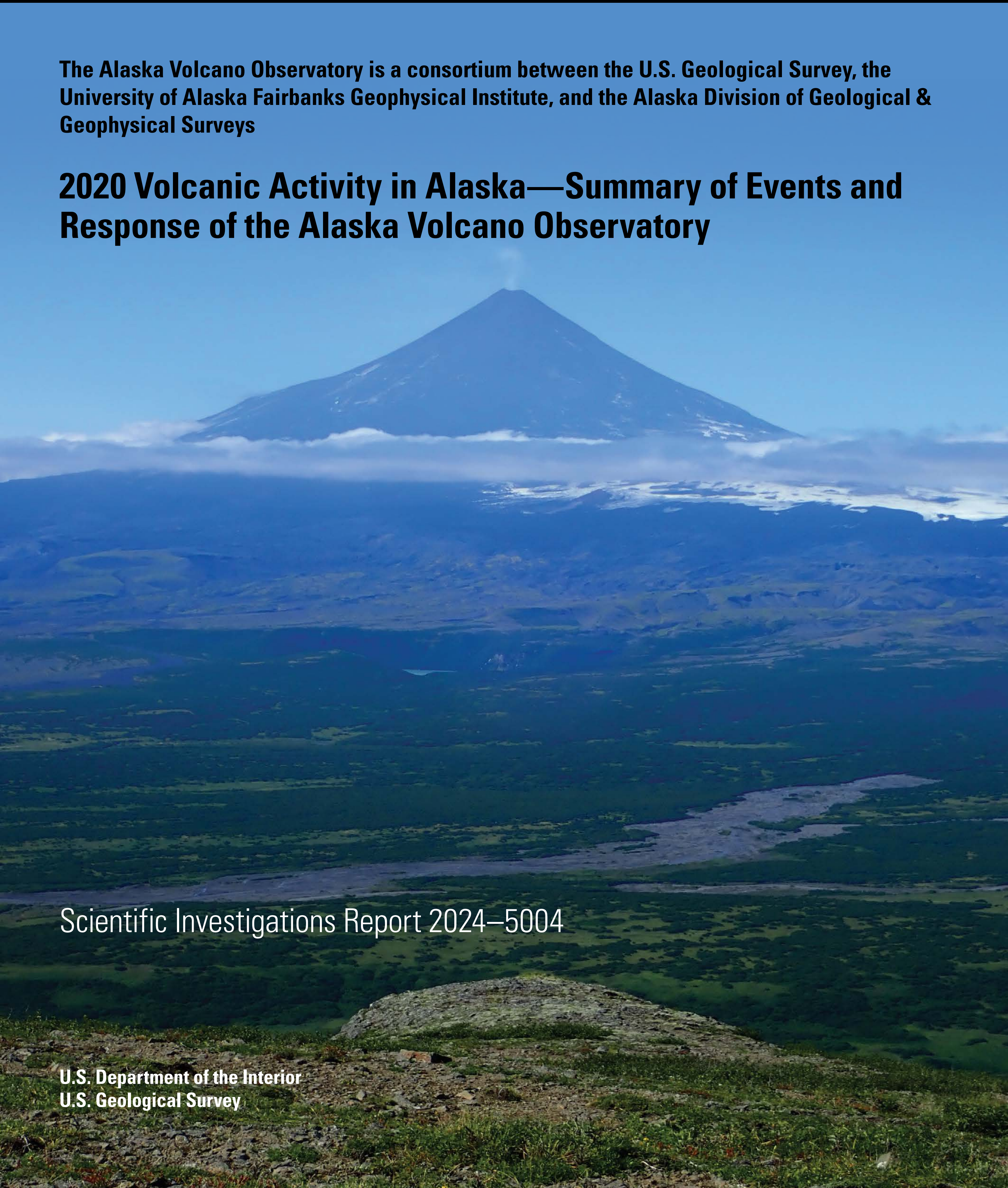
science for a changing world



The Alaska Volcano Observatory is a consortium between the U.S. Geological Survey, the University of Alaska Fairbanks Geophysical Institute, and the Alaska Division of Geological & Geophysical Surveys

2020 Volcanic Activity in Alaska—Summary of Events and Response of the Alaska Volcano Observatory

Scientific Investigations Report 2024–5004

U.S. Department of the Interior
U.S. Geological Survey

Cover. Photograph of Shishaldin Volcano gently outgassing during the 2019–2020 eruption. U.S. Geological Survey photograph by A. Lerner, August 20, 2020.

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By Tim Orr, Cheryl Cameron, Hannah Dietterich, Matthew Loewen, Taryn Lopez, John Lyons, Jenny Nakai, John Power, Cheryl Searcy, Gabrielle Tepp, and Chris Waythomas

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This report represents the work of the entire Alaska Volcano Observatory staff, colleagues from other U.S. Geological Survey (USGS) volcano observatories, and cooperating State and Federal agencies. We thank those members of the public who shared observations and photographs. Technical reviews by David Fee, Skye Kushner, and Michelle Coombs improved the content and consistency of this report. The Alaska Volcano Observatory is funded by the USGS Volcano Hazards Program and the State of Alaska.

Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
foot (ft)	0.000305	kilometer (km)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	3,281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
	Mass flow	
metric ton per day (t/d)	1.1022	ton, long [2,240 lb] per day
metric ton per day (t/d)	0.9842	ton, short [2,000 lb] per day

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Datum

Altitude, as used in this report, refers to distance above sea level of a location in the air.

Elevation, as used in this report, refers to distance above sea level of a location on the land surface.

Depth, as used in this report, refers to distance below sea level.

Locations in latitude and longitude are presented in decimal degrees referenced to the World Geodetic System 1984 (WGS84) datum, unless otherwise noted.

Vertical coordinate information for earthquakes is referenced to the World Geodetic System 1984 (WGS84), and elevations of volcanoes are referenced to the North American Vertical Datum of 1988 (NAVD88), unless otherwise noted.

Abbreviations

#	number
AKDT	Alaska daylight time; UTC–8 hours
AKST	Alaska standard time; UTC–9 hours
ASL	above sea level
AVO	Alaska Volcano Observatory
GNSS	Global Navigation Satellite System
GVP	Smithsonian Institution Global Volcanism Program
HADT	Hawaii-Aleutian daylight time; UTC–9 hours
HAST	Hawaii-Aleutian standard time; UTC–10 hours
inSAR	interferometric synthetic aperture radar
LP	long-period
M_L	local magnitude
PIREP	pilot weather report
RSAM	real-time seismic amplitude measurement
SEM	scanning electron microscope
SWIR	short-wave infrared
TROPOMI	TROPOspheric Monitoring Instrument
UAFGI	University of Alaska Fairbanks Geophysical Institute
USGS	U.S. Geological Survey
UTC	coordinated universal time; same as Greenwich mean time
VT	volcano-tectonic

2020 Volcanic Activity in Alaska—Summary of Events and Response of the Alaska Volcano Observatory

By Tim Orr,[1] Cheryl Cameron,[2] Hannah Dietterich,[1] Matthew Loewen,[1] Taryn Lopez,[3] John Lyons,[1] Jenny Nakai,[1] John Power,[1] Cheryl Searcy,[1] Gabrielle Tepp,[4] and Christopher Waythomas[1]

Abstract

The Alaska Volcano Observatory responded to eruptions, volcanic unrest or suspected unrest, increased seismicity, and other significant activity at nine volcanic centers in Alaska in 2020. The most notable volcanic activity in 2020 was an eruption of Shishaldin Volcano, which produced lava flows, lahars, and ash. Mount Cleveland had one small ash-producing eruption in June but was quiet thereafter. Other activity documented in 2020 consisted of elevated seismicity at the volcanoes Mount Veniaminof, Pavlof Volcano, Makushin Volcano, Atka volcanic complex (Korovin Volcano), Great Sitkin Volcano, and Semisopochnoi Island. Finally, the resuspension of ash deposited during the 1912 Novarupta-Katmai eruption was documented on three occasions.

Introduction

The Alaska Volcano Observatory (AVO) is a joint program of the U.S. Geological Survey (USGS), the University of Alaska Fairbanks Geophysical Institute, and the State of Alaska Division of Geological & Geophysical Surveys. AVO was formed in 1988 and uses Federal, State, and university resources to (1) monitor and study Alaska's hazardous volcanoes (fig. 1) in order to assess the nature, timing, and likelihood of volcanic activity; (2) assess volcanic hazards associated with anticipated activity, including the kinds of events, their effects, and areas at risk; and (3) provide timely and accurate information on volcanic hazards, and warnings of impending dangerous activity, to officials (local, State, and Federal) and the public.

This report summarizes notable unrest and other kinds of activity associated with volcanoes in Alaska during 2020 (tables 1, 2) and briefly describes AVO's response. It contains information about all identified volcanic unrest, even if no formal public notification was issued at the time. Observations, images, and data that are typically not published elsewhere are included in this report. Similar summaries of volcanic unrest and AVO's response have been published annually since 1992. Although AVO faced challenges in 2020 with regards to staff quarantined at home because of the COVID-19 pandemic, appropriate safety precautions were implemented and AVO's field season was ultimately a success.

Table 1. Summary of activity at Alaska volcanoes in 2020, including but not limited to confirmed eruptions, possible eruptions, increases in seismicity, observations of fumarolic activity, and other notable events.

[Volcano locations shown in figure 1. Novarupta is a satellite vent of Mount Katmai. Korovin Volcano is a subfeature of the informally named Atka volcanic complex. Mount Young is a cluster of three cones in the caldera of Semisopochnoi Island]

Volcano	Type of activity
Mount Katmai (Novarupta)	Resuspension of 1912 ash
Mount Veniaminof	Elevated seismic activity
Pavlof Volcano	Elevated seismic activity
Shishaldin Volcano	Explosive eruption with ash emissions, lava flows, and lahars
Makushin Volcano	Elevated seismic activity
Mount Cleveland	Elevated surface temperatures; explosive eruption
Atka volcanic complex (Korovin Volcano)	Elevated seismic activity; gas emissions
Great Sitkin Volcano	Elevated seismic activity
Semisopochnoi Island (Mount Young)	Elevated seismic activity; weak explosive events; ash and gas emissions

The AVO volcano monitoring program involves daily analyses of satellite and webcam imagery, seismicity, and infrasound detections; occasional overflights and ground visits; airborne and ground-based gas measurements; and the compilation of visual observations taken from observatory personnel members, residents, mariners, and pilot weather reports (PIREP; reports of meteorological phenomena encountered by aircraft in flight). AVO also receives real-time ground deformation data from permanent Global Navigation

[1] U.S. Geological Survey.

[2] Alaska Division of Geological & Geophysical Surveys.

[3] University of Alaska Fairbanks.

[4] Seismological Laboratory, California Institute of Technology.

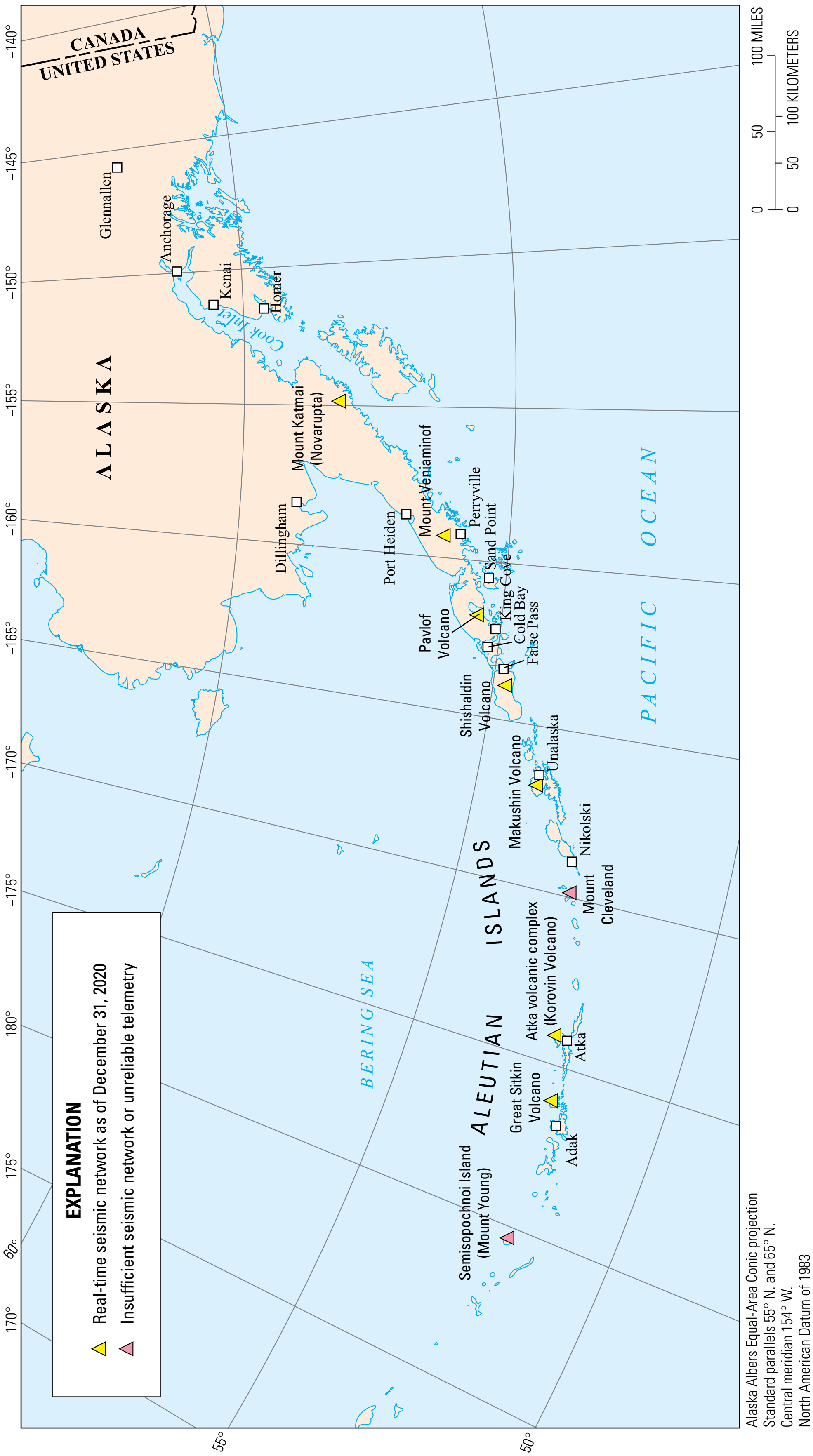


Figure 1. Map of volcanoes discussed in this report and their monitoring statuses.

Table 2. Aviation Color Code and Volcano Alert Level changes in 2020 at Alaska volcanoes discussed in this report.

[See tables 3 and 4 for definitions of Aviation Color Codes and Volcano Alert Levels. Dates shown as month/day/year. Times shown in coordinated universal time (UTC). Novarupta is a satellite vent of Mount Katmai. Korovin Volcano is a subfeature of the informally named Atka volcanic complex. Mount Young is a cluster of three cones in the caldera of Semisopochnoi Island]

Aviation Color Code/ Volcano Alert Level	Date and time of change (UTC)
Mount Katmai (Novarupta)	
GREEN/NORMAL	No change for entire year
Mount Veniaminof	
GREEN/NORMAL	Beginning of year
YELLOW/ADVISORY	06/18/2020 (22:01)
GREEN/NORMAL	08/20/2020 (19:39)
Pavlof Volcano	
YELLOW/ADVISORY	Beginning of year
GREEN/NORMAL	03/03/2020 (19:38)
YELLOW/ADVISORY	09/21/2020 (22:49)
GREEN/NORMAL	10/14/2020 (17:54)
Shishaldin Volcano	
ORANGE/WATCH	Beginning of year
RED/WARNING	01/07/2020 (21:33)
ORANGE/WATCH	01/08/2020 (04:17)
RED/WARNING	01/19/2020 (17:28)
ORANGE/WATCH	01/20/2020 (09:37)
YELLOW/ADVISORY	02/07/2020 (01:20)
ORANGE/WATCH	03/15/2020 (06:31)
YELLOW/ADVISORY	04/16/2020 (19:44)
GREEN/NORMAL	06/24/2020 (20:00)
Makushin Volcano	
GREEN/NORMAL	Beginning of year
YELLOW/ADVISORY	06/16/2020 (02:02)
GREEN/NORMAL	09/08/2020 (21:52)

Aviation Color Code/ Volcano Alert Level	Date and time of change (UTC)
Mount Cleveland	
YELLOW/ADVISORY	Beginning of year
UNASSIGNED	05/07/2020 (23:37)
ORANGE/WATCH	06/02/2020 (07:46)
YELLOW/ADVISORY	06/17/2020 (19:56)
UNASSIGNED	09/03/2020 (01:40)
Atka volcanic complex (Korovin Volcano)	
GREEN/NORMAL	Beginning of year
YELLOW/ADVISORY	10/28/2020 (17:51)
GREEN/NORMAL	12/03/2020 (20:17)
Great Sitkin Volcano	
GREEN/NORMAL	Beginning of year
YELLOW/ADVISORY	02/26/2020 (20:58)
GREEN/NORMAL	10/21/2020 (23:21)
Semisopochnoi Island (Mount Young)	
ORANGE/WATCH	Beginning of year
YELLOW/ADVISORY	01/09/2020 (23:25)
ORANGE/WATCH	02/15/2020 (09:19)
YELLOW/ADVISORY	02/26/2020 (20:59)
ORANGE/WATCH	03/16/2020 (01:24)
YELLOW/ADVISORY	04/01/2020 (20:16)
UNASSIGNED	11/20/2020 (19:00)

Satellite System (GNSS) stations at eight Alaskan volcanoes: Akutan Volcano, Augustine Volcano, Makushin Volcano, Mount Okmok, Redoubt Volcano, Shishaldin Volcano, Mount Spurr, and Westdahl volcano (an ice-clad edifice with no formal name that occupies the west end of Unimak Island). These deformation data are supplemented with Interferometric Synthetic Aperture Radar (InSAR) imagery (for example, Lee and others, 2010).

Observations from these multiple sources inherently relate data to several different datums. Ash altitudes are listed in feet above sea level (ASL) with their metric conversion given in parentheses. Ash altitudes are commonly from PIREPs or, for ash resuspension events from the National Weather Service, are based on analysis of satellite imagery, and the altitudes given herein can be somewhat imprecise. Earthquake depths are modeled in relation to the World Geodetic System of 1984 (WGS 1984), and the accuracy of depth given directly relates to how many stations were used to record the event (that is, accuracy of depth decreases with less recording stations). The summit elevations of the volcanoes are derived from the 2019 Interferometric Synthetic Aperture Radar data. These elevations may differ from past AVO annual summaries, which were taken directly from the AVO database (https://avo.alaska.edu/).

With this information, AVO assigns each monitored volcano an Aviation Color Code and Volcano Alert Level, which indicate its current activity status (Gardner and Guffanti, 2006). No assignment is given to unmonitored volcanoes at background activity levels. The Aviation Color Code addresses the hazards to aviation posed by a volcano, whereas the Volcano Alert Level addresses the hazards on the ground. Although the Aviation Color Code and Volcano Alert Level are usually changed upward or downward together, certain situations may dictate that they are changed independently. For instance, a volcano may produce lava flows that are dangerous on the ground and merit a Volcano Alert Level of **WARNING**, but the hazard to aviation is minimal and merits an Aviation Color Code of **ORANGE**. Where possible, Volcano Alert Level announcements contain additional explanations of volcanic activity and expected hazards. Tables 3 and 4 define each Aviation Color Code and Volcano Alert Level.

Table 3. Definitions of the Aviation Color Codes used by United States volcano observatories.

Aviation Color Code	Definition
GREEN	Volcano is in typical background, noneruptive state or, after a change from a higher level, volcanic activity has ceased and volcano has returned to noneruptive background state.
YELLOW	Volcano is exhibiting signs of elevated unrest above known background level or, after a change from a higher level, volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
ORANGE	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, or eruption is underway with no or minor volcanic-ash emissions [ash-plume height 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 volcano is at typical background level (**GREEN/NORMAL**). When activity at such a volcano increases to the point of being detected by remote sensing instruments, distant seismic networks, or eyewitness reports, an alert level and color code are assigned accordingly. When activity decreases, volcano goes back to **UNASSIGNED** without going through **GREEN/NORMAL**.

Table 4. Definitions of the Volcano Alert Levels used by United States volcano observatories.

Volcano Alert Level	Definition
NORMAL	Volcano is in typical background, noneruptive state or, after a change from a higher level, volcanic activity has ceased, and volcano has returned to noneruptive background state.
ADVISORY	Volcano is exhibiting signs of elevated unrest above known background level or, after a change from a higher level, volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
WATCH	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, or eruption is underway but poses limited hazards.
WARNING	Highly hazardous eruption is imminent, underway, or suspected.
UNASSIGNED	Ground-based instrumentation is insufficient to establish that volcano is at typical background level (**GREEN/NORMAL**). When activity at such a volcano increases to the point of being detected by remote sensing instruments, distant seismic networks, or eyewitness reports, an alert level and color code are assigned accordingly. When activity decreases, volcano goes back to **UNASSIGNED** without going through **GREEN/NORMAL**.

AVO scientists produce daily reports through weekly duty scientist and duty remote sensing rotations. The duty remote sensor produces a daily remote sensing report, whereas the duty scientist summarizes all observations (including remote sensing and seismicity) at volcanoes with elevated Aviation Color Codes and Volcano Alert Levels. The reports also include descriptions of any notable satellite and webcam observations at the other volcanoes AVO monitors. These observations are archived in an internal database structure to assist in retrieving past records. A second rotation of scientists from AVO and the USGS National Earthquake Information Center monitors the volcanoes that have local seismometers and analyzes activity detected on regional infrasound sensors. Each day, this team compiles three separate reports, spaced ~8 hours apart. These reports are also catalogued within a relational database.

The volcanoes in this publication are presented in geographic order from east to west along the Aleutian Arc. Each entry has a title block containing information about that volcano: its identifier number (#) assigned by the Smithsonian Institution Global Volcanism Program (GVP); its latitude, longitude, and summit elevation; the name of its geographic region; and an abbreviated summary of its 2020 activity. The title block is followed by a description of the volcano and a summary of its past activity, then a detailed account of its activity in 2020, often with accompanying figures. This information is derived from formal public AVO information products, internal online electronic logs compiled by AVO staff, and published material (such as Miller and others [1998]).

AVO sometimes uses informal volcano names for clarity; the names provided by the official U.S. Board on Geographic Names (through the Geographic Names Information System) may match imprecisely with the volcanoes themselves. For example, Bogoslof volcano comprises more islands than Bogoslof Island. Alaska also has volcanoes without official place names, such as Takawangha volcano, which require the use of informal names. In this report, volcano locations (in decimal degrees latitude and longitude) are taken from AVO's database of Alaskan volcanoes (Cameron and others, 2022). Measurements are presented in the International System of Units, except for altitudes, which are reported in feet (ft) ASL, in line with federal aviation standards, followed by meters (m). General date references are given in coordinated universal time (UTC) unless specified otherwise. Most volcanoes in Alaska are in the Alaska standard time (AKST) or Alaska daylight time (AKDT) zones, but all Aleutian volcanoes west of Umnak Island (see the community of Nikolski, Alaska, on figure 1) are in the Hawaii-Aleutian standard time (HAST) or Hawaii-Aleutian daylight time (HADT) zones. During 2020, daylight saving time ran from March 8 to November 1.

What is a “Historically Active Volcano”?

AVO defines an active volcano as a volcanic center that has recently had an eruption (see “What is an ‘eruption’ ”) or a period of intense deformation, seismic activity, or fumarolic activity; these are inferred to reflect the presence of magma at shallow levels beneath the volcano. AVO considers the historical period in Alaska to be since 1741, when written records of volcanic activity began. On the basis of a rigorous reanalysis of all volcanic activity accounts in Alaska (from many sources), Cameron and others (2018) concluded that 54 Alaskan volcanoes fit these criteria. In this report, we modify the number of historically active volcanoes to 52, because we consider (1) Korovin Volcano and Mount Kliuchef to be subfeatures of Atka volcanic complex and (2) Novarupta to be a subfeature of Mount Katmai. As geologic understanding of Alaskan volcanoes improves through additional fieldwork and modern radiometric dating techniques, our list of active volcanoes will continue to evolve.

What is an “Eruption”?

The specific use of the term “eruption” varies from scientist to scientist and has no universally agreed-upon definition. Here, we adopt the usage of Siebert and others (2010, p. 17), who define eruptions as “* * * events that involve the explosive ejection of fragmental material, the effusion of liquid lava, or both.” The critical elements of this definition are the verbs “ejection” and “effusion,” which refer to dynamic surface processes that pose some level of hazard. The presence or absence of “juvenile material,” or newly erupted rock, which can sometimes be ambiguous, is not relevant to this use of the term eruption, particularly when communicating a potential hazard. This definition does not, however, include passive volcanic degassing or hydrothermal fluid discharge.

Volcanic Activity in Alaska, East to West Along the Aleutian Arc

Mount Katmai (Novarupta)

GVP# 312170
58.279°, −154.953°
2,057 m
Alaska Peninsula

RESUSPENSION OF 1912 ASH

Mount Katmai and its satellite vent Novarupta, the latter which is thought to have been fed by a shallow sill from a magma body beneath the former (Hildreth and Fierstein, 2000), are located on the Alaska Peninsula, ~440 kilometers (km) southwest of Anchorage, Alaska (fig. 1). The 1912 Novarupta-Katmai eruption—the largest eruption of the 20th century—produced ~17 cubic kilometers (km^3) of fall deposits and 11 km^3 of pyroclastic material that filled nearby valleys around the volcano (Hildreth and Fierstein, 2012). The pyroclastic deposit in these valleys is as much as 200 m thick, and some areas remain almost entirely devoid of vegetation more than a century after the eruption. When the landscape is snow-free, and particularly when the ground has little moisture content, strong winds can pick up this ash and create large ash clouds. The wind can then transport the resuspended ash, most often southeastward across Shelikof Strait, Kodiak Island, and the Gulf of Alaska. These ash clouds are often seen by individuals downwind and are recorded in satellite imagery, where they commonly appear to originate from a broad area rather than a specific volcanic source. Although they look similar to dispersing volcanic ash clouds in satellite imagery, the clouds are not the result of concurrent volcanic activity. This resuspension phenomenon has been observed and documented many times over the last several decades (Hadley and others, 2004; Wallace and Schwaiger, 2019), including three times in 2020.

On September 14 (AKDT), strong winds entrained and resuspended ash from the Katmai region, carrying it northwestward at an altitude of ~4,000 ft (~1,200 m). Strong winds again picked up ash on October 31 (AKDT), carrying it southward at an altitude of ~5,000 ft (~1,500 m), as well as on November 2 (AKDT), carrying the ash southeastward at an altitude of ~5,000 ft (~1,500 m) (fig. 2). During each resuspension event, the National Weather Service Alaska Aviation Weather Unit issued a significant meteorological weather advisory for aviators and AVO issued an information statement. The Aviation Color Code and Volcano Alert Level remained **GREEN** and **NORMAL** for Mount Katmai during 2020.

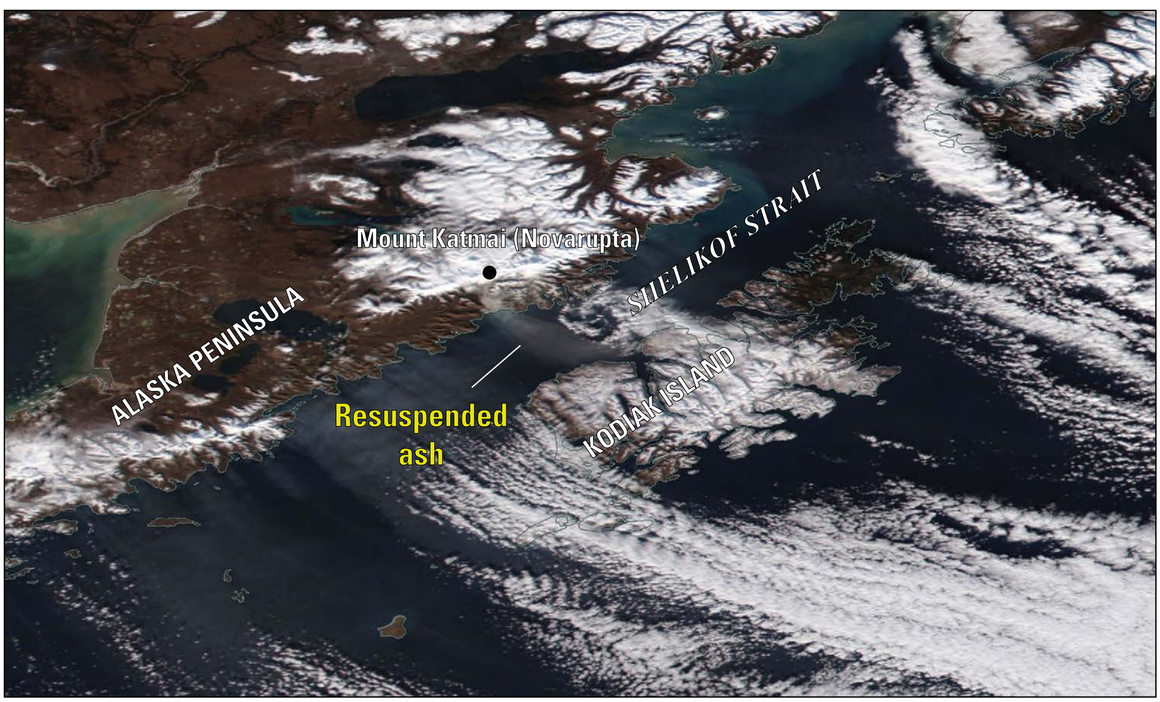


Figure 2. Oblique, true-color satellite image (looking north) showing a resuspended ash plume extending from the Novarupta region across Shelikof Strait to Kodiak Island, southwest Alaska. Image acquired by a Visible Infrared Imaging Radiometer Suite instrument on the Suomi NPP satellite, November 2, 2020.

Mount Veniaminof

GVP #312070
56.198°, −159.393°
2,511 m
Alaska Peninsula

ELEVATED SEISMIC ACTIVITY

Mount Veniaminof is an ice-clad andesite and dacite stratovolcano on the Alaska Peninsula, 775 km southwest of Anchorage and 35 km north of the community of Perryville, Alaska (fig. 1). Featuring an ice-filled caldera 10 km in diameter and with a total volume of ~350 km^3, it is one of the largest and most active volcanoes of the Aleutian Arc (Miller and others, 1998; Bacon and others, 2009). Extensive pyroclastic flow deposits around the volcano indicate two caldera-forming eruptions have taken place during the Holocene (Miller and Smith, 1987). Mount Veniaminof has also erupted at least 20 times in the past 200 years alone, all from its ~300-meter-high intracaldera cone. Its most recent eruption was in 2018 (Cameron and others, 2018; Waythomas, 2021).

Mount Veniaminof did not erupt in 2020, but it did experience a period of elevated seismicity. Beginning on June 14, 2020, this seismicity was characterized by brief periods of continuous tremor (each lasting ~30 seconds to several minutes) and occasional earthquakes (fig. 3). Although no other signs of unrest were observed, this departure from the volcano's background seismic activity prompted AVO to increase its Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** on June 18. The seismicity changed little until early August, when the level of tremor began to gradually decline. The decrease in seismic activity and the lack of evidence for surface change (no increased temperatures or gas emissions) indicated that activity at Mount Veniaminof had returned to background levels. As a result of these observations, AVO decreased the Aviation Color Code and Volcano Alert Level to **GREEN** and **NORMAL** on August 20.

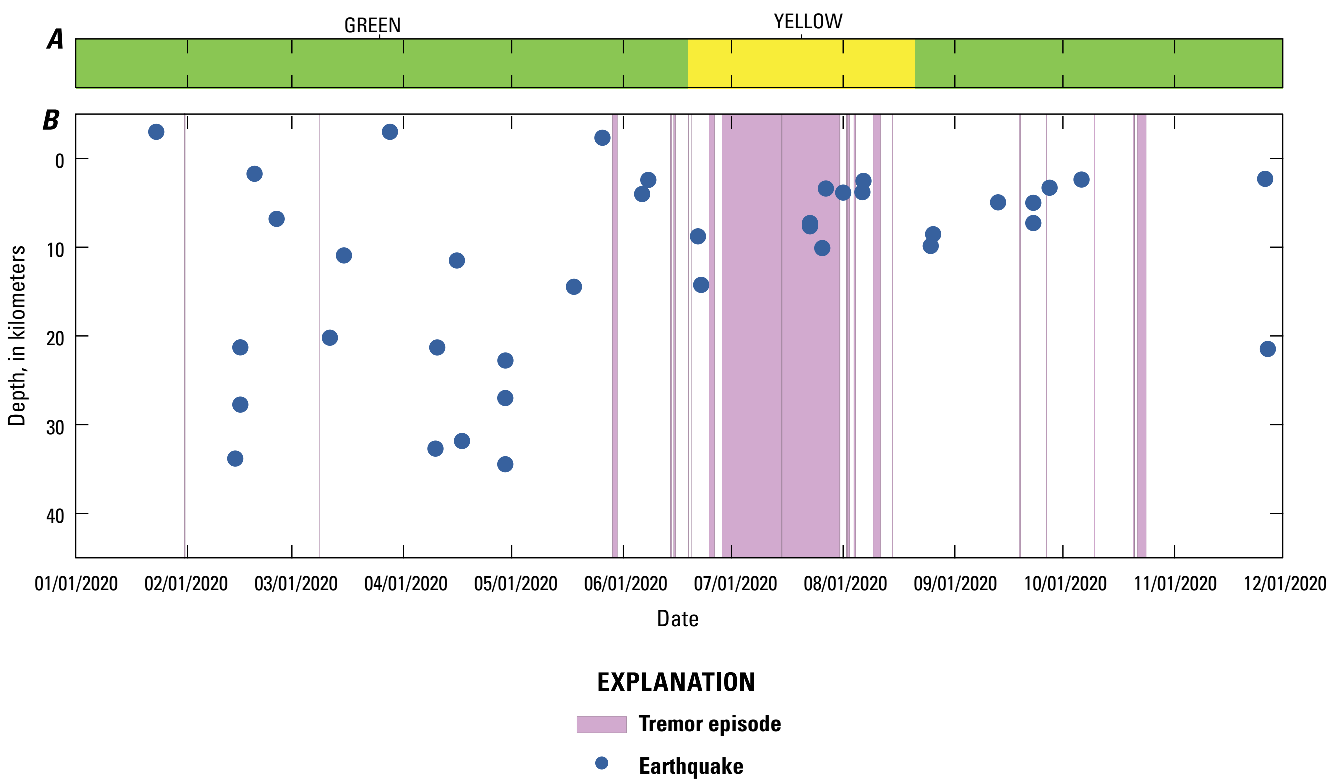


Figure 3. Time series of Aviation Color Codes (*A*) and graph of earthquakes and tremor episodes (*B*) at Mount Veniaminof, Alaska, in 2020. Dates shown as month/day/year.

Pavlof Volcano

GVP #312030
55.417°, −161.894°
2,526 m
Alaska Peninsula

ELEVATED SEISMIC ACTIVITY

Pavlof Volcano is a conical stratovolcano composed of basaltic andesite lava flows and pyroclastic rocks. It is located on the Alaska Peninsula, ~60 km northeast of the City of Cold Bay, Alaska, and 950 km southwest of Anchorage (fig. 1). Eruptions at Pavlof Volcano range in style from Strombolian to Vulcanian (Waythomas and others, 2006), and with at least 37 eruptions since 1790, it is considered one of the most active volcanoes in North America (Miller and others, 1998). The volcano is dominantly an open-vent system, and many of its eruptions have little precursory seismicity or ground deformation visible in InSAR (Lu and Dzurisin, 2014; Pesicek and others, 2018). The last significant eruption at Pavlof Volcano was in March 2016 and was characterized by continuous seismic tremor, infrasound detections, and lightning accompanying an ash cloud that rose to a maximum altitude of ~30,000 ft (~9,100 m) ASL (Fee and others, 2017; Cameron and others, 2020).

Elevated seismicity levels in late December 2019 prompted AVO to raise the Aviation Color Code and Volcano Alert Level of Pavlof Volcano to **YELLOW** and **ADVISORY** on December 28, 2019 (Orr and others, 2023). During January and February 2020, more periods of low-level tremor and minor steaming at the volcano summit were noted, but no other outward signs of unrest were observed and no eruptive activity occurred (fig. 4). In response to declining seismicity, AVO lowered the Aviation Color Code and Volcano Alert Level to **GREEN** and **NORMAL** on March 3.

On June 22, AVO detected a 10-minute-long period of weak seismic tremor and a weak impulsive infrasound signal from Pavlof Volcano that may have been associated with robust gas emissions there. This activity did not lead to any outward signs of unrest and no eruption was confirmed, so the Aviation Color Code and Volcano Alert Level were not changed. Three months of quiescence followed. Then, on September 21–22, periods of harmonic tremor were detected at the volcano. This new activity was considered an increase above background levels, so AVO raised the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** on September 21. Although periods of weaker harmonic tremor continued sporadically thereafter through December, the volcano showed no other signs of increasing unrest, and only minor steaming was observed at its summit. The Aviation Color Code and Volcano Alert Level were lowered to **GREEN** and **NORMAL** on October 14.

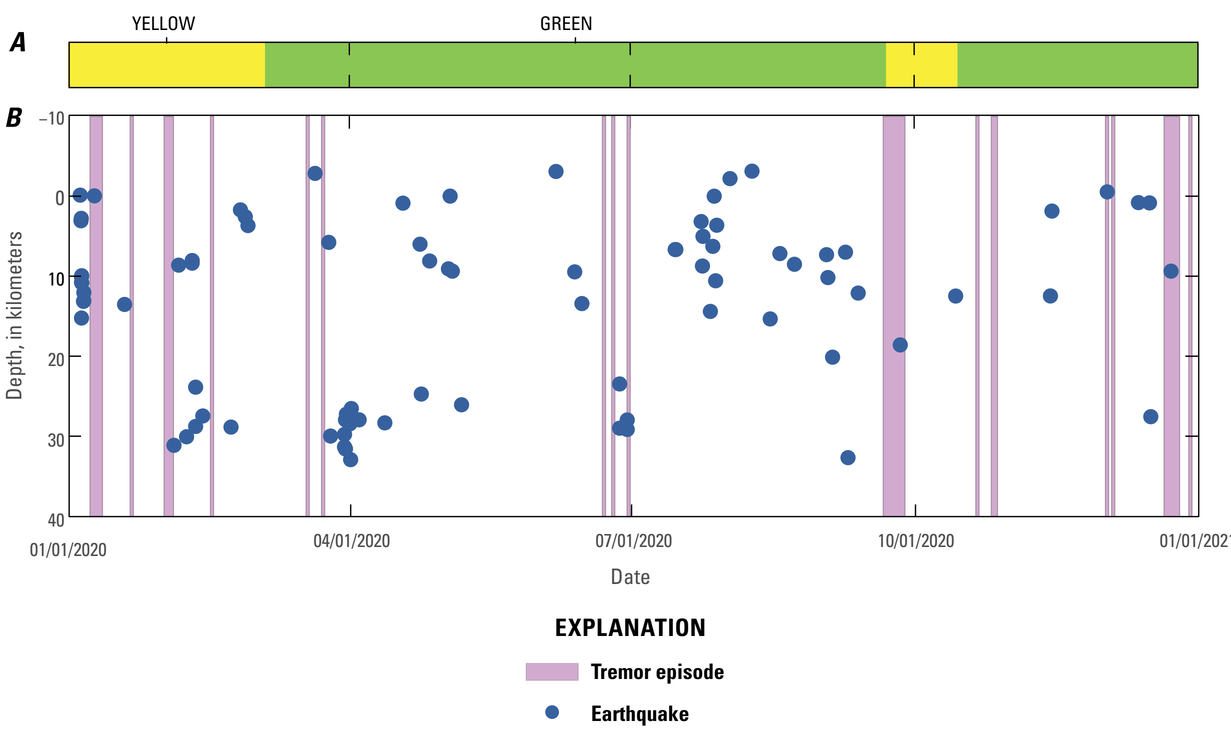


Figure 4. Time series of Aviation Color Codes (*A*) and graph of earthquakes and tremor episodes (*B*) at Pavlof Volcano, Alaska, in 2020. Dates shown as month/day/year.

Shishaldin Volcano

GVP #311360
54.755°, −163.971°
2,858 m
Unimak Islands, Fox Islands, Aleutian Islands

EXPLOSIVE ERUPTION WITH ASH EMISSIONS, LAVA FLOWS, AND LAHARS

Shishaldin Volcano is a spectacular symmetrical cone with a basal diameter of ~16 km. It lies near the center of Unimak Island in the eastern Aleutian Islands, 95 km southwest of the City of Cold Bay and 1,095 km southwest of Anchorage (fig. 1). A steam plume, sometimes containing a minor amount of entrained ash, often emanates from the volcano's small summit crater. Shishaldin Volcano is one of the most active volcanoes in the Aleutian Arc (Miller and others, 1998); most of its historical eruptions comprised small ash and steam plumes, although an eruption in April–May 1999 produced a subplinian ash cloud (Nye and others, 2002).

Shishaldin Volcano erupted from July 2019 to March 2020 (fig. 5). The 2019 activity was documented in Orr and others (2023) and the 2020 activity is documented herein. This eruption was the largest at the volcano since 1999, when an eruption produced lahars, Strombolian activity at the crater and upper flanks, and an ash cloud that reached ~52,000 ft (~16,000 m) ASL (Nye and others, 2002; Stelling and others, 2002; McGimsey and others, 2004). The 2019–2020 eruption was also the first to produce lava flows outside the summit crater since 1976 (Begét and others, 2002).

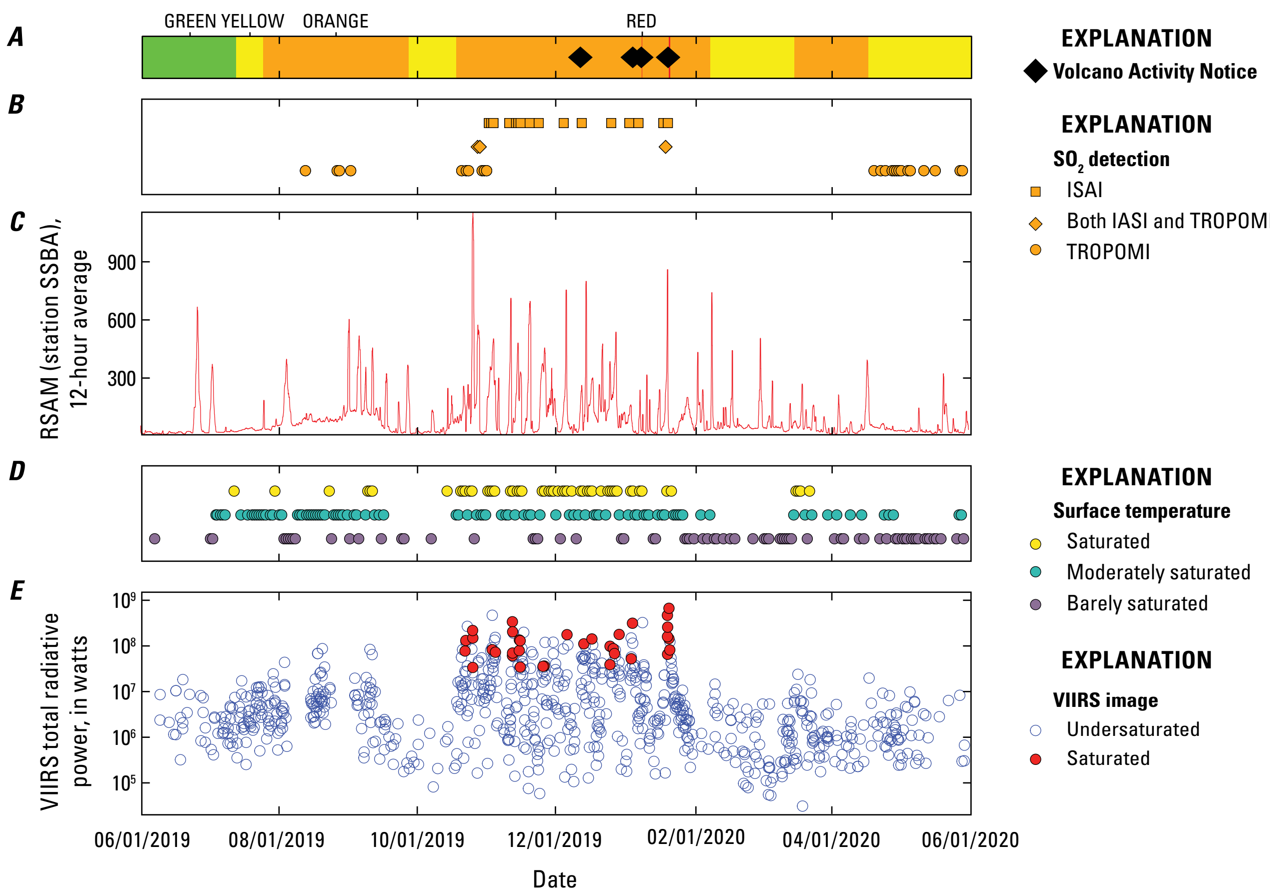


Figure 5. Timeline of eruptive activity during the 2019–2020 eruption of Shishaldin Volcano, Alaska. *A*, Changes in Aviation Color Code. Black diamonds indicate Volcano Activity Notice announcements. *B*, Satellite sulfur dioxide (SO_2) detections by platform (the Infrared Atmospheric Sounding Interferometer [IASI] and the TROPOspheric Monitoring Instrument [TROPOMI]). *C*, Seismic tremor, shown as real-time seismic amplitude measurement (RSAM) (Endo and Murray, 1991) values at station SSBA. *D*, Qualitative surface temperature anomalies from daily satellite reports. *E*, Quantitative radiative power from the Visible Infrared Imaging Radiometer Suite (VIIRS) (following the method described in Loewen and others [2021]). Dates shown as month/day/year.

The 2019–2020 eruption can be divided into 7 phases:

1. An eruption buildup (July 1–23, 2019) consisting of increasing seismicity and surface temperature anomalies, presumably related to magma rising to a shallow level within the open-conduit system.
2. A cone-building eruption (July 24–September 19, 2019) with Strombolian activity that built a small spatter cone confined within the summit crater.
3. An eruption hiatus (September 19–October 13, 2019) after magma withdrawal and tephra cone collapse.
4. A renewed eruption (October 13, 2019–January 3, 2020), which quickly built a large tephra cone that filled the summit crater and enabled lava flows to spill onto the northeast to northwest flanks, generating meltwater lahars. Occasional tephra cone collapse events generated ash clouds and small pyroclastic flows.
5. Ash-rich paroxysms (January 3–20, 2020) consisting of three distinct sequences that each started with Strombolian activity before intensifying to lava fountaining and lava flows. Each paroxysm preceded a days-long pause in eruption. The activity culminated in an ash-rich paroxysm on January 20 that produced clouds reaching altitudes of ~30,000 ft (~9,100 m) ASL and pyroclastic deposits on the upper flanks of the volcano.
6. A second prolonged eruption hiatus (January 20–March 11, 2020) after the final ash-rich paroxysm on January 20.
7. A final renewed eruption (March 11–31, 2020) that resulted in Strombolian cone-building confined to the summit crater.

After phase 7 of the eruptive activity in March, minor unrest and occasional cone collapse events occurred into the summer, but magma was not seen at the surface. Phases 1–4 of the 2019–2020 eruption are described in the 2019 Alaska Volcano Observatory annual report (Orr and others, 2023), whereas this discussion covers phases 5–7, beginning with the eruptive activity in January.

Ash-Rich Paroxysm Sequence (January 1–20)

Eruptive activity at the start of 2020 followed a similar pattern to that established in November 2019: seismic tremor and lava flow activity generally increased over a period of several hours before abruptly shutting down in days-long pauses. Unlike activity in the prior weeks, however, three periods of escalating activity in January culminated in increased ash emissions, prompting AVO to issue a Volcanic Activity Notice (VAN) each time (fig. 6).

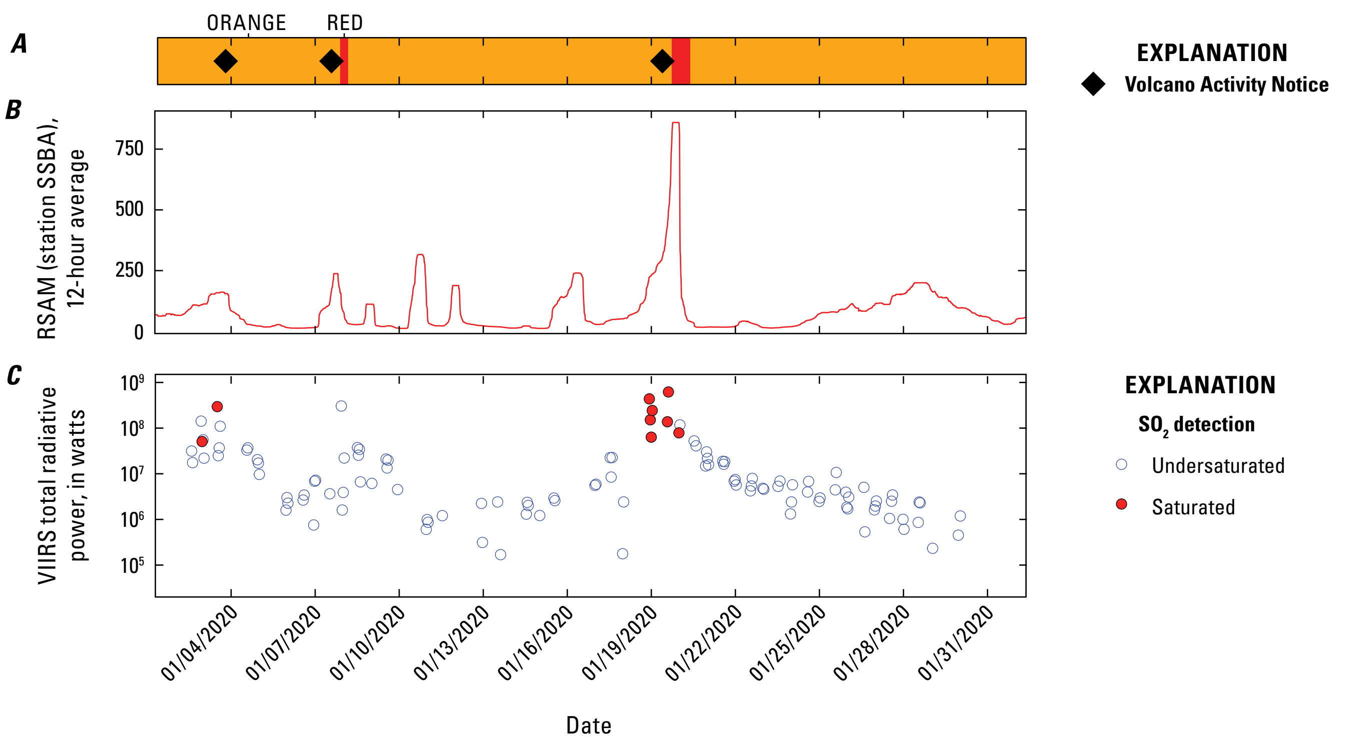


Figure 6. Timeline of eruptive activity at Shishaldin Volcano, Alaska, in January 2020. *A*, Changes in Aviation Color Code. Black diamonds indicate Volcano Activity Notice announcements. *B*, Seismic tremor, shown as real-time seismic amplitude measurement (RSAM) (Endo and Murray, 1991) values at station SSBA. *C*, Quantitative radiative power from the Visible Infrared Imaging Radiometer Suite (VIIRS) (following the method described in Loewen and others [2021]). The offset in ash events from color code changes is due to retrospective timing of the event starting date compared to when formal notifications or color code changes were issued. Dates shown as month/day/year.

Shishaldin Volcano began 2020 with an Aviation Color Code and Volcano Alert Level of **ORANGE** and **WATCH**. Elevated surface temperatures visible in satellite data on January 2 suggested that weak eruptive activity, confined to the vent, was occurring. Seismicity began to increase on January 3, indicating increasing eruptive activity. This was confirmed by a passing pilot, who reported a clear view of lava fountaining and a robust, steam-rich plume that probably contained some ash from the fountaining (fig. 7). At the same time (starting around 19:00 UTC [10:00 AKST]), satellite views and additional PIREPs recorded ash-poor plumes from the volcano that may have reached as high as ~24,000 ft (~7,300 m) ASL. The fountaining at Shishaldin Volcano was associated with increasing seismic tremor and the emplacement of lava flows mostly concentrated on the volcano's northwest flank. AVO issued a VAN at 20:38 UTC (11:38 AKST) but did not change the Aviation Color Code or Volcano Alert Level.

Seismic tremor decreased sharply at 20:48 UTC (11:48 AKST), and at about the same time, a PIREP indicated that the plume height had risen to ~27,000 ft (~8,200 m) ASL. Volcanic lightning was detected at 21:07 UTC (12:09 AKST), suggesting that the concentration of ash in the plume had increased. These ash emissions did not last long; the concentration was decreasing by 21:30 UTC (12:30 AKST). A WorldView-2 satellite image acquired at 22:22 UTC (13:22 AKST) revealed the state of the volcano: the lava flows active earlier in the day had stalled and were cooling, new lobate pyroclastic flow deposits had been emplaced on the west and south flanks, and an ash-rich plume was drifting southeastward (fig. 8*A*). The new pyroclastic flow deposits were the first to affect the south flank of the volcano during this eruption; prior deposits were restricted to the north flank. Deposition on the west and south flanks of the volcano required overtopping the topographic high point of the summit crater, suggesting they were deposits from the collapse of an ash column as opposed to debris from a tephra cone collapse. Eruptive activity associated with the January 3 event was not observed directly afterward. Lava flow activity

Figure 7. Photograph of lava fountaining and an eruption plume at Shishaldin Volcano, Alaska, on January 3, 2020, at about 19:20 coordinated universal time (10:20 Alaska standard time). Image taken from a video copyrighted by Daniel Hustrulid, 2020; used with permission.

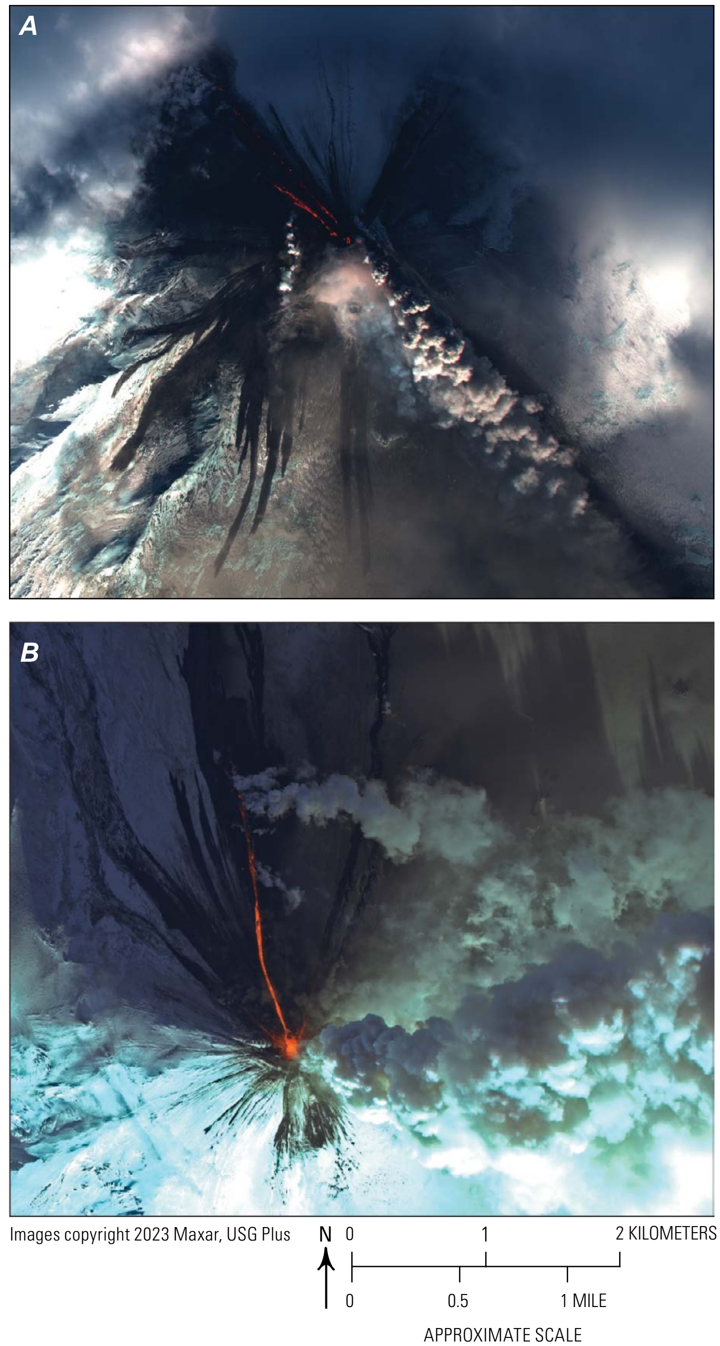


Figure 8. Near-infrared satellite images acquired during paroxysmal phases of the eruption of Shishaldin Volcano, Alaska, on January 3, 2020 (22:22 coordinated universal time [UTC]; 13:22 Alaska standard time [AKST]) (*A*), and January 19, 2020 (22:33 UTC; 13:33 AKST) (*B*). The images are not orthorectified, which results in distance offset owing to satellite viewing angle and terrain. Images acquired by WorldView-2.

at Shishaldin Volcano increased again after January 3, and by January 6, incandescent flows were visible from the City of Cold Bay (fig. 9*A*). The frequent detection of infrasound signals suggested the occurrence of Strombolian explosive activity. Seismic tremor, already elevated, began increasing further on the morning of January 7, and starting around 16:00 UTC (7:00 AKST) that morning, a plume reaching an altitude of ~20,000 ft (~6,100 m) ASL was detected in satellite data. Strong mid-infrared satellite signatures accompanied the plume, suggesting ongoing lava effusion and vigorous lava fountaining, similar to the behavior seen on January 3. A VAN noting this increased activity was issued at 18:39 UTC (9:39 AKST), although the Aviation Color Code and Volcano Alert Level were not changed. At ~20:00 UTC (~11:00 AKST), the seismic tremor started to decline, followed by the detection of volcanic lighting at 20:25 UTC (11:25 AKST). Satellite images acquired shortly afterward indicated that the plume had become more ash-rich and now reached an altitude as high as ~27,000 ft (~8,200 m) ASL (fig. 10*A*), although tremor remained low. These observations prompted AVO to increase

Figure 9. Photographs of lava flow activity on Shishaldin Volcano as viewed from the City of Cold Bay, Alaska, on January 6, 2020 (*A*), and the City of King Cove, Alaska, on January 18, 2020 (*B*). Image *A* copyrighted by Aaron Merculief, 2020; image *B* copyrighted by Savannah Yatchmeneff, 2020; images used with permission.

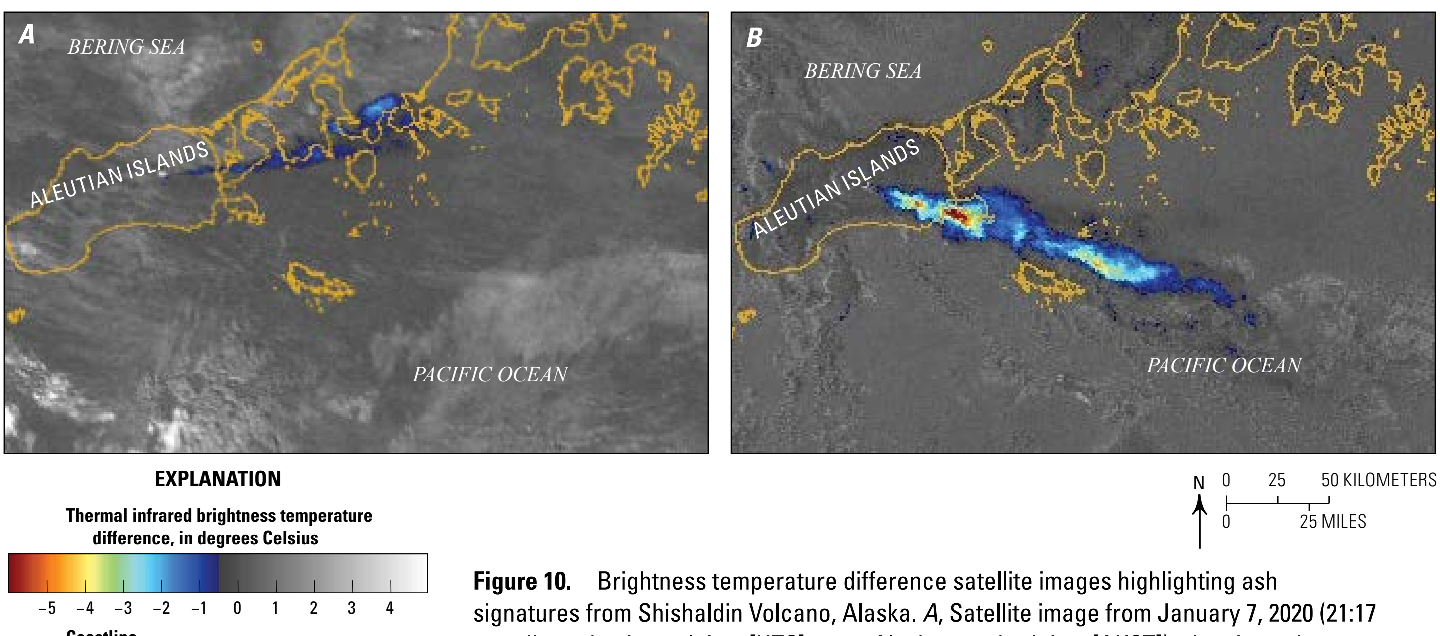


Figure 10. Brightness temperature difference satellite images highlighting ash signatures from Shishaldin Volcano, Alaska. *A*, Satellite image from January 7, 2020 (21:17 coordinated universal time [UTC]; 12:17 Alaska standard time [AKST]), showing ash at an estimated altitude of 27,000 feet (ft) (~8,200 meters [m]) above sea level (ASL). *B*, Satellite image from January 20, 2020 (04:42 UTC; January 19 at 19:42 AKST), showing ash at an estimated altitude of 30,000 ft (~9,100 m) ASL. Images acquired by NOAA-18.

the Aviation Color Code and Volcano Alert Level to **RED** and **WARNING** at 21:33 UTC (12:33 AKST). Light ashfall from this event was reported in the City of Cold Bay.

The plume appeared to have detached from the vent by 22:00 UTC (13:00 AKST), indicating that ash emission had slowed or stopped. The Aviation Color Code and Volcano Alert Level were subsequently lowered to **ORANGE** and **WATCH** on January 8 at 04:17 UTC (January 7 at 19:17 AKST). Synthetic aperture radar images acquired later that day showed that the crater had deepened, and the cone had subsided or collapsed. Like the January 3 event, the January 7 paroxysm was followed by a period of quiescence. The only activity detections at Shishaldin Volcano over the next week were infrasound signals consistent with Strombolian activity on January 10. On January 14, a clear WorldView-2 satellite image showed no volcanic activity within the summit crater or on the flanks.

Eruptive activity increased again on January 18; lava flows were visible on the volcano flanks and seismic tremor intensified (fig. 6). At 17:18 UTC (08:18 AKST), a pilot reported visible lava but no ash emissions. Observers in the Cities of Cold Bay and King Cove, Alaska, documented the incandescent lava flow during clear weather that evening (fig. 9*B*). Overnight webcam images from the south flank of Isanotski Volcano also showed lava fountaining, and by January 19 at 9:30 UTC (00:30 AKST), satellite images showed an ash-poor gas plume rising as high as ~18,000 ft (~5,500 m) ASL. The level of activity continued to increase, and as a result, the Aviation Color Code and Volcano Alert Level were increased to **RED** and **WARNING** at 17:28 UTC (08:28 AKST). By this point, a continuous, 150-kilometer-long plume was visible in satellite images. PIREPs at 18:15 UTC (09:15 AKST) described ongoing lava flow activity and measured that the plume had reached an altitude of ~25,000 ft (~7,600 m) ASL. Over the following hours, seismic tremor continued to increase and trace ashfall was reported in the City of False Pass, Alaska, 38 km northeast of Shishaldin Volcano. A WorldView-2 image captured activity at the vent during this period (fig. 8*B*). Another PIREP at 21:42 UTC (12:42 AKST) indicated that the plume had climbed to ~30,000 ft (~9,100 m) ASL (fig. 11*A*).

The seismic tremor dropped precipitously just after 00:00 UTC on January 20 (January 19 at 15:00 AKST). Satellite data acquired about an hour later showed that the plume had transitioned to a more ash-rich composition, a change confirmed by PIREPs (fig. 11*B*). Ash emissions continued for the next several hours (fig. 10*B*). Then, shortly before 05:00 UTC (20:00 AKST), ash emissions stopped and the plume detached from the vent. With the cessation of eruptive activity at the vent, AVO lowered the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH** at 09:37 UTC (00:37 AKST).

Prolonged Eruption Hiatus (January 20–March 11)

Satellite data after the January 20 paroxysm showed new ash deposition—the ash-poor lava fountaining phase produced trace deposits extending northeastward toward False Pass, whereas the later ash-rich phase produced more substantial deposits extending southeastward (fig. 12). Satellite radar imagery also showed that the volcano crater was larger and deeper after the event. The last detected infrasound and seismic event of note during this period was on January 24,

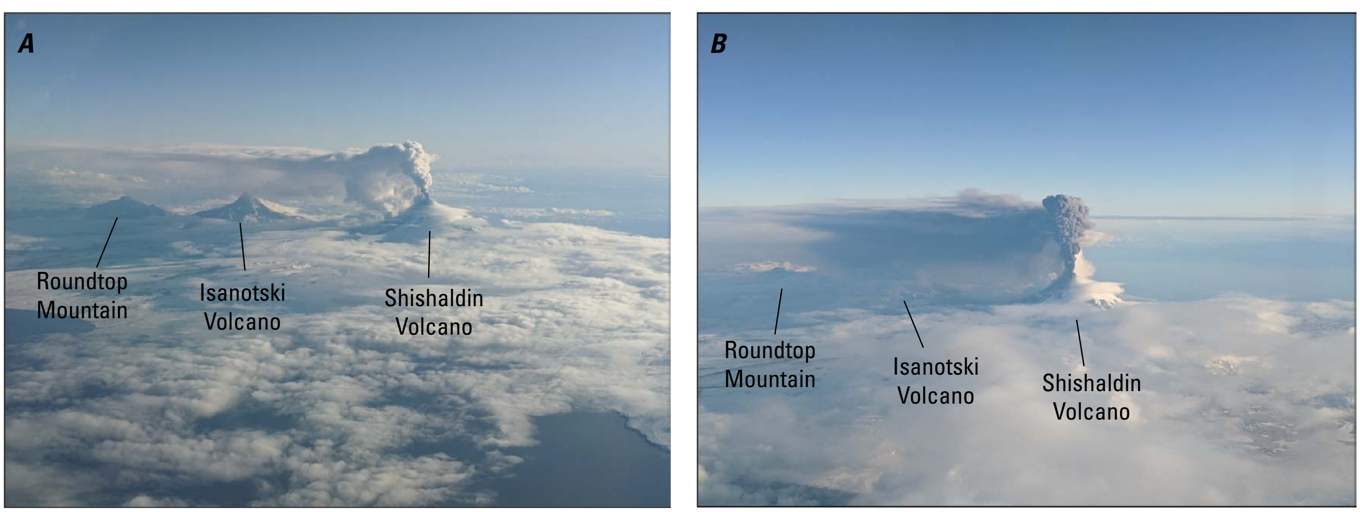


Figure 11. Oblique aerial photographs of Shishaldin Volcano, Alaska, on January 20, 2020 (coordinated universal time [UTC]; January 19 Alaska standard time [AKST]), showing the eruption progression from a gas-rich lava fountain phase early in the eruption (*A*) to an ash-rich plume later that day (*B*). Photograph *A* taken on January 20 at 00:02 UTC (January 19 at 15:02 AKST), looking south. Photograph *B* taken on January 20 at 01:42 UTC (January 19 at 16:42 AKST), looking east. Images copyrighted by Matt Brekke, 2020; used with permission.

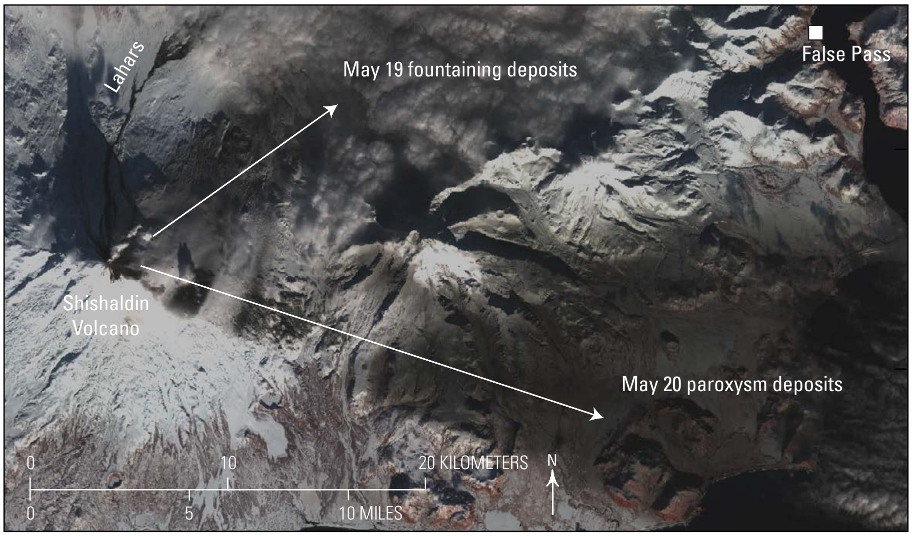


Figure 12. Annotated near-infrared satellite image of Shishaldin Volcano, Alaska, after its final eruption paroxysm in January 2020. Deposits from lava fountaining on January 19 extend northeastward, whereas deposits from the paroxysm on January 20 extend southeastward. Image acquired by Sentinel-2, January 20, 2020 (22:18 coordinated universal time; 13:18 Alaska standard time).

and a WorldView-3 satellite image from January 25 showed no visible eruptive activity. Some discreet seismic events and infrasound signals were detected occasionally later on, but these did not build to a clear eruptive signal like that which followed the eruption events earlier in January. On February 7 at 01:20 UTC (February 6 at 16:20 AKST), the Aviation Color Code and Volcano Alert Level were lowered to **YELLOW** and **ADVISORY**. No other significant activity was detected at the volcano in February, and clear satellite images showed quiet conditions consisting of minor steaming at the vent and cooling lava flow deposits on the flanks.

Final Renewed Eruption (March 11–31)

After weeks of quiescence, eruptive activity resumed in March 2020, although it was contained within the summit crater. The first indication of renewed activity appeared in a WorldView-2 satellite image from March 11 that showed a small area of recent ash deposits near the summit crater (fig. 13*A*). The inside of the crater was mostly obscured by steam in the image, but it was generally similar to its appearance in other high-resolution satellite images from February. In the following days, mid-infrared satellite images began to show increased surface temperatures at the volcano (fig. 5). A WorldView-3 image from March 14 showed a saturated short-wave infrared signature at the summit, indicating that lava was erupting again within the summit crater (fig. 13*B*). In response, AVO increased the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH** on March 15 at 6:31 UTC (22:31 AKDT on March 14).

During the following few weeks, seismicity was elevated and small explosions (probably from Strombolian activity) were detected occasionally in infrasound data. Satellite radar images suggested renewed cone growth, although all eruptive activity was confined within the summit crater. Another WorldView-3 image from March 22 (fig. 13*C*) showed activity similar to that on March 14.

Seismicity declined thereafter through the end of the month, and an April 1 satellite image showed only a steam plume and no evidence of a heat source, suggesting the eruption had ended. On April 2, a clear satellite image with an unobscured view into the summit crater confirmed that no eruptive activity was occurring (fig. 13*D*). Due to an absence of activity, AVO lowered the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** on April 16 at 19:44 UTC (11:44 AKDT).

Aftermath (April 1–End of Year)

Low-level unrest continued at Shishaldin Volcano for months after its 2019–2020 eruption. Elevated surface temperatures continued appearing in satellite images, and frequent satellite detections of SO_2 were made in late April and May (fig. 5). These SO_2 detections also coincided with the increasing ultraviolet radiation of long summer days, which raises the sensitivity of the TROPOspheric Monitoring Instrument (TROPOMI), a satellite instrument used for these detections. Other remote sensing observations made during this period of low-level unrest indicated that magma was still stored shallowly within the conduit, enabling magma degassing, high temperatures, and minor collapse events within the summit crater.

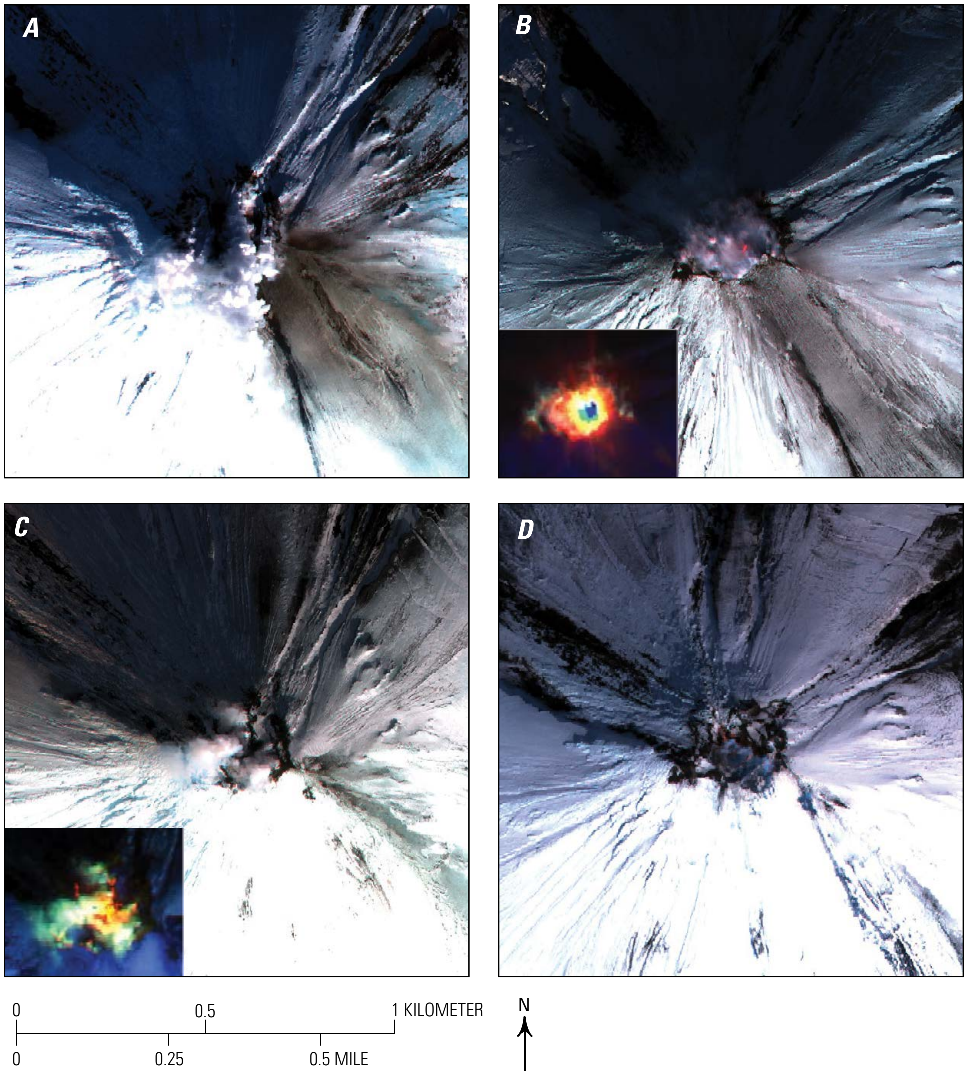


Figure 13. Near-infrared satellite images showing the rejuvenated eruption of Shishaldin Volcano, Alaska, in March 2020. *A*, WorldView-2 image acquired March 11, 2020 (22:18 coordinated universal time [UTC]; 14:18 Alaska daylight time [AKDT]), showing steaming from the summit crater and a trace ash deposit on the volcano's southeast flank. *B*, WorldView-3 image acquired March 14, 2020 (22:06 UTC; 14:06 AKDT), showing incandescence in the summit crater. Inset image (same scale) shows saturated short-wave infrared (SWIR) bands in the summit crater, indicating lava at the surface. *C*, WorldView-3 image acquired March 22, 2020 (22:32 UTC; 14:32 AKDT), showing steaming from the summit crater. Inset image (same scale) shows saturated SWIR bands in the summit crater again. *D*, WorldView-2 image acquired April 2, 2020 (22:08 UTC; 14:08 AKDT), showing light steaming and no eruptive activity within the summit crater. The images are not orthorectified which results in distance offset owing to satellite viewing angle and terrain.

On April 16 at 19:44 UTC (11:44 AKDT), the Aviation Color Code and Volcano Alert Level were lowered to **GREEN** and **NORMAL**, reflecting an overall decrease of activity to background levels at the volcano, although AVO continued recording evidence of additional minor collapse events using satellite radar images. Some of these events appeared to produce trace ash deposits on the upper flanks, as seen on April 29 and May 7. AVO workers carrying out annual geophysics station maintenance in August and September did not observe any eruptive activity, but helicopter gas surveys at the same time detected continued SO_2 degassing at an emission rate of 100±30 metric tons per day. The surveys also measured high carbon dioxide concentrations relative to measurements from 2015 and 2019, which indicated a new deep magma input into the system.

Final Deposits and Samples

The 2019–2020 eruption of Shishaldin Volcano resulted in (1) many lava flows on the north flank of the volcano, (2) pyroclastic flow deposits related to cone collapse events in December and three eruption paroxysms in January, and (3) lahars that inundated drainages north of the volcano and reached the Bering Sea coast. Accurate mapping of the lava flows was difficult because of poor orthorectification in many of the available high-resolution satellite images, in turn caused by the typically oblique image viewing angles and the steep flanks of Shishaldin Volcano.

Satellite images taken on January 14 and January 25 provided close-to-nadir images (11º and 17º off nadir, respectively) that allowed the final deposits to be mapped with reasonable accuracy (fig. 14). The lava flows covered less than 0.9 square kilometers (km^2) and extended as far as 3 km from the vent, primarily occupying three distinct drainages, with each new flow burying the previous one. The pyroclastic flow and lahar deposits were gradational and, in many places, difficult to distinguish from each other in satellite images. Deposits on the volcano's south flank, especially those from the January 3 paroxysm, were likely all pyroclastic flows generated from ash column collapse that overtopped the high point on the crater rim (fig. 8). The lahars and pyroclastic flows to the north were intermixed, forming lobate deposits on the

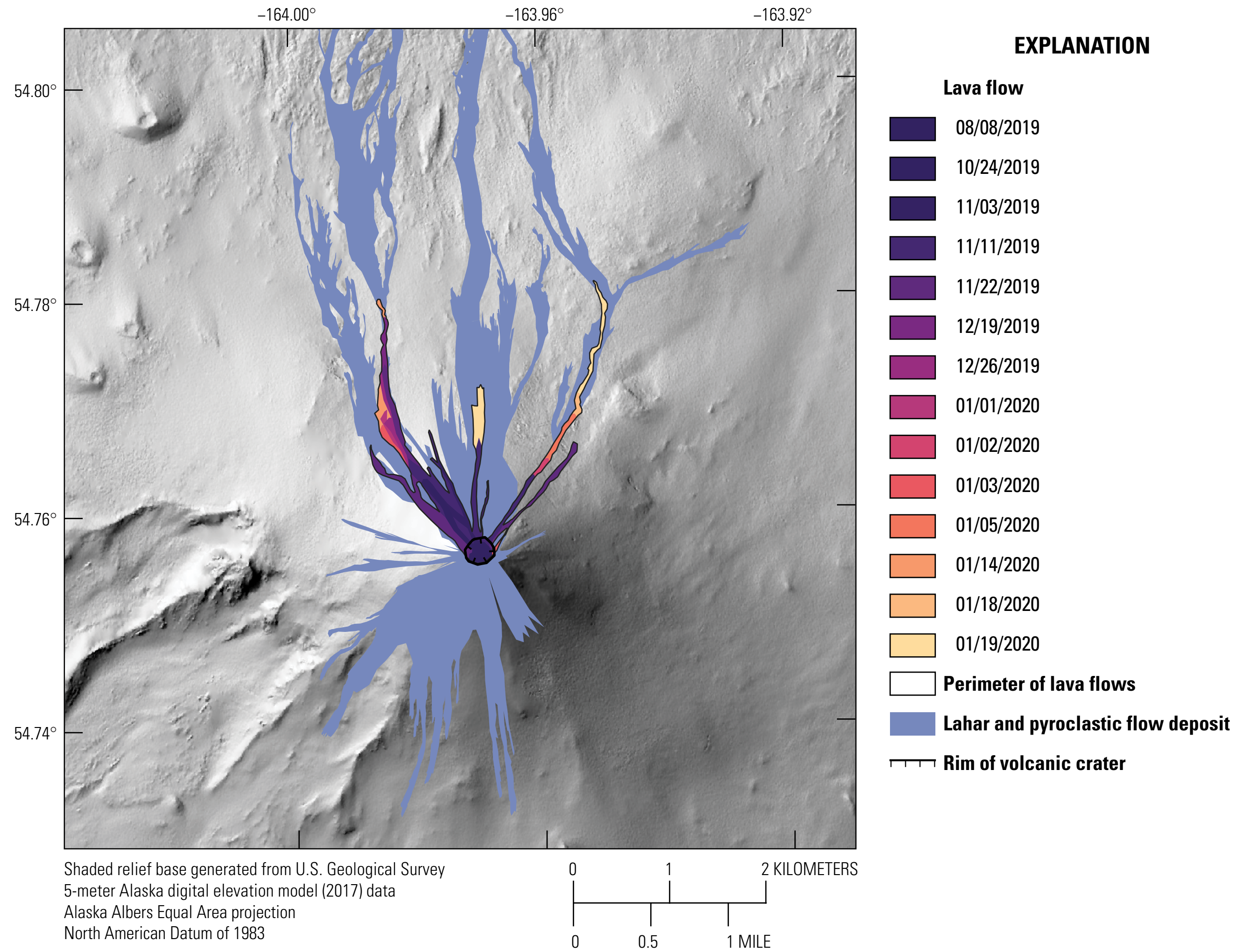


Figure 14. Map of lava flows and mixed lahar and pyroclastic flow deposits emplaced at Shishaldin Volcano, Alaska, during its 2019–2020 eruption. The overall lava flow outlines are mapped on the basis of WorldView-2 images from January 14 (22:17 coordinated universal time [UTC]; 14:17 Alaska daylight time [AKDT]) and January 25, 2020 (22:12 UTC; 14:12 AKDT), that were 11° and 17° off nadir, respectively, reducing orthorectification distortion on the steep slopes of the volcano. The internal lava flow boundaries, as distinguished by dates, are approximate and are based on typically more distorted WorldView-1, -2, and -3 satellite images. Some lahar and pyroclastic flow deposits were difficult to distinguish in satellite images and may be gradational in character; thus, they were mapped as a single layer. The lahar deposits follow drainages and those on the north flank continue to the Bering Sea coast.

flatter plains north of the volcano. The deposits suspected to be pyroclastic flows generally extended no more than 3 km from the summit vent, whereas lahars followed drainages and traveled farther, some reaching all the way to the coast (more than 30 km north of the summit). Because of the difficulty in distinguishing between pyroclastic and lahar deposits using satellite images alone, they are mapped as a single unit in figure 14.

Only a few samples are available from the 2019–2020 eruption. Samples of a tephra deposit from a cone collapse event, collected by field crews on December 20, 2019, are described in Orr and others (2023). AVO field crews also sampled the toe of a lava flow on the northeast flank of the volcano in 2022; this sample is currently being studied. Community members in the City of Cold Bay collected ash from the paroxysm of January 7, 2020; others in False Pass collected ash from the early stage of the January 19 paroxysm (figs. 15, 16). Both of these samples were dominated by roughly equal parts (1) juvenile, highly fluidal and glassy sideromelane grains (fig. 15) and (2) partially devitrified tachylite grains (fig. 16) (classifications by Loewen and others, 2021). However, the samples also contained phenocrysts of plagioclase and olivine, along with microlites of plagioclase, olivine, and magnetite. The glass composition was basaltic and was similar to samples from the 1999 eruption (Stelling and others, 2002).

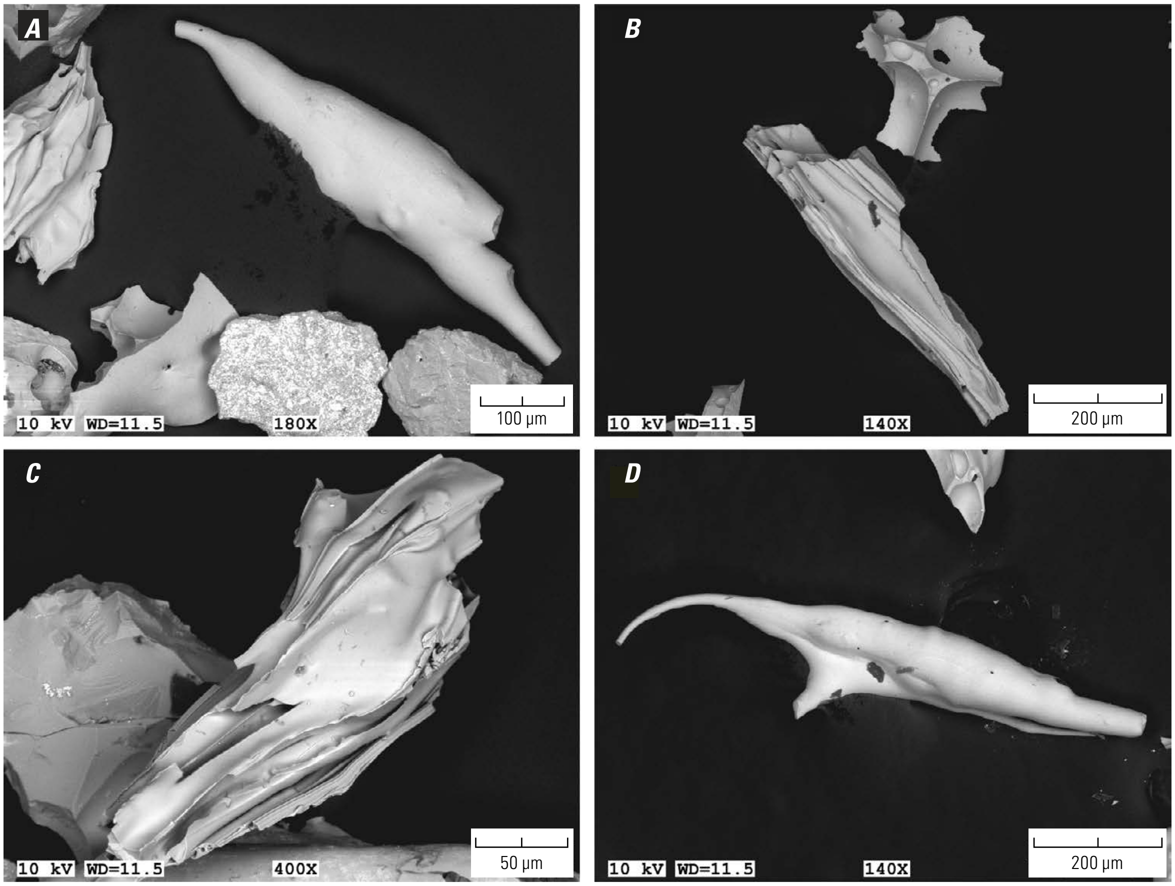


Figure 15. Scanning electron microscope (SEM) images of highly fluidal tephra morphology of material erupted from Shishaldin Volcano, Alaska. *A*, *B*, Samples from the eruption of January 7, 2020, collected in the city of Cold Bay, Alaska. *C*, *D*, Samples from the eruption of January 19, 2020, collected in False Pass, Alaska. Images taken with a JEOL 6510LV SEM in low vacuum mode. kV, kilovolts; WD, working distance; µm, micrometer.

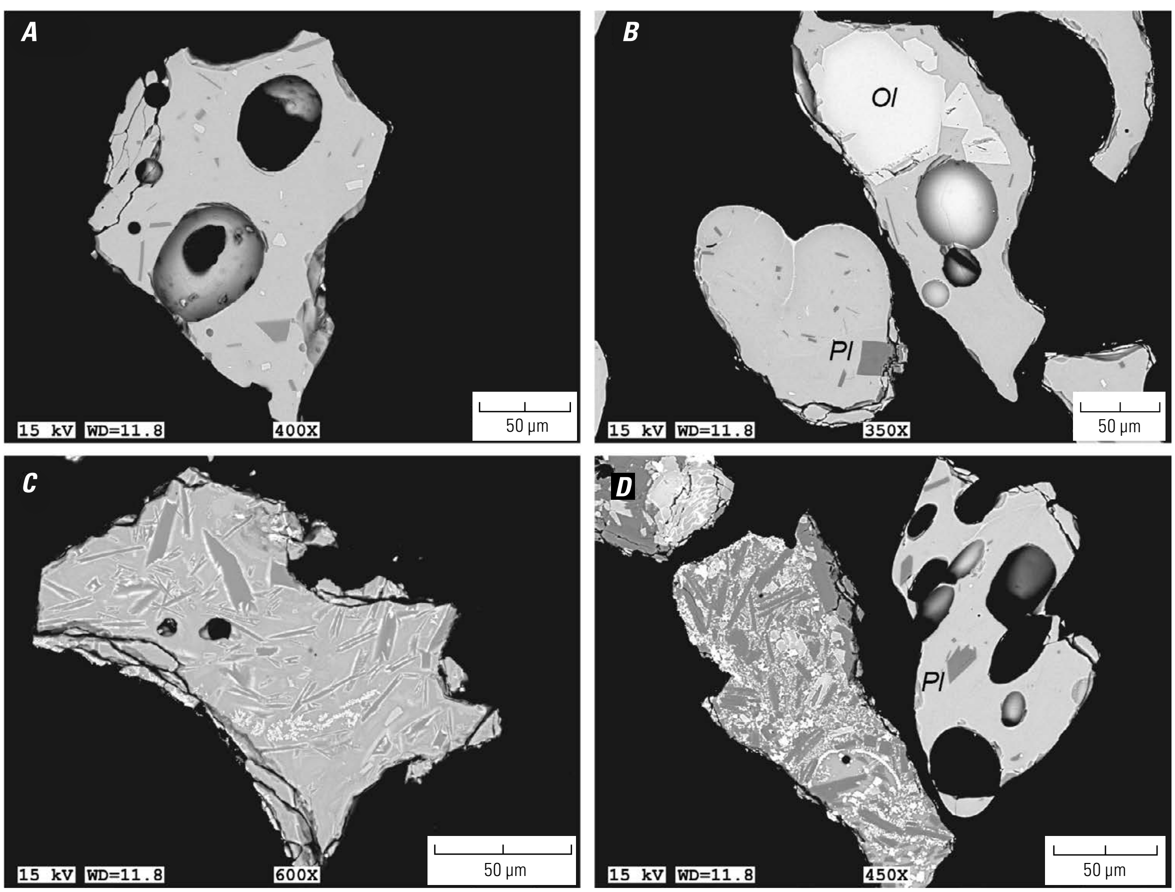


Figure 16. Backscattered electron scanning electron microscope (SEM) images (*A*–*D*) of a tephra sample erupted from Shishaldin Volcano on January 19, 2020. Dark gray crystals are plagioclase (Pl), light gray crystals are olivine (Ol), and tiny white crystals are magnetite. The collected tephra comprised 39 percent sideromelane grains with a glassy matrix and rounded vesicles, 38 percent tachylite grains with partially devitrified matrix glass and dendritic nanolites, and 22 percent lithic grains with no remaining glass and few or no vesicles. Componentry classification following Loewen and others (2021). Images taken with a JEOL 6510LV SEM. kV, kilovolts; WD, working distance; µm, micrometer.

Makushin Volcano

GVP #311310
53.887°, −166.932°
1,820 m
Unalaska Island, Fox Islands, Aleutian Islands

ELEVATED SEISMIC ACTIVITY

Makushin Volcano is on Unalaska Island in the east-central Aleutian Islands, 25 km west of the City of Unalaska and 1,295 km southwest of Anchorage (fig. 1). The volcano is a broad, truncated, and deeply glaciated stratovolcano with a summit caldera ~3 km in diameter. The summit is capped by an icefield with an area of ~40 km^2, but as the ice cover has retreated, a small intracaldera cinder cone hosting a turquoise-colored lake, abundant fumaroles, and an ice cauldron has become a conspicuous feature. Makushin Volcano has had 18 confirmed historical eruptions, the most recent of which took place on January 30, 1995, and which consisted of a small summit explosion that ejected ash to an altitude of ~8,000 ft (~2,400 m) ASL (McGimsey and Neal, 1996; Begét and others, 2000).

Seismic activity near Makushin Volcano increased beginning in the summer of 2020. An earthquake swarm (fig. 17) kicked off on June 15 at 21:16 UTC (13:16 AKDT) with an earthquake of local magnitude (M_L) 4.2 that was located ~12 km east-southeast of the volcano. This event was followed by hundreds of aftershocks in the same general area with several of M_L 3–4, including a M_L 4.1 earthquake on June 16 at 00:34 UTC (June 15 at 16:34 AKDT). The two M_L 4 earthquakes and many of their aftershocks were felt strongly by residents of the City of Unalaska. The earthquake depths during this period ranged from 5 to 14 km.

Elevated seismicity near the volcano continued for the remainder of 2020, although the events gradually decreased in frequency over time (fig. 18). No other signs of unrest or surface deformation were observed at Makushin Volcano in

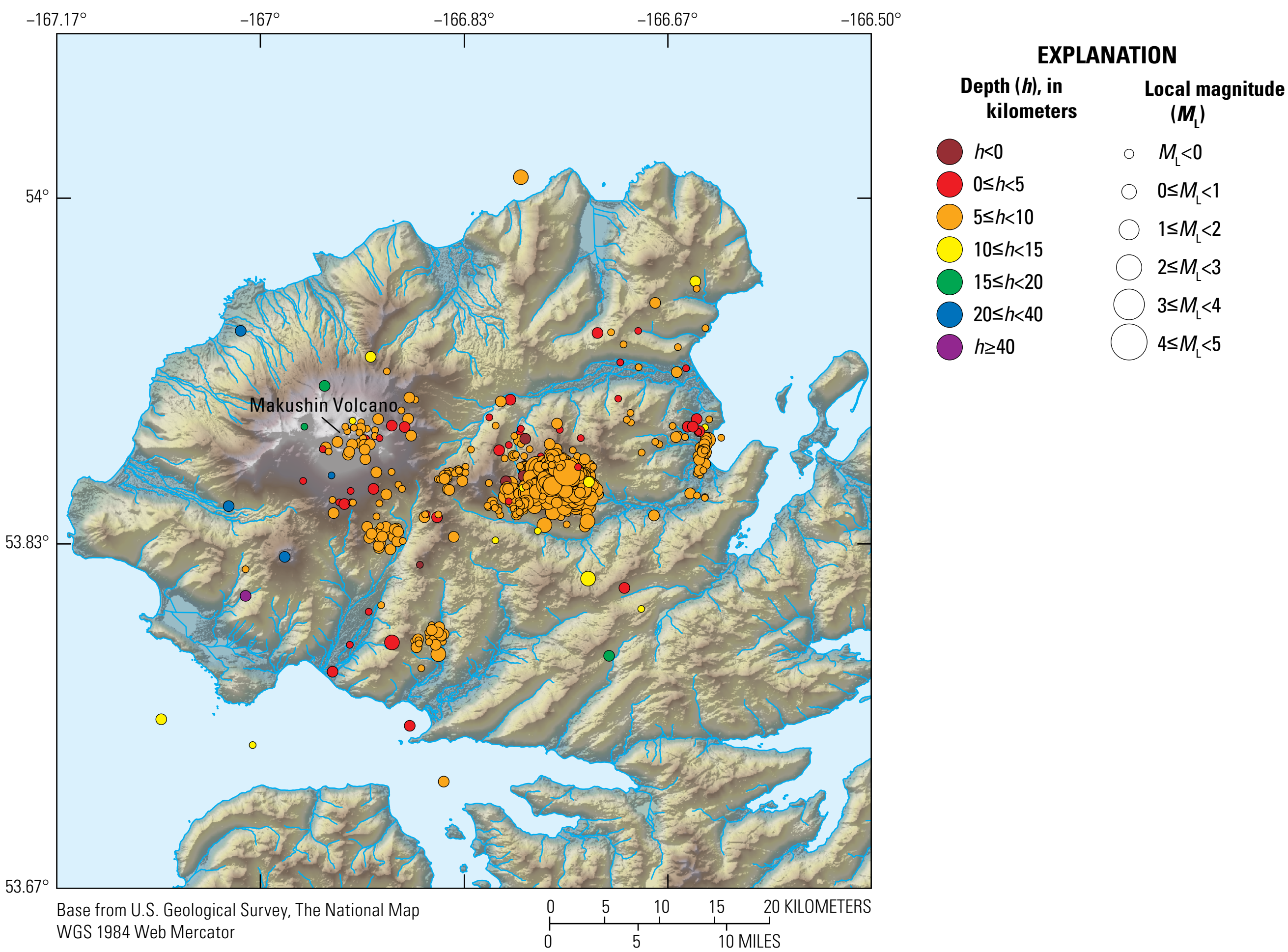


Figure 17. Map showing hypocenters of earthquakes located near Makushin Volcano, Alaska, by the Alaska Volcano Observatory in 2020. Most earthquakes in the cluster east-southeast of the summit were aftershocks of the M_L 4.2 earthquake.

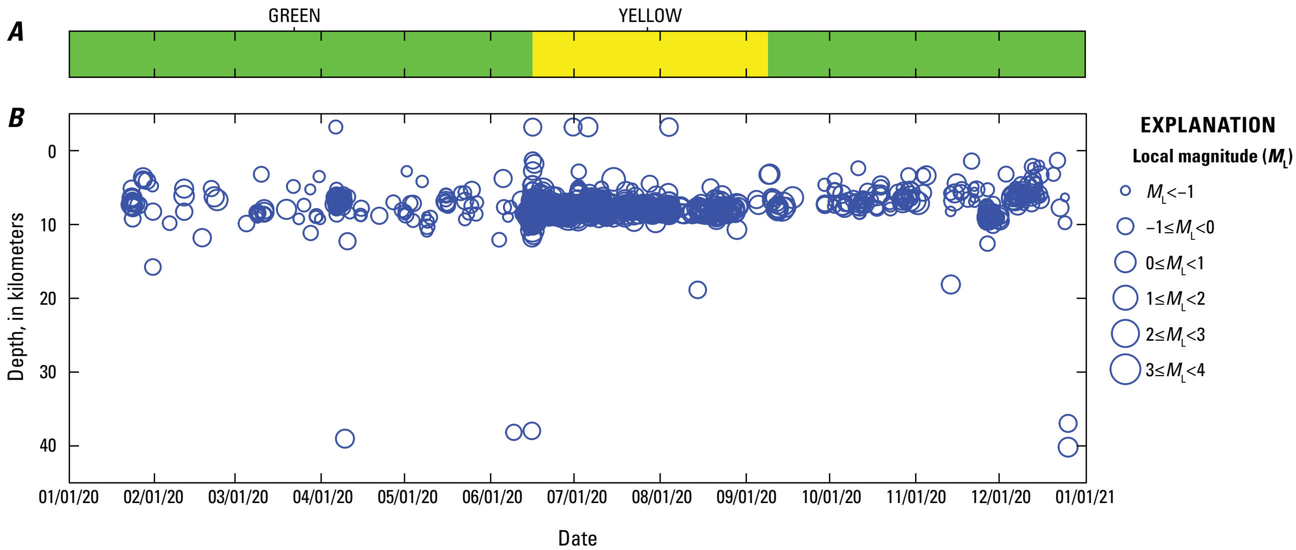


Figure 18. Timeline of Aviation Color Code changes (*A*) and time series of earthquakes (*B*) located at Makushin Volcano, Alaska, by the Alaska Volcano Observatory during 2020.

remote sensing data, gas measurements, GNSS data, InSAR data, or webcam images. However, several deep long-period (LP) earthquakes (depths greater than 9 km) were recorded beneath the volcano's summit prior to and during the June swarm. These LP events may represent magma movement in the lower crust, although such earthquakes are not unusual for Makushin Volcano.

At the time of the swarm, AVO was uncertain whether the earthquake sources were related to tectonic or volcanic stresses. Therefore, on June 16, a seismic watch schedule was implemented, and the Aviation Color Code and Volcano Alert Level were raised to **YELLOW** and **ADVISORY**. On September 8, after seismic activity had returned to background levels and no other signs of volcanic unrest were observed, the Aviation Color Code and Volcano Alert Level were lowered back to **GREEN** and **NORMAL**.

By analyzing the fault plane solutions of the earthquakes in the swarm, Lanza and others (2022) found that many of the larger earthquakes had P-axes oriented consistently with the regional maximum compression, but most of the smaller earthquakes had P-axes perpendicular to the regional maximum compression. On the basis of these findings, they concluded that the triggering mechanism of the earthquakes was most likely a combination of stresses from tectonic and magmatic sources along existing fault lines.

Mount Cleveland

GVP #311240
52.822°, −169.945°
1,745 m
Chuginadak Island, Islands of Four Mountains, Aleutian Islands

ELEVATED SURFACE TEMPERATURES; EXPLOSIVE ERUPTION

Mount Cleveland forms the west side of the uninhabited Chuginadak Island, part of the Islands of Four Mountains group in the east-central Aleutian Islands (figs. 1, 19). Mount Cleveland is ~75 km west of the community of Nikolski and 1,525 km southwest of Anchorage. Historical eruptions of the volcano have been characterized by short-lived ash explosions, lava fountaining, lava flows, and pyroclastic flows. In February 2001, after 6 years of quiescence, Mount Cleveland had three explosive events that sent ash to altitudes as high as ~30,000 ft (~9,100 m) ASL, produced a pyroclastic flow that reached the ocean, and erupted a blocky lava flow (Dean and others, 2004; McGimsey and others, 2005).

Intermittent explosive eruptions have taken place every year since 2001. In 2020, Mount Cleveland had one confirmed explosion.

The character of volcanic activity at Mount Cleveland in late 2019—low seismicity, occasional thermal anomalies, and a small summit steam plume (Orr and others, 2023)—carried over into 2020, and Mount Cleveland began the year at an Aviation Color Code and Volcano Alert Level of **YELLOW** and **ADVISORY** (fig. 20). No changes within the summit crater were observed during the first several months of the year; elevated surface temperatures and a weak steam plume were observed sporadically during periods of clear weather. The low level of thermal activity was corroborated by high-resolution satellite imagery in April and May that showed a partly snow-covered dome, suggesting the surface was cold (fig. 21).

Because of the apparent quiescence at Mount Cleveland, its Aviation Color Code and Volcano Alert Level were changed to **UNASSIGNED** on May 7 at 23:37 UTC (14:37 HADT). Three weeks later, on June 2 at 06:31 UTC (June 1 at 21:31 HADT), a small explosion triggered the infrasound alarm in Adak, Alaska (fig. 22), and was detected shortly thereafter on the infrasound array in the City of Dillingham, Alaska. A small ash cloud was observed shortly afterward in satellite imagery drifting southward at an altitude of ~22,000 ft (~6,700 m). This event was the first explosion detected at Mount Cleveland since January 2019—a span of 17 months and the longest repose period at the volcano since its onset of eruptive activity in 2001. In response, the Aviation Color Code and Volcano Alert Level were elevated to **ORANGE** and **WATCH** on June 2 at 07:46 UTC (June 1 at 22:46 HADT) (fig. 20).

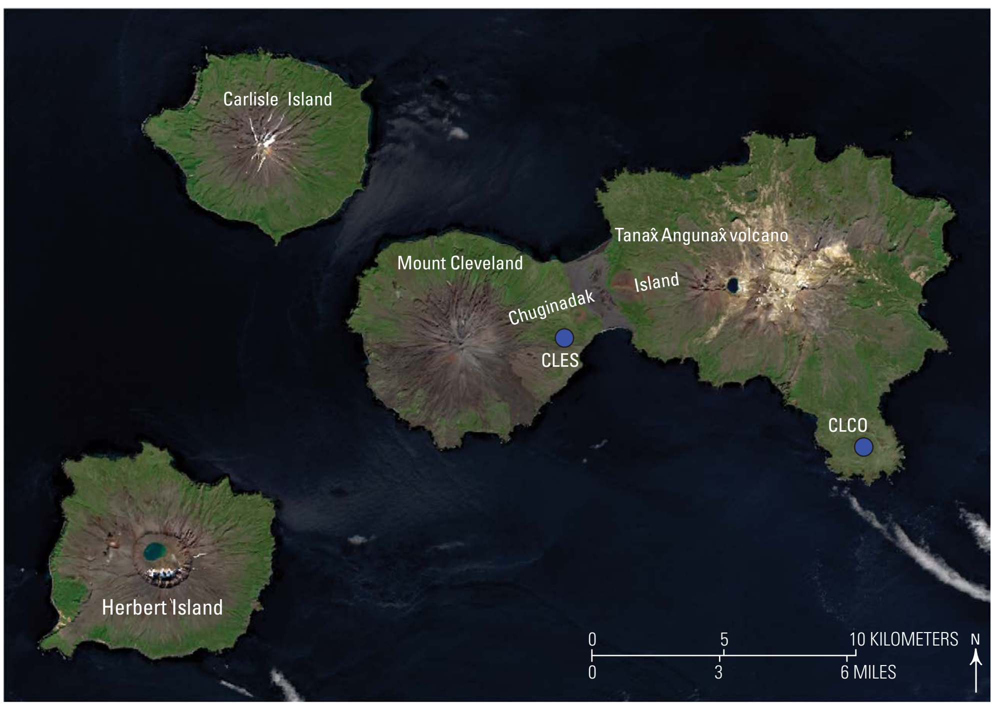


Figure 19. Satellite image of the Islands of Four Mountains group in Alaska, consisting of Chuginadak Island (Mount Cleveland and the informally named Tanax̂ Angunax̂ volcano, which has also been called Tana volcano), Carlisle Island, and Herbert Island. Circles denote geophysical stations used to monitor activity at Mount Cleveland. Image acquired by Sentinel-2, August 23, 2020.

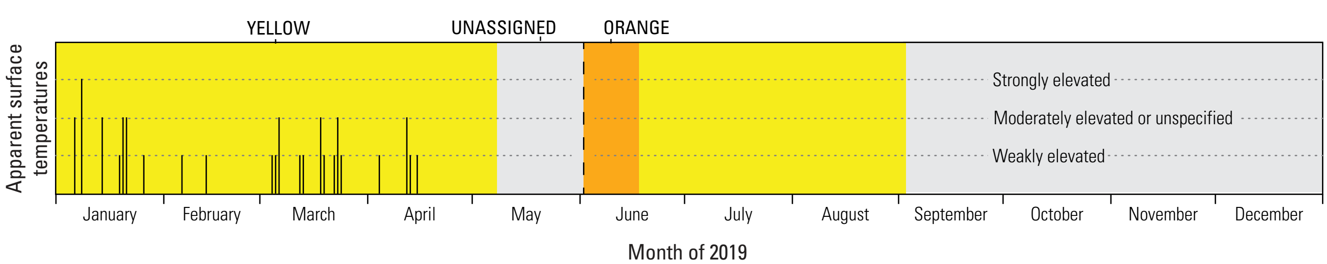


Figure 20. Timeline of Aviation Color Code changes for Mount Cleveland, Alaska, during 2020. The black dashed line between the unassigned and orange Aviation Color Code indicates the explosion on June 2 (June 1 Hawaii-Aleutian daylight time). Black bars indicate thermal anomalies and their subjective strength.

The explosion destroyed ~60 percent of the 2019 dome (fig. 23), excavated and widened the crater slightly, and sent pyroclastic and debris flows as far as ~3 km down the flanks of the volcano (figs. 24, 25). Hot debris landing on snow may have triggered some of these flows by melting and remobilizing mixtures of debris and snow. Satellite imagery acquired after the explosion also showed a trace ash deposit extending southward from the summit, discoloring the snow on the volcano's flanks (fig. 24). Aerial photographs taken on June 3 showed that impact craters from ballistically ejected bombs and blocks dotted the snow (fig. 25), and satellite imagery acquired later showed that the ejecta reached as far as 1,400 m from the summit crater.

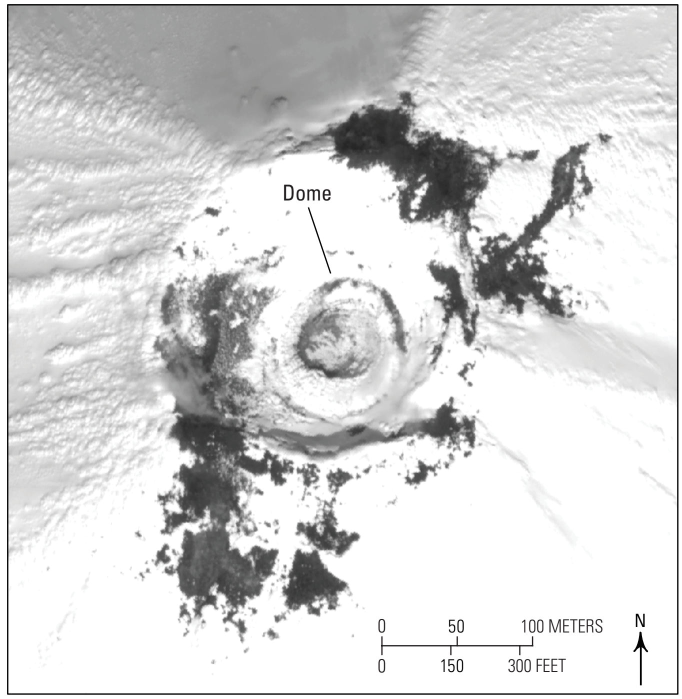


Figure 21. Satellite image of the summit of Mount Cleveland, Alaska, showing weak degassing from the west crater wall and snow covering much of the 2019 dome. Image acquired by WorldView-2, May 15, 2020.

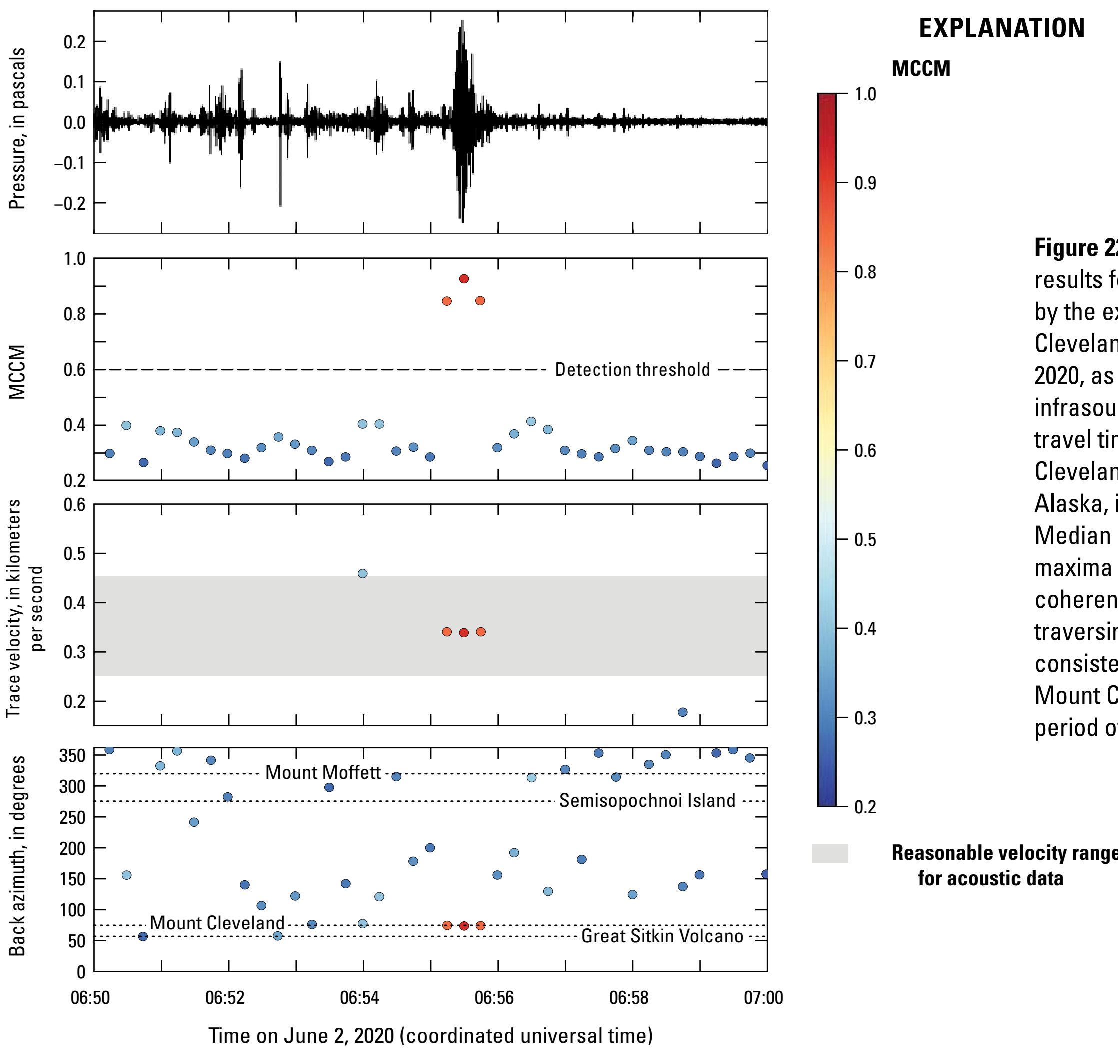
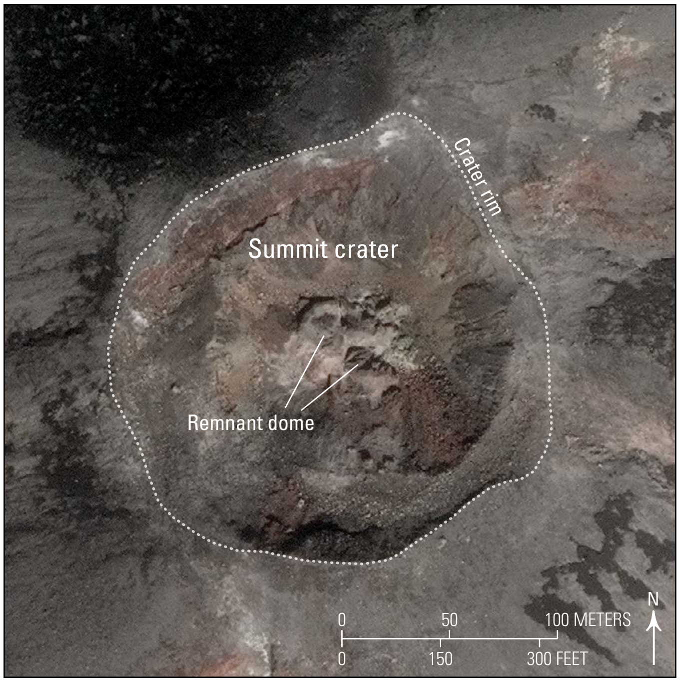
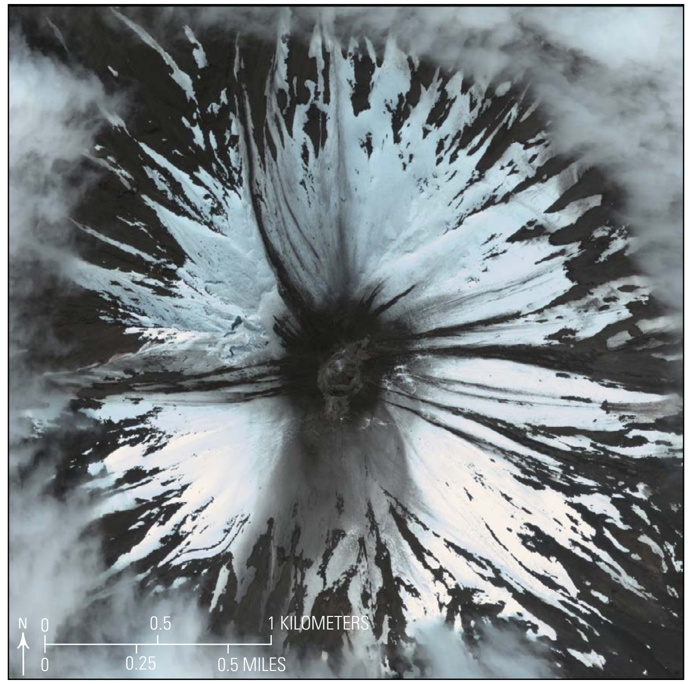


Figure 22. Array processing results for infrasound generated by the explosive event at Mount Cleveland, Alaska, on June 2, 2020, as recorded at the Adak infrasound array. The infrasound travel time between Mount Cleveland and the array in Adak, Alaska, is about 23.5 minutes. Median cross-correlation maxima (MCCM) measure the coherency of acoustic waves traversing the array. Note the consistent back azimuth toward Mount Cleveland during the period of high MCCM.



Base image from Maxar USG Plus, copyright 2023

Figure 23. Satellite image showing the summit crater of Mount Cleveland, Alaska, after the explosion of June 2, 2020. Dotted white line shows approximate crater rim location. Image acquired by WorldView-2, July 19, 2020.



Base image from Maxar USG Plus, copyright 2023

Figure 24. Satellite image of the summit of Mount Cleveland, Alaska, showing tephra and flowage deposits from the explosion of June 2, 2020. A trace ash deposit extends southward from the summit. Image acquired by GeoEye-1, June 22, 2020.

Figure 25. Oblique aerial photograph of the summit of Mount Cleveland, Alaska, on June 3, 2020, after its explosive eruption on June 2, 2020. Dark-colored flowage deposits lie on the east flank of the volcano. Ash, carried downwind during the eruption, coats the snow on the south flank of the volcano (left side of image). Another flowage deposit is visible on the north flank of the volcano (right side of image). Ballistic impact craters mar the snow cover in the foreground. The stratovolcano of Herbert Island is visible in the background. Copyrighted by Burke Mees, 2020; used with permission.

Activity at Mount Cleveland diminished after the June 2 explosion. A weak steam plume dissipated after a few days, and no conspicuous degassing or definitive elevated surface temperatures were observed in satellite imagery thereafter through the rest of the year. Because of the lack of activity, the Aviation Color Code and Volcano Alert Level were downgraded to **YELLOW** and **ADVISORY** on June 17, then to **UNASSIGNED** on September 3, where the volcano stayed for the rest of the year.

Atka Volcanic Complex (Korovin Volcano)

GVP #311161 (Korovin Volcano)
52.379°, −174.155°
1,546 m
Atka Island, Andreanof Islands, Aleutian Islands

ELEVATED SEISMIC ACTIVITY AND GAS EMISSIONS

Atka volcanic complex, which forms the northern part of Atka Island in the central Aleutian Islands, is ~15 km north of the community of Atka, Alaska, and 1,760 km southwest of Anchorage (fig. 1). The ancestral Atka volcano was destroyed during the Pleistocene, forming a 5-kilometer-diameter caldera (Myers and others, 2002). The complex now consists of four post-caldera cones, at least two of which have been active in the Holocene (Mount Kliuchef and Korovin Volcano). The summit of Mount Kliuchef contains a series of five vents arranged in a northeast-southwest alignment. Its two main summit vents and the northeastern most vent appear to be young—the northeasternmost vent was probably the source of an 1812 eruption attributed to nearby Sarichef Volcano (Wood and Kienle, 1990). Korovin Volcano, in contrast, has a pronounced summit crater measuring ~1 km in diameter and several hundred meters deep. This crater, in turn, contains a small lake (Wood and Kienle, 1990). Korovin Volcano was the source of small eruptions in 1973, 1987, and 1998.

The first indication of unrest at Atka volcanic complex in 2020 was a small increase in seismic activity. This activity started in early June and culminated with episodic tremor on June 11–12. The amplitude of the tremor pulses, which each lasted 10–40 minutes, increased slowly and peaked on June 12 at ~13:50 UTC (~04:50 HADT). The tremor then subsided to background levels for the next several months.

Beginning on October 15, the TROPOMI satellite instrument made occasional SO_2 detections (fig. 26) at Atka volcanic complex. These SO_2 detections were the first at the complex in 2020 and indicated elevated volcanic degassing. An additional two satellite SO_2 detections were made during the next two weeks, which also coincided with an increase in the number of earthquakes located in the area. In response to this heightened level of activity, AVO elevated the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** on October 28. No additional satellite SO_2 detections were made in the following weeks, and seismicity declined in late November, indicating a return to background activity. AVO subsequently lowered the Aviation Color Code and Volcano Alert Level back to **GREEN** and **NORMAL** on December 3.

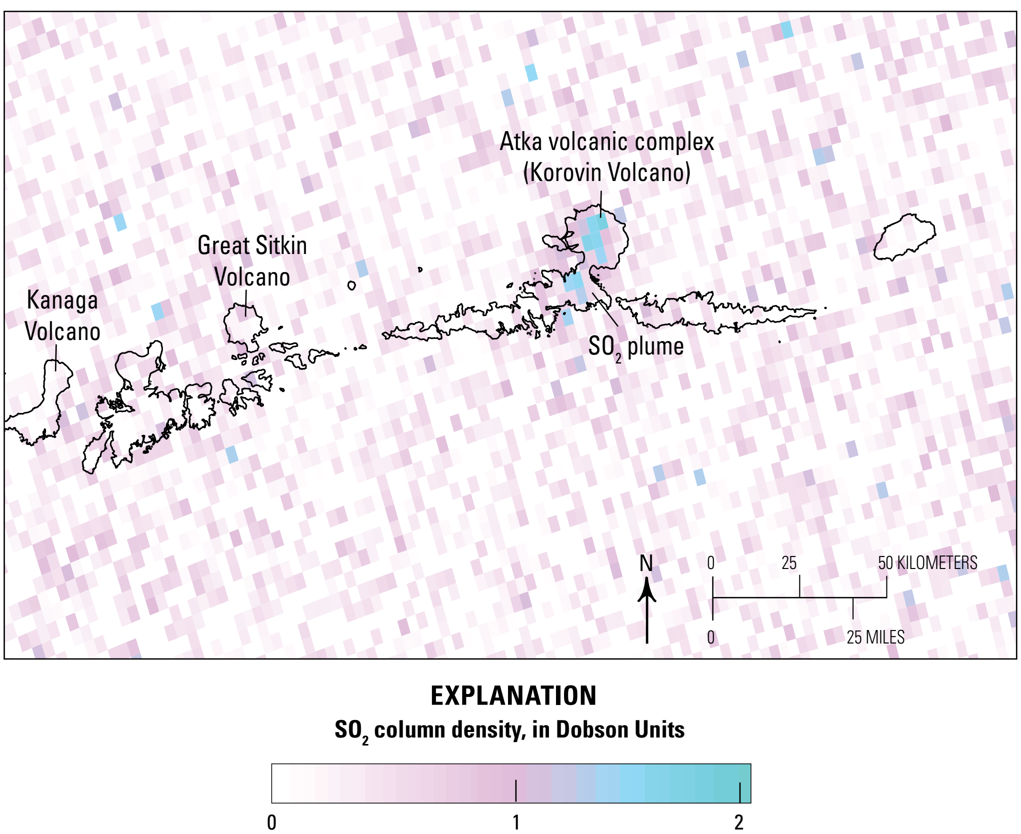


Figure 26. TROPOspheric Monitoring Instrument (TROPOMI) satellite image of sulfur dioxide (SO_2) gas emissions from Korovin Volcano, a subfeature of Atka volcanic complex, Alaska, on October 15, 2020.

Great Sitkin Volcano

GVP #311120
52.077°, −176.111°
1,743 m
Great Sitkin Island, Andreanof Islands, Aleutian Islands

ELEVATED SEISMIC ACTIVITY

Great Sitkin Volcano is a basaltic andesite volcano located 40 km northeast of the City of Adak, Alaska, and 1,880 km southwest of Anchorage (fig. 1). It makes up most of the north half of Great Sitkin Island, part of the Andreanof Islands group of the central Aleutian Islands (Waythomas and others, 2003a, 2003b). The volcano has an older collapsed caldera and a younger parasitic cone, the latter of which contains a summit crater 2–3 km in diameter with a steep-sided dome in its center. Great Sitkin Volcano most recently experienced a small phreatic eruption in 2019, but it erupted at least twice in the 20th century. An eruption in 1974 produced a lava dome in the summit crater and one recorded ash cloud, which reached a maximum altitude of ~10,000 ft (~3,000 m) ASL (Associated Press, 1974). In 1945, a poorly documented eruption also created a lava dome that was then partially destroyed by the 1974 eruption. An additional eruption at Great Sitkin Volcano is not precisely dated but occurred within the past 280 years. This event produced pyroclastic flows that partially filled a valley on the southwest flank of the volcano (Waythomas and others, 2003b).

In late July 2016, Great Sitkin Volcano entered a period of increased unrest characterized by an elevated frequency of earthquakes (fig. 27), anomalous steaming from its summit crater, and small explosive events (Dixon and others, 2020). Similar small earthquakes and steaming from the summit crater continued throughout 2020.

AVO located 3,393 earthquakes at Great Sitkin Volcano during 2020 (fig. 28), a large increase from earlier years. This increase may, in part, reflect network upgrades made during the 2019 field season that replaced older analog sensors with broadband sensors capable of digital telemetry. This new instrumentation has proven more reliable at Great Sitkin Volcano than the older equipment, improving AVO’s ability to detect and locate earthquakes in the area.

In late January 2020, Great Sitkin Volcano began to experience an increase in earthquake activity that was interpreted as unrelated to the recently improved seismic detection capabilities (fig. 27), prompting AVO to raise the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** on February 26. This activity peaked in late March and then slowly declined throughout the remainder of 2020. In response to the declining rates of seismicity, the Aviation Color Code and Volcano Alert Level were lowered back to **GREEN** and **NORMAL** on October 21. No seismic or infrasound signals indicative of explosive events were detected at the volcano during 2020.

The hypocenters of earthquakes at Great Sitkin Volcano in 2020 were principally clustered within the shallow crust, extending from the summit to roughly 10 km depth below sea level (fig. 28). Earthquakes were also recorded at depths between 10 and 35 km; these had waveforms and frequency contents suggesting both volcano-tectonic (VT) and deep

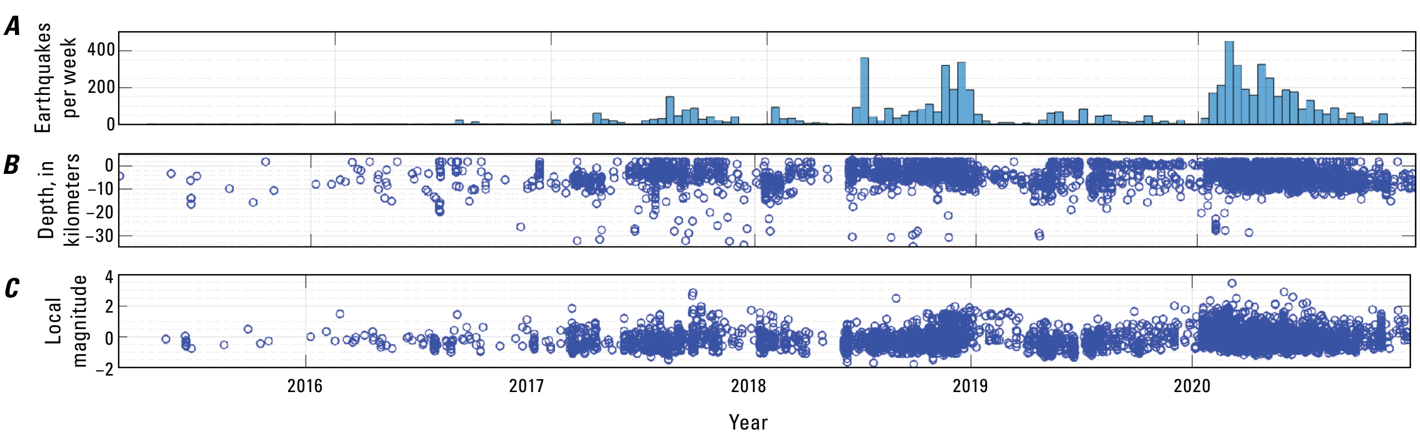
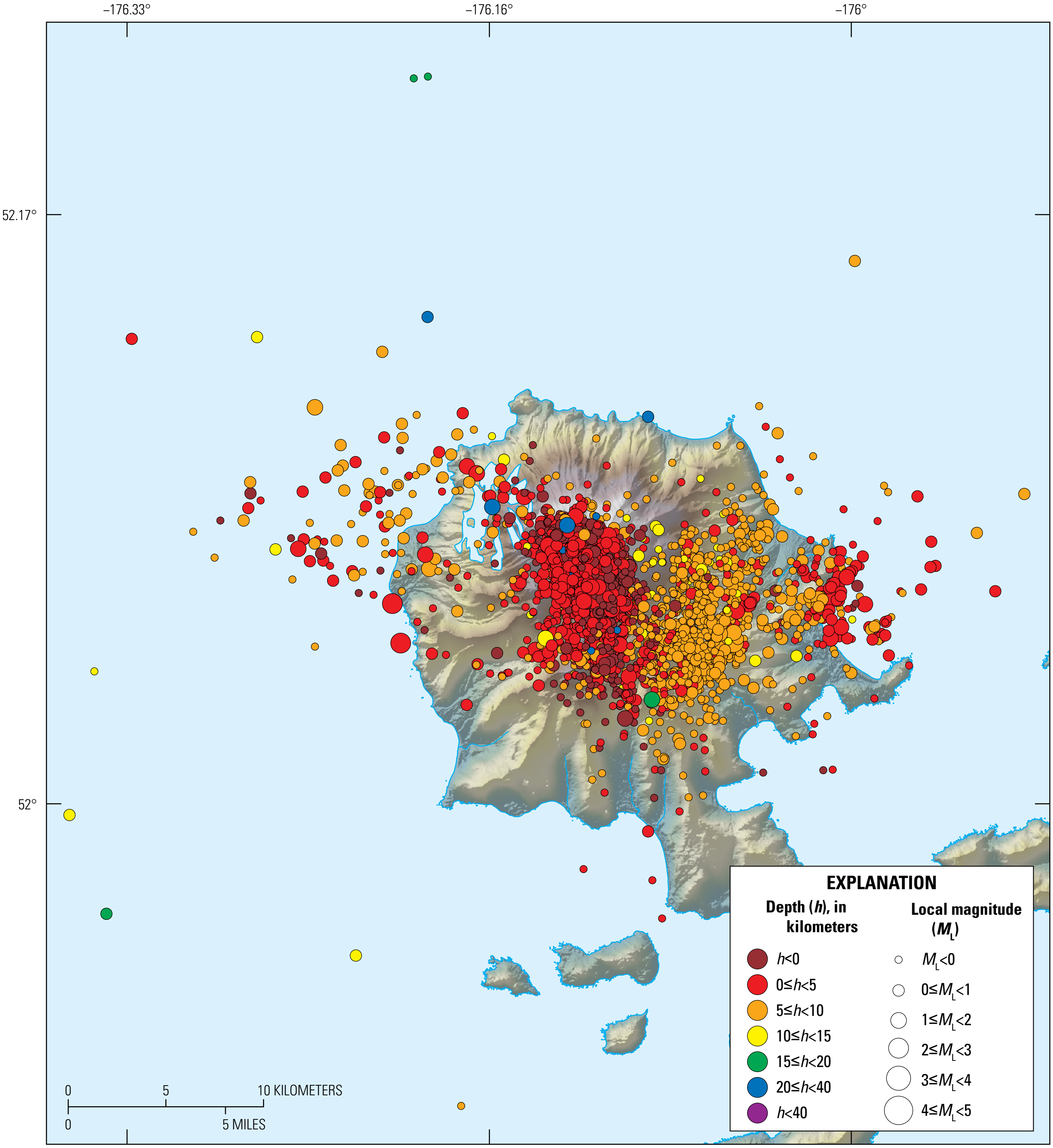


Figure 27. Plots of earthquake data for Great Sitkin Volcano, Alaska, from 2015 through 2020, showing the number of hypocenters determined each month (*A*), earthquake hypocentral depths (*B*), and earthquake magnitudes (*C*). The decline in the number of earthquakes with shallow hypocenters during the first six months of 2019 may reflect the loss of stations in the Great Sitkin Volcano seismic network.



Base from U.S. Geological Survey, The National Map
WGS 1984 Web Mercator

Figure 28. Map showing hypocenters of earthquakes located at Great Sitkin Volcano, Alaska, by the Alaska Volcano Observatory in 2020.

LP events. Located events ranged in magnitude from M_L −1.2 to M_L 3.5. The M_L 3.5 event occurred on March 6 (at 15:31 UTC; 05:31 HAST) under the east rim of the summit crater at a depth of 0.2 km. This earthquake was the strongest event recorded beneath Great Sitkin Volcano since its period of unrest began in 2016 (fig. 29). For comparison, the largest earthquake recorded beneath the volcano's edifice since monitoring began in 1999 was M_L 4.3. That event took place on May 28, 2002, and was located beneath the southeast flank of the volcano (Pesicek and others, 2008).

The other notable earthquake activity at Great Sitkin Volcano in 2020 consisted of a cluster of seven earthquakes that occurred between January 31 and February 1. These seven events ranged from M_L −0.6 to 0.27 and had depths ranging from 22.6 to 27.0 km.

AVO noted no major changes or unusual activity at the summit crater and dome during 2020, although the degree of visible steaming decreased compared to the 2016–2019 period (Dixon and others, 2020; Cameron and others, 2023; Orr and others, 2023). Photographs taken by passing airplanes in March, shortly after the M_L 3.47 earthquake of March 6, show small snow-free areas and minor steaming at the summit of the volcano (fig. 31). Satellite imagery of Great Sitkin Volcano acquired in June and July indicated weakly elevated surface temperatures.

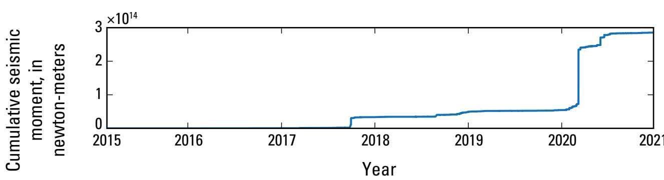


Figure 29. Time series of cumulative seismic moment for all earthquakes located within 20 kilometers of the summit of Great Sitkin Volcano between 2015 and 2021. The large increase in 2020 corresponds to an earthquake of local magnitude 3.47 that occurred on March 6.

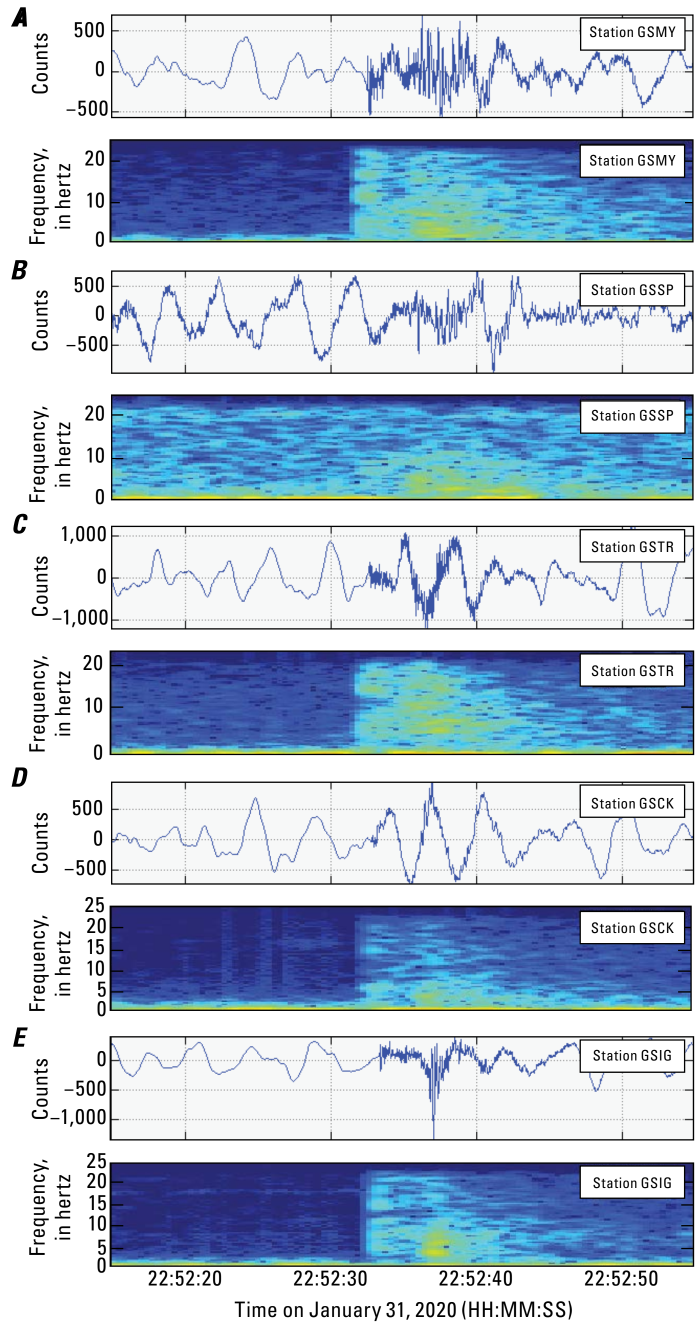


Figure 30. Waveform and spectrogram plots for an earthquake that occurred beneath Great Sitkin Volcano, Alaska, on January 31, 2020 (22:52 coordinated universal time; 12:52 Hawaii-Aleutian standard time), as recorded at seismic stations GSMY (*A*), GSSP (*B*), GSTR (*C*), GSCK (*D*), and GSIG (*E*). The event had a local magnitude of 0.27 and a hypocentral depth of 22.64 kilometers.

Figure 31. Photograph of the summit crater of Great Sitkin Volcano, Alaska, showing weak fumaroles and warm, snow-free areas on the summit lava dome. View to the north. Photograph by Angela McConnell, Alaska Airlines, March 21, 2020.

Semisopochnoi Island (Mount Young)

GVP #311060
51.929°, 179.598°
815 m
Semisopochnoi Island, Rat Islands, Aleutian Islands

ELEVATED SEISMIC ACTIVITY, WEAK EXPLOSIVE EVENTS, AND ASH AND GAS EMISSIONS

Semisopochnoi Island is a young, uninhabited volcanic island in the western Aleutian Islands, 260 km west of Adak and 2,110 km southwest of Anchorage (fig. 1). The island's largest feature is a 7-kilometer-wide caldera that formed 6,900–5,000 years ago, but it also has many post-caldera cones (Coombs and others, 2018). The last recorded eruption before the volcano's ongoing activity (which started in 2018) took place in 1987 at Sugarloaf Peak, located on the south end of the island. This event produced a 90-kilometer-long plume visible in satellite images, and pilots later reported ash deposited on the volcano's flanks (Reeder, 1990). Mount Young, a cluster of three cones within Semisopochnoi Island's caldera, has also erupted repeatedly in the Holocene, producing crystal-rich basaltic andesite lavas and tephra from all three cones. Most fall deposits associated with the cones are consistent with small- to moderate-sized ash clouds, although some lapilli-size units indicate eruption intensities with a volcanic explosivity index as high as 3 (Coombs and others, 2018). The most recent non-eruptive unrest at the volcano prior to its ongoing eruption was a period of increased seismicity and deformation in 2014–2015. Modeling by DeGrandpre and others (2019) explained this as the result of the rapid intrusion of 0.072 km^3 of magma (as two batches) into a spheroidal magma storage zone ~8 km beneath the caldera.

Renewed activity at Semisopochnoi Island began in September 2018 and continued through 2020. This eruption was characterized by (1) low-level ash emissions that occasionally produced local deposits, (2) geophysical indications of small explosions, and (3) steam and gas emissions from the north cone of Mount Young (fig. 32). The local monitoring network documented seismic activity for nearly the full year, but a network outage began on November 11 and continued through the end of 2020. Regional infrasound arrays and satellite remote sensing supported the monitoring of explosive activity and emissions.

Explosive activity and seismic tremor were recorded at Semisopochnoi Island at the end of 2019 (on December 19 and 29, respectively), so the volcano began 2020 at an Aviation Color Code and Volcano Alert Level of **ORANGE** and **WATCH** (fig. 33) (Orr and others, 2023). A pause followed this activity, and AVO lowered the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** on January 9, 2020. The overall seismicity remained elevated, however, and on February 15, a series of small explosions and tremor bursts were detected. No ash emissions or deposits were identified in satellite imagery, which was frequently cloudy, but the seismic activity led AVO to return the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH**. Seismicity did not increase further and clear imagery later confirmed the volcano was not erupting, although steam emissions were visible. On February 26, AVO lowered the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY**.

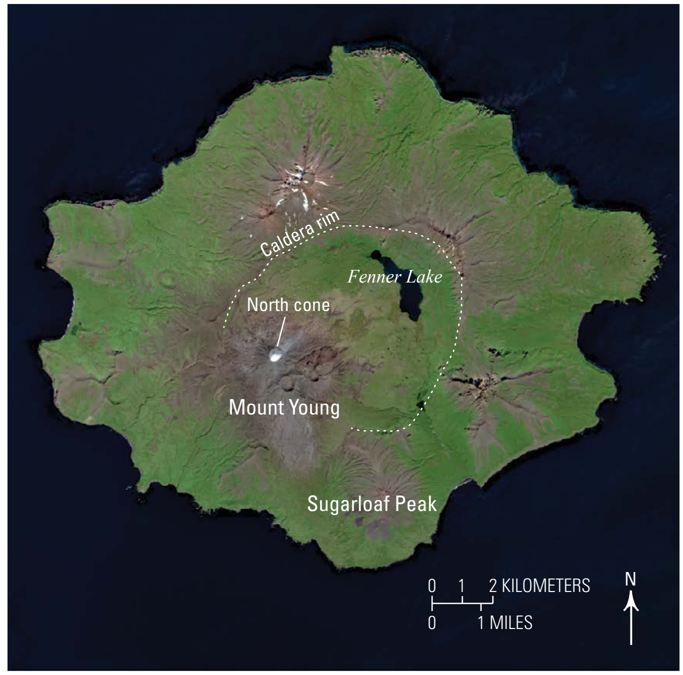


Figure 32. Satellite image of Semisopochnoi Island in the Rat Islands, Alaska, showing active and recently active volcanic features. The north cone of Mount Young is steaming, and a light dusting of gray ash extends south-southeastward across the flank of the edifice. Image acquired by Sentinel-2, August 22, 2020.

Activity in mid-March was characterized by nearly continuous tremor and frequent, small explosion signals, but no observations of ash plumes. Regional infrasound arrays detected an explosion at the volcano on March 11, followed by more on March 15–16, all of which were accompanied by ground-coupled airwaves recorded on the local seismic network. During this March explosive period, a dark ash deposit appeared around the north cone of Mount Young (fig. 34*A*) and TROPOMI imagery showed a possible SO_2 plume. In response to the infrasound and remote sensing observations, AVO raised the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH** on March 16. This activity was short-lived; by

March 22, a partly cloudy WorldView-1 image showed that a robust steam plume emanated from the north cone of Mount Young and a water lake had appeared deep within its crater (fig. 34*B*). After two weeks with no sign of eruption activity, AVO lowered the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** on April 1, 2020.

The volcano emitted steam and SO_2 regularly throughout the spring and summer (fig. 35), and by June 15, the crater lake had mostly dried up. Planet Labs and Sentinel-2 satellite imagery from June 21 captured an ash deposit extending nearly 4 km southward from the north cone crater, accompanied by robust steam emissions and a high-temperature short-wave infrared anomaly within the crater (fig. 34*C*, *D*). The appearance of this deposit was associated with ground-coupled airwaves detected on June 16 and 17, but no infrasound. Seismicity at the volcano initially remained elevated, appearing as low-level tremor and small earthquakes, but AVO detected no further explosions in 2020 and its activity waned in the fall. An outage of local real-time monitoring data began on November 11, 2020. Considering the absence of data, the lack of eruptive activity detected since June, and the decaying trend in seismicity, AVO changed the Aviation Color Code and Volcano Alert Level of Semisopochnoi Island to **UNASSIGINED** on November 20, 2020.

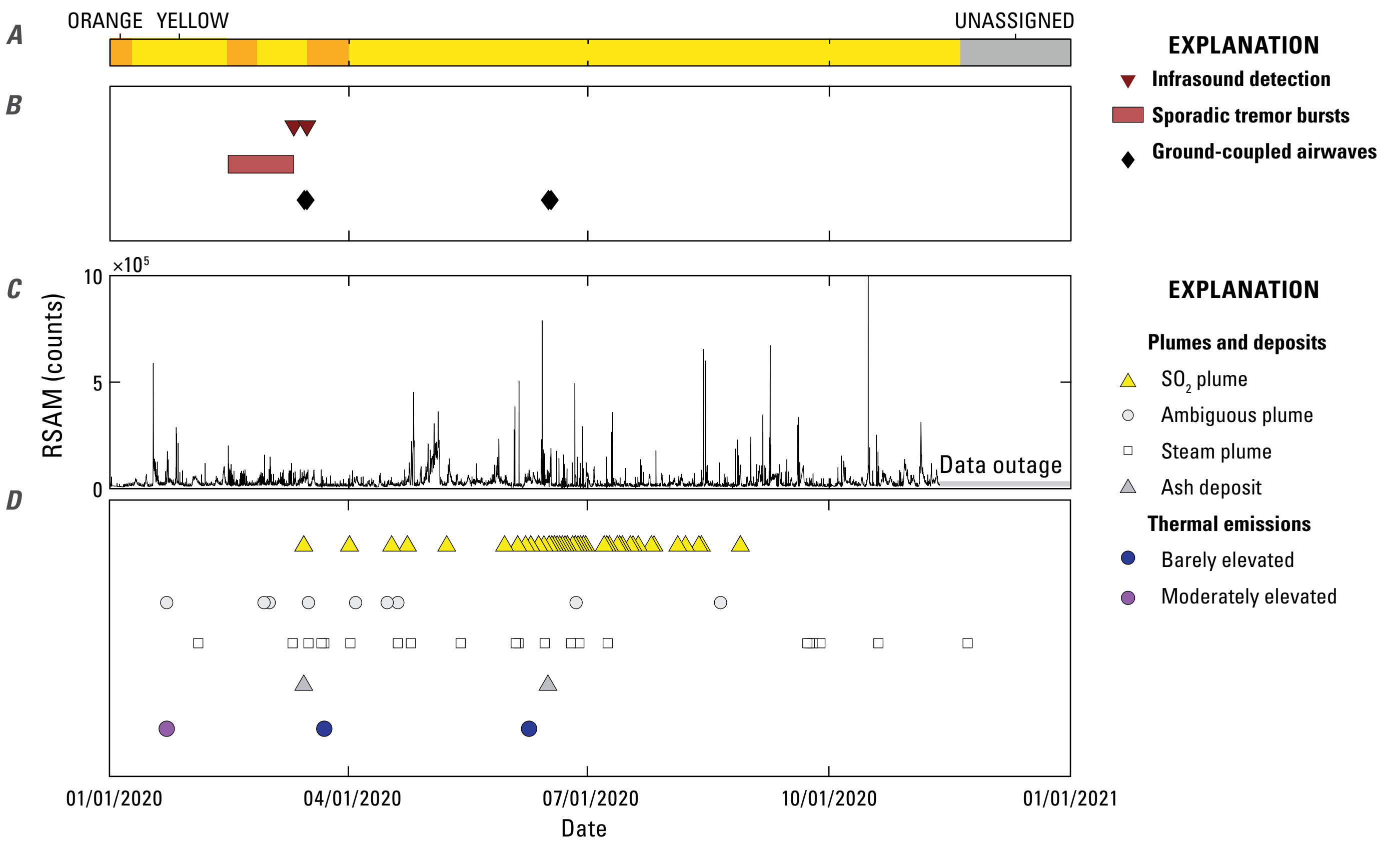


Figure 33. Chronology of activity at Semisopochnoi Island, Alaska, in 2020. *A*, Timeline of changes in Aviation Color Code. *B*, Timeline of geophysical activity detected at the volcano. The period of sporadic tremor bursts spanned February 15 to March 11. *C*, Time series of real-time seismic amplitude measurement (RSAM) values from station CERB. The data outage began on November 11, 2020. *D*, Timeline of activity detected in satellite remote sensing data. Ambiguous plumes are those that had no clear ash or gas signature but were apparent in mid-infrared satellite imagery. Thermal emissions reflect temperatures observed in mid-infrared satellite imagery. Dates shown as month/day/year.

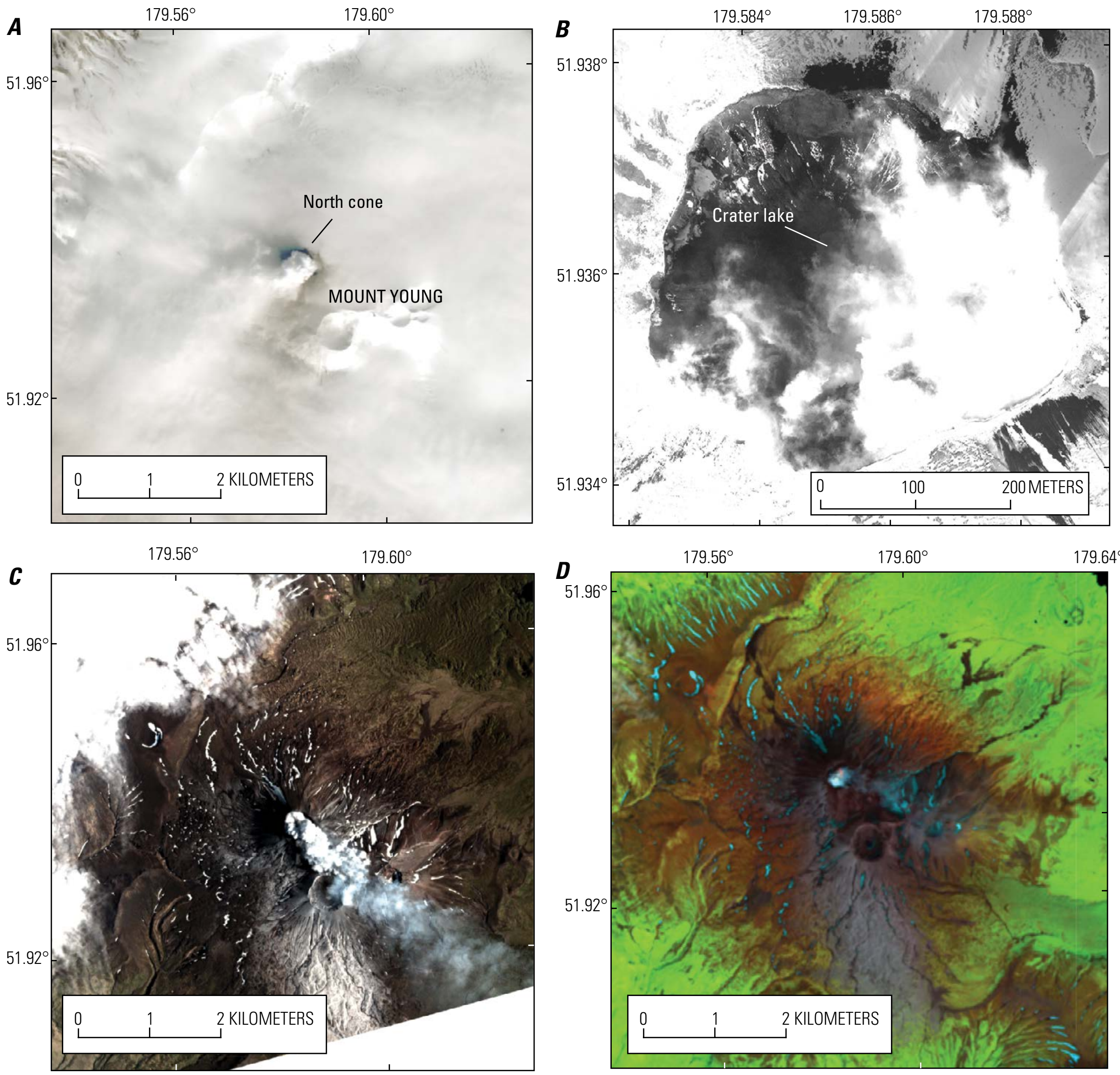


Figure 34. Satellite images showing activity at the north cone of Mount Young on Semisopochnoi Island, Alaska. *A*, Sentinel-2 multispectral image of Mount Young from March 15, 2020. A steam plume appears in the north cone crater. Dark ash deposits surround the crater rim and extend slightly southward. *B*, WorldView-1 panchromatic image of the north cone crater from March 22, 2020. The image shows both a crater lake deep within the crater and a steam plume. *C*, Planet Labs visible color image of Mount Young from June 21, 2020. A light-colored ash deposit coats the south flank of the volcano and robust steam emissions rise from its north cone. *D*, Sentinel-2 short-wave infrared (SWIR) false-color image of Mount Young from June 21, 2020. The same light-colored ash deposit appears on the south flank of the volcano and a small thermal SWIR anomaly (colored red) is shown within the north cone crater.

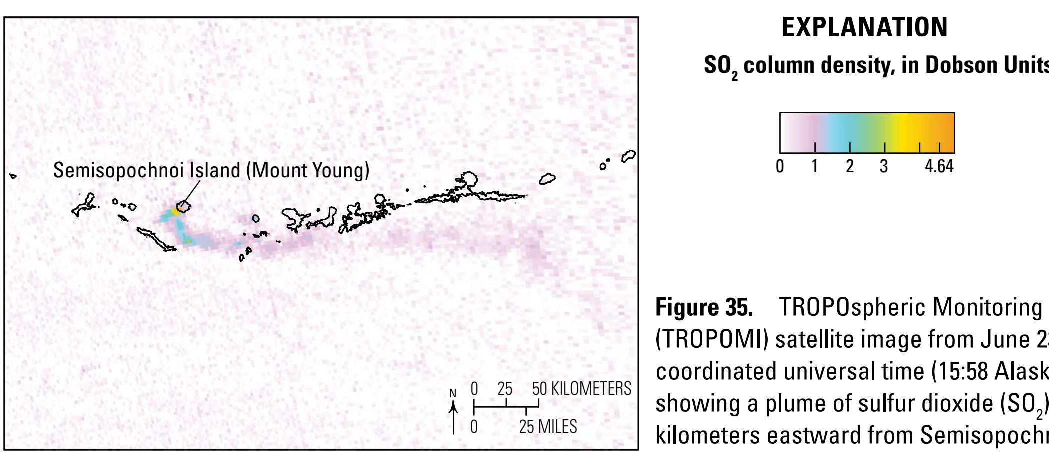


Figure 35. TROPOspheric Monitoring Instrument (TROPOMI) satellite image from June 23, 2020, at 00:58 coordinated universal time (15:58 Alaska standard time), showing a plume of sulfur dioxide (SO_2) gas extending 500 kilometers eastward from Semisopochnoi Island, Alaska.

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Glossary of Selected Terms and Acronyms

A

andesite Volcanic rock composed of about 57–63 weight percent silica (SiO_2).

ash Fine fragments (less than 2 millimeters across) of lava or rock formed in an explosive volcanic eruption.

B

basalt Volcanic rock composed of about 45–52 weight percent silica (SiO_2).

basaltic andesite Volcanic rock composed of about 52–57 weight percent silica (SiO_2).

C

caldera A large, roughly circular depression commonly caused by a volcanic collapse or explosion.

D

dacite Volcanic rock composed of about 63–69 weight percent silica (SiO_2).

F

fumarole A small opening or vent from which hot gases are emitted.

H

Holocene A geologic epoch that extends from 11,700 years ago to the present.

I

incandescence The high-temperature emission of light.

infrasound Low-frequency sound waves, below the threshold of human hearing.

intracaldera Refers to something within the caldera.

J

juvenile material Volcanic material created from magma reaching the surface.

L

lahar A flow of a mixture of pyroclastic material and water.

lava Molten rock that has reached the Earth's surface.

long-period earthquake An earthquake with dominant frequency content between 1 and 5 hertz. Used interchangeably with the term low-frequency earthquake.

M

M_L Local magnitude; an earthquake magnitude scale based on the amplitude of ground motion as measured by a standard seismograph.

magma Molten rock below the surface of the Earth.

P

paroxysm A sudden, violent, explosive eruption.

phreatic activity An explosive eruption caused by the sudden heating of groundwater as it contacts hot volcanic rock or magma, leading to a steam-driven explosion.

Pleistocene A geologic epoch that extends from about 2.58 million to 11,700 years ago.

pyroclast An individual particle ejected during a volcanic eruption; commonly classified by size (for example, ash and lapilli).

R

real-time seismic-amplitude measurement Amplitude of ground shaking caused by earthquakes and volcanic tremor averaged over 10-minute intervals.

S

earthquake swarm A flurry of closely spaced earthquakes or other ground shaking activity; often precedes an eruption.

spatter cone A low, steep-sided cone of spatter built up on a fissure or vent.

steam emissions A general term used herein to indicate visible (partially condensed) degassing of mixed, and typically unquantified, gas compositions from volcanoes and thermal areas.

stratovolcano Also called a stratocone or composite cone; a steep-sided volcano, commonly conical in shape, built of interbedded lava flows and fragmental deposits from explosive eruptions.

Strombolian A type of explosive volcanic eruption characterized by intermittent bursts of fluid lava, commonly basalt or basaltic andesite, from a vent or crater as gas bubbles rise through a conduit and burst at the surface.

subplinian A type of volcanic eruption characterized by an unsteady but sustained convective eruption column that results in atmospheric injection and wide wind dispersal of ash. Plume height is generally less than about 12 miles (20 km).

T

tephra The general name for all volcanic material thrown into the air during a volcanic eruption.

tremor Low-amplitude, continuous earthquake activity commonly associated with magma movement.

V

vent An opening in the Earth's surface through which magma erupts or volcanic gases are emitted.

Volcano Activity Notice A formal announcement of alert-level changes or significant volcanic activity within an alert level; covers all volcanic hazards—lahars (volcanic mudflows), lava flows, ashfall, airborne ash, and pyroclastic flows.

volcanic explosivity index A scale that describes the size of explosive volcanic eruptions on the basis of magnitude and intensity.

volcano-tectonic earthquake An earthquake generated within or near a volcano by brittle rock failure resulting from strain induced by volcanic processes.

Vulcanian A type of volcanic eruption that ejects material to heights less than about 12 miles (20 km) and that lasts on the order of seconds to minutes. They are characterized by discrete, violent explosions, the ballistic ejection of blocks and bombs, atmospheric shock waves, and the emission of tephra.

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