric Administration (NOAA), **"**Washington Volcanic Ash Advisory Center Archive," https://www.ospo.noaa.gov/VAAC/ARCH18/KILA/2018E131934.html.

Notes: The volcanic ash graphic was prepared by the Washington Volcanic Ash Advisory Center. Each panel shows the forecast extent of the ash cloud in 6-hour increments. Top left is the eruption, top right is 6 hours later, bottom left is 12 hours later, and bottom right is 18 hours later. Small triangle marks the summit of Kīlauea. Hachured polygon denotes the forecasted extent of the ash cloud.

Hawaii Interagency Vog Information Dashboard

The Hawaii Interagency Vog Information Dashboard provides information about air quality and about hazards from volcanic gas and ash or particles on the island of Hawai'i. The dashboard is a partnership between the IVHHN, the Hawai'i County Civil Defense Agency (HCCDA), HVO, HAVO, NOAA, the U.S. Department of Agriculture's Farm Service Agency, the County of Hawai'i, the Hawaii State Department of Health, and the Center for the Study of Active Volcanoes at the University of Hawai'i, Hilo. The dashboard provides real-time information about air quality, sulfur dioxide concentration, particles concentration, and vog in the atmosphere, as well as forecasts for the spread of vog and other volcanic gas and ash hazards. NOAA may update

national weather prediction models to incorporate sulfur dioxide emissions and volcanic ash and may incorporate vog in National Air Quality Forecast Capability.[118]

Island of Hawai'i Interagency Operation Plan for Volcanic Eruption

On the island of Hawai'i, the IH plan was developed to improve coordination between HVO; HCCDA, representing the County of Hawai'i (i.e., entire island of Hawai'i); and HAVO.[119] HVO has no jurisdictional authority and is responsible only for informing jurisdictional authorities about volcanic activity, earthquakes, and related hazards. HCCDA's mission is to protect the community from natural and human-made hazards; to strengthen resiliency; and to direct, coordinate, and administrate emergency preparedness and response in Hawai'i County.[120] HCCDA has jurisdictional authority over Hawai'i County, with the exception of federal lands (**Figure 21**).

HAVO's mission is to protect, study, and provide access to Kīlauea and Mauna Loa and to perpetuate endemic Hawaiian ecosystems and the traditional Hawaiian culture connected to these landscapes.[121] HAVO develops and implements plans to protect staff, visitors, and incident responders from incident hazards. Within the park, HAVO is responsible for responding to and stabilizing from incident hazards; monitoring air quality; managing aircraft and vehicles in restricted areas; implementing restricted areas, closures, and evacuations on park lands; managing vehicular traffic; and ensuring safe viewing areas of volcanic activity.[122]

The current IH plan does not include other agencies with some jurisdictional authority on the island of Hawai'i, such as FWS (Hakalau Forest National Wildlife Refuge); DOD (U.S. Army Pōhakuloa Training Area); or the State of Hawaii (**Figure 21**).[123] The current plan also does not discuss how to cooperate with NOAA facilities on the island of Hawai'i, including the Mauna Loa Observatory near the summit of Mauna Loa and the NWS office at Hilo airport.[124]

State and federal emergency responses to volcanic events on the island of Hawai'i follow the principles of the Incident Command System (ICS) of the National Incident Management System.[125] HCCDA directs response actions and operates an ICS. The State of Hawaii provides resources to the County of Hawai'i to support emergency response. If the state issues a disaster

[118] NOAA, *Implementation Plan*, 2025.

[119] USGS, *Island of Hawai'i Interagency Operation Plan for Volcanic Eruption*, 2024.

[120] Hawai'i County Civil Defense Agency, "Hawaii County Civil Defense Agency," at https://hawaii-county-civil-defense-agency-hawaiicountygis.hub.arcgis.com/.

[121] NPS, *Foundation Document: Hawai'i Volcanoes National Park*, January 2017, p. 5, https://www.nps.gov/havo/learn/management/upload/HAVO_FD_SP_508.pdf. Other NPS lands on the Island of Hawai'i were not included in version one of the *Island of Hawai'i Interagency Operation Plan for Volcanic Eruption* (IH plan). Pu'uhonua o Hōnaunau National Historical Park could be inundated by lava flows from Mauna Loa, and Kaloko-Honokōhau National Historical Park could be inundated by lava flows from Hualālai. The Ala Kahakai National Historic Trail could be affected by lava flows from Kīlauea, Mauna Loa, Hualālai, or Mauna Kea.

[122] Two segments of Highway 11 cross Hawai'i Volcanoes National Park (HAVO). The land is owned by HAVO, and the state operates Highway 11 under an easement arrangement. When volcanic activity affects multiple jurisdictions, the IH plan calls for a unified command approach.

[123] USGS, *Island of Hawai'i Interagency Operation Plan for Volcanic Eruption*, 2024.

[124] NOAA, "About Mauna Loa Observatory," https://gml.noaa.gov/obop/mlo/aboutus/aboutus.html.

[125] USGS, *Island of Hawai'i Interagency Operation Plan for Volcanic Eruption*, 2024. See also FEMA, "National Incident Management System," https://www.fema.gov/emergency-managers/nims.

proclamation, the Hawaii Emergency Management Agency (HIEMA) and other state departments, such as Hawaii Army National Guard, provide additional support to the ICS. If the President issues an emergency or major disaster declaration, FEMA provides support to the state and county ICS.[126] The IH plan also describes a single jurisdictional authority response under an ICS and a multi-jurisdictional authority response under a unified area command. In addition, if the volcanic event is of potentially significant local, regional, or national interest, then a Joint Information Center may be established to coordinate and facilitate public information from agencies.

Emergency response to volcanic events on the island of Hawai'i may require airspace coordination, as described in the IH plan.[127] Aircraft face volcanic risks from ash, gases, volcanic ejecta, and heat (thermal effects) from lava flows. In general, HAVO or HCCDA requests a temporary flight restriction (TFR) from the FAA upon the start of an eruption within HAVO lands or on state lands, respectively.[128] A TFR is a regulatory action issued by FAA via a notice to air missions (NOTAM). FAA makes the decision about any TFR, regardless of whether HAVO or HCCDA has requested a TFR. In the past, the FAA's Honolulu Control Facility has allowed a TFR only in a circle shape. According to the IH plan, the Honolulu FAA may allow a polygon shape in the future.[129] The TFR generally restricts air tours, non-air tour aircraft (including charter and personal aircraft), and media flights near an eruption to avoid volcanic hazards and air-traffic congestion. Authorized administrative aircraft must be approved by the jurisdictional agency within the TFR and may include HVO, County of Hawai'i Fire Department, Civil Air Patrol, U.S. Coast Guard (USCG), National Guard, DOD, HAVO, FWS, state landowners, and private landowners.

Emergency response to volcanic events on the island of Hawai'i may require coordination on ocean activities, which has been handled separately by the USCG. The potential hazards of volcanic activity affecting the ocean may include plumes of hot, corrosive seawater with hydrochloric acid and ash particles; explosions of debris and eruptions of scalding water from hot rock entering the ocean; sudden lava delta collapses; and waves associated with explosions and collapses.[130] The USCG established a permanent safety zone surrounding the area of lava entry from Kīlauea volcano into the Pacific Ocean on the southeast side of the island of Hawai'i as of May 11, 2018.[131] The regulation prohibits persons and vessels from being in the safety zone during active lava flow reaching the Pacific Ocean on Kīlauea volcano's southeast coast unless specifically authorized by the Captain of the Port of Honolulu or a designated representative.

[126] FEMA, "How a Disaster Gets Declared," https://www.fema.gov/disaster/how-declared.

[127] The FAA, DOD, Hawai'i Army National Guard, and other aviation partners were not involved in the development of the IH plan. However, it is anticipated that these agencies will be involved in future versions of the plan. USGS, *Island of Hawaii Interagency Operation Plan for Volcanic Eruption*, 2024.

[128] USGS, *Island of Hawaii Interagency Operation Plan for Volcanic Eruption*, 2024; FAA, "Section 2. Temporary Flight Restrictions in the Vicinity of Disaster/Hazard Areas (14 C.F.R. Section 91.137)," https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap20_section_2.html.

[129] A polygon shape may more accurately depict the shape and forecast area of an ash plume moving away from an eruptive vent as described by a VAAC (e.g., see **Figure 20**) and may allow air traffic to more effectively avoid ash in the atmosphere. USGS, *Island of Hawai'i Interagency Operation Plan for Volcanic Eruption*, 2024; FAA, "Section 2. Temporary Flight Restrictions in the Vicinity of Disaster/Hazard Areas (14 C.F.R. Section 91.137)," https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap20_section_2.html.

[130] USGS, "Kīlauea Volcano Erupts," https://www.usgs.gov/news/featured-story/kilauea-volcano-erupts.

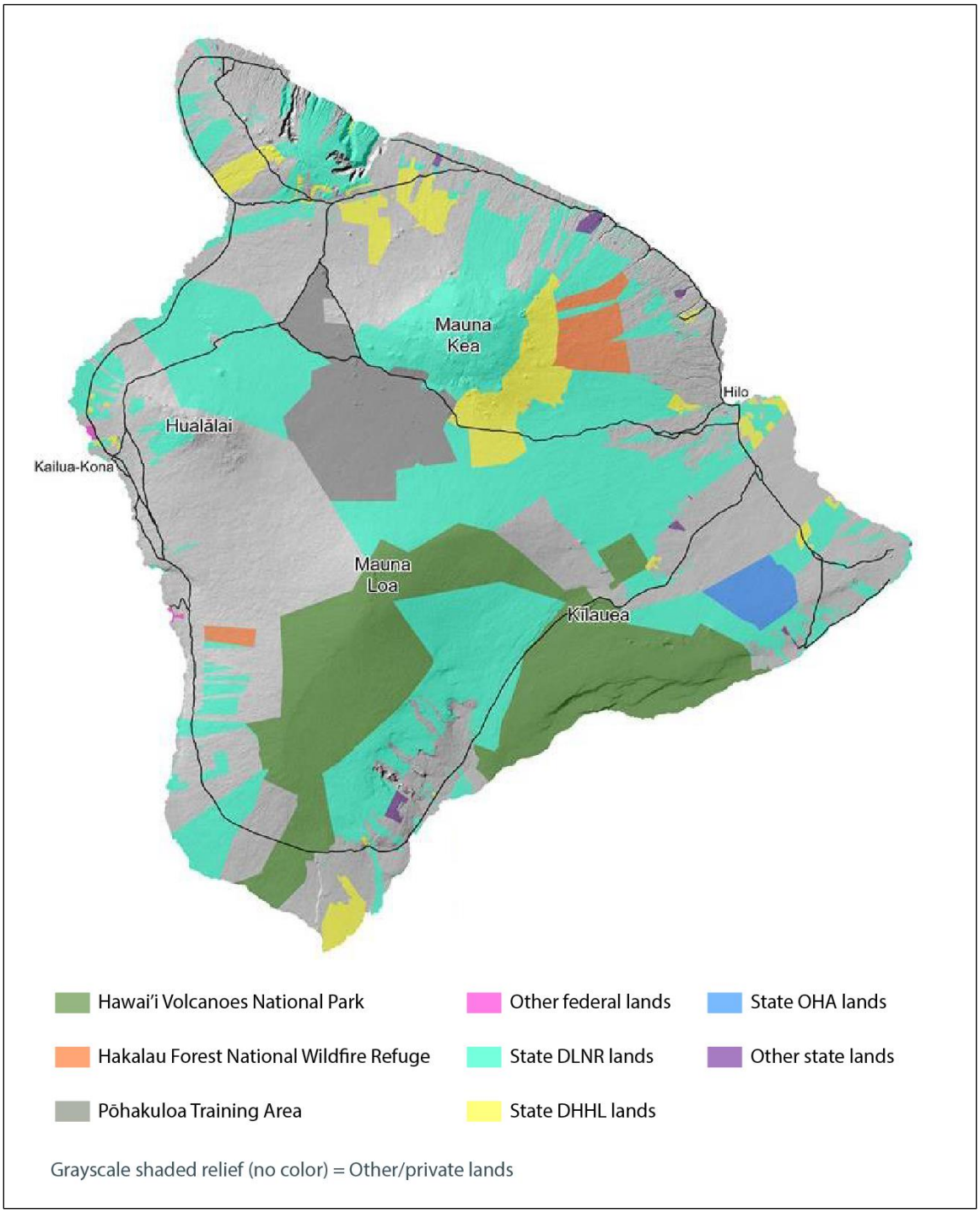
[131] USCG, "Safety Zone; Pacific Ocean, Kīlauea Lava Flow Ocean Entry on Southeast Side of Island of Hawaii, HI," 83 *Federal Register* 21876, May 11, 2018, https://www.federalregister.gov/documents/2018/05/11/2018-10049/safety-zone-pacific-ocean-kilauea-lava-flow-ocean-entry-on-southeast-side-of-island-of-hawaii-hi. According to the *Federal Register* notice, ocean safety concerns began on December 31, 2016, when a lava delta collapsed into the ocean and then additional volcanic activity along the southeast coast generated volcanic hazards.

Research and monitoring by HVO of previous eruptions and the 2018 Kīlauea eruption contributed to the USCG decision to extend the zone for 300 meters (984 feet) from the coastline. At HAVO's recommendation, the USCG made the safety zone flexible based on the location where lava may be entering the ocean.

On July 16, 2018, a Lava Ocean Tours boat was hit by a volcanic bomb that injured 23 passengers.[132] The boat was about 50 meters (164 feet) from the coast where lava from the 2018 Kīlauea eruption was entering the ocean. The USCG had granted permission to the tour boat company, as well as other commercial operators, to come as close as 50 meters to the lava's ocean entry point. After the accident, the USCG rescinded all exemptions to the permanent 300-meter safety zone.

[132] Allison Schaefers, "Tour Boat Operator Involved in a Lava Bomb Incident Has History of Passenger Issues," *Star Advertiser*, July 18, 2018, https://www.staradvertiser.com/2018/07/18/hawaii-news/tour-boat-operator-involved-in-a-lava-bomb-incident-has-history-of-passenger-issues/.

Figure 21. Island of Hawai'i: Land Management



Source: U.S. Geological Survey**,** *Island of Hawai'i Interagency Operation Plan for Volcanic Eruption*, July 12, 2024. https://www.usgs.gov/observatories/hvo/news/volcano-watch-introducing-island-hawaii-interagency-operations-plan-1.

Notes: DLNR = Department of Land and Natural Resources; DHHL = Department of Hawaiian Homelands; OHA = Office of Hawaiian Affairs. The U.S. Army operates the Pōhakuloa Training Area. Kohala volcano (north of Mauna Kea volcano) is not indicated on this map; other volcanoes are labeled with larger text. Two cities are labeled with smaller text. See **Figure 4** for all five volcanoes.

Other Volcano Warning Products in Use in Hawaii

The information and warnings from the USGS (HVO) and NOAA (WVAAC), the two primary federal agencies focused on volcanic activity, are used to develop other volcano warning products used in Hawaii (**Table 1**). In addition to the VAA warning products from WVAAC, the NWS may issue other volcano warning products in Hawaii (**Table 1**). For aviation, the Honolulu MWO may issue Significant Meteorological Information, which serves as the primary warning product to the aviation community for volcanic ash.[133] Central Weather Service Unit (CWSU) meteorologists provide decision support and weather briefing services for 21 FAA Air Route Traffic Control Centers (ARTCCs).[134] CWSU meteorologists, typically located at the Honolulu ARTCC, may issue a Center Weather Advisory or Meteorological Impact Statement as needed, to provide additional information essential to air traffic managers' decisionmaking processes about volcanic ash.

The Honolulu Weather Forecast Office (WFO) may issue ashfall statements, advisories, and warnings for the public and marine communities (**Table 1**). Ashfall is included in Terminal Aerodrome Forecasts as appropriate. The WFOs also assist in the coordination of information during volcanic events by soliciting ashfall reports and briefing local community members and leadership about potential hazards.

In the United States, the FAA advises pilots not to fly through volcanic ash and provides advice about flight operations if a pilot encounters ash while flying, landing, or taking off.[135] The FAA may restrict air space based on the presence of volcanic ash.[136] The FAA may issue a NOTAM about volcanic ash hazards; it also may issue an Urgent Pilot Report or a TFR (**Table 1**).[137] DOD and Hawaii state and county agencies issue other volcano warning products (**Table 1**).

Table 1. Island of Hawai'i: Volcanic Warning Products and Authorities

Organization	Product and/or Authorities
Hawaiian Volcano Observatory	Information release
	Weekly update
	Daily update
	Status report
	Volcano Activity Notice (VAN)
	Volcano Observatory Notice for Aviation (VONA)

[133] The Honolulu MWO falls under the purview of the Honolulu WFO. NWS, "NWS Forecast Office Honolulu, HI," https://www.weather.gov/hfo. The Honolulu MWO maintains a meteorological watch over the central and western Pacific Ocean. The Honolulu MWO is responsible for an ICAO FIR that covers a portion of the Oakland Oceanic FIR south of 30 N and west of 140 W (**Figure 19**). ICAO, *Handbook*, 2024; ICAMS, *National Volcanic Ash Operations*, 2024. See also NOAA, "Aviation Weather Services," https://www.weather.gov/media/aviation/Aviation%20trifold_without%20crop%20marks.pdf.

[134] FAA, "Air Route Traffic Control Centers (ARTCC)," https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/air_traffic_services/artcc.

[135] FAA, "Flight Operations in Volcanic Ash."

[136] FAA, "3-5-3 Temporary Flight Restrictions," in *Aeronautical Information Manual (AIM)*, at https://www.faa.gov/air_traffic/publications/atpubs/aim_html/chap3_section_5.html.

[137] A notice to air missions (NOTAM) prescribes direction used to format and distribute information regarding unanticipated or temporary changes to services, components of, or hazards in the National Airspace System. FAA, "Notice to Air Missions (NOTAM)," https://www.faa.gov/documentLibrary/media/Order/7930.2S_Chg_2_dtd_12-2-21.pdf.

Organization	Product and/or Authorities
Washington Volcanic Ash Advisory Center	Volcanic Ash Advisory (VAA) and Volcanic Ash Graphic (VAG)
Hawaii Interagency Vog Information Dashboard	Vog measurements and forecasts Air quality measurements, advisories, or guidance statements
National Weather Service	Significant Meteorological Information (SIGMET)—Honolulu Meteorological Watch Office (MWO) Meteorological Impact Statement (MIS)—Honolulu Central Weather Service Unit Center Weather Advisory (CWA)—Honolulu Central Weather Service Unit
Honolulu Weather Forecast Office (WFO)	Public Ashfall Advisory and Warning Marine Ashfall Advisory and Warning Special Weather and Marine Weather Statements Terminal Aerodrome Forecast (TAF)
Federal Aviation Administration	Notice to Air Missions (NOTAM) Urgent Pilot Report (UAA) Temporary Flight Restriction (TFR)
U.S. Coast Guard	Notice to Mariners, Marine Information Broadcast Temporary Ocean Restrictions
Department of Defense	Volcanic Ash Bulletin Jurisdictional authority for safety and emergency response in U.S. Army Pōhakuloa Training Area
National Park Service	Jurisdictional authority for safety and emergency response in Hawai'i Volcanoes National Park (HAVO), Kaloko-Honokōhau and Pu'uhonua o Hōnaunau National Historical Parks, Pu'ukoholā Heiau National Historic Site, and the Ala Kahakai National Historic Trail
Hawai'i County Civil Defense Agency (HCCDA)	Jurisdictional authority for safety and emergency response on nonfederal lands on the island of Hawai'i
Hawaii Emergency Management Agency (HIEMA)	Jurisdictional authority for safety and emergency response on nonfederal lands in Hawaii

Source: U.S. Geological Survey, *Island of Hawai'i Interagency Operations Plan for Volcanic Eruptions*, July 2024, https://www.usgs.gov/programs/VHP/coordination-plans; and Air Force, "Renewal ensures wing, Volcanic Ash Advisory Center partnership endures," https://www.af.mil/News/Article-Display/Article/2540260/renewal-ensures-wing-volcanic-ash-advisory-center-partnership-endures/.

Notes: Jurisdictional authority for safety and emergency response may include issuing shelter-in-place or evacuation orders; implementing road or land restrictions; changing operations or closure orders; managing the movement of people or property; and managing boat, vehicle, and/or aircraft traffic. In general, safety and emergency response to volcanic activity is avoidance of volcanic hazards.

Communication of Volcano Warning Products in Hawaii

HCCDA may communicate information about volcanic activity through Hawai'i County alerts (voice or text messages), all-hazard outdoor warning sirens, civil defense AM/FM radio messaging, and hazard impact maps. HCCDA, with HIEMA, also may communicate information about volcanic activity and emergency response through the national Emergency Alert System or the Wireless Emergency Alert.[138]

Each federal agency distributes alert and safety information (i.e., volcano warning products) through various communication portals. HVO issues notification of volcanic activity via telephone call to partner agencies as well as email, website, social media postings, and the USGS Volcano Notification Service. The NWS uses NOAA Weather Wire, marine high frequency and very-high-frequency radio, NOAA Weather Radio, television weathercasts, and the Emergency Alert System, in addition to distribution of text and graphics by its own telecommunications gateway and through radio facsimile, satellite-based SafetyNet Service, and the internet. The USCG broadcasts NWS marine forecasts over high-frequency radio. FAA distributes aviation weather forecasts and warnings from the NWS, flight information, pilot reports, and terminal information via its Aeronautical Fixed Telecommunications Network.

Congressional Considerations

Congress may consider continued oversight of the USGS VHP and of NVEWS more specifically. Congressional considerations may include oversight of plans, progress, and priorities; annual and any potential supplemental appropriations for VHP; potential reauthorization of appropriations for NVEWS (authorized appropriations expired in FY2023); and amendments to NVEWS.

Since the establishment of NVEWS, the USGS generally has divided VHP's activities into volcanic threat assessments, operational support, the Volcano Disaster Assistance Program, and NVEWS activities. Most HVO-conducted research, monitoring, and warning and any integration of HVO with NOAA's WVAAC volcanic ash warning activities generally fall under NVEWS activities. Congress provided supplemental appropriations for new HVO facilities and for the repair or replacement of monitoring equipment after the damaging 2018 Kīlauea eruption.[139] In the future, Congress may consider how HVO is being unified with other observatories and modernized, as well as whether HVO is able to monitor volcanoes in its area of responsibility (i.e., Hawaii and American Samoa) to help prevent undue harm, a primary objective of NVEWS.

[138] Federal Communications Commission (FCC), "The Emergency Alert System," https://www.fcc.gov/emergency-alert-system; FCC, "Wireless Emergency Alerts (WEA)," https://www.fcc.gov/consumers/guides/wireless-emergency-alerts-wea. The Hawaii Emergency Management Agency is a registered Integrated Public Alert and Warning System (IPAWS) alerting authority; FEMA, "IPAWS Alerting Authorities—Agencies and Organizations," https://www.fema.gov/emergency-managers/practitioners/integrated-public-alert-warning-system/public-safety-officials/alerting-authorities/agencies-organizations. See also CRS Report R48363, *The Integrated Public Alert and Warning System (IPAWS): Primer and Issues for Congress*, by Amanda H. Peskin.

[139] CRS In Focus IF12152, *U.S. Geological Survey (USGS): Supplemental Appropriations*, by Anna E. Normand and Linda R. Rowan.

Plans and Progress

NVEWS plans to enhance monitoring at 34 very high- to high-threat volcanoes, including Kīlauea and Mauna Loa, and to establish a 24/7 watch office, an external grants program, and advisory committees, but some of these plans have not been fully implemented.[140] An ongoing issue facing Congress is whether the NVEWS plans and activities ensure Hawaii's active volcanoes are monitored at a level commensurate with each volcano's threat. [141] The USGS is developing a National Volcano Information System that is expected to include a 24/7 watch office and a National Volcano Data Center (pursuant to §5001 of P.L. 116-9), but neither entity had been fully established as of the end of the five-year authorization of appropriations for NVEWS (i.e., FY2023).[142] The 2024 USGS *Volcano Science Center Response Plan for Significant Volcanic Events* calls for temporary 24/7 watch capabilities for significant volcanic events.[143] P.L. 117-263 directs the U.S. volcano observatories to integrate relevant capacities of NOAA, including the VAACs, to observe and monitor volcanic activity in the atmosphere and ocean. In 2025, NOAA submitted an implementation plan to Congress that aims to focus around seven equal priorities to improve (1) monitoring and forecasting of vog; (2) operational planning to warn about debris flows/lahars; (3) the quantification of airborne ash hazards for aviation; (4) the quantification of ashfall hazards; (5) near-real-time data sharing; (6) forecasting volcanogenic tsunamis and submarine eruptions; and (7) the efficacy of USGS and NOAA hazard information products.[144] Congress may be interested in any progress on these implementation plans and whether any actual costs are similar to the plan's cost estimates.

Appropriations and Proposed Amendments

According to the USGS, from FY2019 to FY2023 the agency spent about $162 million (in nominal dollars) for VHP; of those funds, about $48 million (in nominal dollars) were specified for NVEWS activities.[145] P.L. 116-9 authorized $55 million for the USGS to carry out NVEWS for FY2019 to FY2023.[146] The USGS increased its spending for NVEWS activities as the program developed after the enactment of P.L. 116-9 on March 12, 2019, and close to half of the VHP budget in FY2021 to FY2023 was specified for NVEWS activities. For FY2021, USGS

[140] The USGS established an advisory committee in 2024. The 2024 NVEWS advisory committee annual report, available online, describes the status of implementation of NVEWS. USGS, "National Volcano Early Warning System Advisory Committee," https://www.usgs.gov/programs/VHP/national-volcano-early-warning-system-advisory-committee-nvewsac; USGS, *NVEWS Advisory Committee Annual Report 2024*, https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/media/files/.NVEWSAC%20annual%20report%202024_sign.pdf.

[141] USGS, *NVEWS Plan*; USGS, "National Volcano Warning System—Monitoring Volcanoes According to Their Threat," https://www.usgs.gov/programs/VHP/national-volcano-early-warning-system-monitoring-volcanoes-according-their-threat. See also CRS In Focus IF11987, *The National Volcano Early Warning and Monitoring System*, by Linda R. Rowan.

[142] 43 U.S.C. §31k; USGS, *NVEWS Plan*; CRS In Focus IF11987, *The National Volcano Early Warning and Monitoring System*, by Linda R. Rowan; USGS, HVO, "Volcano Watch: A Focus on the National Volcano Information System," posted by the USGS on April 10, 2025, https://www.usgs.gov/observatories/hvo/news/volcano-watch-a-focus-national-volcano-information-service.

[143] USGS, *Response for Volcanic Event*.

[144] Kenneth E. Graham et al., *Implementation Plan*, 2025, pp. 1-19.

[145] USGS, "USGS Budget by Fiscal Year (FY)," https://www.usgs.gov/bfa/usgs-budget-fiscal-year-fy.

[146] USGS, "USGS Budget by Fiscal Year (FY)," https://www.usgs.gov/bfa/usgs-budget-fiscal-year-fy.

divided VHP funding categories into volcanic threat assessments, operational support, the Volcano Disaster Assistance Program, and NVEWS activities.[147]

In the 119th Congress, S. 1052, introduced on March 13, 2025, would amend P.L. 116-9 and reauthorize NVEWS. S. 1052 would reauthorize appropriations for the USGS of $75 million until FY2033 and extend to FY2034 the period of authorization of sums necessary for NOAA to carry out its NVEWS-related activities. S. 1052 would amend NVEWS's statute by adding the Chief of the Forest Service as a coordinating agency and by adding "infrasound arrays, visible and infrared cameras and advanced digital telemetry networks" to the emerging technologies the USGS should apply to modernize NVEWS.[148] Another measure to reauthorize appropriations for NVEWS—H.R. 3176, introduced on May 5, 2025—would provide $55 million for the Secretary of the Interior (striking "the United States Geological Survey" and replacing it with "the Secretary of the Interior" in federal statute) from FY2026 to FY2030. It also would provide, from FY2026 to FY2030, such sums as may be necessary for the Secretary of Commerce (replacing "NOAA") to carry out NVEWS.[149]

Congress also may consider other appropriations for volcano research, monitoring, and warning and how appropriations for other USGS programs may support NVEWS and VHP activities.[150] In 2019, before the enactment of P.L. 116-9 to establish NVEWS, Congress provided supplemental appropriations for HVO to recover from damaging eruptions and for the Alaska Volcano Observatory to recover from a damaging earthquake.[151] Since the 2018 Kīlauea eruption, HVO has repaired or replaced damaged instruments and repaired, modernized, and hardened its digital telemetry networks (see "Monitoring").[152] Besides supplemental appropriations, Congress has funded other USGS programs that support NVEWS and other VHP activities. For example, P.L. 117-169 provided $23.5 million for the 3D Elevation Program, the USGS's lidar-based topography program.[153] HVO uses lidar to map changes in Hawaii's active volcanoes (**Figure 11**).

Congress may consider emerging technologies and proposed amendments related to emerging technologies (S. 1052) to help NVEWS meet its objectives and help HVO effectively research, monitor, and warn about Hawaii's active volcanoes. HVO is using the emerging technologies mentioned in the existing federal statute and in S. 1052, plus others (e.g., the newly acquired gravimeter).[154] Congress could ask the USGS for updated implementation plans with cost estimates that describe which technologies are being used and which are still needed to modernize

[147] See "FY 2021 Volcano Hazards Program Funding by Category" figure on p. 79 of USGS, *Budget Justifications and Performance Information Fiscal Year 2023*, https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/media/files/FY23-USGS-Greenbook.pdf.

[148] The emerging technologies included in 43 U.S.C. §31k(b)(2)(B) are "digital broadband seismometers, real-time continuous Global Positioning System receivers, satellite and airborne radar interferometry, acoustic pressure sensors, spectrometry to measure gas emissions, and unoccupied aerial vehicles."

[149] 43 U.S.C. §31k(c).

[150] CRS In Focus IF13025, *The U.S. Geological Survey (USGS): Background and FY2026 Appropriations*, by Anna E. Normand.

[151] CRS In Focus IF12152, *U.S. Geological Survey (USGS): Supplemental Appropriations*, by Anna E. Normand and Linda R. Rowan.

[152] USGS, *2019 Disaster Relief Act: USGS Recovery Activities*, Fact Sheet 2019-3066, October 2019, https://pubs.usgs.gov/fs/2019/3066/fs20193066.pdf; USGS, "2019 Supplemental Appropriations Activities," https://www.usgs.gov/supplemental-appropriations-for-disaster-recovery-activities/2019-supplemental-appropriations; USGS, HVO, "Volcano Watch: HVO's Ongoing Recovery from the 2018 Kīlauea Eruption," at https://www.usgs.gov/volcanoes/kilauea/news/volcano-watch-hvos-ongoing-recovery-2018-kilauea-eruption.

[153] For more information about lidar and the 3D Elevation Program, seeCRS In Focus IF13079, *The 3D Elevation Program (3DEP) and Its Role in Mapping Hazards and Resources*, by Linda R. Rowan.

[154] 43 U.S.C. 31k(b)(2)(B).

and unify the five observatories while ensuring each volcano is adequately monitored commensurate with its threat level. Such an update could potentially inform any future appropriations for NVEWS, VHP, and other USGS programs.

Appendix A. Acronyms Used in This Report

List of Acronyms Used in This Report

ANSS	U.S. Advanced National Seismic System
ARTCC	Air Route Traffic Control Center
AVO	Alaska Volcano Observatory
CalVO	California Volcano Observatory
CVO	Cascades Volcano Observatory
CWSU	Central Weather Service Unit
DOD	Department of Defense
ERZ	East Rift Zone
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FWS	U.S. Fish and Wildlife Service
HAVO	Hawai'i Volcanoes National Park
HCCDA	Hawai'i County Civil Defense Agency
HIEMA	Hawaii Emergency Management Agency
HISN	Hawaii Integrated Seismic Network
HVO	Hawaiian Volcano Observatory
ICAO	International Civil Aviation Organization
ICS	Incident Command System
IVHHN	International Volcanic Health Hazard Network
MWO	Meteorological Weather Office
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Air Missions
NPS	National Park Service
NVEWS	National Volcano Early Warning and Monitoring System
NWS	National Weather Service
QVA	Quantitative Volcanic Ash
TFR	Temporary Flight Restriction
USCG	United States Coast Guard
USGS	United States Geological Survey
VAA	Volcanic Ash Advisory
VAAC	Volcanic Ash Advisory Center
VAG	Volcanic Ash Graphic
VAN	Volcano Activity Notice
VEI	Volcanic Explosivity Index

VHP	Volcano Hazards Program
VONA	Volcano Observatory Notice for Aviation
VSC	Volcano Science Center
WEA	Wireless Emergency Alert
WFO	Weather Forecast Office
WVAAC	Washington Volcano Ash Advisory Center (located in College Park, MD, outside of Washington, DC)
YVO	Yellowstone Volcano Observatory

Appendix B. Volcano Terms

Terms describing volcanic features, volcanic processes, and volcanic hazards may vary based on volcano type (e.g., stratovolcano or shield volcano), from place to place, and over time as volcano science advances. The following is a list of volcano terms commonly applied to volcanoes in the United States. Hawaiian terms such as *pahoehoe* may be applied to other volcanoes, not just Hawaii's volcanoes.

Glossary of Volcano Terms

Aa	Hawaiian term for a lava flow with a rubbly surface composed of broken lava blocks. Walking on such a flow is difficult and may be hazardous.
Ash	Fine fragments (typically less than 2 to 4 millimeters, or 0.08 to 0.16 inches) of volcanic rock formed by a volcanic explosion or ejection from a volcanic vent.
Ashfall (fallout or tephra fall)	A rain of ash and volcanic debris that falls to the ground from an eruption.
Basalt	Volcanic rock or lava that is typically black to gray with few to no visible crystals (i.e., minerals); rich in iron and magnesium; and lower in silica (silicon dioxide) than most other volcanic rocks such as andesites, dacites, or rhyolites. Basalt is generally more fluid and darker in color than other volcanic rocks because it contains less silica. Basalt forms from direct melting in the Earth's subsurface and the lava cools quickly on the surface, leaving little to no time for larger crystals that are visible with an unaided eye to form in the rock. Basalt is the most common rock type in the Earth's crust, and most of the ocean floor is made of basalt. *Flood basalts* are large volumes of lava erupted over a few million years, such as the Columbia River basalts covering parts of Washington, Oregon, and Idaho. The Hawaiian Islands are composed mostly of basalt.
Bomb	A large rock fragment (typically hand-sized or larger) that is forcibly ejected from a volcano and travels an airborne path during an eruption.
Caldera	A large, basin-shaped depression with a diameter many times larger than any vents within the caldera; diameter may range from 2 to 50 kilometers (1 to 30 miles) across. Commonly formed when magma is withdrawn or erupted from a shallow underground magma reservoir. When large volumes of magma are removed, the overlying rock collapses to form these large depressions. Kīlauea and other Hawaiian volcanoes have classic calderas.
Caldera Complex	A type of volcano consisting of a caldera with a volcanic field filled with eruptive vents over a large and complex magma reservoir. The volcano does not have a shield shape or cone shape but typically is recognized by its extensive caldera and volcanic activity. The Yellowstone Caldera Complex covers about 43 miles by 28 miles on the surface. Other caldera complexes include Valles in New Mexico; Long Valley in California; and Aniakchak Caldera, Fisher Caldera, and the Atka volcanic complex in Alaska.
Crater	A small-to-large circular depression (typically a few hundred meters to tens of kilometers, or less than a mile to several miles across). Created primarily by explosive excavation of rock during eruptions. A crater may become larger and more irregular in shape due to multiple eruptions and volcano growth. Craters are different from calderas in size, shape, and origin, but the terms may be applied interchangeably.
Debris Avalanche	Moving masses of rock, soil, snow, and/or ice that occur when the flank of a mountain or volcano collapses and slides downslope. Debris avalanches may transform into lahars and travel tens of kilometers further away from the volcano.

Effusive Eruption	An eruption dominated by the outpouring of lava flows onto the surface.
Ejecta	Material explosively ejected from a volcano.
Explosive Eruption	An energetic eruption that produces mainly ash, pumice, and fragmental ballistic debris.
Fire Fountain (lava fountain)	Molten hot lava with yellow-to-orange colors that look like fire erupting in a shape that resembles water squirting from a fountain.
Fissure	An elongate fracture or crack at the surface from which lava erupts. Fissure eruptions typically dwindle to a central vent after a period of hours or days. Occasionally, lava will flow back into the ground by pouring into a crack or an open eruptive fissure, a process called *drainback*.
Fumarole	Vents from which volcanic gas escapes into the atmosphere.
Geyser	A hot spring characterized by intermittent discharge of water ejected turbulently and accompanied by vapor. Geysers are rare; there are only a few thousand worldwide. About half of Earth's geysers are in Yellowstone National Park and are associated with the Yellowstone Caldera Complex. Geysers require water, heat, magmatism, rhyolite flows to supply heat and silica, and fractures/cavities that provide a conduit to the surface.
Lahar (volcanic mudflow or debris flow)	A mixture of water and volcanic debris that moves rapidly down a slope or becomes entrained in a stream. The consistency of the mixture can range from muddy dishwater to wet cement. Lahars form by the rapid melting of snow and ice due to pyroclastic flows, intense rainfall on loose volcanic rocks, breakout of a lake dammed by volcanic deposits, or as a consequence of debris avalanches.
Lava Dome	A steep-sided mass of viscous and often blocky lava extruded from a vent; typically has a rounded top and covers a roughly circular area. May be isolated or, alternatively, associated with lobes or flows of lava from the same vent. Typically silicic (rhyolite or dacite) in composition. Novarupta is a lava dome.
Lava Flow	Masses of molten rock that pour onto the Earth's surface during effusive eruption. Molten and solidified rock are referred to as *lava flows*. Lava flows vary in shape, thickness, length, and width depending on the type of lava, the volume of the eruption, the duration of the eruption, and the shape of the surface over which the lava flows. The type of lava varies from the most fluid and least silica-rich to the least fluid and most silica-rich—that is, from basalt to andesite to dacite and finally to rhyolite.
Lava Tube	Conduits through which lava travels beneath the surface of a lava flow. Lava tubes may be partially filled to empty and may erode, creating gaps or uneven surfaces.
Laze Plume	A white plume consisting of hydrochloric acid, steam, and fine volcanic glass particles. Laze forms when hot lava hits the ocean.
Magma Reservoir (magma chamber)	The zone beneath the surface of a volcano where molten rock is concentrated and stored; the subsurface source of molten rock that produces lava flows.
Pahoehoe	Hawaiian term for basaltic lava with a smooth, hummocky, or ropy surface. A pahoehoe typically advances as a series of small lobes and toes that continually break out from a cooled crust.
Pele's Hair	Thin glass fibers (about a micrometer thick and can be as long as a few feet) formed when bubbles of gas near the surface of a lava flow burst, stretching the skin of the molten lava into long threads. The threads are so light that they can be carried away from the volcano by the wind. Pele's hair can accumulate in low-lying areas and form dense mats. These tiny pieces of glass can cause harm if embedded in skin, eyes, or elsewhere.

Phreatic Eruption	Steam-driven explosions of steam, water, ash, and volcanic blocks. Such explosions may happen when water on or below the surface is heated by magma, lava, or hot rocks, causing the water to boil and flash to steam.
Pumice	Highly vesicular (i.e., full of holes) and silicic volcanic ejecta. Pumice essentially is magma that has been frothed up by escaping gases and then cools and solidifies during eruption. Rhyolitic pumice is typically of low enough density that it floats on water.
Pyroclastic Flow	A hot (greater than 800 degrees Celsius, or 1472 degrees Fahrenheit) chaotic mixture of rock fragments, gas, and ash that travels rapidly (tens of meters per second, or tens of miles per hour) away from a volcanic eruption.
Rhyolite	Volcanic rock or lava that is typically white to light gray with few-to-some visible crystals (minerals); rich in silica, sodium, and potassium; and higher in silica than most other volcanic rocks, such as dacites, andesites, or basalts. Rhyolitic lavas are viscous (i.e., not fluid but resistant to flow) and tend to form thick, blocky lava flows or steep-sided piles of lava called *lava domes*. Rhyolite magmas tend to erupt explosively, commonly producing ash and pumice.
Rift Zone	On a volcano, a generally linear zone where the Earth's crust is being pulled apart, often characterized by fissures and vents through which magma erupts, generating volcanic activity and lava flows. More generally, a tectonically active area where the Earth's crust and uppermost mantle thins due to upwelling magma, leading to volcanic activity and the formation of linear cracks or rifts, especially on the ocean floor.
Shield Volcano	A broad shield-shaped volcano that is built by successive, mostly effusive eruptions of primarily basalt. Aa and pahoehoe lava flows are common. Some shield volcanoes are topped with a caldera. The Hawaiian Islands are shield volcanoes.
Stratovolcano	A steep, cone-shaped volcano that is built by successive explosive and effusive eruptions of basalt, andesite, dacite, and/or rhyolite. A stratovolcano may consist of multiple vents, cones, domes and/or craters and sometimes is called a *composite volcano*. Lava flows, pyroclastic flows, lahars, ash, pumice, phreatic explosions, and other volcanic activity may occur. Most of Alaska's volcanoes plus the Cascade Range in California, Oregon, and Washington are stratovolcanoes.
Tephra	A general term for volcanic rock fragments irrespective of grain size produced during an explosive eruption. Volcanic ash is fine tephra, and terms such as *lapilli*, *blocks*, and *bombs* are used to categorize larger fragments.
Tuff	A general term for consolidated (hardened and/or compacted) pyroclastic rocks.
Vent	Any opening at the Earth's surface through which magma erupts or volcanic gases are emitted.
Vog	Volcanic smog consisting of gas, aerosol of tiny particles, and acidic droplets formed when sulfur dioxide and other gases emitted from a volcano chemically interact with sunlight, atmospheric oxygen, moisture, and dust. Vog and other volcanic gas emissions can pose environmental and health risks. Vog is a hazard most often associated with Hawaiian volcanoes, and there is a Hawaii Interagency Vog Information Dashboard for more information and current conditions.
Volcanic Explosivity Index (VEI)	A numeric scale that measures the relative explosivity of historic eruptions. The volume of products, eruption cloud height, and qualitative observations (using terms ranging from *gentle* to *mega-colossal*) are used to determine the explosivity value. The scale is open-ended, with the largest volcanic

	eruptions in history given magnitude 8. A value of 0 is given for nonexplosive eruptions, defined as less than 10,000 cubic meters (350,000 cubic feet) of tephra ejected; a value of 8 represents a mega-colossal explosive eruption that can eject as much as 10^{12} cubic meters (240 cubic miles) of tephra and have a cloud column height of over 20 kilometers (12 miles). The scale is logarithmic, with each interval on the scale representing a tenfold increase in observed ejecta criteria (with the exception of between VEI 0, VEI 1, and VEI 2 representing a less than tenfold increase).
Volcanic Gases	Gases emitted by a volcano may include (1) carbon dioxide, which may become concentrated in low-lying areas and can be lethal to people and animals in high concentrations; (2) sulfur dioxide, which can irritate the eyes, skin, and respiratory system and can cause acid rain, air pollution, and vog; (3) hydrogen sulfide, which can irritate the upper respiratory tract and, with long exposure, can cause pulmonary edema or, with high concentration, cause death; (4) hydrofluoric acid, hydrochloric acid, or hydrobromic acid, which are toxic acids that may cause acid rain or may be present in ashfall, leading to poisoning of surface waters and lands that may impact drinking water supplies, agriculture, grazing, and fishing.

Sources: U.S. Geological Survey (USGS), "Volcano Hazards Program Glossary," at https://volcanoes.usgs.gov/vsc/glossary/; Shaul Hurwitz and Michael Manga, "The Fascinating and Complex Dynamics of Geyser Eruptions," *Annual Review of Earth and Planetary Sciences*, vol. 45 (2017), pp. 31-59, https://www.annualreviews.org/content/journals/10.1146/annurev-earth-063016-015605; Hawaii Volcanoes National Park, "Pele's Hair," at https://www.nps.gov/havo/learn/nature/peles-hair.htm; USGS, "Caldera or Crater ... What's the Difference?," at https://www.usgs.gov/observatories/yvo/news/caldera-or-craterwhats-difference; USGS, "What Is 'Vog'? How Is It Related to Sulfur Dioxide (SO2) Emissions?," at https://www.usgs.gov/faqs/what-vog-how-it-related-sulfur-dioxide-so2-emissions; USGS, "Volcanic Gases Can Be Harmful to Health, Vegetation and Infrastructure," at https://www.usgs.gov/programs/VHP/volcanic-gases-can-be-harmful-health-vegetation-and-infrastructure.

Appendix C. Impacts of the 2018 Kīlauea Eruption

The following information is quoted from the County of Hawai'i Kīlauea Eruption Recovery webpage "2018 Eruption."[155] It lists some of the impacts of the 2018 Kīlauea eruption, tabulated by county. See the webpage for a timeline of eruptive events, starting in mid-March and ending on October 5, 2018, with the reduction of the alert level from watch to advisory after 30 days without seeing lava on the surface.

Natural

- 13.7 square miles or 8,488 acres inundated with lava
- 875 acres new land created along shoreline
- 500 acres of forest reserve destroyed
- 80 anchialine pools inundated
- Loss of Kapoho Bay and Wai'ōpae Tidepools Marine Life Conservation District
- Pu'ala'a low-land rainforest and historic fishing village destroyed
- Ahalanui Beach Park destroyed
- Kīlauea summit collapse
- Approximately 1 cubic kilometer of lava erupted; two-thirds from Fissure 8

Housing

- 1,770 total parcels impacted
- 1,579 inundated parcels
- 612 residences destroyed
- 111 "other" structures destroyed
- 39 inundated agricultural lots
- 19 homes remaining in isolation
- 808 vacant parcels inundated
- Estimated 3,000 residents initially displaced during eruption
- $296 million in home losses

Infrastructure

- Estimated $236.5 million in damages to public infrastructure
- 32.3 miles of roads inundated, including nearly 13 miles of public roads
- 14.5 miles of waterlines destroyed
- Kua O Ka Lā Public Charter School destroyed
- 900 utility poles destroyed
- 2 geothermal wells inundated; 1 isolated
- 1 electrical substation isolated

[155] Kīlauea Eruption Recovery, "2018 Eruption," accessed Marth 21, 2025, https://recovery.hawaiicounty.gov/resources/2018-eruption.

- 1 water well isolated

Economic

- 2,950 jobs lost
- $415 million in revenue lost inland-wide
- Hawai'i Volcanoes National Park closure: $99.4 million in economic loss
- $27.9 million farm losses resulting in decreased agriculture and floriculture production
- Decreased tourism revenue and adjustments to marketing and products

Appendix D. Some Observations and Models Used by International Airways Volcano Watch

Table D-1. Some Observations and Models Used by International Airways Volcano Watch

Organization	Observations or Models	Website
Smithsonian Institution Global Volcanism Program	Data on volcanic activity	http://volcano.si.edu/
National Oceanic and Atmospheric Administration (NOAA)	Volcanic ash dispersion models	https://www.ready.noaa.gov/HYSPLIT.php
NOAA	Volcanic cloud monitoring and models	https://volcano.ssec.wisc.edu
National Aeronautics and Space Administration (NASA)	Global sulfur dioxide monitoring	https://so2.gsfc.nasa.gov/
NASA Worldview	Global earth observations	https://worldview.earthdata.nasa.gov/
U.S. Geological Survey (USGS)	Global volcanic lightning monitor	http://wwlln.net/USGS/Global/
British Geological Survey	Eruption source parameters for volcanoes	https://www.bgs.ac.uk/geology-projects/volcanoes/eruption-source-parameters
World Organization of Volcano Observatories	Data on volcanic activity	https://wovo.iavceivolcano.org/wovodat
Iceland	Catalogue of Icelandic Volcanoes	https://icelandicvolcanos.is
European Union	European Catalogue of Volcanoes and Volcanic Areas in Europe	https://volcanos.eurovolc.eu
Royal Belgian Institute of Space Aeronomy	Support to Aviation Control Service for London and Toulouse Volcanic Ash Advisory Centers	https://sacs.aeronomie.be/

Source: International Civil Aviation Organization (ICAO), *Handbook on the International Airways Volcano Watch*, Doc 9766-AN/968, 2024.

Notes: ICAO's International Airways Volcano Watch lists these additional resources for information about volcanic ash activity observations and volcanic ash models that may be helpful for preparing volcanic ash advisories. These measurements and models are in addition to the information gathered by volcano observatories and volcanic ash advisory centers.

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