Congressional Research Service
Informing the legislative debate since 1914

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

May 8, 2025

Congressional Research Service
https://crsreports.congress.gov
R48529

CRS REPORT
Prepared for Members and
Committees of Congress

Congressional Research Service
Informing the legislative debate since 1914

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

SUMMARY

R48529

May 8, 2025

Linda R. Rowan
Analyst in Natural Resources and Earth Sciences

Alaska has about 140 active volcanoes, and the U.S. Geological Survey (USGS) considers 86 to be threatening to people and property. Most of Alaska's active volcanoes are stratovolcanoes, capable of explosive and effusive eruptions potentially impacting local, regional, and global communities and aviation. A primary risk is ash, which may harm human health and the environment, damage property, damage aircraft, and alter flight operations.

On October 16, 2024, increasing volcanic activity at Mount Spurr in Alaska caused the USGS to raise Mount Spurr's volcano and aviation alert levels, warning that an eruption may be possible and increasing concern about risks to people, property, and aviation. Mount Spurr is about 81 miles from Anchorage, and past eruptions have caused damage. Warning about hazardous volcanic activity relies on various federal, state, and local research, monitoring, forecasting, and alerting collaborations. Alaska's volcanoes are remote and hard to access, and they exist in harsh environments, making research and monitoring difficult. The USGS considers Mount Spurr to be one of 18 very-high-threat to high-threat Alaska volcanoes that are not monitored at a level commensurate with their threats; under-monitoring can hamper timely alerts that would help reduce volcanic risks.

Congress in 2019 and 2022 passed legislation authorizing various federal roles to monitor, warn, and protect people from harm caused by volcanic activity. Issues for the 119th Congress include whether this earlier legislation has been fully implemented and what (if any) additional investments are warranted to enhance the efficacy and efficiency of the international, federal, state, and local collaborations to reduce the threats to lives, property, and aviation in Alaska and to aviation beyond Alaska (i.e., local, regional, national, and international air travel).

Legislation in 2019 and 2022

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) and authorized appropriations of $55 million, which expired in FY2023. The law directed the USGS to establish NVEWS to monitor volcanoes, modernize and unify the monitoring systems of volcano observatories in the United States, warn U.S. citizens of volcanic activity, and protect citizens from "undue and avoidable harm." In 2022, Congress passed legislation (§10501 of P.L. 117-263) that amended NVEWS to direct cooperation and coordination between the USGS's NVEWS and the National Oceanic and Atmospheric Administration's (NOAA's) Volcanic Ash Advisory Centers (VAACs) to strengthen monitoring and warning of volcano hazards in the atmosphere.

Monitoring and Warning

The Alaska Volcano Observatory (AVO)—a partnership between the USGS, the Geophysical Institute of the University of Alaska Fairbanks and the State of Alaska Division of Geological and Geophysical Surveys—studies, monitors, forecasts, warns, and seeks to reduce risks from Alaska's volcano hazards. As of May 2025, the USGS, with AVO serving a leading role, is prioritizing additional monitoring of 18 very-high-threat to high-threat Alaska volcanoes, including Mount Spurr. NOAA's Anchorage Volcanic Ash Advisory Center (AVAAC), with the AVO, studies, monitors, forecasts, and warns about Alaska's volcanic ash hazards in the atmosphere. As of May 2025, NOAA is preparing an implementation plan for its VAACs to cooperate with NVEWS and the USGS is collaborating with NOAA on multiple aspects of volcano hazards and warnings.

Considerations for Congress

The 119th Congress may consider the future of the authorizations and appropriations for the activities that various federal agencies, and in particular the USGS, perform to support the monitoring and warning of volcano hazards affecting the United States, including Alaska's volcano hazards. S. 1052, introduced on March 13, 2025, would reauthorize NVEWS, authorizing appropriations for USGS of $75 million until FY2033, extending the period of authorization of sums necessary for NOAA to carry out its NVEWS activities to FY2034 and amending NVEWS by adding "infrasound arrays, visible and infrared cameras and advanced digital telemetry networks" to the emerging technologies the USGS should apply to modernize NVEWS. Another measure, H.R. 3176, was introduced on May 5, 2025, to reauthorize NVEWS. Congress may assess its options by evaluating the efficiency and effectiveness of NVEWS activities as part of the nation's preparedness and efforts to reduce

volcano hazards' impacts on lives, property, aviation, and economic activity. For example, Congress may evaluate the level of monitoring and warning of very-high-threat to high-threat Alaska volcanoes and how AVAAC/AVO volcanic ash warning products are used by the Federal Aviation Administration, the Department of Defense, and international aviation systems. Congress also may wish to learn more about the USGS's plans for meeting the objectives of NVEWS and about how AVO and AVAAC are cooperating to advance NVEWS.

Contents

Figures

Tables

Appendixes

Contacts

Introduction

The United States has 170 potentially active volcanoes, and the U.S. Geological Survey (USGS) considers about 161 of these volcanoes threatening.[1] In 2019, Congress passed the John D. Dingell Jr. Conservation, Management, and Recreation Act (P.L. 116-9), in which Title V, Section 5001 (43 U.S.C. 31k), authorized the establishment of the National Volcano Early Warning and Monitoring System (NVEWS).[2] The objectives of NVEWS are to organize, modernize, and unify the monitoring systems of the five U.S. volcano observatories—Alaska, California, Cascades, Hawaiian, and Yellowstone—and to monitor all volcanoes at a level commensurate with their threats.[3] The USGS Volcano Hazards Program established the Volcano Science Center to administer and unify the volcano observatories to research and monitor active volcanoes and warn about volcano hazards.[4]

Alaska has about 140 active volcanoes, and the USGS considers 86 to be threatening. Since October 2024, Mount Spurr—about 81 miles from Anchorage, AK—has been in a heightened state of unrest. The USGS has warned of a possible eruption while noting that, at times, bad weather and snow have limited monitoring, and limits to monitoring may inhibit timely volcano warnings to reduce the risks to people and property. Most of Alaska's volcanoes are remote and inaccessible in the winter and bad weather. They also exist in harsh environments, making monitoring challenging. Congress may consider whether NVEWS enables the Alaska Volcano Observatory (AVO) to monitor all of Alaska's active volcanoes at levels commensurate with their threats.

In 2022, Congress passed the James M. Inhofe National Defense Authorization Act for Fiscal Year 2023 (P.L. 117-263) and Title CV, Volcanic Ash and Fumes (§10501), amended NVEWS to strengthen the monitoring and warning systems by integrating relevant capacities of the National Oceanic and Atmospheric Administration (NOAA), including the Volcanic Ash Advisory Centers (VAACs) located in Anchorage, AK, and Washington, DC. A primary risk from Alaska's volcanoes is from ash and ashfall, which may harm human health and the environment and may damage property and aviation. Past eruptions of Redoubt Volcano, Mount Spurr, and Augustine Volcano have disrupted aviation in Alaska and elsewhere. Congress may consider how the USGS and NOAA volcanic ash models, forecasts, and warnings, which are generated using different data and algorithms, may be integrated or improved and how these models and volcanic ash warning products are impacted by modernizing and unifying monitoring systems. Congress also may consider how other federal agencies, such as the Federal Aviation Administration (FAA), and other governments or international organizations use the volcanic ash models and volcanic ash warning products. In addition, Congress may consider how flight operators (e.g., American Airlines, United Airlines) use volcanic ash warning products, because the 2010 Eyjafjallajökull

---

[1] The U.S. Geological Survey (USGS) assessment of threatening volcanoes considers volcanoes that have been active within the past about 11,000 years 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 (hereinafter USGS, *Volcanic Threat Assessment*).

[2] CRS In Focus IF11987, *The National Volcano Early Warning System*, by Linda R. Rowan.

[3] The USGS volcano observatories are the Alaska Volcano Observatory, the California Volcano Observatory, the Cascades Volcano Observatory, the Hawaiian Volcano Observatory, and the Yellowstone Volcano Observatory. USGS, "USGS Operates Five U.S. Volcano Observatories," https://www.usgs.gov/programs/VHP/usgs-operates-five-us-volcano-observatories.

[4] USGS, "Volcano Hazards Program," https://www.usgs.gov/vhp; and USGS, "Volcano Science Center," https://www.usgs.gov/centers/volcano-science-center.

eruption in Iceland led to changes in volcanic ash warning products and flight operation procedures during a volcanic ash event in some European and North Atlantic airspaces.

Primer on Alaska's Active Volcanoes and Hazards

Alaska has about 140 active volcanoes and the U.S. Geological Survey (USGS) considers 86 to be threatening to people and property (**Figure 1** and **Figure 2**).[5] Most of Alaska's active volcanoes originate along the Alaska-Aleutian Arc Subduction Zone and are *stratovolcanoes* capable of explosive and effusive eruptions impacting local, regional, and global communities and aviation (**Figure 3** and **Appendix B**). Alaska's volcanoes may have variable amounts of perennial to seasonal snow and ice, which may contribute to more catastrophic eruptions. Eruptions may incorporate the snow and ice into ash plumes or lava flows, increasing their size and extent. Eruptions may melt the snow and ice, triggering steam- and water-enriched volcano hazards, such as phreatic eruptions, pyroclastic flows, and lahars (mudflows) (**Figure 4**, **Figure 5**, and **Appendix B**). On average, about two volcanoes erupt every year in Alaska. Because many eruptions continue for weeks to months, it is not uncommon for three or four Alaska volcanoes to have experienced eruptive activity in any single year.[6] Volcano hazards include ash, gases, debris avalanches, ejecta, lahars, lava flows, phreatic eruptions, and pyroclastic flows (**Appendix B**).[7] In addition, earthquakes, landslides, and tsunamis may be associated with tectonics near a volcano, volcanic growth, and/or volcanic activity. According to AVO, the most significant and common hazards from Alaska's volcanoes that impact people, property, and aviation are ash clouds and ashfall.[8] Some of the past eruptions in Alaska have been explosive, generating ash clouds and ashfall. Some of Alaska's active volcanoes have eruptions that may range from a moderate to moderate-large volcanic explosivity index (VEI of 2 or 3), with some instances of eruptions with large to very large VEIs ranging from 4 to 6.[9] The largest eruption in the 20th century was the 1912 Novarupta-Katmai eruption in Alaska with a VEI of 6.[10]

---

[5] According to the Alaska Volcano Observatory (AVO), Alaska has about 140 volcanoes that have been active within the past 2.6 million years. About 90 of these volcanoes have been active within the past 11,000 years. AVO, "Alaska Volcano Observatory," https://avo.alaska.edu/volcano/. The USGS assessment of threatening volcanoes considers volcanoes that have been active within the past 11,000 years plus "three notably large and long-lived caldera systems (Yellowstone, Wyoming; Valles, New Mexico; and Long Valley, California)"; therefore, the USGS's 2018 assessment considers 90 volcanoes in Alaska. USGS, *Volcanic Threat Assessment*.

[6] AVO, "Frequently Asked Questions," https://avo.alaska.edu/about/faq.

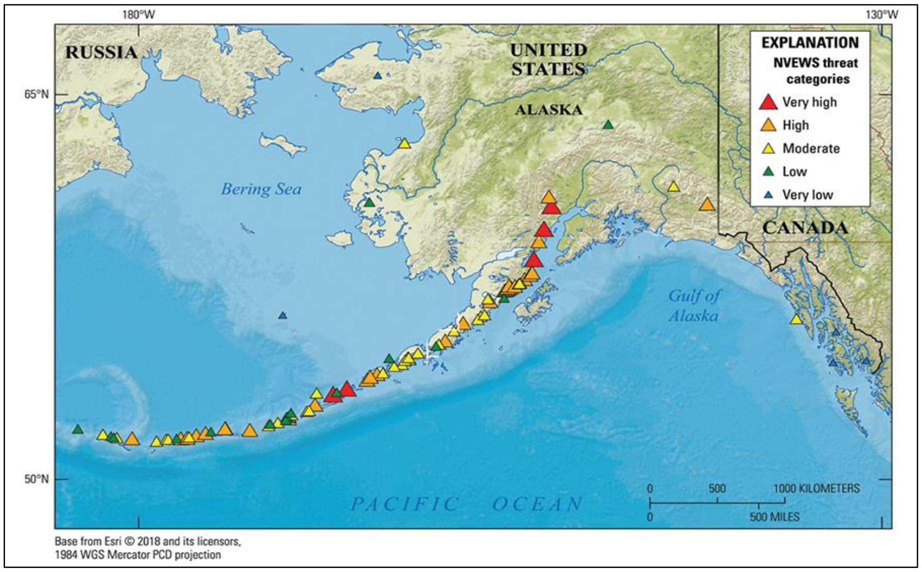
[7] AVO, "Alaska Volcano Observatory," https://avo.alaska.edu/volcano/.

[8] AVO, "Alaska Volcano Observatory," https://avo.alaska.edu/volcano/.

[9] 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 (volcanic explosivity index 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. See Chris Newhall et al., *Anticipating Future Volcanic Explosivity Index (VEI) 7 Eruptions and Their Chilling Impacts*. Geosphere vol. 14, no. 2 (2018), pp. 572-603, https://doi.org/10.1130/GES01513.1 (hereinafter Newhall, *Anticipating Future Eruptions*) for an overview.

[10] The 1991 Pinatubo eruption in the Philippines was the only other 20th century eruption with a VEI of 6. Ben Anderson, "Alaska's Biggest Volcanic Eruptions," *Anchorage Daily News*, February 28, 2012, https://www.adn.com/science/article/alaskas-biggest-volcanic-eruptions/2012/02/28/.

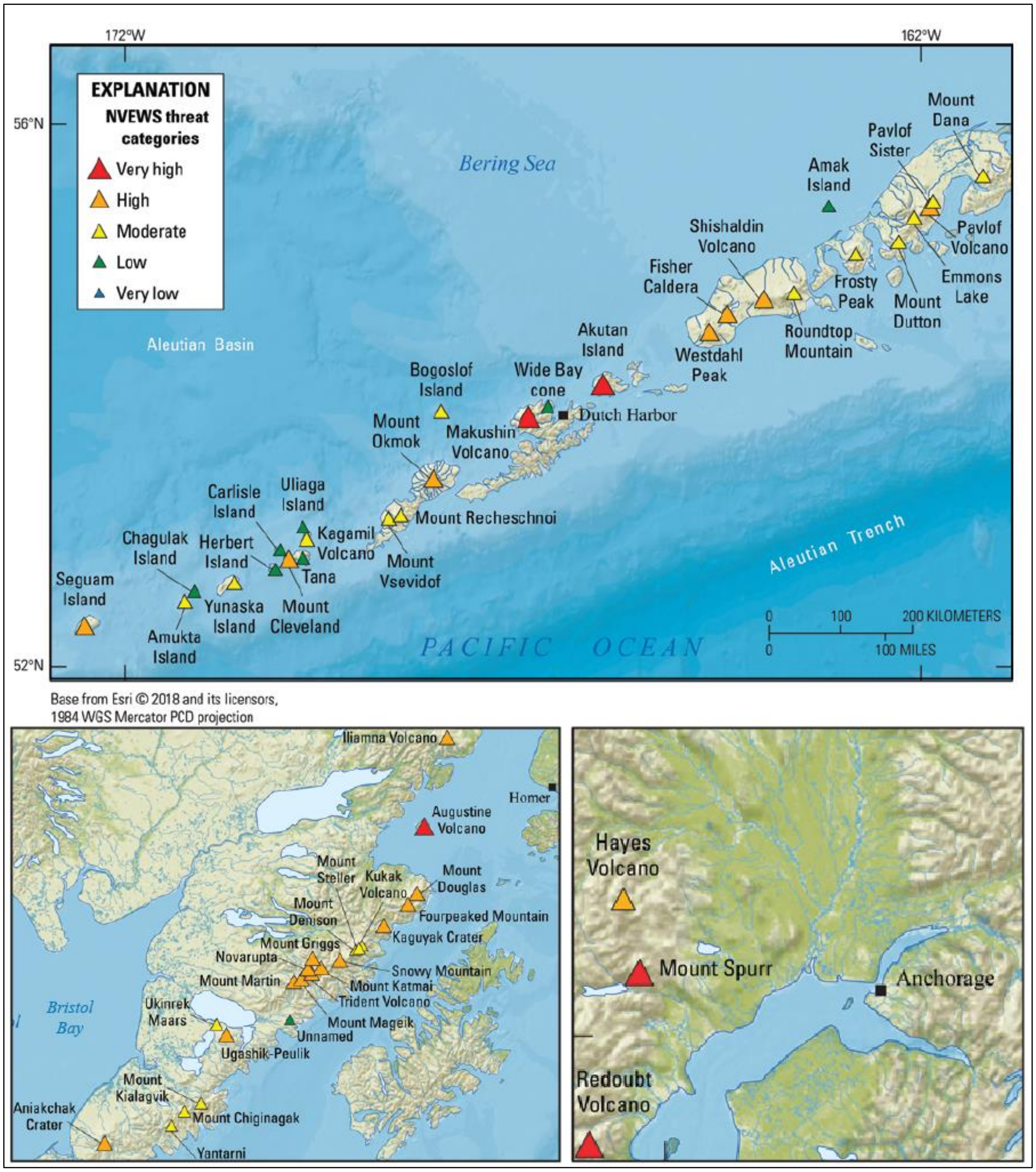
Figure 1. Threat Assessment of Some Active Volcanoes in Alaska



Sources: 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 the USGS and ESRI.

Notes: NVEWS = National Volcano Early Warning and Monitoring System. Triangles with different colors and sizes denote the location and threat level of some volcanoes in Alaska (see legend). The USGS uses 24 volcano hazard factors and the exposure of people and property to those factors to determine each volcano's threat level.

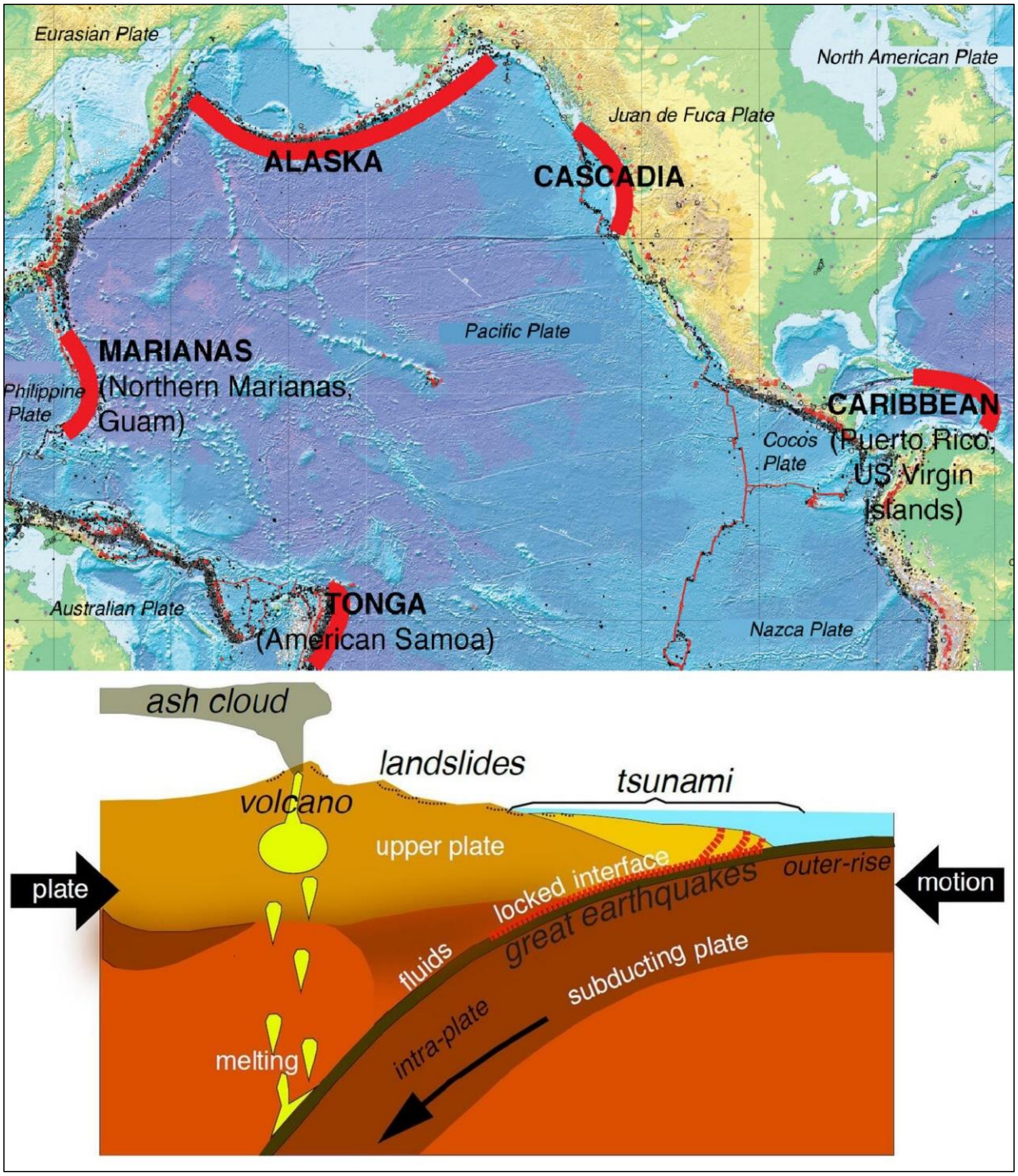
Figure 2. Detailed Maps of Some of the Highest Threat Volcanoes in Alaska



Sources: 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. Maps from the USGS and Esri. Modified by CRS.

Notes: NVEWS = National Volcano Early Warning and Monitoring System. Triangles with different colors and sizes denote the location and threat level of some volcanoes in Alaska. Each volcano name is listed by each triangle. Population centers near volcanoes, such as Dutch Harbor (top), Homer (left), and Anchorage (right), are noted with black squares and labels. The USGS uses 24 volcano hazard factors and the exposure of people and property to those factors to determine each volcano's threat level.

Figure 3. U.S. Subduction Zones Map and Subduction Zone Model



Sources: Top: U.S. Geological Survey (USGS), "Pacific Ocean Subduction Zones," https://www.usgs.gov/media/images/pacific-ocean-subduction-zones. Bottom: USGS, "Subduction Zone Graphic," https://www.usgs.gov/media/images/subduction-zone-graphic.

Notes: Top: Map focused on the Pacific Ocean basin and surrounding "Ring of Fire" subduction zones, where tectonic plates collide, generating volcanoes, earthquakes, tsunamis, and mountainous landslide-prone terrain. Some tectonic plates are labeled. Subduction zones are shown by high densities of earthquakes (circles) and volcanoes (triangles). Subduction zones within the United States and its territories are shaded red. There is one U.S. subduction zone in the Atlantic Ocean—the Caribbean Subduction Zone, which impacts Puerto Rico and the U.S. Virgin Islands. Most of Alaska's active volcanoes are generated at the Alaska-Aleutian Arc Subduction Zone, where the Pacific plate collides and is subducted under the North American plate. Other types of plate boundaries are shown with thin red lines. Colors reflect topography and bathymetry; darker blues and purple offshore are deeper water, while brown and orange are higher land features, such as mountain ranges. Bottom:

Schematic cross section of a subduction zone model showing the four major hazards—earthquakes, landslides, tsunamis, and volcanic eruptions. When tectonic plates converge (movement indicated by the black arrows), one plate slides beneath (*subducts*) the upper plate. At shallow depths, the interface between the plates—a fault—may become stuck (*locked*), causing stresses to build until they exceed the fault's strength and break free, resulting in an earthquake. Volcanoes may form along the surface above a subduction zone because friction between the moving plates produces heat and the heat produces magma (bright yellow features on the schematic) that rises to the surface and erupts. Landslides may be triggered by earthquakes or volcanic activity. Tsunamis may be triggered by earthquakes, landslides, or volcanic activity. For the Alaska-Aleutian Arc Subduction Zone, the Pacific Plate is being subducted beneath the North American Plate along the converging plate boundary shown in the top panel. Joan S. Gomberg and Kristin A. Ludwig, "Reducing Risk Where Tectonic Plates Collide," USGS, fact sheet 2017-3024, 2017, https://doi.org/10.3133/fs20173024.

Figure 4. Shishaldin Volcano Ash Cloud, Pyroclastic Flows, and Lahars

(October 3, 2023)

Source: Photograph by Chris Barnes, available at Alaska Volcano Observatory, "Shishaldin 2023/07," https://avo.alaska.edu/image/view/194974.

Notes: The October 3, 2023, eruption of Shishaldin viewed from the northwest. The ash cloud from the eruption is extending away from the volcano to the southeast while steam emissions continue from the crater. Steam and dark deposits on the flanks are from hot pyroclastic flows and lahars that flowed down the sides of the volcano. Shishaldin's flanks are covered in snow and ice, which may make the volcano hazards more threatening. Roundtop Mountain Volcano is visible in the far left. Blankets of low-lying clouds surround the volcanoes. See **Figure 2**, top panel, for a more detailed map of these volcano locations.

Figure 5. Mount Cleveland Ash Plume

(May 23, 2006)

Source: Courtesy of Jeffrey N. Williams, Flight Engineer and National Aeronautics and Space Administration (NASA) Science Officer, International Space Station Expedition 13 Crew, NASA Earth Observatory.

Notes: Eruption of Mount Cleveland on May 23, 2006, as photographed from the International Space Station at an orbital altitude of approximately 400 kilometers. The photograph (north at the top; Carlisle Island to the northwest) shows the ash plume moving southwest from the summit. Banks of fog (arcuate clouds at upper right) are common features around the Aleutian Islands. The plume reached a height above sea level of about 8.2 kilometers (about 5 miles). A mix of snow and lava flows are also visible on the flanks of the volcano. See **Figure 2**, top panel, for a more detailed map showing the location of Cleveland and Carlisle Island volcanoes.

Ashfall Risks and Largest Eruption in 20th Century

A primary risk from Alaska's volcanoes is from ash and ashfall, which may harm human health and the environment and may damage property and aviation. For example, communities in southcentral Alaska have been affected by ashfalls from relatively moderate eruptions of Redoubt, Spurr, and Augustine (**Figure 6** and **Figure 7**). For the most part, Alaska's active volcanoes are too far from people and property for lava flows or lahars to present a risk.[11]

Studying previous volcanic eruptions provides a greater understanding of volcanic activity, volcano hazards, and the exposure of people and property to volcano hazards. The largest eruption on Earth in the 20th century was the 1912 Novarupta eruption (also known as the 1912

[11] Other risks exist from other volcanic hazards. The level of the risks varies depending on the size and extent of the eruption and the magnitude of the exposure (i.e., the number of people and extent of the built environment in the path of the volcanic hazard).

Novarupta-Katmai eruption), which created the Katmai Caldera and the Valley of Ten Thousand Smokes (**Figure 8**). The eruption launched an ash cloud about 20 miles into the air and caused massive ashfall in Alaska and extensive ashfall as far away as Africa.[12] In Kodiak, the ash and sulfur dioxide gas caused injuries and environmental damage, including making water undrinkable; damaged buildings and infrastructure; and disrupted radio communications and shipping. Animal and plant life were decimated, especially birds and fish. The salmon fishing industry was devastated, especially from 1915 to 1919.[13] According to the USGS, if a similar sized eruption occurred today, the state's economy would be brought to a standstill and hundreds of people would be injured or killed.[14] For comparison, the second-largest eruption in the 20th century, the 1991 Pinatubo eruption in the Philippines, killed 850 people and the much smaller 1980 Mount Saint Helens, WA, eruption killed 57 people (**Figure 7**).[15]

The enhanced understanding afforded by examining these 20th century eruptions can inform research, monitoring, and warning for volcanoes in Alaska and elsewhere. At the same time, each eruption is unique, and even with research, monitoring, and warning, authorities must make decisions about *risk reduction*—that is, avoidance or protective actions for possible volcano hazards—with some uncertainties about the volcano hazards.[16]

[12] Wes Hildreth and Judy Fierstein, *The Novarupta-Katmai Eruption of 1912—Largest Eruption of the Twentieth Century: Centennial Perspectives*, USGS, USGS Professional Paper 1791, 2012, https://pubs.usgs.gov/pp/1791/pp1791.pdf (hereinafter Hildreth and Fierstein, *Novarupta-Katmai Eruption)*; USGS, "The Impact of the 1912 Novarupta/Katmai Eruption on the Pacific Northwest," https://www.usgs.gov/news/impact-1912-novaruptakatmai-eruption-pacific-northwest (hereinafter USGS, "Impact of the 1912 Novarupta/Katmai Eruption"); and Judy Fierstein et al., "Can Another Great Volcanic Eruption Happen in Alaska?," USGS, USGS Fact Sheet 075-98, 1998, https://pubs.usgs.gov/fs/fs075-98/ (hereinafter Fierstein et al., "Another Great Volcanic Eruption").

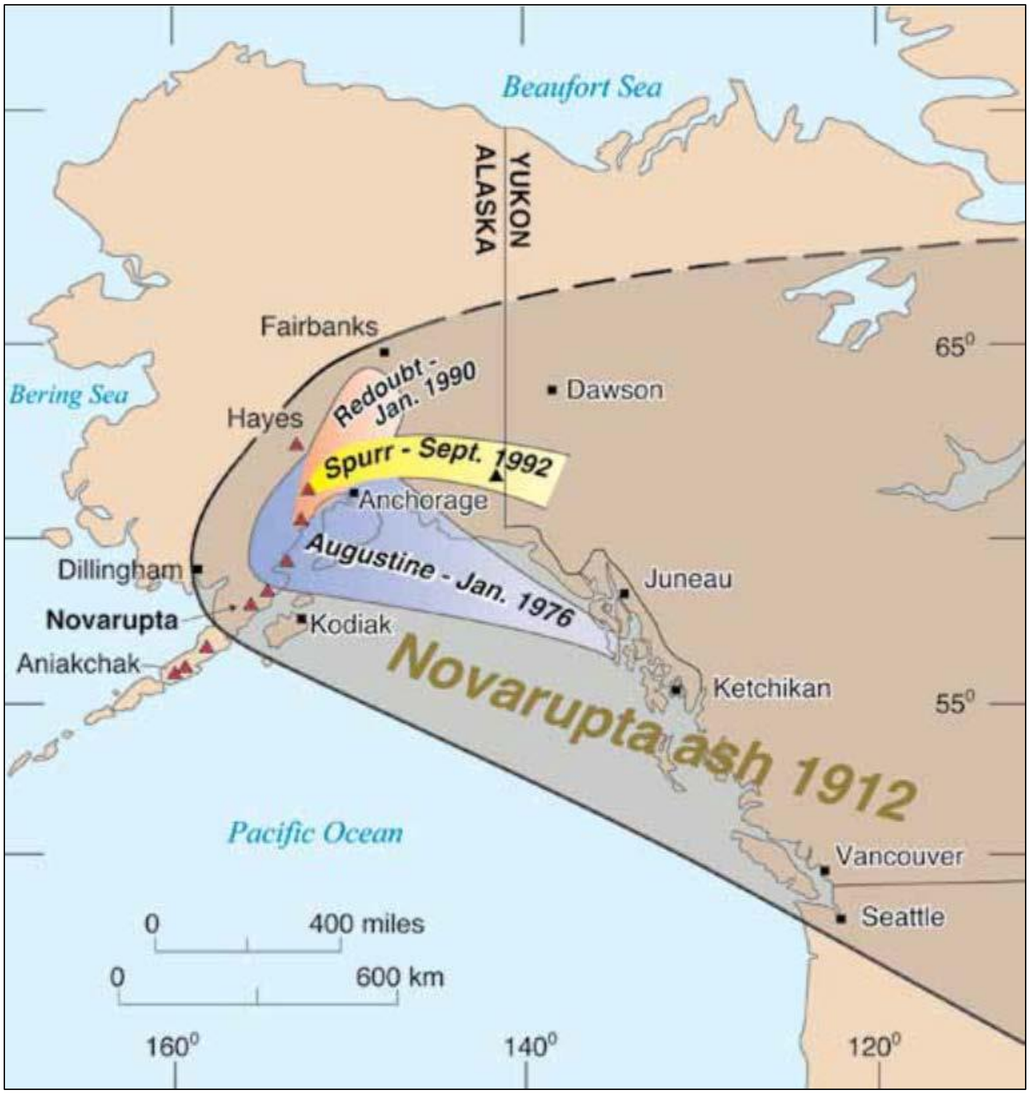
[13] Hildreth and Fierstein, *Novarupta-Katmai Eruption;* USGS, "Impact of the 1912 Novarupta/Katmai Eruption."

[14] Fierstein et al., "Another Great Volcanic Eruption.

[15] According to the USGS, the 1991 Pinatubo eruption could have been even worse without the collaborative work of the USGS and Philippine Institute of Volcanology and Seismology to monitor, forecast, and warn the public. The USGS estimates this work saved more than 5,000 lives and $250 million (in 1991 dollars) in property. USGS, "Remembering Mount Pinatubo 25 Years Ago," https://www.usgs.gov/news/featured-story/remembering-mount-pinatubo-25-years-ago-mitigating-a-crisis. According to the USGS, the Mount Saint Helens catastrophe could have caused fewer fatalities if the restricted zone around the volcano had been larger and had considered the potential for a lateral blast. Of the 57 fatalities, 51 occurred outside the restricted zone set up for a forecasted eruption. Lower Columbia Currents, "Did 57 People Have to Die at Mount St. Helens?," https://andrestepankowsky.substack.com/p/did-57-people-have-to-die-at-mount; USGS, "1980 Cataclysmic Eruption," https://www.usgs.gov/volcanoes/mount-st.-helens/science/1980-cataclysmic-eruption.

[16] Avoidance and protective actions may include evacuations; shelter in place; land, air, or water restrictions; closures; shutting down or changing operations; moving property; and, where possible, removing or cleaning up ashfall deposits to prevent further damage to people, property, or infrastructure. For example, see this study of aircraft avoidance actions for volcanic ash: Juliette Delbrel et al., "An Investigation of Changes to Commercial Aircraft Flight Paths During Volcanic Eruptions," *Journal of Applied Volcanology*, vol. 14, no. 2 2025, https://doi.org/10.1186/s13617-025-00150-7 (hereinafter Delbrel et al., "Aircraft Flight Paths in Eruptions") and Newhall, *Anticipating Future Eruptions*.

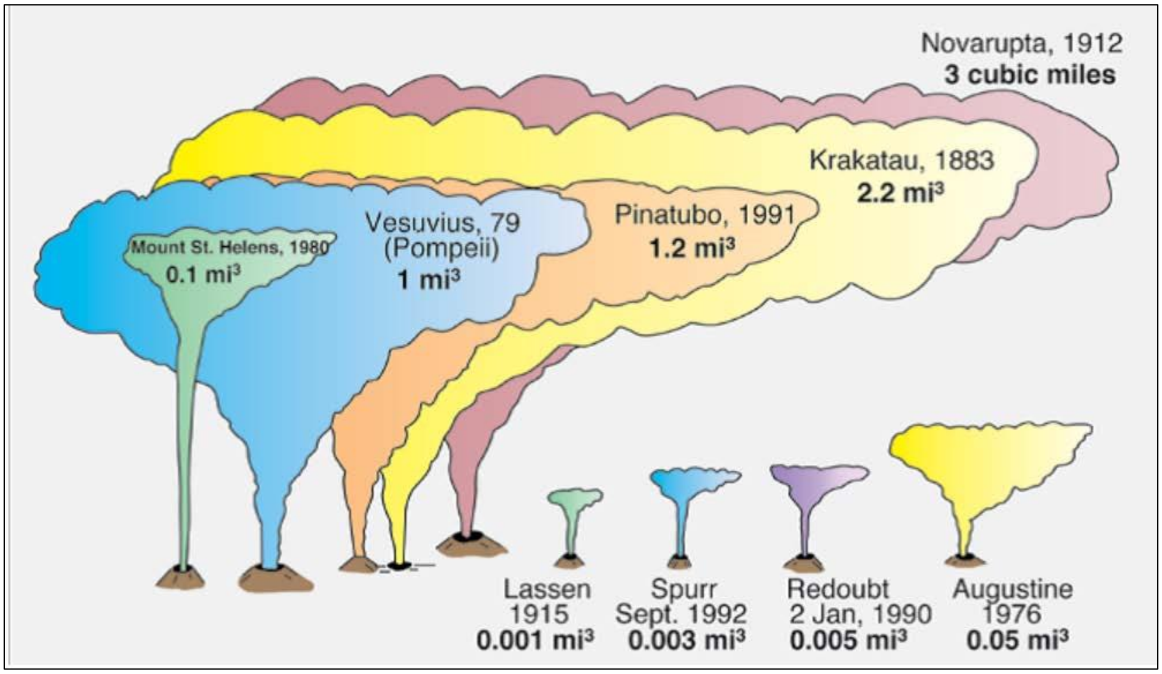
Figure 6. Extent of Ashfall From Some Major Alaskan Eruptions



Sources: U.S. Geological Survey (USGS), "The Impact of the 1912 Navarupta/Katmai Eruption on the Pacific Northwest," https://www.usgs.gov/news/impact-1912-novaruptakatmai-eruption-pacific-northwest; and Judy Fierstein et al., "Can Another Great Volcanic Eruption Happen in Alaska?," USGS, USGS Fact Sheet 075-98, 1998, https://pubs.usgs.gov/fs/fs075-98/.

Notes: Figure shows extent of ashfall from the 1912 Novarupta eruption (gray shaded area; also known as the 1912 Novarupta-Katmai eruption), from a 1976 Augustine eruption (blue shaded area), a 1990 Redoubt eruption (orange shaded area), and a 1992 Spurr eruption (yellow shaded area). The Novarupta-Katmai eruption was the largest eruption in the 20th century. Red triangles denote the locations of volcanoes within 500 miles of Anchorage with notable ashfalls in the past 4,000 years. Black squares denote the location of labeled cities.

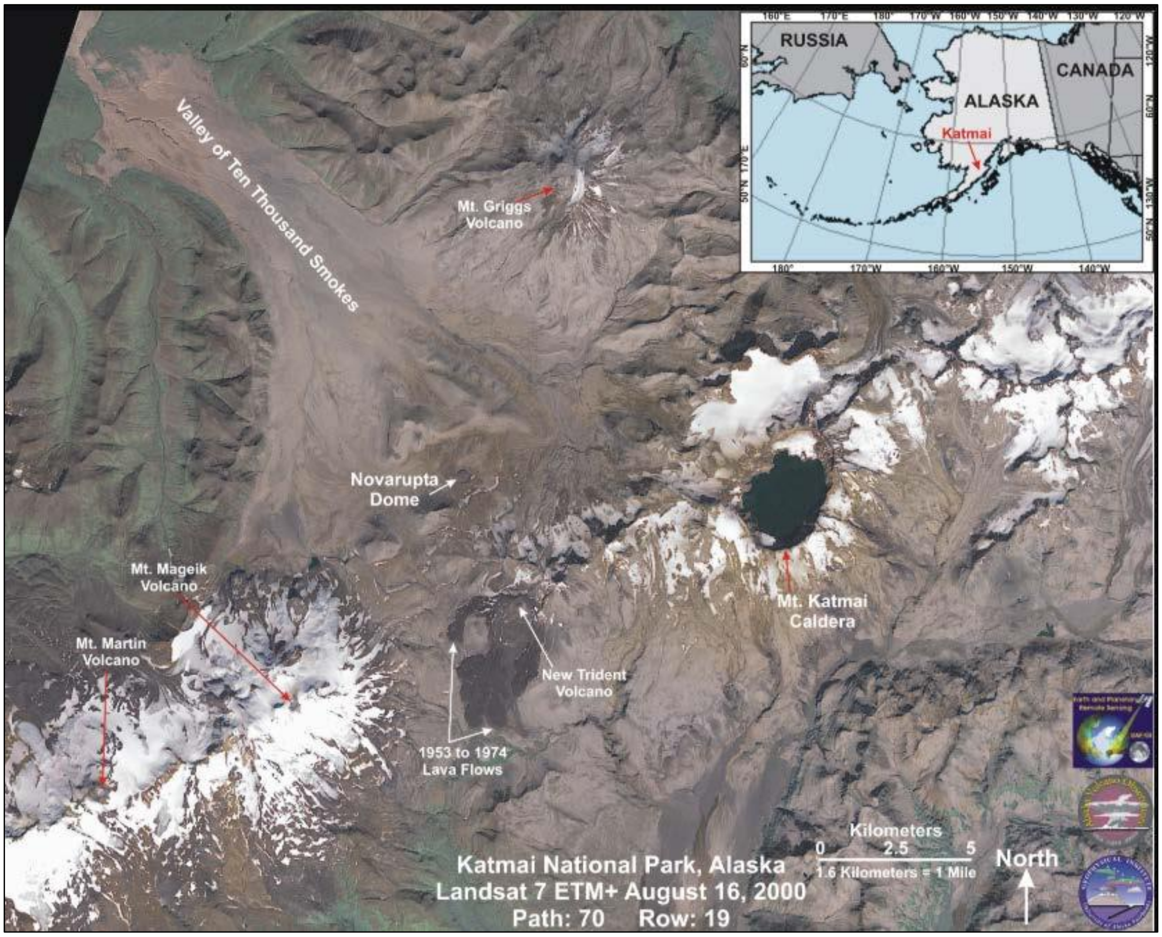
Figure 7. Volume of Major Alaskan and Other Eruptions



Sources: U.S. Geological Survey (USGS), "The Impact of the 1912 Navarupta/Katmai Eruption on the Pacific Northwest," https://www.usgs.gov/news/impact-1912-novaruptakatmai-eruption-pacific-northwest; and Judy Fierstein et al., "Can Another Great Volcanic Eruption Happen in Alaska?," USGS, USGS Fact Sheet 075-98, 1998, https://pubs.usgs.gov/fs/fs075-98/.

Notes: The 1912 Novarupta eruption (also known as the 1912 Novarupta-Katmai eruption) was the largest on Earth in the 20th century. The research shown in this figure calculated the amount of erupted volcanic materials, as expressed in the original volume of molten rock (i.e., magma), shown by schematic ash plumes and labeled with the estimated volume in cubic miles (mi^3). The volume of Novarupta's erupted material was more than double that of the second-largest eruption of that century. There were no fatalities from the Novarupta eruption, primarily because only a small, distant population was exposed to some ashfall hazards.

Figure 8. Satellite Image of Novarupta and Other Volcanoes in Katmai National Park



Sources: Image produced by Steve J. Smith, Volcanology/Remote Sensing Graduate Student from the Geophysical Institute University of Alaska Fairbanks in 2000; Alaska Volcano Observatory, "Alaska Volcano Observatory," https://avo.alaska.edu/image/view/2152.

Notes: True color composite satellite image of Katmai National Park region of Alaska on August 16, 2000. Composite produced with a red-green-blue channel combination of band 3 – band 2 – band 1, respectively. This combination produces an image with colors similar to human eyesight. The eruption of Novarupta and Mount Katmai on June 6, 1912, was the largest volcanic eruption anywhere in the world for the entire 20th century. The 60-hour eruption began at Novarupta, then Mount Katmai collapsed to form a 2-mile-wide caldera. The last part of the eruption was the formation of a lava dome at Novarupta. Most of the pyroclastic deposits from the eruption were deposited in what is now known as the Valley of Ten Thousand Smokes. The valley received this name because the deposits remained so hot for several years after the eruption that steam was released continuously from fumaroles, so it looked as if the ground was always smoking. Some of these deposits may be resuspended depending on weather conditions, and the resuspended ash may become a volcano hazard that leads to a volcanic ash warning. ETM+ is the Enhanced Thematic Mapper Plus instrument on Landsat 7.

Ash Risks for Aviation and Alaska's Large Aviation System

Volcanic ash and sulfur dioxide gas may pose a serious risk for aircraft in flight or on the ground (**Appendix B** and **Appendix C**).[17] Ash clouds can damage aircraft in flight, such as engine and

[17] Federal Aviation Administration (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/ (continued...)

avionic system failures.[18] Ash can make takeoff and landing an aircraft treacherous and can damage aircraft on the ground, incurring costs for cleaning, repair, or even replacement. Alaska's aviation system, which is an international cargo hub and serves more than 80% of Alaskan communities that are only accessible by air, faces significant exposure to volcanic ash and gases from numerous volcanoes (**Figure 1**).[19] In addition, Alaska's largest commercial airports—Anchorage, Fairbanks, and Juneau and the Department of Defense's (DOD's) Joint Base Elmendorf-Richardson—are near very-high-threat to high-threat volcanoes. A review of 94 confirmed aircraft encounters with volcanic ash clouds from 38 volcanoes between 1953 and 2009 found that Augustine and Redoubt volcanic eruptions have each caused five or more, mostly damaging, aircraft encounters.[20]

The 1989-1990 Redoubt Eruption: Lessons Learned About Hazards, Monitoring, and Warnings

The 1989-1990 Redoubt eruption led to a greater understanding of Alaska's volcano hazards: the extent and cost of damage caused by these hazards, the extent to which people and property were exposed to Alaska's volcano hazards (i.e., volcanic risks), and the strengths and weaknesses of research, monitoring, and warnings. From December 14, 1989 to August 30, 1990, a series of explosive and effusive eruptions of Redoubt, about 110 miles southwest of Anchorage (**Figure 2**), generated ash plumes, ash clouds, ashfalls, pyroclastic flows, lava domes and lava flows, and lahars (**Figure 6**, **Figure 9**, and **Appendix B**).[21] Redoubt's eruption damaged property and contributed to other costs associated with evacuations of facilities and closures of airspace, airports, roads, oil production facilities, oil pipelines, schools, businesses, other facilities, and

chap7_section_6.html (hereinafter FAA, "Flight Operations in Volcanic Ash,"). International Civil Aviation Organization (ICAO), *Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds*, Doc 9691, AN954, 3rd edition, 2015 (hereinafter ICAO, *Manual on Volcanic Ash*).

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

[19] Alaska Department of Transportation and Public Facilities, *Airports and Aviation Annual Report 2021*, 2021, https://dot.alaska.gov/documents/aviation/2021-Annual-Report.pdf. See also Alaska Department of Transportation and Public Facilities, "DOT&PF Aviation and Airports," https://dot.alaska.gov/airport-portal.shtml and USGS, *Volcanic Threat Assessment*.

[20] Six other volcanoes caused five or more aircraft encounters, besides Augustine and Redoubt. The other volcanoes include Chaiten in Chile, Mount Saint Helens in the United States, Pacaya in Guatemala, Pinatubo in the Philippines, Sakura-jima in Japan, and Soufriere Hills in Montserrat, Lesser Antilles, United Kingdom. Guffanti et al., *Encounters of Aircraft,* 2010. For comparison, 92 aircraft reported encountering the 2010 Eyjafjallajökull eruption. Delbrel et al., "Aircraft Flight Paths in Eruptions."

[21] The 1989-1990 eruption was similar in terms of explosivity and effusivity to past eruptions at Redoubt and was not as violent or voluminous as some other eruptions elsewhere in the 20th century, such as the 1980 eruption of Mount Saint Helens (**Figure 7**). Steven R. Brantley, *The Eruption of Redoubt Volcano, Alaska, December 14, 1989-August 31, 1990*, USGS Circular 1061, 1990, https://dggs.alaska.gov/webpubs/usgs/c/text/c-1061.pdf (hereinafter, USGS, *Eruption of Redoubt*).

other infrastructure (**Figure 9**).[22] In 1990, the USGS described the Redoubt eruption as the second-most costly U.S. eruption, behind only the 1980 eruption of Mount Saint Helens.[23]

Figure 9. Examples of Hazards from the 1989-1990 Redoubt Eruption

Source: Photos from Alaska Volcano Observatory (AVO) as described below.

Notes: Upper left: Photograph by R. Clucas, April 21, 1990. AVO activity archive. Ascending eruption cloud from Redoubt volcano as viewed to the west from the Kenai Peninsula. The mushroom-shaped plume rose from avalanches of hot debris (pyroclastic flows) that cascaded down the north flank of the volcano. A smaller, white steam plume rose from the summit crater. Upper right: Photograph by R. McGimsey, U.S. Geological Survey (USGS), AVO activity archive. Gray ash from the February 21, 1990, eruption of Redoubt Volcano blankets the snow in Indian, AK, a community about 32 kilometers (20 miles) southeast of Anchorage and 200 kilometers (124 miles) northeast of Redoubt Volcano. Lower left: Photograph by C. Gardner, USGS, AVO activity archive. Aerial view, looking southwest, of the Drift River valley following the 1989-1990 eruption of Redoubt volcano. Two bedrock islands (informally called the *Dumbbell Hills*) are visible at bottom center. Lahar deposits cover the valley floor. Lower right: Photograph by C. Neal, USGS, AVO activity archive. Pyroclastic-flow deposits from the April 15 (lower two-thirds of section) and April 21 (upper one-third of section), 1990, eruptions of Redoubt volcano exposed in a gully along the western margin of the piedmont lobe of drift glacier. Shovel (about 1.5 feet tall) at base of section shows scale to understand the thickness of these deposits. See **Figure 2**, bottom right, for a more detailed map of the location of Redoubt, near Anchorage.

[22] USGS, *Eruption of Redoubt*; Thomas J. Casadevall, "The 1989-1990 Eruption of Redoubt Volcano, Alaska: Impacts on Aircraft Operations," *Journal of Volcanology and Geothermal Research*, vol. 62, no. 1-4 (1994), https://doi.org/10.1016/0377-0273(94)90038-8 (hereinafter Casadevall, Redoubt Impact on Aircraft); Zygmunt J. Przedpelski and Thomas J. Casadevall, "Impact of Volcanic Ash from 15 December 1989 Redoubt Volcano Eruption on GE CF6-80C2 Turbofan Engines," *Proceedings of the first international symposium on volcanic ash and aviation safety, U.S. Geological Survey Bulletin 2047*, 1994, https://avo.alaska.edu/explore/reference/2121 (hereinafter Przedpelski and. Casadevall, "Impact of Volcanic Ash from 15 December 1989 Redoubt Volcano Eruption").

[23] USGS, *Eruption of Redoubt*.

Seismic Monitoring

According to the USGS, seismic monitoring established on Redoubt less than two months before eruptive activity began allowed for sufficient warning and time for emergency protective actions by authorities for some eruptive events.[24] That is, prior to the eruption, Congress provided funding for Alaska volcano monitoring in FY1988 appropriations and the Alaska Volcano Observatory (AVO) was established in 1988.[25] AVO installed seismic instruments on Redoubt, and the seismic network was operational by October 1989, just before the eruption started. Seismic instruments recorded earthquakes, volcanic tremor attributed to magma movement, and other ground vibrations attributed to flows and lahars. The seismic instruments provided the only dedicated and continuous information about the size and extent of eruptive activity at Redoubt. For example, a series of earthquakes beneath the volcano's summit began 24 hours before the first major eruption on December 14, 1989. AVO warned officials that Redoubt might erupt soon, and officials took protective actions that reduced the risks of the volcano hazards from the first major eruption.

Pyroclastic Flows and Lahars

The Redoubt eruption's most damaging volcano hazard for property on the ground was a series of pyroclastic flows and massive lahars formed when hot lava melted parts of the Drift glacier and winter snowpack along the volcano's slope (**Appendix B**).[26] AVO warned officials about some flows and lahars. Authorities evacuated the Drift River Oil Terminal,[27] shut down terminal and oil pipeline activities, and shut down nearby oil production facilities that were supplying oil to the pipelines. The flows and lahars damaged some terminal buildings and other infrastructure, but there were no oil spills (**Figure 9**).[28]

There was additional concern about ashfall causing damage to people and property on the ground. Along the populated Kenai Peninsula, the public was told to stay indoors, and schools and other facilities were closed to avoid health problems from ashfall. Gas-powered turbines at the Beluga power plant, a primary power supplier for Anchorage, were partially shut down to avoid ashfall damage to the turbines.

Volcanic Ash and Aviation

The Redoubt eruption's most damaging volcano hazard for aviation was ash (**Appendix C**). The 1989-1990 eruption was a seminal event for understanding ash hazards and ash damage to aircraft because at least seven aircraft (five in Alaska and two in Texas) flew through ash, causing major to minor damage and interrupting flight operations.[29] Five commercial aircraft near Anchorage encountered ash over the first three months of the eruption. The most serious encounter occurred on December 15, the second day of the eruption, when a KLM passenger plane entered an ash cloud about 150 miles northeast of Redoubt.[30] The plane temporarily lost power to all four

---

[24] USGS, *Eruption of Redoubt.*

[25] In FY1988 appropriations, S. Rept. 100-165 provided $750,000 for monitoring of Augustine volcano.

[26] USGS, *Eruption of Redoubt.*

[27] Shipnext, "Drift River Oil Terminal (United States)," https://shipnext.com/port/drift-river-marine-terminal-usdrf-usa.

[28] USGS, *Eruption of Redoubt.*

[29] USGS, *Eruption of Redoubt*; Casadevall, Redoubt Impact on Aircraft; Przedpelski and Casadevall, "Impact of Volcanic Ash from 15 December 1989 Redoubt Volcano Eruption."

[30] According to a former head of the AVO, the pilots of the KLM flight did not see an AVO warning that had been sent (continued...)

engines.[31] The aircraft was at an altitude of about 5 miles and descended about 2 miles over 12 minutes before two of the engines restarted. The aircraft was able to return to the airport in Anchorage. The airplane was sandblasted by the ash, leaving pit marks on the windshield, other windows, and other external surfaces; all four engines and all of the electrical and avionic equipment had to be replaced; and the plane had to be cleaned of ash.[32] Two other commercial aircraft in west Texas encountered a Redoubt ash cloud, about 55 hours after an eruption and 2,900 nautical miles away from the volcano, highlighting the ash risks for aviation far from an eruption in space and time (**Appendix C**). In addition to aircraft damaged by ash, the ash hazards caused delays and cancellations at Anchorage International Airport, Merrill Field, Elmendorf Air Force Base, and many smaller airports in Alaska.

There was no dedicated monitoring of the ash hazards before or during the 1989-1990 eruption. As such, there was little to no information about the size, extent, and direction of the ash clouds and plumes to be able to forecast or provide specific warnings about ash hazards. The only information came from the seismic monitoring, reconnaissance observations during volcano quiescence, and opportunistic observations from some distance away from the volcano, such as the photograph in **Figure 9**.[33]

After the damaging encounters of aircraft with Reboubt ash clouds, the National Weather Service (NWS) organized an Alaska Aviation Weather Unit (AAWU), which includes a Meteorological Watch Office (MWO) and the Anchorage Volcanic Ash Advisory Center (AVAAC), to monitor ash hazards and provide warnings.[34] The AVO and AVAAC became contributing members of the International Civil Aviation Organization's (ICAO's) International Airways Volcano Watch.[35] The U.S. volcano observatories submit weekly reports on volcanic activity for U.S. volcanoes, the Smithsonian Institution Global Volcanism Program submits weekly reports on volcanic activity for volcanoes outside the United States, and AVO and AVAAC provide information and warnings for Alaska's active volcanoes to ICAO.[36]

Eruption Uncertainties

Not every volcanic eruption in Alaska and elsewhere is preceded by precursory signals, such as earthquakes, so forecasts and early warnings may not be possible for every volcanic event. Furthermore, the earthquake and ground vibration activity monitored by the seismic network during the 1989-1990 Redoubt eruption was not always followed by an eruptive event, so

---

by fax to officials before taking off. Geophysical Institute, "Redoubt's Big Impact 30 Years Ago," https://www.gi.alaska.edu/alaska-science-forum/redoubts-big-impact-30-years-ago.

[31] Casadevall, Redoubt Impact on Aircraft.

[32] Casadevall, Redoubt Impact on Aircraft.

[33] When it was considered safe and feasible during periods of Redoubt's quiescence, reconnaissance flights and field work combined with other observations from aircraft and satellites helped to measure the size and extent of some of Redoubt's hazards after the first series of eruptions. USGS, *Eruption of Redoubt*.

[34] National Weather Service (NWS), "Alaska Aviation Weather Unit," https://storymaps.arcgis.com/stories/9ec2090f634e48efae91ecb5a2153d20; NWS, "Alaska Aviation Weather Unit (AAWU)," https://www.weather.gov/aawu/.

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

[36] Smithsonian Institution, "Global Volcanism Program," https://volcano.si.edu/. The U.S. volcano observatories are the Alaska Volcano Observatory, the California Volcano Observatory, the Cascades Volcano Observatory, the Hawaiian Volcano Observatory, and the Yellowstone Volcano Observatory. USGS, "USGS Operates Five U.S. Volcano Observatories," https://www.usgs.gov/programs/VHP/usgs-operates-five-us-volcano-observatories.

forecasts of eruptive activity were uncertain. In addition, not every volcanic eruption is a singular event of short duration; some eruptions, such as the 1989-1990 Redoubt eruption, may have eruptive events over days to months, where forecasts and warnings would benefit most from preexisting and continuous monitoring.

Studies of the 1989-1990 Redoubt eruption and others concluded that even with volcanic unpredictability, forecasts and early warnings about changing volcanic activity and warnings after an eruption starts would benefit from preexisting and continuous monitoring. A 1990 USGS report on the Redoubt eruption concluded that a suite of monitoring tools could provide forecasts and early warning for some eruptions and more information about the extent and risk of volcano hazards for ongoing and not forecasted eruptions.[37] Additional assessments of U.S. volcanic risks recommended advancing volcano research and monitoring to improve forecasts and early warning about changing volcanic activity and to improve warnings about eruptions.[38]

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).[39] 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."[40] In addition, under the Stafford 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. The USGS organizes NVEWS activities within the Volcano Hazards Program (VHP), and the Volcano Science Center serves the VHP's mission. The 2019 law specifies that the system's objective is to monitor U.S. volcanoes at a level commensurate with the volcanic threats. NVEWS is to have 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.

The USGS has submitted several reports and plans regarding NVEWS. It submitted a five-year plan for establishing and managing NVEWS to Congress in 2020, annual reports to Congress charting the progress of NVEWS, a 2024 recommended monitoring plan, and a 2024 USGS *Volcano Science Center Response Plan for Significant Volcanic Events*.[41] Through these reports

[37] USGS, *Eruption of Redoubt*.

[38] John W. Ewert et al., *An Assessment of Volcanic Threat and Monitoring Capabilities in the United States: Framework for a National Volcano Early Warning System*, USGS, Open File Report 2005-1164, 2005, https://pubs.usgs.gov/of/2005/1164/2005-1164.pdf; National Academies of Sciences, Engineering, and Medicine (NAS), *Volcanic Eruptions and Their Repose, Unrest, Precursors, and Timing*, 2017, doi: https://doi.org/10.17226/24650 (hereinafter NAS, *Volcanic Eruptions*).

[39] CRS In Focus IF11987, *The National Volcano Early Warning System*, by Linda R. Rowan.

[40] 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.

[41] 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*). 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*); Seth C. Moran (continued...)

and plans, the USGS has detailed updates to monitoring systems; the establishment of a National Volcano Information System, which is expected 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).[42]

In 2022, Congress passed legislation that amended NVEWS to direct cooperation and coordination between the USGS volcano monitoring and NOAA's Volcanic Ash Advisory Centers (VAACs) (§10501 of P.L. 117-263). The law directs 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.[43] The law also directs the Secretary of Commerce to submit cost estimates for NVEWS activities at NOAA to the Secretary of the Interior that should be incorporated into the NVEWS management plan. As of May 2025, NOAA is preparing an implementation plan with cost estimates for its VAACs. The USGS is collaborating with NOAA on multiple aspects of volcano hazards and warnings, such as volcano-induced tsunamis and the health impacts of volcanic ash.[44] In June 2022, the USGS, in cooperation with NOAA and other federal agencies, published an updated *Alaska Interagency Plan for Volcanic Ash Episodes*.[45]

The following sections of this report focus on AVO's and AVAAC's roles in research, monitoring, and warning for Alaska's active volcanoes and how these efforts may meet the objectives of NVEWS.

Role of the Alaska Volcano Observatory

The AVO researches, monitors, forecasts, warns about, and seeks to reduce risks from volcano hazards in Alaska.[46] AVO is a partnership between the USGS, the Geophysical Institute of the University of Alaska Fairbanks, and the State of Alaska Division of Geological and Geophysical Surveys.[47] An AVO duty scientist is to be available 24/7 via cell phone. In addition, a duty seismologist, duty remote sensing scientist, and duty alarm analyst are to be available 24/7 via cell phone. AVO may establish a 24/7 watch operation for a volcanic event.[48] Geologists and geophysicists at all three entities share research, data processing, analysis, and hazard communication duties.

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*).

[42] USGS, "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.

[43] 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 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.

[44] Correspondence between CRS and USGS, March 31, 2025.

[45] USGS, *Alaska Interagency Plan for Volcanic Ash Episodes*, June 2022, https://www.usgs.gov/programs/VHP/coordination-plans (hereinafter, USGS, *Alaska Interagency Plan*).

[46] AVO, "Alaska Volcano Observatory," https://avo.alaska.edu/volcano/. AVO acts as the backup for all USGS volcano observatories. In the event that the AVO is unable to serve as a backup, the Cascades Volcano Observatory generally would assume this critical function. USGS, *Response for Volcanic Event*.

[47] USGS, "Volcano Hazards Program," https://www.usgs.gov/programs/VHP; University of Alaska Fairbanks, "Geophysical Institute," https://www.gi.alaska.edu/; State of Alaska, "Geological & Geophysical Surveys," https://dggs.alaska.gov/.

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

As needed, AVO may involve other USGS Volcano Science Center staff from Volcano Observatories in the Cascades, Hawaiian, California, and Yellowstone or other USGS offices.[49] AVO communicates with international agencies involved in volcanic ash cloud and ashfall warnings including ICAO, the Canadian Meteorological Centre, and Montreal VAAC. AVO is available to consult with partner agencies about significant eruptions from Russian volcanoes, including the Tokyo VAAC and the Petropavlovsk MWO.

Research

AVO describes the scope of its research to include the following[50]

- Geological mapping to determine eruptive histories of active volcanoes
- Investigations of hydrologic hazards such as lahars and floods associated with eruptions of snow- and ice-clad volcanoes
- Characterization and analysis of eruptive processes and their impacts
- Geophysical and geochemical exploration of the interiors of volcanoes and mechanisms of eruption
- Development of new instrumentation, analytical tools, and models to aid in interpretation of volcanic unrest and eruption and hazard detection and forecasting

Monitoring

In its volcano monitoring, AVO "utilizes a variety of instrumentation and techniques to detect and interpret signs of volcanic unrest or eruption. Instruments and techniques include seismicity, infrasound, ground deformation, satellite imagery and data, lightning data, gas emissions, webcams and direct visual observations, including local and pilot reports"[51] (**Figure 10**).

AVO uses aviation the most of any U.S. volcano observatory for research and monitoring because there are more than 100 active volcanoes in Alaska, many of which are remote and only accessible by air. Helicopters and airplanes can take researchers to visit a volcano for field studies or to install, repair, or maintain monitoring sites (**Figure 10**). In addition, airplanes, helicopters, and unoccupied aircraft systems can have monitoring instruments installed on the aircraft to measure properties of a volcano (**Figure 10**).[52] AVO also uses weather data and weather forecasts from NOAA and weather and ash data from pilot reports.[53] AVO utilizes Earth observations from

---

[49] USGS, *Response for Volcanic Event*; USGS, *Alaska Interagency Plan*.

[50] Alaska Volcano Observatory, "About AVO–Volcano Hazard Research Program," https://avo.alaska.edu/about/.

[51] Alaska Volcano Observatory, "About AVO–Volcano Monitoring," https://avo.alaska.edu/about/.

[52] FAA, "Drones," https://www.faa.gov/uas. *Unoccupied aircraft systems* (UASs) also may be called *unmanned aerial systems* or *unmanned aircraft systems* or referred to as *unoccupied aerial vehicles* (UAVs) and related terms.

[53] 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 in either 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*. Pilots typically complete a Volcanic Activity Report (VAR, example of the form available at FAA, AIM, https://www.faa.gov/air_traffic/publications/atpubs/aim_html/appendix_2.html), which may contain extra details about the physical characteristics of ash clouds, after concluding flight operations or during flight debriefings. It also can 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*, (continued...)

satellites for research, monitoring, and warning about Alaska's volcanoes.[54] The satellites may include the USGS/NASA Landsat Mission,[55] NASA's Earth Observing System,[56] NOAA's Satellites,[57] and the European Space Agency's Sentinel Mission, among others.[58] AVO uses a web-based tool "VolcView" to examine satellite data and "AshCam" to examine webcam data.[59]

ICM-P35-2024, December 2024, https://www.icams-portal.gov/resources/icams/related_documents/2024_nvaopa.pdf (hereinafter ICAMS, *National Volcanic Ash Operations*).

[54] Table 1.2, "Satellite-Borne Suite for Volcano Monitoring," in NAS, *Volcanic Eruptions*; Mastin et al., *Progress in Protecting Air Travel*.

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

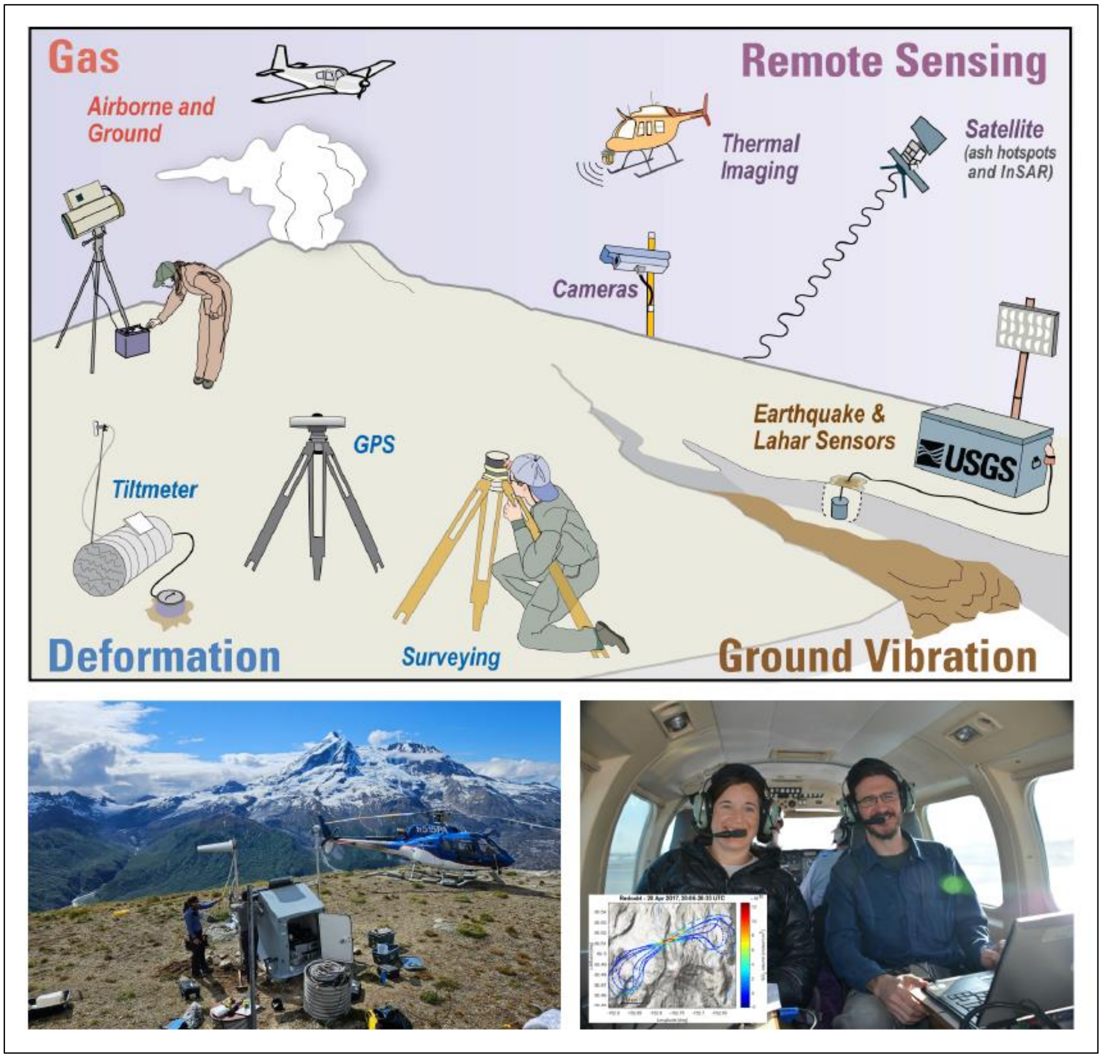
[56] NASA, "NASA's Earth Observing System," https://eospso.nasa.gov/content/nasas-earth-observing-system-project-science-office.

[57] NOAA, "Satellites," https://www.noaa.gov/satellites; NWS, "Alaskan Region HQ," https://www.weather.gov/arh/.

[58] European Space Agency, "The Sentinel Missions," https://www.esa.int/Applications/Observing_the_Earth/Copernicus/The_Sentinel_missions.

[59] USGS, "VolcView," https://volcview.wr.usgs.gov/; USGS, "AshCam," https://volcview.wr.usgs.gov/.

Figure 10. Volcano Monitoring



Sources: U.S. Geological Survey (USGS) Volcano Hazards Program and the Alaska Volcano Observatory.

Notes: Top: USGS Infographic. The USGS monitoring includes measurements of volcanic gases, ground movement (deformation [i.e., rise, fall, or sideways movement of surface] or vibration [i.e., shaking] related to magma movement, earthquakes, flows or lahars, or landslides); and remote sensing (via camera, aircraft and satellite imaging/measurements) of eruptive activities. Bottom left: Photograph by Jimmy Finney, AVO activity archive. Maintenance of field site RDDF by Malcolm Herstand and Tara Shreve, with Redoubt in the background. Equipment includes a camera, seismometer, and infrasound plus power supplies and communications. Bottom right: Photograph by Taryn Lopez, University of Alaska, Fairbanks Geophysical Institute/AVO. USGS Volcano Emissions Project scientists Laura Clor and Peter Kelly prepare to collect airborne volcanic gas measurement during the 2017 Cook Inlet Gas Flight. Inset image: map showing the location and abundance of sulfur dioxide gas released from Redoubt as measured during the flight.

Over the past few years, AVO has replaced all analog-based telemetry with digital-based telemetry, replaced at least 53 outdated instruments, and installed at least 55 new instruments on very-high-threat and high-threat Alaska volcanoes and on Mount Edgecumbe.[60] Even though

---

[60] *Telemetry* involves the automatic gathering, processing, and transmission of data from distant or inaccessible points to a central location for analysis and monitoring. According to the USGS fourth annual report to Congress on NVEWS covering FY2023, digital telemetry "was achieved in August 2022 and ensures Alaska volcano monitoring networks (continued...)

there has been progress in monitoring, the USGS considers Redoubt an under-monitored volcano. Redoubt does not have the requisite instrumentation recommended by the USGS.[61] Among the other very-high-threat to high-threat volcanoes in Alaska (**Figure 2**), the USGS considers Akutan Island, Makushin Volcano, Mount Spurr, Augustine Volcano, Mount Okmok, Iliamna Volcano, Aniakchak Crater, Mount Katmai, Mount Veniaminof, Korovin Volcano, Hayes Volcano, Mount Churchill, Kanaga Volcano, Kaguyak Crater, Kasatochi Island, Mount Moffett, and Seguam Island to be under-monitored compared with their threat levels.[62] Warnings of eruptions may not be possible for under-monitored volcanoes.

Warnings

The AVO provides warnings of volcanic activity using an alert system designed by the USGS VHP and in coordination with the ICAO and the FAA. The alert system has two parts: (1) ranked terms (unassigned, normal, advisory, watch, and warning) to inform people on the ground about a volcano's status (**Figure 11**) and (2) ranked colors (unassigned, green, yellow, orange, and red) to inform the aviation sector about airborne ash hazards (**Figure 12**).

Figure 11. Alert-Level Terms for Volcanic Activity for Informing Ground Populations

ALERT-LEVEL TERMS	When the Volcano Alert Level is changed, a Volcano Activity Notice (VAN) is issued.
NORMAL	Volcano is in typical background, non-eruptive state **OR**, after a change from a higher level, volcanic activity has ceased, and volcano has returned to non-eruptive 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.
UNASSIGNED	Ground-based instrumentation is insufficient to establish that a volcano is in a typical background level (GREEN / NORMAL). When activity at such a volcano increases to the point of being detected by remote sensing, distant seismic networks, or eyewitness reports, an alert level and color code are then assigned accordingly. When activity decreases, the volcano goes back to UNASSIGNED without going through GREEN / NORMAL.

Source: U.S. Geological Survey, *Alaska Interagency Plan for Volcanic Ash Episodes*, June 2022, https://www.usgs.gov/programs/VHP/coordination-plans.

now comply with National Telecommunications and Information Administration (NTIA) authorizations for radio frequency spectrum used by USGS." Mount Edgecumbe volcano was not considered a threatening volcano in the 2018 USGS assessment; however, volcanic unrest related to a swarm of earthquakes in April 2022 led to a retrospective analysis of past earthquakes and past ground deformation measured in satellite data showing volcanic activity. The AVO installed instruments to monitor Edgecumbe and declared it an "officially monitored" volcano in 2023. USGS, "Newest Volcano Notice Including Edgecumbe, Alaska Volcano Observatory Information Statement," Edgecumbe, VNUM #315040, February 9, 2024, https://volcanoes.usgs.gov/hans-public/volcano/ak90.

61 USGS, *Volcanic Threat Assessment*; USGS, *NVEWS Plan*; and USGS, *Recommended Monitoring*.

62 USGS, *Volcanic Threat Assessment*; USGS, *NVEWS Plan*; and USGS, *Recommended Monitoring*.

Figure 12. Aviation Color Codes for Volcanic Activity

AVIATION COLOR CODES When the volcano color code changes, a Volcano Observatory Notification for Aviation (VONA) is issued.	
GREEN	Volcano is in typical background, non-eruptive state **OR**, *after a change from a higher level,* volcanic activity has ceased, and volcano has returned to non-eruptive 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 specified, if possible).
RED	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 specified, if possible).
UNASSIGNED	Ground-based instrumentation is insufficient to establish that a volcano is in a typical background level (GREEN / NORMAL). When activity at such a volcano increases to the point of being detected by remote sensing, distant seismic networks, or eyewitness reports, an alert level and color code are then assigned accordingly. When activity decreases, the volcano goes back to UNASSIGNED without going through GREEN / NORMAL.

Source: U.S. Geological Survey, *Alaska Interagency Plan for Volcanic Ash Episodes*, June 2022, https://www.usgs.gov/programs/VHP/coordination-plans.

Notes: As of November 2024, International Civil Aviation Organization (ICAO) guidance allows a VONA to include an UNASSIGNED colorless code for volcanoes that have insufficient information available to evaluate the status of the volcano or volcanic activity. Also as of November 2024, volcano observatories may report resuspension of ash in a VONA. ICAO, *Handbook on the International Airways Volcano Watch*, Doc 9766-AN/968, 2024.

AVO notifies the public about the status of each Alaskan volcano via the online AVO Volcano Map (**Figure 13**).[63] For example, the AVO Volcano Map accessed on February 20, 2025, shows the Great Sitkin Volcano is at alert level *watch* and at aviation level *orange* (**Figure 14**). In addition, anyone can sign up to receive emails or text messages about volcanic activity at U.S.-monitored volcanoes through the Volcano Notification Service.[64]

[63] AVO, "Alaska Volcano Observatory," https://avo.alaska.edu/.

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

Figure 13. Alaska Volcano Observatory Volcano Status Map on February 20, 2025

Source: U.S. Geological Survey, "Alaska Volcano Observatory," https://avo.alaska.edu/, accessed on February 20, 2025.

Notes: Screenshot of the online interactive map. A user can examine a specific volcano for more information about volcanic activity and monitoring equipment on the interactive map.

Figure 14. Great Sitkin Volcano: Alert Status Map on February 20, 2025

Source: U.S. Geological Survey, "Alaska Volcano Observatory," https://avo.alaska.edu/, accessed on February 20, 2025.

Notes: Screenshot of the online interactive map. A user can examine a specific volcano for more information about volcanic activity and monitoring equipment on the interactive map. In many cases, the user can see real-time data as measured by the instrument or camera, by accessing the instrument page from the map.

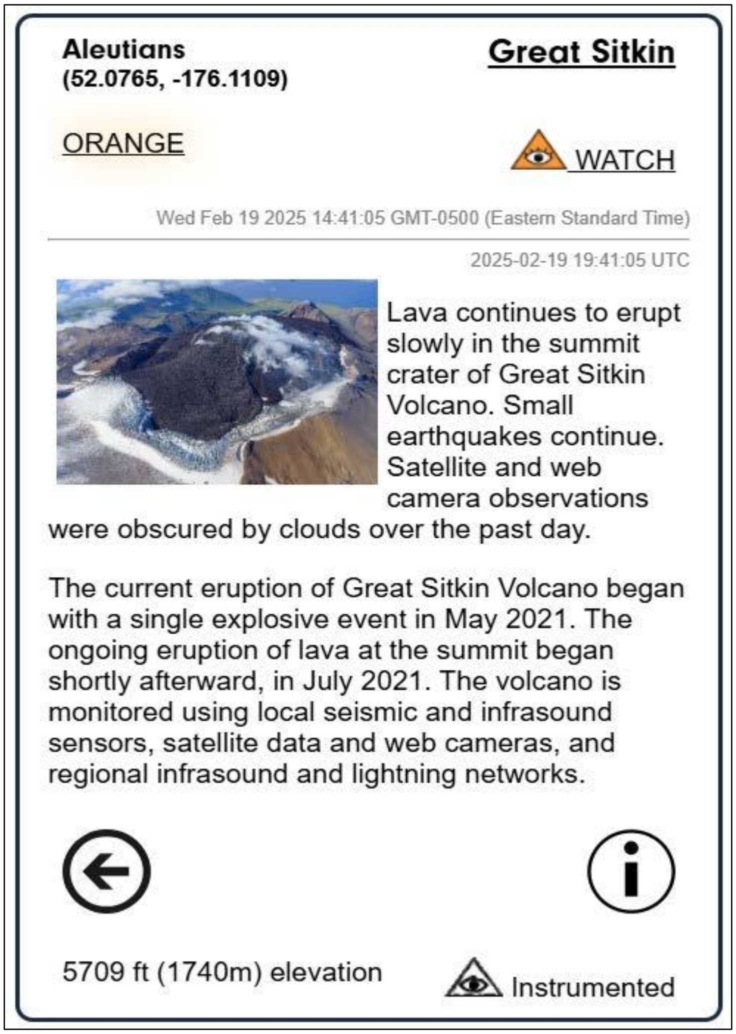
AVO may issue a Volcano Activity Notice (VAN) and a Volcano Observatory Notification for Aviation (VONA).

- A *Volcano Activity Notice* (VAN) is to be issued when a volcano's alert level changes (**Figure 11** and **Figure 12**), there is significant volcanic activity (**Figure 15**), or there is a significant ash resuspension event. Ash from previous eruptions may be resuspended in the atmosphere by strong winds and may pose a threat to people and property.[65]
- *Volcano Observatory Notification 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 volcano 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, MWOs, and AVAAC.[66]

[65] Resuspension of ash from the 1912 Novarupta-Katmai eruption is among the most common and most impactful for Alaskan communities and aviation in Alaska (**Figure 8**). For any alerts, the AVO identifies the volcano that is the source area for the resuspension and specifies that the volcano is not erupting. AVO identifies the volcano as "Katmai" for resuspension in the Novarupta-Katmai region. USGS, *Alaska Interagency Plan*. See also Mastin et al., *Progress in Protecting Air Travel*, for more about resuspension ash cloud forecasts and the use of satellite data.

[66] As of November 2024, Volcano Observatory Notifications for Aviation (VONAs) include an unassigned colorless code for volcanoes that have insufficient information available to evaluate the status of the volcano or volcanic activity, and volcano observatories may report resuspension of ash as a volcanic activity in a VONA. ICAMS, *National Volcanic Ash Operations*; ICAO, *Handbook*.

Figure 15. Great Sitkin Volcano Activity Notice on February 19, 2025



Source: U.S. Geological Survey, "Alaska Volcano Observatory," accessed February 20, 2025, https://avo.alaska.edu/.

The AVO follows the 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 the *Alaska Interagency Plan for Volcanic Ash Episodes*, among other plans.[67] AVO communicates with the NWS; FAA; DOD; and Alaska's Division of Homeland Security and Emergency Management, Department of Environmental Conservation, and Department of Health; among other federal, state, and local agencies, to provide observational data and consistent interpretations and notifications of volcanic activity and hazards. AVO coordinates as needed with federal (e.g., U.S. Fish and Wildlife Service, National Park Service), state (e.g., Department of Natural Resources), and private land managers that have jurisdiction over the land encompassing an active or restless volcano.[68]

[67] USGS, *Response for Volcanic Event*; USGS, *Alaska Interagency Plan*.

[68] USGS, *Alaska Interagency Plan*.

Every volcanic event is unique, and a volcanic event may grow in time and space into heightened volcanic unrest that requires a larger-scale response to mitigate volcanic risks.[69] The USGS has developed plans to scale up or scale down a response, depending on the volcanic event. The AVO is responsible for an initial response to changes in volcanic activity through release of VANs and VONAs to the public and federal, state, and local officials.[70] If the volcanic event becomes more significant, the AVO may scale up its response by establishing an Observatory Volcanic Event Response Team, which typically includes a 24/7 watch. If the volcanic event becomes even more significant, the Volcano Science Center Director, who is supervised by the USGS Alaska Regional Director, may establish a Center Volcanic Event Response Team. The plans describe roles and responsibilities of the team members and considerations for increasing the size of the team by bringing in staff from other volcano observatories or other USGS programs. 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.[71] In the event of a presidential disaster declaration, AVO typically coordinates with FEMA. In addition, AVO is part of Alaska's interagency response to volcanic ash episodes, national volcanic ash operations plans, and international volcanic ash operations plans.[72]

Role of Anchorage Volcanic Ash Advisory Center

The NOAA AVAAC, together with the AVO, studies, monitors, forecasts, and warns about volcanic ash hazards in the atmosphere to reduce risks to people, property, and aviation.[73] The 1989-1990 Redoubt eruption and aircraft encounters with Redoubt ash motivated the NWS to establish the Alaska Aviation Weather Unit (AAWU), including the AVAAC, soon after the eruption. AVAAC is part of the AAWU and colocated with the NWS Weather Forecast Office (WFO) and the Alaska Regional Operations Center in Anchorage. The AAWU is one of three ICAO Meteorological Watch Offices (MWOs) in the United States and the only MWO of the three that is also a VAAC.[74]

[69] The USGS defines a *volcanic event* as any instance of heightened volcanic unrest, which may include a volcanic eruption but does not require an eruption where magma reaches the surface. USGS, *Response for Volcanic Event*, p. 5.

[70] The USGS's federal authority to monitor and warn about volcanic activity is codified in a National Volcano Early Warning and Monitoring System (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 Stafford 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. The USGS Volcano Science Center is not currently an Integrated Public Alert and Warning System (IPAWS) alerting authority, required to issue warnings via wireless emergency alerts (WEA), unlike the USGS Earthquake Science Center in California that has this authority to issue earthquake early warning messages. Federal Emergency Management Agency (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 and CRS Report R47121, *The ShakeAlert Earthquake Early Warning System and the Federal Role*, by Linda R. Rowan.

[71] USGS, *Response for Volcanic Event*; FEMA, "National Incident Management System," https://www.fema.gov/emergency-managers/nims.

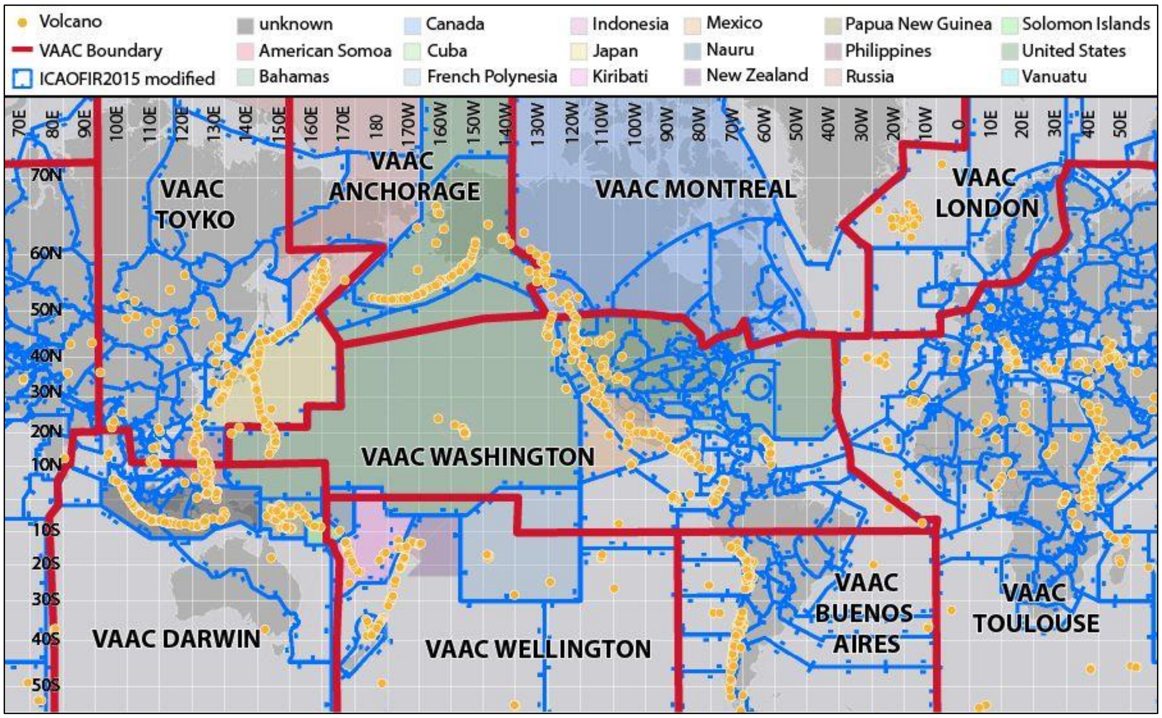
[72] USGS, *Alaska Interagency Plan*; ICAMS, *National Volcanic Ash Operations*; ICAO, *Manual on Volcanic Ash*; ICAO, *Handbook*.

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

[74] ICAO, *Manual on Volcanic Ash*; ICAO, *Handbook*.

AVAAC is one of nine VAACs organized by ICAO to monitor volcanic ash around the world and its potential impacts on aviation (**Figure 16**).[75] A single VAAC generally issues Volcanic Ash Advisories (VAAs) for a continuous ash cloud at one time, although two VAACs may issue simultaneous VAAs for different ash clouds from the same volcano. As ash nears and crosses VAAC boundaries, VAACs transfer, or handover, responsibility of VAA issuance to the downstream VAAC.[76]

Figure 16. Volcanic Ash Advisory Centers (VAACs): Areas of Responsibility



Source: International Civil Aviation Organization (ICAO)—global map from ICAO. Modified by CRS.

Notes: The National Oceanic and Atmospheric Administration (NOAA) operates the Anchorage VAAC and the Washington VAAC. These centers are responsible for observing, measuring, and modeling volcanic ash plume distribution in the atmosphere and providing volcanic ash advisories about volcano 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," https://www.weather.gov/vaac/, and NOAA, "Washington Volcanic Ash Advisory Center," https://www.ospo.noaa.gov/products/atmosphere/vaac/. Air space 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, https://www.ngdc.noaa.gov/hazel/view/hazards/volcano/loc-data.

[75] ICAO, "ICAO," https://www.icao.int/Pages/default.aspx; ICAO, *Manual on Volcanic Ash*; and ICAO, *Handbook*.

[76] The Anchorage Volcanic Ash Advisory Center (AVAAC) accepts handovers from the Tokyo Volcanic Ash Advisory Center (VAAC) and hands over responsibility for issuance of volcanic ash advisories (VAAs) to the Washington VAAC, whose area of responsibility borders that of AVAAC to the south, and to Montreal VAAC, whose area of responsibility borders that of AVAAC to the east. AVAAC is generally notified of an eruption on Russia's Kamchatka Peninsula or in the Kurile Islands by receipt of a VAA and a volcanic ash graphic (VAG) from the Tokyo VAAC or a significant meteorological event (SIGMET) from the Petropavlovsk Meteorological Watch Office. AVAAC relies on the Washington VAAC for its primary backup. ICAMS, *National Volcanic Ash Operations*.

Research

Research on volcanic ash hazards and their movement in the atmosphere includes observations and modeling. In the United States, the USGS, NOAA, NASA, and the National Science Foundation have supported much of this research at the federal level.[77]

Models

AVAAC is an operational center that uses research on volcanic ash hazards for monitoring and warning. AVAAC uses NOAA's HYSPLIT Volcanic Ash Model to prepare warnings.[78] The HYSPLIT model inputs volcano location and eruption duration, summit height, ash column height, and forecast meteorology, such as wind direction, and outputs forecasts of the dispersion and concentration of ash as it moves away from the volcano. In December 2022, the capability to generate ensemble forecasts became operational; HYSPLIT employs the 31 separate forecasts members from NOAA's weather model, the Global Ensemble Forecast System (GEFS).[79]

The USGS has advanced another model, Ash3d, to study and forecast ash clouds and ashfall hazards.[80] Ash3d inputs a volume of erupted ash from a volcanic source with wind models to forecast the thickness of ashfall on the ground and the concentration of ash in the dispersing ash cloud (see **Figure 17** for an example). Ash3d uses NOAA's Global Forecast System at 0.5 degrees of resolution, which does not use the 31 separate forecasts members of GEFS and may yield different results.[81]

---

[77] ICAMS, *National Volcanic Ash Operations*.

[78] NOAA, "HYSPLIT," https://www.arl.noaa.gov/hysplit/; NOAA, "HYSPLIT Volcanic Ash Model," .

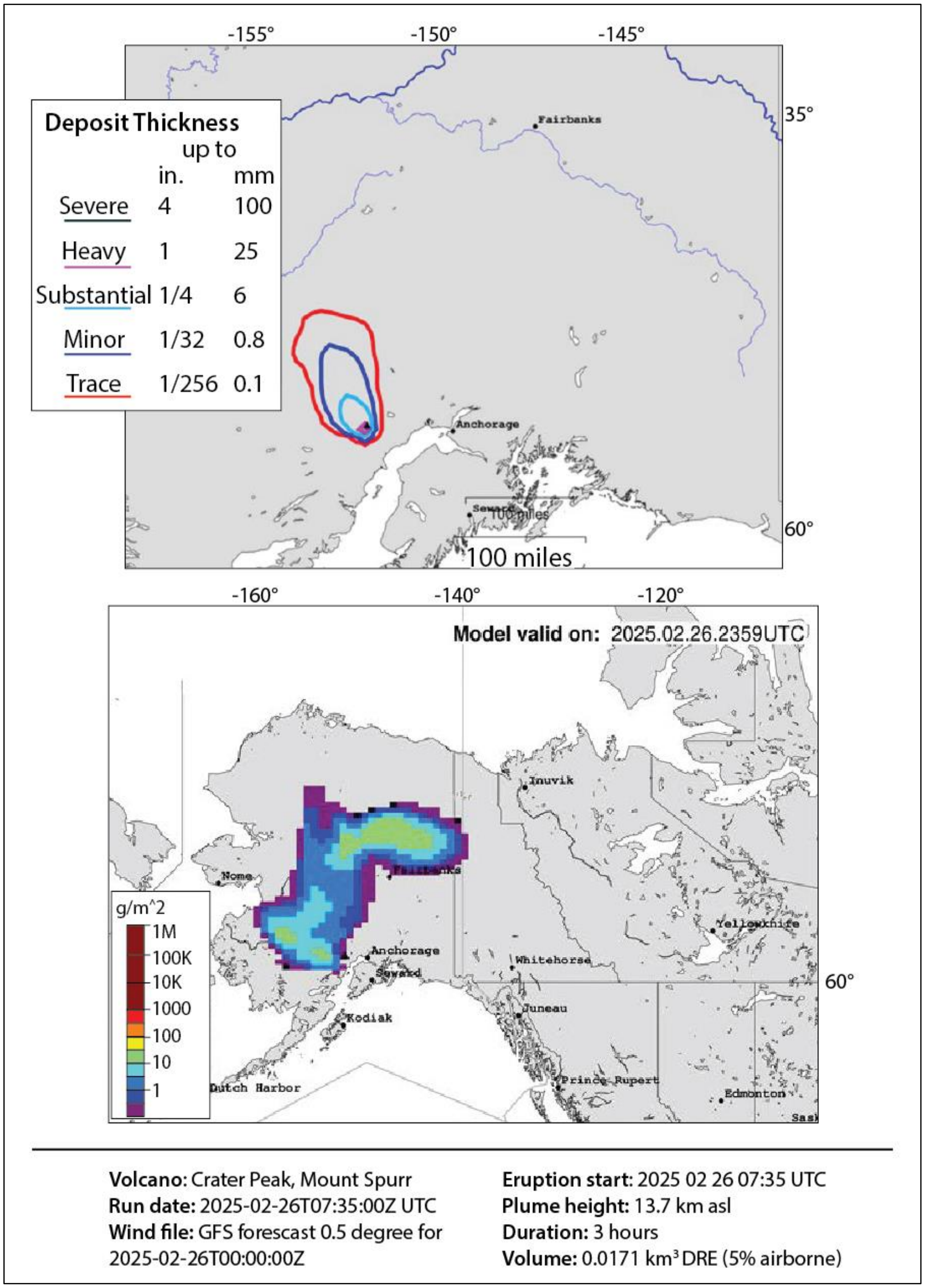
[79] ICAMS, *National Volcanic Ash Operations*; NOAA, "Global Ensemble Forecast System (GEFS)," https://www.ncei.noaa.gov/products/weather-climate-models/global-ensemble-forecast; National Centers for Environmental Prediction Central Operations, "NCEP Products Inventory," https://www.nco.ncep.noaa.gov/pmb/products/gens/.

[80] USGS, "Ash3d," https://vsc-ash.wr.usgs.gov/ash3d-gui/#!/.

[81] NOAA, "Global Forecast System," https://www.ncei.noaa.gov/products/weather-climate-models/global-forecast; ICAMS, *National Volcanic Ash Operations*.

Figure 17. Models of Mount Spurr Ashfall and Ash Cloud Dispersion

(February 26, 2025, eruption)



Source: U.S. Geological Survey, "Ash3d Public Run Results," accessed February 27, 2025, https://vsc-ash.wr.usgs.gov/ash3d-gui/#!/publicruns. These map displays of the model results have not been modified by CRS.

Notes: The top panel shows estimated ashfall thickness on the ground. The bottom panel shows the integrated ash mass load in grams per cubic meter in the atmosphere. Both estimates start with an erupted volume of 0.0171 cubic kilometers dense-rock equivalent (DRE) for a duration of 3 hours for a plume height of 13.7 kilometers (km) above sea level (asl). The estimates use winds from the Global Forecast System (GFS) with a 0.5 degrees resolution for the time listed.

Satellite Observations

In addition to models, the increased observations by satellites and web cameras have led to better ash detection and tracking to inform forecasts of ash movement and dispersion over time. 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 Eyjajallajokull ash cloud once every 15 minutes, 2021 eruptions at Soufriere, St. Vincent, were imaged once per minute. As of 2022, every VAAC could access high-quality images at least every 15 minutes and several volcanic arcs were routinely imaged every 2.5 or 5 minutes.[82]

Besides ash dispersion models and forecasts based on NOAA's GEFS or Global Forecast System (GFS), AVAAC may use NOAA's satellite-based ash-tracking products. The Satellite Analysis Branch of the National Environmental Satellite, Data, and Information Service (NESDIS) operates the Washington VAAC in conjunction with the NWS's National Centers for Environmental Prediction.[83] Additionally, the NESDIS Center for Satellite Application and Research is responsible for developing satellite products that support VAAC operations. Notably, the NESDIS Volcanic Cloud Analysis Toolkit 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.[84]

Ash Concentration and Aircraft Damage

The 2010 Eyjafjallajökull eruption in Iceland forced the closure of airspace over large areas of Europe for an extended period of time based on the London VAAC ash dispersal models and forecasts.[85] More than 100,000 flights were canceled, more than 10 million passengers were affected, and there was an estimated $5 billion in economic damage.[86] During part of the initial phase of the eruptive event,[87] various impacted European airspaces followed the general protective action of aircraft avoiding any concentration of volcanic ash, which led to airspace restrictions and closures causing significant impact to air travel. As the eruption continued, the European Organisation for the Safety of Air Navigation and the European Commission took a coordinating role and, in agreement with jet engine experts, developed different aircraft avoidance criteria for the rest of the 2010 eruption, allowing commercial aircraft to fly through certain low-ash-concentration thresholds.[88] The change in procedures required the London VAAC

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

[83] 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.

[84] 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.

[85] Met Office, "Volcanic Ash Advisory Centre (VAAC)," https://www.metoffice.gov.uk/services/transport/aviation/regulated/international-aviation/vaac/index.

[86] Reichardt et al., "Volcanic Ash and Aviation."

[87] The eruption waxed and waned for several weeks, causing multiple VAAs. See Global Volcanism Program, "Report on Eyjafjallajokull (Iceland)," *Bulletin of the Global Volcanism Network*, vol. 36, no. 4 (April 2011) https://doi.org/10.5479/si.GVP.BGVN201104-372020.

[88] Tatiana Bolic and Zarko Sikcev, "Eruption of Eyjafjallajökull in Iceland: Experience of European Air Traffic Management," *Transportation Research Record*, vol. 2214, no. 1 (2011), DOI: 10.3141/2214-17.

to issue supplemental ash dispersal models and forecasts showing low, medium, and high ash concentrations.

Subsequent studies of this eruption and others have led to advances in volcanic ash measurements, models, and forecasts.[89] Since the 2010 eruption, the ICAO and the European Union Aviation Safety Agency have developed new procedures for aviation to deal with volcanic ash hazards in Europe.[90] 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 forecasted volcanic ash contamination was transferred from air traffic management to commercial aircraft operators.[91] Aircraft operators must have safety risk assessments that include decisions about flight operations in known or forecasted volcanic ash.[92]

The ICAO collaborated with the International Coordinating Council of Aerospace Industries Associations to establish a set of ash concentration thresholds and ranges for commercial aviation.[93] The benefits of advances in ash observations and ash forecasting, however, may be of limited benefit for flight operators across all nations for developing safety risk assessments, because there is limited research on the impact of ash on jet engines.[94] The ICAO is asking VAACs to develop a quantitative volcanic ash (QVA) product that provides forecast probabilities of ash concentration at aircraft altitudes or quantifies the concentration of ash with height, enabling operators to move away from traditional criteria for visible (to the human eye) or discernable (by satellite) volcanic ash aloft.[95]

[89] 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*.

[90] 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."

[91] This transfer has implications for U.S. flight operators that may wish to fly in certain European and North Atlantic flight information regions. Near a volcano with significant volcanic activity, air traffic management makes decisions about flight restrictions and closures. In addition, any state may in the interest of public safety temporarily impose flight restrictions or closures over part or all of its territory. The European and North Atlantic flight information regions in ICAO fall under the responsibility of different VAACs—Montreal, Washington, London, and Toulouse VAACs serve the North Atlantic region; London, Toulouse, Anchorage, and Tokyo VAACs serve the European region. EASA's safety bulletin only applies in the Western European and northern North Atlantic regions, essentially the regions covered by the London and Toulouse VAACs. Since the 2010 Eyjafjallajökull eruption, the London and Toulouse VAACs have issued supplementary information about ash concentrations and have worked to improve forecasts through advances in modeling and observations as well as testing. Other VAACs are collaborating on research, monitoring, and warning about volcanic ash and improving volcanic ash warning products. 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 (hereinafter Beckett, "Conducting Volcanic Ash Cloud Exercises").

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

[93] ICAMS, *National Volcanic Ash Operations*.

[94] Reichardt et al., "Volcanic Ash and Aviation"; Delbrel et al., "Aircraft Flight Paths in Eruptions." See also T. V. Abramchuk et al., "Model for Generation the Liquid Phase Zones for Volcanic Ash Melt in the Combustion Chamber of a Turbojet: Different Flight Modes for a Mainline Aircraft," *Thermophysics and Aeromechanics*, vol. 31 (March 12, 2025), pp. 659-667, https://doi.org/10.1134/S0869864324040048.

[95] The ICAO initiated the development of the quantitative volcanic ash (QVA) product so flight operators may use the QVA with their safety management program to optimize airspace and plan more efficient routes during significant (continued...)

Monitoring

AVAAC uses observations, measurements, and forecasts from AVO and NOAA to forecast, advise, and monitor the movement of volcanic ash in AVAAC's assigned airspace. AVAAC is typically staffed 24/7 to provide guidance and support to Alaska's MWO and the aviation community.[96] Duty meteorologists or satellite analysts continuously monitor remote sensing data, pilot reports, and AVO VANs. AVAAC runs ash dispersion models, determines the current and forecast area extent of the ash, and produces ash warnings. AVAAC can request a HYSPLIT run whenever necessary by contacting the senior duty meteorologist and providing essential details such as the eruption's start time, duration, and eruption height.

Warning

AVAAC may issue a volcanic ash advisory with a volcanic ash graphic.[97]

- *A volcanic ash advisory* (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, the eruption time, the observed position of the ash cloud, and the forecasted position of the ash cloud. In cases where the ash cloud is crossing into another VAAC's area of responsibility, handoff information also is included in the VAA.
- *A volcanic ash graphic* (VAG) provides information from the VAA in a graphical format (**Figure 18**).[98]

As noted in the "Research" section, above, VAACs are developing QVAs and are expected to begin providing QVAs as part of VAAs as early as November 2025. In addition, VAAs and VAGs are anticipated to be digital by 2030.[99] The advances in observations and modeling are seen as improving the timeliness and resolution of the VAAs while reducing uncertainties in the forecasts.[100]

volcanic ash cloud events. The London and Toulouse VAACs have been required to issue supplemental QVAs since the end of 2024 to satisfy updated Europe and North Atlantic guidance. EASA, *Flight in Volcanic Ash*; ICAO, *Volcanic Ash European and North Atlantic*; Beckett, "Conducting Volcanic Ash Cloud Exercises." The other seven VAACs are expected to issue QVAs for significant eruptions after 2025, and all VAACs are expected to issue QVAs as a standard for significant events in Annex 3 by November 2030. ICAO, *Annex 3 - Meteorological Service for International Air Navigation*, 20th Edition, 2018. After 2030, VAAs and VAGs are anticipated to be issued only for ash cloud events that are not significant events. Amendment 82 to ICAO Annex 3 and ICAMS, *National Volcanic Ash Operations*.

[96] ICAMS, *National Volcanic Ash Operations*.

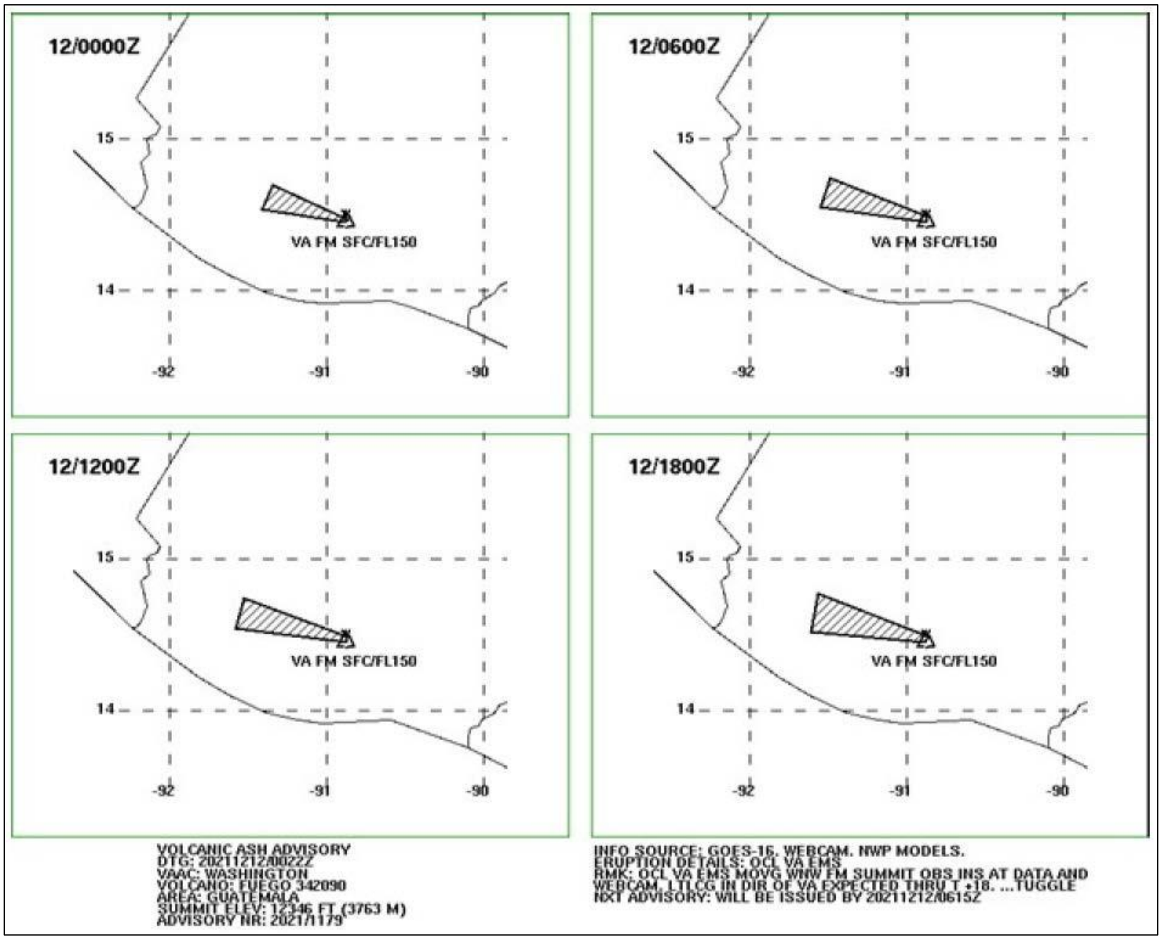
[97] ICAMS, *National Volcanic Ash Operations*.

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

[99] The World Meteorological Organization, sponsored by the ICAO, has developed and currently maintains the IWXXM data format. This format is designed to report aviation weather information in the widely recognized XML standard for data exchange over the internet. The product representations of IWXXM are intended for machine-to-machine operational exchanges of meteorological information essential to aviation, which includes volcanic activity. These IWXXM products are expected to replace legacy Time Activity Curve (TAC)-formatted and text-based products by 2030. ICAMS, *National Volcanic Ash Operations*.

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

Figure 18. Example of a Volcanic Ash Graphic (VAG)



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 example is for a 2021 eruption of the Fuego Volcano in Guatemala. The VAG was prepared by the Washington Volcanic Ash Advisory Center. Each panel shows the forecasted 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.

Other Volcano Warning Products in Use in Alaska

The information and warnings from the AVO and AVAAC, the two primary federal agencies focused on volcanic activity, are used to develop other volcano warning products for Alaska (**Figure 19**). AVAAC is part of the NWS and generally communicates information and warnings following NWS protocols and coordination. In addition to the VAA warning products from AVAAC, the NWS may issue other volcano warning products in Alaska (**Figure 19**). The Anchorage MWO may issue *Significant Meteorological Information*—the primary warning product to the aviation community for volcanic ash. The Anchorage Center Weather Service Unit (CWSU), which is located in the FAA's Air Route Traffic Control Center, is staffed by an NWS meteorologist. The CWSU is the liaison between FAA facilities and other NWS offices. Forecasters issue a *Center Weather Advisory* or a *Meteorological Impact Statement*, as needed, to provide additional information essential to air traffic managers' decisionmaking processes.

The NWS Alaska Region operates three WFOs, located in Anchorage, Fairbanks, and Juneau. WFOs participate in the volcanic eruption response by issuing ashfall statements, advisories, and warnings for the public and marine communities (**Figure 19**). Ashfall is included in Terminal Aerodrome Forecasts as appropriate. The WFO also issue flash-flood products as deemed necessary for impactful lahars or volcanic debris flows after coordination with AVO and the Alaska Pacific River Forecast Center. In addition, the WFOs 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.[101] The FAA may restrict air space based on the presence of volcanic ash.[102] The FAA may issue a Notice to Air Missions about volcanic ash hazards, an Urgent Pilot Report, or a Temporary Flight Restriction (**Figure 19**).[103] DOD and Alaska state agencies issue other volcano warning products (**Figure 19**).

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

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

[103] A Notice to Air Missions 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. FAA also changed the acronym from Notice to Air Men to Notice to Air Missions. ICAO and ICAMS may use the term *Notice to Air Men*, *Notice to Airman*, or *Notice to Airmen*.

Figure 19. Some Volcano Warning Products in Use in Alaska

Alaska Volcano Observatory (AVO)

- Information Release
- Weekly Update
- Daily Update
- Status Report
- Volcanic Activity Notice (VAN)
- Volcano Observatory Notice for Aviation (VONA)

National Weather Service (NWS)

- SIGMET (Significant Meteorologic Information)
- VAA (Volcanic Ash Advisory)
- MIS (Meteorologic Impact Statement)
- CWA (Center Weather Advisory)
- Public Ashfall Advisory & Warning
- Marine Ashfall Advisory & Warning
- Special Weather & Marine Weather Statements
- TAF (Terminal Aerodrome Forecast)

Federal Aviation Administration (FAA)

- NOTAM (Notice to Airman)
- UAA (Urgent Pilot Report)
- TFR (temporary flight restriction)

Alaska Department of Homeland Security and Emergency Management (DHS&EM)

- SITREP (Situation Report)
- Community Alert Press Release

U.S. Coast Guard (USCG)

- Marine Info. Broadcast (Notice to Mariners)

Department of Defense (DOD)

- Volcanic Ash Notification (VAN)

Alaska Department of Environmental Conservation, Division of Air Quality (DEC)

- Air Quality Advisory or guidance statements

Alaska Department of Environmental Conservation, Drinking Water Program (DEC)

- Drinking Water Advisory or guidance statements

Alaska Department of Health & Social Services (DHSS)

- Public Service Announcement
- Alaska Public Health Alert Network (PHAN)

71

Municipality of Anchorage (MOA)

- Air Quality Advisory

Source: U.S. Geological Survey, Appendix J in *Alaska Interagency Plan for Volcanic Ash Episodes*, June 2022, https://www.usgs.gov/programs/VHP/coordination-plans.

Dissemination of Volcano Warning Products in Alaska

If a volcanic event may be an immediate threat to life, the State Emergency Operation Center (SEOC), located on Joint Base Elmendorf-Richardson near Anchorage, can coordinate dissemination of volcano warnings through the national Emergency Alert System (EAS), Wireless Emergency Alert (WEA), and National Warning System/Alaska Warning System (AKWAS).[104]

Each agency distributes alert and safety information (i.e., volcano warning products) through various communication portals. AVO issues notification of volcanic activity via telephone call-down to partner agencies as well as via email, website, social media postings, and the Volcano Notification Service. NWS uses NOAA Weather Wire, marine high-frequency and very-high-frequency radio, NOAA Weather Radio, the statewide Alaska television weathercast, and EAS 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 United States Coast Guard 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 the Aeronautical Fixed Telecommunications Network, and radio, data, and voice communications for transmitting flight plans, clearances, and other information.[105] SEOC can redistribute critical information via email systems, Alaska Land Mobile Radio, Amateur Radio, commercial radio, television, and cable and internet services in addition to EAS, WEA, and AKWAS.

Congressional Considerations

The number of active volcanoes in Alaska, and the difficulty of monitoring those volcanoes due to their remoteness and harsh environment, present unique challenges for the USGS and its partners. Congress may wish to assess the USGS's plans for addressing these challenges in Alaska and meeting the objectives of NVEWS (§5001 of P.L. 116-9; 43 U.S.C. 31k) and its progress on these plans.[106]

Congress may want information on the USGS's ability to efficiently and effectively employ remote sensing (e.g., satellite-based observations) to provide additional volcanic activity information that could enhance warning capability relative to the cost of installing and maintaining additional monitoring equipment at volcanoes in Alaska. Congress also could evaluate current USGS efforts to organize, modernize, standardize, and stabilize the monitoring

[104] USGS, *Alaska Interagency Plan*; Federal Communications Commission, "The Emergency Alert System," https://www.fcc.gov/emergency-alert-system; Federal Communications Commission, "Wireless Emergency Alerts (WEA)," https://www.fcc.gov/consumers/guides/wireless-emergency-alerts-wea; State of Alaska, *Emergency Alert System Plan*, 2025, https://ready.alaska.gov/Documents/Operations/EAS/EASPlan/Alaska%20EAS%20Plan%202025.pdf. See also CRS Report R48363, *The Integrated Public Alert and Warning System (IPAWS): Primer and Issues for Congress*, by Amanda H. Peskin.

[105] SKYbrary, "Aeronautical Fixed Telecommunications Network," https://skybrary.aero/articles/aeronautical-fixed-telecommunication-network-aftn. See also FAA, "Section 4. International Operations and Messages," https://www.faa.gov/air_traffic/publications/atpubs/fs_html/chap6_section_4.html.and ICAO Store, "Annex 10 – Aeronautical Telecommunications," https://store.icao.int/en/annexes/annex-10.

[106] The USGS submitted a five-year plan for establishing and managing NVEWS to Congress in 2020 (USGS, *NVEWS Plan*), annual reports to Congress charting the progress of NVEWS, a 2024 report with recommendations for volcano monitoring (USGS, *Recommended Monitoring*), and a 2024 response plan for volcanic events (USGS, *Response for Volcanic Event*).

systems of the five U.S. volcano observatories and consider whether the USGS NVEWS plans may ensure Alaska's active volcanoes are monitored at a level commensurate with each volcano's threat.[107] 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 had been fully established as of the end of the five-year authorization of appropriations for NVEWS (which ended in FY2023).[108] The 2024 USGS *Volcano Science Center Response Plan for Significant Volcanic Events* calls for temporary 24/7 watch capabilities for significant volcanic events as described in the plan.[109]

AVAAC is responsible for VAAs (including VAG) and for developing QVAs in Alaskan air space and other flight regions within its area of responsibility (**Figure 16**). It remains unclear how AVAAC's VAA products are coordinated with the USGS Ash3d products, the Washington VAAC, and the NESDIS Volcanic Cloud Analysis Toolkit. The ICAO initiated the development of the QVA, which quantifies ash concentrations in ash cloud forecasts, so that flight operators may use the QVA with their safety risk assessment to optimize airspace and plan more efficient routes during significant volcanic ash cloud events. ICAO expects all VAACs to issue QVAs as a standard product by November 2030 and to retire VAAs sometime after 2030. Although the FAA uses VAAs among other volcano warning products (**Figure 19**), it has not provided guidance about using QVAs in the future.

In 2022, Congress passed legislation that amended NVEWS to direct cooperation and coordination between the USGS's volcano monitoring and NOAA's VAACs (P.L. 117-263). As of May 2025, the Secretary of Commerce and the Secretary of the Interior had not completed implementation plans and cost estimates for cooperative support for integrating VAAC research, modeling, and warning with NVEWS. Congress may consider oversight of NOAA's VAACs to understand how AVAAC products may evolve and how AVAAC/AVO volcanic ash products may be used by the FAA, DOD, and others. In addition, flight operators may benefit from AVAAC/AVO research, monitoring, and warning in preparing safety risk assessments about volcanic ash that are necessary for flight operations in parts of Europe and the North Atlantic.

Congress may consider oversight of NVEWS, particularly plans, progress, and priorities; amending NVEWS further; or reauthorizing appropriations for NVEWS (authorized appropriations expired in FY2023) to meet the objectives of NVEWS while ensuring research, monitoring, and warning about Alaska's active volcanoes at levels commensurate with their threats.

In the 119th Congress, S. 1052, introduced on March 13, 2025, would reauthorize NVEWS, authorizing appropriations for USGS of $75 million until FY2033, extending the period of authorization of sums necessary for NOAA to carry out its NVEWS-related activities to FY2034, and amending NVEWS (41 U.S.C. § 31k(b)(2)(B)) by adding "infrasound arrays, visible and infrared cameras and advanced digital telemetry networks" to the emerging technologies the USGS should apply to modernize NVEWS. Another measure, H.R. 3176, was introduced on May

---

[107] For example, the USGS indicates that some very-high to high-threat Alaska volcanoes may remain under-monitored in its five-year plan for NVEWS. 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 System*, by Linda R. Rowan.

[108] 43 U.S.C. 31k; USGS, *NVEWS Plan*; CRS In Focus IF11987, *The National Volcano Early Warning System*, by Linda R. Rowan; USGS, "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.

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

5, 2025, to reauthorize NVEWS. Over the past few years, AVO has replaced all analog-based telemetry with digital-based telemetry for Alaska's volcanoes, replaced at least 53 outdated instruments, and installed at least 55 new instruments, including some infrasound and cameras, on very-high-threat and high-threat Alaska volcanoes and on Mount Edgecumbe.[110]

[110] The emerging technologies included in 41 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."

Appendix A. Acronyms Used in This Report

Table A-1. Acronyms Used in This Report

AAWU	Alaska Aviation Weather Unit
AKWAS	Alaska Weather Alert Service
AVAAC	Anchorage Volcano Ash Advisory Center
AVO	Alaska Volcano Observatory
CWSU	Central Weather Service Unit
DOD	Department of Defense
EAS	Emergency Alert System
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
GEFS	Global Ensemble Forecast System
GFS	Global Forecast System
ICAO	International Civil Aviation Organization
MWO	Meteorological Weather Office
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NVEWS	National Volcano Early Warning and Monitoring System
NWS	National Weather Service
QVA	Quantitative Volcano Ash
SEOC	State Emergency Operation Center
USGS	U.S. 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

Appendix B. Glossary of Volcano Terms

Terms describing volcanic features, volcanic processes, and volcano hazards may vary based on volcano type (stratovolcano or shield volcano), from place to place, and over time, as volcano science advances. The following volcano terms are commonly applied to volcanoes in the United States. Alaska's active volcanoes are mostly stratovolcanoes and are different from Hawaii's active volcanoes, which are shield volcanoes. Nonetheless, Hawaiian terms, such as *pahoehoe* may be applied to some of Alaska's volcanoes. Volcano hazards that may harm people and the environment and damage property include lava flows, lahars, pyroclastic flows, volcanic gases, boiling water/fluid, steam, volcanic ejecta, and volcanic ash. Earthquakes and landslides are related hazards as the volcano grows or as magma moves.

Glossary

Aa	Rubbly surface composed of broken lava blocks. Walking on such a flow is difficult and may be painful.
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 that 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.
Caldera	A large, basin-shaped depression with a diameter many times larger than its depth and included vents; 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. Kilauea 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	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 (Tephra)	Material explosively ejected from a volcano. Any type and size of rock fragment that is forcibly ejected and travels an airborne path. May include ash, bombs, and scoria.
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.
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 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 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/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, 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.
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 composed of 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 is sometimes called a *composite volcano*. Lava flows, pyroclastic flows, lahars, ash, pumice, phreatic explosions, and other volcanic activity may occur. Most of Alaska's volcanoes are stratovolcanoes. The Cascade Range in California, Oregon, and Washington consists of mostly stratovolcanoes.
Tuff	A general term for consolidated (hardened and/or compacted) pyroclastic rocks.
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 that is most often associated with Hawaiian volcanoes, and there is a Hawaii Interagency Vog Information Dashboard for more information and current conditions.
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 eyes, skin, and the 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, death; and (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," 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; National Park Service, Hawaii Volcanoes National Park, "Pele's Hair," https://www.nps.gov/havo/learn/nature/peles-hair.htm; USGS, "Caldera or Crater ... What's the Difference?," https://www.usgs.gov/observatories/yvo/news/caldera-or-craterwhats-difference; USGS, "What Is 'Vog'? How Is It Related to Sulfur Dioxide (SO2) Emissions?" 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," https://www.usgs.gov/programs/VHP/volcanic-gases-can-be-harmful-health-vegetation-and-infrastructure.

Appendix C. Examples of Problems for Aircraft from Volcanic Ash and Gas Hazards

During a volcanic eruption, volcanic ash with or without toxic volcanic gases, such as sulfur dioxide, can reach and exceed the cruising altitude of turbine-powered airplanes within minutes and may spread over large geographical areas within days. The volcanic risks to aircraft may be immediate or delayed in time and space to the actual volcanic eruption that produced the volcanic plume and cloud. Some of the problems an aircraft may encounter include the following:[111]

- malfunction (or failure) of one or more engines, leading not only to reduction (or complete loss) of thrust but also to failures of electrical, pneumatic, and hydraulic systems;
- blockage of pitot and static sensors resulting in unreliable airspeed indications and erroneous warnings;
- windscreens rendered partially or completely opaque;
- smoke, dust, and/or toxic chemical contamination of cabin air requiring crew use of oxygen masks, thus impacting communications (electronic systems also may be affected);
- erosion of external and internal aircraft components;
- reduced electronic cooling efficiency leading to a wide range of aircraft system failures;
- need for aircraft to be maneuvered in a manner that conflicts with other aircraft; and
- deposits of volcanic ash on a runway degrading braking performance, most significantly if the ash is wet; in extreme cases, this can lead to runway closure.

Author Information

Linda R. Rowan
Analyst in Natural Resources and Earth Sciences

[111] International Civil Aviation Organization, *Volcanic Ash Contingency Plan, European and North Atlantic Regions*, EUR Doc 019, NAT Doc 006, Part II, January 2024.

Disclaimer