The Alaska Volcano Observatory is a cooperative program of the U.S. Geological Survey, University of Alaska Fairbanks Geophysical Institute, and the Alaska Division of Geological and Geophysical Surveys. The Alaska Volcano Observatory is funded by the U.S. Geological Survey Volcano Hazards Program and the State of Alaska.

2011 Volcanic Activity in Alaska: Summary of Events and Response of the Alaska Volcano Observatory

Scientific Investigations Report 2014–5159

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

Cover: Aerial photograph of the August 2011 lava dome in the summit crater of Cleveland volcano. The lava dome is about 60 m (200 ft) in diameter in a 200-m-wide (660 ft) crater, and was extruded sometime between July 7 and August 8, 2011. Photograph courtesy of Dave Withrow, National Oceanic and Atmospheric Administration, taken on August 8, 2011. AVO database image at URL: http://www.avo.alaska.edu/images/image.php?id=36312.

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By Robert G. McGimsey, J. Zebulon Maharrey, and Christina A. Neal

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

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

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Contents

Figures

Tables

Conversion Factors and Datum

Conversion Factors

Inch-Pound to SI

Multiply	By	To obtain
acre	4,047	square meter (m^2)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
foot (ft)	0.000305	kilometer (km)
foot (ft)	0.3048	meter (m)
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
ton per day (ton/d)	0.9072	metric ton per day

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

$$°C = (°F-32)/1.8$$

SI to Inch-Pound

Multiply	By	To obtain
centimeter (cm)	0.3937	inches (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
kilometer (km)	3,281	foot (ft)
square meter (m^2)	0.0002471	acre
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
metric ton per day	1.1022	ton per day (ton/d)

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

$$°F = (1.8×°C)+32.$$

Datum

Altitude and elevation as used in this report, refers to distance above sea level, unless otherwise noted.

2011 Volcanic Activity in Alaska: Summary of Events and Response of the Alaska Volcano Observatory

By Robert G. McGimsey,[1] J. Zebulon Maharrey[2], and Christina A. Neal[1]

Abstract

The Alaska Volcano Observatory (AVO) responded to eruptions, possible eruptions, and volcanic unrest at or near three separate volcanic centers in Alaska during 2011. The year was highlighted by the unrest and eruption of Cleveland Volcano in the central Aleutian Islands. AVO annual summaries no longer report on activity at Russian volcanoes.

Introduction

The Alaska Volcano Observatory (AVO) monitors, reports, and studies volcanic unrest at Alaskan volcanoes. The year 2011 was dominated by the eruption of Cleveland volcano in the central Aleutian Islands. AVO also responded to new and ongoing volcanic unrest at two other volcanoes in Alaska, Aniakchak, and Okmok volcanoes (fig. 1).

Of the 52 historically active volcanoes in Alaska (Schaefer and others, 2014), 33 were monitored in 2011 with a network of seismometers sufficiently reliable in their operation to consistently track earthquake activity (fig. 1; table 1) (Dixon and others, 2012). Korovin was delisted (considered not seismically monitored) in October 2011 because of low signal-to-noise problems with two of the four stations in the seismic network (J. Dixon, USGS, written commun., 2013), reducing the number of seismically monitored volcanoes to 32. Seismic stations are in place at two additional volcanoes (Little Sitkin and Semisopochnoi, fig. 1); however, telemetry links are intermittent and background seismicity has not been confidently determined. Thus, AVO does not yet consider these volcanoes formally monitored with seismic instrumentation. AVO's routine monitoring program in 2011 included twice-daily analysis of seismicity and satellite imagery, web cameras, occasional overflight observations, airborne-gas measurements, and a compilation of pilot reports and observations from local residents and mariners. Additionally, AVO receives real-time deformation information from permanent Global Positioning System (GPS) stations at four Alaskan volcanoes (Okmok, Augustine, Akutan, and Mount Spurr). In recent years, periodic analysis of Interferometric Synthetic Aperture Radar (InSAR) imagery also has been used to detect deformation at volcanoes in Alaska (Lu and others, 2003, 2007; Lu, 2007).

AVO continues to participate by formal agreement with the Kamchatkan Volcanic Eruption Response Team (KVERT) and the Sakhalin Volcanic Eruption Response Team (SVERT) to aid in satellite monitoring of Russian volcanoes and support dissemination of hazard information (Neal and others, 2009). As of 2011, AVO will no longer report on Russian volcanoes in the Annual Summary; however, the Observatory continues to assist in broadcasting alerts about eruptive activity at Russian volcanoes in Kamchatka and the Central Kuriles. Readers interested in following the activity of Russian volcanoes are referred to the web sites of the Kamchatka and Sakhalin Volcanic Eruption Response Teams (http://www.kscnet.ru/ivs/kvert/index_eng.php and http://www.imgg.ru/?id_d=659) and to the Smithsonian Institution Global Volcanism Network (GVN) volcano database available at URL: http://www.volcano.si.edu/.

This report summarizes volcanic activity in Alaska in 2011 and briefly describes AVO's operational response. Descriptions are presented in geographic order from northeast to southwest along the Aleutian Arc. Each event summary ends with a paragraph providing background comments on the volcano in question. Information is derived primarily from AVO daily status reports, weekly updates and special information releases/statements, AVO email and internal electronic logs, and the Global Volcanism Program Bulletins. Table 1 is a history of seismic monitoring of Alaskan volcanoes from August 1971 through December 2011.

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Figure 1. Map showing historically active volcanoes in Alaska along with place names used in this report. From January 1, 2011 through December 31, 2011, 32 of the volcanoes were considered seismically monitored (red triangles). As of October, 2011, Korovin Volcano (orange triangle) was delisted (considered not seismically monitored) because of low signal-to-noise problems with two of the four stations in the seismic network (J. Dixon, USGS, written commun., 2013). Map modified from Schaefer and others (2014). Shaded relief from Riehle and others (1997). Bathymetry from Smith and Sandwell (1977).

Table 1. History of seismic monitoring of Alaskan volcanoes from August 1971 through December 2011.

[History of seismic monitoring compiled by J. Dixon. "First station installed" refers to the date when AVO first received real-time data from the station. This date can be many months following initial fieldwork at the volcano. Alaska Volcano Observatory (AVO) considers the seismic network "complete" following installation and data transmission from a minimum of four seismic stations. Typically, AVO seismologists monitor the seismicity at the volcanic center for at least six months to understand background rates of seismicity before formally declaring a volcano seismically monitored and adding it to the monitored list. We note here the first mention of the seismic status of each monitored volcano in the AVO weekly update. Regularly issued written information statements began during the Redoubt eruption in 1989–90 and were expanded to include all Cook Inlet volcanoes in April 1991. The magnitude of completeness is the lowest magnitude earthquake that can confidently be located for activity at the volcanic center with an operational seismograph network. For more information on specific seismic network histories, readers are referred to the series of annual seismic summaries prepared by AVO (for example, Dixon and others, 2012)]

Volcano	Approximate start date of seismic monitoring	Magnitude of completeness
Wrangell	First station installed – July 2000 Network complete – **August 2001** Added to monitored list in weekly update – November 2001	0.9
Spurr	First station installed – August 1971 Network complete – **August 1989** Added to monitored list in weekly update – April 1991	0.2
Redoubt	First station installed – August 1971 Network complete – **August 1988** Added to monitored list in weekly update – April 1991	0.4
Iliamna	First station installed – September 1987 Network complete (Min 4 stations) – **September 1994** Added to monitored list in weekly update – April 1991	-0.4
Augustine	First station installed – October 1976 Network complete – **August 1978** Added to monitored list in weekly update – April 1991	0.1
Fourpeaked	First station installed – September 2006 Network complete (Min 4 stations) – **October 2006** Added to monitored list in weekly update – October 2006	0.5
Katmai-North (Snowy)	First station installed – August 1988 Network complete – **October 199**8 Added to monitored list in weekly update – December 1998	0.6
Katmai-Central (Griggs, Katmai, Novarupta, Trident)	First station installed – August 1988 Network complete (Min 4 stations) – **July 1991** Added to monitored list in weekly update – November 1996	0.6
Katmai-South (Martin, Mageik)	First station installed – August 1988 Network complete – **July 1996** Added to monitored list in weekly update – November 1996	0.6
Ukinrek Maars/ Peulik	First station installed – March 2005 Network complete (Min 4 stations) – **March 2005** Added to monitored list in weekly update – April 2005	0.9
Aniakchak	First station installed – July 1997 Network complete – **July 1997** Added to monitored list in weekly update – November 1997	1.4
Veniaminof	First station installed – February 2002 Network complete – **February 2002** Added to monitored list in weekly update – September 2002	1.5
Pavlof	First station installed – July 1996 Network complete – **July 1996** Added to monitored list in weekly update – November 1996	1.0
Dutton	First station installed – July 1988 Network complete – **July 1996** Added to monitored list in weekly update – November 1996	1.0

Table 1. History of seismic monitoring of Alaskan volcanoes from August 1971 through December 2011.—Continued

[History of seismic monitoring compiled by J. Dixon. "First station installed" refers to the date when AVO first received real-time data from the station. This date can be many months following initial fieldwork at the volcano. Alaska Volcano Observatory (AVO) considers the seismic network "complete" following installation and data transmission from a minimum of four seismic stations. Typically, AVO seismologists monitor the seismicity at the volcanic center for at least six months to understand background rates of seismicity before formally declaring a volcano seismically monitored and adding it to the monitored list. We note here the first mention of the seismic status of each monitored volcano in the AVO weekly update. Regularly issued written information statements began during the Redoubt eruption in 1989–90 and were expanded to include all Cook Inlet volcanoes in April 1991. The magnitude of completeness is the lowest magnitude earthquake that can confidently be located for activity at the volcanic center with an operational seismograph network. For more information on specific seismic network histories, readers are referred to the series of annual seismic summaries prepared by AVO (for example, Dixon and others, 2012)]

Volcano	Approximate start date of seismic monitoring	Magnitude of completeness
Shishaldin (and Isantoski)	First station installed – July 1997 Network complete – **July 1997** Shishaldin added to list in weekly update – November 1997 Isantoski added to list in weekly update – December 1998	0.5
Westdahl (and Fisher)	First station installed – August 1998 Network complete – **October 1998** Added to monitored list in weekly update – December 1998	1.1
Akutan	First station installed – March 1996 Network complete – **July 1996** Added to monitored list in weekly update – November 1996	0.3
Makushin	First station installed – July 1996 Network complete – **July 1996** Added to monitored list in weekly update – November 1996	0.7
Okmok	First station installed – January 2003 Network complete – **January 2003** Added to monitored list in weekly update – January 2004	0.9
Korovin	First station installed – July 2004 Network complete – **July 2004** Added to monitored list in weekly update – December 2005	0.7
Great Sitkin	First station installed – September 1999 Network complete – **September 1999** Added to monitored list in weekly update – December 1999	0.6
Kanaga	First station installed – September 1999 Network complete – **September 1999** Added to monitored list in weekly update – December 2000	1.2
Tanaga	First station installed – August 2003 Network complete – **August 2003** Added to monitored list in weekly update – June 2004	1.1
Gareloi	First station installed – August 2003 Network complete – **September 2003** Added to monitored list in weekly update – June 2004	1.2
Semisopochnoi (Cerberus)	First station installed – September 2005 Network complete – **September 2005** Added to monitored list in weekly update – not yet added	1.0
Little Sitkin	First station installed – September 2005 Network complete – **September 2005** Added to monitored list in weekly update – not yet added	0.6

Table 2 summarizes 2011 volcanic activity in Alaska. Table 3 summarizes changes in Aviation Color Codes in 2011 for Alaskan volcanoes. Table 4 presents cross-referenced lists of volcanic activity by year and by volcano for all previous reports (1992–2010).

Only activity that resulted in a significant investment of staff time (defined here as several hours or more for reaction, tracking, and follow-up) is included. Where more extensive published documentation for an episode of unrest exists, we provide key references. Over the course of the year, AVO typically receives dozens of reports of steaming, unusual cloud sightings, or false eruption reports. Most of these are resolved very quickly and are not tabulated here as part of the response record.

On rare occasions, AVO issues an information statement to dispel rumors of volcanic activity. In years past, the phrase "suspect volcanic activity" (SVA) has been used to characterize unusual activity that has subsequently been determined to be normal, or merely enhanced fumarolic activity, weather-related phenomena, or other non-volcanic events. Beginning with the 2006-year report, use of this term has ceased as it has presented us with problems of consistency.

This annual summary departs from including information about Russian volcanoes, a practice started in 1997 to recognize the cooperative relationship between AVO and KVERT. Beginning in 2005, information on the Kurile volcanoes also was included because of an additional collaboration with SVERT. We are ending this practice to acknowledge the success of both KVERT and SVERT in their reliable reporting on volcanic unrest and eruptions. As of 2011, AVO is no longer a formal partner with KVERT; however, we remain strong collaborators and continue to maintain situational awareness regarding eruptions in Kamchatka.

Table 2. Summary of 2011 volcanic activity in Alaska, including actual eruptions, possible eruptions, unusual increases in seismicity or fumarolic activity.

[Location of volcanoes shown in figure 1]

Volcano	Date of activity	Type of activity
Mount Cleveland	Throughout the year.	Explosions and small ash clouds, vapor plumes, thermal anomalies.
Aniakchak	Between late July 2010 and April 2011; probably in August or September 2010 based on local observations of heavy precipitation.	Catastrophic flood from the larger of two maars located on the eastern floor of the caldera.
Okmok	Throughout the year.	Inflation of caldera floor.

Table 3. Alaskan volcanoes with Aviation Color Code and Volcano Alert Level changes in 2011.

[Description of Aviation Color Codes is shown in appendix 1. Local times are only shown where color code changes were short-lived during rapidly evolving events. Volcanoes that do not have a real-time seismic network are not assigned a color code **GREEN** because without seismic data, Alaska Volcano Observatory has no definitive information that the level of activity at the volcano is at background. For these volcanoes, AVO uses the designation **UNASSIGNED**]

Color Code	Date of change
CLEVELAND	
YELLOW/ADVISORY	January 1–March 31
UNASSIGNED	March 31–July 20
YELLOW/ADVISORY	July 20–August 2
ORANGE/WATCH	August 2–August 30
YELLOW/ADVISORY	August 30–September 6
ORANGE/WATCH	September 6–November 3
YELLOW/ADVISORY	November 3–December 29
ORANGE/WATCH	December 29 (07:55 UTC)–December 30 (13:57 UTC)
YELLOW/ADVISORY	December 30 (13:57 UTC)–December 31

During 2011, our Remote Sensing program continued to evaluate Russian activity as part of its daily reporting, which was shared with our Russian colleagues. AVO also continues to alert U.S. and Canadian authorities when KVERT changes Aviation Color Code or during other significant activity that is likely to impact U.S. airspace or international airways. In 2011, AVO remained a formal partner in SVERT.

Altitudes and elevations reported are in feet and/or meters above sea level (ASL) unless otherwise noted, and time is reported as Alaska Standard Time (AKST) or Alaska Daylight Time (AKDT), as needed, with Coordinated Universal Time (UTC) in parentheses. For most satellite or geophysical instrumentation references, times are given in UTC. We preserve English or Inch-Pound units of measurement especially where they reflect the primary observations of distance or altitude such as those commonly received via pilot reports and aviation authorities in the United States. Elsewhere, measurements are presented in International System of Units (SI) with Inch-Pound Units in parentheses for convenience. Volcano locations in latitude and longitude and summit elevations are taken from the Alaska Volcano Observatory database and may differ slightly from previously published compilations.

Increasing monitoring, increasing information, more to report

As AVO has expanded instrumental monitoring and made use of the increasing number of high-resolution satellite platforms, the threshold of detection of volcanic unrest in Alaska has lowered considerably. In addition, increasing air and marine-vessel traffic in the Aleutians, along with improved Internet and other telecommunications infrastructure in remote Alaska, and the highly visible web presence of AVO may contribute to the increased number of reports of volcanic activity we receive, evaluate, and log. The focus of this report is on volcanic activity that represents a significant departure from ‘background,’ a somewhat loosely defined state of quiet at a given volcano. For a more quantitative picture of the level of volcanic unrest, readers are referred to the catalog of seismicity at Alaskan volcanoes, also produced on an annual basis (for example, Dixon and others, 2012).

What is an “eruption”?

The specific use of the term ‘eruption’ varies from scientist to scientist and there is no universally agreed-upon definition. Here, we adopt usage of the Smithsonian Institution’s Global Volcanism Program, which defines eruptions as, “…events that involve explosive ejections of fragmental material, the effusion of liquid lava, or both. This fragmental material may be old as well as new; the explosive interaction of volcanically generated heat and near-surface water can cause dramatic eruptions without any fresh volcanic material reaching the surface…” (http://www.volcano.si.edu/faq.cfm#q2). The element of this definition we wish to emphasize are the verbs ‘eject’ and ‘effuse’ which refer to dynamic surface processes that pose some level of hazard. The presence or absence of often ambiguous ‘juvenile material’ or fresh magma is not relevant to this use of the term eruption, particularly when communicating a potential hazard, which makes no distinction between juvenile and non-juvenile eruption products. This definition would not, however, include passive volcanic degassing or hydrothermal-fluid discharge unless accidental solid fragments are entrained.

What is an “historically active volcano”?

AVO defines an “active” volcano as a volcanic center that has had an eruption (see above) or period of intense seismic or fumarolic activity that is inferred to reflect magma at shallow levels within the volcano. The “historic” period in Alaska is considered to be post mid-1700s when written records of volcanic activity were first compiled. We include some volcanoes on our list of ‘potentially active’ volcanoes that do not exactly fit these criteria because geologic evidence suggests that they have been active within the last few thousand years and as such, although not historically active, they retain a potential for hazardous activity that requires careful monitoring. As geologic understanding of Alaska’s volcanoes improves through additional fieldwork and modern radiometric-dating techniques, our list of “active” volcanoes will undoubtedly evolve. A case in point from 2006: Fourpeaked Mountain, thought not to have erupted in the Holocene, produced a phreatic eruption in the fall of 2006. It now ranks as an historically active volcano, despite not appearing on the list prior to 2006.

Table 4a. Compilation by year of volcanoes included in an Alaska Volcano Observatory Annual Summary, 1992–2011.

[Volcanoes are presented in geographical order from northeast to southwest along the Wrangell-Aleutian volcanic arc and north to south along Kamchatka and the Kurile Islands. Prior to 1995 and after 2010, Alaska Volcano Observatory did not report on Russian volcanoes]

Volcanoes mentioned	
Alaskan	**Russian**
1992	
Spurr/Crater Peak	
Iliamna	
Redoubt	
Mageik (Katmai Group)	
Westdahl	
Akutan	
Bogoslof	
Seguam	
1993	
Churchill	
Sanford	
Spurr/Crater Peak	
Veniaminof	
Shishaldin	
Makushin	
Seguam	
Kliuchef (Atka)	
Kanaga	
1994	
Sanford	
Iliamna	
Katmai Group (Martin, Mageik, Trident)	
Veniaminof	
Kupreanof	
Shishaldin	
Makushin	
Cleveland	
Kanaga	
1995	
Katmai Group (Martin)	Bezymianny
Veniaminof	Karymsky
Shishaldin	
Makushin	
Kliuchef (Atka)	
Kanaga	
1996	
Wrangell	Klyuchevskoy
Iliamna	Bezymianny
Katmai Group (Martin, Mageik, Trident, Mount Katmai)	Karymsky
	Avachinsky
	Mutnovsky
Pavlof	Alaid (Kurile Islands)
Shishaldin	
Westdahl	
Akutan	
Amukta	
Korovin (Atka)	
Kanaga	
1997	
Wrangell	Sheveluch
Sanford	Klyuchevskoy
Shrub Mud	Bezymianny
Iliamna	Karymsky
Katmai Group (Martin, Mageik, Snowy, Kukak)	Alaid (Kurile Islands)
Chiginagak	
Pavlof	
Shishaldin	
Okmok	
Cleveland	
Amukta	
1998	
Shrub Mud	Sheveluch
Augustine	Klyuchevskoy
Becharof Lake	Bezymianny
Chiginagak	Karymsky
Shishaldin	
Akutan	
Korovin (Atka)	
1999	
Wrangell	Sheveluch
Shrub Mud	Klyuchevskoy
Iliamna	Bezymianny
Veniaminof	Karymsky
Pavlof	
Shishaldin	
Vsevidof	
2000	
Wrangell	Sheveluch
Katmai Group (Snowy)	Klyuchevskoy
Chiginagak	Bezymianny
Shishaldin	Karymsky
	Mutnovsky
2001	
Katmai Group (Snowy/Kukak)	Sheveluch
	Klyuchevskoy
Pavlof	Bezymianny
Frosty	Karymsky
Shishaldin	Avachinsky
Makushin	
Okmok	
Cleveland	
Great Sitkin	

Table 4a. Compilation by year of volcanoes included in an Alaska Volcano Observatory Annual Summary, 1992–2011.—Continued

[Volcanoes are presented in geographical order from northeast to southwest along the Wrangell-Aleutian volcanic arc and north to south along Kamchatka and the Kurile Islands. Prior to 1995, Alaska Volcano Observatory did not report on Russian volcanoes]

Volcanoes mentioned	
Alaskan	**Russian**
2002	
Wrangell	Sheveluch
Katmai Group (Martin, Mageik)	Klyuchevskoy
Veniaminof	Bezymianny
Mt. Hague (Emmons Lake Caldera)	Karymsky
Shishaldin	
Great Sitkin	
2003	
Wrangell	Sheveluch
Redoubt	Klyuchevskoy
Iliamna	Bezymianny
Augustine	Karymsky
Katmai Group (Mageik)	Alaid
Veniaminof	Chikurachki
Pavlof	
Mt. Hague (Emmons Lake Caldera)	
Shishaldin	
Akutan	
2004	
Mt. Crillon (non-volcanic peak)	Sheveluch
Mount Spurr	Klyuchevskoy
Katmai Group (Martin)	Bezymianny
Veniaminof	Karymsky
Shishaldin	Chirinkotan (Kuriles)
Westdahl	
2005	
Mount Spurr	Sheveluch
Iliamna	Klyuchevskoy
Augustine	Bezymianny
Katmai Group (Martin, Mageik, Trident)	Karymsky
Chiginagak	Avachinsky
Aniakchak	Mutnovsky
Veniaminof	Ebeko
Pavlof/Mt. Hague	Chikurachki
Shishaldin	
Cleveland	
Korovin	
Kasatochi	
Tanaga	

Volcanoes mentioned	
Alaskan	**Russian**
2006	
Klawasi	Sheveluch
Mount Spurr	Klyuchevskoy
Augustine	Bezymianny
Fourpeaked	Karymsky
Katmai Group (Martin, Mageik, Trident)	Ebeko
Veniaminof	Severgin
Cleveland	Berga
Korovin	
Kasatochi	
2007	
Redoubt	Sheveluch
Augustine	Klyuchevskoy
Fourpeaked	Bezymianny
Veniaminof	Karymsky
Pavlof	Gorely and Mutnovsky
Akutan	Chikurachki
Cleveland	Berga
Korovin	
2008	
Redoubt	Sheveluch
Aniakchak	Klyuchevskoy
Veniaminof	Bezymianny
Shishaldin	Karymsky
Okmok	Koryaksky
Cleveland	Gorely and Mutnovsky
Kasatochi	Chikurachki
	Tyatya
2009	
Sanford	Sheveluch
Redoubt	Kluchevskoy
Fourpeaked	Bezymianny
Aniakchak	Kizimen
Veniaminof	Karymsky
Shishaldin	Koryaksky
Okmok	Gorley
Cleveland	Ebeko
	Sarychev
	Raikoke

Table 4a. Compilation by year of volcanoes included in an Alaska Volcano Observatory Annual Summary, 1992–2011.—Continued

[Volcanoes are presented in geographical order from northeast to southwest along the Wrangell-Aleutian volcanic arc and north to south along Kamchatka and the Kurile Islands. Prior to 1995, Alaska Volcano Observatory did not report on Russian volcanoes]

Volcanoes mentioned	
Alaskan	**Russian**
2010	
Wrangell	Sheveluch
Mt. Sanford	Klyuchevskoy
Redoubt	Bezymianny
Fourpeaked	Kizimen
Katmai Group	Karymsky
Becharof Lake	Gorely
Aniakchak	Ekarma
Veniaminof	
Westdahl	
Makushin	
Cleveland	
Kasatochi	
2011	
Aniakchak	
Okmok	
Cleveland	

Table 4b. Compilation by volcano for particular years included in an Alaska Volcano Observatory Annual Summary, 1992–2011.

[Suspect Volcanic Activity (SVA) is defined as a report of eruption or possible eruption that is normal fumarolic activity or non-volcanic phenomena, such as weather related. PIREP, pilot weather report]

Volcano	Year mentioned	Type of activity
	Alaska (east to west)	
Churchill	1993	SVA, anomalous seismicity
Wrangell	1996	SVA, steam plume
	1997	SVA, steam plume
	1999	SVA, steaming and phreatic ash emission
	2000	SVA, steam plumes
	2002	SVA, suspicious clouds, redistributed ash
	2003	SVA, anomalous clouds
	2007	Triggered seismicity, vapor clouds, wind-blown ash
	2010	Anomalous clouds
Sanford	1993	SVA, reported steam plume likely from avalanche
	1994	SVA, reported steam plume likely from avalanche
	1997	SVA, large steam cloud from SW face
	2009	Anomalous cloud
	2010	Anomalous cloud from SW face
Shrub Mud	1997	Eruption; energetic ejection of saline mud and CO_2
	1998	Eruption continues; ejection of saline mud and CO_2
	1999	Eruption continues; ejection of saline mud and CO_2
Klawasi Mud	2006	Possible new mud vent
Spurr	1992	Subplinian eruptions; ash, pyroclastic flows, lahars
	1993	SVA, glacial outburst produces seismicity
	2004	Heat flux to summit; lahars; cauldron develops
	2005	Continued heat to summit; cauldron evolves
	2006	Continued heat to summit; cauldron evolves
Redoubt	1992	SVA, steam plume from still-cooling dome
	2003	SVA, anomalous weather cloud
	2007	Possible steaming and increased thermal flux
	2008	Pre-eruption increase in gas emissions and thermal flux from summit crater
	2009	Major magmatic eruption
	2010	Vapor and gas clouds; brief uptick in seismicity
Iliamna	1992	SVA, PIREP of large steam plume, media frenzy
	1994	SVA, vigorous steam plume, avalanche
	1996	Intense seismicity related to magmatic intrusion
	1997	SVA; anomalous seismic swarm; avalanche
	1999	SVA, avalanche
	2003	SVA, avalanche
	2005	SVA, rock avalanche
Augustine	1998	1986 dome spine partially collapses, generates mudflow
	2005	Precursory activity prior to eruption in early 2006
	2006	Explosive and effusive eruption
	2007	Strong seismicity and steam plumes
Fourpeaked	2006	Phreatic eruption
	2007	Ongoing fumarolic emissions, seismicity
	2009	Continued decrease in steam and gas emissions
	2010	Decreasing fumarolic emissions, sporadic earthquake swarms

Table 4b. Compilation by volcano for particular years included in an Alaska Volcano Observatory Annual Summary, 1992–2011.—Continued

[Suspect Volcanic Activity (SVA) is defined as a report of eruption or possible eruption that is normal fumarolic activity or non-volcanic phenomena, such as weather related. PIREP, pilot weather report]

Volcano	Year mentioned	Type of activity
Alaska (east to west)—Continued		
Katmai Group		
Mageik	1992	SVA, anomalous cloud
Martin/Mageik/Trident	1994	SVA, plume-like cloud
Martin	1995	SVA, large steam plume
Martin/Mageik/Trident/Mount Katmai	1996	SVA, anomalous seismicity
Martin/Mageik/Snowy/Kukak	1997	SVA, PIREPS of ash and steam plumes
Snowy	2000	SVA, steaming hole in glacier
Snowy/Kukak	2001	SVA, steaming hole in glacier
Martin/Mageik	2002	SVA, steam plume
Mageik	2003	SVA, steaming, large cloud of re-suspended ash
Martin	2004	SVA, large steam plume
	2006	Earthquake swarm
	2010	Re-suspended ash
Martin/Mageik/Trident	2005	SVA, steam cloud, re-suspended ash, new crater?
Becharof Lake	1998	SVA, intense seismic swarm and inflationary episode
	2010	Earthquake swarm
Chiginagak	1997	Minor eruptive activity, new fumarole field
	1998	SVA, continuation of increased fumarolic activity
	2000	SVA, steam emissions from fumarole field
	2005	Heat to summit; acidic flood; cauldron develops
Aniakchak	2005	SVA, anomalous seismicity, thermal anomaly
	2008	Weather related noise on seismic stations
	2009	Anomalous seismicity; network outage
	2010	Low frequency earthquake swarms
	2011	Anomalous seismicity
Veniaminof	1993	Low-level eruption and lava flows
	1994	Strombolian eruption and lava flows
	1995	Strombolian eruptions
	1999	SVA, extreme discharge and turbid river
	2002	Low-level phreatic eruptions
	2003	Low-level phreatic eruptions
	2004	Weak phreatic and Strombolian eruption
	2005	Intermittent phreatic and Strombolian eruption
	2006	Intermittent phreatic and Strombolian eruption
	2007	Decline in vapor plumes
	2008	Weak phreatic emissions and vapor plumes
	2009	Minor phreatic eruptions
	2010	Sporadic seismicity, vapor plumes
Kupreanof	1994	SVA, PIREP of unusual steam plume
Pavlof	1996	Strombolian eruption
	1997	Strombolian eruption concludes
	1999	SVA, summit snow melt, ash dustings, steam plumes
	2001	SVA, steaming, possible ash, sulfur smell
	2005	SVA, mis-located steam plume
	2007	Strombolian eruption, lava flows, lahars
Hague (Emmons Lake Caldera)	2002	SVA, increase in fumarolic activity in summit crater
	2003	SVA, crater lake drains, refills, drains
	2005	SVA, steam plume
Frosty	2001	SVA, rock fall avalanches

Table 4b. Compilation by volcano for particular years included in an Alaska Volcano Observatory Annual Summary, 1992–2011.—Continued

[Suspect Volcanic Activity (SVA) is defined as a report of eruption or possible eruption that is normal fumarolic activity or non-volcanic phenomena, such as weather related. PIREP, pilot weather report]

Volcano	Year mentioned	Type of activity
	Alaska (east to west)—Continued	
Shishaldin	1993	Minor phreatic
	1994	SVA, PIREP of minor steam/ash
	1995	Minor eruptive activity, steam/ash
	1996	Eruption; steam/ash and thermal anomaly
	1997	Minor eruptive activity, steam/ash
	1998	Minor eruptive activity, steam/ash
	1999	Strombolian eruption
	2000	Minor eruptive activity, steam/ash
	2001	Minor unrest, seismicity increase, steam clouds
	2002	SVA, shallow seismicity; PIREP of possible eruption
	2003	SVA, steam plumes
	2004	Small steam and ash plumes
	2005	SVA, increased seismicity, steam plumes prompt PIREPS
	2008	Minor phreatic (?) ash emission and vigorous vapor plumes
	2009	Increased seismicity, small steam plumes, thermal anomalies
Westdahl	1992	Fissure eruption, lava fountains, ash clouds, lava flow
	1996	SVA, suspicious weather cloud on satellite image
	2004	SVA, seismic swarm
	2010	Increase in lower crustal seismicity
Akutan	1992	SVA, steam/ash emissions
	1996	Intensive seismicity, ground cracking
	1998	SVA, tremor-like seismicity
	2003	SVA, anomalous steam plume
	2007	Triggered seismicity; inflation; anomalous steaming
Makushin	1993	Minor phreatic
	1994	SVA, PIREP of minor steam/ash
	1995	SVA, steam plume
	2001	SVA, increase in seismicity
	2008	Discolored seawater in Unalaska Bay
	2010	Seismicity, anomalous clouds reported
Bogoslof	1992	Dome extrusion, ash and steam emissions
Okmok	1997	Strombolian eruption
	2001	SVA, seismic swarm
	2008	Major Phreatomagmatic eruption
	2009	Caldera floor uplift, tremor burst
	2011	Inflation
Vsevidof	1999	SVA, sighting of ash after regional earthquake
Cleveland	1994	SVA, possible steam/ash emission
	1997	Minor eruption, steam/ash
	2001	Eruption; gas/ash, lava/debris flows
	2005	Intermittent explosions
	2006	Intermittent explosions
	2007	Intermittent explosions, small ash clouds, ballistics
	2008	Intermittent explosions; small ash clouds
	2009	Thermal anomalies, minor ash and gas emissions, flowage and ballistics deposits
	2010	Explosions, small ash clouds, vapor plumes, thermal anomalies
	2011	Intermittent explosions, small ash clouds
	2012	Lava extrusion, explosions, small ash clouds
Amukta	1996	Small eruption; ash emission
	1997	SVA, PIREP of small ash eruption

Table 4b. Compilation by volcano for particular years included in an Alaska Volcano Observatory Annual Summary, 1992–2011.—Continued

[Suspect Volcanic Activity (SVA) is defined as a report of eruption or possible eruption that is normal fumarolic activity or non-volcanic phenomena, such as weather related. PIREP, pilot weather report]

Volcano	Year mentioned	Type of activity
Seguam/Pyre Peak	1992	Minor eruptive activity, steam/ash emissions
	1993	Fissure eruption produces lava flow and ash cloud
Kliuchef (Atka)	1993	SVA, audible rumbling, strong sulfur odor
	1995	SVA, large steam plume, strong sulfur odor
Korovin (Atka)	1996	SVA, PIREP of ash cloud, suspicious cloud on satellite image
	1998	Eruption; explosions and ash fall
	2005	Minor eruption, steam and ash
	2006	Seismic swarms, uplift, increased fumarolic activity
	2007	Seismic swarms; fumarolic activity
Kasatochi	2005	SVA, unusual bubbling; floating scum on crater lake
	2006	Continued bubbling in intracaldera lake
	2008	Major explosive eruption
	2010	Fumarolic emission, diffuse degassing, coastal erosion
Great Sitkin	2001	SVA, anomalous seismicity
	2002	SVA, seismic swarm, tremor
Kanaga	1993	SVA, increased steaming
	1994	Eruption; steam/ash and lava flow
	1995	Minor eruptive activity, steam/ash and lava
	1996	Possible eruption and ash emission
Tanaga	2005	SVA, anomalous seismicity, including a period of tremor
Kamchatka and northern Kurile Islands (north to south) — activity through 2010		
Sheveluch	1997	Dome extrusion
	1998	Lava dome growth
	1999	Lava dome growth and collapse, ash
	2000	Lava dome growth, ash
	2001	Lava dome growth and collapse, ash
	2002	Lava dome growth, ash, pyroclastic flows
	2003	Lava dome growth, ash, pyroclastic flows, lahar
	2004	Lava dome growth, pyroclastic flows, lahars, ash
	2005	Lava dome growth, dome collapse, pyroclastic flows, ash
	2006	Lava dome growth, dome collapse, explosions
	2007	Lava dome growth, dome collapse, explosions
	2008	Lava dome growth, dome collapse, explosions
	2009	Lava dome growth, dome collapse, explosions
	2010	Lava dome growth, dome collapse, explosions
Klyuchevskoy	1996	Gas/ash eruption
	1997	Gas/ash eruption
	1998	Gas/ash eruption
	1999	Gas/ash eruption
	2000	Vulcanian explosions
	2001	Fumarolic plume
	2002	Elevated seismicity, gas-rich explosion
	2003	Elevated seismicity, ash explosion, Strombolian activity
	2004	Elevated seismicity
	2005	Strombolian eruption, lava flows, lahars
	2006	Increased seismicity, thermal anomaly, no eruption
	2007	Ash emission, Strombolian lava fountaining, lava flows
	2008	Strombolian lava fountaining, lava flows, lahars, phreatic explosions
	2009	Strombolian, Vulcanian activity, lava flow production, ash falls
	2010	Strombolian lava fountaining, explosions, lava flows, lahars

Table 4b. Compilation by volcano for particular years included in an Alaska Volcano Observatory Annual Summary, 1992–2011.—Continued

[Suspect Volcanic Activity (SVA) is defined as a report of eruption or possible eruption that is normal fumarolic activity or non-volcanic phenomena, such as weather related. PIREP, pilot weather report]

Volcano	Year mentioned	Type of activity
Kamchatka and northern Kurile Islands (north to south) — activity through 2010—Continued		
Bezymianny	1995	Explosive eruption
	1996	Lava extrusion
	1997	Dome collapse and explosive eruption
	1998	Degassing and spalling of new dome
	1999	Degassing and spalling of new dome, ash
	2000	Dome growth, explosive eruption
	2001	Accelerated dome growth, pyroclastic flows
	2002	Accelerated dome growth, explosions, pyroclastic flows
	2003	Dome growth and explosive collapse
	2004	Minor explosive eruptions, gas and steam emissions
	2005	Dome growth continues, two explosive episodes
	2006	Dome growth continues, two explosive episodes
	2007	Dome growth continues, pyroclastic avalanches, ash clouds
	2008	Dome growth continues, ash explosion
	2009	Dome growth continues
	2010	Dome growth continues, ash explosion
Karymsky	1995	Increased seismicity
	1996	Explosive eruption
	1997	Low level Strombolian eruptions
	1998	Low level Strombolian eruptions
	1999	Low level Vulcanian and Strombolian eruptions
	2000	Low level Vulcanian and Strombolian eruptions
	2001	Low level Vulcanian and Strombolian eruptions
	2002	Low level Vulcanian and Strombolian eruptions, explosions, avalanches
	2003	Vulcanian and Strombolian eruptions intensify
	2004	Low level Vulcanian and Strombolian eruptions
	2005	Low level Vulcanian and Strombolian eruptions, explosions, lava, ash fall
	2006	Low level Vulcanian and Strombolian eruptions
	2007	Low level Vulcanian and Strombolian eruptions
	2008	Low level Vulcanian and Strombolian activity
	2009	Low level Vulcanian and Strombolian activity
	2010	Low level Vulcanian and Strombolian activity
Koryaksky	2008	Phreatic explosions and ash emission
Avachinsky	1996	Increased seismicity
	2001	Increased seismicity, phreatic explosion
	2005	Increased seismicity, thermal anomalies
Mutnovsky	1996	Fumarolic plume
	2000	Gas and steam explosion
	2005	Increased fumarolic activity
	2007	Increased seismicity; uncertain source
	2008	Increased seismicity; uncertain source and fumarolic activity at Gorely

Table 4b. Compilation by volcano for particular years included in an Alaska Volcano Observatory Annual Summary, 1992–2011.—Continued

[Suspect Volcanic Activity (SVA) is defined as a report of eruption or possible eruption that is normal fumarolic activity or non-volcanic phenomena, such as weather related. PIREP, pilot weather report]

Volcano	Year mentioned	Type of activity
Kamchatka and northern Kurile Islands (north to south) — activity through 2010—Continued		
Gorley	2007	Increased seismicity; uncertain source
	2008	Increased seismicity; uncertain source and fumarolic activity at Gorely
	2009	
	2010	Increased seismicity, thermal output, degassing
Alaid (Kurile Islands)	1996	Ash plume
	1997	SVA
Ebeko	2005	Increased fumarolic activity and phreatic eruptions
	2006	Increased fumarolic activity
Chikurachki	2003	Stombolian and Vulcanian eruption, ash fall
	2005	Brief explosion produces ash and ash fall
	2007	Ash explosions
	2008	Explosions and limited ash clouds
Severgin	2006	Phreatic or fumarolic activity
Sarychev	2009	Major magmatic eruption; check location in table
Chirinkotan	2004	Brief, low-level steam, gas, and ash emission
Ekarma	2010	Phreatic eruption, lahar detected after the fact; sheck location in table
Berga	2006	Phreatic or fumarolic activity
	2007	Possible phreatic or fumarolic activity
Tyatya	2008	Possible increase in fumarolic activity

Table 4c. Citations for Alaska Volcano Observatory Annual Summary reports, 1992–2011.

Year	Citation	URL
1992	McGimsey, R.G., Neal, C.A., and Doukas, M.P., 1995, Volcanic activity in Alaska: Summary of events and response of the Alaska Volcano Observatory 1992: U.S. Geological Survey Open-File Report 95-83, 26 p.	http://pubs.er.usgs.gov/publication/ofr9583
1993	Neal, C.A., McGimsey, R.G., and Doukas, M.P., 1996, 1993 Volcanic activity in Alaska: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report 96-24, 21 p.	http://pubs.usgs.gov/of/1996/0024/
1994	Neal, C.A., Doukas, M.P., and McGimsey, R.G., 1995, 1994 Volcanic activity in Alaska: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report 95-271, 20 p.	http://pubs.usgs.gov/of/1995/0271/
1995	McGimsey, R.G., and Neal, C.A., 1996, 1995 Volcanic activity in Alaska and Kamchatka: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report 96-738, 22 p.	http://pubs.usgs.gov/of/1996/0738/
1996	Neal, C.A., and McGimsey, R.G., 1997, 1996 Volcanic activity in Alaska and Kamchatka: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report 97-433, 34 p.	http://pubs.usgs.gov/of/1997/0433/
1997	McGimsey, R.G., and Wallace, K.L., 1999, 1997 Volcanic activity in Alaska and Kamchatka: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report 99-448, 42 p.	http://pubs.usgs.gov/of/1999/0448/
1998	McGimsey, R.G., Neal, C.A., and Girina, Olga, 2003, 1998 Volcanic activity in Alaska and Kamchatka: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report 03-423, 35 p.	http://pubs.usgs.gov/of/2003/of03-423/
1999	McGimsey, R. G., Neal, C. A., and Girina, Olga, 2004a, 1999 Volcanic activity in Alaska and Kamchatka: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report OF 2004-1033, 49 p.	http://pubs.usgs.gov/of/2004/1033/
2000	Neal, C.A., McGimsey, R.G., and Chubarova, Olga, 2004, 2000 Volcanic activity in Alaska and Kamchatka: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report 2004-1034, 37 p.	http://pubs.usgs.gov/of/2004/1034/
2001	McGimsey, R.G., Neal, C.A., and Girina, Olga, 2004b, 2001 Volcanic activity in Alaska and Kamchatka: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report 2004-1453, 57 p.	http://pubs.usgs.gov/of/2004/1453/
2002	Neal, C.A., McGimsey, R.G., and Girina, Olga, 2005, 2002 Volcanic activity in Alaska and Kamchatka: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report 2004-1058, 55 p.	http://pubs.usgs.gov/of/2004/1058/
2003	McGimsey, R.G., Neal, C.A., and Girina, Olga, 2005, 2003 Volcanic activity in Alaska and Kamchatka: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report 2005-1310, 62 p.	http://pubs.usgs.gov/of/2005/1310/
2004	Neal, C.A., McGimsey, R.G., Dixon, J.P., and Melnikov, Dmitry, 2005, 2004 Volcanic activity in Alaska and Kamchatka: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report 2005-1308, 71 p.	http://pubs.usgs.gov/of/2005/1308/
2005	McGimsey, R.G., Neal, C.A., Dixon, J.P., Ushakov, Sergey, 2007, 2005 Volcanic activity in Alaska, Kamchatka, and the Kurile Islands: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Scientific Investigations Report 2007-5269, 94 p.	http://pubs.usgs.gov/sir/2007/5269/
2006	Neal, C.A., McGimsey, R.G., Dixon, J.P., Manevich, Alexander, and Rybin, Alexander, 2009, 2006 Volcanic activity in Alaska, Kamchatka, and the Kurile Islands: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Scientific Investigations Report 2008-5214, 102 p.	http://pubs.usgs.gov/sir/2008/5214/

Table 4c. Citations for Alaska Volcano Observatory Annual Summary reports, 1992–2011.—Continued

Year	Citation	URL
2007	McGimsey, R.G., Neal, C.A., Dixon, J.P., Malik, Nataliya, and Chibisova, Marina, 2011, 2007 Volcanic activity in Alaska, Kamchatka, and the Kurile Islands: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Scientific Investigations Report 2010–5242, 110 p.	http://pubs.usgs.gov/sir/2010/5242/
2008	Neal, C.A., McGimsey, R.G., Dixon, J.P., Cameron, C.E., Nuzhdaev, A.E., and Chibisova, M., 2011, 2008 Volcanic activity in Alaska, Kamchatka, and the Kurile Islands: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Scientific Investigations Report 2010–5243, 87 p.	http://pubs.usgs.gov/sir/2010/5243/
2009	McGimsey, R.G., Neal, C.A., Girina, O.A., Chibisova, Marina, and Rybin, Alexander, 2013, 2009 Volcanic activity in Alaska, Kamchatka, and the Kurile Islands: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Scientific Investigations Report 2013–5213, 125 p.	http://pubs.usgs.gov/sir/2013/5213/
2010	Neal, C.A., Herrick, J., Girina, O., Chibisova, M., Rybin, A., McGimsey, R., and Dixon, J., 2013, 2010 Volcanic activity in Alaska, Kamchatka, and the Kurile Islands: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Scientific Investigations Report 2013-5034, 76 p.	http://pubs.usgs.gov/sir/2013/5034/
2011	McGimsey, R.G., Maharrey, J.Z., and Neal, C.A., 2014, 2011 Volcanic activity in Alaska—Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Scientific Investigations Report 2014–5159, 50 p.	http://pubs.usgs.gov/sir/2014/5159

Volcanic Activity in Alaska, Northeast to Southwest Along Aleutian Arc

Aniakchak Volcano

CAVW# 1102-09-
56°54'N 158°13'W
1,341 m (4,400 ft)

Alaska Peninsula

DRAINAGE OF MAAR LAKE, destructive downstream flooding

In late August 2011, AVO was alerted by Troy Hamon, Chief of Resource Management, Katmai National Park, that the larger of two maar crater lakes on the caldera floor of Aniakchak Volcano had recently drained, leaving a gaping notch in the crater rim. The flood had ravaged the downstream drainage and alluvial fan as well as the upper reaches of the Aniakchak River, which drains Surprise Lake and the eastern caldera floor through The Gates. During September 8–9, 2011, authors Tina Neal and Game McGimsey, accompanied by Troy Hamon (on September 8), visited the site to document and study the activity.

Aniakchak caldera formed about 3,600 years ago in a colossal eruption (Neal and others, 2001). Subsequent eruptive activity has occurred from many intracaldera vents, including eruptions that formed two maar craters, subsequently filling with water, that are situated on the southeastern caldera floor between the central Vent Mountain cone and the sheer inner east caldera wall (fig. 2). The larger maar is about 450 m (1,476 ft) by 515 m (1,690 ft), as measured rim to rim in Google EarthTM imagery (fig. 3); the smaller maar is 170 m (558 ft) in diameter at the rim. The maars formed subsequent to the draining of a caldera-wide lake, at least 1,000 years before present (BP), but they may be much younger, perhaps less than 400 years old.

Geological investigations in 1992 documented that a low point on the maar rim was about 10– 15 m (33–49 ft) above the lake surface, although higher strand lines were visible in the deposits surrounding the maar, one of which was located nearly at the low point (figs. 3 and 4; Neal and others, 2001). On the outboard flank of the maar-rim low-point, a seep—piping through the maar crater wall deposits to the lake—occurred near the base of the flank and formed the headwater for the stream that courses between a prominent lava flow from Vent Mountain and the colluvial slopes extending out from the eastern caldera wall (fig. 3). This stream flows about 1.7 km (1 mi) northward from its source at the maar to the Aniakchak River immediately inboard of The Gates, a prominent notch in the caldera wall through which the river drains the entire caldera (fig. 2).

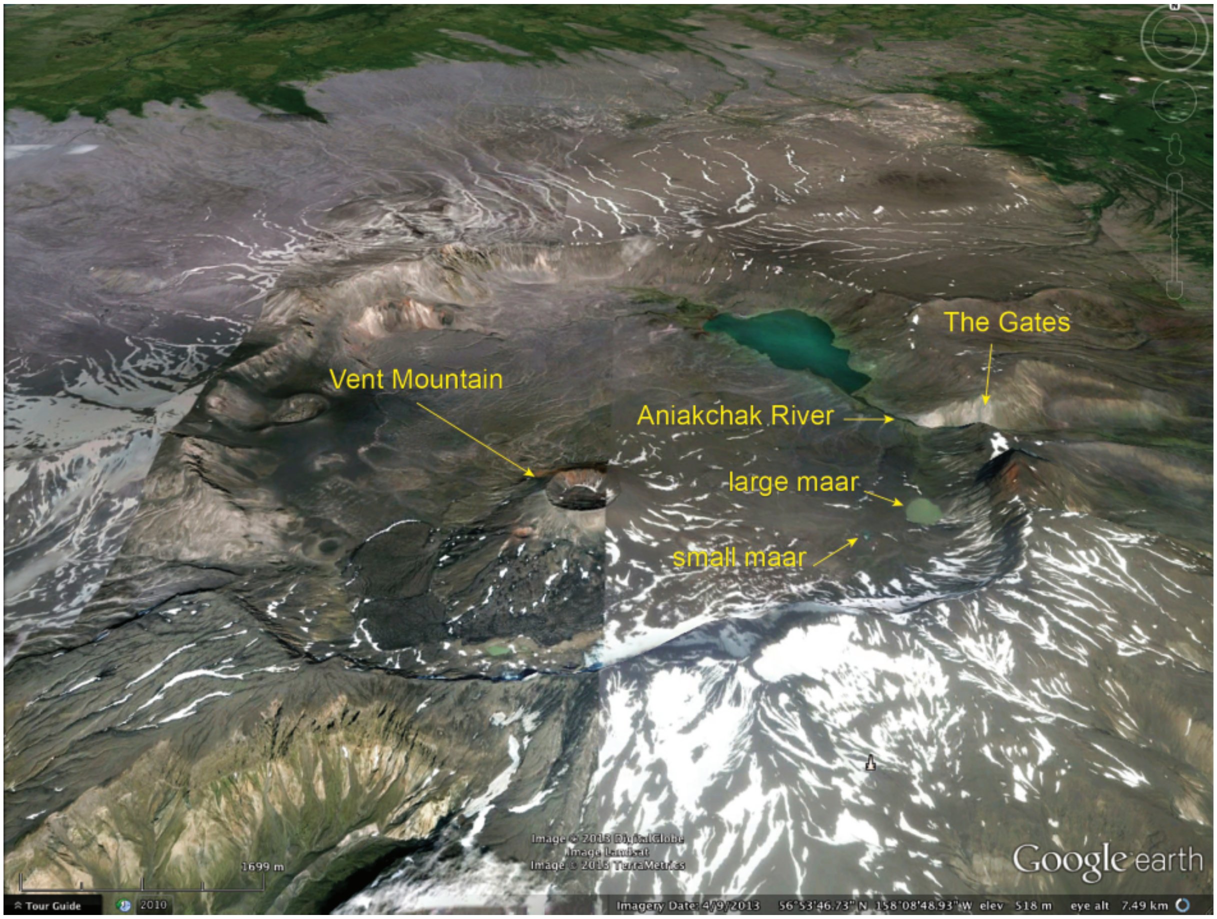

Figure 2. Oblique Google EarthTM view of Aniakchak caldera looking to the north. The larger of two maar craters lie on the southeastern floor of the caldera adjacent to the steep eastern caldera wall. The caldera is about 10 km (6.2 mi) in diameter. The larger maar is 450 m (1,476 ft) by 515 m (1,690 ft), and the smaller maar is 170 m (558 ft) in diameter at the rim. The maar craters lie along the caldera ring fracture system. This Google EarthTM image was taken on August 8, 2007, prior to the maar flood. AVO database image at URL: http://www.avo.alaska.edu/images/image.php?id=57531.

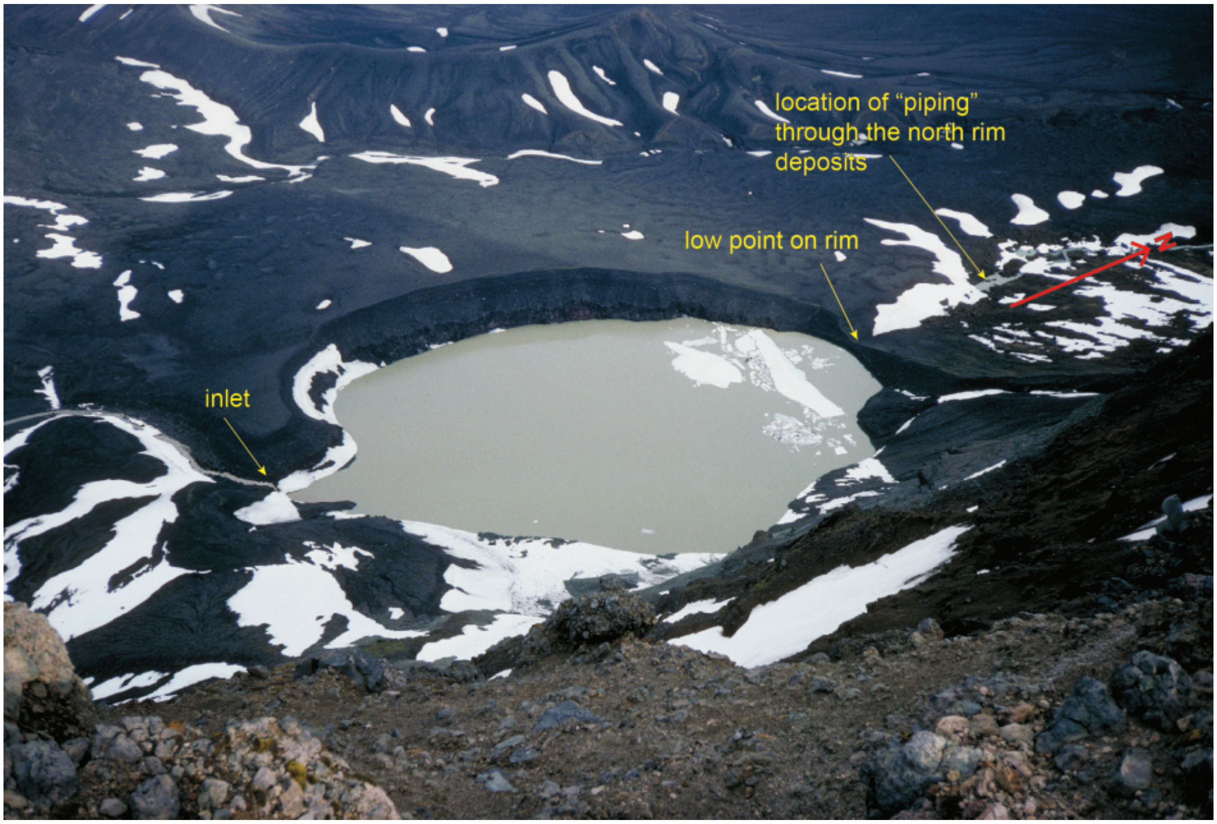

Figure 3. Photograph showing larger of two maar craters on the southeastern floor of Aniakchak caldera as viewed from the southeastern caldera rim. The crater is about 450 m (1,476 ft) by 515 m (1,690 ft), measured rim to rim. The low point on the rim is where flood water exited the crater, flowing northward 1.7 km (1 mi) to the Aniakchak River. The southeastern corner of the caldera drains into the lake and lake level is maintained by "piping" through the northern rim deposits. Photograph by C.A. Neal, AVO/USGS, June 29, 1992. AVO database image at URL: http://www.avo.alaska.edu/images/image.php?id=10405.

The maar breakout flood scoured and excavated the channel and banks of the stream north of the maar, cutting deeply into the colluvial slopes on the eastern side of the drainage (fig. 4). The previously well-vegetated alluvial fan near The Gates was entirely covered by flood deposits up to 1.5 m (4.9 ft) thick (fig. 5). Clumps of vegetation, up to about 1 m (3.3 ft) in length, were strewn on and within the deposit. The Aniakchak River was pressed even more tightly against the northern wall opposite the fan, causing some bank erosion, and the downstream river channel, sand bars, and banks were noticeably disrupted for more than 20 km (12.4 mi) beyond The Gates (fig. 6). The area of the breach on the maar rim was dramatically altered as downcutting progressed until a new base level was established. Discharge through the outflow at the northern end of the maar now approximates inflow at the southern end (primarily at the waterfall, fig. 3).

Field measurements and observations indicate that the maar lake level declined 4.65 m (15.3 ft) from its recent high stand (determined from photographs taken July 18, 2010 (fig. 7), as well as measurements made in the field in September 2011); this high stand was below the low-point on the northern rim where the breach occurred. The volume of water lost was at least 645,000 m^3 (844,000 yds^3), but this represents a minimum volume because there is no way of knowing how much additional water flooded into the maar immediately prior to initiation of the breakout flooding.

Based on analysis of photographs, weather data, and observations from a local guide, the maar flood likely occurred between late July and late September 2010. Evidence of recent flooding on the southern floor and wall of the caldera, which drain into the maar, suggests that the maar flood was likely caused by the rapid and voluminous

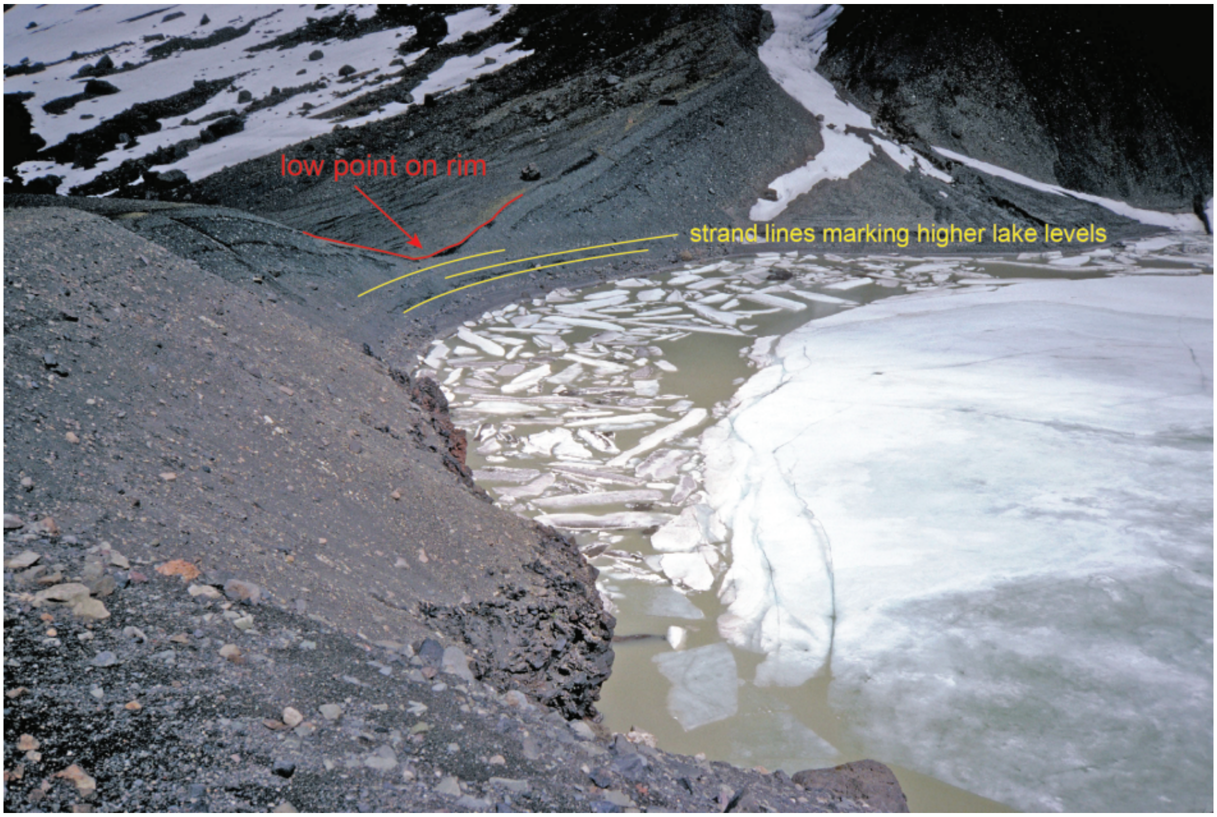

Figure 4. Photograph of the northwestern rim of the maar; view is toward the low point on the northern rim. Several strand lines mark higher stands of the lake, and the low point is likely a former spillway. Photograph by C.A. Neal, AVO/USGS, June 24, 1992. AVO database image at URL: http://www.avo.alaska.edu/images/image.php?id=10402.

influx of water into the maar lake during a period of unusually heavy rainfall. The lake level rose rapidly and the low point on the maar rim may have been reached and spilled over. The increased hydraulic head may have simultaneously initiated failure of the crater wall at that location where groundwater seepage and possibly piping within the mantling deposit was occurring. The heavy precipitation may have further increased saturation of the deposit. Once the breach began, by either rapid downcutting, or structural failure of the wall, or both, rapid release of water occurred, resulting in a short-lived but massive flood down the drainage to—and then down—the Aniakchak River (figs. 8 and 9).

Aniakchak is a circular caldera 10 km (6.2 mi) in diameter and as deep as 1 km (3,280 ft) from the rim to the caldera floor. The caldera formed during a huge eruption about 3,600 years ago (Miller and Smith, 1987; Dreher and others, 2005). Numerous lava domes, lava flows, and scoria cones occupy the interior of the caldera (Neal and others, 2001); the largest intracaldera cone is Vent Mountain, 2.5 km (1.5 mi) in diameter and rising 430 m (1,410 ft) above the floor of the caldera. The only historical eruption of Aniakchak, a powerfully explosive event that covered a large portion of the eastern Alaska Peninsula with ash, occurred in 1931 (Hubbard, 1931; Neal and others, 2001; Nicholson, 2003).

Figure 5. Photographs of drainage between the maar and the Aniakchak River before and after the flood event showing displacement of the stream channel and erosion of the flood plain and fan. Arrows point to several prominent features common on both images. Image on the left was taken by Ryan Rumelhart, NPS, August 4, 2005. AVO database image at URL: http://www.avo.alaska.edu/images/image.php?id=57541. Image on the right was taken by Game McGimsey, AVO/USGS, September 7, 2011. AVO database image at URL: http://www.avo.alaska.edu/images/image.php?id=57551.

Figure 6. Comparative aerial oblique views east showing the Aniakchak River exiting the caldera through The Gates. Image on the left was taken prior to the maar breakout flood; note the lush green alluvial fan center right, where streams draining the eastern side of the caldera join the Aniakchak River. Image on the right shows the effects of the 2010 flood on the alluvial fan as well as to the Aniakchak River (arrow), where the flood plain was swept of vegetation and flood debris was deposited; the alluvial fan has been inundated by the maar flood debris, and the course of the main stream has shifted to the western margin of the fan (down in the image). Image on the left was taken by Game McGimsey, AVO/USGS, July 22, 1993. AVO database image at URL: http://www.avo.alaska.edu/images/image.php?id=10534. Image on the right was taken by Game McGimsey, AVO/USGS, September 7, 2011. AVO database image at URL: http://www.avo.alaska.edu/images/image.php?id=57561.

Figure 7. Comparative images of the large maar in Aniakchak caldera. Lake level dropped declined at least 4.65 m (15.3 ft) when the northern rim of the maar failed, releasing at least 645,000 m^3 (844,000 yds^3) of lake water. Image on top was taken by Tom O'Keefe, July 18, 2010. AVO database image at URL: http://www.avo.alaska.edu/images/image.php?id=57571. Image on bottom was taken by Game McGimsey, AVO/USGS, September 7, 2011. AVO database image at URL: http://www.avo.alaska.edu/images/image.php?id=57581.

Figure 8. View south of the breach in the northern rim of the maar crater lake on the eastern floor of Aniakchak caldera. The coarse debris in the middle ground is the toe of a rockslide that had mantled the base of the colluvial eastern slope of the eastern caldera wall. The flood winnowed the fine material and left the coarser boulders as lag. The breach occurred at the lowest point on the maar rim immediately to the right of the large boulder above the left side of cut. Groundwater seepage or piping through the rim deposits had been occurring at the area shown at the extreme bottom of image. Photograph by Game McGimsey, AVO/USGS, September 7, 2011. AVO database image at URL: http://www.avo.alaska.edu/images/image.php?id=57591.

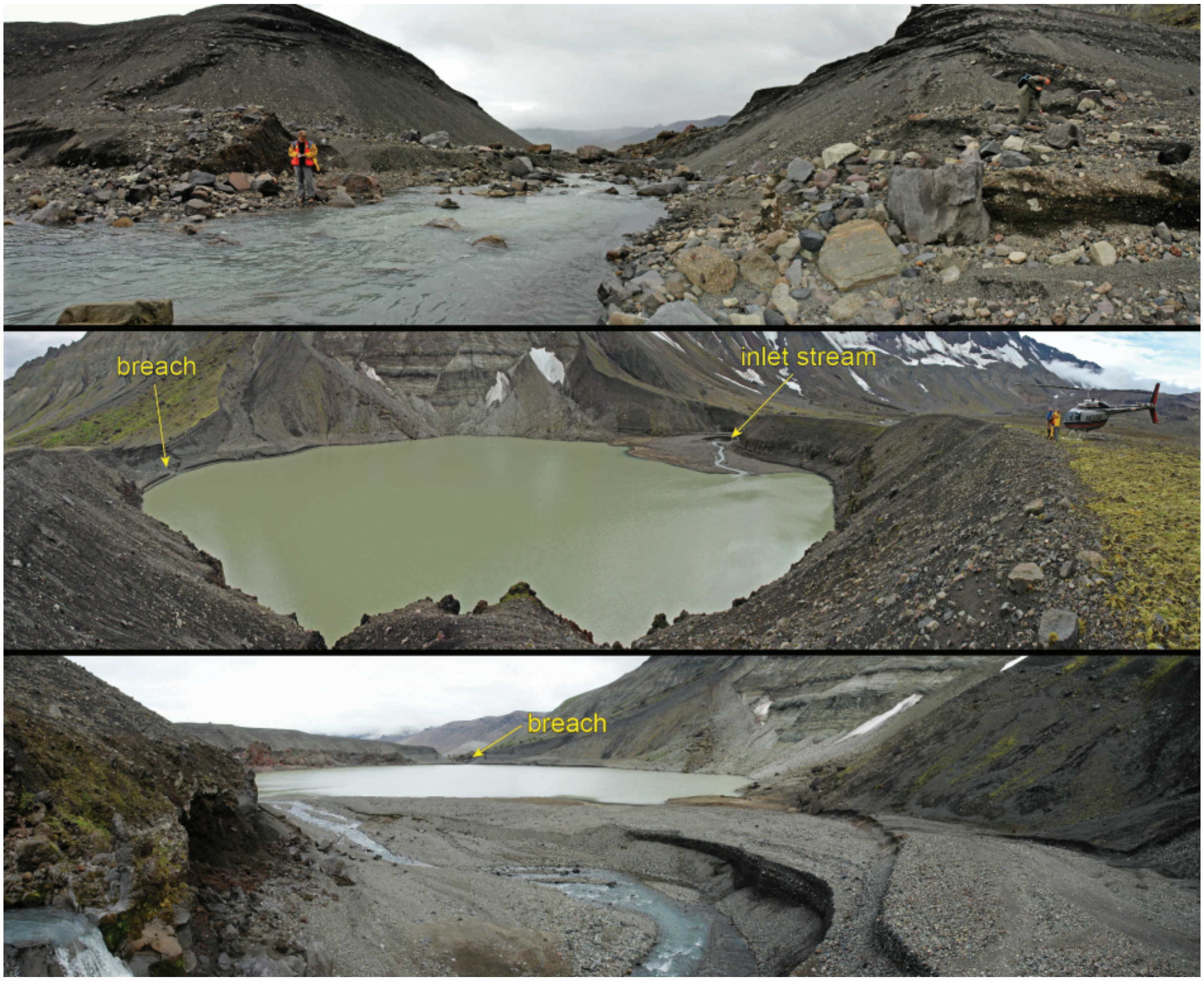

Figure 9. Panoramic views of the maar lake. Top: Breach through the northern rim of the maar crater lake; geologist Tina Neal (left) and NPS Resource Manager Troy Hamon (right) for scale. The lake level prior to the flood event was at least 4.65 m (15.3 ft) above the stream where Tina Neal is standing in this view. Center: Maar lake viewed from the western rim showing both the inlet stream and breach. Bottom: View north from the inlet stream across the incised delta of sediments and the maar lake. Images were taken by Game McGimsey, AVO/USGS, September 7, 2011. AVO database images at URL: http://www.avo.alaska.edu/images/image.php?id=57651 (top); http://www.avo.alaska.edu/images/image.php?id=57661 (center); http://www.avo.alaska.edu/images/image.php?id=57681 (bottom).

Okmok Volcano

CAVW# 1101-29-

53°25'N 168°08'W
1,073 m (3,502 ft)

Umnak Island, eastern Aleutian Islands

INFLATION OF CALDERA FLOOR CONTINUES

Okmok volcano had a dramatic phreatomagmatic eruption over a 5-week period during the summer of 2008 (Neal and others, 2011). The eruption ended in August 2008 with seismic activity returning to background levels and remaining there until the morning of March 2, 2009, when a series of strong tremor-like events were recorded over a 24-hour period. Deformation (uplift) of the caldera floor began in August 2008 as the eruption ended and campaign GPS data from September 1, 2008, to March 1, 2009, showed a linear progression of 9 cm (3.5 in.) of uplift in the center of the caldera (see McGimsey and others, 2014). This rapid inflation slowed somewhat by the middle of 2010. In 2011, the inflation at Okmok continued, increasing over recent (2010) rates (5–6 cm over a 12-month period ending in September 2011), but still at a lower rate than was recorded following the 2008 eruption (M. Kaufman, UAFGI, written commun., September 7, 2011). In summary, the inflation at Okmok continues—albeit in pulses—with rates in the 5–7 cm/yr range (J. Freymueller, UAFGI, written commun., September 28, 2013).

Okmok Volcano is a 10-km-wide (6.2-mi) caldera that occupies most of the eastern end of Umnak Island, located 120 km (75 mi) southwest of the important fishing and transportation hub of Unalaska/Dutch Harbor in the eastern Aleutian Islands. Okmok has had several historic eruptions typically consisting of ash emissions occasionally more than 9 km (30,000 ft) ASL, but generally much lower; lava flows crossed the caldera floor in 1945, 1958, and 1997 (Begét and others, 2005). The nearest settlement is Nikolski, 72 km (45 mi) west of the volcano, with a population of 27 (Alaska Community Database, Community Information Summaries: http://www.commerce.state.ak.us/dca/commdb/CIS.cfm; accessed November 14, 2012). A ranch caretaker family lives at Fort Glenn on the flank of the volcano about 10 km (6.2 mi) east of the caldera rim.

Cleveland Volcano

CAVW# 1101-24-

52°49'N 169°57'W
1,730 m (5,676 ft)

Chuginadak Island, east-central Aleutian Islands

THERMAL ANOMALIES, LAVA DOME EXTRUSION, AND MINOR ASH PLUMES
Ash clouds, thermal anomalies, lava dome growth, fumarole steaming, and ballistics observed

Cleveland volcano remained at Aviation Color Code **YELLOW** and Volcano Alert Level **ADVISORY** throughout the first 3 months of 2011. In February, an eyewitness pilot report (**PIREP**) described Mount Cleveland's summit as lightly steaming, with no visible signs of recent activity present on the volcano's upper flanks. On March 31, AVO downgraded the Aviation Color Code/Volcano Alert Level from **YELLOW/ADVISORY** to **UNASSIGNED** following the continued absence of thermal anomalies at Cleveland in the twice-daily AVO satellite monitoring shifts. Cleveland remained **UNASSIGNED** from March 31 to July 20. On July 20, AVO upgraded the Aviation Color Code/Volcano Alert Level from **UNASSIGNED** to **YELLOW/ADVISORY** after thermal anomalies were observed in satellite imagery during routine satellite monitoring on July 16–17 (fig. 10). On August 2, the Aviation Color Code/Volcano Alert Level was upgraded to **ORANGE/WATCH** based on persistent thermal anomalies detected at the volcano's summit (fig. 11) as well as satellite evidence of new lava in the summit crater on July 31.

In 2011, Cleveland's summit crater was about 200–225 m (660–740 ft) wide at the rim; its depth varies through time with the impacts of eruptive activity, but can be as much as 80–100 m (260–330 ft). Extrusion of lava in the summit crater presumably began around the time of the onset of persistent thermal anomalies, during July 16–17; a new dome in late July 2011 was approximately 40 m (130 ft) across. Satellite images of the summit on August 3 showed the dome to be approximately 50 m (160 ft) across and no more than 20 m (65 ft) above the summit crater floor. The dome may have grown to 60 m (200 ft) across by August 6 implying an approximate lava volume of 115,000 m^3 (150,420 yds^3) or 7 percent of the crater's total volume of approximately 1.6 million m3 (2.1 million yds3). Satellite imagery (fig. 12) showed no significant new tephra deposits indicating that activity from mid-July into early August was primarily extrusive. This was consistent with an August 9 WorldView-1 satellite image of Cleveland's summit showing steaming, light-colored alteration deep inside the summit crater around the new lava dome (fig. 13), and with oblique aerial photographs taken on August 8 by NOAA scientists (fig. 14).

On August 10, AVO received a mariners report from the National Weather Service (NWS) Ocean Prediction Center of possible ash floating on the sea surface approximately 25 km (13.5 nmi) north-northwest of Cleveland. The same source reported the absence of any floating ash earlier in the day at about 30 km (16 nmi) north of the volcano. No ash clouds were detected in satellite data during the times of these reports. Analysis of satellite data indicated that during August 6–13, the lava dome grew only slightly larger than detected in the previous image acquired on August 6. Although it is possible that these accounts of drifting ash are valid, AVO was unable to confirm them.

On August 30, AVO downgraded Cleveland's Aviation Color Code/Volcano Alert Level from **ORANGE/WATCH** to **YELLOW/ADVISORY** based on the absence of distinct thermal signals at the summit. Satellite observations on September 6 indicated that the lava dome had grown to about 120 m (390 ft) in diameter and consistently elevated surface temperatures were again observed. As a result of these observations, AVO upgraded Cleveland to Aviation Color Code/Volcano Alert Level **ORANGE/WATCH**. By this time, the lava dome essentially filled the summit crater.

TerraSAR-X satellite radar images from the German Remote Sensing Data Center (DFD) and the German Aerospace Center (DLR), acquired over Cleveland volcano from August to November 2011, provided an image time series showing the partial growth of the 2011 lava dome in the summit crater (fig. 15).

The lava dome continued to grow through late September, expanding in diameter from approximately 120 m (390 ft) on September 6 to approximately 168 m (550 ft) by September 20 and reaching a height approximately 15–20 m (50–65 ft) below the crater rim by September 26. Additional growth of the dome past October 20 was minor (fig. 15).

Extrusion of lava either slowed or ceased between October 1 and October 5. Satellite data from October 9 indicated that the central portion of the lava dome became slightly depressed, indicating minor deflation of the dome. Subsidence of the dome continued into late October.

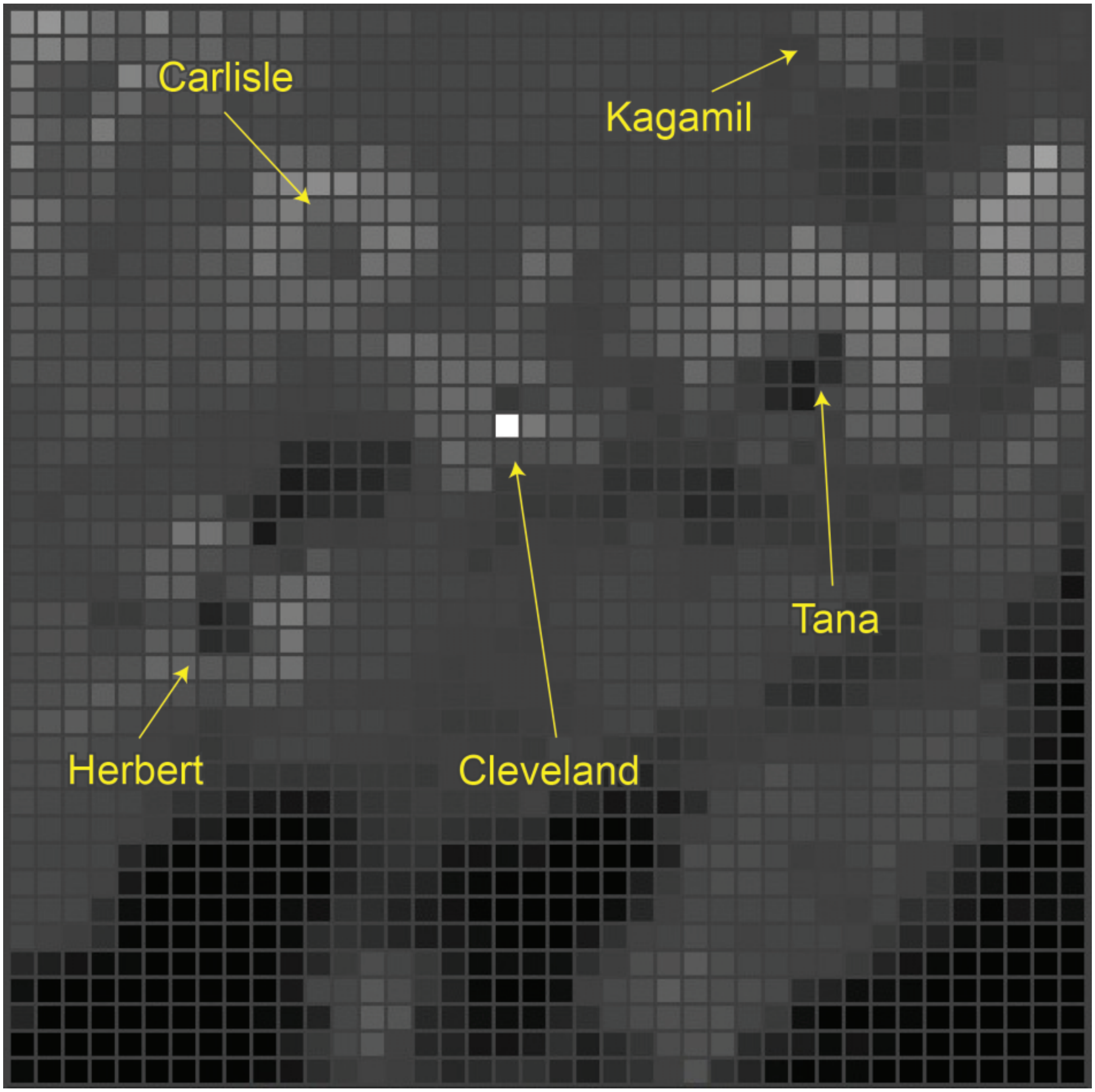

Figure 10. Elevated temperature anomaly (white pixel) at the summit of Cleveland volcano in a NOAA Advanced Very High Resolution Radiometer (AVHRR) satellite image, channel 3 (thermal band) from 06:12 UTC July 17, 2011. This screen shot is from output generated by the University of Alaska Fairbanks Geophysical Institute's Remote sensing group's Hotspot Viewer tool. Outlines of the islands of Carlisle, Herbert, and Kagamil are faintly visible; Cleveland and Tana volcanoes comprise Chuginadak Island.

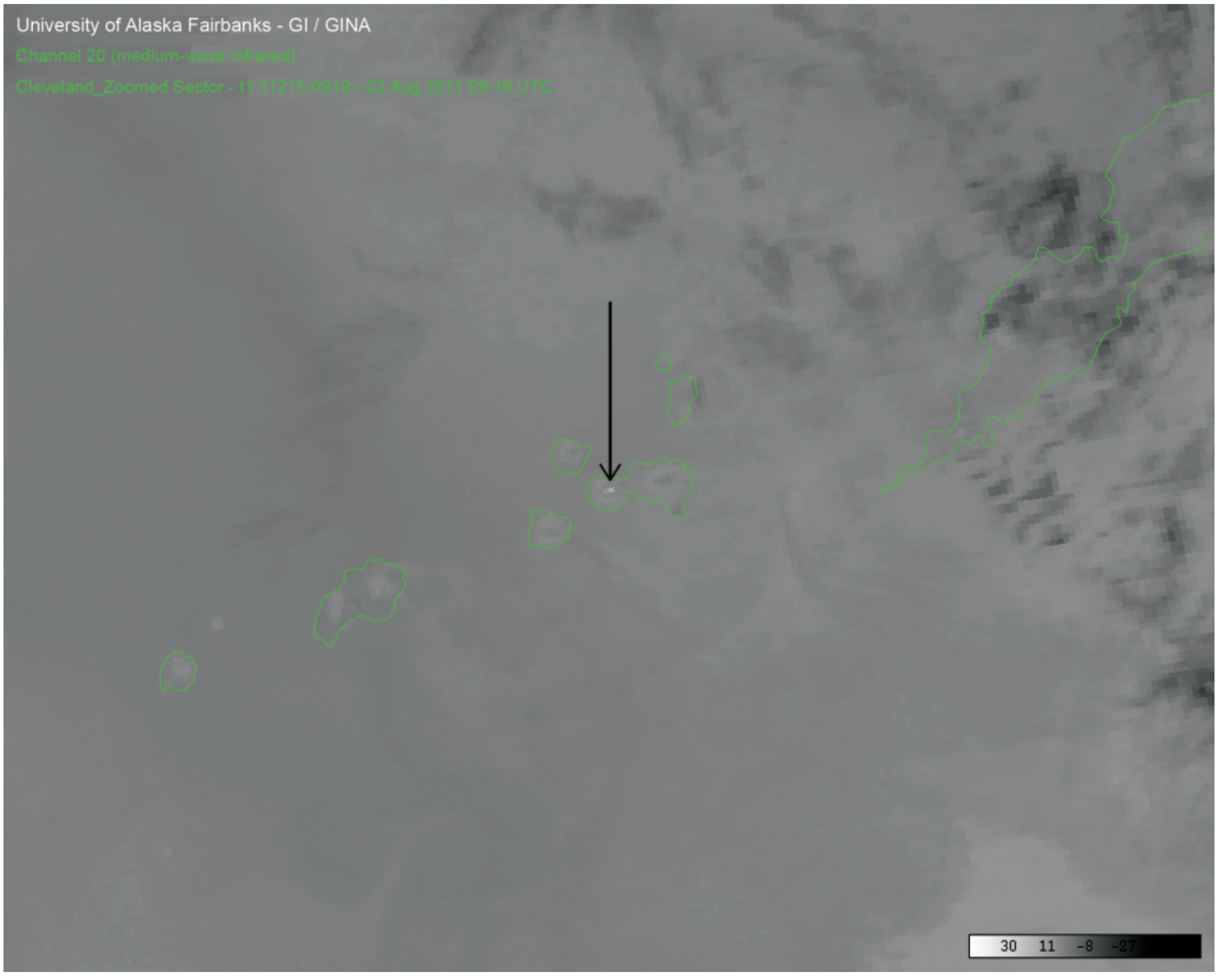

Figure 11. MODIS satellite thermal image (250-m resolution) of the Islands of the Four Mountains and Umnak Island in the eastern Aleutians on August 3, 2011. An area of elevated temperature at the summit of Cleveland volcano (arrow) was consistent with presence of lava at the surface. Such thermal signals are often masked by heavy cloud cover in the Aleutians. Image courtesy Peter Webley, UAFGI.

Figure 12. Landsat images of Cleveland volcano from August 7, 2011. (*A*) Landsat ETM+ 15m panchromatic band. (*B*) Landsat ETM+ 30m multi-spectral. Green line is the outline of the southwestern part of Chuginadak Island. Red pixel in multi-spectral image (*B*) shows elevated temperatures of the lava dome within the summit crater. Diagonal black lines are data gaps. Images courtesy Rick Wessels, USGS.

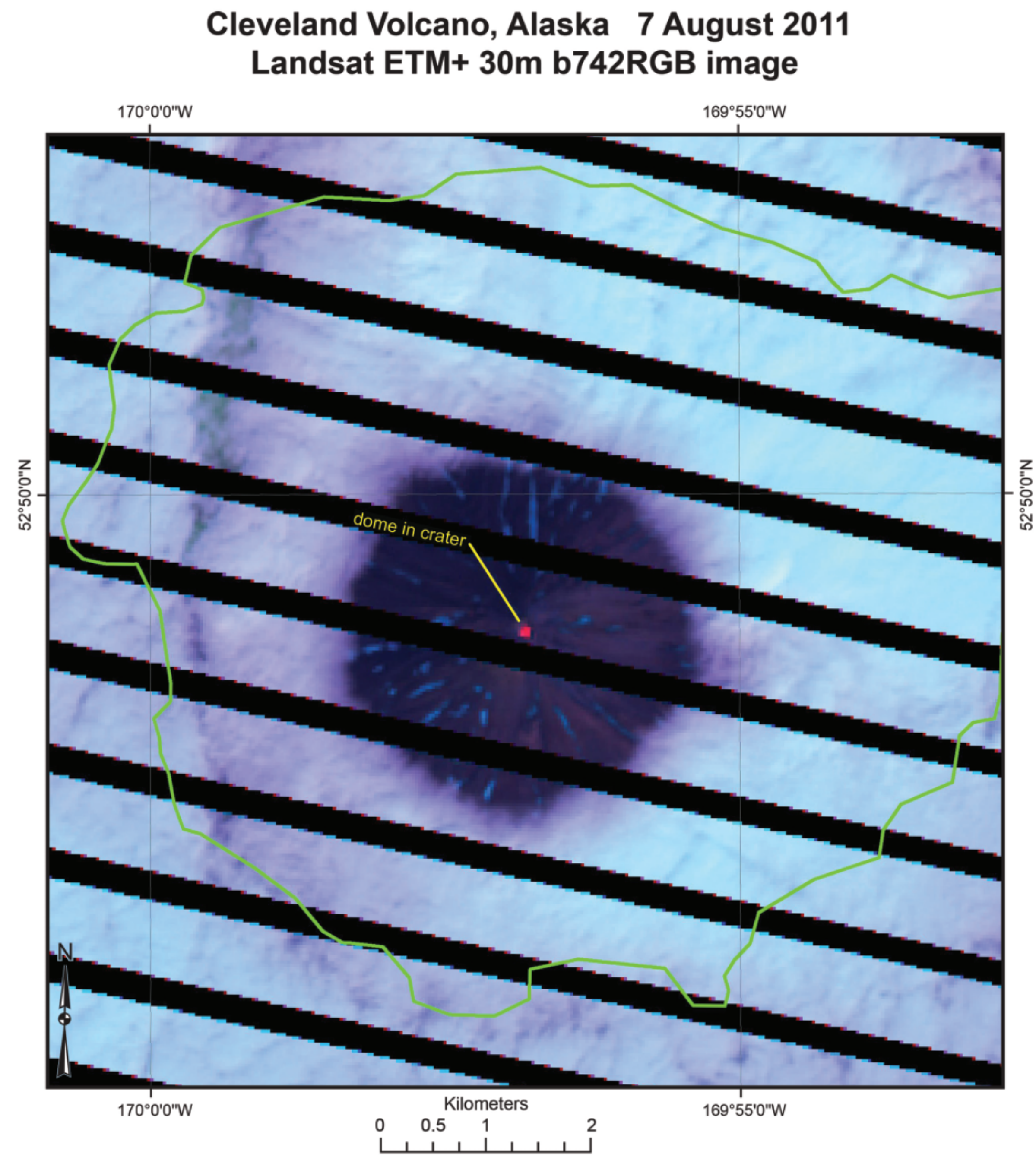

Figure 12.—Continued

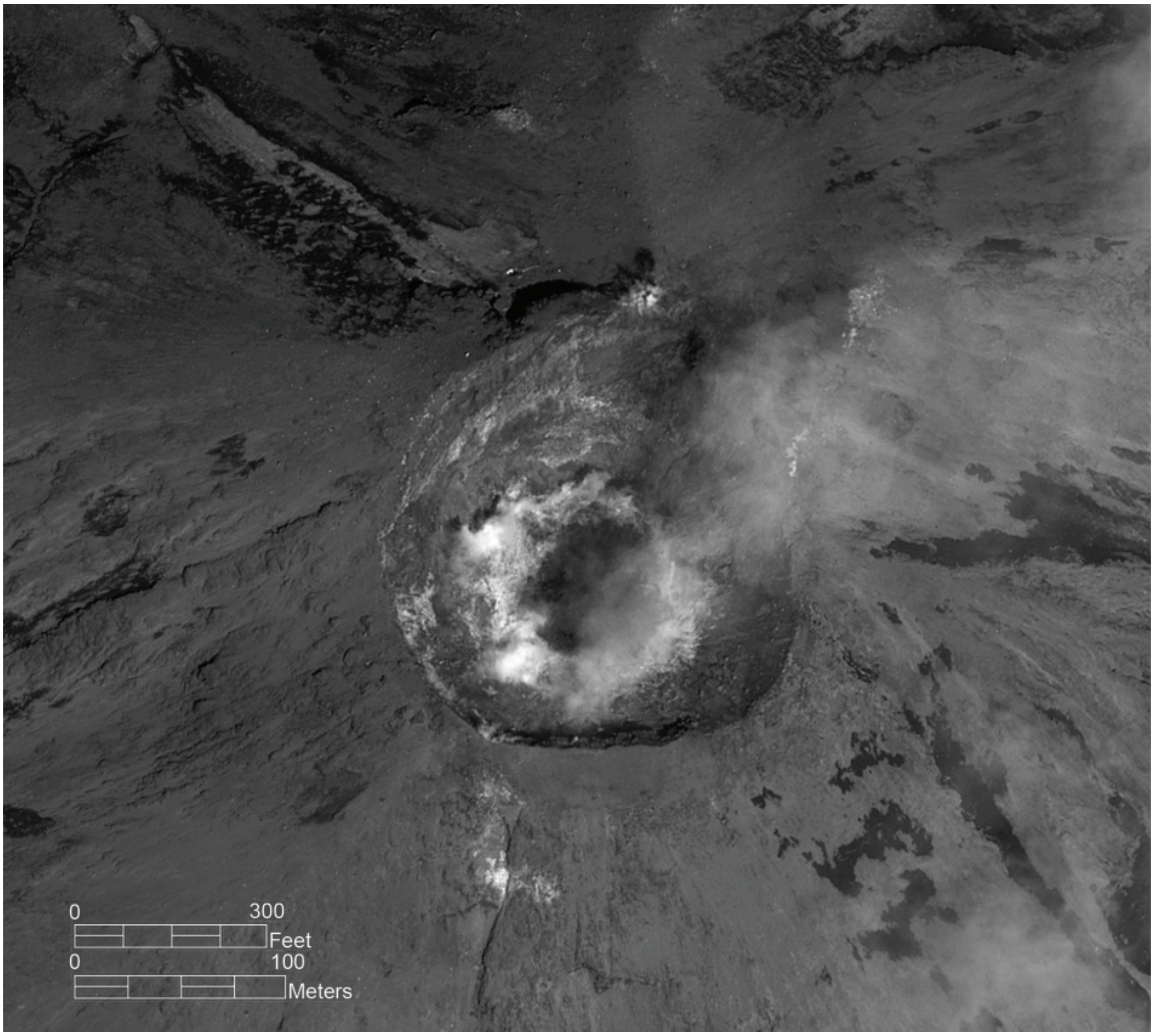

Figure 13. WorldView-1 satellite image of the summit of Cleveland volcano, August 9, 2011.

Figure 14. Oblique aerial photographs of the summit crater of Cleveland volcano on August 8, 2011. (*A*) Fume billows from the growing lava dome erupting onto the floor of the crater. At this time, the dome was at least 60 m (200 ft) in diameter. (*B*) View of the dome inside the 200 to 225 m (660 to 740 ft) diameter crater filled with fume. Note the light colored deposits on the crater floor and walls around the dome, presumably sulfur and other precipitates. In both images, the upper flanks of the cone are mantled by recently erupted gray tephra. Photographs courtesy Dave Withrow, NOAA. AVO database image (*A*) at URL: http://www.avo.alaska.edu/images/image.php?id=36322. AVO database image (*B*) at URL: http://www.avo.alaska.edu/images/image.php?id=36422.

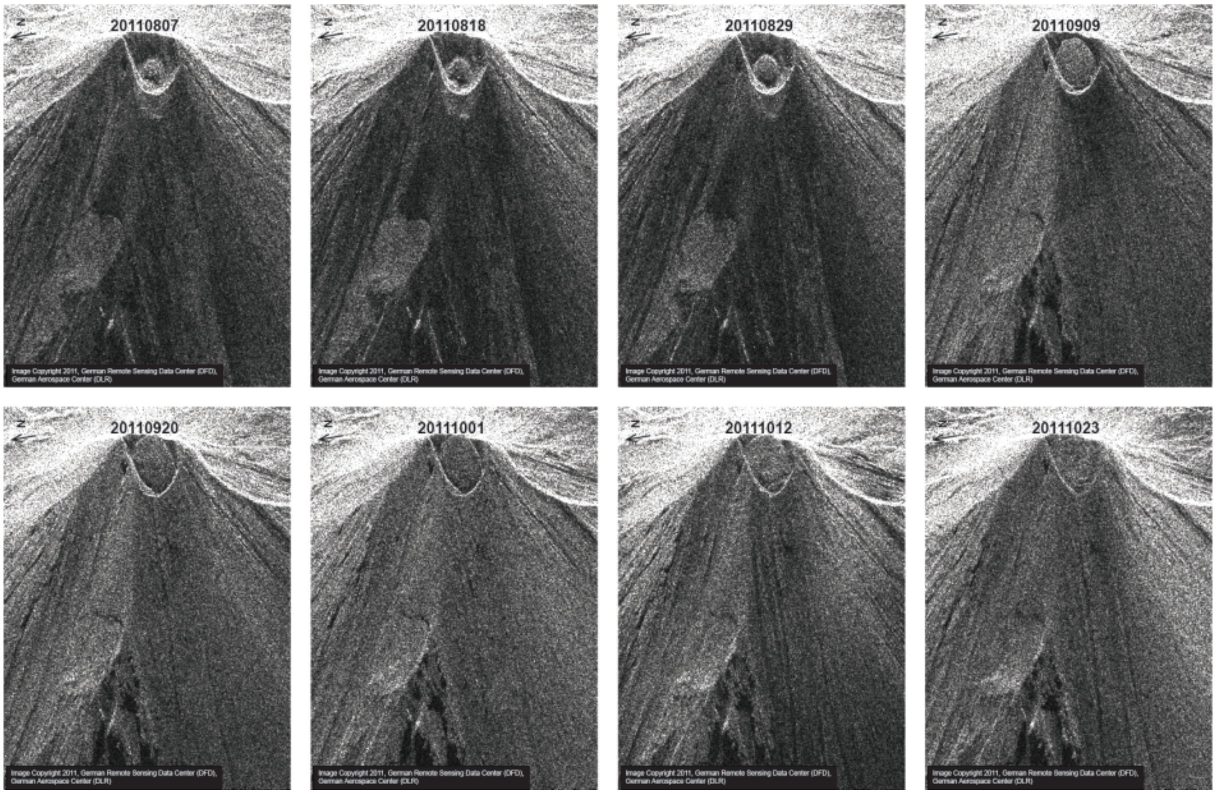

Figure 15. Time sequence of TerraSAR-X images of the Cleveland cone and summit crater from August 7 to October 23, 2011, gathered by Zhong Lu of the USGS Cascade Volcano Observatory. Successive panels show the growth of the lava dome as it filled the 200–225 m (660– 740 ft) diameter summit crater nearing the elevation of the eastern rim (see last panel). North is to the left in all images. Images are copyright German Remote Sensing Data Center (DFD), German Aerospace Center (DLR).

AVO downgraded Cleveland's Aviation Color Code/ Volcano Alert Level from **ORANGE/WATCH** to **YELLOW/ ADVISORY** on November 3 based on the absence of consistent thermal anomalies in satellite images and apparent cessation of lava effusion after October 9.

On November 10, satellite images showed that a small secondary dome had emerged atop the center of the semi-deflated lava dome. The diameter of this new dome was approximately 15–20 m (50–65 ft) and it likely began to grow on or before November 2. The original dome remained unchanged in size.

Lava within the summit crater remained mostly unchanged from November 10 to November 24. A satellite image from November 25 showed that the small secondary dome had subsided into a broad blocky, hummocky depression approximately 70 m (230 ft) in diameter and the overall dome had subsided approximately 30–35 m (100–115 ft) from its maximum elevation in early October. The dome continued to subside into early December, and by December 7, nearly the entire extrusive feature had collapsed into the conduit and its surface was approaching the pre-August crater-floor elevation.

On December 29 at approximately 04:12:07 AKST (13:12:07 UTC), an explosion from Cleveland produced a small ash cloud that rose to approximately 3.5 km (11,500 ft) ASL. The ash cloud drifted to the east and over the southwestern tip of Umnak Island (fig. 16). The eruption triggered two operational ash alarms used by AVO. The first alarm was triggered at approximately 05:33 AKST (14:33 UTC) indicating likely ash signatures in NOAA's AVHRR satellite image n19.11363.1402 (fig. 16) A NOAA-NESDIS ash cloud alarm was triggered at approximately 05:34 AKST (14:34 UTC) from the same AVHRR satellite image. Calculations based on the satellite data and local meteorological conditions indicated a maximum ash cloud height of 3.5 km (11,500 ft) ASL, with a mean effective ash particle radius of 5.06 microns (1.99×10^{-4} in.), a total mass of 0.84 kt (925 tons), and a total area of 173 km^2 (66.8 mi^2) (M. Pavolonis, written commun., December 29, 2011).

In response to the ash cloud, AVO upgraded the Aviation Color Code/Volcano Alert Level from **YELLOW/ ADVISORY** to **ORANGE/WATCH** at 07:55 AKST (16:55 UTC) on December 29, 2011.

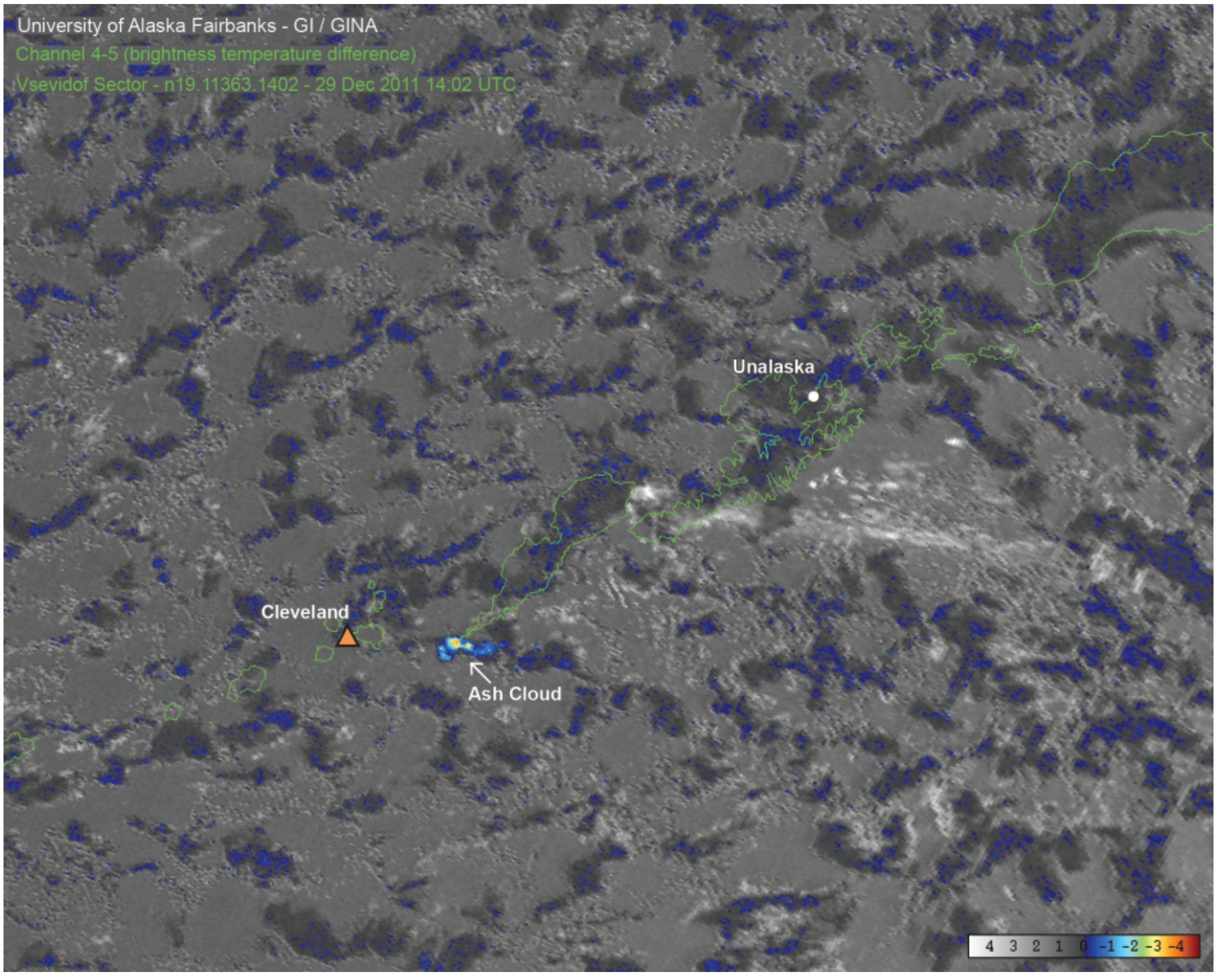

Figure 16. NOAA AVHRR satellite image from 14:02 UTC on December 29, 2011. The brightly colored region indicated ash in the atmosphere over the southwestern tip of Umnak Island. This is a brightness temperature difference image (BTD). Satellite data provided by UAFGI/GINA.

Infrasound signals from the December 29 explosion were detected on seismic stations and infrasound arrays deployed at Okmok volcano, located approximately 139 km (90 mi) northeast of Cleveland on Umnak Island (fig. 17). Infrasonic waves are sound waves that span a frequency range from below 20 Hertz (the lower limit of human hearing) to 0.001 Hertz. Infrasound signals are recorded at seismic stations by the infrasound airwaves coupling with the ground at seismic station(s) and mechanically vibrating the ground in which the seismometer sits. The recorded seismic signal is known as a ground-coupled airwave produced by a volcanic explosion or eruption. Based on the speed of sound in Earth's atmosphere and the distance between seismic station OKWE and the summit of Cleveland the origin time of the explosion was calculated at approximately 04:12:07 AKDT (13:12:07 UTC) (Matt Haney, David Fee, and Silvio de Angelis, UAFGI, written commun., December 29, 2011).

AVO downgraded the Aviation Color Code/Volcano Alert Level for Cleveland volcano from **ORANGE/WATC**H to **YELLOW/ADVISORY** at 13:57 AKST (22:57 UTC) on December 29 following no additional reports of eruptive activity occurring at the volcano. Cleveland remained at Aviation Color Code/Volcano Alert Level **YELLOW/ ADVISORY** throughout the remainder of 2011.

A review of the infrasound data prior to the December 29 explosion revealed several small explosive eruptions from Cleveland volcano on December 25. The first occurred at approximately 03:13 AKST (12:13 UTC) and had an infrasound amplitude of approximately one-half the December 29 event. The second eruption occurred on December 25 at approximately 06:32 AKST (15:32 UTC).

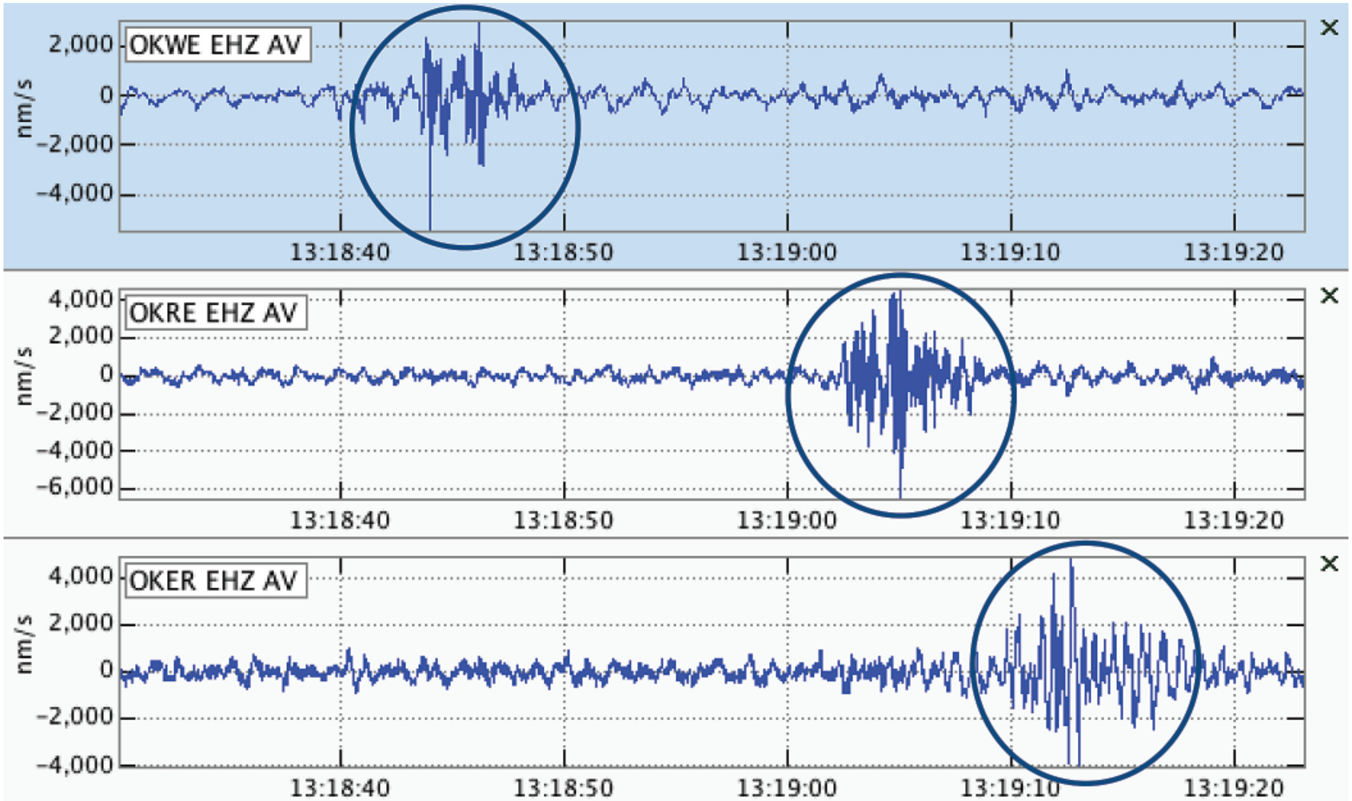

Figure 17. Record of the December 29, 2011, explosion at Cleveland volcano on seismic stations OKWE, OKRE, and OKER (circles). Image courtesy Matt Haney, AVO/USGS.

A small ash cloud also was retrospectively detected in satellite imagery for the December 25 event. The eruption cloud was very minor, did not have a large ash signal at the image's collection time of 06:32 AKST (15:32 UTC), and was only weakly visible in a thermal infrared image. The cloud had dissipated by the time the next image was acquired at 06:46 AKST (15:46 UTC).

Satellite data from December 26 displayed evidence of ejected blocks that had rolled down the upper northern and western flanks of the volcano, some as far as about 1.5 km (5,000 ft) from the crater's rim. There was no indication of fresh ash deposits on the volcano's upper northern and western flanks.

As in previous years, AVO tracked and responded to Cleveland activity in 2011 by relying heavily on satellite data and to reports received from pilots or other sources. AVO has no seismic instruments located on Chuginadak Island, therefore monitoring of Cleveland volcano is accomplished by analyzing daily satellite images, occasional pilot and mariner reports, and on rare clear days, a Web camera located in Nikolski. Table 5 is a compilation of Aviation Color Code and Volcano Alert Level changes, activity, ground and air observations of ash clouds, elevated surface temperatures, other satellite observations, and seismic network and infrasound detection or other alarm triggers.

Mount Cleveland volcano forms the western part of Chuginadak Island, an uninhabited island in the Islands of Four Mountains group in the east-central Aleutians. Cleveland is located about 75 km (45 mi) west of the community of Nikolski, and 1,500 km (940 mi) southwest of Anchorage. Historical eruptions have been characterized by short-lived ash explosions, lava fountaining, lava flows, and pyroclastic avalanches down the flanks. In February 2001, after 6 years of quiescence, Cleveland had three explosive events that produced ash clouds as high as 12 km (39,000 ft) ASL (Dean and others, 2004), a rubbly lava flow, and a hot avalanche that reached the sea. Intermittent explosive eruptions have occurred in every year since 2001.

Table 5. Compilation by date of activity and observations at Cleveland volcano.

[Condensed version of an internal, unpublished table constructed by AVO staff Elizabeth Redlinger and Kristi Wallace]

Date	Color Code/ Alert Level	Activity	Ground or air observations of volcano and ash cloud	Elevated surface temperatures, satellite sensor (number of pixels)	Other satellite observations	Seismic network and infrasound detection or other alarm triggers
01-01-11	YELLOW	Elevated temperatures		1 MODIS		
01-22-11	YELLOW	Elevated temperatures		1 AVHRR		
01-12-11	YELLOW	Elevated temperatures		2 AVHRR, 2 MODIS		
01-16-11	YELLOW	Elevated temperatures		1 AVHRR		
01-24-11	YELLOW					
01-25-11	YELLOW	Elevated temperatures		1 AVHRR		
02- 09-11	YELLOW		Security Aviation pilot Jerry Morris saw some slight puffing. Puffs were pure white and small. Occurred at 10–15 second intervals and dissipated at 500–700 ft.		Minor steaming from bottom of crater and no deposits on flanks.	
02-16-11	YELLOW				Minor steaming from summit crater.	
02-22-11	YELLOW	Elevated temperatures		1 MODIS		
02-28-11	YELLOW	Elevated temperatures		1 MODIS		
03-01-11	YELLOW	Elevated temperatures		1 AVHRR		
03-02-11	YELLOW	Elevated temperatures		2 AVHRR	Minor steaming from summit crater and fresh deposit of snow on crater floor.	
03-03-11	YELLOW	Elevated temperatures		3 AVHRR, 2 MODIS		
03-04-11	YELLOW	Elevated temperatures		1 AVHRR		
03-11-11	YELLOW	Elevated temperatures		1 AVHRR, 1 MODIS		
03-31-11	UNASSIGNED	No evidence of further explosions since 09-12-10		2 MODIS		
04-01-11	UNASSIGNED	Elevated temperatures		1 AVHRR	Bottom of summit crater is nearly snow free. Minor steaming. Snow on upper flanks clean 1.5 km downslope.	
04-13-11	UNASSIGNED	Elevated temperatures		1 AVHRR, 1 MODIS		
05-01-11	UNASSIGNED	Elevated temperatures		1 MODIS		
05-03-11	UNASSIGNED	Elevated temperatures		1 MODIS		
05-10-11	UNASSIGNED	Elevated temperatures		3 AVHRR, 1 MODIS		
05-11-11	UNASSIGNED	Elevated temperatures		1 AVHRR		
05-27-11	UNASSIGNED				Landsat 5 TM shows dark deposits on snow. Shows strong TIR and SWIR anomalies.	

Table 5. Compilation by date of activity and observations at Cleveland volcano.—Continued

[Condensed version of an internal, unpublished table constructed by AVO staff Elizabeth Redlinger and Kristi Wallace]

Date	Color Code/ Alert Level	Activity	Ground or air observations of volcano and ash cloud	Elevated surface temperatures, satellite sensor (number of pixels)	Other satellite observations	Seismic network and infrasound detection or other alarm triggers
06-19-11	UNASSIGNED				Landsat 5 TM shows dark deposits or meltin features on snow extending SE from summit. The 120-m TIR image shows a weak thermal feature at the summit.	
06-20-11	UNASSIGNED	Elevated temperatures		1 AVHRR, 2 MODIS		
06-21-11	UNASSIGNED	Elevated temperatures		1 AVHRR, 1 MODIS		
06-23-11	UNASSIGNED	Elevated temperatures		1 AVHRR		
06-24-11	UNASSIGNED	Elevated temperatures		1 AVHRR		
07-04-11	UNASSIGNED	Elevated temperatures		1 AVHRR, 2 MODIS		
07-07-11	UNASSIGNED				Minor steaming from summit crater. No new deposits.	
07-13-11	UNASSIGNED	Elevated temperatures		1 MODIS		
07-14-11	UNASSIGNED	Elevated temperatures		1 AVHRR, 1 MODIS		
07-17-11	UNASSIGNED	Elevated temperatures consistent over a number of days; larger in area		4 AVHRR, 2 MODIS		
07-20-11	YELLOW	Elevated temperatures		1 AVHRR, 2 MODIS		
07-22-11	YELLOW	Elevated temperatures		1 AVHRR		
07-27-11	YELLOW	Elevated temperatures		1 AVHRR, 1 MODIS		
07-29-11	YELLOW				New lava dome in summit crater, rough surface texture, 40 m across.	
07-31-11	YELLOW	Lava effusion in summit crater; elevated temperatures		1 MODIS		
08-02-11	ORANGE	Elevated temperatures		1 MODIS	Lava dome now 50 m across and about 20 m high. Surface is fractured.	
08-03-11	ORANGE	Elevated temperatures		2 MODIS		
08-05-11	ORANGE	Elevated temperatures		1 AVHRR, 1 MODIS		
08-06-11	ORANGE	Elevated temperatures		2 AVHRR, 3 MODIS	Lava dome now 60 m across and about 20 m high. Crater floor covered by mineral deposits. No evidence of ash emission.	
08-08-11	ORANGE	Elevated temperatures	Many by Dave Withrow, NOAA.	1 AVHRR, 2 MODIS		

Table 5. Compilation by date of activity and observations at Cleveland volcano.—Continued

[Condensed version of an internal, unpublished table constructed by AVO staff Elizabeth Redlinger and Kristi Wallace]

Date	Color Code/ Alert Level	Activity	Ground or air observations of volcano and ash cloud	Elevated surface temperatures, satellite sensor (number of pixels)	Other satellite observations	Seismic network and infrasound detection or other alarm triggers
08-09-11	ORANGE	Elevated temperatures		1 AVHRR, 1 MODIS	Worldview satellite image shows lava dome slightly obscured by steam, light-colored mineral deposits on the crater floor.	
08-10-11	ORANGE	Elevated temperatures		1 MODIS		
08-13-11	ORANGE	Elevated temperatures		1 AVHRR	No change in dome	
08-14-11	ORANGE	Elevated temperatures	Nye reported small white popcorn puffs ascending 100–200 ft.	1 AVHRR		
08-16-11	ORANGE	Elevated temperatures		1 MODIS		
08-20-11	ORANGE				No change in dome	
08-21-11	ORANGE	Elevated temperatures		1 AVHRR		
08-23-11	ORANGE				No change in dome	
08-29-11	ORANGE	No changes in summit lava dome; decreasing summit temperatures.		1 AVHRR		
08-30-11	YELLOW					
09-03-11	YELLOW	Elevated temperatures		1 AVHRR, 1 MODIS		
09-04-11	YELLOW	Elevated temperatures		1 MODIS		
09-06-11	ORANGE	Renewed growth of summit lava dome.			Lava dome now 120 m across.	
09-09-11	ORANGE	Elevated temperatures		1 AVHRR, 1 MODIS		
09-12-11	ORANGE	Elevated temperatures		1 AVHRR		
09-16-11	ORANGE	Elevated temperatures		2 AVHRR, 1 MODIS		
09-17-11	ORANGE	Elevated temperatures		1 AVHRR, 1 MODIS		
09-18-11	ORANGE	Elevated temperatures		1 AVHRR, 1 MODIS		
09-19-11	ORANGE					Beginning of regular analysis of airwaves on seismic networks to look for Cleveland explosions.
09-20-11	ORANGE				TerraSAR-X radar image suggests that the dome has reached the crater rim; other observations suggest the dome is about 168 m in diameter and tens of m below the rim.	
09-23-11	ORANGE	Elevated temperatures		3 AVHRR, 2 MODIS		

Table 5. Compilation by date of activity and observations at Cleveland volcano.—Continued

[Condensed version of an internal, unpublished table constructed by AVO staff Elizabeth Redlinger and Kristi Wallace]

Date	Color Code/ Alert Level	Activity	Ground or air observations of volcano and ash cloud	Elevated surface temperatures, satellite sensor (number of pixels)	Other satellite observations	Seismic network and infrasound detection or other alarm triggers
09-26-11	ORANGE				Lava dome continues to grow. Estimated to be within 15–20 m of crater rim. Surface texture consists of closely-spaced radial fractures around a relatively smooth center. Pressure ridges are roughly concentric about the center.	
09-28-11	ORANGE	Elevated temperatures		1 MODIS		
10-01-11	ORANGE	Elevated temperatures		2 AVHRR, 2 MODIS	Worldview-2 visible wavelength satellite image shows the lava dome as a dark feature with a small steam plume. New TerraSAR-X image suggests additional dome growth since 20 September.	
10-04-11	ORANGE	Elevated temperatures		1 MODIS		
10-05-11	ORANGE				Lava dome now at the level of the SW rim. Dome has expanded towards the ENE. Surface texture is now more chaotic.	
10-06-11	ORANGE	Elevated temperatures		1 MODIS		
10-08-11	ORANGE	Elevated temperatures		2 AVHRR		
10-09-11	ORANGE				Lava dome may have deflated slightly. Dome is now 12 m below the SW rim. Possible slight depression on the top of the dome.	
10-12-11	ORANGE				TerraSAR-X image shows growth from 7 August to 12 October in. Dome growth in N-S direction, movement towards west.	
10-15-11	ORANGE	Elevated temperatures		2 AVHRR, 1 MODIS		
10-16-11	ORANGE	Elevated temperatures		2 AVHRR		
10-17-11	ORANGE	Elevated temperatures		1 AVHRR		
10-18-11	ORANGE	Elevated temperatures		2 AVHRR, 1 MODIS		
10-18-11	ORANGE				No changes in the lava dome which remains at least 10 m below the rim.	
10-22-11	ORANGE				No changes from October 18.	
10-23-11	ORANGE				TerraSAR-X image shows subsidence or deflation of the dome.	

Table 5. Compilation by date of activity and observations at Cleveland volcano.—Continued

[Condensed version of an internal, unpublished table constructed by AVO staff Elizabeth Redlinger and Kristi Wallace]

Date	Color Code/ Alert Level	Activity	Ground or air observations of volcano and ash cloud	Elevated surface temperatures, satellite sensor (number of pixels)	Other satellite observations	Seismic network and infrasound detection or other alarm triggers
10-26-11	ORANGE				No significant changes from October 22. Possible slight deflation.	
10-29-11	ORANGE				No significant changes from October 26.	
11-02-11	ORANGE	Elevated temperatures		1 AVHRR		
11-03-11	YELLOW					
11-08-11	YELLOW	Elevated temperatures		2 AVHRR, 1 MODIS		
11-09-11	YELLOW	Elevated temperatures		2 AVHRR, 2 MODIS		
11-10-11	YELLOW	Elevated temperatures		4 AVHRR, 1 MODIS	New lava dome in summit crater, 20 m across, nested inside the earlier dome. May have begun growing on or before November 2.	
11-13-11	YELLOW	Elevated temperatures		2 AVHRR, 1 MODIS		
11-14-11	YELLOW	Elevated temperatures		3 AVHRR, 1 MODIS		
11-17-11	YELLOW	Elevated temperatures			No significant change from November 10.	
11-18-11	YELLOW	Elevated temperatures		1 AVHRR, 1 MODIS		
11-21-11	YELLOW	Elevated temperatures		2 AVHRR		
11-22-11	YELLOW	Elevated temperatures		3 AVHRR		
11-24-11	YELLOW				No significant change from November 10.	
11-25-11	YELLOW				Continued gradual subsidence and disintegration of the summit dome. The November 10 dome is now a broad depression, about 70 m across, within a blocky, hummocky surface that covers the crater floor. Total vertical subsidence from the original pancake dome in late September may be on the order of 30–35 m.	
11-30-11	YELLOW	Elevated temperatures		2 AVHRR		
12-01-11	YELLOW	Elevated temperatures		1 AVHRR, 1 MODIS		
12-02-11	YELLOW	Elevated temperatures		2 MODIS		
12-04-11	YELLOW	Elevated temperatures		1 AVHRR, 1 MODIS		
12-05-11	YELLOW	Elevated temperatures		1 AVHRR		

Table 5. Compilation by date of activity and observations at Cleveland volcano.—Continued

[Condensed version of an internal, unpublished table constructed by AVO staff Elizabeth Redlinger and Kristi Wallace]

Date	Color Code/ Alert Level	Activity	Ground or air observations of volcano and ash cloud	Elevated surface temperatures, satellite sensor (number of pixels)	Other satellite observations	Seismic network and infrasound detection or other alarm triggers
12-07-11	YELLOW				Lava dome continues to deflate or drain back into the conduit. It is approaching the level of the pre-dome floor.	
12-08-11	YELLOW	Elevated temperatures		1 AVHRR		
12-19-11	YELLOW				Steaming from the summit crater. The crater floor has subsided significantly since December 7 and is now about 70–90 m below the rim. The subsidence is marked by ring fractures around the crater walls.	
12-25-11	YELLOW	Elevated temperatures		1 MODIS		Explosion detected on Okmok infrasound and seismic stations and on Dillingham and Fairbanks infrasound arrays.
12-29-11	YELLOW	Explosion and ash cloud; elevated surface temperatures	A detached drifting ash cloud 11,500 ft ASL in satellite images 80 km ESE.	2 AVHRR	Ballistics and rolling trails visible down the western to northern flanks as far as 1.5 km from the crater rim (12-26-11 satellite data). Snow is tephra-free except for large blocks and trails. Other flanks could have blocks also but they are obscured.	Ground-coupled airwaves detected on Okmok stations OKWE, OKRE, and OKER.
12-30-11	YELLOW	No further explosions.		1 MODIS	A new, approximately 60 m-diameter pit in the summit crater floor. The 2011 lava dome appears to be completely removed. The summit area is littered with blocks and there is a widespread tephra mantle.	

Summary

The Alaska Volcano Observatory (AVO) responded to volcanic unrest at three volcanic centers in Alaska, including an ongoing eruption from Cleveland, one of Alaska's most frequently active volcanoes. Relatively rapid inflation of the caldera floor at Okmok, which began immediately following the 2008 eruption, continued. Partial draining of the larger of two maar crater lakes at Aniakchak, which occurred in late summer 2010, was discovered and investigated in 2011. AVO annual summaries from 1995 to 2010 have included reports on activity at Russian volcanoes. In 2011, AVO ceased including Russian activity in the annual summary.

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Sources of Photographs in this Report and Other Images of Alaska

Online sources of digital images from this report:
http://libraryphoto.cr.usgs.gov/
http://www.avo.alaska.edu/images/
http://pubs.usgs.gov/dds/dds-39/
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Glossary of Selected Terms and Acronyms

AAWU “Alaska Aviation Weather Unit” of the National Weather Service.

\`a\`a Hawaiian term for lava flows characterized by a rough, jagged, blocky surface.

AEIC Alaska Earthquake Information Center.

AFTN Aeronautical Fixed Telecommunications Network.

AKDGGS Alaska Division of Geological & Geophysical Surveys.

AKDT “Alaska Daylight Time”; UTC -8 hours AKDT.

AKST “Alaska Standard Time”; UTC -9 hours AKST.

andesite volcanic rock composed of about 53–63 percent silica (SiO2,; an essential constituent of most minerals found in rocks).

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

ASL above sea level.

ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer.

Aura a multi-national NASA scientific research satellite in orbit around the Earth, studying the Earth's ozone layer, air quality and climate.

AVHRR “Advanced Very High Resolution Radiometer”; AVHRR provides one form of satellite imagery.

AVO Alaska Volcano Observatory.

basalt general term for dark-colored igneous rock, usually extrusive, containing about 45–52 weight percent silica (SiO2, an essential constituent of most minerals found in rocks).

bomb boulder-size chunk of partly solidified lava explosively ejected from a volcano.

BTD Brightness temperature difference. The subtraction of channel 5 data from channel 4 is BTD.

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

CAVW Smithsonian Institute’s “Catalog of Active Volcanoes of the World” (Simkin and Siebert, 1994).

cinder cone small, steep-sided conical hill built mainly of cinder, spatter, and volcanic bombs.

COSPEC “Correlation Spectrometer,” a device for measuring sulfur-dioxide emissions.

CWSU “Center Weather Service Unit” of the National Oceanic and Atmospheric Administration, stationed at the Air Route Traffic Control Center.

CVO Cascade Volcano Observatory.

DFD German Remote Sensing Data Center.

DLR German Aerospace Center.

ERSDAC Earth Remote Sensing Data Analysis Center.

FAA Federal Aviation Administration.

fallout a general term for debris which falls to the Earth from an eruption cloud.

fault A fracture along which the blocks of the Earth’s crust on either side have moved relative to one another parallel to the fracture.

FIR Flight Information Region.

fissure a roughly linear or sinuous crack or opening on a volcano; a type of vent which commonly produces lava fountains and flows.

FLIR “Forward Looking Infrared Radiometer,” used to delineate objects of different temperature.

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

GINA Geographic Information Network of Alaska. GINA is a mechanism within the University of Alaska for sharing data and technical capacity among Alaskan, Arctic, and world communities.

GSFC Goddard Space Flight Center.

glaciolacustrine pertaining to sediments deposited in glacial lakes, and resulting landforms.

GMS Geostationary Meteorological Satellite.

GOES Geostationary Operational Environmental Satellite.

GPS Global Positioning System.

GVN "Global Volcanism Network" of the Smithsonian Institution.

Holocene geologic epoch extending from the present to 10,000 years ago.

incandescent glowing red or orange due to high temperature.

InSAR Interferometric Synthetic Aperture Radar.

interferogram a pattern formed by wave interference, especially one represented in a photograph or diagram

intracaldera refers to something within the caldera.

ISS International Space Station.

JAROS Japan ASTER Science Team.

JMA Japanese Meteorological Agency.

JPEG "Joint Photographic Experts Group," type of digital photographic file.

Ka thousands of years before the present.

lapilli pyroclasts or volcanic fragments that are between 2 mm and 64 mm in diameter.

lava molten material at the Earth's surface.

magma molten material below the surface of the Earth.

METI Ministry of Economy, Trade, and Industry.

MODIS Satellite-based "Moderate-resolution Imaging Spectroradiometer."

MWO Meteorological Watch Office.

NASA National Aeronautics and Space Administration.

NESDIS NOAA's National Environmental Satellite, Data, and Information Service.

NOAA National Oceanic and Atmospheric Administration.

NOGAPS Navy Operational Global Atmospheric Prediction System.

NOPAC North Pacific air route corridors.

NOTAM "Notice to Airmen," a notice containing information [not known sufficiently in advance to publicize by other means] concerning the establishment, condition, or change in any component [facility, service, or procedure of, or hazard in the National Airspace System] the timely knowledge of which is essential to personnel concerned with flight operations.

NPS National Park Service.

NWS National Weather Service.

OMI Ozone Mapping Instrument.

phreatic activity an explosive eruption caused by the sudden heating of ground water as it comes in contact with hot volcanic rock or magma.

phreatic ash fine fragments of volcanic rock expelled during phreatic activity; this ash usually is derived from existing rock and not from new magma.

PIREP "Pilot Weather Report"; a report of meteorological phenomena encountered by aircraft in flight.

pixel contraction of "picture element." A pixel is one of the many discrete rectangular elements that form a digital image or picture on a computer monitor or stored in memory. In a satellite image, resolution describes the size of a pixel in relation to area covered on the ground. More pixels per unit area on the ground means a higher resolution.

PK "Petropavlovsk"; capital city of Kamchatka, Russia.

Pleistocene geologic epoch extending from 2–3 million years ago to approximately 10,000 years before present.

PUFF a volcanic ash tracking model (see at URL: http://puff.images.alaska.edu/monitoring.shtml).

pyroclast an individual particle ejected during a volcanic eruption; usually classified by size, for example, ash, lapilli.

RSAM Real-time Seismic-Amplitude Measurement.

regional earthquake earthquake generated by fracture or slippage along a fault; not caused by volcanic activity.

RFE Russian Far East.

SAB "Synoptic Analysis Branch" of NOAA.

SAR Synthetic Aperture Radar.

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

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

shield volcano a broad, gently sloping volcano usually composed of fluid lava flows of basalt composition (for example, Mauna Loa, Hawaii).

SI International System of Units.

SIGMET SIGnificant METeorological information statement, issued by NWS.

SRTM Shuttle Radar Topography Mission.

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

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

sub-plinian style of explosive eruptions characterized by vertical eruption columns and widespread dispersal of tephra.

SVA Suspect Volcanic Activity.

SVERT "Sakhalin Volcanic Eruption Response Team" monitors and reports on Kurile Island volcanoes.

SWIR Short Wave Infrared.

tephra a general term covering all fragmental material expelled from a volcano (ash, bombs, cinders, etc.).

TA thermal anomaly.

TerraSAR-X A German built active radar microwave x-band imaging satellite.

TFR "Temporary Flight Restriction," issued by FAA.

TIR Thermal Infrared.

UAFGI University of Alaska Fairbanks Geophysical Institute.

USCG United States Coast Guard.

USFWS United States Fish and Wildlife Service.

USGS United States Geological Survey.

UTC "Coordinated Universal Time"; same as Greenwich Mean Time (GMT).

UUA Urgent pilot report.

VAAC Volcanic Ash Advisory Center.

VAA Volcanic Ash Advisory.

vent an opening in the earth's surface through which magma erupts or volcanic gasses are emitted.

VNIR Very Near Infrared.

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

Vulcanian style of explosive eruption consisting of repeated, violent ejection of incandescent fragments of viscous lava, usually in the form of blocks, along with volcanic ash. Sometimes, Vulcanian eruptions involve water mixing with erupting magma.

Appendix 1. Volcano Alert Levels and Aviation Color Codes Used by United States Volcano Observatories.

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Alert levels address the overall activity at the volcano, not just the hazard to aviation. There may be situations where a volcano is producing lava flows that are dangerous on the ground and merit a WATCH or WARNING, however, the hazard to aviation is minimal. Alert levels announcements contain additional explanation of volcanic activity and expected hazards where possible. (Gardner and Guffanti, 2006).

Alert Levels	
NORMAL	Volcano is in typical background, noneruptive state. *Or, after a change from a higher level:* Volcanic activity has ceased and volcano reverted to its noneruptive 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:* A minor eruption is underway that poses limited hazards.
WARNING	Eruption is underway but poses limited hazards.

Level of Concern Codes for Aviation	
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 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].

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