

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.

2023 Volcanic Activity in Alaska and the Northern Mariana Islands—Summary of Events and Response of the Alaska Volcano Observatory



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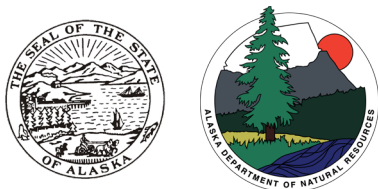
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Cover. Aerial view of Shishaldin Volcano, November 25, 2023. Photography by Brian Reedy.



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Data Availability Statement

This work is supported by the following data. Where applicable a URL to their location is provided.

- Loewen, M.W., Gomez-Patron, A., Fee, D., Lopez, T., Mota, R., Saunders-Shultz, P., Merritt, K., Dietterich, H., Brewster, I., Wallace, K., 2026, Shishaldin Volcano 2019–2020 and 2023 Eruption Chronology Data: Alaska Division of Geological & Geophysical Surveys Raw Data File 2026-xx, <https://doi.org/10.14509/32077>
- Alaska Volcano Observatory (AVO) image database (<https://avo.alaska.edu/image>)
- ANSS Comprehensive Earthquake Catalog (ComCat) (<https://earthquake.usgs.gov/data/comcat/>)
- NOAA/NASA Suomi (Visible Infrared Imaging Radiometer Suite) VIIRS data viewed through USGS VolcView (<https://volcview.wr.usgs.gov/vv-gui/>)
- NOAA Advanced Very High Resolution Radiometer (AVHRR) viewed through USGS VolcView (<https://volcview.wr.usgs.gov/vv-gui/>)
- Federal Aviation Administration (FAA) webcams viewed through USGS Ashcam (<https://volcview.wr.usgs.gov/ashcam-gui/>)
- Alaska Volcano Observatory (AVO) Webcams viewed through USGS Ashcam (<https://volcview.wr.usgs.gov/ashcam-gui/>)
- National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellite (GOES) data viewed through either the CIRA slider (<https://rammb-slider.cira.colostate.edu>) or on NOAA's S3 bucket (<https://registry.opendata.aws/noaa-goes/>)
- NOAA ETOPO and bathymetric data (<https://www.ncei.noaa.gov/maps/bathymetry/>)
- European Space Agency Sentinel-1, Sentinel-2, Tropospheric Monitoring Instrument (TROPOMI) data viewed either through the Copernicus Browser (<https://browser.dataspace.copernicus.eu/>), SentinelHub (<https://www.sentinel-hub.com/>), or USGS VolcView (<https://volcview.wr.usgs.gov/vv-gui/>)
- Japanese Aerospace Exploration Agency (JAXA) Advanced Land Observing Satellite (ALOS) 2 (https://www.eorc.jaxa.jp/ALOS/en/dataset/alos_open_and_free_e.htm)
- Satellite Argentino de Observacion Con Microondas (SAOCOM) (<https://catalog.saocom.conae.gov.ar/catalog/#/>)
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Contents

Acknowledgments	iv
Data Availability Statement	iv
Conversion Factors	viii
Datum	viii
Abbreviations	ix
Abstract	1
Introduction	1
What is an “Eruption”?	8
What is a “Recently Active Volcano”?	8
Volcanic Activity in Alaska	9
Mount Edgecumbe	9
Iliamna Volcano	12
Mount Katmai (Novarupta)	15
Trident Volcano	19
Aniakchak Crater	23
Pavlof Volcano	27
Shishaldin Volcano	29
Eruption Buildup and Event 1 (July 10–July 14)	29
Event 2 (July 15–16)	31
Event 3 (July 18)	33
Event 4 (July 21–23)	34
Event 5 (July 25–26)	35
Event 6 (August 3–4)	35
Event 7 (August 14–15)	35
Event 8 (August 24–26)	38
Event 9 (September 5)	39
Event 10 (September 15–16)	41
Event 11 (September 22–25)	41
Event 12 (October 2–3)	42
Event 13 (November 2–3)	45
Post-eruption Unrest	45
Bogoslof Volcano	47
Mount Cleveland	49
Great Sitkin Volcano	50
Kanaga Volcano	53
Takawangha and Tanaga volcanoes	56
Semisopochnoi Island (Mount Young)	59
Volcanic Activity in the Commonwealth of the Northern Mariana Islands	61
Ahyi Seamount	61
Ruby Seamount	63
References Cited	67
Appendix 1. Glossary of Selected Terms and Acronyms	73
Appendix 2. Aniakchak Crater earthquake catalog additional information	75

Figures

1. Map of volcanoes in Alaska and the Commonwealth of the Northern Mariana Islands highlighted in this summary.....	2
2. Cumulative line-of-sight displacement map from InSAR data at Mount Edgecumbe, Alaska, from April 2017 to January 2024	10
3. Overview map of Mount Edgecumbe, Alaska, showing geophysical monitoring sites installed in August 2023 and earthquakes located in 2023.....	11
4. Photographs of the new geophysical monitoring network installed at Mount Edgecumbe, Alaska, in August 2023.....	11
5. Depth-time plot of earthquakes located at Mount Edgecumbe, Alaska, in 2023	11
6. Seismic waveforms and spectrogram of the June 6, 2023, Red Glacier avalanche recorded at Iliamna Volcano, Alaska	13
7. Comparison of seismic signals from the 2016, 2019, and 2023 Red Glacier avalanches at Iliamna Volcano, Alaska.....	13
8. WorldView-3 satellite imagery of the Red Glacier avalanche deposits at Iliamna Volcano, Alaska, on July 22, 2023.....	14
9. Photographs of the 2023 Red Glacier avalanche rupture area and runout at Iliamna Volcano, Alaska	15
10. Satellite imagery of resuspended volcanic ash clouds originating from the Katmai region, Alaska, in 2023	16
11. Web camera images of resuspended volcanic ash clouds in the Katmai region, Alaska, in 2023..	17
12. Examples of trace amounts of ash fallout from resuspended ash clouds from the Katmai region in 2023.....	17
13. Photograph of hazy skies observed from the city of Kodiak, Alaska, on October 9, 2023.	17
14. Map of earthquakes near Trident Volcano and the Katmai volcanic cluster, Alaska, from January 2020 through December 2023.	20
15. Cumulative earthquake counts for shallow and deep seismicity near Trident Volcano and Mount Martin/Mageik, Alaska, from 2020 to 2023	20
16. Depth cross section of earthquakes along profile A–A' near Trident Volcano and Novarupta, Alaska, in 2023.....	21
17. Depth cross section and histogram of earthquakes along profile B–B' near Trident Volcano and Novarupta, Alaska, in 2023.....	21
18. Filtered seismic waveform and spectrogram showing deep long-period earthquakes and tremor at Trident Volcano, Alaska, on July 6, 2023.	22
19. Interferometric Synthetic Aperture Radar (InSAR) interferogram from the Katmai volcanic cluster taken on 05/27/2023 and 06/03/2023.	22
20. Timeline of located earthquakes at Aniakchak Crater, Alaska, from January 2022 to October 2023	24
21. Focal depth versus time for earthquakes at Aniakchak Crater, Alaska, from 2021 to 2023	24
22. Map of earthquakes and annotated satellite image of Aniakchak Crater, Alaska, from October 2022 to April 2023	25
23. InSAR interferograms showing ground displacement at Aniakchak Crater, Alaska, during 2022–2023 unrest	26
24. Photograph of Pavlof and Pavlof Sister Volcanoes, Alaska, showing lahar deposits and a wind-generated dust plume in 2023.....	28
25. Overview map of Unimak Island, Alaska, showing volcanoes and Alaska Volcano Observatory monitoring sites.....	30
26. Timeline of the 2023 eruption of Shishaldin Volcano, Alaska, showing multiparameter monitoring data	30

27. Timeline of Shishaldin Volcano Event 1, Alaska, including activity in the days prior to the first paroxysm in July 2023.....	32
28. Photograph of lava erupting from Shishaldin Volcano, Alaska, on July 12, 2023, taken by the U.S. Coast Guard.....	32
29. Satellite images of pyroclastic density current and lahar deposits at Shishaldin Volcano, Alaska, on July 18, 2023.....	33
30. Webcam images on July 18, 2023, of the Event 3 ash plume.....	34
31. July 22–23, 2023, Geostationary operational environmental satellite (GOES)-18 images for Shishaldin Volcano Event 4.....	36
32. WorldView-3 satellite image of ash deposits at Shishaldin Volcano, Alaska, on August 1, 2023...	37
33. Geostationary Operational Environmental Satellite (GOES)-18 multispectral products from the Event 7 paroxysm	38
34. Timeline of Event 8 at Shishaldin Volcano, Alaska, showing plume heights and seismic amplitude in 2023	39
35. Webcam image of a crater rim collapse event on the northeast side of Shishaldin Volcano, Alaska, in 2023.....	40
36. Sequential webcam images of lava fountaining and ash-rich paroxysm during Event 9 at Shishaldin Volcano, Alaska, on September 5, 2023.	40
37. Timeline of Event 11 at Shishaldin Volcano, Alaska, showing lightning, infrasound, tremor, and peak ash heights in 2023	43
38. Photographs of ashfall impacts in Cold Bay and False Pass, Alaska, during Shishaldin Volcano Event 11 on September 25, 2023	44
39. Webcam images of Event 12 eruptive activity at Shishaldin Volcano, Alaska, on October 2–3, 2023	44
40. October 3, 2023, Geostationary operational environmental satellite (GOES)-18 images for Shishaldin Volcano Event 12	46
41. Histogram and cumulative count of earthquakes at Bogoslof volcano, Alaska, from October 10 to November 15, 2023.	48
42. Map of earthquake hypocenter locations at Bogoslof volcano, Alaska, from October 10 to November 15, 2023	48
43. Timeseries of Aviation Color Code, thermal anomalies, and earthquake detections at Mount Cleveland, Alaska, in 2023	49
44. Aerial photograph of the Great Sitkin Volcano summit lava flow, Alaska, taken in late summer 2023.....	51
45. Sequence of synthetic aperture radar imagery capturing growth of the Great Sitkin Volcano lava flow, Alaska, in 2023.....	51
46. Chronology of eruptive activity at Great Sitkin Volcano, Alaska, in 2023, showing surface temperatures, steam detections, and earthquake data	52
47. Map of earthquake detections at Great Sitkin Volcano, Alaska, in 2023	52
48. Backscattered electron image mosaics of lava samples collected at Great Sitkin Volcano, Alaska, in late summer 2023	53
49. Map of Alaska Volcano Observatory seismic monitoring station locations on Kanaga Island, Alaska.....	54
50. Seismic and infrasound waveforms and spectrograms from the December 19, 2023, explosive event at Kanaga Volcano, Alaska.....	54
51. WorldView-3 satellite image showing cracks and snow-free areas at the summit of Kanaga Volcano, Alaska, on January 16, 2024	55
52. Earthquake activity detected at Kanaga Volcano surrounding the December 19, 2023 eruption ..	55
53. Map of 2023 earthquake epicenters near Takawangha and Tanaga Volcanoes on Tanaga Island, Alaska.....	57

54. East-west cross section and depth-time plot of earthquakes near Tanaga Island, Alaska, from January 2021 to December 2023.....	58
55. Hypocenter maps showing the progression of earthquakes beneath Tanaga Island, Alaska, in early March 2023	58
56. Webcam images of ash and gas emissions from Mount Young on Semisopochnoi Island, Alaska, in 2023.....	60
57. Chronology of eruptive activity at Mount Young, Semisopochnoi Island, Alaska, in 2023.....	60
58. Chronology of volcanic activity at Ahyi seamount, Commonwealth of the Northern Mariana Islands, from September 2022 through July 2023	62
59. Satellite images of submarine plumes of discolored water from Ahyi seamount, Commonwealth of the Northern Mariana Islands, in January and March 2023	62
60. Sentinel-3 satellite image of the eruption of Ruby seamount, Commonwealth of the Northern Mariana Islands, on September 14, 2023	64
61. Map of Ruby seamount and proximity to Alaska Volcano Observatory monitoring stations on Saipan, Commonwealth of the Northern Mariana Islands	64
62. Helicorder plot of seismic data showing volcanic tremor from Ruby seamount recorded at Saipan station FLX on September 14, 2023	66
63. Helicorder plot of seismic data showing strong seismicity from Ruby seamount recorded at Saipan station FLX on September 15, 2023	66

Tables

1. Definitions of the Aviation Color Codes used by United States volcano observatories	3
2. Definitions of the Volcano Alert Levels used by United States volcano observatories	3
3. Summary of activity at Alaska and Northern Mariana Islands volcanoes in 2023	4
4. Aviation Color Code and Volcano Alert Level changes during 2023 at volcanoes in Alaska and the Commonwealth of the Northern Mariana Islands in this report.....	5
5. Summary of ash resuspension events from the Katmai region observed in 2023	18

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 meter (m ²)	10.76	square foot (ft ²)
square kilometer (km ²)	0.3861	square mile (mi ²)
Volume		
liter (L)	0.2642	gallon (gal)
cubic meter (m ³)	35.31	cubic foot (ft ³)
cubic kilometer (km ³)	0.2399	cubic mile (mi ³)
Velocity		
meter per second (km/s)	3,281	foot per second (ft/s)
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:

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32.$$

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 (BSL).

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 WGS84, and elevations of volcanoes are referenced to the North American Vertical Datum of 1988 (NAVD88), unless otherwise noted.

Abbreviations

AKDT	Alaska daylight time; UTC–8 hours
AKST	Alaska standard time; UTC–9 hours
ALOS-2	Advanced Land Observing Satellite-2
ASL	above sea level
AVO	Alaska Volcano Observatory
BSL	below sea level
ChST	Chamorro standard time; UTC +10 hours
CNMI	Commonwealth of the Northern Marianas Islands
CO ₂	carbon dioxide
DOAS	Differential Optical Absorption Spectroscopy
DLP	deep long-period
ESA	European Space Agency
GOES	Geostationary Operational Environmental Satellite
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
H ₂ O	water (including water vapor and ice)
InSAR	Interferometric Synthetic Aperture Radar
IR	infrared
LOS	line-of-sight
LP	long-period
MultiGAS	multi-component gas analyzer system
M/ML	magnitude/local magnitude
NEIC	National Earthquake Information Center
NMI	Northern Marianas Islands
NWS	National Weather Service
#	number
PDC	pyroclastic density current
PIREP	pilot weather report
RMS	root mean square
SO ₂	sulfur dioxide
SIGMET	Significant Meteorological Information notice
TROPOMI	the TROPOspheric Monitoring Instrument
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
UTC	coordinated universal time; same as Greenwich mean time
VAN/VONA	Volcanic Activity Notice/Volcano Observatory Notice for Aviation
VIIRS	Visible Infrared Imaging Suite
VT	volcano-tectonic
WGS84	World Geodetic System 1984 datum

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Abstract

In 2023, the Alaska Volcano Observatory responded to eruptions, volcanic unrest or suspected unrest, increased seismicity, and other significant activity at 16 volcanoes from 15 volcanic centers in Alaska and in the Northern Mariana Islands. Eruptive activity in Alaska consisted of repeated small, ash-producing, phreatomagmatic explosions from Mount Young on Semisopochnoi Island; a small phreatic explosion at Kanaga Volcano; the continued eruption of a thick lava flow within the summit crater at Great Sitkin Volcano; a months-long eruption of Shishaldin Volcano; and the tail end of an eruption at Pavlof Volcano. Continuing deformation and increased seismicity were tracked at Mount Edgecumbe, Aniakchak Crater, and Tanaga Volcano and Takawangha volcano on Tanaga Island. Anomalous seismicity was also detected at Bogoslof volcano and Trident Volcano. Other activity documented in 2023 includes ash resuspension events at Mount Katmai, an ice avalanche and accompanying seismic signals at Iliamna Volcano, and a period of unrest at Mount Cleveland, though no eruptive activity took place. In the Commonwealth of the Northern Marianas Islands, hydroacoustic detections and submarine plumes observed in satellite data at Ahiy and Ruby seamounts indicated underwater eruptive activity.

Introduction

The Alaska Volcano Observatory (AVO) is a joint program of the U.S. Geological Survey (USGS); the University of Alaska Fairbanks, Geophysical Institute (UAF-GI); and the Alaska Division of Geological & Geophysical Surveys (DGGS). AVO was formed in 1988, and uses Federal, State, and university resources to (1) monitor and study Alaska's hazardous volcanoes (fig. 1) 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, including the aviation sector. AVO also monitors the volcanoes in the Commonwealth of the Northern Mariana Islands (CNMI) (fig. 1).

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; the compilation of visual observations taken from observatory personnel, residents and mariners, as well as pilot weather report accounts (PIREPs and reports of meteorological phenomena encountered by aircraft in flight). AVO also monitors volcano ground deformation using real-time data from

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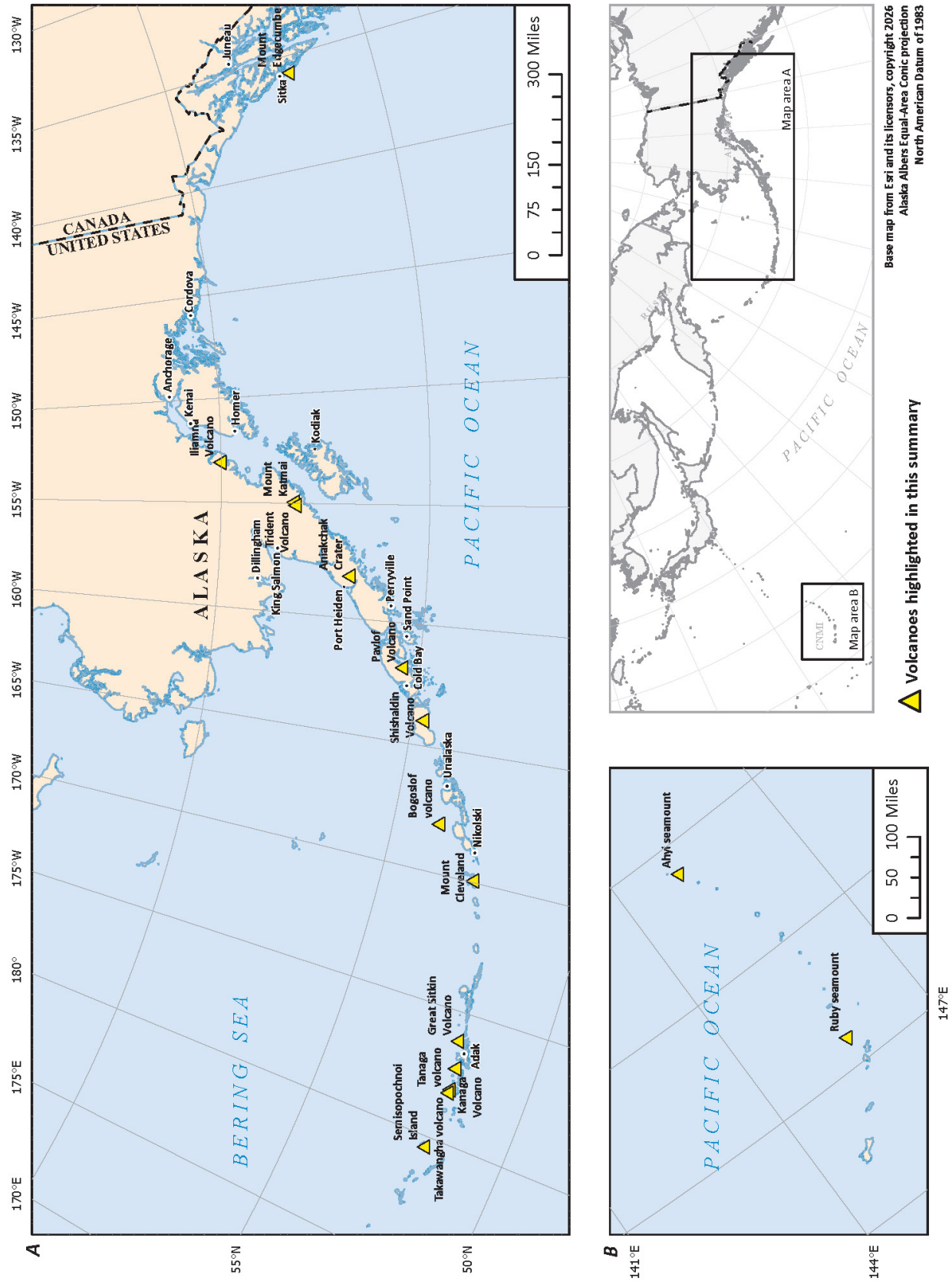


Figure 1. Map of volcanoes in Alaska and the Commonwealth of the Northern Mariana Islands highlighted in this summary. A) Map of Alaska volcanoes; B) Commonwealth of the Northern Mariana Islands volcanoes.

permanent Global Navigation Satellite System (GNSS) stations and Interferometric Synthetic Aperture Radar (InSAR) imagery (for example, Lee and others, 2010).

Observations from these different sources inherently relate data to 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 are based on analysis of satellite imagery, and the altitudes given herein can be imprecise. Earthquake depths are modeled in relation to WGS 1984, and the accuracy of the given depth

directly relates to how many stations were used to record the event (that is, accuracy of depth decreases with fewer recording stations). The summit elevations of the volcanoes are derived from the 2019 InSAR data (U.S. Geological Survey, 2019). These elevations may differ from past AVO annual summaries taken directly from the AVO database (<https://avo.alaska.edu/>).

With this information, AVO assigns each monitored volcano an Aviation Color Code (table 1) and Volcano Alert Level (table 2) to indicate its current activity status (Gardner and Guffanti, 2006). No assignment is given to

Table 1. 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 2. 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.

volcanoes that lack local seismic monitoring and appear to be at background level. However, these seismically unmonitored volcanoes are assigned an Aviation Color Code and Volcano Alert Level if regional seismic networks, satellite data, or other monitoring streams indicate ongoing activity or elevated unrest. 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 together, there could be situations where they are changed independently. For instance, a volcano might produce lava flows that are dangerous on the ground, which would require a Volcano Alert Level of **WARNING**, but the hazard to aviation would be minimal, meriting an Aviation Color Code of **ORANGE**. Where possible, Volcano Alert Level announcements contain additional explanations of volcanic activity and expected hazards. Tables 1 and 2 define each Aviation Color Code and Volcano Alert Level.

AVO duty scientists are responsible for

compiling all monitoring data to provide scheduled and event-driven public notices, as appropriate. Some AVO scientists also participate in a weekly remote-sensing rotation, during which time they produce daily reports summarizing satellite and webcam observations at volcanoes with elevated Aviation Color Codes and Volcano Alert Levels. The reports also describe any notable observations at other volcanoes the AVO monitors. All observations are archived in a relational database. Other AVO scientists and scientists from the USGS National Earthquake Information Center monitor volcano seismicity and infrasound using local and regional sensors. This team compiles three separate seismic reports daily, spaced ~8 hours apart. Like the daily remote sensing reports, the seismic reports are catalogued in a relational database. Many AVO scientists fill these two roles simultaneously.

This report summarizes eruptive activity and other notable unrest associated with volcanoes in Alaska and the CNMI during 2023 (tables 3, 4) and briefly describes AVO's response. It contains information about all identified volcanic unrest,

Table 3. Summary of activity at Alaska and the Commonwealth Northern Mariana Islands volcanoes in 2023, including confirmed eruptions, possible eruptions, increases in seismicity, observations of fumarolic activity, and other notable events.

[Volcanoes presented in geographic order from east to west in Alaska, and north to south in the Commonwealth of Northern Mariana Islands. Volcano locations shown in Figure 1.]

Volcano	Type of activity
Mount Edgecumbe	Ground deformation; elevated seismicity
Iliamna Volcano	Rock-ice avalanche and accompanying seismicity
Mount Katmai (Novarupta)	Resuspension of 1912 ash
Trident Volcano	Elevated seismicity
Aniakchak Crater	Ground deformation; elevated seismicity
Pavlof Volcano	End of explosive eruption
Shishaldin Volcano	Explosive eruption including ash emissions; pyroclastic density currents; lava fountaining within summit crater
Bogoslof Island	Elevated seismicity
Mount Cleveland	Elevated surface temperatures; gas emissions; elevated seismicity
Great Sitkin Volcano	Eruption of lava flow
Kanaga Volcano	Phreatic explosion; elevated seismicity
Takawangha and Tanaga volcanoes	Ground deformation; elevated seismicity
Semisopochnoi Island (Mount Young)	Weak explosive activity; ash and gas emissions
Ahyi Seamount	Hydroacoustic detections, indicating underwater explosions; plume of discolored water observed
Ruby Seamount	Hydroacoustic detections, indicating underwater explosions; plume of discolored water observed

Table 4. Aviation Color Code and Volcano Alert Level changes during 2023 at volcanoes in Alaska and the Commonwealth of the Northern Mariana Islands in this report.

[Volcanoes presented in geographic order from east to west in Alaska, and north to south in the Commonwealth of Northern Mariana Islands. See tables 1 and 2 for definitions of Aviation Color Codes and Volcano Alert Levels. Dates shown as MM/DD/YYYY. Times shown as HH:MM in coordinated universal time (UTC) and local time (AKDT/AKST, HAST/HADT, or ChST depending on the volcano location).]

Aviation Color Code/Volcano Alert Level	Date and time of change	
	UTC	local
Mount Edgecumbe		
UNASSIGNED	No change entire year	
Iliamna Volcano		
GREEN/NORMAL	Beginning of year	
YELLOW/ADVISORY	06/06/2023 (00:54)	06/05/2023 (16:54)
GREEN/NORMAL	06/06/2023 (03:43)	06/05/2023 (19:43)
Mount Katmai (Novarupta)		
GREEN/NORMAL	No change entire year	
Trident Volcano		
GREEN/NORMAL	Beginning of year	
YELLOW/ADVISORY	02/22/2023 (18:48)	02/22/2023 (09:48)
Aniakchak Crater		
GREEN/NORMAL	Beginning of year	
YELLOW/ADVISORY	02/23/2023 (01:44)	02/22/2023 (16:44)
GREEN/NORMAL	08/17/2023 (17:00)	08/17/2023 (09:00)
UNASSIGNED	10/30/2023 (22:14)	10/30/2023 (13:14)
Pavlof Volcano		
YELLOW/ADVISORY	Beginning of year	
GREEN/NORMAL	01/19/2023 (20:51)	01/19/2023 (11:51)
Shishaldin Volcano		
GREEN/NORMAL	Beginning of year	
YELLOW/ADVISORY	07/11/2023 (22:39)	07/11/2023 (14:39)
ORANGE/WATCH	07/12/2023 (20:13)	07/12/2023 (12:13)
RED/WARNING	07/16/2023 (07:57)	07/15/2023 (23:57)
ORANGE/WATCH	07/16/2023 (15:34)	07/16/2023 (07:34)

RED/WARNING	07/18/2023 (15:56)	07/18/2023 (07:56)
ORANGE/WATCH	07/18/2023 (20:08)	07/18/2023 (12:08)
RED/WARNING	07/23/2023 (07:43)	07/22/2023 (23:43)
ORANGE/WATCH	07/23/2023 (12:18)	07/23/2023 (04:18)
RED/WARNING	08/04/2023 (18:17)	08/04/2023 (10:17)
ORANGE/WATCH	08/05/2023 (03:55)	08/04/2023 (19:55)
RED/WARNING	08/25/2023 (20:04)	08/25/2023 (12:04)
ORANGE/WATCH	08/26/2023 (08:31)	08/26/2023 (00:31)
RED/WARNING	09/05/2023 (17:01)	09/05/2023 (09:01)
ORANGE/WATCH	09/05/2023 (22:14)	09/05/2023 (14:14)
RED/WARNING	09/16/2023 (01:41)	09/15/2023 (17:41)
ORANGE/WATCH	09/16/2023 (08:44)	09/16/2023 (00:44)
RED/WARNING	09/25/2023 (14:02)	09/25/2023 (06:02)
ORANGE/WATCH	09/25/2023 (20:34)	09/25/2023 (12:34)
RED/WARNING	10/03/2023 (14:12)	10/03/2023 (06:12)
ORANGE/WATCH	10/03/2023 (18:36)	10/03/2023 (10:36)
YELLOW/ADVISORY	10/31/2023 (20:51)	10/31/2023 (12:51)
ORANGE/WATCH	11/03/2023 (04:31)	11/02/2023 (20:31)
Bogoslof Island		
UNASSIGNED	Beginning of year	
YELLOW/ADVISORY	10/24/2023 (22:56)	10/24/2023 (14:56)
UNASSIGNED	11/24/2023 (19:13)	11/24/2023 (10:13)
Mount Cleveland		
YELLOW/ADVISORY	Beginning of year	
UNASSIGNED	01/05/2023 (20:09)	01/05/2023 (10:09)
YELLOW/ADVISORY	07/19/2023 (20:18)	07/19/2023 (11:18)
GREEN/NORMAL	08/25/2023 (18:06)	08/25/2023 (09:06)
Great Sitkin Volcano		
ORANGE/WATCH	No change entire year	

Kanaga Volcano		
GREEN/NORMAL	Beginning of year	
YELLOW/ADVISORY	12/19/2023 (21:02)	12/19/2023 (11:02)
Takawangha volcano		
YELLOW/ADVISORY	Beginning of year	
ORANGE/WATCH	03/10/2023 (02:23)	03/09/2023 (16:23)
YELLOW/ADVISORY	03/16/2023 (18:40)	03/16/2023 (09:40)
GREEN/NORMAL	07/19/2023 (00:29)	07/18/2023 (15:29)
Tanaga Volcano		
GREEN/NORMAL	Beginning of year	
YELLOW/ADVISORY	03/08/2023 (07:15)	03/08/2023 (21:15)
ORANGE/WATCH	03/10/2023 (02:20)	03/09/2023 (16:20)
YELLOW/ADVISORY	03/16/2023 (18:40)	03/16/2023 (09:40)
GREEN/NORMAL	07/19/2023 (00:29)	07/18/2023 (15:29)
Semisopochnoi Island (Mount Young)		
ORANGE/WATCH	Beginning of year	
YELLOW/ADVISORY	02/22/2023 (18:47)	02/22/2023 (08:47)
ORANGE/WATCH	03/19/2023 (20:47)	03/19/2023 (11:47)
YELLOW/ADVISORY	05/17/2023 (21:25)	05/17/2023 (12:25)
GREEN/NORMAL	08/03/2023 (23:42)	08/03/2023 (14:42)
Ahiy Seamount		
YELLOW	Beginning of year	
UNASSIGNED	04/25/2023 (21:04)	04/26/2023 (07:04)
YELLOW	05/22/2023 (20:39)	05/23/2023 (06:39)
UNASSIGNED	07/18/2023 (01:02)	07/18/2023 (11:02)
Ruby Seamount		
UNASSIGNED	Beginning of year	
YELLOW	09/19/2023 (03:06)	09/19/2023 (13:06)
UNASSIGNED	10/05/2023 (23:50)	10/06/2023 (09:50)

even if no formal public notification was issued at the time. Observations, images, and information 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. A glossary of scientific terms used in this report can be found in appendix 1.

The volcanoes in this report are presented in geographic order from east to west in Alaska, and then north to south in CNMI. Each entry has a title block containing information about the volcano: identifier number (#) assigned by the Smithsonian Institution Global Volcanism Program (GVP); latitude, longitude, and summit elevation; name of geographic region; and an abbreviated summary of 2023 activity. After the title block is a description of the volcano and a summary of its past activity. Then, a detailed account of its activity during the year, often with accompanying tables, images, figures, or all three. This information is derived from formal public AVO information products, internal online electronic logs compiled by AVO staff, and published material.

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 poorly 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 Alaska volcanoes (Cameron and others, 2022). The depth below sea level (BSL) of Ahyi seamount comes from Tepp and others (2019). The depth of Ruby seamount comes from Merle and others (2003). Measurements are presented in the International System of Units, except for altitudes, which are reported in feet above sea level (ASL), in line with federal aviation standards, followed by meters (m) in parentheses. Date references are given in local time, followed by UTC time, unless specified otherwise. General date references (without times) are dates in local time, followed by the UTC

date when it differs from the local date—where the UTC and local dates match, only one date is shown. Most volcanoes in Alaska are in the Alaska standard time (AKST) or Alaska daylight time (AKDT) zones. Volcanoes west of Umnak Island (see the community of Nikolski, Alaska, on fig. 1) are in the Hawaii-Aleutian standard time (HAST) or Hawaii-Aleutian daylight time (HADT) zones. Ahyi and Ruby seamounts fall within the Chamorro standard time (ChST) zone. During 2023, daylight saving time ran from March 12 to November 5 (daylight saving time is not observed in the CNMI).

What is an “Eruption”?

The specific use of the term “eruption” varies from scientist to scientist and has no universally agreed-upon definition. Herein, eruptions are defined as “* * * events that involve the explosive ejection of fragmental material, the effusion of liquid lava, or both” (Siebert and others, 2010, p. 17). 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.

What is a “Recently 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 inferred to reflect the presence of magma at shallow levels beneath the volcano. AVO considers the recent (post-contact) period in Alaska to be since 1741, when written records of volcanic activity began. Based on a rigorous reanalysis of all volcanic activity accounts in Alaska (from many sources), Cameron and others (2023) concluded that 54 Alaska volcanoes fit these criteria. We concur with this number in this report, but with a slight reclassification—we consider Novarupta to be a subfeature of Mount Katmai but also count Tanaga Volcano and Takawangha volcano as separate volcanoes. As geologic understanding

of Alaska volcanoes improves through additional fieldwork and modern radiometric dating techniques, we expect the list of active volcanoes to evolve.

Volcanic Activity in Alaska

Mount Edgecumbe

GVP# 315040
57.051°, -135.761°
1,010 m

Kruzof Island, Southeast Alaska

GROUND DEFORMATION AND ELEVATED SEISMICITY



Mount Edgecumbe is a 1,010-m-high stratovolcano on Kruzof Island located 25 kilometers (km) west of Sitka, Alaska, and 928 km southeast of Anchorage, Alaska (fig. 1). It is part of a broader volcanic field of lava domes and craters on southern Kruzof Island and the surrounding offshore area that has been active over the past 600,000 years. The Queen Charlotte-Fairweather Fault Zone, a major transform fault system, lies about 15 km west of Mount Edgecumbe. Mount Edgecumbe comprises a 35 km³ basal shield of basalt, basaltic andesite, and andesite lava flows, and a 3.5 km³ composite cone consisting mostly of andesite (Wood and Kienle, 1990). The adjacent edifice of Crater Ridge comprises an additional 3.5 km³ of low-silica rhyolite domes (Wood and Kienle, 1990).

A period of increased eruptive activity 14,600 to 13,100 years ago has been attributed to ice loss following the last glacial maximum (Praetorius and others, 2016), driven by decompression melting (e.g., Jull and McKenzie, 1996). This activity produced a widespread regional tephra (ash) layer about 1 m thick near Sitka and over 30 m thick on parts of Kruzof Island (Riehle, 1996). Smaller eruptions occurred between 5,800 and 4,200 years ago (Riehle and others, 1992). There are no written observations of eruptions from the volcanic field, although Tlingit oral history describes small eruptions that may have occurred about 800 years ago (Kitka, 1988). Notably, Larsen and others (2005) report rapid uplift of the region since the late 1700s, which they attribute to viscoelastic relaxation of

the mantle due to the melting of the Little Ice Age glaciers. Elliott and Freymueller (2010) and Hu and Freymueller (2019) similarly link ongoing regional uplift and its varying rates to elastic and viscoelastic responses to ongoing glacial melt.

The primary hazards of past eruptions, and thus likely hazards in future eruptions, have been volcanic ash emissions producing local and regional ashfall and drifting ash clouds. Volcanic lahars, pyroclastic flows, and lava flows have also occurred on the flanks of Mount Edgecumbe. Mount Edgecumbe and the subaerial portion of the surrounding volcanic field lie within the Tongass National Forest.

In 2022, an earthquake swarm was detected at Mount Edgecumbe using the regional seismic network. Interferometric analysis of satellite radar observations acquired by the European Space Agency (ESA)'s Sentinel-1 satellite since its launch in 2014 showed ground inflation (fig. 2), centered about 3 km east of Mount Edgecumbe, that started in August 2018 and evolved at a steady rate. About 25 centimeters (cm) of deformation occurred in the satellite line-of-sight (LOS) between then and the end of November 2021, corresponding to a deformation rate as much as 7 centimeters per year. Grapenthin and others (2022) modeled this deformation as owing to magma migrating from a reservoir about 20-km deep through a narrow conduit into a 10-km deep tabular body dipping about 22 degrees east. In response to this activity, AVO installed one temporary geophysical monitoring station at Mount Edgecumbe in 2022 to supplement the regional network.

During 2023, inflation at Mount Edgecumbe continued, with some deformation rate reduction in the second half of the year (fig. 2). InSAR observations suggest this might be due to a halt of the magma migration upwards into the shallow reservoir. The first half of 2023 saw another seismic swarm on May 30–31 that was similar to the swarm in 2022 (Grapenthin and others, 2022). The earthquakes occurred mostly north and northeast of Mount Edgecumbe and ranged in magnitude (M) up to M2 (fig. 3).

In August 2023, AVO engineers installed a seismic and geodetic monitoring network at Mount Edgecumbe, consisting of three

additional seismometers and four continuous GNSS stations, all co-located (figs. 3 and 4). The network enhancement detected and located additional earthquakes, with smaller magnitudes, than the previous regional network was capable of, including 132 earthquakes in 2023 located along a northwest-to-southeast trend across Crater Ridge, slightly northeast of Mount Edgecumbe (fig. 3). The events cluster at depths between about 9–5 km (fig. 5), in line with the previous interpretation that earthquakes may predominantly relieve stress built up due to recharge and pressurization of a magma chamber at about 9 km depth (Grapenthin and others, 2022).

In May 2023, AVO personnel visited Sitka for community outreach work, which included community presentations, radio interviews, a guided geologic walk, and a movie showing. In August, AVO performed geological work and gas sampling. One Information Statement was released on February 23, 2023, providing an update on observations and the state of the volcano. The color code remained at **UNASSIGNED** during the whole of 2023. While the additional stations installed in August gave Mount Edgecumbe a complete monitoring network, time was required to develop knowledge of Mount Edgecumbe's typical background state before the volcano could be moved to **GREEN/NORMAL** (which occurred in January 2024).

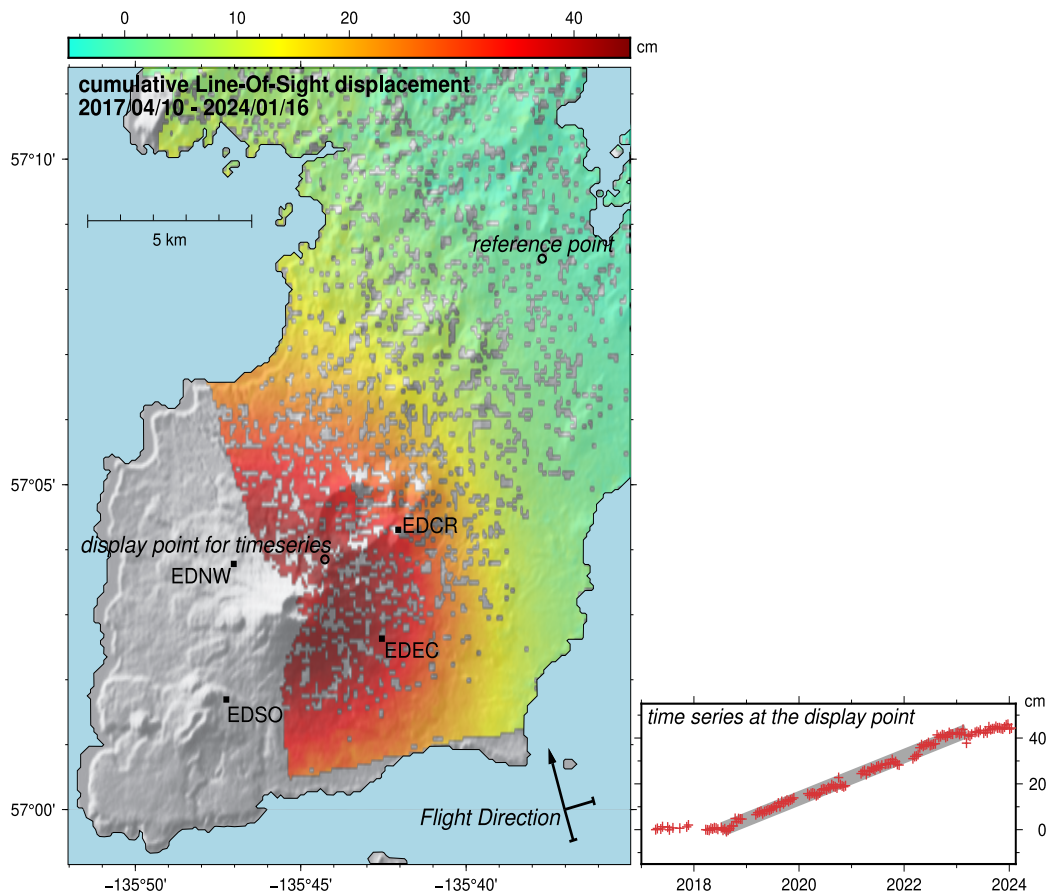


Figure 2. Cumulative line-of-sight displacement map from InSAR data at Mount Edgecumbe, Alaska, from April 2017 to January 2024. Cumulative Line-of-Sight (LOS) displacement map from 04/10/2017 to 01/16/2024 based on Sentinel-1 interferograms on path 79, frame 186. Geophysical stations are labeled. Arrow shows flight direction of the satellite and look direction perpendicular to it. Reference point is labeled, and time series shown in inset is for the labeled point in the summit region. Inset time series shows cumulative LOS deformation timeseries in centimeters, and the gray background line shows trend until mid-2023, indicating the drop-off in deformation rate in the second half of the year.

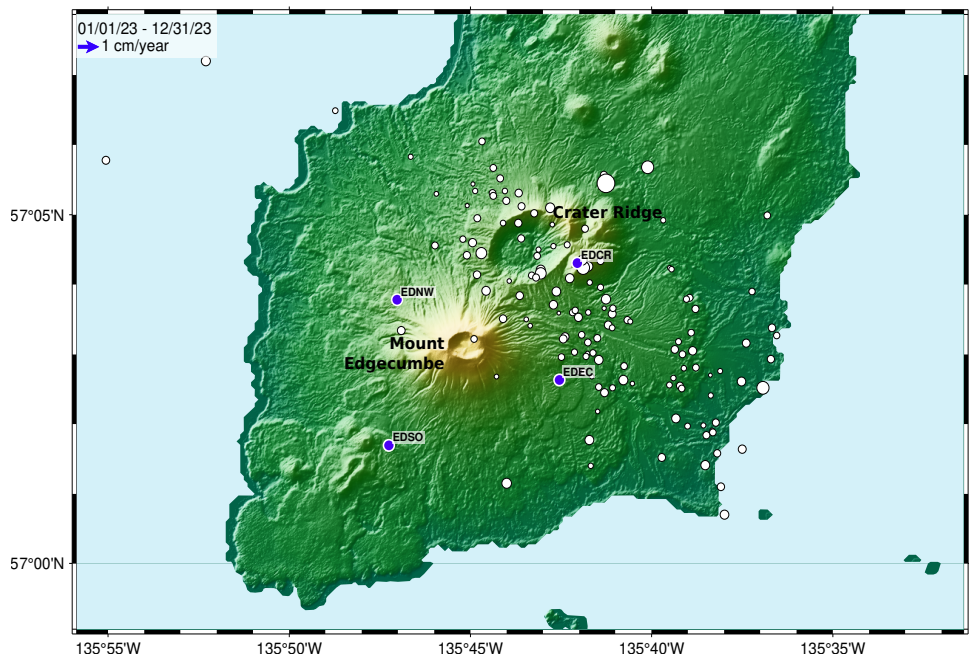


Figure 3. Overview map of Mount Edgecumbe, Alaska, showing geophysical monitoring sites installed in August 2023 and earthquakes located in 2023. Earthquake locations shown as white dots and sized according to earthquake magnitude.

Figure 4. Photographs of the new geophysical monitoring network installed at Mount Edgecumbe, Alaska, in August 2023 comprising co-located broadband seismographs and continuous GNSS. Site locations are shown in Figures 2 and 3. AVO image database IDs clockwise from top left: 194903, 194915, 194913, 194898.

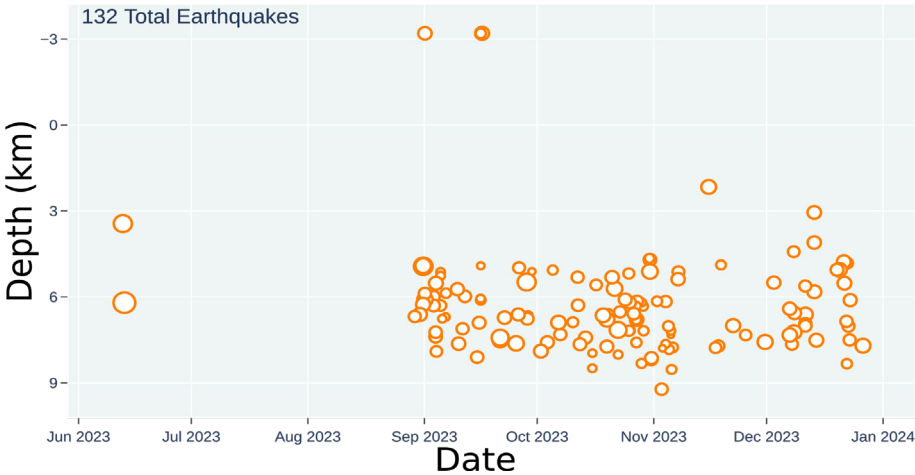


Figure 5. Depth-time plot of earthquakes located at Mount Edgecumbe, Alaska, in 2023. No earthquakes located prior to June 2023. Large increase in earthquakes starting in late August 2023 is improved detection due to the installation of the 4-station seismic network, which allows location of smaller events. Additional earthquakes were previously noted on the existing single station but were not locatable. Larger dots represent larger earthquake magnitudes.

Iliamna Volcano

GVP# 313020
60.032°, -153.092°
3,046 m
Cook Inlet



ROCK-ICE AVALANCHE AND ACCOMPANYING SEISMICITY

Iliamna Volcano is a glacier-carved stratovolcano on the southwest coast of Cook Inlet, ~215 km southwest of Anchorage (fig. 1). Although Iliamna Volcano has no eruptions within written history, past geologic studies document evidence of late Holocene explosive activity and repeated, extensive mass wasting of its steep, hydrothermally altered edifice (Waythomas and Miller, 1999). Fumaroles at an elevation of ~2,740 m on the east flank of the volcano almost continuously produce plumes of steam condensate and volcanic gas (Werner and others, 2011). In the past three decades, researchers have documented two magmatic intrusions beneath Iliamna Volcano (Roman and Power, 2011; Prejean and others, 2012).

A large rock-ice avalanche occurred on Red Glacier on Iliamna Volcano on June 6, 2023. This event closely resembled previous landslides on Red Glacier in 2016 and 2019, and the event was recorded clearly by AVO seismic and infrasound stations in the region. AVO detected precursory seismicity prior to the main rupture and moved to Volcano Alert Level **ADVISORY** and Aviation Color Code **YELLOW** during this build-up. Below we discuss the June 2023 Red Glacier avalanche and AVO's response.

An unusually high number of large rock-ice avalanches occur on Iliamna Volcano. The most prominent of these occur on Red Glacier on the eastern flank of Iliamna Volcano, with a recurrence interval of approximately 1–3 years since 1994. The main avalanche rupture is typically preceded by hours of precursory seismicity (e.g., Caplan-Auerbach and Huggel, 2007). Volcanic heating near the summit of Iliamna Volcano likely contributes to the high avalanche recurrence interval, and they typically occur in late spring/early summer. The run-out length of these events is generally 7–10 km, and slide volumes are typically $3\text{--}20 \times 10^6 \text{ m}^3$ (Waythomas and others, 2000). The past two Red

Glacier avalanches occurred on May 22, 2016, and June 21, 2019. Toney and others (2021) detailed seismoacoustic signals from these events, compared them to satellite-derived parameters, and modeled the seismic signals to estimate realistic acceleration, velocity, and directionality.

The AVO seismic analyst on duty noted precursory avalanche seismicity on June 5th, 2023, at ~14:45 AKDT (23:45 UTC), although elevated seismicity had been occurring for approximately 3 hours at that time (fig. 6). The precursory seismicity consisted of small repeating earthquakes. The amplitude of these earthquakes generally increased over time and the inter-event times decreased. However, unlike previous events, seismicity never transitioned from discrete earthquakes to continuous seismicity. AVO began internal discussions and additional analysis after the initial 14:45 AKDT (23:45 UTC) report. AVO scientists believed these earthquakes were precursors to a Red Glacier avalanche based on their similarity to past events and the time of year, but a volcanic source could not be entirely ruled out due to the longer duration of precursory earthquakes compared to previous avalanches and a couple pauses in seismicity (fig. 6). AVO noted this interpretation when it moved Iliamna Volcano to **ADVISORY/YELLOW** at 15:53 AKDT (00:53 June 6 UTC).

At 16:14 AKDT (01:14 June 6 UTC), seismic signals extremely similar to those from previous avalanches were recorded (fig. 7). Based on this similarity, AVO quickly determined that this represented the avalanche rupture time. Webcam and visual views of the volcano were blocked by clouds during the build-up and rupture. The avalanche seismicity consisted of an energetic pulse of broadband seismic energy with a tapered onset and end (fig. 7). Seismic force modeling also indicated that Red Glacier was the source and that the avalanche size and run-out were similar to the 2016 and 2019 events. Weak infrasound signals were recorded on regional stations. These infrasound signals were not as clear as in 2016 and 2019, likely related to less favorable propagation and higher local noise levels. With the avalanche concluded, AVO issued a Volcanic Activity Notification/Volcanic Observatory Notice for Aviation (VAN/VONA) lowering the color code to **GREEN/NORMAL** at

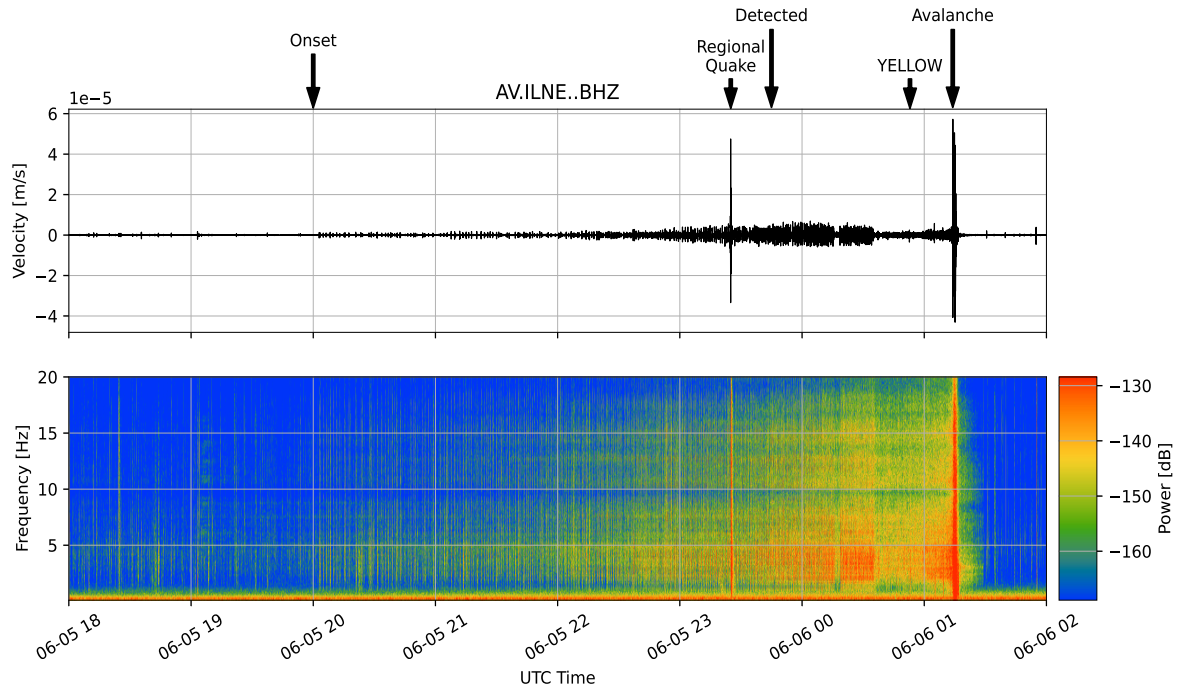


Figure 6. Seismic waveforms and spectrogram of the June 6, 2023, Red Glacier avalanche recorded at Iliamna Volcano, Alaska. The pre-avalanche seismicity consists of repeating, discrete events followed by a broadband pulse produced by the avalanche.

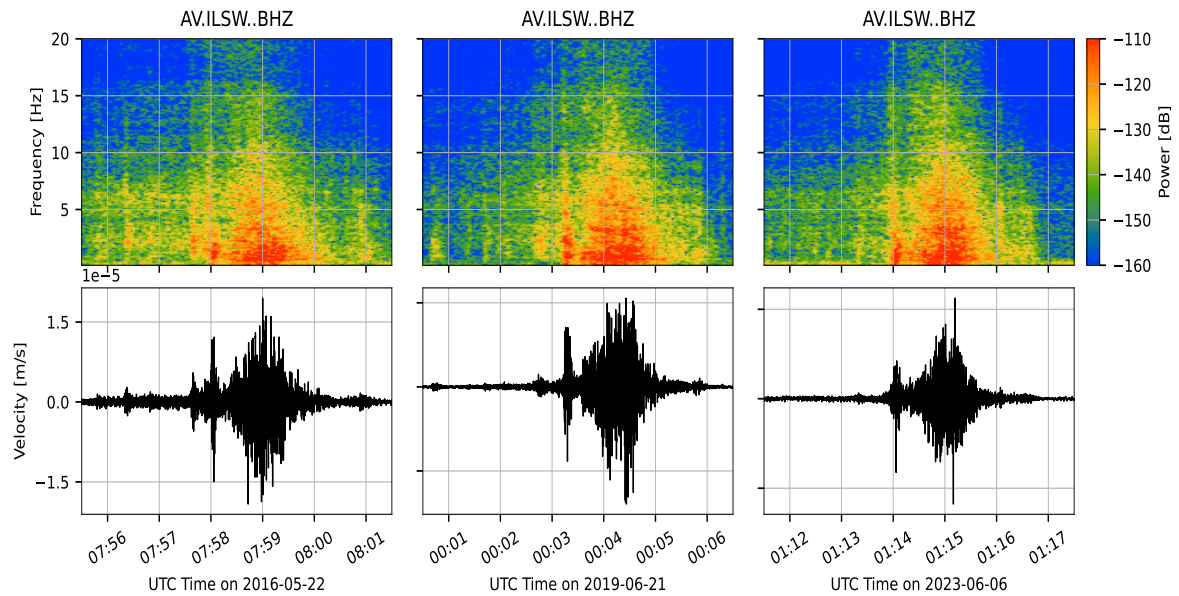


Figure 7. Comparison of seismic signals from the 2016, 2019, and 2023 Red Glacier avalanches at Iliamna Volcano, Alaska. Seismic signals from the 2016 (left), 2019 (middle), and 2023 (right) Red Glacier avalanches. The top panels are spectrograms and the bottom are 100 s high-passed waveforms from station ISLW. The events show a remarkable similarity and consist of multiple transient events followed by an energetic, tapered burst of seismicity for 2 minutes. The events also produce notable long-period (LP) seismic energy. Figure is modified from Figure 4 in Toney and others (2021).

18:43 AKDT (03:43 June 6 UTC).

Continued cloudiness over the next 10–14 days limited observations of the avalanche. The first partially clear satellite views on June 14 (10 days later) confirmed the source to be

Red Glacier. Better viewing conditions in a WorldView-3 image on July 22 (fig. 8) showed an approximately 8 km runout, similar to previous events. Geophysical field crews in the area in late July documented the avalanche slip area and runout (fig. 9).

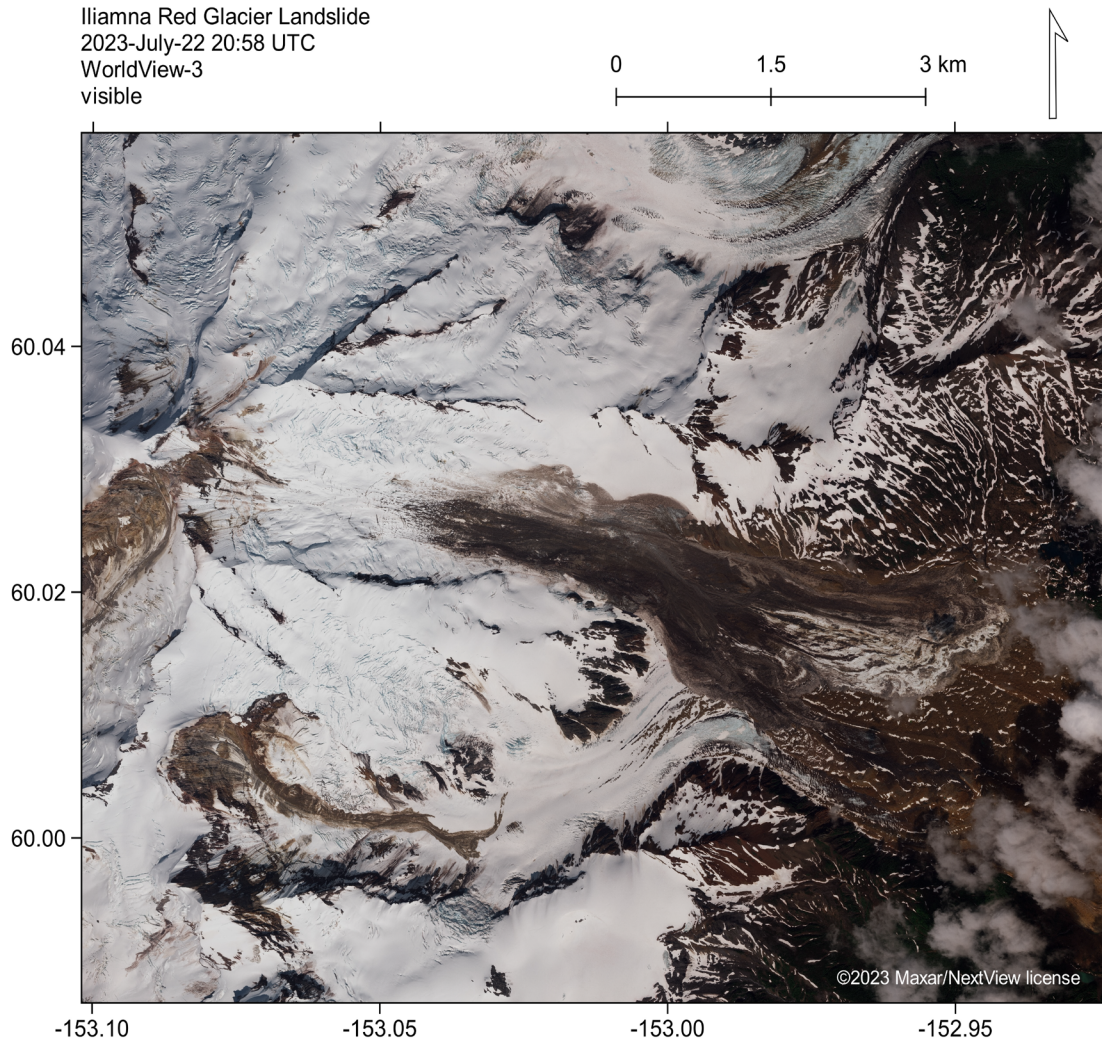


Figure 8. WorldView-3 satellite imagery of the Red Glacier avalanche deposits at Iliamna Volcano, Alaska, on July 22, 2023. Image copyright 2023 Maxar, USG Plus.

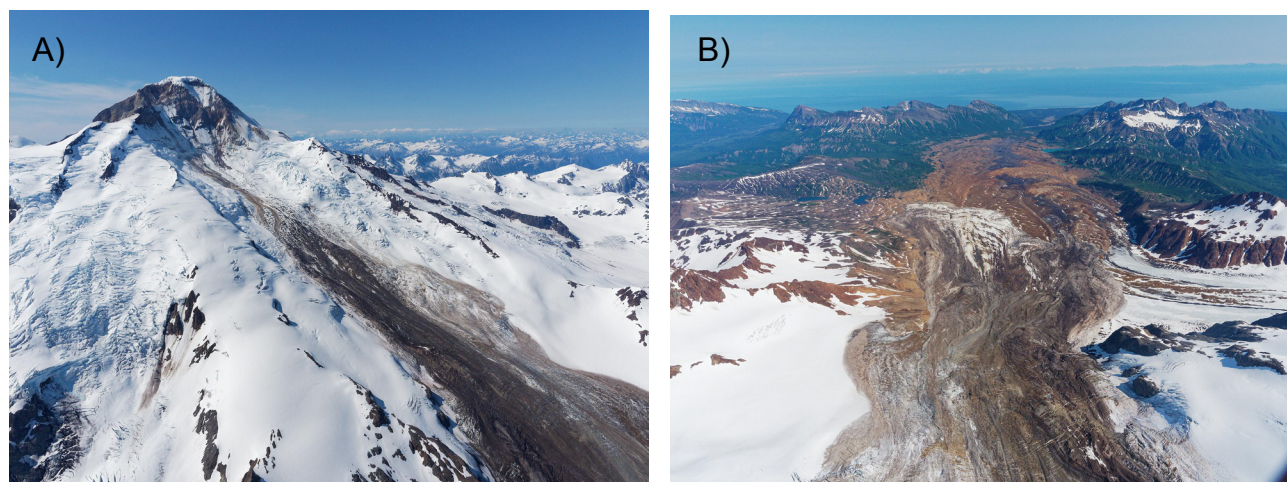


Figure 9. Photographs of the 2023 Red Glacier avalanche rupture area and runout at Iliamna Volcano, Alaska. A) Avalanche rupture area; B) Avalanche runout. Photos by Malcolm Herstand, AVO/USGS.

Mount Katmai (Novarupta)

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



RESUSPENSION OF 1912 ASH

Volcanic ash is hazardous not only during an eruption but also long afterward. Strong winds can lift previously deposited loose ash, creating dust clouds that pose ongoing risks. Mount Katmai, located on the Alaska Peninsula about 160 km northwest of Kodiak and 430 km southwest of Anchorage (fig. 1), erupted in 1912 in what was the largest volcanic event of the 20th century (Hildreth and Fierstein, 2000; 2012). The eruption, centered at the Novarupta vent, produced approximately 17 cubic km of ash and 11 cubic km of pyroclastic material, filling nearby valleys and forming the Valley of Ten Thousand Smokes (Fierstein and Hildreth, 1992). Ash deposits in this valley reach up to 200 m thick, and the area remains largely barren of vegetation.

Resuspension of fine-grained ash from the Katmai region has been documented repeatedly over the past several decades and likely occurs whenever conditions are favorable (Hadley and others, 2004; Wallace and Schwaiger, 2019). When the ground is snow-free and dry, strong winds can loft loose ash into the atmosphere, generating dust clouds. These clouds are typically

attributed broadly to the Katmai area rather than a specific vent and are observed via satellite imagery (fig. 10), web cameras (fig. 11), and reports from downwind communities (figs. 12 and 13) and pilots. Dust clouds generally occur between 4,000 and 11,000 ft (1–3.4 km) ASL, can travel up to 250 km, and often drift southeast over Shelikof Strait, Kodiak Island, and the Gulf of Alaska (Wallace and Schwaiger, 2019).

Composed primarily of volcanic glass shards identical to eruption-produced ash, these clouds pose hazards to aviation (Hadley and others, 2004) and human health. Trace ashfall—typically less than 1 mm (1/32 in)—has reached Kodiak Island communities, including during events in 2023 (fig. 12).

Resuspended volcanic ash clouds from the Katmai region were detected 12 times in 2023, including prolonged periods of several days. The National Weather Service (NWS) Weather Forecast Office forecasted most resuspension events in 2023, and if they occurred, AVO issued Information Statements corroborating formal hazard notifications issued by the NWS. Because resuspended ash clouds are not the result of eruptive activity, the events observed in 2023 did not warrant a change in the Aviation Color Code and Volcano Alert Level, which remained **GREEN** and **NORMAL** throughout the year. A summary of 2023 ash resuspension events and select images documenting their occurrence are presented in table 5 and figures 10–13.

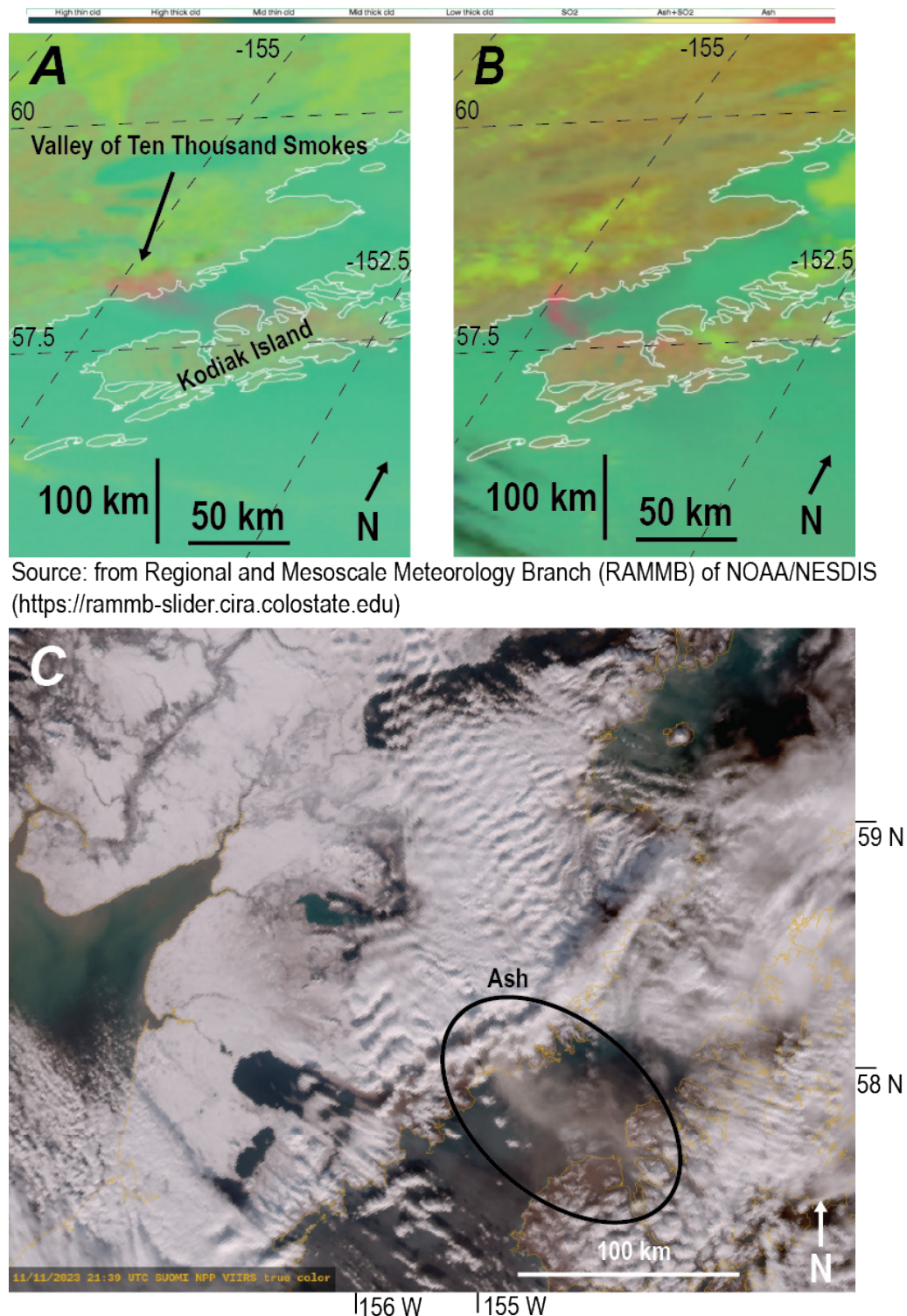


Figure 10. Satellite imagery of resuspended volcanic ash clouds originating from the Katmai region, Alaska, in 2023. Examples of typical resuspended volcanic ash clouds originating from the Katmai region (including the Valley of Ten Thousand Smokes) and observed in satellite imagery (looking north) as they drift southeast towards Kodiak Island in 2023. A) Geostationary Operational Environmental Satellite (GOES)/Visible Infrared Imaging Suite (VIIRS) multispectral imagery from April 23, 2023, showing a resuspended ash cloud that reached an altitude of 6,000 ft (1.8 km) ASL; B) GOES-17 oblique, processed satellite images from September 27, 2023, showing a resuspended ash cloud that reached an altitude of 6,000 ft (1.8 km) above sea level; C) Oblique true-color satellite image from November 11, 2023, showing a resuspended ash cloud that reached an altitude of 6,000 ft (1.8 km) ASL; image acquired by a Visible Infrared Imaging Radiometer Suite instrument on the Suomi-NPP (Suomi National Polar-orbiting Partnership) satellite.

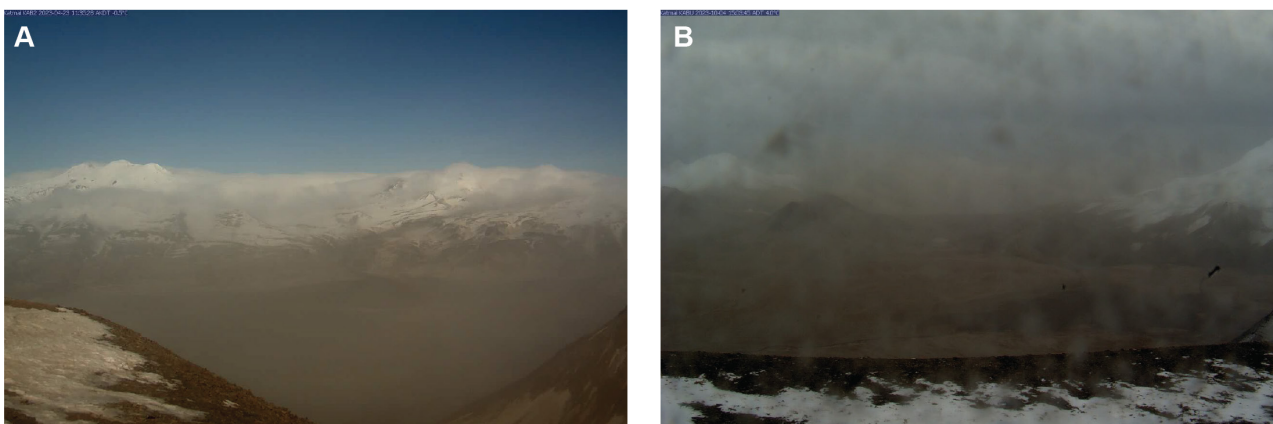


Figure 11. Web camera images of resuspended volcanic ash clouds in the Katmai region, Alaska, in 2023. Examples of 2023 resuspended volcanic ash clouds in the Katmai region as seen by ground-based web cameras. A) Image taken from a web camera (KAB2) in the upper Katmai River, looking northwest over the upper Katmai River valley towards Mount Mageik and Trident Volcano, shows an example of resuspended ash from the northwest to the southeast (typical) on April 23, 2023. AVO Image ID 194303; B) Image taken from a web camera (KABU) in the Valley of Ten Thousand Smokes, looking east-northeast, shows an example of resuspended ash from the south toward the west (atypical) on October 4, 2023.

Figure 12. Examples of trace amounts of ash fallout from resuspended ash clouds from the Katmai region in 2023. A) Photo of trace ashfall on a vehicle bumper in the city of Kodiak, AK on April 25, 2023; B) Photo of small amounts of ashfall on car windshield in the city of Kodiak September 28, 2023. Photos by Stephen Bodnar, Kodiak, AK.

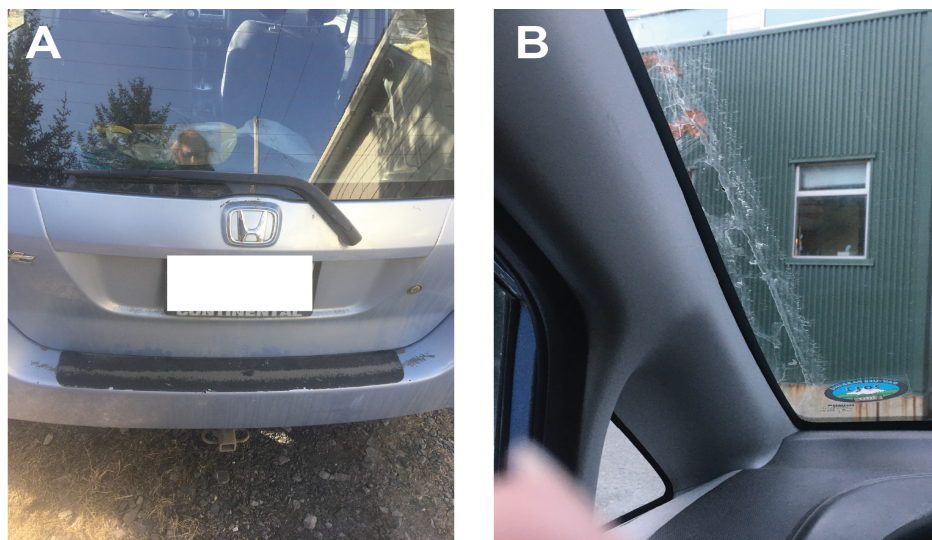


Figure 13. Photograph of hazy skies observed from the city of Kodiak, Alaska, on October 9, 2023. Photo by Stephen Bodnar, Kodiak, AK.



Table 5. Summary of ash resuspension events from the Katmai region observed in 2023. Ash cloud heights are estimated by the NWS Aviation Weather Unit. VAAC: Volcanic Ash Advisory Center. SIGMET: Significant Meteorological Information notice. WFO: Weather Forecast Office.

Date in 2023	Wind direction from	Max cloud height, ft (km)	Response actions			Ashfall reported
			VAAC (aviation)	AVO (volcano)	NWS-WFO (ashfall)	
April 8–9	northwest	8,000 ft (2.4 km)	SIGMET	Information Statement		
April 16–17	northwest	6,000 ft (1.8 km)	SIGMET	Information Statement		
April 23	northwest	6,000 ft (1.8 km)	SIGMET	Information Statement	Special Weather Statement	City of Kodiak
August 4–5	northwest	6,000 ft (1.8 km)	SIGMET	Information Statement		
September 27–28	northwest	6,000 ft (1.8 km)	SIGMET	Information Statement	Special Weather Statement	City of Kodiak
October 2–3	northwest	5,000 ft (1.5 km)	SIGMET	Information Statement	Special Weather Statement	
October 4	east	5,000 ft (1.5 km)	SIGMET	Information Statement		
October 9–10	northwest	3,000 ft (0.9 km)	SIGMET	Information Statement		
October 18	northwest	5,000 ft (1.5 km)	SIGMET	Information Statement		
November 5	northwest	5,000 ft (1.5 km)	SIGMET	Information Statement		
November 11	northwest	5,000 ft (1.5 km)	SIGMET	Information Statement		
December 5	northwest	5,000 ft (1.5 km)	SIGMET	Information Statement		

Trident Volcano

GVP# 312160
58.234°, -155.103°
1,849 m
Alaska Peninsula

ELEVATED SEISMICITY



Trident Volcano is part of the Katmai volcanic cluster within Katmai National Park and Preserve on the Alaska Peninsula. It is located 148 km southeast of King Salmon, Alaska, and 440 km southwest of Anchorage (fig. 1). Trident Volcano consists of a complex of four cones and several lava domes, all andesite and dacite in composition, that stand as high as 1,849 m. An eruption beginning in 1953 produced about 0.5 km³ of fragmental material and intercalated lava flows that constructed a new cone, known informally as Southwest Trident (Coombs and others, 2000; Hildreth and others, 2000). This eruption continued sporadically through 1974 and produced ash (an initial plume rose to ~30,000 ft [~9,100 m]), bombs, and lava at various times. Fumaroles remain active on the summit of Southwest Trident and on the southeast flank of the oldest, central cone.

Seismic unrest that began at Trident Volcano in August 2022 continued throughout 2023. Earthquake rates continued above background levels in late 2022 through early 2023, and on February 22, AVO raised the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY**. Starting in May 2023, AVO began detecting a marked increase in low-frequency earthquakes at both shallow and deep levels in the region between Trident Volcano and Novarupta, and surface uplift was observed in satellite radar data between October 6, 2022, and June 3, 2023. These observations prompted AVO to release an Information Statement on July 25, 2023. Elevated rates of regular and low-frequency earthquakes continued, and the Aviation Color Code and Volcano Alert Level remained at **YELLOW** and **ADVISORY** for the rest of 2023.

Earthquakes in the Katmai volcanic cluster are typically located in three regions: Trident Volcano and Novarupta, Mount Katmai to the northeast, and Mount Martin and Mount Mageik to the southwest (fig. 14). Unrest in 2023 included elevated earthquake rates in both

the Trident Volcano–Novarupta region, as well as beneath Mount Martin and Mount Mageik (fig. 15), but only Trident Volcano showed evidence of magma movement in the form of low-frequency earthquakes. Mount Katmai did not exhibit elevated seismicity. The initial unrest in the region starting in 2022 was centered beneath Trident Volcano, and the ongoing unrest there was deeper and more characteristic of magmatic processes. These observations suggest that the increased seismicity observed at Mount Martin and Mount Mageik is a secondary effect from increased stress or changes in the shallow hydrothermal system caused by magma movement beneath Trident Volcano.

Earthquakes beneath Trident Volcano occurred at both shallow and deep levels (figs. 16 and 17) with an overall rate that averaged 10 to 20 earthquakes per day and occasionally reached rates several times higher. The earthquakes were typically below M1, but dozens of M2–3 earthquakes were recorded. Most of the earthquakes were regular volcano-tectonic (VT) events representing brittle failure in the upper crust between 3–6 km (figs. 16 and 17). These events spanned a broad region between Trident Volcano and Novarupta but predominantly occurred beneath Trident Volcano.

A second cluster of seismicity was concentrated between 30–34 km deep (figs. 16 and 17). These events occurred slightly closer to Novarupta than Trident Volcano and were mostly long-period (LP) earthquakes, which often indicate movement of magma or magmatic fluids at depth. Deep long-period (DLP) earthquake activity increased markedly from mid-May through the end of July, and at times merged into semi-continuous tremor (fig. 18), which is also a signal of deep fluid movement. Additional shallow LP earthquakes were also recorded during this period beneath Trident Volcano at depths of 3–15 km (fig. 17).

Ground uplift at Trident Volcano was also detected with satellite radar data. Data from June 3, 2023, indicates ~6 cm of ground uplift occurred at Trident Volcano since May 27, 2022 (fig. 19). Uplift was concentrated on the volcano's south flank. Snow cover prohibits quality winter observations, which limits our ability to provide precise timing, but uplift likely began sometime in December 2022.

Figure 14. Map of earthquakes near Trident Volcano and the Katmai volcanic cluster, Alaska, from January 2020 through December 2023. Colors separate seismicity associated with Mount Martin and Mount Mageik (orange) with that of Trident Volcano and Novarupta (blue). The same colors are used in Figure 15. Gray circles mark earthquakes near Mount Katmai. A – A' and B – B' lines mark cross-sections shown in Figure 16 and Figure 17, respectively.

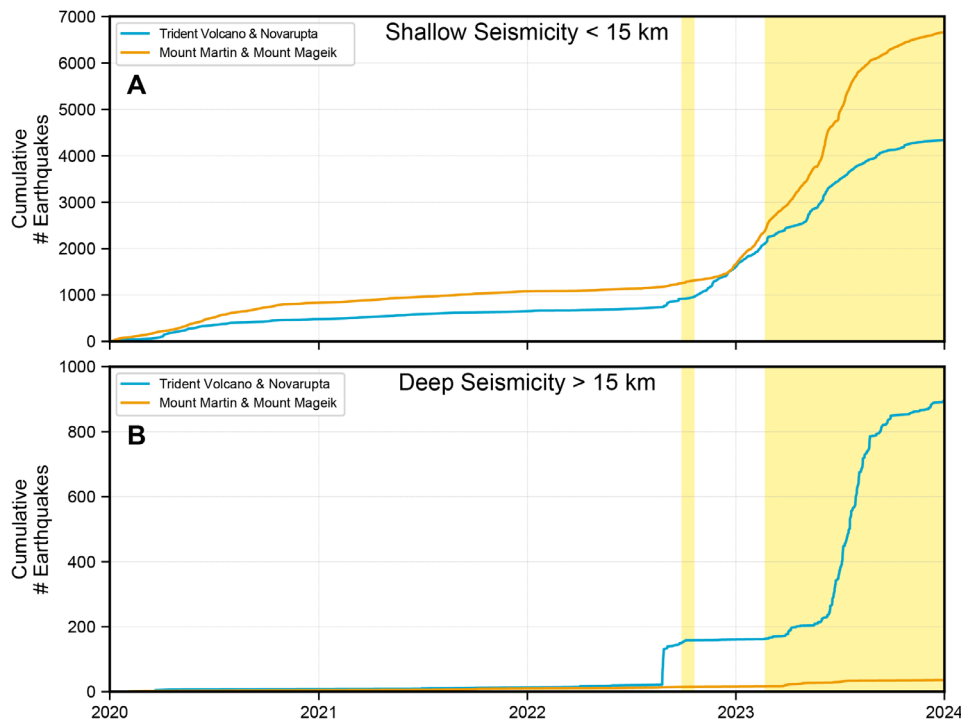
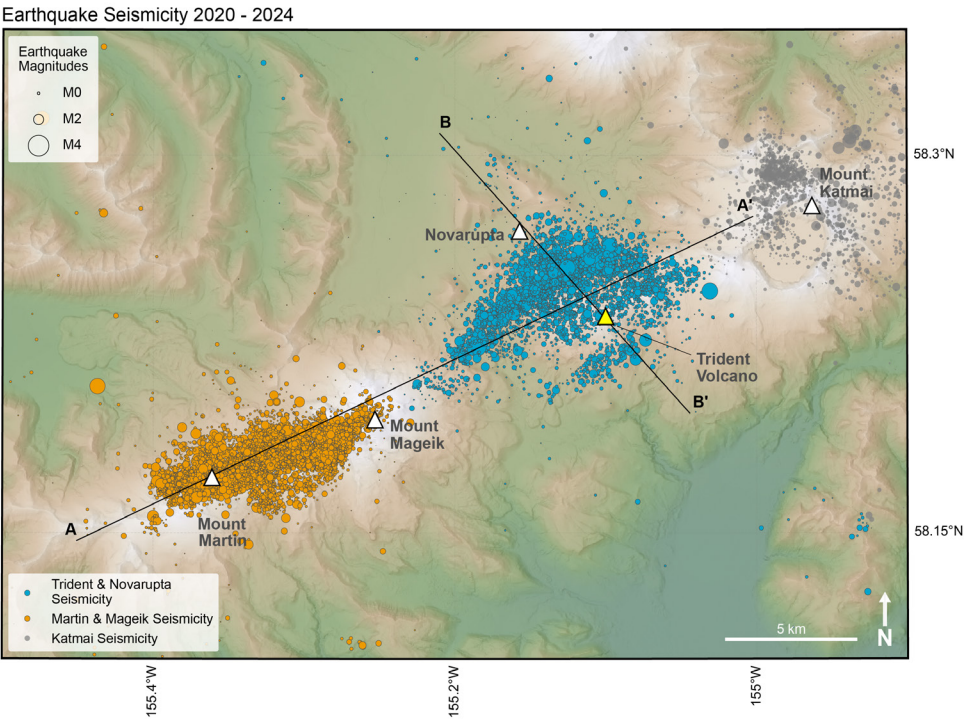


Figure 15. Cumulative earthquake counts for shallow and deep seismicity near Trident Volcano and Mount Martin/Mageik, Alaska, from 2020 to 2023. Cumulative total number of shallow (<15 km depth) (A) and deep (>15 km depth) (B) earthquakes for a four-year period in the vicinity of Trident Volcano and Novarupta (blue line) and Mount Martin and Mount Mageik volcanoes (orange line). Note scales differ between deep and shallow seismicity. Time period and colors match the earthquakes plotted in the map in Figure 14. Yellow shaded areas mark where Trident Volcano was at elevated Aviation Color Code YELLOW and Volcano Alert Level ADVISORY.

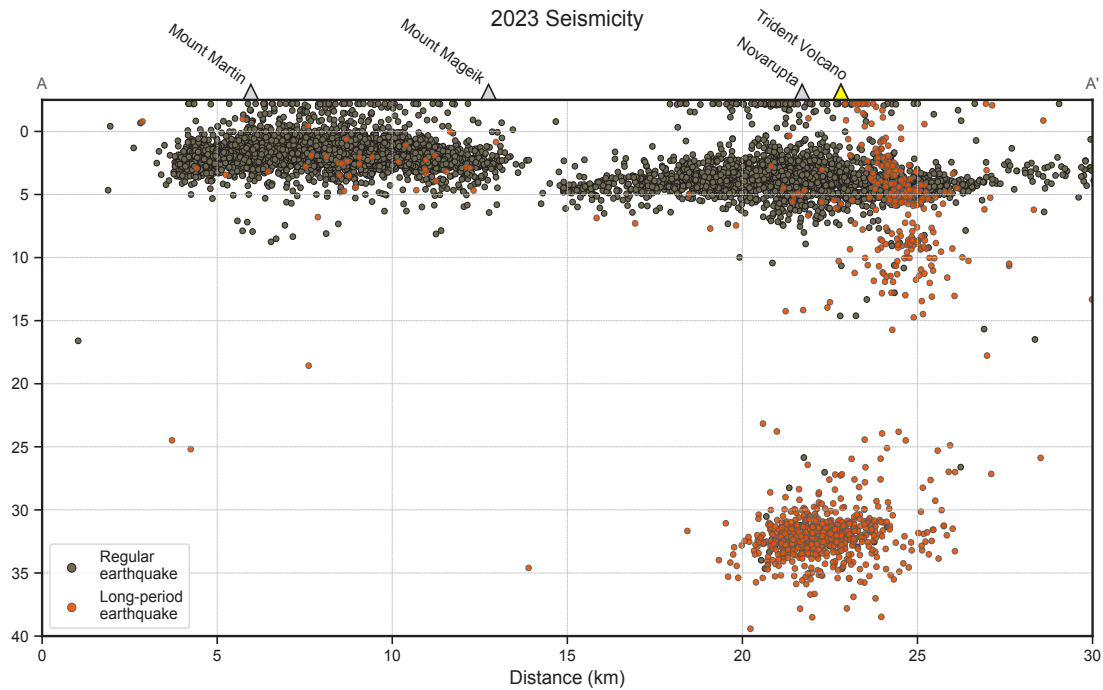


Figure 16. Depth cross section of earthquakes along A–A' line shown in Figure 14. Earthquakes are limited to events in 2023 within 5 km of A–A'. Dark grey circles are regular tectonic earthquakes. Red circles are long-period earthquakes, which lack high-frequency energy and are often attributed to the movement of magmatic fluids. Deep seismicity is concentrated beneath Novarupta and Trident Volcano. Many of the deep events (>25 km) were accompanied by longer-duration bursts of continuous tremor (fig. 18).

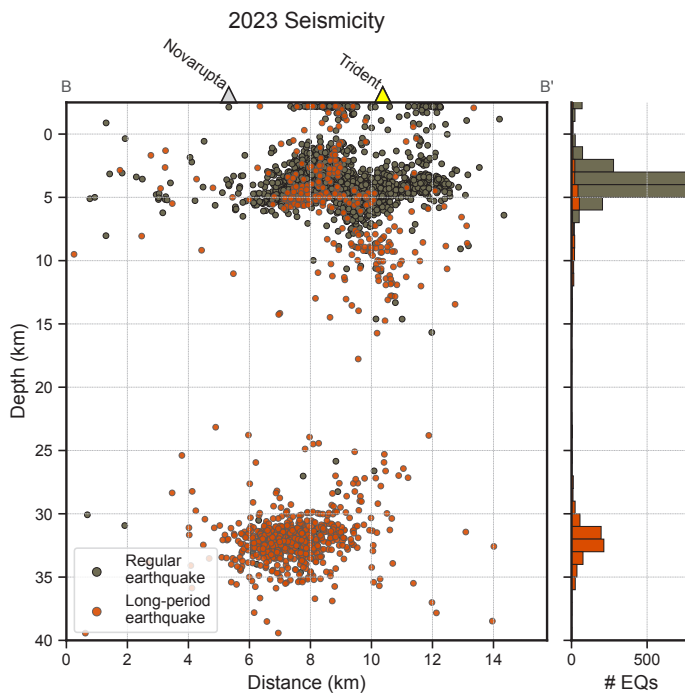


Figure 17. Depth cross section of earthquakes along B–B' line shown in figure 14. Earthquakes (EQ) are limited to events in 2023 within 5 km of B–B'. Dark grey circles are regular tectonic earthquakes. Red circles are long-period (LP) earthquakes, which lack high-frequency energy and are often attributed to the movement of magmatic fluids. Deep seismicity occurs between Novarupta and Trident Volcano. Many of the deep events (>25 km) were accompanied by longer-duration bursts of continuous tremor. (right) Depth histogram of number earthquakes.

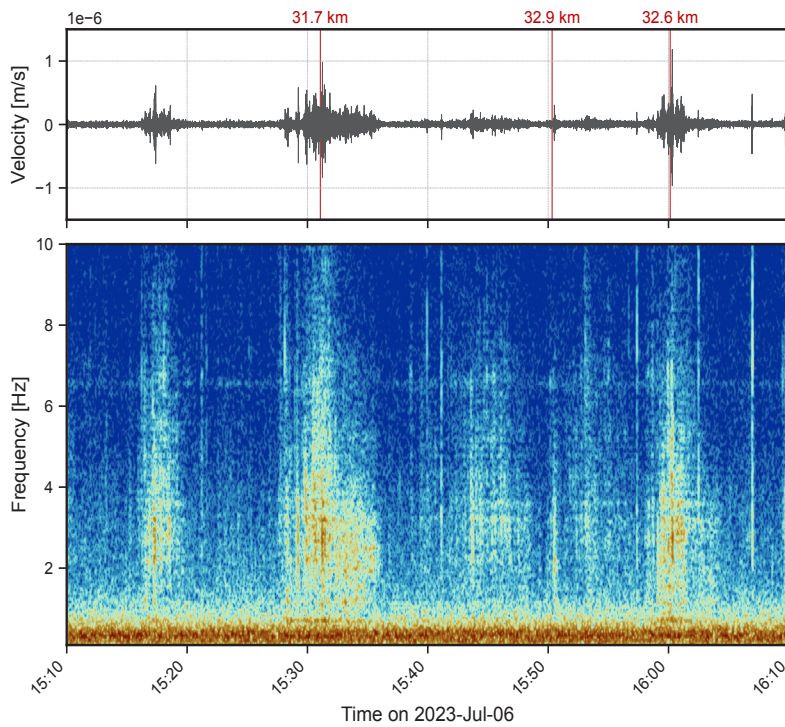


Figure 18. Filtered seismic waveform and spectrogram showing deep long-period earthquakes and tremor at Trident Volcano, Alaska, on July 6, 2023. (Top) Filtered (1–10 Hz) waveform from July 6, 2023, 06:10 to 07:10 AKDT (15:10 to 16:10 UTC). Red vertical lines mark the times of located deep long-period (DLP) earthquakes, which are labeled by event depth. (bottom) Spectrogram over the same hour showing minutes-long bursts of 1–8 Hz deep tremor energy.

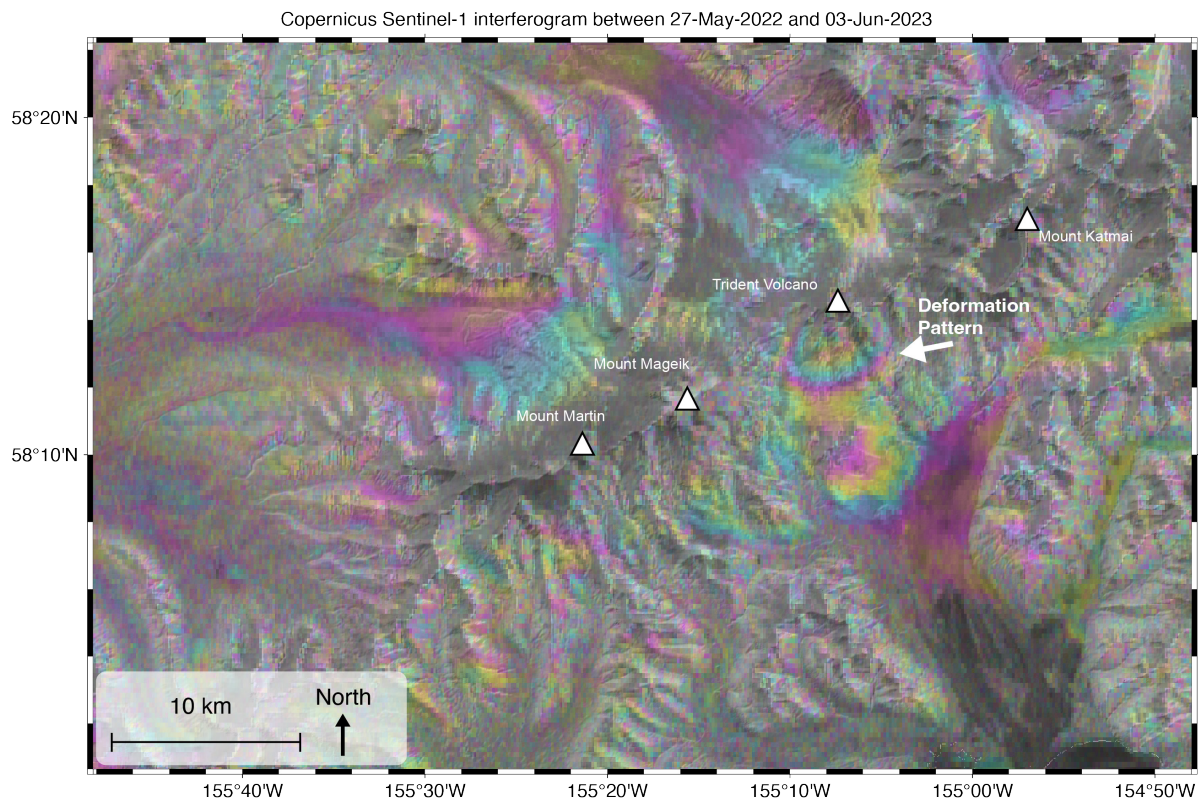


Figure 19. Interferometric Synthetic Aperture Radar (InSAR) interferogram from the Katmai volcanic cluster taken on 05/27/2022 and 06/03/2023. Topography changes are marked by fringes of consecutive repeating colors, suggesting up to 6 cm of vertical uplift on the southeast flank of Trident Volcano. Copernicus Sentinel data from 2014 to 2023, retrieved from the Alaska Satellite Facility Distributed Active Archive Center, processed by European Space Agency (ESA).

Aniakchak Crater

GVP# 312090
56.906°, -158.209°
1,298 m
Alaska Peninsula



GROUND DEFORMATION; ELEVATED SEISMICITY

Aniakchak Crater is located on the Alaska Peninsula about 25 km east-southeast of Port Heiden, Alaska, and about 665 km southwest of Anchorage (fig. 1). It is a circular caldera, 10-km in diameter and 1-km deep, that formed about 3,400 years ago during a catastrophic event that erupted 75 km³ of material (Miller and Smith, 1987; Dreher and others, 2005; Bacon and others, 2014). Numerous lava domes, lava flows, and scoria cones occupy the interior of the caldera (Neal and others, 2000; Bacon and others, 2014). The largest intracaldera cone is Vent Mountain, which is 2.5-km in diameter and stands 430 m above the floor of the caldera. The only eruption at Aniakchak Crater since 1741 was a powerful explosive event that took place in 1931, covering a large part of the eastern Alaska Peninsula with ash (Nicholson and others, 2011). In recent years, Aniakchak Crater was the site of anomalous seismicity and thermal anomalies, swarms of low frequency earthquakes, and non-volcanic earthquakes and ash resuspension (Dixon and others, 2020; Orr and others, 2024b). Background seismicity at Aniakchak Crater includes deep (>15 km) LP events occurring at a rate of ~4 earthquakes per month. The last measured deformation episode at Aniakchak Crater had subsidence rates of 6–10 mm/yr measured by InSAR from Envisat and European Remote Sensing satellite images spanning 2003–2010 and 1992–2010, respectively (Lu and Dzurisin, 2014). There was no clear deformation signal in Sentinel-1 interferograms prior to 2023.

On October 8, 2022, a few months after a monitoring network upgrade at Aniakchak Crater, a small earthquake swarm began, marking the start of a prolonged period of above-background seismic activity (fig. 20). In the following months, there was an increase in the number of VT events located <9 km BSL (up to 16 per day; fig. 21). Between October 2022 and the beginning of 2023, the largest earthquake was a shallow M_L 2.9 on November 18, which was recorded despite

local network outages. From December 1–15, 2022, 42 events were detected at Aniakchak Crater, an increase from previous weeks.

After a decrease in seismicity in January 2023, another increase in seismicity was observed on February 8, 2023 (despite a partial network outage), followed by a brief decrease on February 11 (fig. 20). Following a M_L 3.7 (local magnitude or M_L 3.26) earthquake on February 17 and increasing and shallowing of VT seismicity, a VAN/VONA was issued on February 22. This increased the Aviation Color Code to **YELLOW** and the Volcano Alert Level to **ADVISORY**. The highest earthquake rate during the entire period of unrest (104 events/day) occurred around February 21, 2023, according to a Repeating Earthquake Detector in Python (REDPy) analysis (Hotovec-Ellis, 2024).

Around the same time, Sentinel-1 InSAR measured uplift of the ground surface. Almost 15 cm of displacement was measured in the center of Aniakchak Crater in images spanning February to March 2023 (~4 cm/week). The onset of uplift cannot be well-constrained, but the Sentinel-1 InSAR time series suggests it may have begun as early as November 2022 (fig. 20). This signal was consistent with a pressure source located at 3–4 km BSL centered beneath the caldera. There were no obvious signs of surface changes in satellite optical imagery (fig. 22). AVO issued an Information Statement on April 13 to summarize these observations. The main conclusion was that the unrest was likely caused by magma intruding at a depth of 3–4 km BSL, centered under Aniakchak Crater. It also communicated that the primary hazard, if an eruption were to occur, would be volcanic ashfall and drifting ash clouds. This could impact local communities and infrastructure, as well as disrupt air travel.

The week of April 17–24, possible deep low frequency seismicity was recorded at nearby geophysical monitoring stations (ANNW, PTHD, and BPPC), and the rate of seismicity began to decrease during the week of April 10–18. On April 10, AVO installed a seismometer and webcam in Port Heiden in response to the ongoing unrest and continued partial outages of the permanent Aniakchak monitoring network. The following day, AVO employees gave a presentation and question-and-answer session

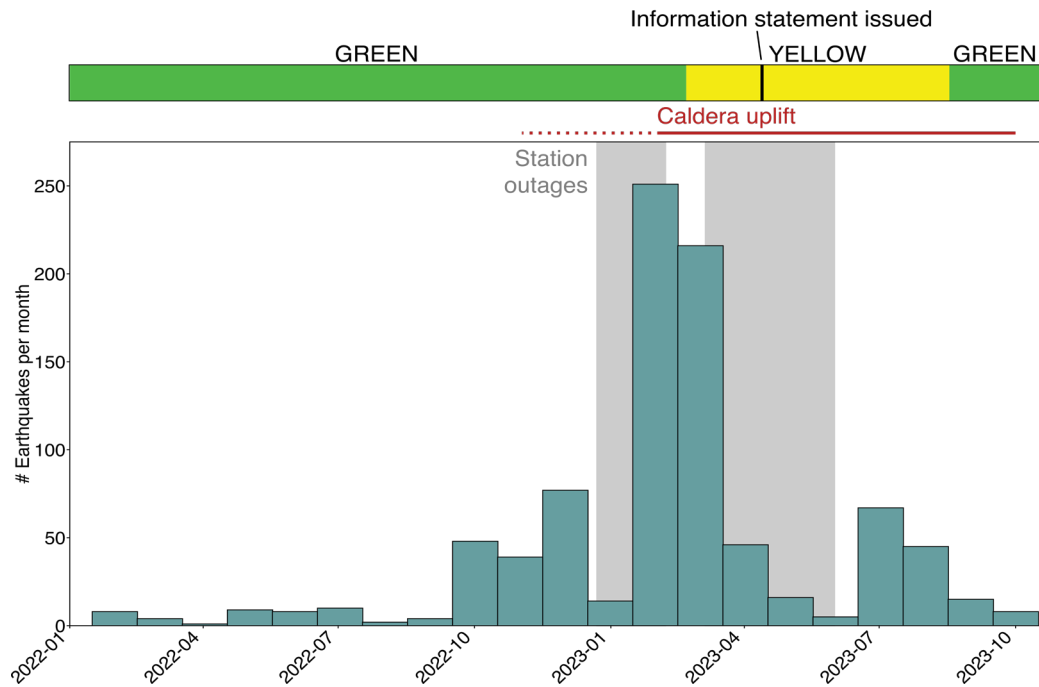


Figure 20. Timeline of located earthquakes at Aniakchak Crater, Alaska, from January 2022 to October 2023. Increased numbers of earthquakes began in October 2022 and lasted until August 2023, with three distinct peaks during this time period. Grey bars show periods when Alaska Volcano Observatory's seismic network had partial outages, affecting the ability to locate smaller earthquakes in the area. The red bar at the top shows the period of time that surface uplift was observed using satellite radar data (see fig. 23). The dashed red line indicates the period that the onset of uplift cannot be constrained, but uplift may have begun as early as November 2022, according to Sentinel-1 InSAR time series. The corresponding Aviation Color Code is shown in the top bar. (Adapted from <https://avo.alaska.edu/image/view/194295>).

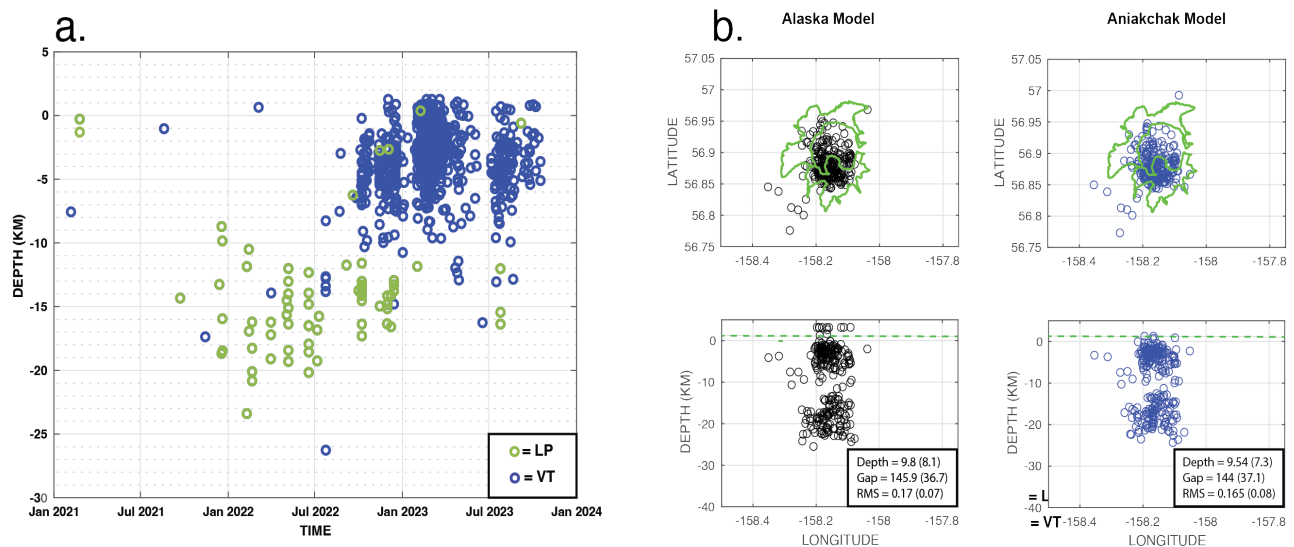


Figure 21. Focal depth versus time for earthquakes at Aniakchak Crater, Alaska, from 2021 to 2023. Green symbols are long-period (LP) events and blue symbols are volcano-tectonic (VT) earthquakes. This plot suggests that the 2022–2023 unrest at Aniakchak Crater may have begun with an increase in deep long-period (DLP) events in late 2021 that continued through 2022, with occasional DLP events in 2023. Gaps in recording likely represent network and station failures, which occur when fewer than four seismic stations are operating.

at the Port Heiden village office to update the community on the unrest. The presentation included an unrest summary, information on how to follow updates, and how the community will learn about future activity. In addition, an internal AVO event tree and unrest scenario discussion was held in April. The goal of this discussion was to summarize possible outcomes of the unrest (e.g., eruption probability and type). After a decrease in seismicity from April to June (during which network outages may have limited sensitivity to smaller events), an uptick occurred the last week of July. DLPs were recorded on July 25, which is more typical of background activity at Aniakchak Crater.

On August 17, due to the decrease in earthquake rate and measurable uplift declining to background levels, a VAN/VONA was issued to lower the Aviation Color Code to **GREEN** and the Volcano Alert Level to **NORMAL**. A partial failure of seismic monitoring equipment resulted in another VAN/VONA issued on October 30 to change the Aviation Color Code and Volcano Alert Level to **UNASSIGNED/UNASSIGNED**, with repair planned for the following summer.

Nonetheless, DLPs were noted at Aniakchak Crater in late November/early December.

The location and depth of earthquakes evolved over the course of the unrest episode. In 2022, VT seismicity was located under Vent Mountain and the southwest caldera rim (fig. 22). In 2023, VTs were in the east caldera near the Gates and outside the east caldera rim (fig. 22). Seismicity to the east persisted through summer 2023, while activity under Vent Mountain and the southwest caldera rim diminished.

Aside from the unrest episode, the NWS issued a SIGMET (Significant Meteorological Information) for an ash resuspension event on August 4, which produced an ash cloud that drifted to the northwest. The maximum cloud height was 6000 ft (1.8 km) ASL. A second ash resuspension event occurred on October 26, when strong winds carried loose volcanic ash to the northwest, and NWS issued a SIGMET for a maximum cloud height of 3000 ft (0.9 km) ASL.

See appendix 2 for more information about earthquake catalog relocation for Aniakchak Crater.

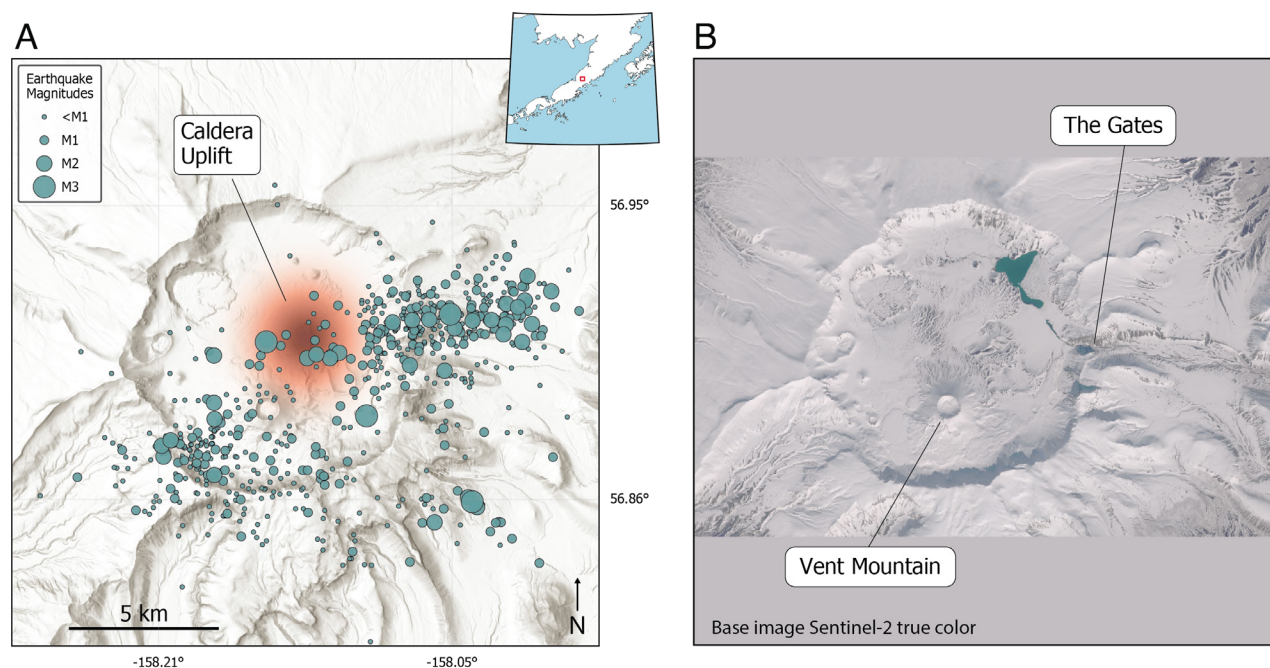


Figure 22. Map of earthquakes and annotated satellite image of Aniakchak Crater, Alaska, from October 2022 to April 2023. A) Map of Aniakchak Crater showing earthquakes located from October 7, 2022, to April 11, 2023. The size of each circle is proportional to earthquake magnitude. The pink shading in the caldera shows the generalized region where uplift was detected in early February 2023, as shown by satellite radar measurements (InSAR). Inset map shows the location of Aniakchak Crater on the Alaska Peninsula (red circle). (<https://avo.alaska.edu/image/view/194294>); B) Annotated highlight optimized natural color Sentinel-2 image of Aniakchak Crater and the surrounding area from the afternoon of April 10, 2023 (Adapted from <https://avo.alaska.edu/image/view/194291>).

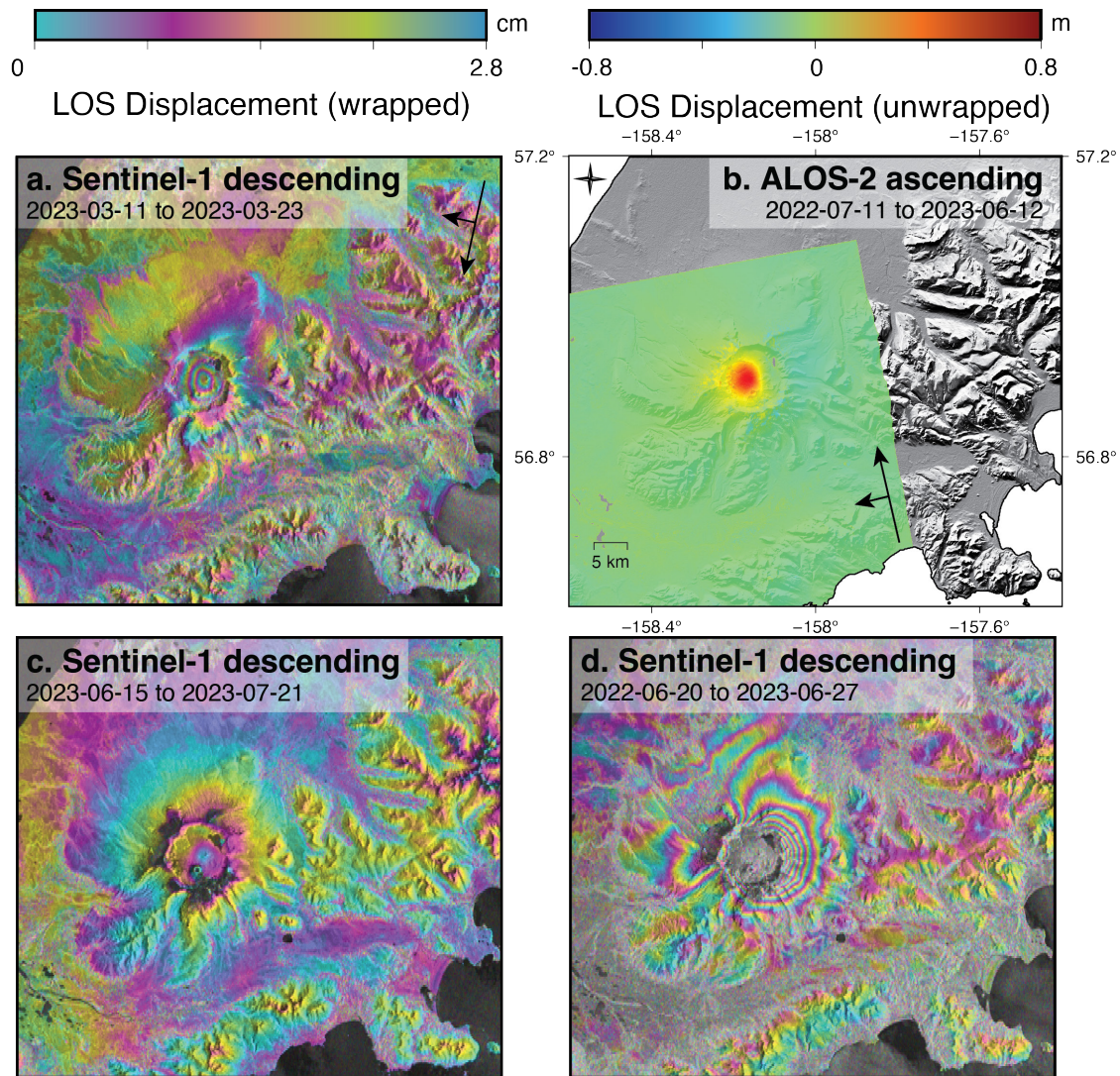


Figure 23. InSAR interferograms showing ground displacement at Aniakchak Crater, Alaska, during 2022–2023 unrest. Ground displacement decreased to rates of 3 cm/week in Sentinel-1 InSAR measurements spanning March 23 to April 4. Displacement slowed further in June, with 5 cm Land Observing Satellite (LOS) change between June and September, when deformation ended. Continuous Global Positioning System (GPS) measurements, installed in July during seasonal network maintenance, also indicated inflation rates of ~ 1 cm/month before deformation ended. Summer-to-summer interferograms from Sentinel-1, Advanced Land Observing Satellite-2 (ALOS-2) and *Satélite Argentino de Observación COn Microondas-1* (SAOCOM-1) measured more than 60 cm of LOS displacement, with deformation extending beyond the caldera. A) Wrapped Sentinel-1 interferogram from descending Path 102 spanning 11 March to 23 March 2023, showing >2 fringes (corresponding to ~ 6 cm) within the caldera. For all wrapped interferograms, one fringe is ~ 2.8 cm. Arrow shows flight direction of the satellite, and perpendicular line shows look direction (also applies to C and D); B) Unwrapped one-year ALOS-2 interferogram from ascending Path 86 spanning the unrest episode. More than 60 cm of deformation is measured spanning July 11, 2022, to June 12, 2023, with displacement extending outside of the caldera. Arrow shows flight direction of the satellite, and perpendicular line shows look direction. Data available through the Japanese Aerospace Exploration Agency and 3rd Research Announcement on the Earth Observations, PI ER3A2N006, and processed with the InSAR Scientific Computing Environment (ISCE2) (Rosen and others. 2012); C) Wrapped Sentinel-1 interferogram from the same track as in A, showing slowed deformation from June 15 to July 21, 2023, with at most 3 cm (one fringe) of displacement; D) Wrapped Sentinel-1 interferogram from the same track as in A, showing displacement spanning June 20, 2022, to June 27, 2023. This spans a similar time frame to the ALOS-2 interferogram in B. Note the limited coherence within the caldera, indicating a high deformation rate and/or significant changes to surface conditions. A, C, and D contain Copernicus Sentinel data from 2022 to 2023, retrieved from the Alaska Satellite Facility Distributed Active Archive Center, processed by ESA. Sentinel-1 interferograms processed according to Grapenthin and others (2022).

Pavlof Volcano

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

END OF EXPLOSIVE ERUPTION



of unvegetated lahar deposits from previous eruptions since 1741. These deposits contain significant quantities of volcanogenic silt and fine sand. When this material dries out it becomes susceptible to wind erosion, and when strong winds sweep the area, visible low-level dust clouds develop (fig. 24).

Pavlof Volcano, a conical stratovolcano composed of basaltic andesite lava flows and pyroclastic rocks, is located on the Alaska Peninsula about 60 km northeast of Cold Bay, Alaska, and 950 km southwest of Anchorage (fig. 1). Eruptions at Pavlof Volcano normally range in style from Hawaiian fountaining to Strombolian bursts, although more violent ultra-Strombolian to sub-Plinian explosive behavior has been documented (Waythomas and others, 2006). Pavlof Volcano has erupted at least 38 times since 1741 and is considered one of the most active volcanoes in North America (Miller and others, 1998). The volcano exhibits open-vent behavior and many of its eruptions have little precursory seismicity or ground deformation visible in InSAR (Lu and Dzurisin, 2014; Pesicek and others, 2018). A significant eruption of Pavlof Volcano began in August 2021 and continued throughout the remainder of 2021 and the entirety of 2022.

Pavlof Volcano began 2023 at Aviation Color Code **YELLOW** and Volcano Alert Level **ADVISORY**. The last known explosive activity associated with the 2021–2022 eruption occurred on December 11, 2022. Weakly elevated surface temperatures and minor steaming from the recently active vent were observed intermittently in satellite and webcam imagery during the first three weeks of January 2023. These observations are consistent with the signals produced by cooling of previously erupted lava. Seismicity in January was slightly above background level and was characterized by weak, low-frequency earthquakes. By January 19, 2023, the overall degree of unrest had fallen to background levels and the Aviation Color Code and Volcano Alert Level were lowered to **GREEN/NORMAL**. No further eruptive activity or significant unrest occurred at Pavlof Volcano in 2023.

Clouds of dust on the north side of Pavlof Volcano were observed in August 2023 (fig. 24). The area north of the volcano consists

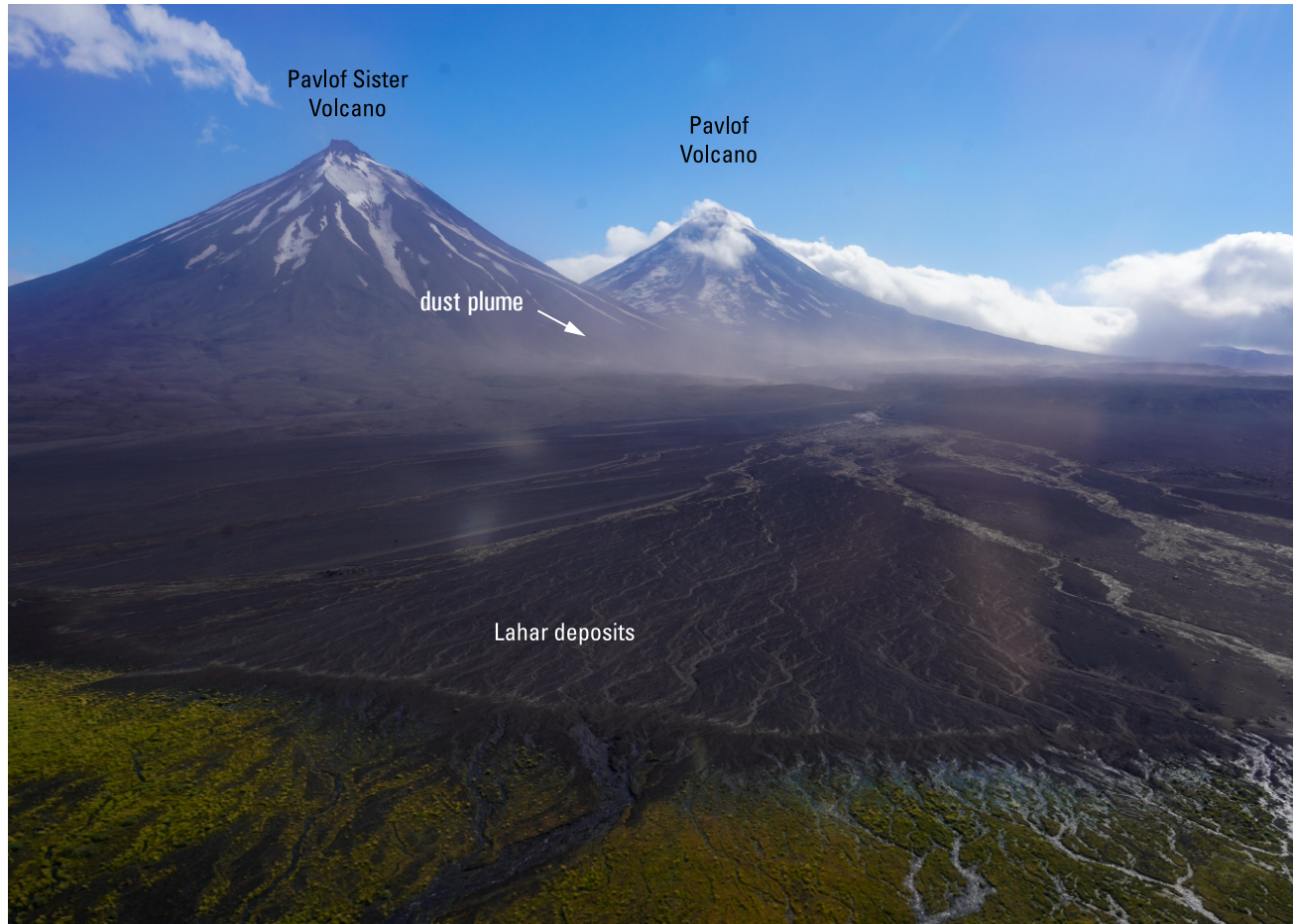


Figure 24. Photograph of Pavlof and Pavlof Sister Volcanoes, Alaska, showing lahar deposits and a wind-generated dust plume in 2023. Northeast side of Pavlof and Pavlof Sister Volcanoes with extensive fan of lahar deposits in the foreground. Arrows indicate a dust plume produced by wind erosion of the lahar deposits. Such plumes develop when the lahar deposits dry out and strong winds sweep across the area. View is toward the southwest. Alaska Volcano Observatory image database photo ID 194724.

Shishaldin Volcano

GVP# 311360

54.755°, -163.971°

2,858 m

Unimak Island, Fox Islands,
Aleutian Islands



LARGE ERUPTION WITH 13 PAROXYSM EVENTS

Shishaldin Volcano, located near the center of Unimak Island in the eastern Aleutian Islands (figs. 1, 25), is a conical stratovolcano with a base diameter of approximately 10 km and a summit elevation of 2857 meters ASL. It is one of the most active volcanoes in the Aleutian volcanic arc, with over 40 eruptions observed since 1741 (Beget and others, 2002). Most eruptions are relatively small, although eruptions in 1999 and 2023 generated ash columns that reached between 30,000 ft (9 km) and 42,000 ft (13 km) ASL.

Shishaldin Volcano erupted from July through November 2023. The eruption most notably produced 13 paroxysmal explosive events with ash cloud heights 17,000 to 46,000 ft. (5–14 km) ASL (fig. 26). These paroxysms progressed gradually, beginning with low-level strombolian activity within the summit crater, increasing to high lava fountaining, and culminating with gradual to abrupt coarse ash plumes and pyroclastic flows down the volcano flanks. The pyroclastic flows generated meltwater lahars down drainages on the north flank, with distal hyperconcentrated flows occasionally reaching the Bering Sea coast. Unlike the most recent eruption in 2019–2020 (Orr and others, 2024a), no lava flows were observed outside of the summit crater. The bulk composition of erupted products was basaltic and identical to historical eruption samples from 1999 and 2020. A notable result of the 2023 eruption was partial destruction of the previously conical summit crater, which now has a graben-like trough cutting the cone in a northeast-southwest orientation. This breach was the source of frequent rockfall events, lasting through the following year, and was perhaps the most drastic morphological change documented in the post-1741 eruption record at Shishaldin Volcano.

This summary documents the entire 2023 eruption, organized by paroxysmal events (Loewen and others, 2026). The eruption consists

of three broad phases. The first phase included the precursory eruption buildup and the first five explosive events from July 14 through July 26. Maximum ash plume heights for these events were variable, from 17,000 ft (5 km) ASL for two events (Event 2 and 5) to 39,000 ft (12 km) ASL for Event 4. Events were irregularly spaced 2 to nearly 5 days apart. A second phase of activity from Event 6 (August 4) to Event 12 (October 3) had longer 8–11 day gaps between paroxysms, and plume heights were 29,000 to 46,000 ft (9 to 14 km) ASL. The third and final phase of the eruption began with Event 12 and ended with Event 13. This phase was characterized by significant post-event unrest, including weeks-long periods after explosive events where tremor and sulfur dioxide (SO₂) emissions remained notably above background. Following Event 13, volcanic unrest continued to decline in December 2023, with seismic tremor and weak infrasound detections but no observations of ash emission or elevated surface temperatures, apart from cooling deposits from previous events. The following sections, organized by event, provide details on eruption observations and observatory operational response.

Eruption Buildup and Event 1 (July 10–July 14)

Continuous seismic tremor began at Shishaldin Volcano on July 9 around 11:30 AKDT (07:30 July 10 UTC) and gradually increased over the next 4 days (fig. 27). Overnight satellite images from July 11 indicated elevated surface temperatures consistent with magma near or at the surface, first in an Advanced Very High Resolution Radiometer (AVHRR) image at 00:44 AKDT (08:44 UTC) and later in a VIIRS image at 03:50 AKDT (11:50 UTC, see fig. 27). Subsequent VIIRS images that night detected volcanic radiative power values at least 10⁸ watts, likely reflecting lava at the surface within the summit crater. This increase in surface temperatures prompted AVO to raise the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** on July 11 at 14:39 AKDT (22:39 UTC). A PIREP from a flight near the summit later that day did not observe any activity, nor were deposits detected on the flanks in clear daytime satellite and webcam images from July

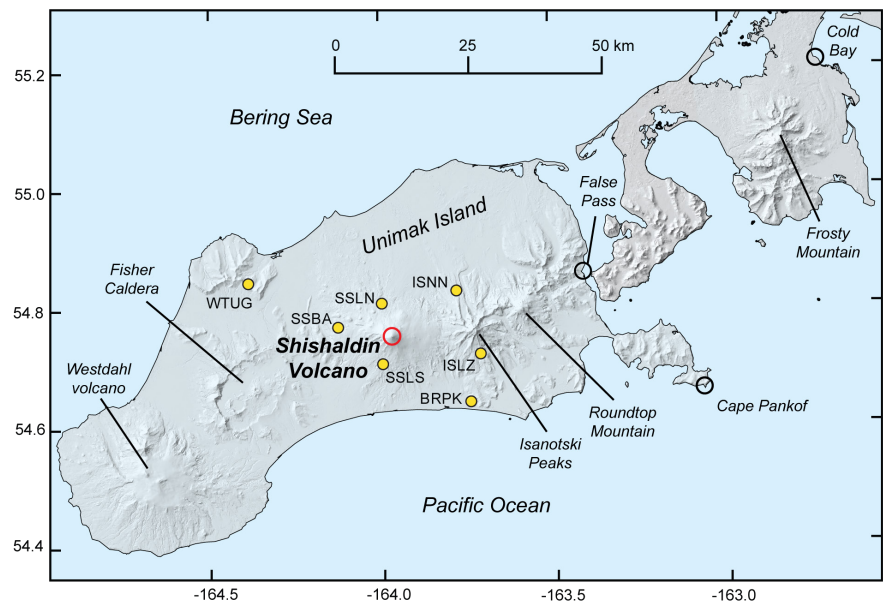
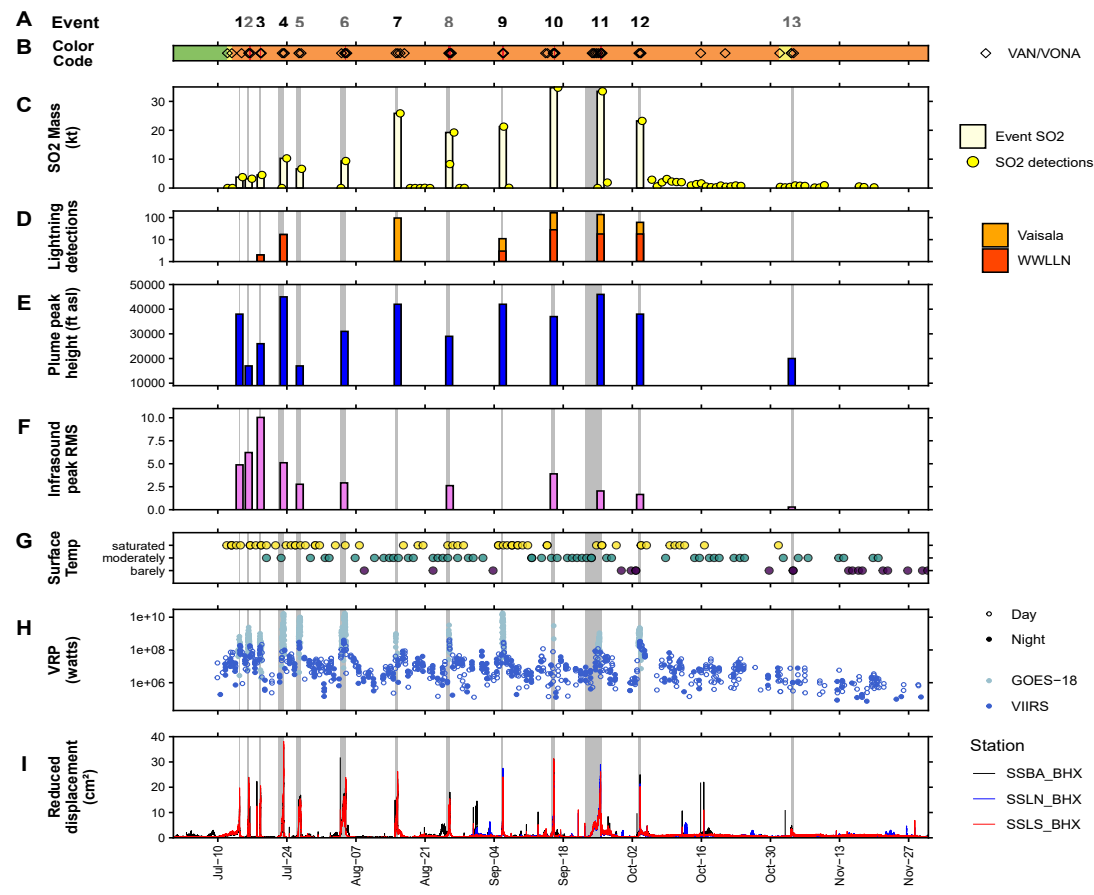


Figure 25. Overview map of Unimak Island, Alaska, showing volcanoes and Alaska Volcano Observatory monitoring sites. From west to east: Westdahl volcano, Fisher Caldera, Shishaldin Volcano, Isanotski Peaks, Roundtop Mountain, Frosty Mountain. Alaska Volcano Observatory monitoring sites are labeled in yellow circles.

Figure 26. Timeline of the 2023 eruption of Shishaldin Volcano, Alaska, showing multiparameter monitoring data. A) Event numbers, also are highlighted on all panels with gray bars representing the start and end time of elevated seismic activity associated with each paroxysm; B) Aviation Color Code and VAN/VONA notifications; C) Sulfur dioxide (SO₂) data, with columns representing total SO₂ emissions per individual paroxysm, centered at the time of peak ash emission (though actual satellite detections by the Tropospheric Monitoring Instrument (TROPOMI) sensors followed the event



by several hours). SO₂ was also detected between events; D) Lightning detections from Vaisala and World Wide Lightning Location Network (WWLLN) networks; E) Peak plume heights derived from Geostationary Operational Environmental Satellite (GOES)-18 images. Columns are centered at the time of peak plume height; F) Infrasound peak root mean square (RMS) from Fee and others (2026), with columns centered at the time of peak signal. Not all events had resolvable infrasound signals due to background (wind) noise. G) Surface temperatures, typically from polar orbiting weather satellites determined from qualitative duty checks ("Surface Temp"), or H) volcanic radiative power (VRP) from VIIRS following Saunders-Shultz (2024) or GOES-18. I) Reduced displacement from Fee and others (2026) from three seismic stations proximal to Shishaldin Volcano (scaled to give similar results to historical data at SSBA). All data used in this figure and other chronology figures in this section are available in Loewen and others (2026).

11–12. TROPOMI satellite data, however, did show weak SO₂ emissions on July 11 at 15:32 AKDT (23:32 UTC).

Overnight satellite images on July 12 indicated much stronger mid-infrared (mid-IR) values, with both Advanced Very High Resolution Radiometer (AVHRR) and VIIRS detectors showing saturated pixels at the summit crater. Faint incandescence at the summit crater was noted in a clear nighttime webcam image at 01:53 AKDT July 12 (09:53 UTC). These observations confirmed suspected surface lava and accordingly AVO raised the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH** on July 12 at 12:13 AKDT (20:13 UTC). Video observations from a U.S. Coast Guard C-130 overflight around 15:30 AKDT (23:30 UTC) provided spectacular footage of a small lava lake with low-level strombolian activity in the summit crater (fig. 28). Weather conditions deteriorated over the following days, obscuring satellite and webcam observations, but tremor remained elevated.

Eruptive activity began increasing again over the night of July 14 and culminated in the first ash-producing paroxysm of the eruption. Infrasound detections consistent with more vigorous explosions started at 21:31 AKDT on July 13 (05:31 July 14 UTC). Tremor amplitude began increasing sharply at 00:30 AKDT on July 14 (08:30 UTC). Satellite images detected an ash cloud starting at 01:10 AKDT (09:10 UTC) and peaking at 01:30 AKDT (09:30 UTC) reaching 32,000 ft (9.8 km) ASL. The plume detached from the summit at 02:20 AKDT (10:20 UTC) and drifted south-southeast over the North Pacific. Trace ashfall was reported on a nearby Canadian Coast Guard ship. Several small ash emission events were noted during the morning at 07:10 AKDT (15:10 UTC) and 10:00 AKDT (18:00 UTC), in webcam and satellite images, with ash reaching an estimated 15,000 ft (4.6 km) ASL.

Automated alarms that alerted AVO personnel to subsequent events at Shishaldin Volcano in 2023 were not active for Event 1, and as a result AVO was unaware of the escalation of activity until around six hours following the event during routine checks of data in the morning. No color code or alert level change was issued but a

Volcanic Activity Notification was issued at 11:34 AKDT (19:34 UTC) noting the large overnight event and ongoing low-level ash emissions. Following this event, satellite images and photos from passing airplanes showed lobes of small pyroclastic density current deposits blanketing the upper flanks of the volcano and water-rich mass flows extending beyond the pyroclastic deposits.

Event 2 (July 15–16)

Seismic tremor and infrasound detections began building towards a second paroxysm on July 15–July 16. Geostationary Operational Environmental Satellite (GOES)-18 images also detected increased surface temperatures around this time. Ash emissions were first detected in satellite images at 20:50 AKDT on July 15 (04:50 July 16 UTC). The ash emissions were initially low, but gradually built to 17,000 ft (5.2 km) ASL. Two Volcanic Activity Notifications were released for this event. The first at 21:52 AKDT (05:52 July 16 UTC) noted ash to 15,000 ft (4.6 km) ASL and retained the Aviation Color Code and Volcano Alert Level at **ORANGE** and **WATCH**. The second at 23:57 AKDT (07:57 July 16 UTC) raised the Aviation Color Code and Volcano Alert Level to **RED** and **WARNING** and noted ash heights had increased to 20,000 ft (6.1 km) ASL, and a continuous ash plume was moving south-southeast into the north Pacific.

Unrelated to the Event 2 eruption, a M7.2 regional earthquake occurred 200 km east-southeast of Shishaldin at 06:48 (<https://earthquake.usgs.gov/earthquakes/eventpage/us7000kg30/executive>). At the same time, AVO response staff were considering increasing the volcano alert level due to the ongoing continuous ash emissions. The earthquake and the eruption were not in any way related. The earthquake occurred around 30 minutes after peak tremor and ash emission height during the Event 2 paroxysm. However, the coincident events complicated eruption response and messaging to the public.

Ash emissions ended by 23:50 AKDT (07:50 July 16 UTC), leaving a detached low-level ash plume drifting over the north Pacific Ocean. The Aviation Color Code and Volcano Alert Level were decreased to **ORANGE** and **WATCH** at 07:34 AKDT on July 16 (15:34 UTC). High-

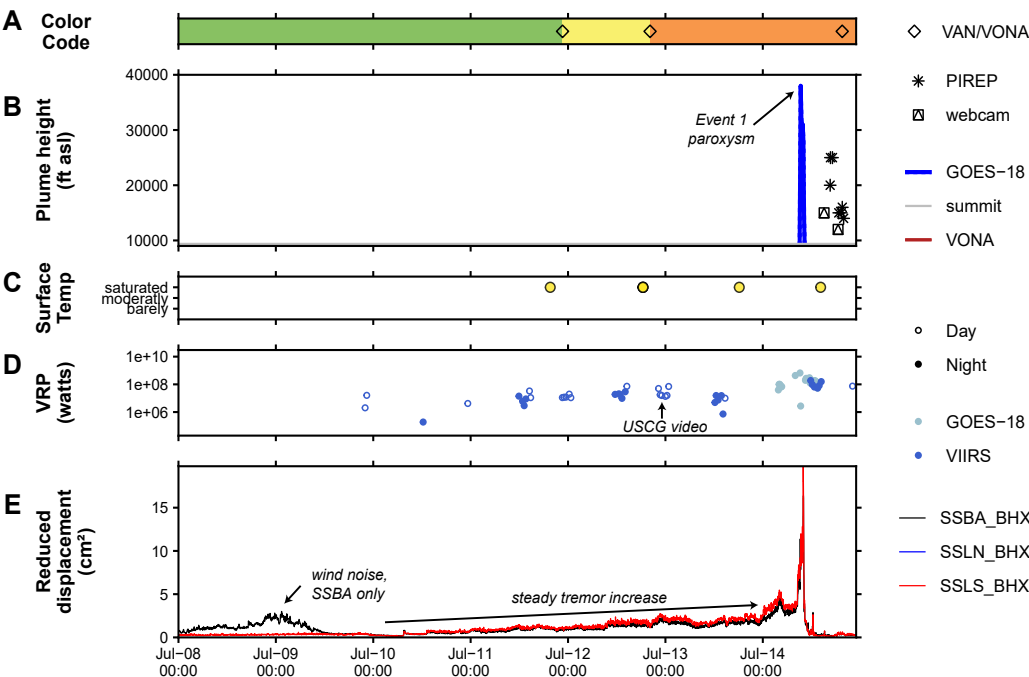


Figure 27. Timeline of Shishaldin Volcano Event 1, Alaska, including activity in the days prior to the first paroxysm in July 2023. The alert level was first elevated on July 11 following review of overnight satellite images that showed evidence for strongly elevated surface temperatures overnight. Continued elevated surface temperature prompted a further elevation of the alert level July 12, signifying likelihood that lava was erupting at the surface. This was confirmed that same day by a U.S. Coast Guard (USCG) overflight and video (fig. 28). See Figure 26 for a description of the individual panels. PIREP: pilot report. GOES: Geostationary operational environmental satellite. VIIRS: Visible infrared imaging radiometer suite. VRP: Volcanic radiative power.

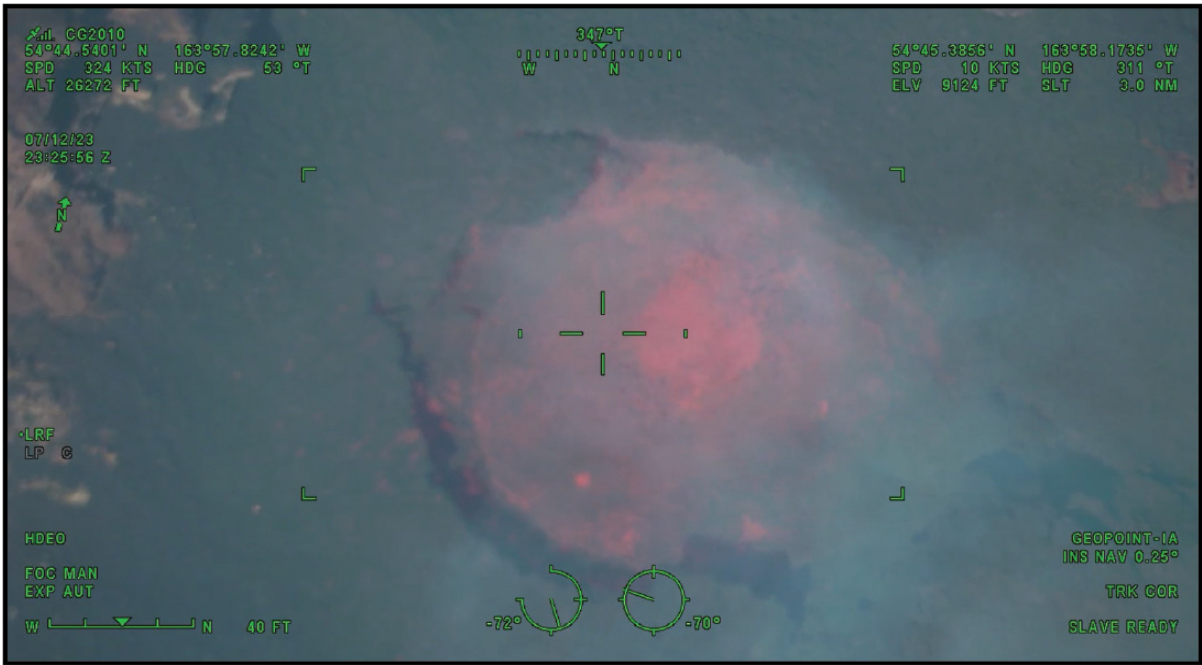


Figure 28. Photograph of lava erupting from Shishaldin Volcano, Alaska, on July 12, 2023, taken by the U.S. Coast Guard. Lava erupting from Shishaldin Volcano on July 12, 2023, at 15:25 AKDT (23:25 UTC), forming a small cone and roiling lava lake within the summit crater. Image is a screenshot from a video taken by a U.S. Coast Guard crew on a C-130 deployed from USCG Air Station Kodiak. Video used with permission from the USCG. AVO image ID 194572 (video).

resolution satellite images in the days following this event documented Event 1 and 2 deposits, both of which produced south-southeast directed ash plumes, small pyroclastic flows on all flanks, and water-rich mass flows extending down drainages north of Shishaldin Volcano (fig. 29). Notably, diffuse co-pyroclastic density current (PDC) ashfall deposits were seen downwind of the pyroclastic flow lobes in addition to vent-derived ashfall.

Event 3 (July 18)

The buildup to event three was first identified in overnight webcam images on July 17–18 showing incandescence from the summit crater. This observation was corroborated by increased surface temperatures in satellite images, infrasound detections, and tremor that began increasing around 03:00 AKDT (11:00 UTC). Unlike Event 2, the ash-rich explosive phase of

Event 3 began abruptly at 06:30 AKDT (14:30 UTC) and was noted in webcam images from False Pass by 07:41 AKDT (15:41 UTC) (fig. 30). In response to the ash emissions, AVO raised the Aviation Color Code and Volcano Alert Level to **RED** and **WARNING** at 07:56 AKDT (15:56 UTC). The peak ash height of 26,000 ft (7.9 km) ASL was recorded in GOES-18 data at 08:10 AKDT (16:10 UTC). AVO issued another Volcanic Activity Notice at 08:37 AKDT (16:37 UTC) updating the plume height observations. Major ash emissions ended by 09:50 AKDT (17:50 UTC) and were followed by very low-level ash emissions visible only in webcam images. AVO lowered the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH** at 12:08 AKDT (20:08 UTC). Similar to Events 1 and 2, the plume drifted south-southeast from the volcano over the north Pacific Ocean. A high-resolution satellite image was acquired during

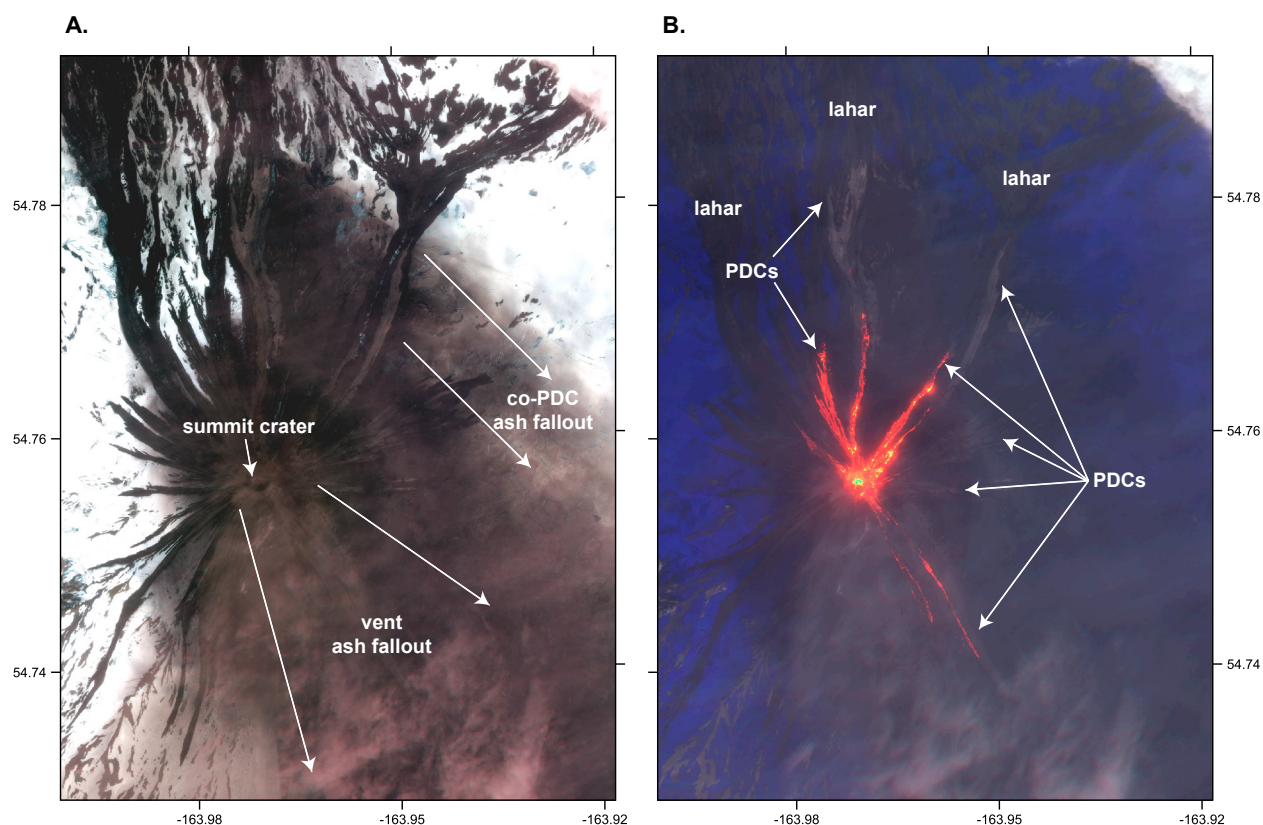


Figure 29. Satellite images of pyroclastic density current and lahar deposits at Shishaldin Volcano, Alaska, on July 18, 2023. Images acquired July 18, 2023, at 13:51 AKDT (21:51 UTC) during the end of Event 3 activity. A) Near-infrared (IR) image with co-pyroclastic density current (PDC) ash fallout highlighted from lighter colored PDC flows, and vent-derived ash fallout downwind of the summit crater; B) Shortwave IR image highlighting still hot (red to yellow) or dry (light gray) PDC deposits and wet (dark gray) lahar deposits that formed downhill of the PDC deposits. Modified from Alaska Volcano Observatory image IDs 194526 and 194444. Images ©2025 Maxar Technologies.

the waning phases of this event at 13:51 AKDT (21:51 UTC), capturing the residual low-level ash emissions and warm PDC deposits (fig. 29).

Following Event 3, AVO personnel worked to improve the network connection of data linked through King Cove, Alaska. This work resulted in availability of real-time data from station SSLS on the south flank of Shishaldin Volcano and provided additional webcam images from stations ISLZ and BRPK on the south side of Unimak Island (fig. 25).

Event 4 (July 21–23)

Unrest prior to the Event 4 paroxysm was somewhat obscured by poor weather conditions. Tremor began increasing on July 21 around 16:00 AKDT (00:00 July 22 UTC) but it was unclear if the signal was due to wind noise or volcanic activity until 12:00 AKDT on July 22 (20:00 UTC). Despite cloud cover over the volcano, elevated surface temperatures were detected in morning polar orbiting satellite data (04:44 to 05:35 AKDT or 12:44 to 13:35 UTC). In addition, AVO noted SO₂ emissions from the volcano in a TROPOMI satellite image from this time. These data led AVO to issue a Volcanic Activity Notification on July 22 at 16:53 AKDT (00:53 July 23 UTC) forecasting an imminent eruption and noting that ash emissions could reach as high as 20,000 ft (6.1 km) ASL without

detection due to regional cloud cover.

Low-level ash was first noted at 19:13 AKDT (03:13 July 23 UTC) in a PIREP and at 21:20 AKDT (05:20 July 23 UTC) in satellite data. The stronger ash-rich paroxysm began abruptly at 23:40 AKDT (07:40 July 23 UTC) with a simultaneous strong mid-IR signal (fig. 31A) from the vent followed by a rapidly growing ash plume that reached an estimated 39,000 ft (11.9 km) ASL (fig. 31B). AVO quickly responded to the paroxysm by raising the Aviation Color Code and Volcano Alert Level to **RED** and **WARNING** at 23:43 AKDT (07:43 July 23 UTC). Retrospective analysis of satellite data indicated the ash plume associated with Event 4 reached about 45,000 ft (13.7 km) ASL by July 22 at 00:10 AKDT (08:10 July 23 UTC). The AVO alert was only to an initial plume estimate of 9.1 km (30,000 ft) asl, but a National Weather Service alert was to 12.2 km (40,000 ft) asl. In order to not flood the public with eruption messaging and given that the correct plume height had been issued by the National Weather Service Alert (which was available to aviation users), AVO decided not to issue a correction to AVO products.

Unlike events 1–3, winds directed the Event 4 ash cloud northeast with potential ashfall impacts to Cold Bay and Sand Point, Alaska, and NWS issued an ashfall advisory for these communities (fig. 31C, D). No subsequent ash

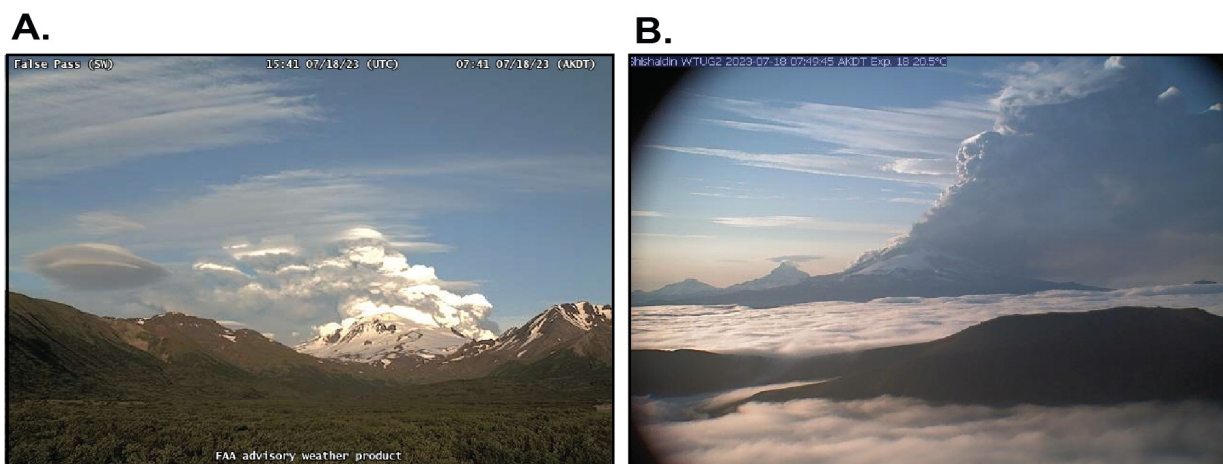


Figure 30. Webcam images on July 18, 2023, of the Event 3 ash plume. A) View from False Pass Federal Aviation Administration webcam at 07:41 AKDT (15:41 UTC) with a well-developed plume rising over Roundtop Mountain in the foreground (Shishaldin Volcano edifice not visible); B) Image from WTUG webcam west of Shishaldin Volcano at 07:50 AKDT (15:50 UTC). AVO image ID 194430 and 194432.

was reported, however, apart from a fishing vessel northeast of False Pass which reported trace coarse ash on their boat the next morning. Ash emissions were not detected in satellite data after 01:30 AKDT July 23 (09:30 UTC). AVO decreased the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH** at 04:18 AKDT (12:18 UTC).

The trajectory of ash to the northeast and oblique to the equatorial perspective of GOES-18 provided a clear view of the ash spectral character seen in many of the 2023 paroxysms (fig. 31). The paroxysm was preceded by and, if not blocked by ash emissions, coincident with strong surface heat signatures seen in mid-IR satellite images (fig. 31A). The paroxysmal plume was highlighted by a tall (cold) plume seen in IR satellite images (fig. 31B). It lacked an ash-multispectral signature but was distinct in SO₂ multispectral products (fig. 31C). This reflects the high plume phase being water and gas rich, and poor in the fine-grained ash that shows up in satellite spectral processing. Later low-level plumes that followed the paroxysmal event typically had stronger ash signatures (fig. 31D).

Event 5 (July 25–26)

Tremor began escalating prior to the Event 5 paroxysm on July 25 at 22:00 AKDT (06:00 July 26 UTC). At 02:11 AKDT on July 26 (10:11 UTC), AVO issued a VAN/VONA forecasting an imminent ash-producing event, and another at 03:51 AKDT (11:51 UTC) noting ash emissions moving east-northeast at 15,000 ft (4.6 km) ASL, corresponding to a NWS notification. Retrospective examination of satellite data showed ash emissions only above the meteorological clouds at 05:30 AKDT (13:30 UTC) with plume heights from 15,000 to 17,000 ft (4.6 to 5.2 km) ASL. Ash emissions were no longer detected after 09:30 AKDT (17:30 UTC); however, cloud cover made detection of activity difficult at this time. Tremor levels dropped abruptly at 13:00 AKDT (21:00 UTC) signifying the end of the paroxysm. This event was like Event 2, with a relatively low ash plume and no abrupt increase in ash emission. While a trace ashfall warning was issued by the NWS for Cold Bay and Sand Point, AK, no impacts were reported. AVO issued a VAN confirming the end of the event at 13:27 AKDT

(21:27 UTC); at no time were the Alert Level or Color Code changed for Event 5.

After Event 5, occasional low-level strombolian activity was detected, but high-resolution satellite images on July 30 and August 1 confirmed no active surface lava within the vent (fig. 32). These images documented ashfall and pyroclastic flow deposits from events 1–3 to the south and events 4–5 to the north and northeast.

Event 6 (August 3–4)

Tremor levels began increasing on August 3 at 10:00 AKDT (18:00 UTC). GOES-18 images showed elevated surface temperatures at the summit by 17:20 AKDT (01:20 August 4 UTC). At 17:36 AKDT (01:36 August 4 UTC), AVO issued a VAN forecasting an imminent ash-producing event. A protracted ramp-up of activity continued through the afternoon and evening. TROPOMI satellite data at 15:00 AKDT (23:00 UTC) showed a small SO₂ plume from the volcano accompanying this activity. Low-level ash was first detected in satellite imagery on August 4 at 04:50 AKDT (12:50 UTC) slightly above metrological clouds, consistent with a height around 25,000 ft (7.6 km) ASL. The plume height gradually increased and peaked around 08:30 AKDT (16:30 UTC) at 31,000 ft (9.4 km) ASL. This plume height and its dispersal led AVO to issue a VAN at 09:04 AKDT (17:04 UTC) for ash to 25,000 ft (7.6 km) ASL. At 10:17 AKDT (18:17 UTC), AVO increased the Aviation Color Code and Volcano Alert Level to **RED** and **WARNING** with an updated plume height estimate of 30,000 ft (9.1 km) ASL. Another VAN at 14:07 AKDT (22:07 UTC) noted the plume had reached 31,000 ft (9.4 km) ASL and extended 180 km from the volcano. Ash emissions appeared to end, however, slightly before this update at 13:00 AKDT (21:00 UTC). AVO did not lower the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH** until 19:55 AKDT (03:55 August 5 UTC), partly due to uncertainty about ongoing ash emission after metrological clouds up to 30,000 ft (9.1 km) ASL obscured the volcano.

Event 7 (August 14–15)

With Event 6, the eruption moved into a more regular phase of activity, with almost

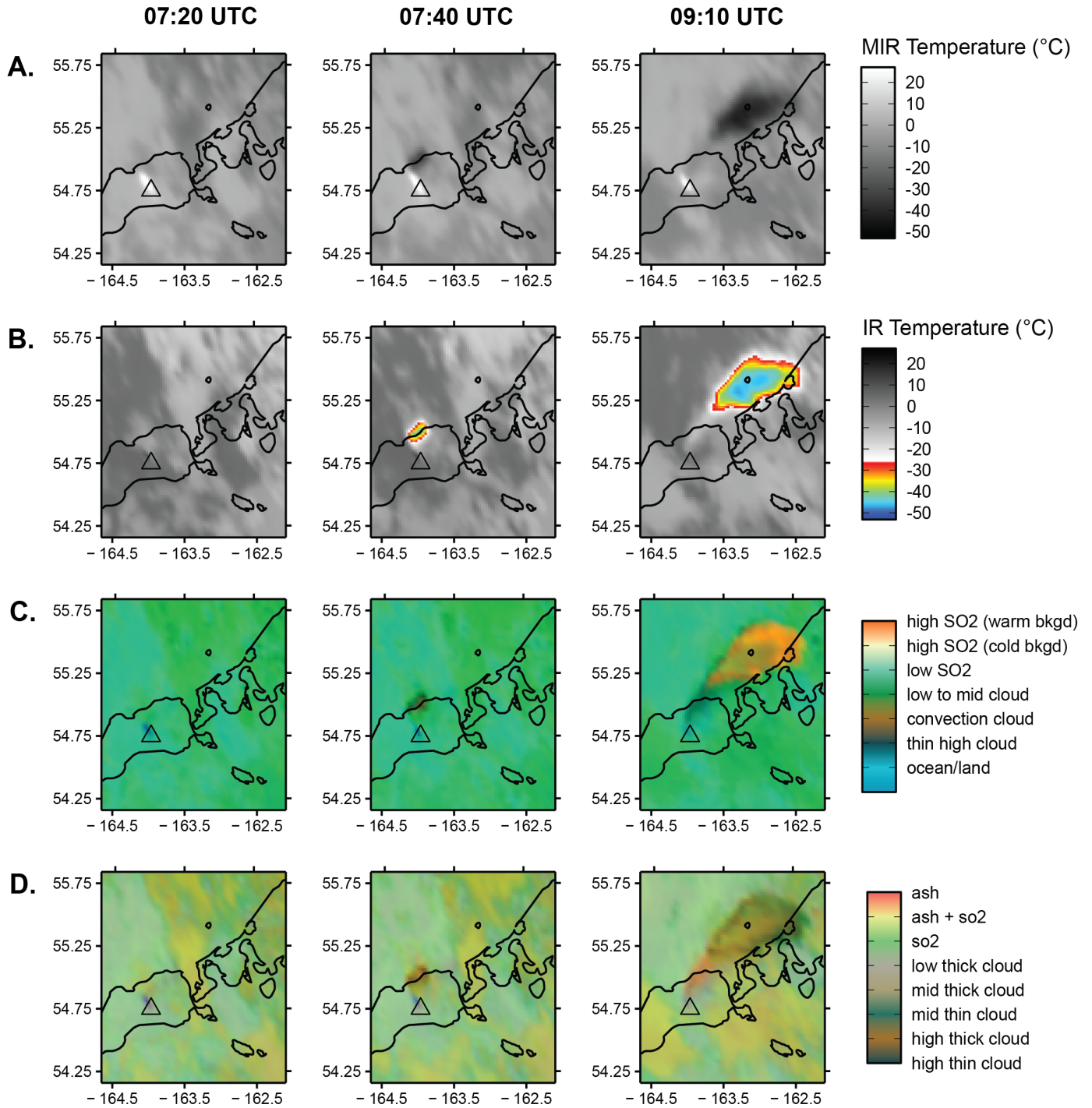


Figure 31. July 22–23, 2023, Geostationary operational environmental satellite (GOES)-18 images for Shishaldin Volcano Event 4. A) mid-infrared (IR) images show high radiative values over the summit from lava fountaining before and during the paroxysm, late on July 22 local time; B) Infrared images reflect the rapidly growing plume as it forms around 23:40 AKDT (07:40 July 23 UTC) and drifts northeast; C) SO₂ multispectral product tracks this initial paroxysm plume as it drifts downwind; D) The ash multispectral product shows that the ash-rich phase of the plume is primarily seen (red) in the trailing, low-elevation plume following the paroxysm.

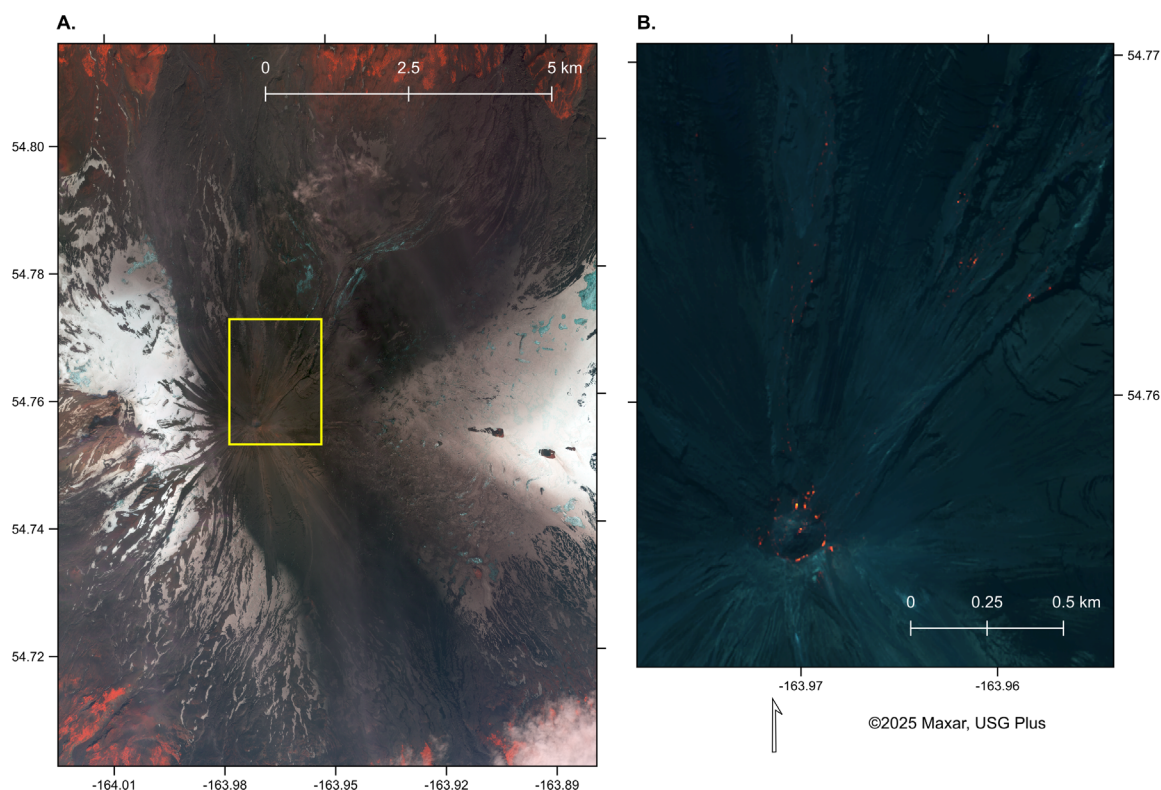


Figure 32. WorldView-3 satellite image of ash deposits at Shishaldin Volcano, Alaska, on August 1, 2023. Image captured on August 1 at 14:08 AKDT (22:08 UTC), following Event 5. A) Near-infrared (IR) image shows ash deposits dispersed southeast (events 1–3) and north-northeast (events 4, 5) of the summit vent. Yellow outline is extent of panel B; B) Shortwave IR image shows no active lava at the surface within the summit crater and small hot areas (red) from cooling deposits of prior events. Images ©2025 Maxar Technologies.

predictable paroxysm events occurring every 8–11 days. Prior to Event 7, tremor started increasing on August 14 at 12:00 AKDT (20:00 UTC). Elevated surface temperatures were indicated in satellite data starting by 16:00 AKDT (00:00 August 15 UTC). At 18:27 AKDT (02:27 August 15 UTC), AVO issued a VAN forecasting an imminent ash-producing event. High clouds moved over the volcano during the evening hours, obscuring surface observations leading up to the paroxysm.

Ash was first detected at 01:20 AKDT August 15 (09:20 UTC) and was followed by lightning detection at 02:13 AKDT (10:13 UTC). The eruption cloud was cold and water-rich and with a stronger SO_2 multispectral signal and almost no ash signal, complicating its detection in real-time (fig. 33). The peak ash height was measured at 02:50 AKDT (10:50 UTC) and reached 42,000 ft (12.8 km) ASL. By 03:10 AKDT (11:10 UTC) all ash emissions were

below the 20,000 ft (6.1 km) ASL metrological cloud tops. Later, emissions 20,000 to 25,000 ft. (6.1 to 7.6 km) ASL were detected from 06:30 to 13:00 AKDT (14:30 to 21:00 UTC) in satellite data and confirmed by several PIREPs until after 14:00 AKDT (22:00 UTC). Tremor had precipitously dropped from its peak during this time but remained elevated.

During the event, AVO determined the ash plume had reached 25,000 ft (7.6 km) ASL, and thus, issued VANs at 03:35 AKDT (11:35 UTC) and again at 15:03 AKDT (23:03 UTC) for continuing low level ash. AVO did not raise the Aviation Color Code and Volcano Alert Level which remained at ORANGE/WATCH.

Two reports of minor airplane-ash encounters were noted during this event. At 03:25 AKDT (11:25 UTC) on August 15, a pilot flying near False Pass at 25,000 ft (7.6 km) ASL reported sulfur smell in the cockpit. Later, at

06:00 AKDT (14:00 UTC), a flight almost 400 km north of Shishaldin Volcano flying at 32,000 ft (9.6 km) ASL reported a 1-minute discharge of static electricity (St. Elmo's fire) on the windshield (Loewen and others, 2026).

AVO issued a VAN declaring the end of Event 7 on August 16 at 11:16 AKDT (19:16 UTC). Following Event 7 and starting August 18 at 10:30 AKDT (18:30 UTC), increased earthquakes were detected about 10 km west of Shishaldin Volcano's summit. These earthquakes were located near the hypocenter of a M5.2 earthquake that occurred during the 1999 eruption (Moran and others, 2002).

AVO field crews began maintenance of geophysical stations near Shishaldin Volcano on August 20 and 21. The teams observed that small

notches had appeared along the northeast and southwest rim of the summit crater. They were also able to collect tephra samples on the volcano and at sites north of Isanotski Peaks in line with the events 4–7 northeast-directed plume axes.

Event 8 (August 24–26)

Tremor began increasing prior to Event 8 on August 24 at 22:00 AKDT (06:00 August 25 UTC). Ash was first observed by a pilot on August 25 at 11:22 AKDT (19:22 UTC), which indicated an ash plume extending to 20,000 ft (6.1 km) ASL. Ash was also detected in GOES-18 data at 11:30 AKDT (19:30 UTC). At 11:36 AKDT (19:36 UTC), AVO issued a VAN forecasting an imminent ash-producing event. This was followed quickly by another VAN

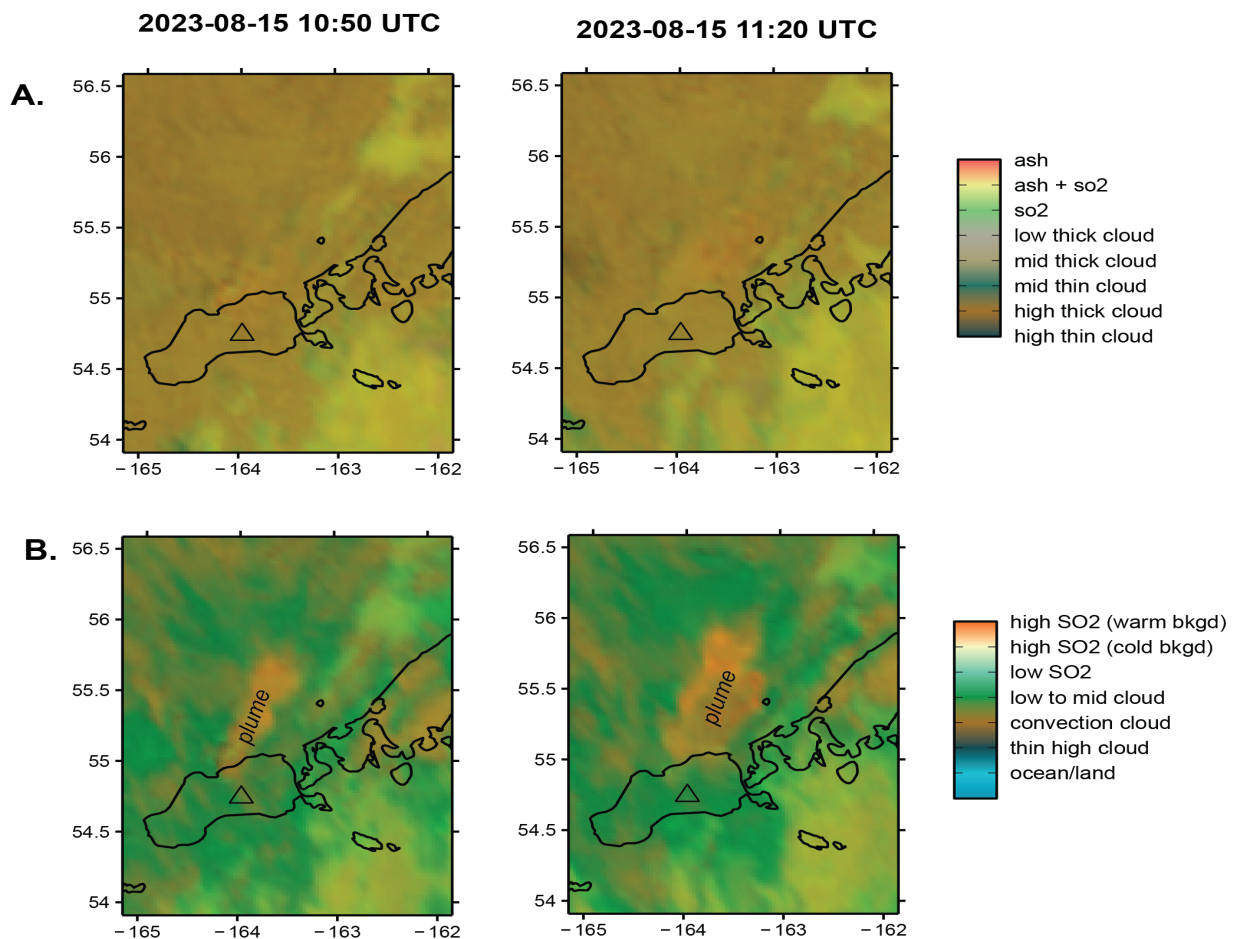


Figure 33. Geostationary Operational Environmental Satellite (GOES)-18 multispectral products from the Event 7 paroxysm. Meteorological clouds around 20,000 ft (6.1 km) above sea level (ASL) obscured low-level activity leading up to and during the eruption, including mid-infrared (IR) signals related to elevated surface temperatures. The high ash plume was not visible in ash multispectral products (A) but could be seen in longwave-IR and SO₂ multispectral products (B). This spectral characteristic was typical for high Shishaldin Volcano volcanic plumes, which contain little fine-grained ash.

increasing the Aviation Color Code and Volcano Alert Level to **RED** and **WARNING** at 12:04 AKDT (20:04 UTC) and noting that the ash cloud had reached 28,000 ft (8.5 km) ASL. The plume quickly increased in height, reaching a peak of about 29,000 ft (8.8 km) ASL at 13:20 AKDT (21:20 UTC). Like previous events, a meteorological cloud deck of about 30,000 ft (9.1 km) ASL obscured observations and complicated real-time detection of ash. Two more VANs issued during the event updated the ash cloud height to 30,000 ft (9.1 km) ASL at 17:32 AKDT (01:32 August 26 UTC) and 21,000 ft (6.4 km) ASL at 20:20 AKDT (04:20 August 26 UTC). AVO lowered the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH** at 00:31 AKDT on August 26 (08:31 UTC). The tremor pattern had two peaks over the paroxysm near the start and end of the most vigorous ash production (fig. 34).

After the event, the *R/V Sikuliaq*, working in Bristol Bay 300 km northeast of the volcano, noted that they received trace ash fall on the ship deck by the morning of August 26. AVO field teams returned to Unimak Island on August 26.

While working at a station (WTUG) west of Shishaldin Volcano, they observed a significant collapse event from the northeast crater rim down the northeast flank of the volcano on August 26 at 17:20 AKDT (01:20 August 27 UTC, fig. 35). This collapse produced an ash cloud that reached up to 15,000 ft (4.6 km) ASL. Similar collapses were observed for the remainder of the eruption due to instability of the steep inner crater walls, which was breached on the northeast and southwest flanks over the course of events 7 and 8.

Event 9 (September 5)

Tremor began increasing prior to Event 9 on September 5 at 03:00 AKDT (11:00 UTC). Ash was first seen in satellite images at 07:20 AKDT (15:20 UTC). High lava fountaining and a low-concentration ash plume were seen in a webcam image at 08:10 AKDT (16:10 UTC, fig. 36). Lightning was detected at 08:42 AKDT (16:42 UTC), and subsequently AVO issued a VAN raising the Aviation Color Code and Volcano Alert Level to **RED** and **WARNING** at 09:01 AKDT (17:01 UTC). By 09:10 AKDT (17:10 UTC), a dark vertical ash plume was

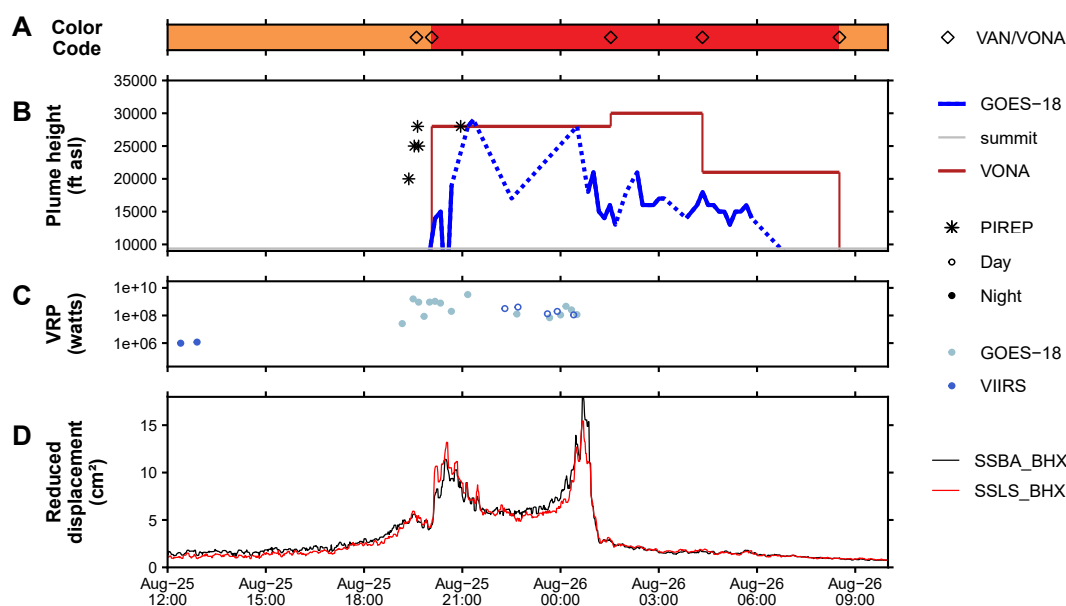


Figure 34. Timeline of Event 8 at Shishaldin Volcano, Alaska, showing monitoring data over the course of the event. A) color code and information product timeline, B) plume height, C) volcanic radiative power (VRP) output, D) Real time seismic amplitude measurement (RSAM) values. All subplots share the same x axis to show how they compare over the duration of the event. Ash heights estimated from satellite data were obscured by cloud cover (indicated by dashed lines), but two peaks corresponding to peaks in real-time seismic amplitude measurement were observed and closely match pilot report (PIREP) heights, although these interestingly preceded the satellite detections. Alert VAN/VONA ash height warnings tracked eruption activity very closely in time and height. See Figure 26 for a more detailed explanation of the individual panels.



Figure 35. Webcam image of a crater rim collapse event on the northeast side of Shishaldin Volcano, Alaska, in 2023 Event 8. Significant rim collapse event on the northeast side of Shishaldin Volcano, viewed from Alaska Volcano Observatory (AVO) monitoring network site WTUG. Note that meteorological clouds are also present in the scene; one partially obscures the upper part of the ash cloud. AVO image ID 194746.

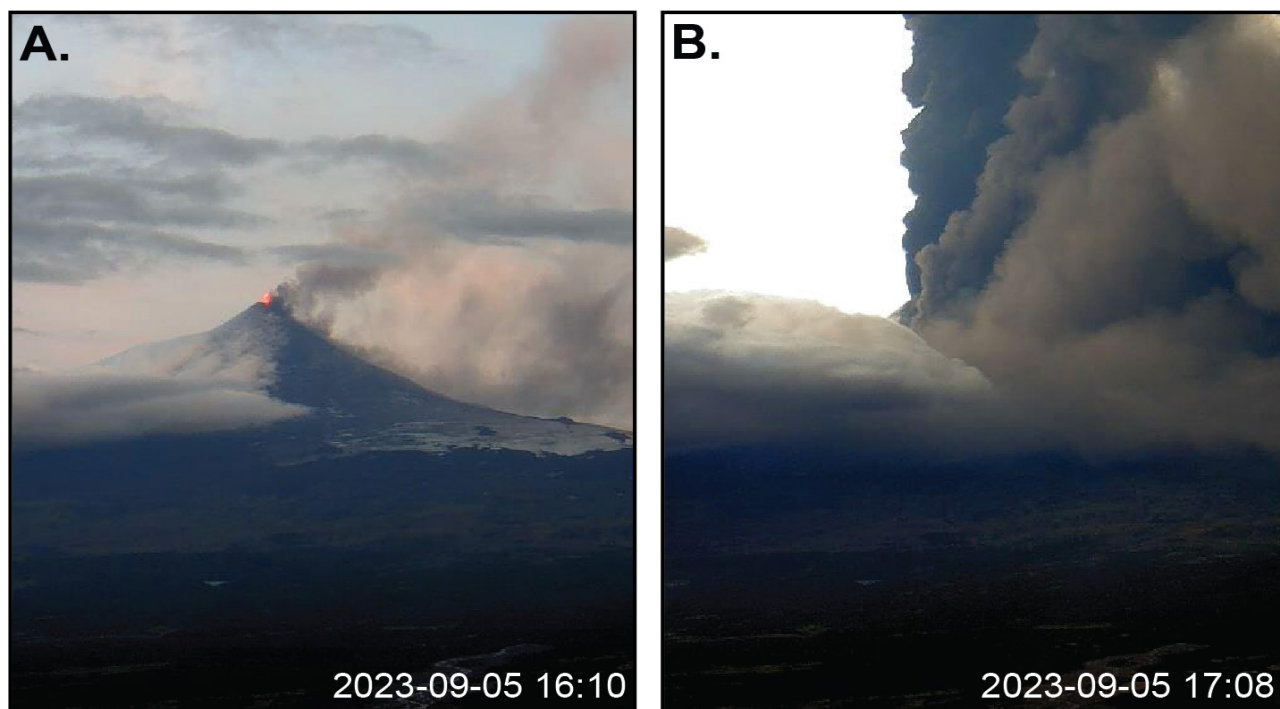


Figure 36. Sequential webcam images of lava fountaining and ash-rich paroxysm during Event 9 at Shishaldin Volcano, Alaska, on September 5, 2023. Images show a transition from high lava fountaining to an ash-rich paroxysm viewed from the south at Alaska Volcano Observatory (AVO) site BRPK. A) Lava fountaining with a diffuse ash plume is visible at 08:10 AKDT September 5 (16:10 UTC); B) An ash-rich paroxysm plume extending above the webcam field of view one hour later at 09:08 AKDT (17:08 UTC). AVO image ID 194824 and 194825.

visible in webcam imagery, extending above the camera field of view (fig. 36B). A peak plume height of 42,000 ft (12.8 km) ASL occurred at 10:20 AKDT (18:20 UTC). Ash was no longer detected after 13:30 AKDT (21:30 UTC) and AVO lowered the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH** at 14:14 AKDT (22:14 UTC).

Unlike the previous five events, which were directed northeast or south, Event 9's ash plume was directed to the east-southeast. On the day following the event, diffuse low-level ash was observed around the volcano, probably the result of a collapsing unstable slopes in the summit trough which may have grown during the paroxysm. The change in plume character was also reflected in the spectral characteristics of the satellite data, with the early plume appearing as a water/ice rich cloud with no ash signature and the later, low-level plume clearly ash-rich, probably reflecting its composition of finer-grained material.

In the week after Event 9, AVO noted small earthquakes and brief periods of elevated tremor, including a small infrasound detection consistent with a Strombolian explosion. The summit vent, however, was quite deep, and no surface activity or new deposits were noted. On the evening of September 13, AVO personnel observed steadily increasing tremor, and suspected that this would lead to another paroxysm. Webcam images showed incandescence at 01:34 AKDT on September 14 (09:34 UTC). AVO issued a VAN forecasting an imminent ash-producing event at 01:58 AKDT (09:58 UTC). No significant ash emissions were detected, however, and tremor levels soon decreased to background levels. A VAN noting this return to background was issued at 11:34 AKDT (19:34 UTC). While this period did not result in a strong paroxysm, it did appear to partially fill the crater with new material, consistent with a period of slightly elevated eruption activity between events 9 and 10.

Event 10 (September 15–16)

Tremor began increasing prior to Event 10 on September 15 around 04:00 AKDT (12:00 UTC). AVO issued a VAN forecasting an imminent ash-producing event at 14:52 AKDT (22:52 UTC). Webcam images from station ISLZ

southeast of the volcano first showed evidence of ash emissions at 17:05 AKDT (01:05 September 15 UTC), apparently from a PDC going down the volcano's northeast flank. A lightning detection at 17:28 AKDT (01:28 September 16 UTC) likely indicated the development of a much higher ash plume and prompted AVO to issue a VAN raising the Aviation Color Code and Volcano Alert Level to **RED** and **WARNING** at 17:41 AKDT (01:41 September 16 UTC). Peak lightning rates occurred around 17:40 AKDT (01:40 September 16 UTC) and peak ash height, as determined from satellite data, was 37,000 ft (11.3 km) ASL at 18:00 AKDT (02:00 September 16 UTC). Satellite data indicated ash emissions ended by 20:48 AKDT (04:48 September 16 UTC). AVO issued an updated VAN at 21:24 AKDT (05:24 September 16 UTC) stating that activity had decreased but was continuing at low levels. At 00:44 AKDT September 16 (08:44 UTC), AVO lowered the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH**.

Event 10 resulted in the first significant community ashfall event, with minor (5 mm) ash reported in False Pass, Alaska, between 18:00 and 20:30 AKDT on September 15 (02:00 and 04:30 September 16 UTC). Coarse lapilli-sized clasts also fell on a boat near Cape Pankof. The main plume axis was centered south of False Pass, coincident with this boat's location, and illustrating that coarse lapilli was carried in the ash plume over 40 km from the vent. Satellite observations after Event 10 showed continued growth of the northeast–southwest trough through the summit crater rim.

Event 11 (September 22–25)

Tremor began increasing prior to Event 11 on September 22 around 04:00 AKDT (12:00 UTC). This event had the longest duration (62.4 hours) of tremor prior to the onset of significant ash emissions. AVO issued the first VAN for an imminent ash-producing event on September 23 at 12:28 AKDT (20:28 UTC). Notifications confirming continued high levels of tremor were issued on September 23 at 18:11 AKDT (02:11 September 24 UTC), and on September 24 at 00:25 AKDT (08:25 UTC), 11:00 AKDT (17:00 UTC), and 18:14 AKDT (02:14 September 25

UTC). Over this time, tremor increased steadily, and satellite observations showed highly elevated surface temperatures at the summit, reflecting active eruption of lava inside the summit crater (fig. 37).

Low-level ash emissions near 10,000 ft (3 km) ASL were noted as early as 17:50 AKDT on September 24 (01:50 September 25 UTC) in satellite data and pilot reports. Meteorological clouds obscured the volcano starting around midnight (08:00 September 25 UTC). At 05:25 AKDT on September 25 (13:25 UTC) a VAN was issued indicating that ash was erupting up to 15,000 ft (4.6 km) ASL. Lightning was first detected at 05:42 AKDT (13:42 UTC), indicating the start of a more significant paroxysm. The peak ash height from this event reached 46,000 ft (14 km) asl at 05:50 AKDT (13:50) and was the highest measured plume during the eruption. AVO's notifications lagged event activity slightly with the first notice for observed ash emissions issued at 06:02 AKDT (14:02 UTC) when the Aviation Color Code and Volcano Alert Level were increased to **RED** and **WARNING**, but only noting ash emissions up to 20,000 ft (6.1 km) ASL. An update was issued at 07:09 AKDT (15:09 UTC), noting the ash had reached 45,000 ft (13.7 km) ASL. Seismicity and the main ash plume were short lived. A short secondary pulse of infrasound and associated ash emission occurred around 08:00 to 08:30 AKDT (16:00 to 16:30 UTC). At 12:34 AKDT (20:34 UTC), AVO lowered the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH** (fig. 37).

The ash plume was directed east along the Alaska Peninsula, with minor ashfall reported in False Pass, and trace ashfall reported in Cold Bay, King Cove, and Sand Point, Alaska (fig. 38). Flights were cancelled to and from Cold Bay, Sand Point, and False Pass throughout the day on September 25. Additional flight cancellations included flights to and from Unalaska/Dutch Harbor, the top fishing port in the United States. Ashfall at Cold Bay and the drifting ash cloud impacted local and international flight operations. Cold Bay's main runway is the fifth largest in Alaska and is used for scheduled passenger and cargo flights as well as by the U.S. Coast Guard and private medevac companies. It is a

key emergency alternate airport for twin-engine international flights and its lack of availability due to ashfall and the ash cloud resulted in diversions by passenger and air freight carriers.

After Event 11, the northeast–southwest notch in the summit crater appeared as a prominent feature bisecting the summit cone, and steaming persisted across its length in the following days.

Event 12 (October 2–3)

Event 12 tremor began around 21:00 AKDT on October 2 (05:00 October 3 UTC). Clear conditions after sunset allowed a few webcam images of incandescence starting at 21:31 AKDT (05:31 October 3 UTC). Webcam images starting at 23:31 AKDT (07:31 October 3 UTC) showed incandescence down the northeast flank from deposits of hot pyroclastic flows and lava fountaining at the summit (fig. 39). AVO issued a VAN describing active lava fountaining and potential for increased ash emission at 23:43 AKDT (07:43 October 3 UTC). Ash was first visible in satellite images at 02:50 AKDT on October 3 (10:50 UTC) and peaked at 05:50 AKDT (13:50 UTC) with a height of 38,000 ft (11.6 km) ASL, coincident with the first lightning detections at 05:47 AKDT (13:47 UTC, fig. 39). At 06:12 AKDT (14:12 UTC), AVO issued a VAN raising the Aviation Color Code and Volcano Alert Level to **RED** and **WARNING**. This notice was updated at 09:31 AKDT (17:31 UTC) stating ash emissions were continuing.

Morning webcam images showed ash drifting south off the volcano, probably from collapse events at the summit but also from notable plumes rising off the northeast flank (fig. 39F). The most obvious low-level ash-rich plumes were visible in satellite data until around 14:30 AKDT (22:30 UTC, fig. 40). While this activity was gradually decreasing, AVO lowered the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH** at 10:36 AKDT (18:36 UTC).

Satellite radar imagery acquired in the days following Event 12 indicated that there were several small explosion pits where pyroclastic flows had deposited hot material on glaciers. Some of these could have been the source of the secondary plumes observed on the northeast flank. Collapse

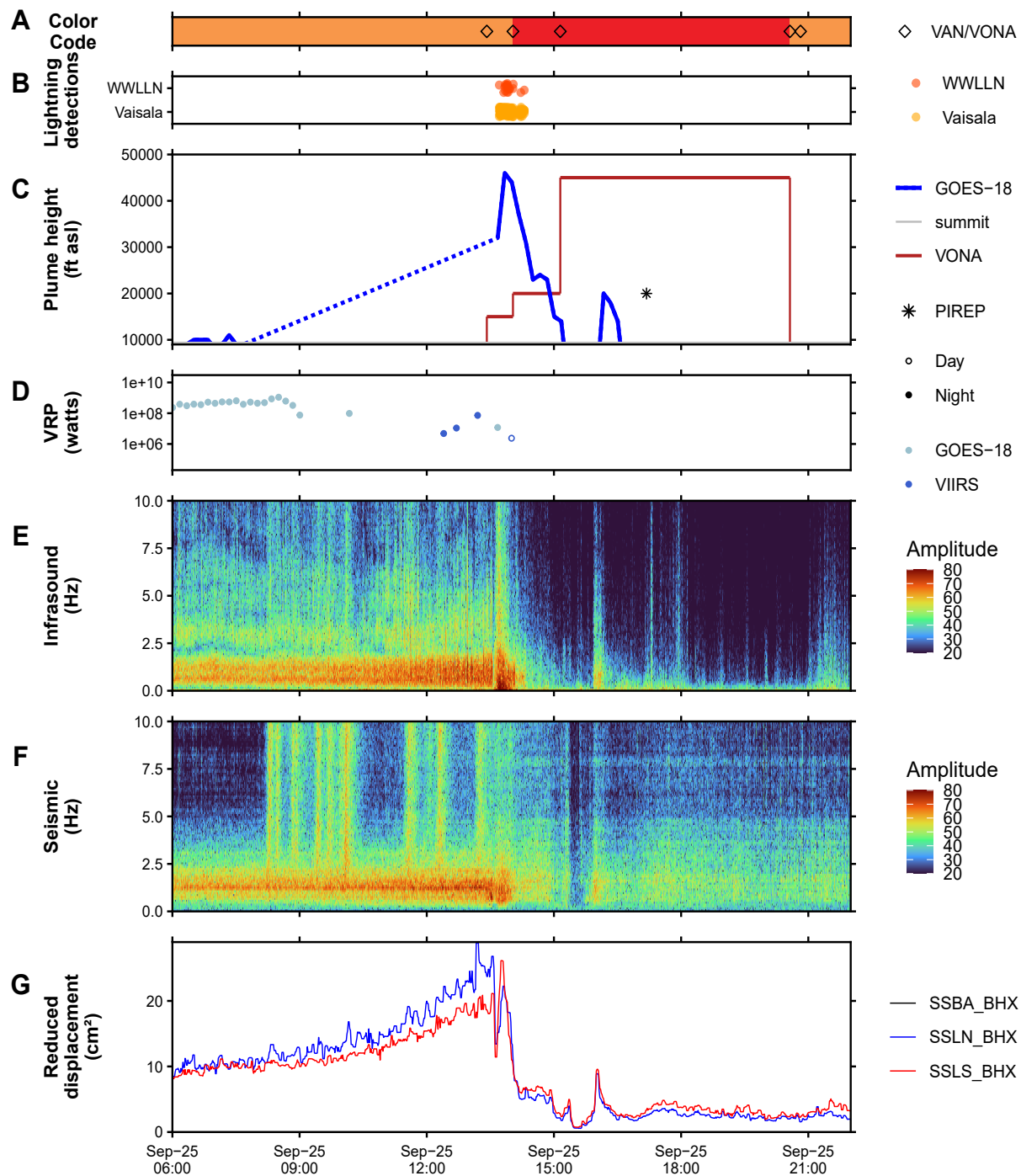


Figure 37. Timeline of Event 11 at Shishaldin Volcano, Alaska, showing monitoring data over the course of the event. Lightning, infrasound, and tremor all closely coincided with peak ash heights observed in satellite images. Eruptive activity in the hours immediately prior to the paroxysm was obscured by low-level clouds. See Figure 26 for a more detailed description of individual panels.

A.



B.



Figure 38. Photographs of ashfall impacts in Cold Bay and False Pass, Alaska, during Shishaldin Volcano Event 11 on September 25, 2023. A) Ashfall in Cold Bay, Alaska, at 11:57 AKDT (19:57 UTC) on September 25 following the end of ashfall, showing a 12×12-inch measured area sample (photo by Alison Williamson, USFWS); B) A pickup truck in False Pass, Alaska, at 10:30 AKDT (18:30 UTC) on September 25 (photo by Melanie Hoblet). Alaska Volcano Observatory (AVO) image database IDs 194934 and 194929.



Figure 39. Webcam images of Event 12 eruptive activity at Shishaldin Volcano, Alaska, on October 2–3, 2023. Images are from ISLZ southeast of Shishaldin Volcano on October 2–3 of Event 12 activity (annotated times are in UTC). A) In the evening of October 2, the volcano was quiet and the cone breach from earlier paroxysms clearly visible; B) Lava activity at the summit was clearly visible at night; C) Lava fountaining increased overnight, resulting in a series of pyroclastic flows down the northeast flank visible before and during the main paroxysm phase; D) By daybreak on October 3, the vent plume was mostly steam, and low-level residual ash was visible drifting south; E) Continued collapse events from the steep sides of the summit crater were visible throughout the day, creating continued pyroclastic flows down the northwest flank; F) In addition, a distinct plume source was visible from the northeast flank, possibly from explosions where hot pyroclastic debris were interacting with underlying glacier ice.

events and small plumes from the northeast flank continued for several days after Event 12. In addition to repeated collapse events and associated ash clouds, the post-Event 12 activity included persistently elevated seismic tremor and SO₂ emissions. Thermal anomalies were observed along the northeast–southwest trough through the summit cone. During favorable atmospheric conditions, an impressive steam plume from the summit was seen. On October 15 at 12:43 AKDT (20:43 UTC), AVO issued a VAN noting this robust steam plume and stating that ash emissions were not occurring.

An Information Statement issued by AVO on October 20 at 11:42 AKDT (19:42 UTC) discussed the ongoing activity at Shishaldin Volcano after Event 12, and specifically the persistent elevated surface temperature, SO₂ emissions, and the prominent presence of a northeast–southwest trough across the summit. The statement noted that the volcano appeared more “open-system,” which would somewhat decrease the likelihood of future explosive activity, but that collapse events from the unstable summit were likely and could generate ash clouds up to 25,000 ft (7.6 km) ASL with little or no warning.

On October 31 at 12:51 AKDT (20:51 UTC), AVO lowered the Aviation Color Code and Volcano Alert Level to **YELLOW** and **ADVISORY** due to a decline in seismic activity and SO₂ emissions over the previous week. The decrease in activity suggested a pause in the eruption.

Event 13 (November 2–3)

The period at lower alert level was short-lived. On November 2 at 19:00 AKDT (03:00 November 3 UTC), tremor began increasing. Recognizing this renewal of activity, AVO raised the Aviation Color Code and Volcano Alert Level to **ORANGE** and **WATCH** at 20:31 AKDT (04:31 November 3 UTC). In retrospect, low-level ash emissions were visible in satellite images as early as 19:40 AKDT (03:40 November 3 UTC) and continued until 06:40 AKDT on November 3 (14:40 UTC). Peak cloud heights were only 20,000 ft (6.1 km) ASL and partially obscured by meteorological clouds. At 21:45 AKDT on November 2 (05:45 November 3 UTC) AVO issued an update noting the low-level

and ongoing ash emissions. At 08:31 AKDT on November 3 (16:31 UTC), a notice was issued that ash was no longer visible, and seismic activity had decreased. Persistent cloudy conditions obscured more detailed observations of Event 13.

Post-eruption Unrest

Event 13 was the final explosive event of the 2023 eruption of Shishaldin Volcano. Throughout November, elevated seismicity, SO₂ emissions, elevated surface temperatures along the northeast–southwest summit notch and steaming from the summit crater were observed. This activity continued but at a diminished rate in December until the end of the year.

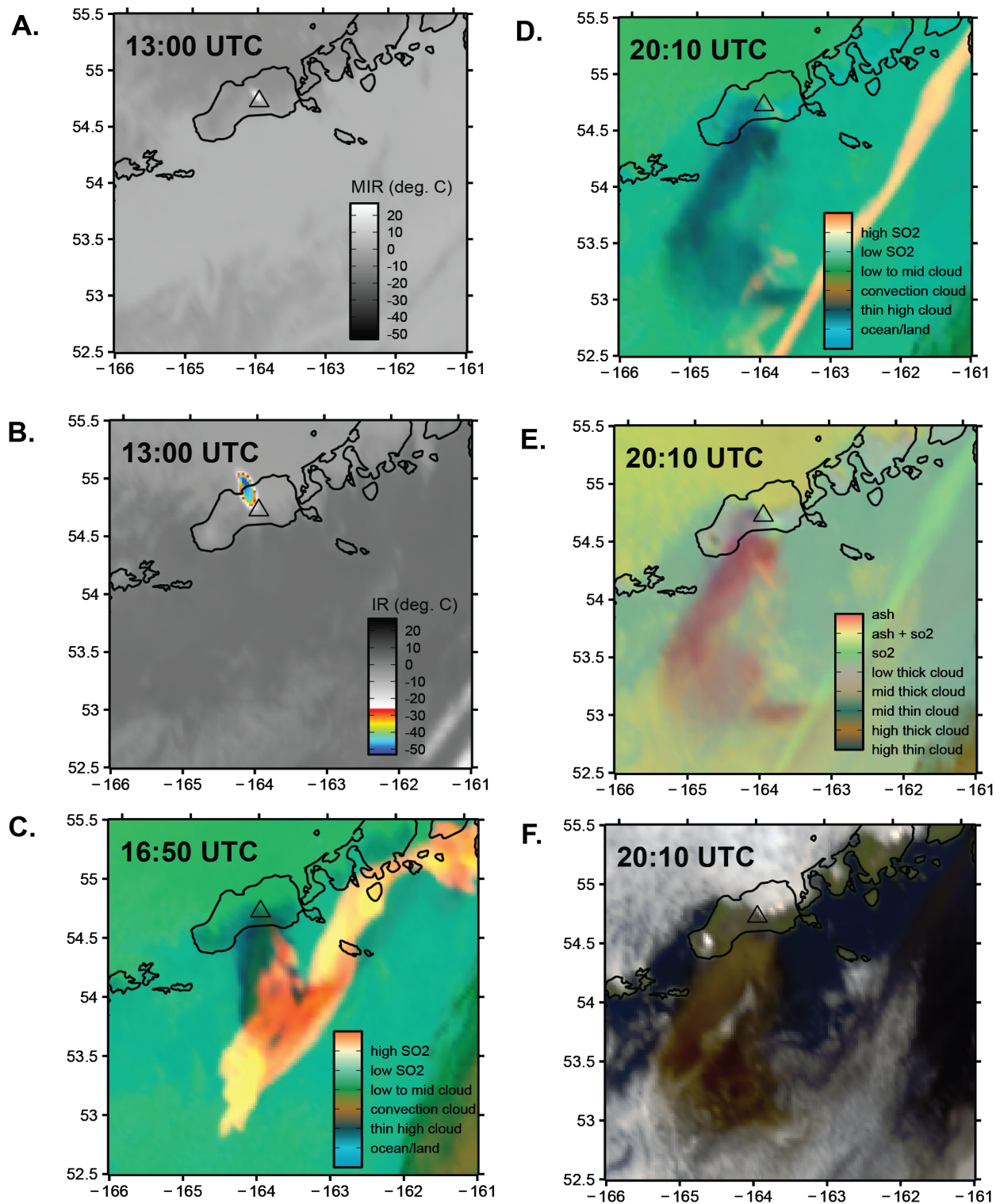


Figure 40. October 3, 2023, Geostationary operational environmental satellite (GOES)-18 images for Shishaldin Volcano Event 12. A) Pre-paroxysm lava fountaining reflected in a strong mid-infrared (IR) signature; B) Initial paroxysm plume is highlighted by a rapidly cooling (tall) plume offset to the north due to parallax; C) The initial high paroxysm plume drifting east, where there was trace ash reported in Cold Bay, and south and distinguished with a strong SO₂ multispectral signature; D–F) The trailing plume the following day differed from the paroxysm plume which is only seen as a thin stretched band in SO₂ products (D), but had a strong ash multispectral signature (E) and was visibly brown in daytime visible light images (F).

Bogoslof Volcano

GVP# 311300
53.927°, -168.034°
88 m
Fox Islands, Aleutian Islands

ELEVATED SEISMICITY



Bogoslof volcano is a submarine, back-arc stratovolcano in the Bering Sea with an emergent summit comprised of several small, low-lying islands. The highest point of the volcano above sea level prior to the 2016–2017 eruption was about 100 m (300 ft). However, the volcano is frequently altered by both eruptions and wave erosion (Waythomas and Cameron, 2018). The two main islands currently above sea level are Fire Island and Bogoslof Island; both located about 98 km (61 mi) northwest of Unalaska-Dutch Harbor, Alaska, 123 km (76 mi) northeast of Nikolski, Alaska, and 149 km (93 mi) northeast of Akutan, Alaska.

There have been nine eruptions documented at Bogoslof volcano since 1741 (Waythomas and Cameron, 2018), the last of which occurred in 2016–2017 (Coombs and others, 2019). Eruptions of the volcano are often characterized by multiple explosive, ash-producing events and the growth of new lava domes.

On October 22, 2023, AVO seismologists noted a rapid increase in seismic activity at Bogoslof volcano above background rates. Event rates peaked that day at a rate of over 200 events/day, whereas in contrast, only one event had been recorded between the conclusion of the volcano's last eruption in 2016–2017 (Coombs and others, 2019) and the onset of the 2023 seismic activity. Despite a lack of other signs of volcanic unrest, the intensifying earthquake activity prompted AVO to raise the Aviation Color Code to **YELLOW** and Volcano Alert Level to **ADVISORY** on October 24. Throughout the earthquake sequence, more than 40 events recorded a magnitude M_L 2.0 and above. The largest event, a M_L 2.98, occurred on October 26. Event rates and magnitudes gradually declined towards the end of October. By November 1, event rates had fallen to 1–2 events/day, and isolated earthquakes continued to occur once every few days until the end of the month. Noting

the decay of seismicity at Bogoslof volcano, AVO lowered the Aviation Color Code and Volcano Alert Level to **UNASSIGNED** on November 24.

Retrospective matched-filter analysis using seismic waveforms recorded on seismic station MAPS (located on Unalaska Island, 73 km from Bogoslof volcano) revealed subtle fluctuations in earthquake rates throughout the duration of the seismic swarm (fig. 41) (following methods of Wech and others, 2018). The analysis suggested that seismic activity had increased around October 20, 04:34 local time (13:34 UTC), although several isolated, low-confidence detections were made in the preceding months. Another interesting characteristic of the 2023 seismic swarm was its seemingly linear distribution of hypocenter locations along a northwest–southeast axis (fig. 42). Retrospective evaluation of the largest principal error of the calculated hypocenters suggested poorer locational constraints along a 295° azimuth, which aligns well with the observed hypocenter scatter. This suggests that network geometry and station spacing were likely the primary cause of the linear distribution, rather than it being due to a subsurface fault or volcanic feature.

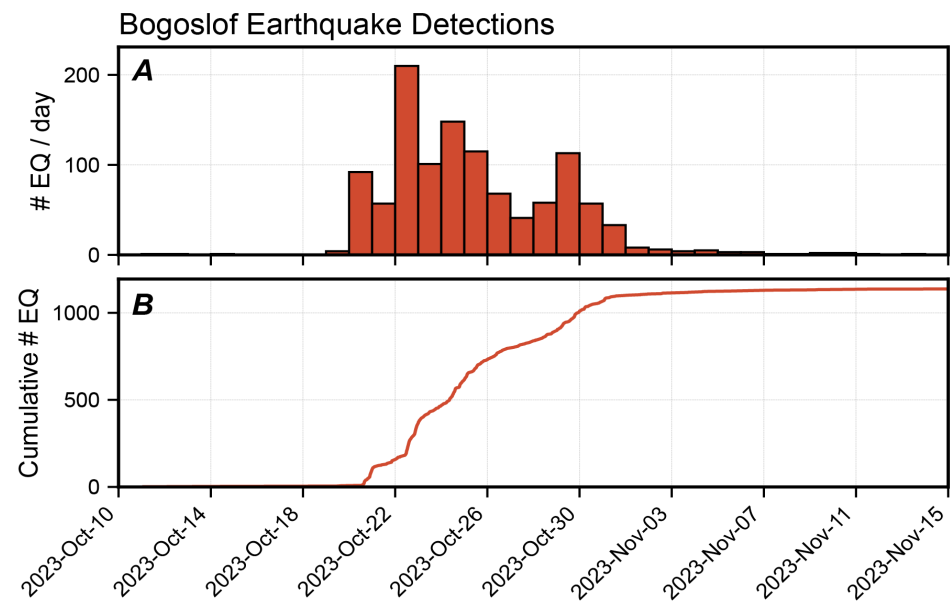


Figure 41. Histogram and cumulative count of earthquakes at Bogoslof volcano, Alaska, from October 10 to November 15, 2023. A) Histogram of earthquakes occurring per day at Bogoslof volcano from October 10, 2023, to November 15, 2023, as determined by matched-filter analysis using MAPS.BHN (Wech and others, 2018); B) Graph of the cumulative earthquake counts over the same time period.

AVO Catalog (2023/10/15 to 2023/11/15)

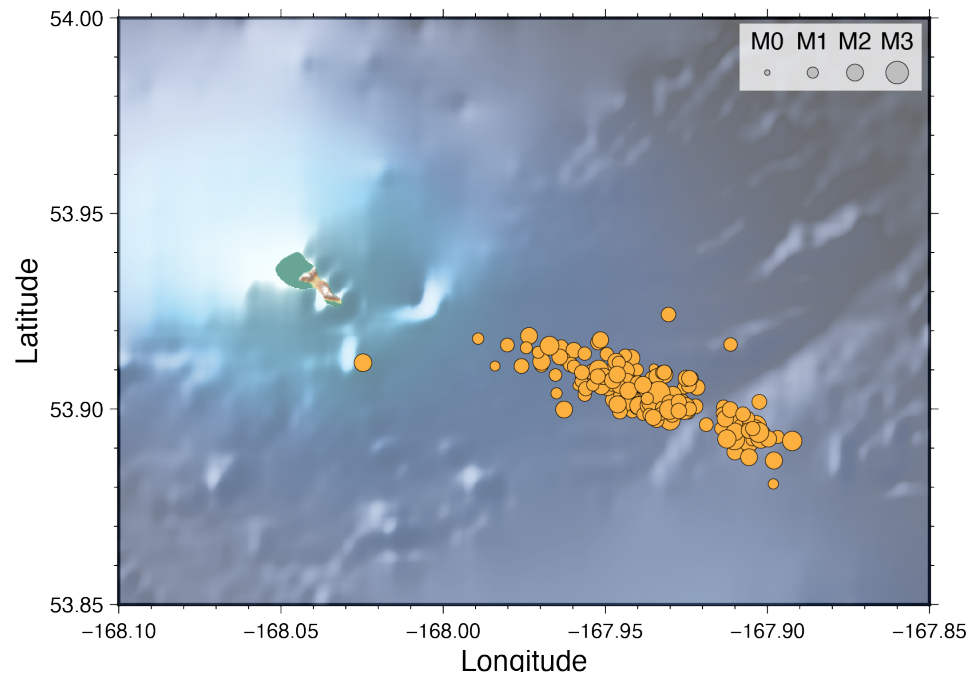


Figure 42. Map of earthquake hypocenter locations at Bogoslof volcano, Alaska, from October 10 to November 15, 2023. Events are sized by magnitude. The northwest-southeast trend of hypocenter locations was likely an artifact related to network geometry and station spacing.

Mount Cleveland

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

ELEVATED SURFACE TEMPERATURES, GAS EMISSIONS, ELEVATED
SEISMICITY



Mount Cleveland forms the west side of the uninhabited Chuginadak Island, which is part of the Islands of the Four Mountains group in the east-central Aleutian Islands (fig. 1). Mount Cleveland is ~75 km west of the community of Nikolski and 1,525 km southwest of Anchorage (fig. 1). Its eruptions since 1741 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 took place every year from 2001 to 2020 (Iezzi and others, 2020)—the last explosive eruption at Mount Cleveland occurred in June 2020 (Orr and others, 2024a).

The 2023–2024 period at Mount Cleveland was characterized by relatively low activity. The

volcano began the year at Aviation Color Code and Volcano Alert Level **YELLOW/ADVISORY** (fig. 43A), which it had been at since May 11, 2022, due to a high number of satellite observations of elevated surface temperatures and SO_2 . As a response to a decreasing number of thermal detections and their associated radiative power, AVO lowered the Aviation Color Code and Volcano Alert Level to **UNASSIGNED** on January 5, 2023. From January to early July 2023, elevated surface temperatures were routinely observed in satellite images (fig. 43B). Between July 10–11, 2023, a small ($M_L > 0.5$) earthquake swarm was detected by the Mount Cleveland seismic network. Another swarm on July 18 (fig. 43C) which included two events of $M_L 1.85$ and $M_L 1.08$ within 3 km of the summit at a shallow depth (> 5 km). As a response to these seismic swarms, the Aviation Color Code and Volcano Alert Level at Mount Cleveland was raised from **UNASSIGNED** to **YELLOW/ADVISORY** on July 19, 2023. Mount Cleveland remained relatively inactive after the color/alert level was raised. Due to an expansion of the seismic network during 2023 fieldwork, Mount Cleveland now met the criteria for listing as a “monitored” volcano (Coombs and others, 2024) for the first time since the founding of AVO. As a result of continually decreasing activity, the Aviation Color Code and Volcano Alert Level for Mount Cleveland was lowered from **YELLOW**

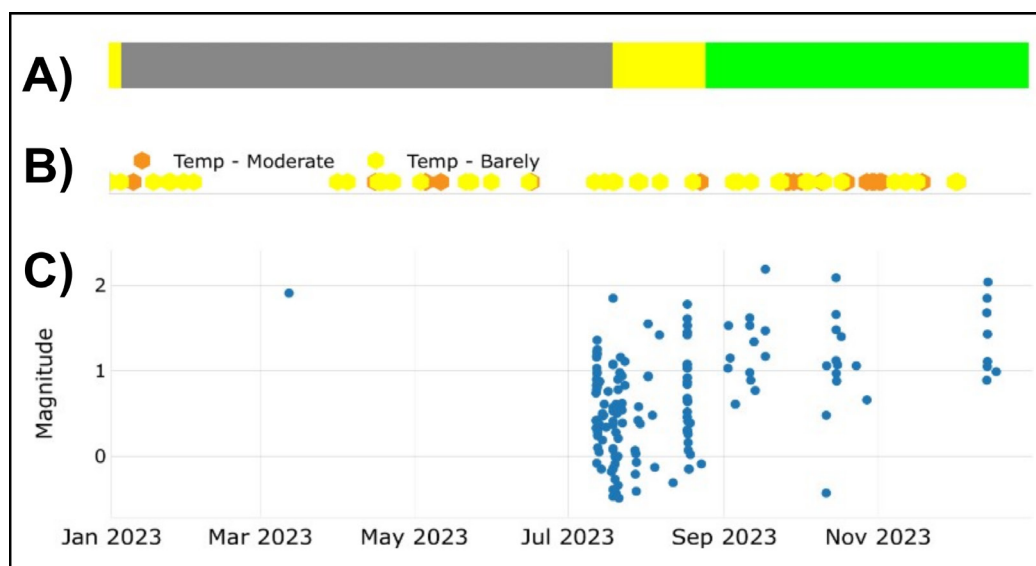


Figure 43. Timeseries of Aviation Color Code, thermal anomalies, and earthquake detections at Mount Cleveland, Alaska, in 2023. A) Timeseries of Mount Cleveland demonstrating the Aviation Color Code during 2023. Yellow indicates Aviation Color Code YELLOW; grey indicates Aviation Color Code UNASSIGNED; green indicates Aviation Color Code GREEN; B) Timeseries of thermal anomaly detections for Mount Cleveland 2023. Yellow hexagons indicate a thermal anomaly which is qualitatively “barely” above background and orange hexagons indicate a thermal anomaly which is qualitatively rated as “moderate” compared to background; C) Timeseries of earthquake detections at Mount Cleveland during 2023. A lack of earthquakes during the winters may be indicative of a decreased ability to detect events due to network degradation.

to **GREEN** for the first time on August 25, 2023. An increase in the frequency of thermal anomaly detections started around September 26 and continued for a period of ~2 weeks (fig. 43B). Activity remained low at Mount Cleveland for the rest of the year

A volcanic gas geochemical survey of Mount Cleveland was conducted on June 1, 2023, using helicopter-mounted multi-component gas analyzer system (MultiGAS) and Differential Optical Absorption Spectroscopy (DOAS) instrumentation. Water vapor (H_2O), carbon dioxide (CO_2), and SO_2 gas species were all detected by MultiGAS during two plume punch-throughs. A permanent scanning DOAS instrument was installed during the 2023 field season at Mount Cleveland, expanding the network to two scanning DOAS instruments.

Great Sitkin Volcano

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

ELEVATED SEISMICITY



Great Sitkin Volcano is an intermediate composition 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 consists of an older caldera partially filled by a younger parasitic cone, containing a summit crater 2–3 km in diameter partly filled by young lava flows. Great Sitkin Volcano erupted at least twice in the 20th century. In 1974, a lava dome formed in the summit crater during which time at least one ash cloud, with a maximum altitude of ~10,000 ft (~3,000 m) ASL, was observed (Associated Press, 1974). A poorly documented eruption in 1945 also produced a lava dome, which was then partially destroyed by the 1974 eruption. One other previous eruption at Great Sitkin may have occurred within the past 280 years; this event produced pyroclastic flows that partially fill 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, anomalous steaming from its summit crater, and small explosive events (Dixon and others, 2020). This activity culminated in a Vulcanian explosion on May 25, 2021, followed in mid-July by an effusive eruption that began to gradually fill the summit crater, overtopping the crater rim in two places (Orr and others, 2023). Effusion continued unabated thereafter, and the volcano was kept at **ORANGE** and **WATCH** for the rest of 2021, all of 2022 (Orr and others, 2025), and all of 2023.

Lava flow activity in 2023 was dominantly characterized by the steady eastward expansion of the “phase 2” lobe of the flow (fig. 44). In late December, however, this eastward expansion halted, and activity consisted of inflation of the central part of the flow (fig. 45). This ultimately culminated in the opening of a north-northwest–south-southeast trending crack at the end of December (fig. 45D).

Overall seismic activity increased at Great Sitkin Volcano from 2022 to 2023, and AVO detected 502 earthquakes at Great Sitkin in 2023. The majority of these occurred between the beginning of July and the end of December (fig. 46) and were located largely beneath the summit (fig. 47). There was, however, a small swarm of earthquakes at the beginning of 2023 located just offshore to the east of Great Sitkin Island (fig. 47). Regardless of location, earthquakes were dominantly located between 5- and 15-km depth (fig. 46).

Weather at Great Sitkin Volcano was largely cloudy for 2023, obscuring many webcam and satellite views. When clear weather occurred, weakly elevated surface temperatures with occasional minor steaming from the summit lava flow were typically observed (fig. 46A). While it is tempting to correlate increased observations of steam to increased earthquake detections starting around July, a preferred explanation is that the increased observations in steaming from the summit are simply due to seasonal variations in humidity and viewing conditions (i.e., dark background in summer). Furthermore, elevated surface temperatures show a uniform distribution throughout the year.

Figure 44. Aerial photograph of the Great Sitkin Volcano summit lava flow, Alaska, taken in late summer 2023. Photo is looking to the southwest from above the northeast flank of the volcano, taken during fieldwork in late summer 2023. Annotated on the photo are polygons for different phases of the lava flow and different eruptions. Yellow markers indicate locations where samples were collected. In the foreground of the annotated polygons is the intracrater ice field. Alaska Volcano Observatory image database ID 194814.

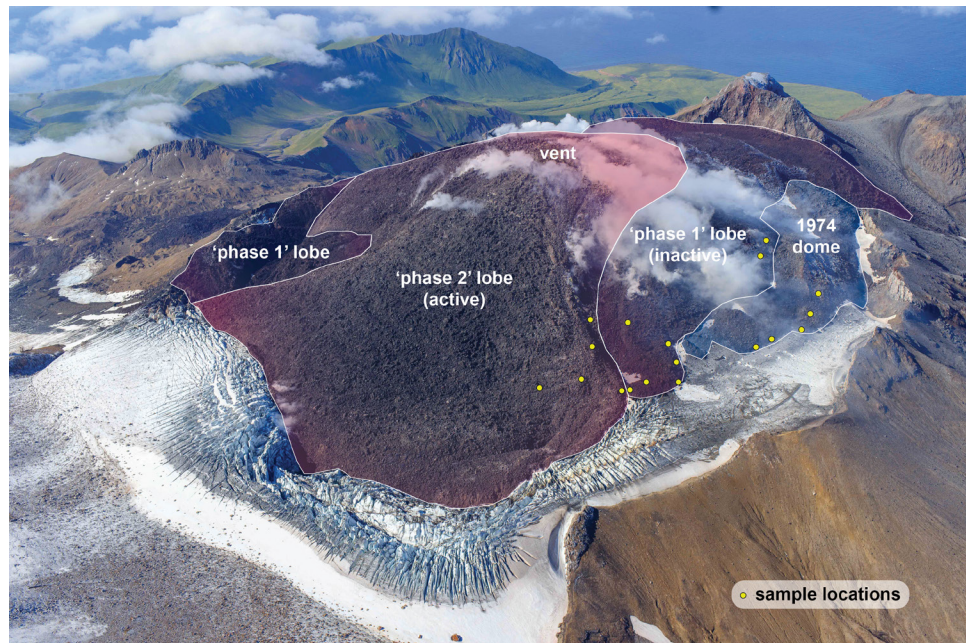
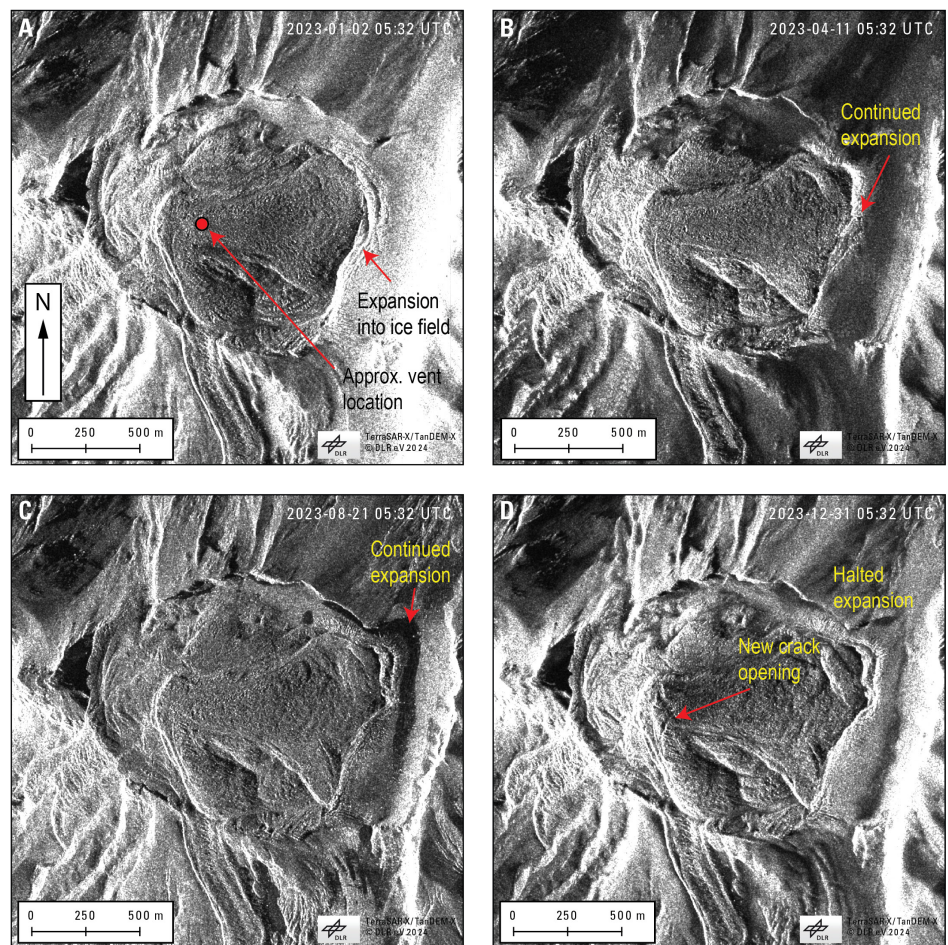


Figure 45. Sequence of synthetic aperture radar imagery capturing growth of the Great Sitkin Volcano lava flow, Alaska, in 2023. Satellite imagery from TerraSAR-X and TerraSAR-X add-on for Digital Elevation Measurement (TanDEM-X) captures the growth of the Great Sitkin Volcano lava flow field in 2023, as well as the deformation of the glacier surrounding the lava flow front. A) January 2, 2023, image showing the active eastern lobe of the Great Sitkin Volcano lava flow flowing into the intracrater glacier, which has arcuate cracks parallel to the lava flow margin; B) April 11, 2023, image showing growth of this active eastern lava lobe further into the glacier to the east and along the glacial margin to the south since January; C) August 21, 2023, image showing continued expansion and thickening of the lava flow to the east and south against the glacier. The summer snow-free glacial surface reveals numerous radial cracks away from the lava flow in addition to the parallel arcuate ones; D) December 31, 2023, image shows further thickening but only minor expansion of the eastern lava lobe. Inflation and radial crack opening on the lava flow surface above the vent region that began in November 2023 is now visible. Imagery © DLR e.V. 2024, courtesy of Simon Plank (German Aerospace Center).



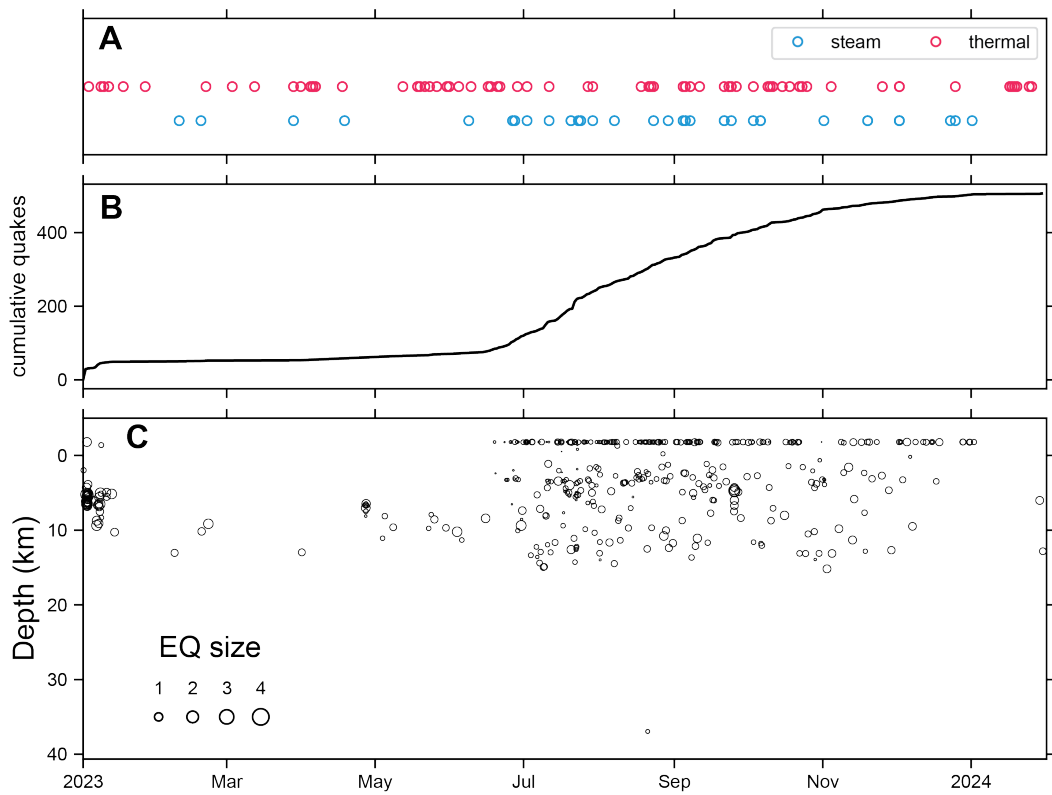


Figure 46. Chronology of eruptive activity at Great Sitkin Volcano, Alaska, in 2023, showing surface temperatures, steam detections, and earthquake data. A) Remote Sensing Database detections for both elevated surface temperatures (red) and steam (blue); B) cumulative earthquakes; C) Earthquakes plotted as a function of their depth and magnitude.

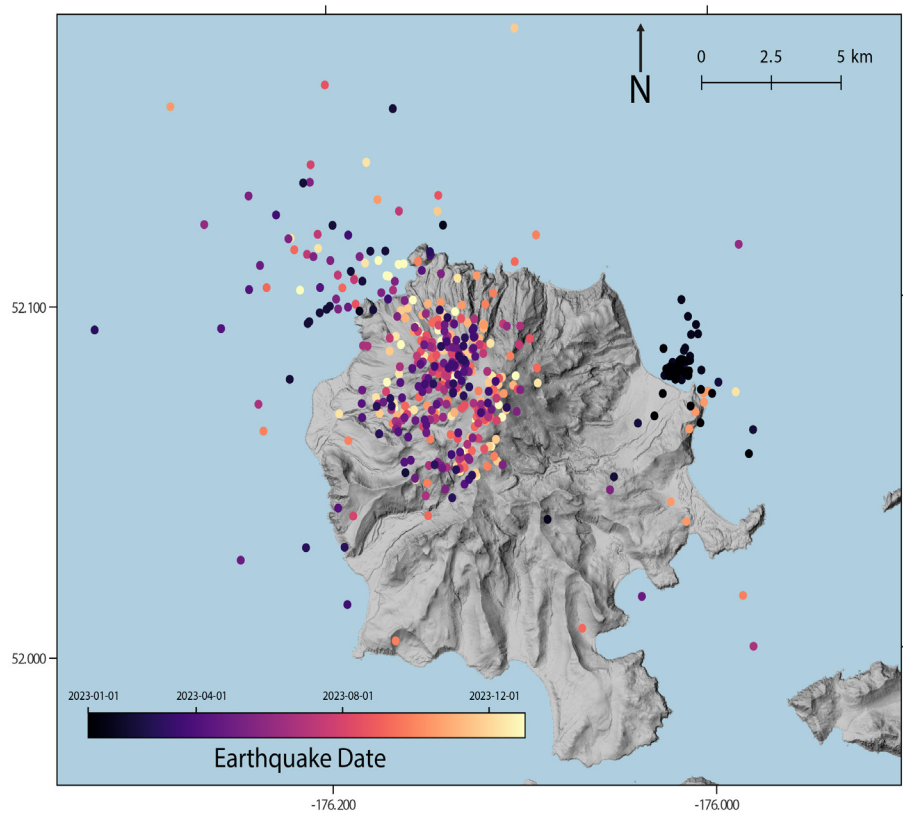


Figure 47. Map of earthquake detections at Great Sitkin Volcano, Alaska, in 2023. Earthquake detections are colored by the date they occurred. This illustrates the initial swarm in early 2023 well and how it differs from the majority of earthquakes that occurred throughout the year.

AVO completed geologic fieldwork at Great Sitkin Volcano during the second half of August and the first week of September 2023. Samples of the 05/2021–09/2023 lava flow were collected and a structure from motion (SfM) flight was completed. Figure 44 illustrates sampling locations. Initial textural observations of lavas from different phases of the lava flow show both are crystal rich with phenocrysts of plagioclase, orthopyroxene, clinopyroxene, and minor Fe-Ti oxides. Minor olivine is also present in some samples. There is little to no matrix glass present and matrix material is dominated by microcrystalline groundmass of a similar

composition to phenocrysts. Both plagioclase and pyroxene display frequent zoning. There is no obvious textural difference between different phases of the lava flow, although this remains an area of active research (fig. 48).

Kanaga Volcano

GVP# 311110
51.924°, -177.162°
1,296 m
Kanaga Island, Andreanof Islands,
Aleutian Islands
PHREATIC ERUPTION

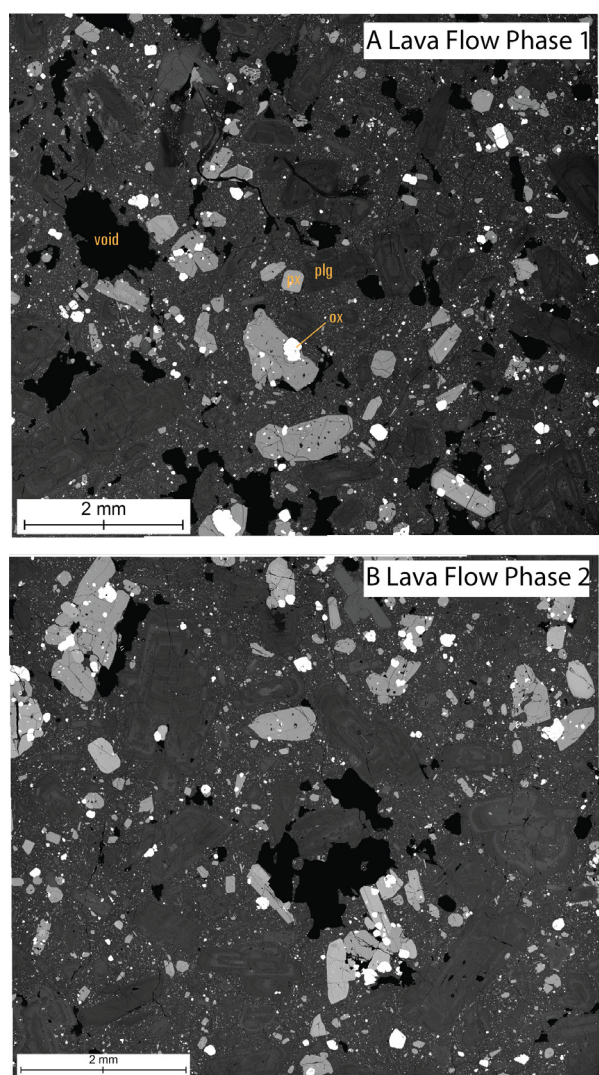


Figure 48. Backscattered electron image mosaics of lava samples collected at Great Sitkin Volcano, Alaska, in late summer 2023. Representative backscattered electron (BSE) image mosaics for phase 1 (A) and phase 2 (B) of lava samples collected during fieldwork in late summer of 2023 illustrating the textural and phase similarity of both phases of the lava flow. Darker gray phases are plagioclase (plg), light gray are pyroxene (px), white are Fe-Ti oxides (ox), and black regions are void space.

Kanaga Volcano is a symmetrical stratocone located on the northern end of Kanaga Island in the western Aleutian Islands, 33 km west of the community of Adak. Numerous eruptions have been recorded since the mid-1700s (Waythomas and others, 2002), with the most recent occurring in 2012 (Herrick and others, 2014) that produced a fracture across the southwest summit in a northwest–southeast direction. Active fumaroles persist in the summit region and hot springs occur near the base of the volcano. AVO monitors the volcano with local seismic stations (fig. 49), a single infrasound sensor, and a webcam, as well as regional infrasound and lightning networks and a variety of satellite data.

Infrasound provides conclusive evidence that a discrete explosive event occurred 10 seconds after the M_L 2.6 earthquake at 21:31:49 HAST December 18 (07:31:49 UTC December 19). Station KINC is equipped with both a seismic and infrasound sensor and is located 2.5 km from Kanaga Volcano's summit. A clear acoustic arrival is apparent at 21:31:56 HAST December 18 (07:31:56 UTC December 19), and the acoustic travel time from Kanaga Volcano to KINC is ~7 s (fig. 50C, D). The infrasound signal has a peak amplitude of 37 Pa, broadband energy up to at least 20 Hz, and lasts ~60 s. No infrasound from this event was detected on regional infrasound arrays. Based on the seismic and infrasound interpretations, AVO raised the Volcano Alert Level to **ADVISORY** and Aviation Color Code to **YELLOW** on December 19 at 11:02 HAST (21:02 UTC).

High-resolution satellite imagery revealed

multiple new cracks, or fractures, in the summit area following the explosive event (fig. 51). A northwest–southeast trending crack crosses the summit rim on the western portion, and a west–east oriented crack intersects the large crack from the 2012 eruption. A northeast–southwest trending crack along the eastern edge of the rim may also be present. Weakly elevated surface temperatures were also observed at the summit in

VIIRS nighttime mid-IR imagery in clear views on December 24–25. No post-event imagery showed clear signs of an ash deposit or ballistics, presumably related to the short duration and relatively small plume expected from this event.

Figure 52 displays the earthquakes detected surrounding the explosive event. As noted earlier, no obvious precursory seismicity was detected prior to the December 19 eruption. Twenty-nine

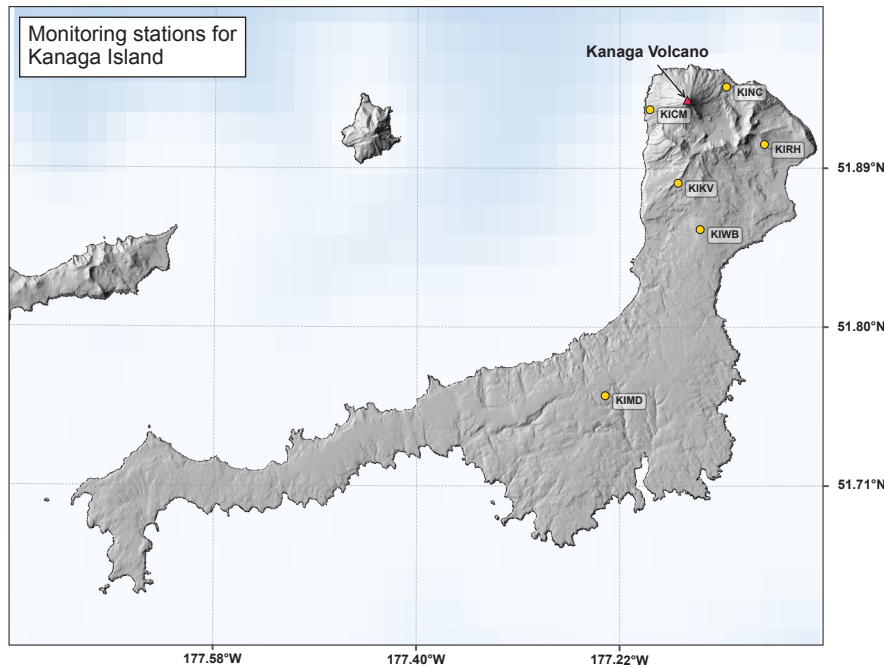


Figure 49. Map of Alaska Volcano Observatory seismic monitoring station locations on Kanaga Island, Alaska.

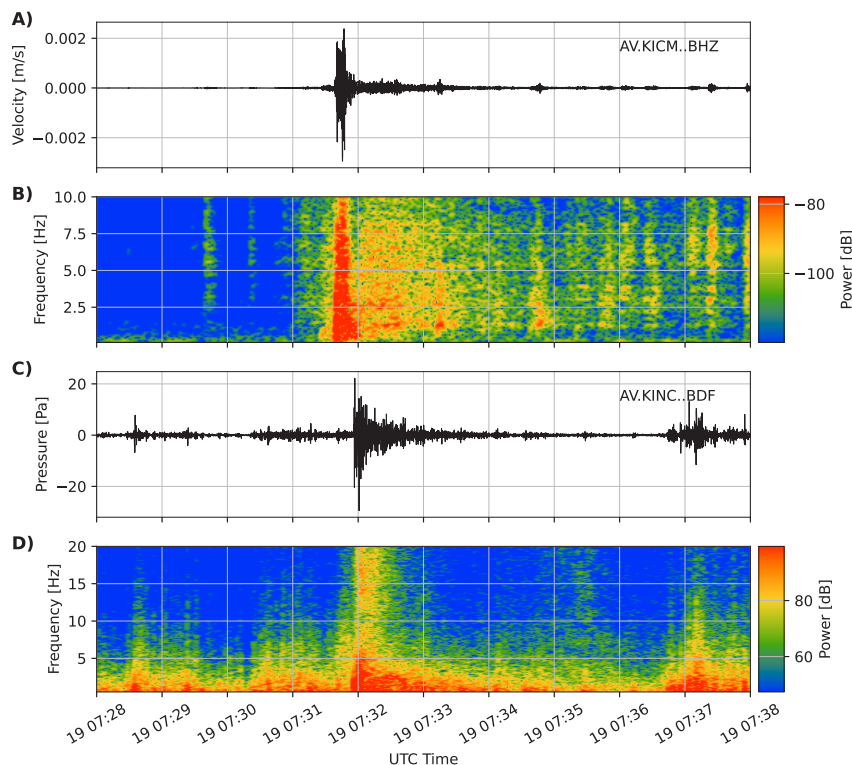


Figure 50. Seismic and infrasound waveforms and spectrograms from the December 19, 2023, explosive event at Kanaga Volcano, Alaska. A) Seismic waveforms, B) Spectrogram of the data in A, C) Infrasound waveform, D) Spectrogram of the data in C. All timeseries are for duration immediately around the December 19 explosive event as recorded on station KICM (seismic) and KINC (infrasound). A weak seismic event occurs around 21:29:30 HAST December 18 (07:29:30 UTC December 19), followed by low-level tremor at 21:30:00 HAST December 18 (07:30:00 December 19), and then a discrete earthquake and explosion starting at 21:31:39 HAST December 18 (07:31:39 UTC December 19). Discrete events and tremor occur after the eruption. The seismic waveforms are filtered between 0.5–10 Hz. A clear, impulsive infrasound signal is detected and lasts ~60 s. The infrasound waveforms are filtered between 1–10 Hz.

earthquakes were then detected on December 18–19 with depths ranging from the surface to 14 km. Seismicity remained elevated through the end of December and consisted of occasional small earthquakes at a rate of a few per day. On January 2, 2024, a weather-related monitoring network outage occurred in the region, resulting in the loss of local geophysical and webcam data. Satellite images, when not obscured by

clouds, showed no changes at Kanaga Volcano. Geophysical data returned on January 28 and low rates of earthquakes continued to be detected. Weak seismic tremor was detected on February 11. Seismicity slowly decreased to background levels and on February 27, 2024, AVO lowered the Aviation Color Code and Volcano Alert Levels to **GREEN/NORMAL**.

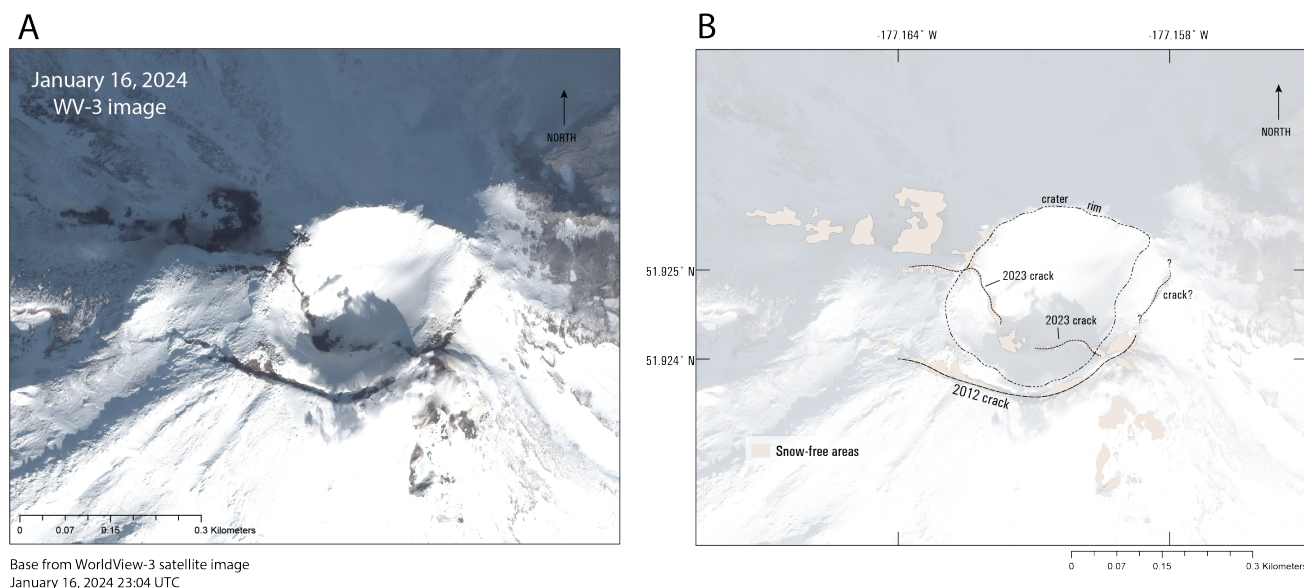


Figure 51. WorldView-3 satellite image showing cracks and snow-free areas at the summit of Kanaga Volcano, Alaska, on January 16, 2024. A) WorldView-3 image ©2025 Maxar Technologies; B) Annotated map at same scale labeling the features visible in the satellite image.

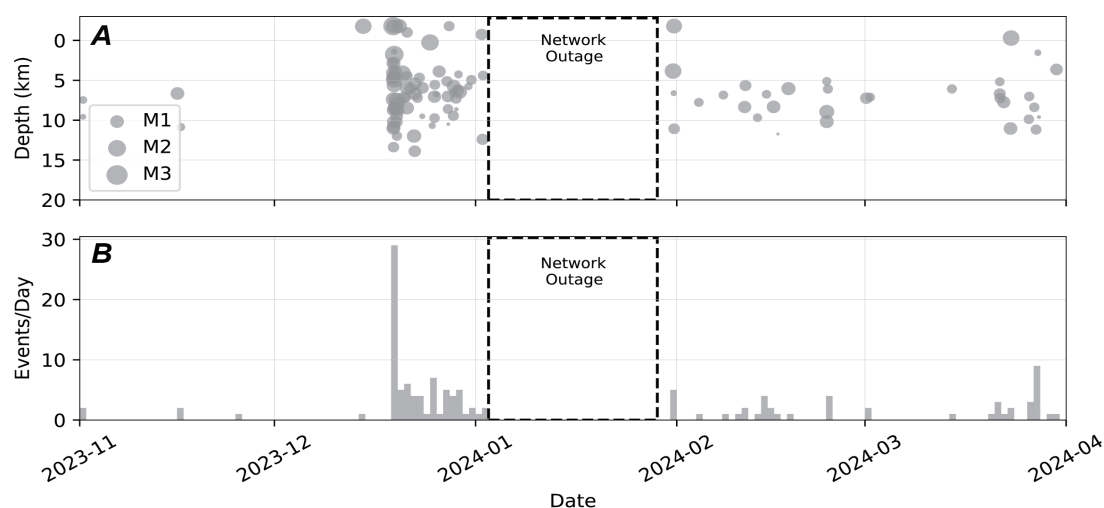


Figure 52. Earthquake activity detected at Kanaga Volcano surrounding the December 19, 2023 eruption. The top panel (A) shows the earthquakes depths versus time, with each earthquake marker sized by the magnitude. The bottom panel (B) shows the number of earthquakes per day. A regional seismic network outage in January 2024 limited observations.

Takawangha and Tanaga volcanoes

GVP# 311090, #311080

51.867°, -178.027° / 51.884°, -178.143°

1,442 m / 1,805 m

Tanaga Island, Andreanof Islands,
Aleutian Islands

GROUND DEFORMATION, ELEVATED SEISMICITY



Takawangha volcano and Tanaga Volcano are located on the northern portion of Tanaga Island, in the Andreanof Islands. They are roughly 95 and 100 km west of the City of Adak, Alaska, respectively, and 1,880 km southwest of Anchorage (fig. 1). Takawangha volcano, a stratovolcano, lies across a saddle from the Tanaga Volcano complex to the west. Takawangha volcano's summit is mostly ice-covered, except for four craters that have erupted ash and produced lava flows in the last few thousand years. Although no eruptions have been documented at Takawangha volcano since 1741, geologic field work shows recent eruptions have occurred and it is possible that historical eruptions attributed to Tanaga Volcano may instead have come from Takawangha volcano (Coombs and others, 2007). Tanaga Volcano is a volcanic complex located on the western end of the island. The volcano includes three overlapping stratocones: Sajaka volcano on the west flank, Tanaga Volcano in the center, and another vent, informally called East Tanaga, on the northeast flank. There are several records of recent eruptions including in 1763–1770, 1791, 1829, and 1914. Deposits on the flanks of the volcano show that typical eruptions produce blocky lava flows and occasional ash clouds. Edifice collapse into the sea occurred from the Sajaka cone at least once within the last few thousand years (Jicha and others, 2012).

During March of 2023, the volcanoes of Tanaga Island experienced the strongest earthquake swarm observed at this set of volcanoes since seismic monitoring at Tanaga Island began in 2003 (figs. 53 and 54). Hypocenters in this swarm developed in a complex pattern and occurred beneath Tanaga Volcano, East Tanaga volcano, Sajaka volcano, and Takawangha volcano, as well as east of Takawangha volcano (fig. 55), all of which have been seismically active in the past (Lally and others, 2023). Hypocentral depths ranged from the summit to as much as 20

km BSL and the largest earthquake, occurring on March 9th, had a depth of roughly 5 km beneath Takawangha volcano.

In total, AVO located 4,491 earthquakes beneath Tanaga Island in 2023. The earliest known earthquakes clearly associated with the 2023 activity seem to occur between March 1 and 5 both under the summit of Tanaga Volcano at depths of 10- to 20-km and east of Takawangha volcano at depths of 2 to 8 km. On March 5 and 6, hypocenters beneath the Tanaga Volcano summit had shallowed to depths of 9 to 13 km and the activity east of Takawangha volcano had diminished. By March 7 and 8, earthquake activity had increased greatly and had shallowed further to depths of 2-to 10-km. These hypocenters were occurring between East Tanaga and Takawangha volcano and beneath the Takawangha volcano summit. This pattern continued through roughly March 13. AVO classified the majority of these earthquakes as VT events. Increased earthquake activity continued between East Tanaga and Takawangha volcano until mid-August, while activity to the east of Takawangha volcano continued through the remainder of 2023 (fig. 55).

The 2023 seismic unrest was preceded by a mid- to lower-crustal increase in DLP events and VT earthquakes that occurred beneath Tanaga Volcano summit between June and October 2021 at depths of 21- and 33-km (fig. 54). Such an increase in mid- to lower-crustal seismicity had not been observed at Tanaga Volcano since monitoring began in 2003. An additional increase in earthquake activity was observed beneath Takawangha volcano and extended to the east starting in November of 2022 (fig. 55). However, a direct causal linkage between these two episodes of seismicity and the strong seismic unrest that began in March 2023 cannot be established.

An InSAR image covering the period from August 16, 2022, to July 18, 2023 shows a complex pattern of both subsidence southwest of Tanaga Volcano and uplift between Tanaga Volcano and Takawangha volcano. The observed deformation evolved over time, with deformation southwest of Tanaga Volcano being active first and, after stabilizing, the deformation between Tanaga Volcano and Takawangha volcano dominated. This complex pattern is suggestive of

the involvement of magma intrusion as well as the displacement on local faults. Additionally, when compared to deformation patterns associated with an earthquake swarm in 2005, the 2023 pattern is significantly more widespread. This can be attributed to the greater seismic moment release in 2023 as compared to the 2005 activity.

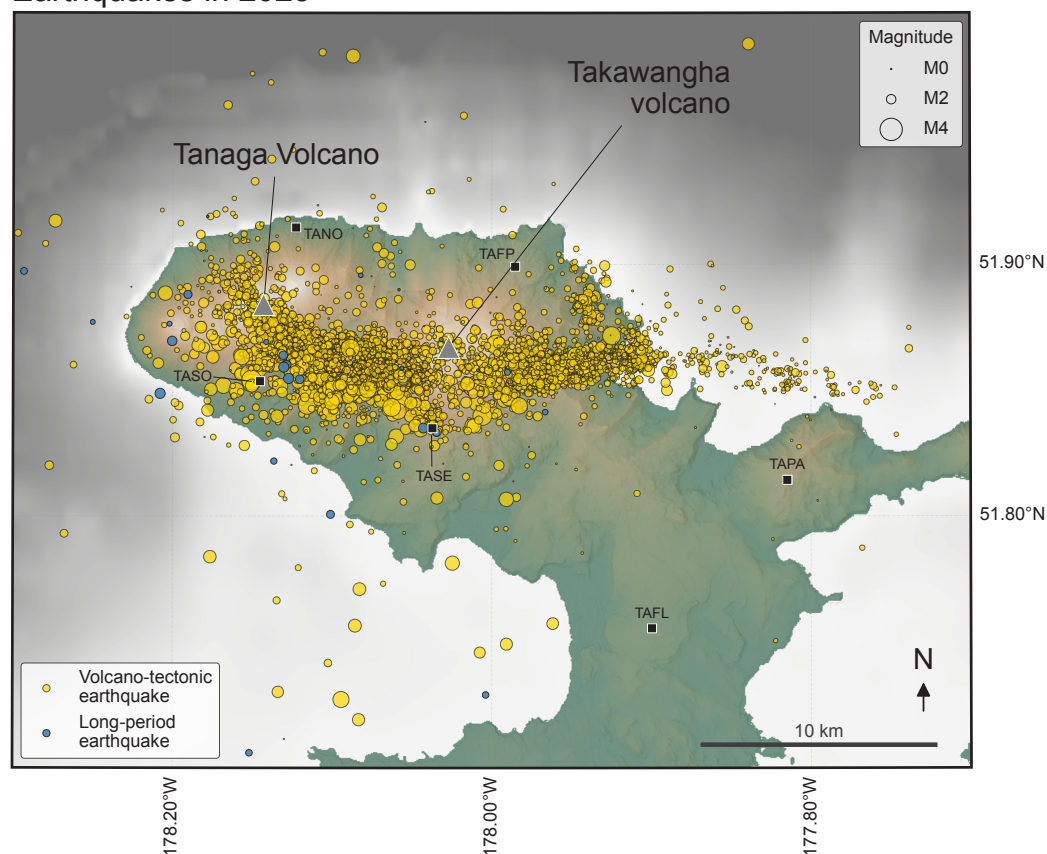
The spatial and temporal development of hypocenters in 2023 suggests a similar progression to the unrest observed at Tanaga Island in 2005. In 2005, hypocenters began under Tanaga Volcano summit and then migrated beneath Takawangha volcano, and uplift was observed in InSAR imagery beneath Takawangha volcano (Lu and Dzurisin, 2014; Lally and others, 2023). This was attributed to an inclined magma source zone that extends from Tanaga Volcano to Takawangha volcano (see Lu and Dzurisin, 2014, fig. 6.27; Lally and others, 2023, fig. 12). The 2023 seismicity follows a similar pattern and suggests

magma and associated volatiles may have followed a similar path, but the 2023 seismicity was much more energetic, and earthquake epicenters covered a broader area especially to the east of Takawangha volcano.

In response to the increasing earthquake activity, and the inability to definitively forecast the site of an eruption (i.e., Tanaga or Takawangha), AVO raised the color code to **YELLOW/ADVISORY** on March 8 and to **ORANGE/WATCH** on March 10 (fig. 54). As the rate of earthquake activity declined the color code was subsequently lowered to **YELLOW/ADVISORY** on March 16 and to **GREEN/NORMAL** on July 19.

Figure 53. Map of 2023 earthquake epicenters near Takawangha and Tanaga Volcanoes on Tanaga Island, Alaska. Symbols are scaled by earthquake magnitude. Yellow symbols correspond to hypocenters identified as volcano-tectonic and blue symbols note location of earthquakes identified as long-period events. Alaska Volcano Observatory (AVO) seismic stations are plotted as squares on the map for reference.

Earthquakes in 2023



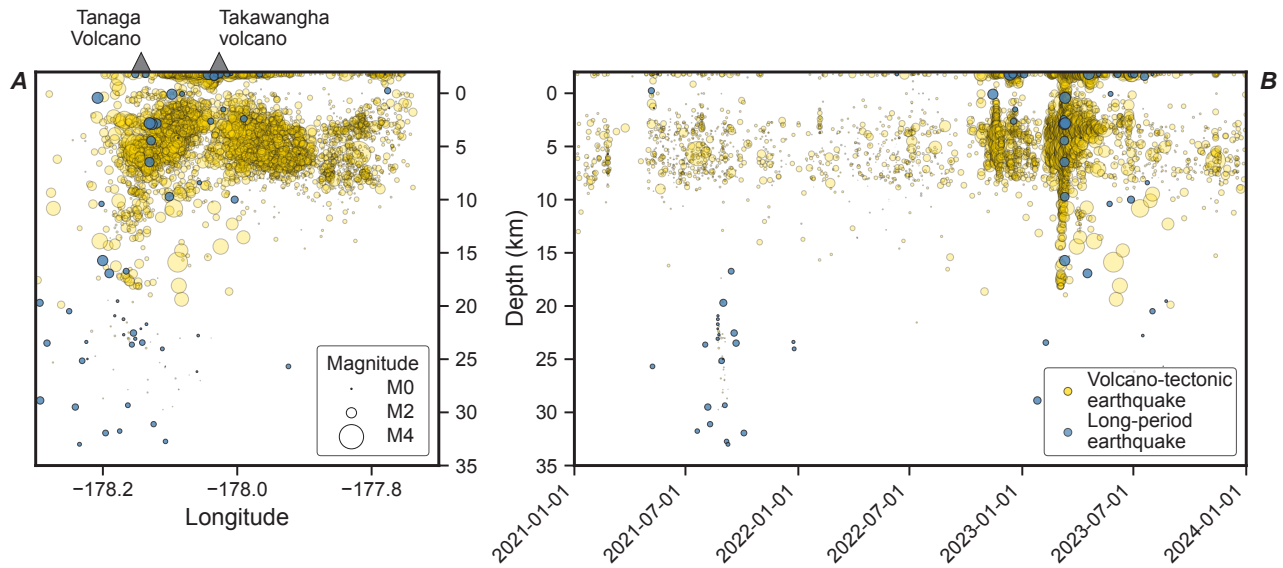


Figure 54. East-west cross section and depth-time plot of earthquakes near Tanaga Island, Alaska, from January 2021 to December 2023. East-west cross section (A), and hypocenter focal depth versus time (B) for all hypocenters near Tanaga Island between Jan 1, 2021 and Dec 31, 2023. Symbols are scaled by earthquake magnitude. Yellow symbols correspond to hypocenters identified as volcano-tectonic and blue symbols note location of earthquakes identified as long-period events.

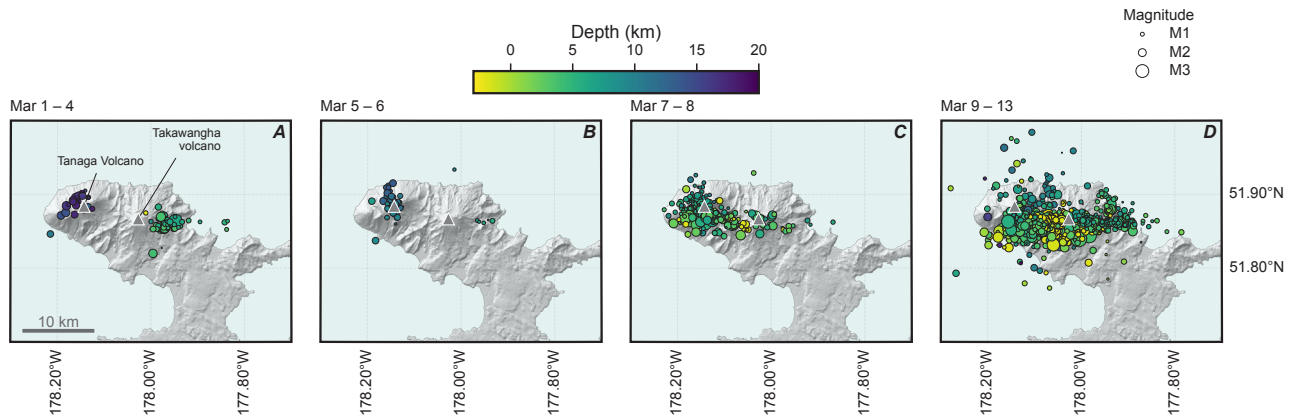


Figure 55. Hypocenter maps showing the progression of earthquakes beneath Tanaga Island, Alaska, in early March 2023. Individual panels highlight activity from March 1–4 (A), 5–6 (B), 7–8 (C), and 9–13 (D). Symbols are colored by earthquake depth below sea level and scaled by earthquake magnitude.

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



Semisopochnoi Island is a young, uninhabited volcanic island in the western Aleutian Islands, ~260 km west of the City of Adak, Alaska, and 2,110 km southwest of Anchorage (fig. 1). Its largest feature is a 7-km-wide caldera that formed during the early Holocene; it also has many post-caldera cones (Coombs and others, 2018). The last recorded eruption before its most recent activity (beginning in 2018) took place in 1987 at Sugarloaf Peak, on the south end of the island. This event produced a 90-km-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 volcano's caldera, has also erupted repeatedly in the Holocene and has produced 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 coarse units dominated by lapilli indicate eruption intensities with a volcanic explosivity index (VEI) as high as 3 (Coombs and others, 2018). The most recent non-eruptive unrest at Semisopochnoi volcano before the 2018 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 km³ of magma (as two batches) into a spheroidal magma storage zone ~8-km beneath the caldera.

The most recent period of eruptive activity at Semisopochnoi Island began in September 2018 and consisted of intermittent to frequent small eruptions that produced minor ash deposits within the vicinity of the north cone of Mount Young. Leading into 2023, Semisopochnoi Island was at an elevated Aviation Color Code of **ORANGE** and Volcano Alert Level of **WATCH**, after ash emissions and minor ash deposits were observed on December 28, 2022. In the first week of January 2023, explosion signals continued

to be observed in local seismic and infrasound data at Semisopochnoi Island, with occasional clear webcam images showing fresh ash deposits on top of its snow-laden edifice (fig. 56A). Most other webcam images of Semisopochnoi Island, such as the one captured on January 20 (fig. 56B), show voluminous steam plumes emanating from the north cone of Mount Young, which was typical of its current episode of activity. By January 25, explosions had ceased and seismicity at Semisopochnoi Island mostly consisted of infrequent episodes of tremor (fig. 57). Throughout February, observations of steam plumes continued, but no evidence of ash emissions or explosive activity was observed. This, along with the absence of strong tremor signals, led AVO to lower the Aviation Color Code to **YELLOW** and Volcano Alert Level to **ADVISORY** on February 22.

Aside from the regular steam plume observations, Semisopochnoi Island stayed relatively quiet until March 19, where low-level ash emissions from the north crater of Mount Young were once again observed in web camera images (fig. 56C). Small explosions and volcanic tremor signals were also observed on geophysical data that same day. This resurgence in emission and seismic activity prompted AVO to raise the Aviation Color Code and Volcano Alert Level back to **ORANGE/WATCH**. Semisopochnoi volcano continued to exhibit elevated volcanic activity until the first week of May, when it started to show signs of decline in eruption intensity. Explosion signals were last observed on April 25 on local seismic and infrasound data, and evidence of ash emissions were last observed on May 5, which consisted of a light dusting of ash on the northwest flank of Mount Young. On May 17, AVO lowered the Aviation Color Code to **YELLOW** and Volcano Alert Level to **ADVISORY**.

The decline in eruption intensity persisted over the next few months, with earthquake activity remaining steadily at low levels. A sample of very fine volcanic ash, collected in June 2023 from material found drifted inside the CERB hut during a geophysics site visit, was also found to be similar to samples collected in late May 2021. The sample likely represents an aggregate of tephra fall after the 2021 CERB visit and

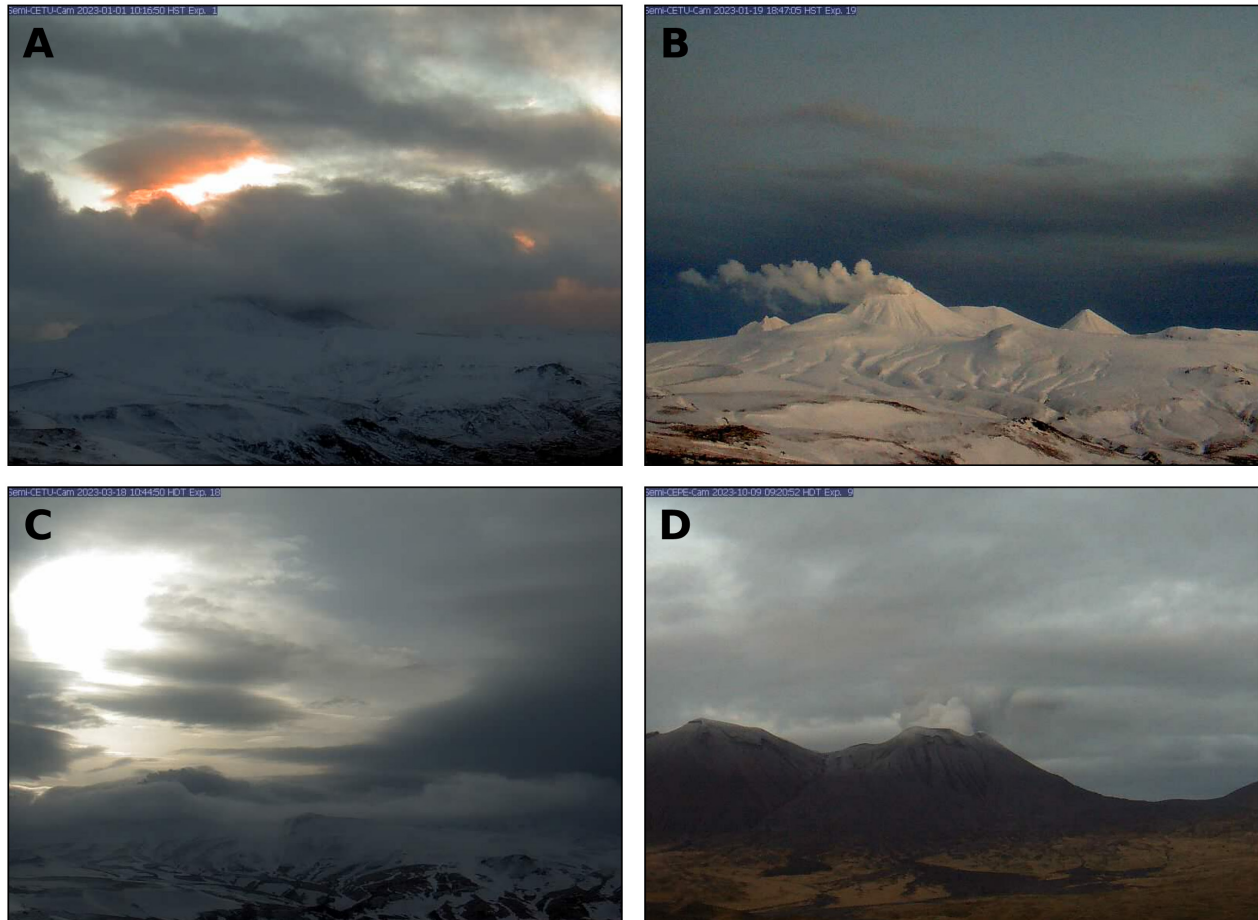


Figure 56. Webcam images of ash and gas emissions from Mount Young on Semisopochnoi Island, Alaska, in 2023. A) Ash deposit to the south-southwest of Mount Young observed on CETU webcam, image taken on January 1, 2023; B) Steam plume observed during a period of clear viewing conditions on CETU webcam, image taken on January 20, 2023; C) Low-level ash-loaded plume seen on CETU webcam, image taken on March 18, 2023; D) Minor steaming observed on CEPE webcam images months after the conclusion of the eruption, image taken on October 9, 2023.

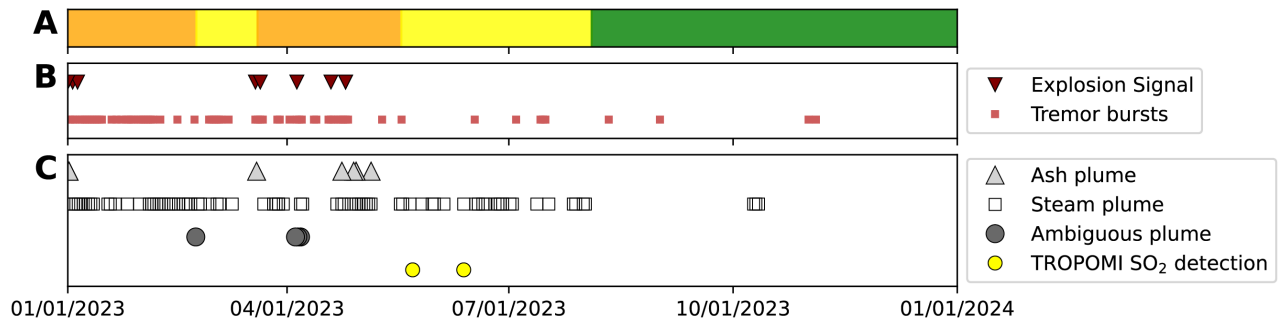


Figure 57. Chronology of eruptive activity at Mount Young, Semisopochnoi Island, Alaska, in 2023. A) Timeline of changes in Aviation Color Code; B) Timeline of geophysical signals detected at the volcano; C) Timeline of activity detected in satellite remote sensing data. Ambiguous plumes are those that had no clear ash or gas signature but were apparent in mid-IR satellite imagery.

remobilized tephra from throughout the eruption, and similarity to ash collected in 2021 suggested no substantial change in process. The volcano showed little indication of possible resurgent activity, AVO lowered the Aviation Color Code to **GREEN** and Volcano Alert Level to **NORMAL** on August 3, marking the conclusion of the multi-year eruption sequence that had persisted since September 2018. Steam plumes continued to be observed from the north crater of Mount Young through the end of the year (e.g., fig. 56D). Although steaming was not observed from this vent prior to the start of this eruption, it is common for steam plumes to persist at volcanoes for years following an eruption as the volcano slowly cools. AVO continues to closely monitor Semisopochnoi Island using its local seismic and infrasound network, local web cameras, regional lightning and infrasound sensors, and satellite-based observations.

Volcanic Activity in the Commonwealth of the Northern Mariana Islands

Ahyi Seamount

GVP# 284141
20.42°, 145.03°
-79 m

Commonwealth of the Northern Mariana Islands

HYDROACOUSTIC DETECTIONS SUGGESTING UNDERWATER EXPLOSIONS; PLUME OF DISCOLORED WATER

Ahyi seamount is a large conical submarine volcano that rises to within 79 m of the sea surface near the northern end of the Northern Mariana Islands (fig. 1), about 18 km southeast of the island of Farallon de Pajaros and 600 km north of the island of Saipan. The remote location of the seamount has made eruptions difficult to detect, although several have been documented. The most recent submarine eruptive activity (prior to 2022) occurred in 2014 and was detected by the regional Northern Mariana Islands seismic network and more distant seismic stations, and by hydroacoustic stations at Wake Island, 2,270 km to the east (Tepp and others, 2019). Submarine explosions during the eruption were also heard and felt by National Oceanic and Atmospheric Administration (NOAA) scuba divers at Farallon

de Pajaros, and a multibeam sonar bathymetric survey collected afterward found that a crater about 100 m deep had formed at the summit of the volcano (Tepp and others, 2019).

Another apparent submarine eruption of Ahyi seamount began in October 2022. Activity from this is documented in Orr and others (2025). Throughout November and December, plumes of discolored seawater in satellite images, along with hydroacoustic signals from the direction of Ahyi seamount detected from Wake Island were noted frequently (fig. 58). At the end of December 2022, the Aviation Color Code and Volcano Alert Level were at **YELLOW** and **ADVISORY**. This report describes activity at Ahyi seamount starting on January 1, 2023, through the end of the year.

Plumes of discolored water were frequently detected in satellite images of the sea surface over Ahyi seamount in January, February, and March 2023 (fig. 59). These plumes were typically around 2-km long and typically had a clear point-source origin corresponding to a location along the Ahyi seamount summit ridge, similar to the location of plumes detected in late 2022. On January 20 and February 6, 2023, plumes could be tracked as far as 12 km from the source in Sentinel-3 images. Despite the frequency of observed plumes in the water, only one inferred seismic and/or explosive event was detected by Wake Island hydroacoustic sensors (located 2,270 km east of Ahyi) between January 7 and March 10, 2024. After this period of hydroacoustic inactivity, more than 100 events/day were detected March 10, 11, 12, 20, and 21.

Satellite images showed no evidence for volcanic activity from March 22 to May 21, 2024. Hydroacoustic detections were also low during this period. In response to this lull in activity, the Aviation Color Code and the Volcano Alert Level were lowered to **UNASSIGNED** on April 25, 2023.

Submarine volcanic activity resumed on May 21, when 121 hydroacoustic events were detected by the Wake Island array. The following day, a plume of discolored water was detected in a Landsat satellite image. The plume was from the same origin and similar in character to prior plume events. With the observation of resumed

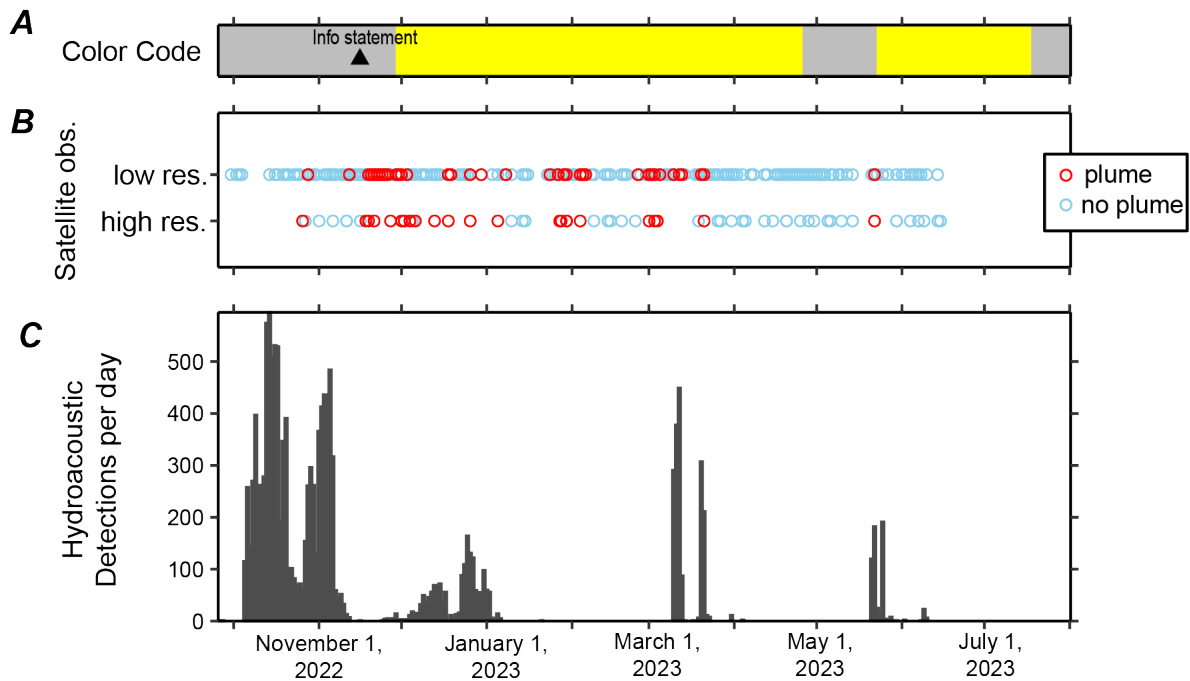


Figure 58. Chronology of volcanic activity at Ahji seamount, Commonwealth of the Northern Mariana Islands, from September 2022 through July 2023. A) Color bar timeline showing the Aviation Color Code and Volcano Alert Level (grey is UNASSIGNED, yellow is YELLOW/ADVISORY). An information statement issued on November 14, 2022, is shown as a triangle, while VAN/VONA alerts were issued with all color code and alert level changes; B) Cloud-free low-resolution (Sentinel-3, VIIRS, and Moderate Resolution Imaging Spectroradiometer (MODIS)) and high-resolution (Sentinel-2, Landsat, WorldView-1, -2, and -3) satellite observations. Blue circles indicate images showing no underwater plume; red circles indicate images showing a discolored plume in the water; C) Number of hydroacoustic events per day detected by the Wake Island array from the direction of Ahji seamount.

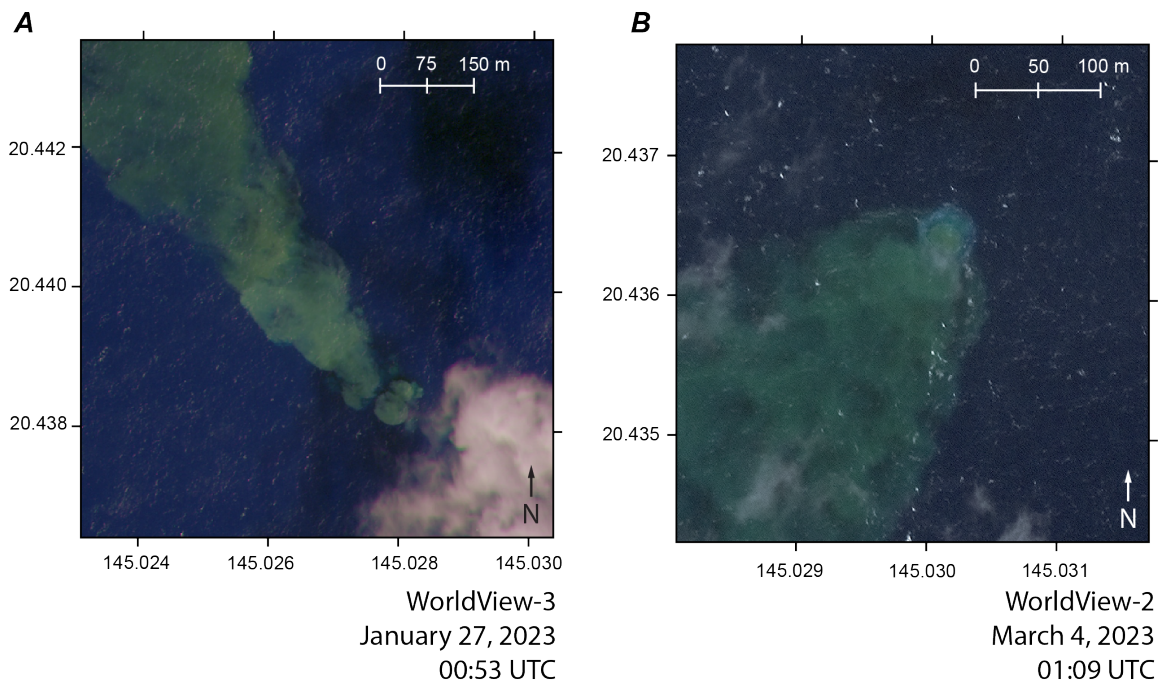


Figure 59. Satellite images of submarine plumes of discolored water from Ahji seamount, Commonwealth of the Northern Mariana Islands, in January and March 2023. A) WorldView-3 false color satellite image of Ahji seamount on January 27, 2023, at 00:53 UTC. Image is a combination of bands 4, 3, and 1, which are roughly equivalent to red, green, and indigo visible light; B) WorldView-2 false color satellite image of Ahji seamount on March 4, 2023, at 01:09 UTC (same bands at A). Note images are at different scales. Image ©2025 Maxar Technologies.

volcanic activity, the Aviation Color Code and the Volcano Alert Level were returned to **YELLOW** and **ADVISORY** on May 22, 2023. No other plumes were detected in satellite data in the following days, but hydroacoustic detections remained elevated, with up to 191 events per day detected through May 25, and occasional events until June 10, 2023.

With no submarine plumes detected after May 22 and no hydroacoustic activity detected after June 10, the Aviation Color Code and the Volcano Alert Level were lowered to **UNASSIGNED** on July 18, 2023, where they remained through the end of the year. On December 24 and 31, however, plumes of discolored water were again detected in satellite images. No action was taken with those observations until the new year.

Ruby Seamount

GVP# 284202
15.605°, 145.572°
-180 m

Commonwealth of the Northern Mariana Islands

HYDROACOUSTIC DETECTIONS SUGGESTING UNDERWATER EXPLOSIONS; PLUME OF DISCOLORED WATER



Ruby seamount is a submarine volcano that rises to within 180 m of the sea surface near the southern end of the Mariana arc 50 km northwest of the island of Saipan, in the Northern Mariana Islands (NMI). The volcano was first detected in eruption in 1966 by sonar signals and was named in a 1973 publication discussing that eruption (Johnson, 1973). In 1995, submarine explosions were heard, accompanied by a fish kill, sulfurous odors, bubbling water, and the detection of volcanic tremor. The summit depth used here is from a mapping expedition in 2003, which used sidescan sonar to produce bathymetry for Ruby seamount and many other seamounts in the CNMI (Merle and others, 2003). A survey in 2006 found evidence of an active hydrothermal system at Ruby seamount based on water chemistry (Resing and others, 2009).

A submarine volcanic eruption occurred at Ruby seamount over several hours during September 14–15, 2023. The 2023 eruption did not breach the surface but did produce a circular

submarine plume visible in satellite imagery with a diameter of about 10 km, as shown in figure 60. At the time of the eruption, the closest real-time geophysical instruments to Ruby seamount consisted of two seismometers and one infrasound sensor on Saipan (fig. 61). The next-closest seismometer was located on the island of Guam as part of the Global Seismograph Network (GSN). Eruption signals were also recorded on two distant hydrophone arrays at Wake Island, located about 2250 km to the east-northeast of Ruby seamount and operated by the Comprehensive Test Ban Treaty Organization (CTBTO). The eruption signals on the north hydrophone array had lower levels of noise than the south array. Hydrophonic signals can be efficiently transmitted to long ranges owing to the Sound Fixing and Ranging (SOFAR) channel in the ocean.

At the time of the eruption, data from the hydrophone arrays and one of the Saipan seismometers were not being received in real-time at AVO. The signals on the remaining Saipan seismometer and infrasound sensor were insufficient to identify a volcanic source at Ruby seamount during routine data checks. The eruption was detected retrospectively on September 19 using a combination of satellite imagery and seismic data from Saipan by the Laboratoire de Geophysique in Tahiti, who quickly contacted AVO staff. As a result, the Aviation Color Code and Volcano Alert Level were raised from **UNASSIGNED** to **YELLOW/ADVISORY** for Ruby seamount on September 19, 2023.

The submarine plume initially became visible in satellite imagery at 06:50 ChST, September 15 (20:50 UTC September 14), at sunrise in the NMI. However, there were some indications of warming on the water surface as early as 18:00 UTC in multispectral IR remote sensing data. Hours earlier, between approximately 23:00 September 13–06:00 September 14 ChST (09:00–16:00 UTC September 14), the functioning seismic station on Saipan recorded continuous volcanic tremor (fig. 62) and this is the earliest known sign of unrest at Ruby seamount in 2023. Following the decline of the volcanic tremor, seismicity was at low levels until a series of eight strong seismic events during the first nine hours of September 15 (fig. 63).

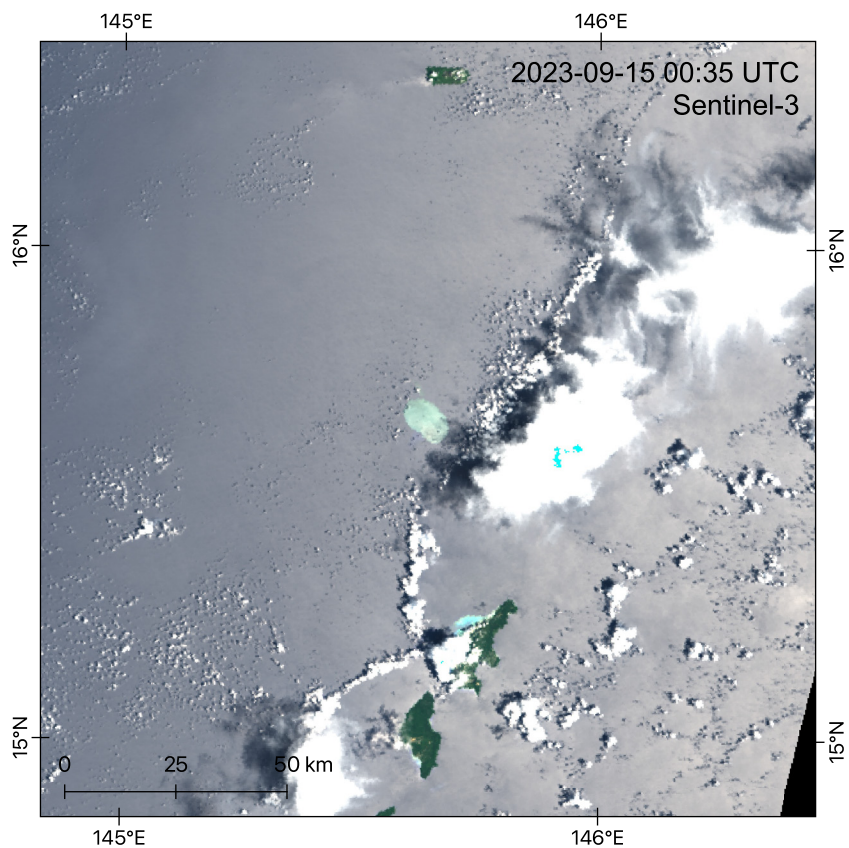
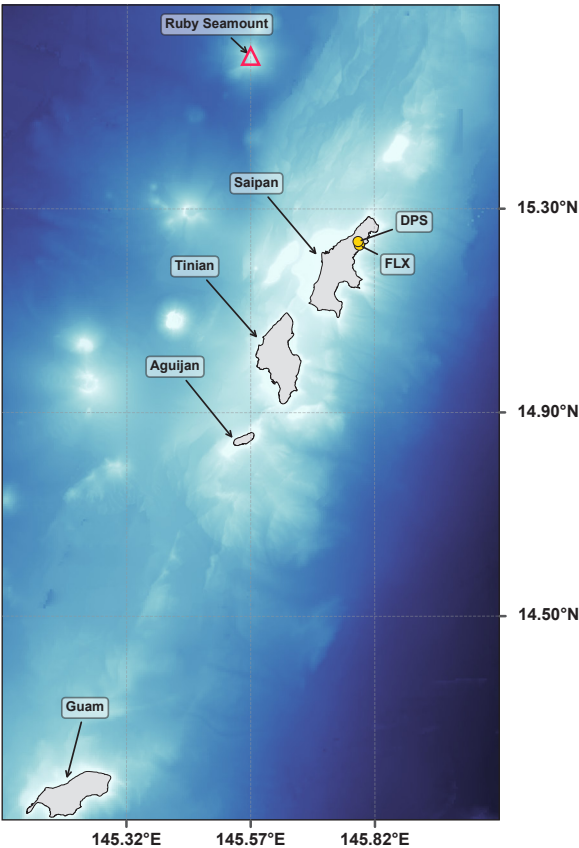


Figure 60. Sentinel-3 satellite image of the eruption of Ruby seamount, Commonwealth of the Northern Mariana Islands, on September 14, 2023. Image is from 14:35 ChST September 14 (00:35 September 15, 2023 UTC). The eruption resulted in discoloration of the ocean surface near the center of the image in a nearly circular shape with a diameter of approximately 10 km. The island of Saipan can be seen about 50 km south of Ruby seamount.

Figure 61. Map of Ruby seamount and proximity to Alaska Volcano Observatory monitoring stations on Saipan, Commonwealth of the Northern Mariana Islands. Closest stations on Saipan are FLX and DPS. The island of Guam is shown for reference as there are also Global Seismograph Network stations there.



The events were strong enough that significant ground-shaking excited the atmosphere locally at the infrasound sensor on Saipan and signals were recorded as ground-to-air coupled waves. Both the tremor on September 14 and the strong events on September 15 were picked up well on the north Wake Island hydrophone array. Beamforming of the array data showed a backazimuth to the source between the backazimuths of Anatahan and Saipan, which is consistent with the location for Ruby seamount. After the last strong event on September 15, seismicity declined and returned to background levels by September 16. The last unequivocal seismic event occurred at about 11:40 ChST (21:40 UTC) September 15. The submarine plume detached from the volcano also on September 16 and no other eruption signals were observed after that time. Due to a lack of volcanic activity, the Aviation Color Code and Volcano Alert Level were lowered from **YELLOW/ADVISORY** to **UNASSIGNED** for Ruby seamount on October 4, 2023.

Retrospective analysis by the National Earthquake Information Center (NEIC) in Golden, Colorado, led to the location of ten seismic events associated with the Ruby seamount eruption, with M4–5. The earliest located event was a M4.5 at 05:28:26 ChST (15:28:26 UTC) on September 14 (near the end of the volcanic tremor episode) and the last located event was a M4.8 at 22:00:48 ChST on September 14 (08:00:48 UTC Sep. 15) — the last of the strong events in this sequence. The last located event had the largest magnitude of all ten seismic events. The locations of the seismic events were based entirely on P-wave arrival time picks; no S-wave arrival times were picked for the events. This suggests that the events were not classical VT earthquakes and were likely associated with the submarine eruption process at the vent. Owing to the sparse distribution of seismic stations in the NMI region, the depths of the seismic events were not well-constrained but are consistent with a source depth in the upper 10-km of the crust. If the events are associated with the eruption process, then the depth would be very close to the ocean floor.

The located seismic events by NEIC also provide a useful comparison to a previous submarine eruption in the NMI, the 2010

eruption of South Sarigan Seamount. At that time, NEIC located six earthquakes with M4–5. Whereas Ruby seamount had ten seismic events between 4 and 5 over the course of 17 hours, South Sarigan Seamount had 6 such events over 8 hours. The maximum magnitude for a Ruby seamount event was M4.8 and for South Sarigan Seamount it was M4.7. Therefore, the two submarine eruptions had similar levels of seismicity and similar durations. However and in contrast to Ruby seamount, the South Sarigan Seamount submarine eruption broke through the ocean surface and produced a subaerial volcanic plume. Although Ruby seamount's eruptive products remained in the ocean, the eruption did produce a circular submarine plume with a diameter up to 10-km during September 14–15, and local fishermen reported green water in the area.

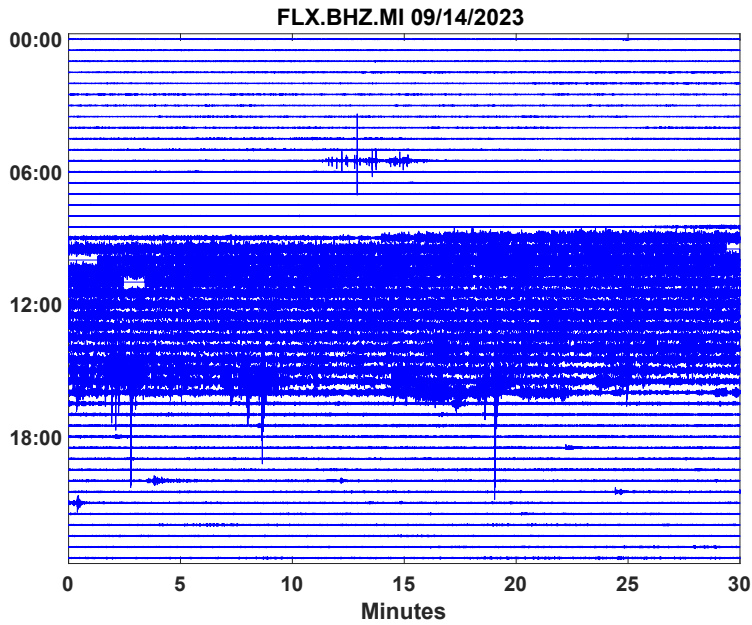


Figure 62. Helicorder plot of seismic data showing volcanic tremor from Ruby seamount recorded at Saipan station FLX on September 14, 2023. Volcanic tremor from Ruby seamount registered on the seismometer for seven hours between 23:00 ChST September 13 – 06:00 ChST September 14 (9:00–16:00 UTC). The first satellite imagery showing a submarine plume was at 10:50 ChST (20:50 UTC); images for several hours prior to that were dark due to it being nighttime locally.

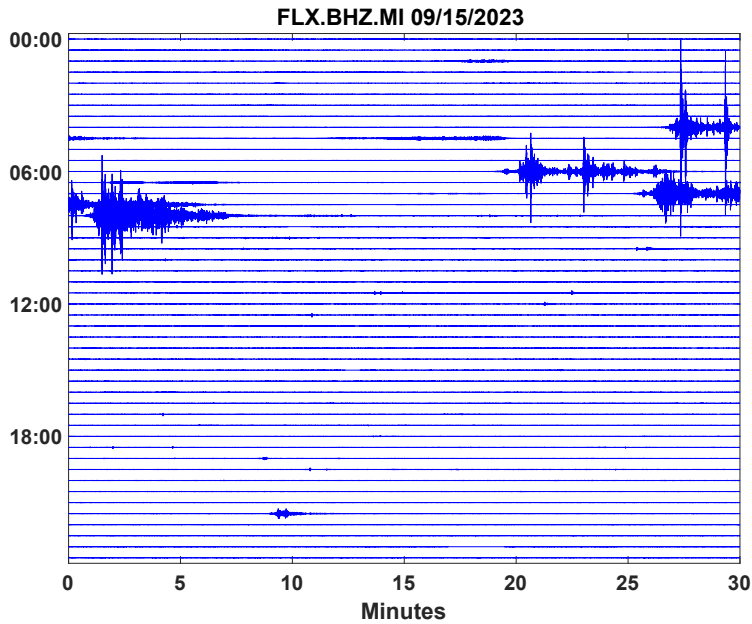


Figure 63. Helicorder plot of seismic data showing strong seismicity from Ruby seamount recorded at Saipan station FLX on September 15, 2023. Strong seismicity occurred during the first ten hours of the day and consisted of tremor and discrete seismic events that had magnitudes as high as M4.8.

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Appendix 1. Glossary of Selected Terms and Acronyms

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.

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).

caldera Large, roughly circular depression commonly caused by volcanic collapse.

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

effusion An eruption dominated by the outpouring of lava onto the ground.

epicenter The point on Earth's surface directly above the hypocenter or focus of an earthquake.

fumarole Small opening or vent from which hot gases are emitted.

Hawaiian A type of effusive eruption characterized by lava fountaining and/or lava rivers.

helicorder A device that translates the results of a seismometer into a format that can be viewed.

Holocene Geologic epoch that extends from the present to about 11,700 years ago.

hydrothermal Related to the circulation of groundwater that is heated by proximity to volcanically heated rocks (in this context). Hydrothermal phenomena include fumaroles and hot springs.

hypocenter The point within the Earth that is the center of an earthquake. The initial point of rupture during an earthquake. Also known as the focus of an earthquake.

incandescence The high-temperature emission of light.

infrared The part of the electromagnetic spectrum with wavelengths longer than those in the visible range but shorter than those in

the microwave range. The infrared spectrum is divided into near-infrared (closest to visible) or NIR, shortwave-infrared or SWIR, mid-infrared, longwave-infrared, and far-infrared, from shortest to longest wavelength. Satellite observations of SWIR, mid-infrared, and longwave-infrared give information about how hot an object is.

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

intracaldera Refers to a point or area within the caldera.

intrusion The process of emplacement of magma in pre-existing rock. Also, the term refers to igneous rock mass so formed within the surrounding rock.

lahar Flow of a mixture of pyroclastic material, sediments and organic ground cover, and water.

lapilli Rock fragments between 2 and 64 mm (0.08–2.5 in) in diameter that were ejected from a volcano during an explosive eruption.

lava Molten rock that has reached Earth's surface.

local magnitude (ML) Earthquake magnitude scale based on the amplitude of ground motion as measured by a standard seismograph

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

magma Molten rock below the surface of Earth.

mass flow A general term for any phenomenon that causes volcanic material (other than lava) to flow downslope. Mass flows include pyroclastic density currents, lahars, and debris avalanches.

open vent A term used to describe volcanoes that erupt with a similar style over long periods, including volcanoes with persistent degassing, lava lakes, and long-lived Strombolian or Hawaiian eruptions. The exact definition is somewhat controversial. Open system is also used.

paroxysm A sudden violent outburst in the

course of a volcanic eruption. This term is often applied to more energetic episodes at basaltic, open-vent volcanoes.

phreatic eruption An explosive volcanic eruption caused when water and heated volcanic rocks

pyroclastic density current (PDC) An eruptive phenomenon consisting of a high-speed flow of hot ash and volcanic debris. PDCs include both pyroclastic flows, which have higher densities and typically follow topography downhill, and pyroclastic surges, which are less dense and flow over topographical barriers. Both are extremely deadly to any living thing in their path.

Plinian An explosive eruption in which a steady, turbulent stream of fragmented magma and magmatic gases is released at a high velocity from a vent. Large volumes of tephra and tall eruption columns are characteristic.

real-time seismic amplitude measurement (RSAM) A technique for characterizing a volcano's changing seismicity in real time (as it is occurring), in which the average amplitude of ground shaking caused by earthquakes and volcanic tremor is calculated over 10-minute intervals.

SAR interferometry Synthetic aperture radar (SAR) interferometry (InSAR) is a powerful remote sensing technique for measuring the distance to the Earth's surface. It requires that the surface is imaged by the radar at least twice from almost the same position in space. The property measured is the phase of the reflected radar signal. The differences in phase between the two images produce an interferogram with interferometric fringes that will represent both the topography of the surface and any changes in position of the surface during the period between the acquisition of the two images.

satellite vent Subsidiary volcanic vent located on the flank of a larger volcano.

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

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

stratovolcano Steep-sided volcano, commonly conical in shape, built of interbedded

lava flows and fragmental deposits from explosive eruptions. Also called a stratocone or composite cone.

Strombolian 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.

sub-Plinian A type of explosive eruption between Vulcanian and Plinian in intensity. Eruption columns tend to be less than 12 km, as in Vulcanian eruptions, but are sustained rather than consisting of discrete explosions.

thermal anomaly A thermal anomaly is an unexpected increase in the radiant temperature of a pixel in satellite imagery relative to its neighbors. Thermal anomalies may be caused by volcanic activity, but they have several other causes as well.

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

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

volcanic explosivity index (VEI) Scale that describes the size of explosive volcanic eruptions based on magnitude and intensity.

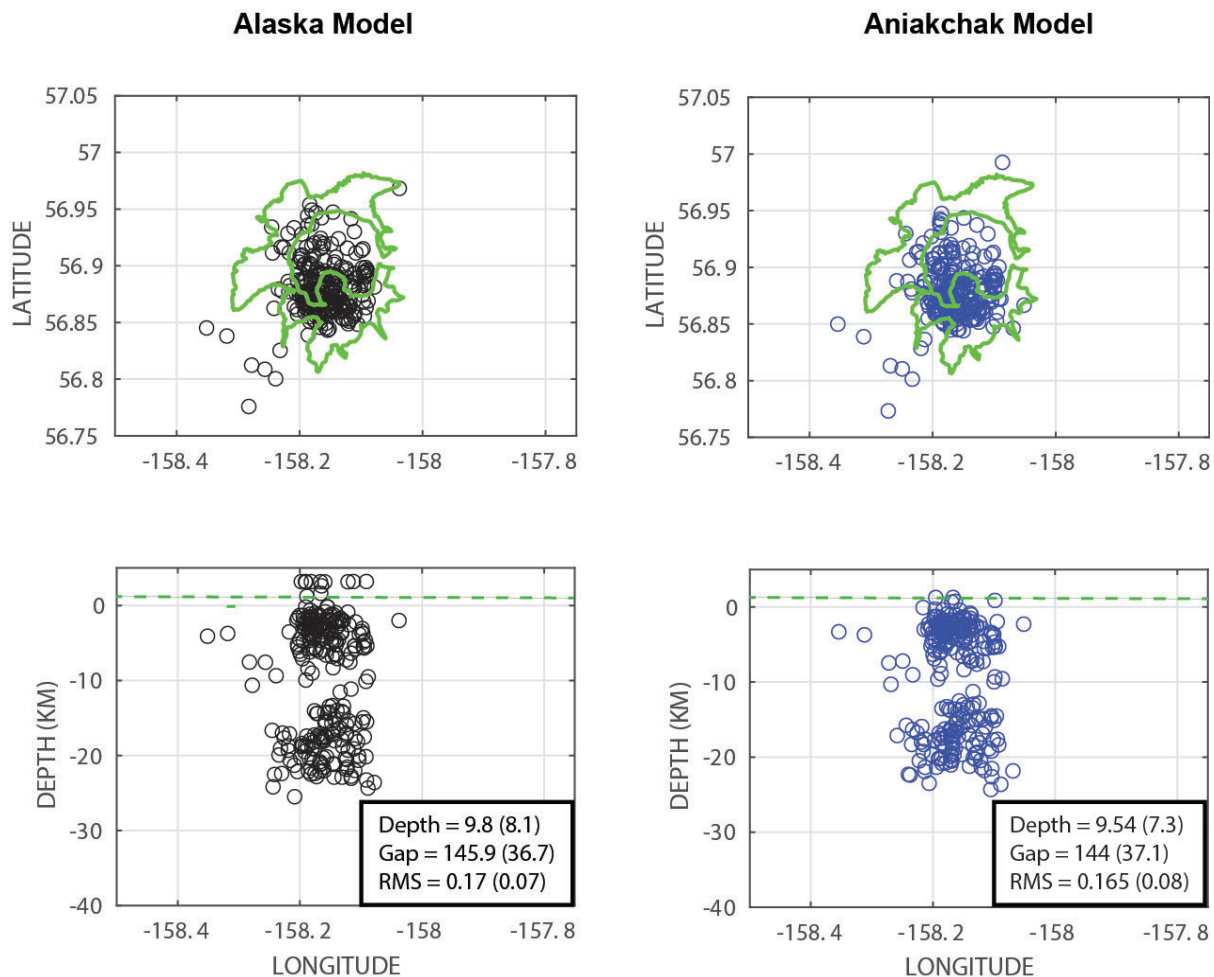
volcanic radiative power The energy emitted by a volcano per unit time, usually expressed in units of watts (joules per second).

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

Vulcanian Type of volcanic eruption that ejects material to heights less than about 12 miles (20 km) and 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, the emission of tephra, and small-scale pyroclastic density currents.

Appendix 2. Aniakchak Crater earthquake catalog additional information

Earthquakes shown in the Aniakchak Crater section of this report were relocated using an improved one-dimensional velocity model centered on Aniakchak Crater, that provides a greater accuracy of hypocenter determination than the Alaska Regional Model (see Dixon and others, 2019 for discussion of seismic velocity models in use by AVO). This model was derived from 255 well-located hypocenters (azimuthal gap or GAP < 220, RMS < 0.3) from 1997 to May 1, 2023. This model was formulated using the Katmai velocity model (Searcy, 2003) and adjusting layer thickness, Vp/Vs ratio, and velocity until the lowest RMS was achieved for the 255 earthquakes. We also adjust the top of the model to 1341 m which corresponds to the highest point on the caldera rim. The final model is shown in the table and uses a Vp/Vs ratio of 1.78. We then relocated the entire Aniakchak Crater catalog with this model.



1 Dimensional velocity model used for earthquake relocations at Aniakchak Crater

Vp (km/s)	Depth (km)
2.55	0.0
5.05	0.5
5.1	4.0
5.41	5.0
5.49	6.0
5.65	7.0
5.67	8.0
5.69	9.0
5.76	10.0
5.80	11.0
6.00	12.0
6.04	13.0
6.08	15.0