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RESEARCH

Examples of eruption response teams from the Alaska Volcano Observatory

Michelle Coombs[1] · Kristi Wallace[1] · Ronni Grapenthin[2] · Jordan Lubbers[1] · Thomas Murray[3]

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Abstract
During times of eruption response, volcano observatories need to organize themselves differently than during normal operations. The number of formal operational roles grows to ensure that critical responsibilities are covered, including management of all activities at the observatory as well as increased staffing to ensure proper surveillance of data and issuance of timely notices and warnings. The scope and approach differ for each observatory and, in fact, for different eruptions. The Alaska Volcano Observatory (AVO) maintains an extensive monitoring program and issues forecasts and warnings about volcanic eruptions and unrest in Alaska. Since 2000, AVO has used formal roles to perform these duties and has implemented a variety of team approaches to respond to larger eruptions. For the Augustine (2006) and Redoubt (2009) eruptions, management scaled from 3 up to ~ 8 people in a command team to cover all aspects of the response. During these and other eruptions (e.g., Okmok, 2008), an operations room was staffed continuously to cover real-time responsibilities pertaining to monitoring and issuing alerts while the command team focused on overall management. More recently, such as for Bogoslof in 2016–2017 and Shishaldin in 2019 and 2023, AVO used a virtual real-time response team to handle warning tasks and variations of an Observatory Volcanic Event Response Team (OVERT; Moran et al. 2024) to manage overall observatory response activities. In 2025, AVO employed a formal OVERT for the first time to oversee its response to unrest at Mount Spurr. Frequent implementation, nimble scaling, constant evaluation, flexibility, and good communication make the team approach effective. We present examples of several response teams used over the last 25 years, and lessons learned from them, in the hope that these will be helpful to other observatories facing crisis responses. These examples may also allow stakeholders and the public to better understand how observatories work.

Keywords Volcano observatory · Hazard communication · Eruption response · Science management

Introduction

Two of the primary functions of volcano observatories include monitoring volcanoes and responding appropriately to unrest and eruption. There are myriad essential elements to a successful good response, including planning, availability of appropriate monitoring data, making science-based decisions, communicating effectively, collaborating with partners and stakeholders, and post-response assessment (e.g., Lowenstern et al. 2022). A fundamental pillar of all these activities is properly organizing staff within the observatory to maximize results and to avoid burnout and confusion. As stated by Newhall et al. (2021) with respect to observatories, "the essential element is the team of scientists fulfilling its responsibilities." Observatories are usually interdisciplinary and home to scientists, engineers, and other specialists. The day-to-day operations of observatories can vary in the overall size, structure, and level of hierarchical nature. Some will have discrete areas of responsibility that cover a single volcano with a small staff, and some are responsible for entire regions with staff who conduct hazard assessments and volcanological research, maintain expansive monitoring networks, and work with numerous partner agencies and institutions (Barsotti et al. 2024; Forte

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✉ Michelle Coombs
mcoombs@usgs.gov

[1] U.S. Geological Survey, Alaska Volcano Observatory, Volcano Science Center, Anchorage, AK, USA

[2] Geophysical Institute & Alaska Volcano Observatory, University of Alaska Fairbanks, Fairbanks, AK, USA

[3] U.S. Geological Survey, Retired, Anchorage, AK, USA

et al. 2021; Lowenstern et al. 2021). Because of their background, many observatory scientists may be independent thinkers and not used to rigid management structures. This approach may be fine during quieter "blue sky" times, but during times of response—whether to unrest or significant eruptions—overprinting a clear, hierarchical management structure on an observatory is essential to ensure that expectations are met and that key functions are fulfilled. Many eruptions and unrest episodes are marathons, not sprints, and clear roles and responsibilities can help ensure that staff remain effective for the duration, keep routine tasks going, and avoid burnout. Organizational charts, formal roles, and checklists are all ways to assure that the duties and tasks required for a successful response are completed and communicated (Newhall et al. 2021; Hidalgo et al. 2023).

Following the response to the complex and impactful 2018 eruption of Kīlauea in Hawai'i, the U.S. Geological Survey (USGS) published an after-action review that described many ways in which the response by the USGS Hawaiian Volcano Observatory and Volcano Science Center (VSC) was an overwhelming success (Williams et al. 2020) (Fig. 1). The review also recommended that future responses to large, complex eruptions would benefit from improved internal response plans. A resulting USGS report (Moran et al. 2024) focuses on responses to significant unrest or eruptions where the scale of the response exceeds the capacity of the responding observatory. The VSC plan described in the report draws heavily from responses to the Mount St. Helens 2004–2006 and the Kīlauea 2018 eruptions and is also strongly influenced by principles of the Incident Command System, or ICS, which is used by the U.S. Federal Government for managing emergency responses (FEMA 2008). A key facet of the plan is the use of the Observatory Volcanic Event Response Team, or OVERT. The OVERT structure allows the responding observatory to pivot from routine operations to a more formal response approach, with written roles and clear lines of command.

This paper describes the Alaska Volcano Observatory's (AVO) internal operational approach to responding to volcanic events. Over the past 25 years, AVO has scaled up from routine operations—which involve monitoring dozens of volcanoes, with at least one almost always in a state of unrest—to managing eruptions that vary widely in magnitude, duration, and impact. We first describe our approach to routine monitoring and responding to unrest and minor eruptions, followed by a discussion of several more significant responses (Fig. 1), that each posed unique challenges and offered valuable lessons.

We focus on internal organization, acknowledging that while observatories collaborate closely with other science and emergency response agencies, effective response begins with a well-structured internal framework. This is accomplished through a flexible adaptation of the ICS concept, tailored to the scale of the event and integrated with the observatory's existing duty roles. We hope that this paper will provide concrete examples for other observatories who are striving to respond effectively to unrest and eruptions in their areas of responsibility.

Alaska Volcano Observatory—goals and objectives

Founded in 1988, AVO is one of five U.S. observatories funded by the USGS Volcano Hazards Program. Through these five entities, the Volcano Hazards Program enhances public safety and minimizes social and economic disruption from volcanic unrest and eruption by delivering forecasts, warnings, and information about volcano hazards. AVO's area of responsibility includes Alaska as well as the Commonwealth of the Northern Marianas Islands (Tepp et al. 2019). In these regions, AVO is tasked with: monitoring volcanoes commensurate with their threat level; providing timely and accurate information on volcanic hazards,

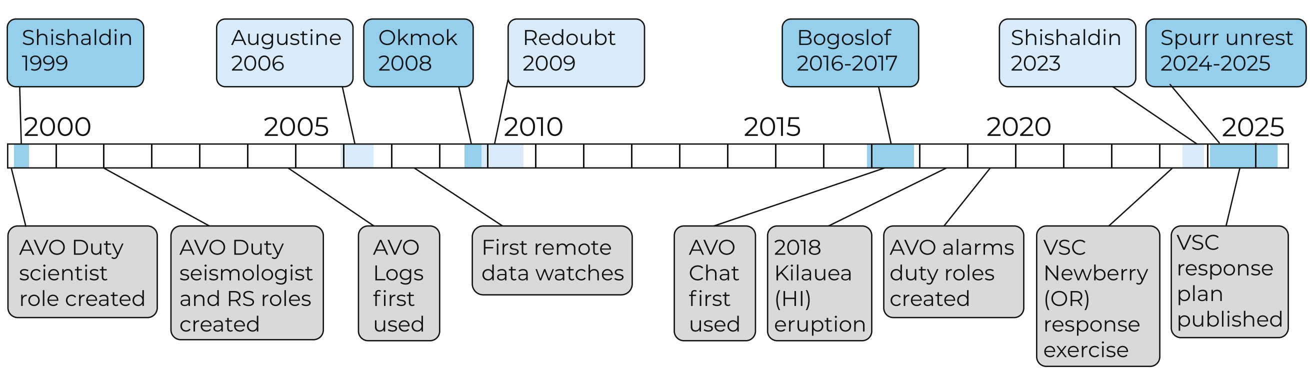

Fig. 1 Timeline showing major Alaska eruptions and unrest episodes (in blue) and other landmarks (in gray) at the Alaska Volcano Observatory (AVO) and U.S. Geological Survey Volcano Science Center (VSC), 1999–2025, as discussed in text. Many Alaska eruptions and unrest periods are not shown for clarity. Shades of blue used to distinguish responses that are close in time. RS, remote sensing

warnings of dangerous activity, and eruption notifications to local, State, and Federal officials and the public; contributing to community and interagency preparedness; assessing volcanic hazards associated with anticipated activity, including kinds of events, their effects, and areas at risk; and conducting and coordinating research on volcanic processes.

Alaska is home to 86 volcanoes that are considered active or potentially active in a recent USGS threat assessment (Ewert et al. 2018); 54 have erupted or shown unrest since ~1700 CE (Fig. 2). Over the past 20 years, there have been an average of two eruptions and six episodes of notable unrest annually at Alaska volcanoes. Because most of Alaska's volcanoes are distant from communities and infrastructure, the main hazards that they pose are volcanic ash clouds and ashfall. Ash hazards posed to the aviation sector are particularly important, as over 60,000 people per day fly through the airspace above Alaska volcanoes (Ewert et al. 2018). Anchorage is also one of the Nation's busiest cargo hubs and, in 2024, was the fourth busiest cargo airport in the world (Alaska International Airport System 2025). In addition to impacts to trans-Pacific flights, Alaska communities are isolated, and impacts to local air travel can have cascading effects by cutting off transport of goods and services. Eruptions in the Cook Inlet region also pose ground-based ashfall hazards, with recent eruptions of Mount Spurr (1992), Augustine Volcano (2006), and Mount Redoubt (1989–90 and 2009) depositing ash on southcentral Alaska communities and infrastructure (Neal et al. 1995, 2010; Schaefer (ed.) et al. 2011). In addition to the direct impact of volcanic products, secondary hazards such as lahars or tsunamigenic processes are important at volcanoes such as Redoubt and Augustine (e.g., Waythomas et al. 2006, 1997).

During unrest and eruptions, a primary objective of AVO is to issue timely alerts of activity and coordinate with partners who have eruption response responsibilities. For volcanoes where monitoring networks exist, advance warning of eruptive activity is often possible; for those volcanoes that lack local instrumentation, detection of activity may be the best outcome. Communication tools used by AVO and all U.S. observatories include the Hazard Notification System (HANS, https://volcanoes.usgs.gov/hans-public/) for issuing formal volcano alert notifications, including all formal text products that describe volcanic activity and unrest, hazards, and related volcano observatory activities. Volcano alert notifications aim to improve public safety by providing timely, relevant, up-to-date, and dependable information about the status of U.S. volcanoes. During quiet, pre-emergency times, succinct and predictably spaced notifications build awareness, relevance, and trust of AVO. The Volcano Alert-Level and Aviation Color-Code system (Gardner and Guffanti 2006) is used to communicate the status of volcanoes in the USA and associated hazards to the public (Table 1.). Unlike some alert-level systems globally, the system employed by the USGS does not include information directing mitigation or response actions, such as evacuations (Fearnley and Beaven 2018).

All formal volcano information products are automatically posted to the AVO website and distributed to emergency responders, stakeholders, and the public via subscription-based tools. The Volcano Notification Service

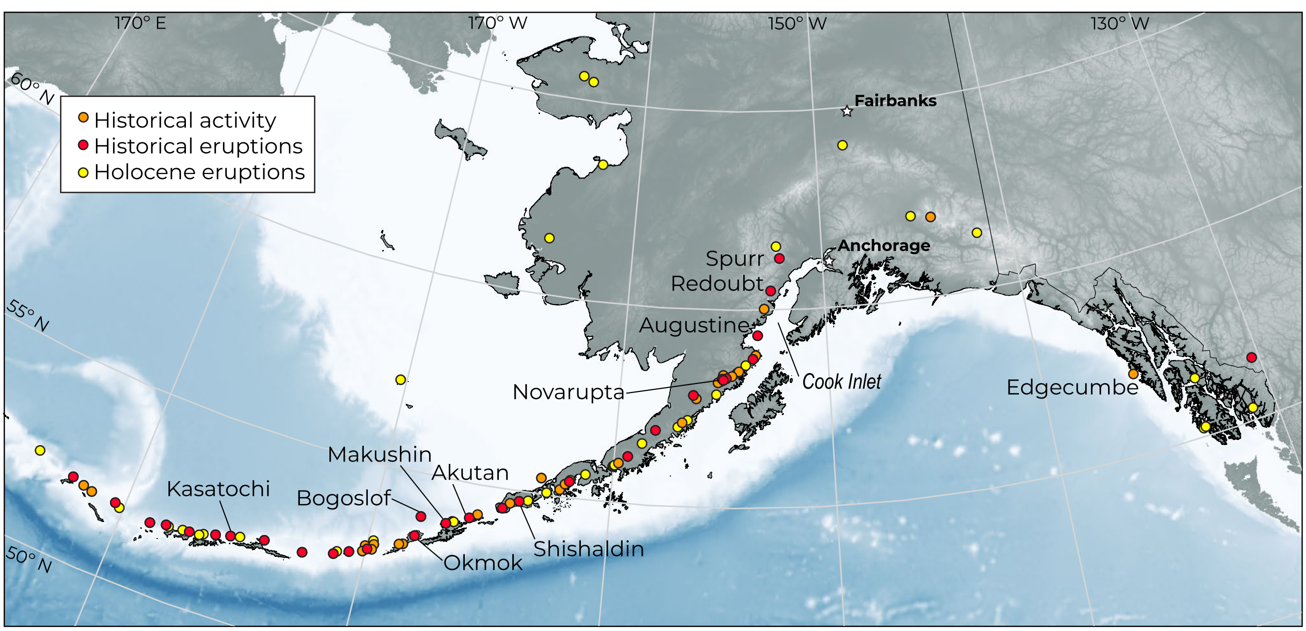

Fig. 2 Map of Alaska showing volcanoes that have had Holocene eruptions (yellow dots), historical eruptions (red dots), and historical unrest (orange dots). Volcanoes mentioned in the text are labeled

Table 1 U.S. Geological Survey volcano alert level (left) and aviation color code (right) definitions. Modified from Gardner and Guffanti (2006)

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

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

UNASSIGNED	Ground-based instrumentation is insufficient to establish that a volcano is in a typical background level (GREEN / NORMAL). When activity at such a volcano increases to the point of being detected by remote sensing, distant seismic networks, or eye witness reports, an alert level and color code are then assigned accordingly. When activity decreases, the volcano goes back to UNASSIGNED without going through GREEN / NORMAL.

(VNS, https://volcanoes.usgs.gov/vns2) is a subscription system that allows users to sign-up to receive email notifications for specific volcanoes and specific notification types. Table 2 describes the various volcano notifications and their purpose.

While AVO and other U.S. observatories have responsibility to issue formal notifications of volcanic unrest and activity, Federal, State, and local partners have the responsibility to advise on mitigative action based on information provided by AVO. Since 1994, AVO has maintained a formal interagency plan that is an overview of an integrated, multiagency response to the threat of volcanic ash in Alaska. It includes an agency-by-agency description of the roles and responsibilities for Federal, State, and local agencies that have a formal role during an eruption response (e.g., MET office, aviation authority, health authorities, marine authorities, emergency managers, land managers). The plan facilitates a well-coordinated response to ensure the flow of timely, consistent, and useful information to those at risk. The plan is updated every 2–3 years with sector-specific as well as all-hands meetings held annually or more often as needed to support coordination.

Timeliness of warnings of explosive eruptive activity is paramount, to ensure the Federal Aviation Administration

Table 2 Event-drive and scheduled hazard notifications used at the U.S. Geological Survey Alaska Volcano Observatory

Event-driven notifications	
Volcanic Activity Notification (VAN)	For alert-level changes, other significant changes in activity, or every ~6 h for large events; covers all volcanic hazards
Volcano Observatory Notice to Aviation (VONA)	For alert-level changes, other significant changes in activity, or every ~6 h for large events; covers aviation hazards
Information statement	Topical, non-urgent information, including long-term prognoses, changes in volcano monitoring status, or non-volcanic events
Scheduled notifications	
Daily report	Daily for any volcano not Green/Normal or Unassigned
Weekly report	Weekly summary of activity for all volcanoes
Volcano updates	Hourly for large eruptions near populated areas

(FAA) and National Oceanic and Atmospheric Administration (NOAA) have adequate time to warn the aviation sector of ash clouds. As a result, AVO has strived for timeliness in notifications of impending or just-begun eruptions (Coombs et al. 2018; Power and Cameron 2018) and works closely with partners to coordinate responses.

The frequency of volcanic activity in Alaska means that AVO is well-practiced in responses at a variety of scales ranging from small episodes of volcanic unrest, to remote eruptions with aviation impacts, to major eruptions that impact local populations and require assistance from other U.S. observatories. As a result, AVO has developed internal protocols and maintained long-standing and frequently used plans to work with interagency partners during volcanic ash episodes.

AVO organization and routine operations

AVO is a consortium of the USGS, the University of Alaska Fairbanks Geophysical Institute (UAFGI), and the State of Alaska Division of Geological & Geophysical Surveys (ADGGS). About 30 USGS-AVO staff, part of the USGS Volcano Science Center, work in Anchorage (Fig. 2). About 14 UAFGI staff, professors, and students work part- to full-time for AVO, and ADGGS, also in Fairbanks, has 5 full-time AVO staff. Scientists and staff from other U.S. observatories also contribute substantially to many aspects of AVO's operations and research (and vice versa); this is especially true during response episodes (Dietterich and Neal 2022).

All AVO activities are overseen by the AVO Scientist-in-Charge (SIC), a USGS employee based in Anchorage. The UAFGI Coordinating Scientist (CS) acts as the principal UAFGI liaison to the SIC, is the spokesperson for UAFGI activities of AVO, and coordinates AVO activities that occur at the UAFGI. The ADGGS Volcanology Section Chief acts as the principal ADGGS liaison to the SIC, as the spokesperson for ADGGS activities of AVO, and coordinates AVO activities that occur at the ADGGS. These three individuals make up the AVO management team (Fig. 3).

The SIC oversees and manages activities within AVO, including eruption response. However, all or part of this latter responsibility can also be delegated. They are the official spokesperson and line manager for AVO/USGS staff. The SIC coordinates all AVO monitoring, hazards assessment, and information dissemination and is on call 24 h a day.

Standing teams within AVO comprise individuals from all partner agencies and include field engineering (monitoring networks), information technology (IT), communications, discipline-focused teams (including geology, geophysics, remote sensing, and gas), and management. These are generally informal groups with staff members often participating in multiple groups. Teams meet on a regular basis (weekly to monthly) and participate in annual planning for the observatory and the parent institutions. While these teams perform critical functions during responses, for the remainder of this paper, we focus primarily on teams whose functions directly relate to evaluation and interpretation of monitoring data, issuance of warnings, public communication, and overall response management. Essential functions such as research, maintenance of monitoring networks, and ensuring smooth flow of data must continue unabated through all phases of observatory activities and are mostly captured under "other observatory operations and teams" in Fig. 3 (for more details see Coombs et al. (2024)). The exception to this is for the most "significant" eruptions during which all teams for observatory activities are explicitly and formally engaged in the response.

Volcano surveillance and standing duty roles

AVO does not maintain 24/7 in-person staffing during normal operations, although it does depend on 24/7 availability for some duty roles. Currently, off-hours monitoring is achieved using on-call personnel, scheduled checks, and automated alarms. Alarms at AVO were used as early as 1999 (Nye et al. 2002), and AVO has become more dependent on them over time as data streams have become more abundant and alarms more sophisticated. AVO maintains an operations center in Anchorage that is equipped for 24/7 in-person staffing if the situation warrants.

In the early days of AVO, the SIC typically served as the single point-of-contact of the observatory and played a primary role in many of the routine operational tasks. As AVO's area of responsibility grew, the ability of a single person to serve these roles became untenable. Starting in 2000, an AVO duty scientist role was created to assist the SIC as the point person in terms of volcanic activity, and additional formal duty roles for seismology and remote sensing were added in 2001 (Figs. 1 and 3A). These duty roles are filled by weekly rotations among 8–10 staff scientists. Each role has written duties and authorities. In addition to these rotating roles, the AVO SIC also has written responsibilities related to monitoring and response, and this role is filled by an acting SIC if the SIC is unavailable. Descriptions of most of these roles were included as supplements in Lowenstern et al. (2022).

Since 2017, AVO has also assigned weekly primary alarm and backup alarm duty roles (Fig. 3B). All roles require 24/7 availability since AVO does not maintain a 24/7 operations center except during significant eruptions (such as the Augustine and Redoubt eruptions described below). The response-related responsibilities of each of these roles include:

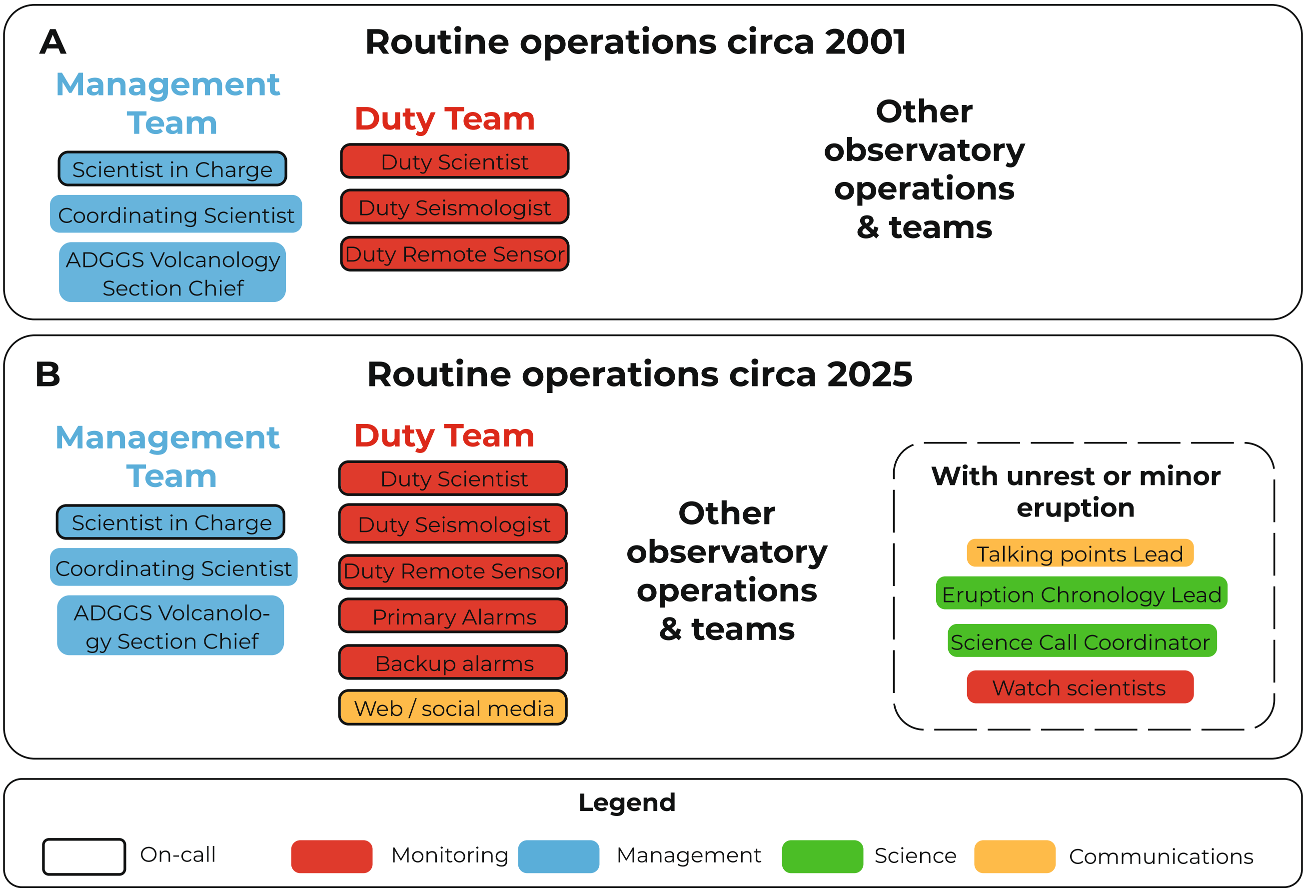

Fig. 3 Organization of the Alaska Volcano Observatory (AVO) during routine operations (times of no or minor unrest, or during eruptions with minor impacts) in 2001 (**A**) and 2025 (**B**). Many operational roles at the observatory, such as maintaining monitoring networks, data transmission and information technology (IT), research, and administrative tasks, are not shown and are instead combined under "Other observatory operations and teams" ADGGS, Alaska Division of Geological and Geophysical Surveys

- The *duty scientist* maintains overall situational awareness, writes scheduled and event-driven information products, and serves as public information officer. Duty scientists are drawn from the USGS-AVO science staff in Anchorage and carry a cell phone that requires them to stay within coverage areas 24 h a day. The duty scientist is supported by other duty personnel (see below) and is the main point of contact during routine volcanic unrest. They lead a summary and discussion of volcanic activity at weekly staff meetings, including discussion of alert-level changes as warranted. Duty scientists typically have postgraduate training in some aspect of volcanology and have worked at AVO for at least 2 years prior to assuming the role.
- The *duty seismologist* performs twice-daily reviews of all seismic and infrasound data streams. All observations are entered into a relational database, which allows text descriptions, keywords, and images to be uploaded for individual volcanoes. Duty seismologists are professional scientists or advanced graduate students in volcano seismoacoustics.
- The *duty remote sensor* conducts a once-daily review of all available data from web cameras as well as meteorological and high-spatial-resolution satellite sources. Observations are entered into a relational database and include information about all volcanoes at elevated alert levels, as well as any other volcanoes with notable observations. Duty remote sensors are professional scientists or advanced graduate students with training in remote sensing or volcano geology.
- *Primary and backup alarm* roles receive a variety of infrasound and seismic alarms that notify AVO staff of potential eruptive activity, such as detected explosions or strong tremor. Individuals in these roles are responsible for assessing the nature of the alarm and taking action if needed. The primary alarm is filled by a volcano geophysicist whereas the backup role may be filled by any duty scientist.

- In addition to the roles listed above, several other positions are required to maintain continuous data and information flow. These include (field) engineering, IT, website, and social media roles. Field engineering and IT roles are filled by professionals with education in either physical sciences, IT technology, computer science, or engineering; on-the-job training is crucial for these specialized jobs. AVO does not have a formal public information officer like some observatories, so staff serve on a rotational basis to produce content for social media, the website, and other communication venues.

These formal roles allow AVO to monitor and respond to volcanic unrest and activity across the spectrum from background activity to minor levels of unrest and eruption, enabling the remainder of the AVO staff to have time and space to focus on performing other essential observatory activities (e.g., research, IT and monitoring network operations).

Responding to unrest and eruptions

With so many active volcanoes in Alaska, responding to volcanic unrest is a routine aspect of AVO operations. When new unrest begins—typically observed by duty personnel—the nature, intensity, and location of the unrest guide the next steps. AVO duty personnel follow a checklist for evaluating and responding to unrest (Supplement 1), with the checklist encompassing activities such as data analysis, decision-making, internal coordination, and preparation of public communication strategies and information products. These tasks are generally carried out by those in formal duty roles at the time but are often supported in an ad hoc manner by others who volunteer, facilitated by transparent internal communication channels.

For many unrest episodes, the standing duty team is able to perform the required tasks, allowing the rest of the observatory staff to focus on other work. For situations when there is novel unrest or when there is uncertainty about the assignment of alert levels, a *science call* is convened (Fig. 3B) that can involve all or some AVO staff and sometimes scientists from other observatories or organizations. These calls—held during the early stages of unrest, or throughout prolonged episodes—provide an opportunity for all observatory staff to share background information, contextualize new data across disciplines, discuss possible outcomes, and to determine necessary operational steps. The call is led by the *science call coordinator*, who may be the SIC, duty scientist, or scientist familiar with the volcano in unrest. The science call coordinator organizes presentations and facilitates the meeting. Science calls are not held on a fixed schedule but are initiated as needed, usually by the SIC. While a single call may suffice for minor unrest, more significant events or eruptions often require frequent and ongoing discussions, as described below.

If unrest escalates rapidly or its origin is uncertain, data watches staffed by *watch scientists* may be initiated in several forms. One approach involves scheduled data checks at regular intervals (e.g., every 2, 4, or 6 h), while another involves continuous monitoring in multi-hour shifts. The specific format and frequency of these checks is determined by the AVO SIC, often in consultation with an ad hoc group that typically includes the UAFGI Coordinating Scientist. Participation is generally voluntary, provided individuals meet minimum training requirements. Guidelines for performing checks outline which data streams to review, how to report the findings, who to contact in case of unusual activity, and the criteria for escalating concerns (e.g. Supplement 2). This level of surveillance is especially valuable when the likelihood of eruption is elevated or when the nature of the unrest complicates automated alarm implementation.

In the event of significant unrest, *talking points* may also need to be established, especially if a media response is anticipated. Talking points are important for coordinated and consistent messaging and are especially important for AVO because staff and core partners are distributed across three agencies and are not collocated. Talking points generally include information about the volcano's (1) current status, (2) recent observations, (3) what to expect or prognosis, (4) monitoring status, (5) hazards, (6) eruption history (for context), and (7) other background information (e.g., location, nearby towns, summit elevation, threat ranking). The cadence of updating talking points depends on activity, available observations, and demand for information and is an assigned duty.

In addition, AVO establishes *eruption chronologies* to keep track of key chronological monitoring data, observations, and operational response landmarks and actions over time. Eruption chronologies are established during significant unrest and nearly all eruptions. For larger responses, an *eruption chronology lead* is assigned to oversee chronology maintenance; for ongoing, low-level unrest or eruptions, they may be maintained using a group approach. They have evolved over time from simple chronological tabulations of activity reported in the AVO logs (an online observation database) and accompanying simplified summaries, to complex spreadsheets with multiple tabs dedicated to various data streams, observational data, and response actions, including (1) aviation color code, (2) information products issued, (3) pilot reports, (4) satellite remote sensing observations, (5) gas results, (6) fieldwork, (7) infrasound, (8) seismology, (9) geodesy, (10) plume height, (11) operational milestones, (12) ashfall accounts, and (13) summary by event or major milestone. The most sophisticated of these spreadsheets include machine-readable formats allowing chronological data to be quickly summarized visually. In addition to data visualization, chronologies are useful for allowing staff to know what is happening and has happened at a volcano, establishing consistent baselines for discussing unrest/eruption by large research groups, eruption forecasting, research, and updating talking points. The chronologies form a critical reference in research efforts that may occur years or decades after the unrest or eruption and most recently are available as standalone data releases (e.g., Loewen et al. 2026). AVO maintains a detailed chronology template that serves as the starting point for all chronologies and gets filled out commensurate with activity.

Significant eruptions unrest episodes

In this section, we highlight several eruptions whose scale and impacts required a significant departure from routine operations to ensure an effective response. Each event had distinct challenges and highlighted how AVO's response strategies have evolved over time.

Augustine 2006

Augustine Volcano, the most historically active volcano in Alaska's Cook Inlet region, last erupted in 2006 (Power et al. 2010). Months of escalating seismic unrest, ground deformation, and gas emissions culminated in an eruption from January 11 to mid-March of 2006 (Fig. 4A), its fifth major eruption in 75 years. The eruption began with a series of 13 short-lived explosions over 20 days that sent ash clouds as high as 15 km above sea level (asl) drifting hundreds of kilometers downwind (Coombs et al. 2010). Punctuated explosive activity gave way to effusion of lava and block-and-ash flows on the volcano's north flank that continued through mid-February. In mid-March, renewed effusion resulted in the building of a new, higher summit lava dome and two blocky lava flows on the north and northeast flanks of the cone. The eruption resulted in trace ashfall on inhabited areas in south-central Alaska and significant interruptions of air travel into and out of Anchorage and other nearby communities (Neal et al. 2010). During the entire eruptive

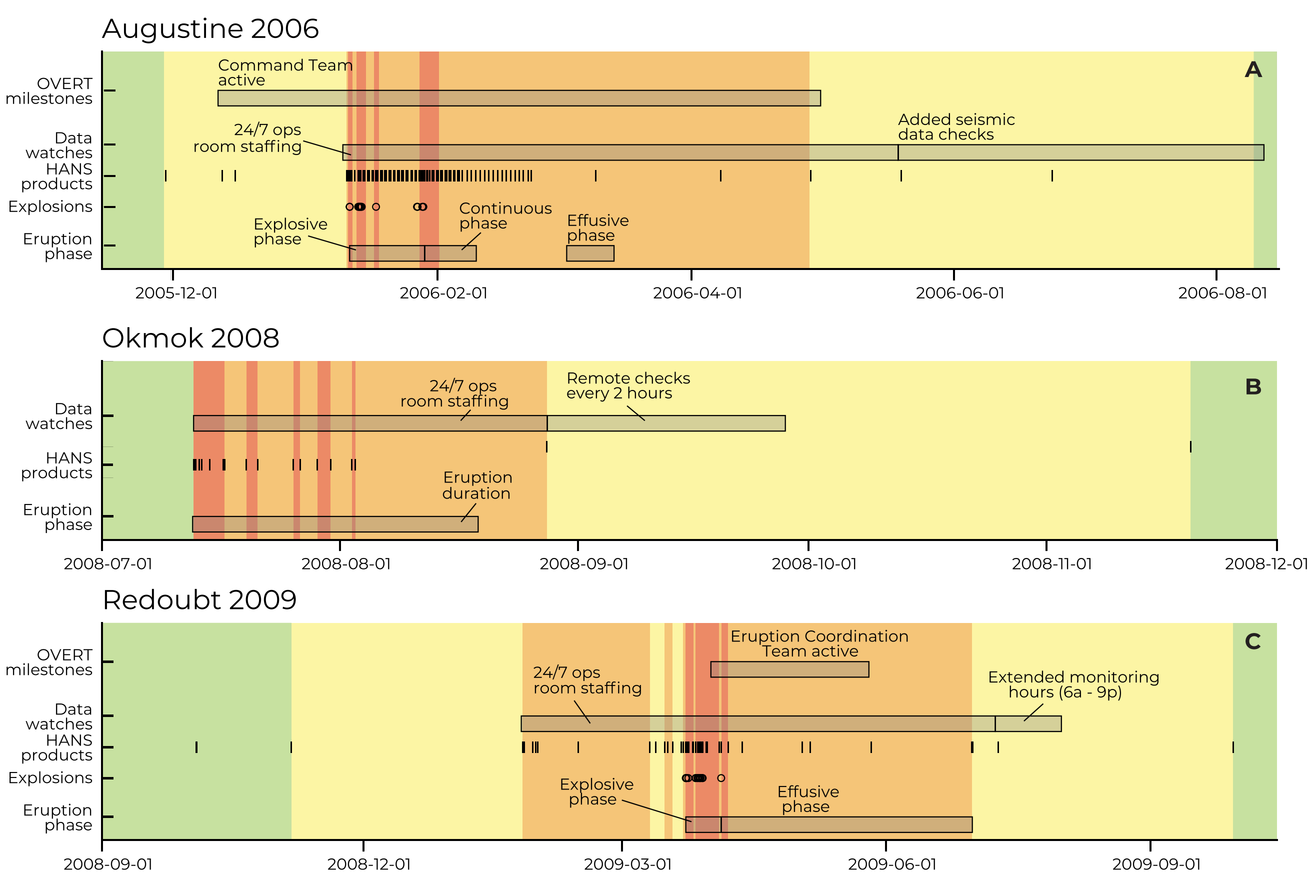

Fig. 4 Timelines of Alaska Volcano Observatory (AVO) responses to significant eruptions from 2006 to 2009 of Augustine (**A**), Okmok (**B**), and Redoubt (**C**) volcanoes highlighting response activities. Colors represent the aviation color code (see Table 2). For each timeline, eruptive phases and explosive events are shown at the bottom, and AVO response activities are highlighted above. HANS, USGS Hazard Notification Service. OVERT, Observatory Volcanic Event Response Team. Data for Augustine from Coombs et al. (2010) and Neal et al. (2008). Okmok data from Neal et al. (2011). Redoubt data from Schaefer et al. (2011)

sequence, AVO issued dozens of formal notices, including 12 alert-level changes. The pace of public notices was highest during the earlier, most explosive phases of the eruption from mid-January through February.

The response to the initial unrest in 2005 was managed by individuals in standing duty roles or contributing on an ad hoc basis. As unrest intensified in December 2005, the AVO SIC established the *Augustine command team* to coordinate eruption response activities (Neal et al. 2010; Fig. 5). The roles and responsibilities of each team member were clearly defined in writing (Supplement 3). The team consisted of five positions filled by AVO staff based in Anchorage and Fairbanks. A *chief of operations* assumed responsibility for the overall response and led the command team meetings and assigned tasks. They coordinated both field and office operations, including staffing, budgeting, and personnel management in consultation with other AVO managers. They were also responsible for identifying and addressing resource gaps. In this case, the SIC served as the chief of operations.

The *science coordinator* led technical discussions and maintained a synoptic view of scientific activities, data streams, analysis, and requirements to ensure accurate hazard assessment, forecasts of activity, and to maximize research opportunities. They also chaired a scientific advisory committee that included at least two external scientists and coordinated publication of scientific results.

A *media/communications coordinator* was responsible for producing key graphics and briefing materials as well as overseeing updates to the AVO Web page throughout the eruption. AVO's public outreach and communications efforts during the eruption are summarized in Adleman et al. (2010).

The *information and data coordinator* was responsible for maintaining the health and continuity of AVO's computer networks across its distributed facilities. They also managed data security, implemented data sharing protocols, and addressed telecommunications needs.

Finally, a *hazards information coordinator* was responsible for developing hazard messages during the eruption and worked closely with the science coordinator to produce talking points. This person served as the primary point of contact for other government agencies and addressed interagency coordination issues. Had a formal interagency Joint Information Center (JIC) been established to coordinate and disseminate official information during the eruption, the hazards information coordinator would have served as the AVO representative.

The decision to keep the command team small was guided by the "span-of-control" ICS principle that states that no

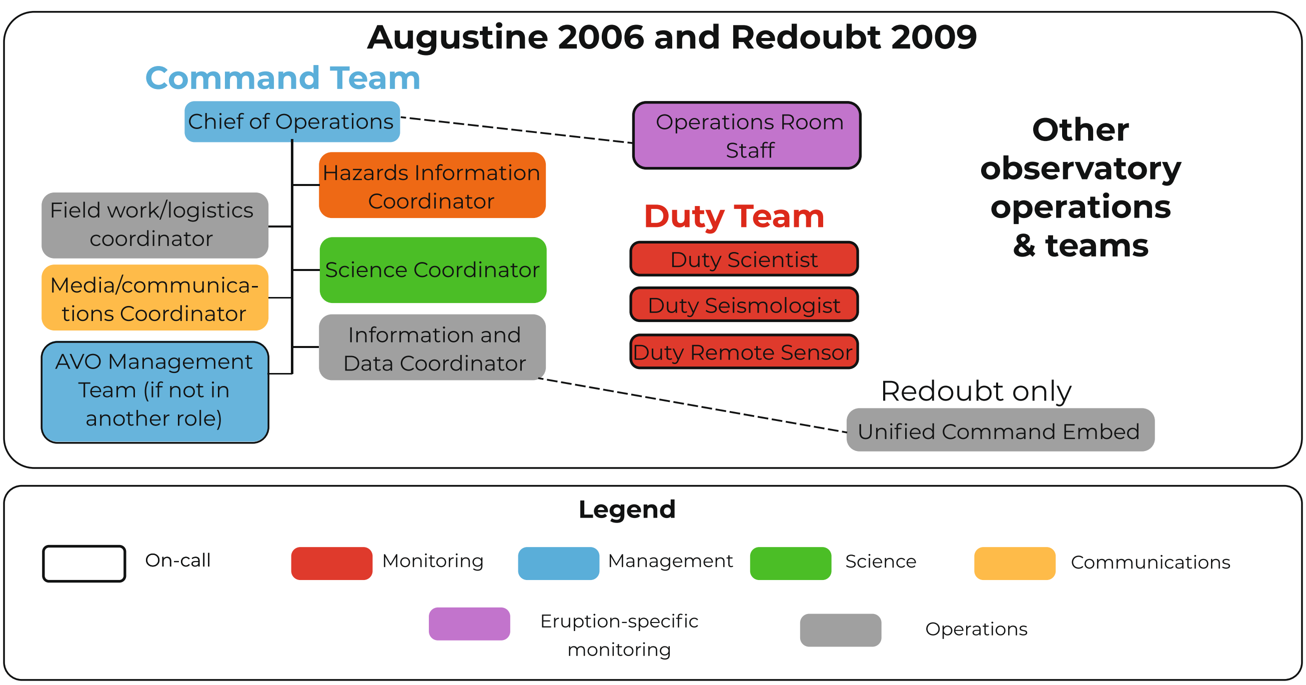

Fig. 5 Response team and roles used at the Alaska Volcano Observatory (AVO) during the eruptions of Augustine in 2006 and Redoubt in 2009. Eruption-specific roles include those involved with science coordination (green), real-time data analysis and hazard alerts (purple), communications (yellow), and interagency coordination (orange). Note that during these two eruptions, the AVO operations room was staffed 24/7 to handle real-time data monitoring and hazard notifications. Many routine operational roles at the observatory, such as maintaining monitoring networks, data transmission and information technology, research, and administrative tasks, are not shown and are instead combined under "Other observatory operations and teams"

individual should supervise fewer than three or more than seven people. The command team's role was to quickly assess the situation, make decisions and plans, delegate tasks, and then execute those tasks. Meetings were held daily, or as needed, to repeat this assess–plan–execute cycle. This streamlined approach became increasingly important as the response scaled up and additional staff, including those from other observatories, were brought in to assist.

The Augustine command team represented one of the earliest implementations of a formal command structure used within the USGS Volcano Science Center and is a direct predecessor of the OVERT described in Moran et al. (2024). Whereas the full OVERT has many positions subordinate to the command team, the AVO SIC in 2006 determined that such a level of granularity was unnecessary for the Augustine response. Instead, the team was structured to allow management to occur in a less rigidly defined manner, with command team members encouraged to engage openly with all staff, and AVO staff were encouraged to share concerns and ideas freely with any member of the command team.

The threats and impacts posed by Augustine's eruption necessitated that AVO conduct relatively frequent field work and overflights to repair and augment the monitoring network, make field observations, and conduct thermal and gas surveys. Between December 2, 2005, and April 11, 2006, AVO conducted 29 fixed-wing gas and observation flights from Anchorage and 22 helicopter missions from Homer. To support safe field operations, the command team developed eruption-specific safety protocols, including helicopter-use protocol areas.

Another notable element of the Augustine response was the move to 24/7 staffing in the AVO operations room in Anchorage, which continued for several months (Fig. 4A) (the seismic laboratory at UAFGI was also staffed 24/7 for most of the eruption). To meet the increased personnel demands, scientists from other U.S. observatories were brought in under the chief of operations (Fig. 5). Operations room staff were responsible for continuous data monitoring, responding to inquiries from the public and partner agencies, and issuing formal notices in response to volcanic activity. The duty roles (at that time, duty scientist, duty remote sensing specialist, and duty seismologist) remained active and were also tasked with responding to other unrest episodes during the Augustine eruption, such as a seismic swarm at Mount Martin (Dixon and Power 2009).

Okmok and Kasatochi, 2008

AVO responded to two significant eruptions in 2008 at Okmok and Kasatochi volcanoes in the Aleutian Islands (Fig. 2). The 2008 phreatomagmatic eruption of Okmok (Fig. 4B) commenced suddenly on July 12 and lasted for 5 weeks, resulting in substantial ashfall, pyroclastic surges, and lahars on Umnak Island and ash clouds as high as 15.9 km asl (Neal et al. 2011). AVO commenced 24/7 staffing at the onset of the eruption and continued it through August 28. After August 28, staff performed remote data checks every 2 h through the month of September. The relative brevity of the response meant that no help from outside observatories was needed, and no OVERT-style team was implemented for this Okmok eruption.

AVO conducted two helicopter-based field campaigns, one during and one after the eruption. Additional notable response activities included travel to Unalaska Island to meet with emergency managers and community members (Neal et al. 2011). Over the course of the eruption, AVO issued 17 volcanic activity notices (VANs) and two information statements.

Kasatochi, a small unmonitored island volcano (Fig. 2), also erupted in the summer of 2008. The first signs of unrest occurred in mid-July, when seismic analysts detected increased earthquake activity near the volcano on the regional seismic network (Waythomas et al. 2010). On August 4, U.S. Fish and Wildlife Service (USFWS) biologists on the island reported felt seismicity for several days. On August 6, following continued seismicity, AVO issued a VAN raising the Aviation Color Code to Yellow and the Alert Level to Advisory. The next day, biologists reported near continuous shaking and a strong sulfur smell. AVO responded by raising the Aviation Color Code to Orange and the Alert Level to Watch. Shortly afterward, satellite imagery confirmed the eruption, just 30 min after the biologists had been evacuated from the island. The VEI4 eruption lasted about 24 h and consisted of at least five discrete explosive events. The small island was blanketed in thick pyroclastic deposits, and the eruption cloud reached over 15 km asl and caused at least 40 flight cancellations, two minor aircraft-ash cloud encounters, and was visible for thousands of miles downwind.

Because AVO was already operating 24/7 in response to the Okmok eruption, no major changes to staffing or procedures were required. Operations room staff and other duty personnel responded to both Okmok and Kasatochi concurrently.

Redoubt 2009

Redoubt Volcano, an ice-covered stratovolcano on the west side of Cook Inlet (Fig. 2), erupted in March 2009 causing major disruptions to southcentral Alaska (Schaefer et al. 2011). Precursory seismicity lasted approximately 6 months with the first weak tremor recorded in September 2008 (Fig. 4C). A small phreatic explosion occurred on March 15 and the first magmatic explosion on March 22. The onset of magmatic explosions was preceded by a strong, shallow swarm of repetitive earthquakes that began on March 20.

In total, 19 explosions generated ash clouds that reached heights between 5.2 and 18.9 km asl. The Ted Stevens International Airport in Anchorage, a major international cargo hub, was shut down for 20 h from March 28 to 29 due to ashfall. On March 23 and April 4, lahars inundated parts of the Drift River Terminal, an active oil storage and transfer facility 42 km downstream from the volcano. The final explosive event occurred on April 4 and effusion of the final lava dome ceased in early July.

AVO began 24/7 in-person staffing of the Anchorage operations room on January 25, when the alert level and aviation color code were raised from Yellow/Advisory to Orange/Watch due to the onset of sustained seismic tremor and increased fumarolic output. Initially, Anchorage-based AVO staff provided coverage in 6-h shifts. Within a week, staff from the Fairbanks AVO office, as well as from the broader VSC, were brought in to assist, particularly with overnight shifts. One or two staff members were present in the operations room at any given time. As additional support arrived, shift length was extended from 6 to 8 h long. Operations room duties included monitoring seismic and remote sensing data, maintaining situational awareness of wind direction and external agencies' warnings, fielding phone inquiries, issuing hourly updates, and issuing event-driven VANs as needed. AVO maintained continuous 24/7 coverage through July 9.

AVO's field response to the Redoubt eruption consisted of fixed-wing gas and observation flights and helicopter missions to conduct field work to repair and augment the monitoring network, as well as collect rock and water samples and make geologic observations. Between September 2008 and August 2009, AVO conducted 30 fixed-wing flights and 40 helicopter missions.

A formal response team was implemented in early April 2009 (Fig. 5). The Redoubt eruption coordination team (Supplement 4) was similar in structure to the one created for Augustine 2006 eruption. For Redoubt, however, the chief of operations—responsible for overseeing the overall response—was someone other than the SIC. Another difference was the addition of a *press information scientist*, who served as the primary liaison with the USGS communications team and the media. They oversaw the creation of daily talking points, emphasizing consistent terminology, minimizing jargon, and focusing on communicating hazards rather than scientific details.

The presence of the Drift River Terminal (DRT), an oil storage facility downstream from the volcano, prompted the U.S. Coast Guard, the Alaska Department of Environmental Conservation, and the Cook Inlet Pipeline Company (operator of the DRT) to create a unified command (UC) to manage and coordinate the response following the lahars generated on March 23 (Schaefer et al. 2011). The UC focused on the primary objectives of protecting the safety of citizens and response personnel and protecting of the environment. Key tasks included developing plans to remove the more than 6 million barrels of crude oil stored at the facility, assessing damage from lahars generated on March 23, and preparing for future lahar-generating events. In late March, the UC established an Incident Command Post in Anchorage, staffed by more than 50 personnel from various agencies. AVO scientists with expertise in the eruption and lahar hazards were embedded at the post while it remained active through early April (Fig. 5). To support the coordination, AVO implemented a dedicated calldown protocol to rapidly notify the UC of any eruptive activity or change to the volcano's status; this was especially important while personnel were present at the DRT during the eruption.

Bogoslof 2016–2017

Bogoslof, a back-arc volcano in the eastern Aleutian volcanic arc (Fig. 2), erupted over a 9-month period from 2016 to 2017, producing at least 70 explosive events (Fig. 6A). These explosions, ranging from a few minutes to several hours in duration, sent ash clouds as high as 13 km asl (Coombs et al. 2019). The eruption began in December 2016 with a series of explosive events that persisted through mid-March 2017. After a 6-week hiatus, activity resumed on May 17 and persisted through the end of August 2017, including additional explosions and the formation of two short-lived subaerial lava domes in June and August. For most of the eruption, Bogoslof's vent was submerged in shallow seawater. Three events produced ashfall on nearby communities and ships, and the eruption resulted in dozens of flight cancellations and diversions.

Because the volcano had no local monitoring stations, AVO relied on distant seismic stations at Okmok (54 km) and Makushin (72 km) volcanoes, regional infrasound sensors, lightning detection from the Worldwide Lightning Location Network, and satellite imagery (Coombs et al. 2018). Preeruptive seismicity was detected for 12 events during the first half of the eruption; for all other events, detection was based solely on co-eruptive signals.

At the onset of the eruption, AVO implemented ad hoc data watches to monitor available geophysical and remote sensing data. Initially, experienced analysts filled watch shifts until formal guidelines were developed, allowing a broader pool of staff to participate. Watchers were responsible for notifying the duty scientist of any anomalous observations and, with the help of the SIC and a small group of other scientists, issuing alerts, working with partners, and performing call downs.

As frequent explosions continued into early 2017, AVO developed a protocol that allowed for rapid detection of unrest or eruption onset, followed by timely characterization of eruption plumes and dissemination of critical information

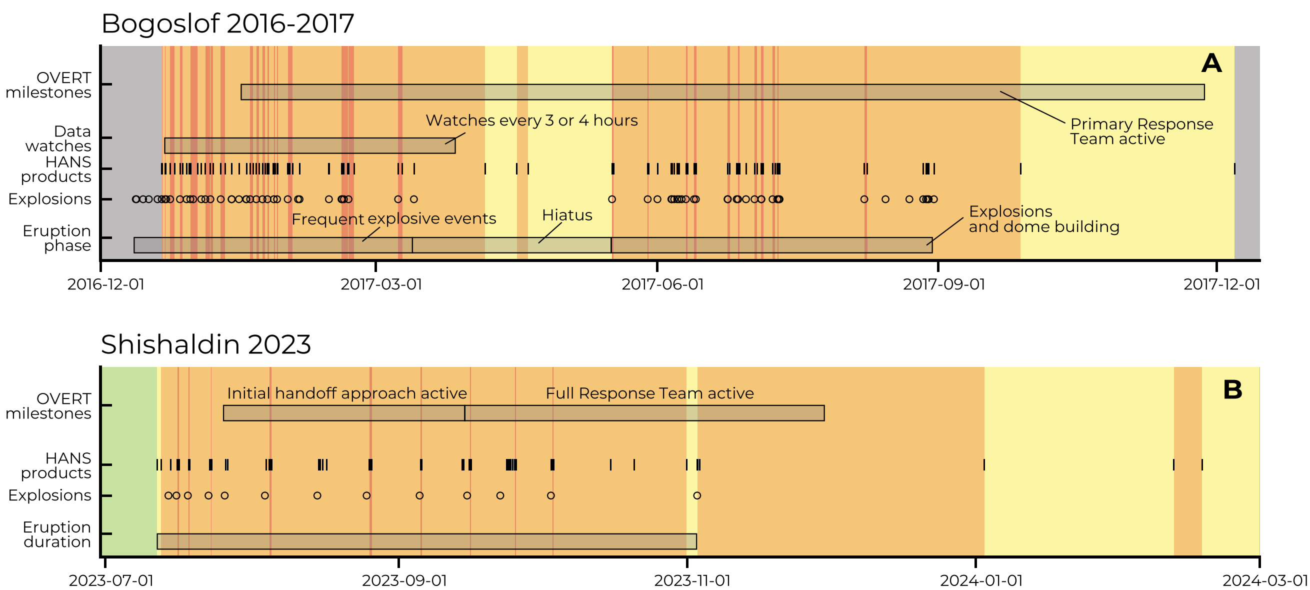

Fig. 6 Timelines of Alaska Volcano Observatory (AVO) responses to eruptions at Bogoslof in 2016–2017 (top) and Shishaldin in 2023 (bottom) highlighting response activities. Colors represent the aviation color code; gray denotes unassigned (see Table 2). For each timeline, eruptive phases and explosive events are shown at the bottom, and AVO response activities are highlighted above. HANS, USGS Hazard Notification Service. OVERT, Observatory Volcanic Event Response Team. Bogoslof data from Coombs et al. (2019). Shishaldin data from Loewen et al. (2026)

to stakeholders (Coombs et al. 2018). The protocol was implemented by the *primary response team*, which was a second, sometimes overlapping group that complemented the standing AVO duty roles (Fig. 7A; Supplement 5). This group consisted of the following:

- *Response geophysicist*, who received alarms and analyzed infrasound and seismic data
- *Response remote sensor*, who received alarms, analyzed satellite data, and acted as primary liaison with the Anchorage Volcanic Ash Advisory Center (VAAC)
- *Ash3D specialist*, who ran event-specific ash dispersion models using the program Ash3D (Schwaiger et al. 2012) and, when necessary, was the primary liaison with the National Weather Service Forecast office responsible for ashfall forecasts
- The AVO duty scientist (or SIC, if necessary), who integrated all data streams and wrote and distributed formal warning products

AVO staff were assigned to these roles on a weekly basis and remained on call throughout their rotation. Much of the activity took place outside of normal working hours, with communication relying on phone and text messaging. During the eruption, AVO implemented use of an internal instant messaging platform (“AVO Chat”), still in use today, that is accessible via computer or mobile device. This tool facilitated real-time coordination among team members and allowed other observatory staff to follow discussion and stay informed.

Although a formal response management team was not created during the Bogoslof eruption, several other non-real-time roles were filled, including *alarm coordinator*, *talking points lead*, *eruption chronology lead*, *science coordinator*, and *web and social media leads* (Supplement 5). AVO also implemented remote data watches, which required a dedicated watch scheduler and numerous watch scientists.

The Bogoslof eruption marked a turning point for how AVO responds to eruptions. Despite the high number of ash-producing events, the entire response was conducted remotely without staffing AVO’s in-person operations room. This was facilitated by automated alarms, the use of an internal instant messaging platform, and the primary response team model, which ensured adequate on-call staffing for a virtual response. Another milestone is that this was the first operational use of Ash3D (Schwaiger et al. 2012) during an Alaska eruption to rapidly generate event-specific ash-dispersion and ashfall forecasts following explosive activity.

Shishaldin 2023

Shishaldin volcano, located on Unimak Island (Fig. 2), erupted for ~ 9 months starting in July 2023 (Fig. 6B). The eruption was dominated by 13 paroxysmal events that produced ash plumes reaching as high as 13.7 km asl and drifting as far as 320 km from the volcano.

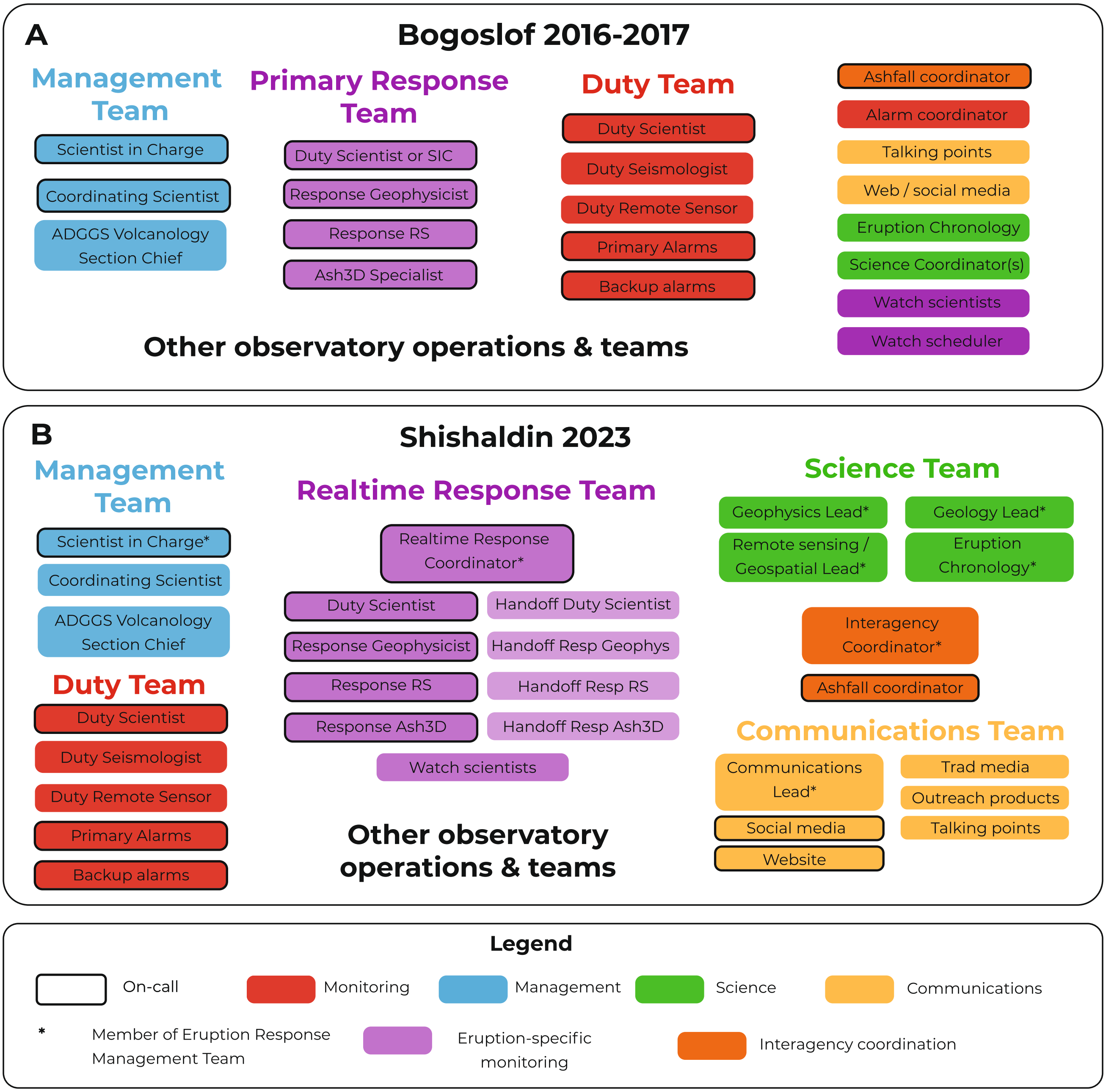

Fig. 7 Response teams at the Alaska Volcano Observatory used during eruptions at Bogoslof in 2016–2017 (**A**) and Shishaldin in 2023 (**B**). During the Bogoslof eruption, the real-time aspects of the response were handled remotely with a primary response team (PRT) that often overlapped with the main duty team. A handful of other roles were also assigned to individuals (at right). At Shishaldin in 2023, hours-to-days long unrest periods prior to many of the 13 paroxysms required a modified approach to the PRT, now real-time response team (RRT), where response roles could be handed off during longer runups. This complexity required creation of a real-time response coordinator role. For both responses, many routine operational roles at the observatory, such as maintaining monitoring networks, data transmission and IT, research, and administrative tasks, are not shown and are instead combined under "Other observatory operations and teams." SIC, Scientist in Charge; RS, remote sensing; ADGGS, Alaska Division of Geological and Geophysical Surveys; IT, information technology

Several of the events deposited ash on ships in the surrounding marine areas, and two resulted in ashfall on nearby communities, including Cold Bay, False Pass, King Cove, and Sand Point. The immediate vicinity of the volcano is uninhabited; therefore, the primary hazards during the eruption were aviation impacts and distant ashfall. The monitoring network at Shishaldin consistently detected precursory unrest hours to days prior to each event, which allowed AVO to issue timely warnings of imminent explosive activity.

Initially, AVO employed a primary response team similar to that used for the Bogoslof 2016–2017 eruption. However, unlike Bogoslof, where explosive events often occurred with little or no warning, Shishaldin's activity was typically preceded by prolonged periods of increasing seismic tremor (e.g., Figure 8). AVO quickly realized that it was unrealistic for members of the primary response team to continuously monitor data during extended runups without becoming overly fatigued. To address this, AVO implemented a "hand-off" approach in late July where weekly duty rosters were expanded to include not only the four-person primary response team but also a secondary "handoff" group. This second group was on call and prepared to take over during responses lasting longer than several hours. While this approach worked well, it added extra staffing demands and highlighted the need for a dedicated coordinator to manage the increased complexity, particularly the timing and execution of team handoffs during event response.

In September, a formal Shishaldin OVERT was created (Fig. 7B; Supplement 6). This included creating a *real-time response coordinator* role to manage prolonged event responses. This role oversaw the transition, or handoff, from the primary response team to the handoff team, allowing primary response team members to step away for rest or attend to other responsibilities. The real-time response coordinator also had the authority to develop duty shifts, call in additional qualified staff, or set up data watch schedules as needed.

The OVERT structure also included a four-person *science team* whose members did not rotate weekly and did not have real-time responsibilities (though, in practice, some individuals served in both roles). The science team was composed of leads for *geology*, *geophysics*, and *remote sensing*. Each of these leads was responsible for setting priorities for their discipline, creating discipline-based teams as needed, summarizing relevant data streams, ensuring proper data archiving and organization, and coordinating input into observatory-wide science calls. In addition to the three discipline-based leads, there was also an *eruption chronology coordinator*, who was tasked with maintaining a detailed and accurate timeline of eruptive activity.

Another new role in the Shishaldin OVERT was the *communications team*, led by the *communications lead*, which was responsible for social media, the public website, and coordinating interactions with traditional media outlets. They prepared and updated talking points and identified appropriate outreach products and ensured their creation,

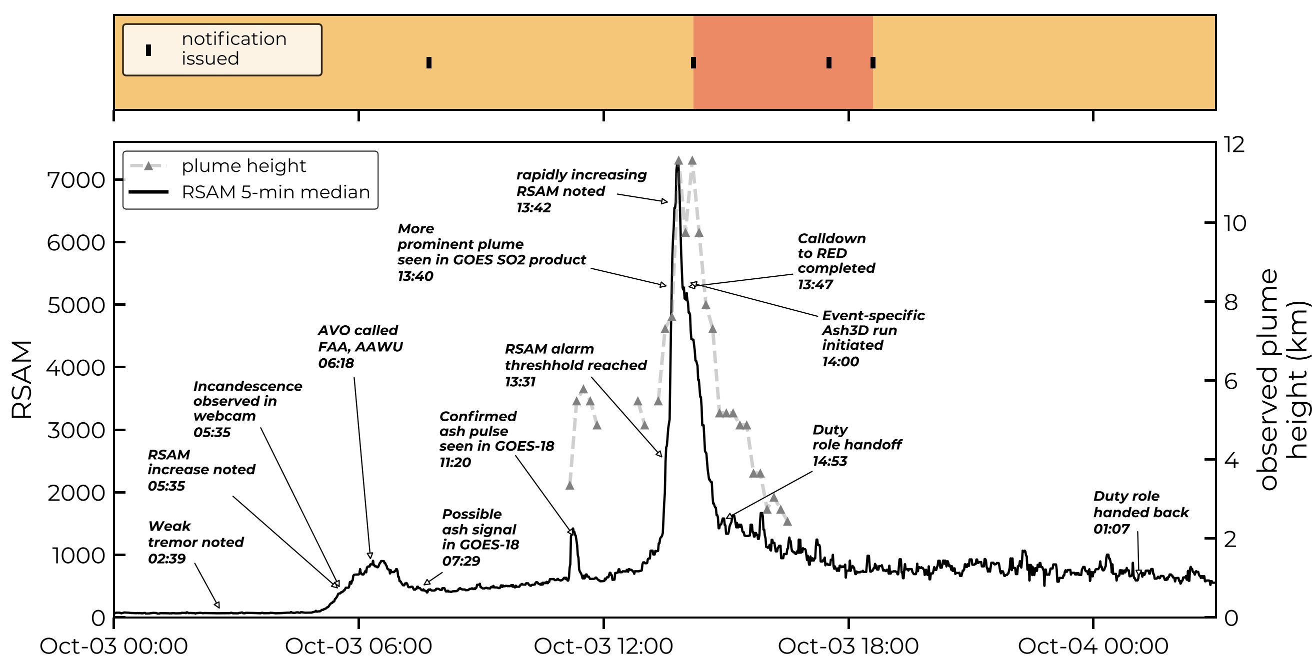

Fig. 8 Timeline for the October 3 paroxysm (event 12) of the 2023 Shishaldin eruption. Upper panel shows Aviation Color Code and VANs (Volcano Activity Notice) issued. Lower panel shows real-time seismic amplitude measurement (RSAM) from station SSLN, located approximately 6 km northwest of the vent, and plume heights derived from Geostationary Operational Environmental Satellite (GOES) data (Loewen et al. 2026). Plume heights are based on retrospective analysis and differ slightly from those estimated in real time by the Alaska Volcano Observatory (AVO) and the National Weather Service; however, the overall trends are the same. Overlain on the lower panel are indicators showing when observations were first noted, when alarms were activated, and when other actions that were part of AVO's operational response occurred

approval, and dissemination. Tasks described above were done by individuals who rotated as needed.

Lastly, the Shishaldin OVERT included an *interagency coordinator* whose role was to ensure smooth communications with the National Weather Service (NWS), the FAA, Alaska Department of Homeland Security and Emergency Management (DHSEM), and other partners as needed to resolve issues that arose during the response. Additional responsibilities included updating the calldown list, discussing Temporary Flight Restrictions with FAA, overseeing ashfall coordination, and working with downwind communities, DHSEM, and the NWS Anchorage Weather Forecast Office when ashfall on local communities was expected.

To illustrate how some of the real-time response roles worked in practice, Fig. 8 shows a timeline of the October 3 paroxysm (event 12) that occurred during the 2023 eruptive sequence. The primary real-time monitoring parameter used to track escalating activity during this and other explosive events was real-time seismic amplitude measurement (RSAM; Endo and Murray, 1991), which quantifies the average seismic amplitude over short time intervals. An initial increase in RSAM that peaked at 0634 UTC was concurrent with observations of incandescence in webcam images; this likely corresponded to fountaining and pyroclastic flows on the upper flanks of the volcano. After a slight decline immediately following that peak, RSAM began gradually increasing from 0730 to 1300 UTC, an increase that was temporarily broken by a short, sharp peak at 1100 UTC that coincided with a confirmed ash pulse as seen in satellite imagery. RSAM then ramped up sharply from 1300 to about 1350 UTC, an increase that correlated with the first satellite observations of ash rising above 11 km asl. After 1350 UTC, the amplitude fell almost as sharply over the next hour. However, ash emissions continued, with clouds heights of ≥ 7 km through 1440 UTC as determined by GOES satellite data.

To illustrate AVO's operational response during this event, Fig. 8 also shows the aviation color code timeline, formal notifications, and key response actions taken. These actions were carried out by the real-time response team, which included the duty scientist (who also served as the duty remote-sensing specialist), the response geophysicist, and the Ash3D modeler. As with many of the paroxysms in the 2023 eruption, the several hours of gradually increasing seismicity allowed AVO to notify primary partners via phone at 0618 UTC and issue a VAN/VONA at 0743 UTC stating that an eruption was likely imminent; these notifications occurred about 7.5 and 6 h before the main eruption, respectively. During the rapidly escalating RSAM increase at ~ 1340 UTC, AVO staff watched satellite, infrasound, seismic, and lightning data, and elevated the aviation color code to Red. This alert-level change prompted a full calldown to partners which was completed by 1357 UTC. At 1400 UTC, the Ash3D specialist initiated an event-specific ashfall forecast, and the formal VAN/VONA that raised the alert level was sent at 1412 UTC. At 1453 UTC, the real-time response coordinator facilitated a hand-off from the primary response team to the handoff team to ensure sustained monitoring without fatigue. The primary team resumed duties later that day at 0107 UTC on 4 October.

This successful response occurred approximately 3 months into the eruptive sequence, benefiting from lessons learned during earlier events. By this point, the volcano's behavior had become more predictable. In contrast, response to earlier paroxysms was often complicated by poor weather conditions, ambiguous monitoring data, and communication challenges amongst duty staff.

Spurr 2024–2025 unrest

During the writing of this paper, unrest at Mount Spurr, a stratovolcano 80 miles west of Anchorage (Fig. 2), prompted the creation of a formal response team to deal with a potentially significant Cook Inlet eruption. Seismic and geodetic unrest began at Mount Spurr in early 2024, peaked in January through April of 2025, along with elevated gas emissions, and then declined. AVO issued a series of Information Statements about the unrest in 2024 and raised the alert level to Advisory and the aviation color code to Yellow in October 2024. The alert levels remained elevated until August 20, 2025, when they were lowered to Normal/Green and the unrest episode was deemed over. Historical eruptions of Spurr's Crater Peak vent occurred in 1953 and 1992, and a stalled intrusion under the volcano's summit caused unrest from 2004 to 2006 but no eruption (Coombs et al. 2006). The 1953 and 1992 eruptions caused ashfall in Anchorage and other nearby communities and widespread ash clouds (Waythomas and Nye 2022).

For the first 8–9 months of the unrest, routine duty personnel and other observatory staff handled response duties on an ad hoc basis. As seismicity and gas emissions increased, indicating that an eruption was more likely, AVO implemented an OVERT in March 2025 to respond to the unrest and prepare for a potentially larger response in the event of an eruption (Fig. 9).

In the Spurr OVERT, the response management team (RMT) was similar to the command team used in Augustine 2006 and Redoubt 2009 and based on the OVERT management team of Moran et al. (2024). The RMT was led by the SIC and included the UAFGI Coordinating Scientist, the ADGGS Volcanology Section Chief, and leads for real-time response, science, communications and interagency coordination, real-time data and products, and operations (Fig. 9; Supplement 7).

The *real-time response coordinator* was tasked with determining the best approach for 24/7 surveillance during

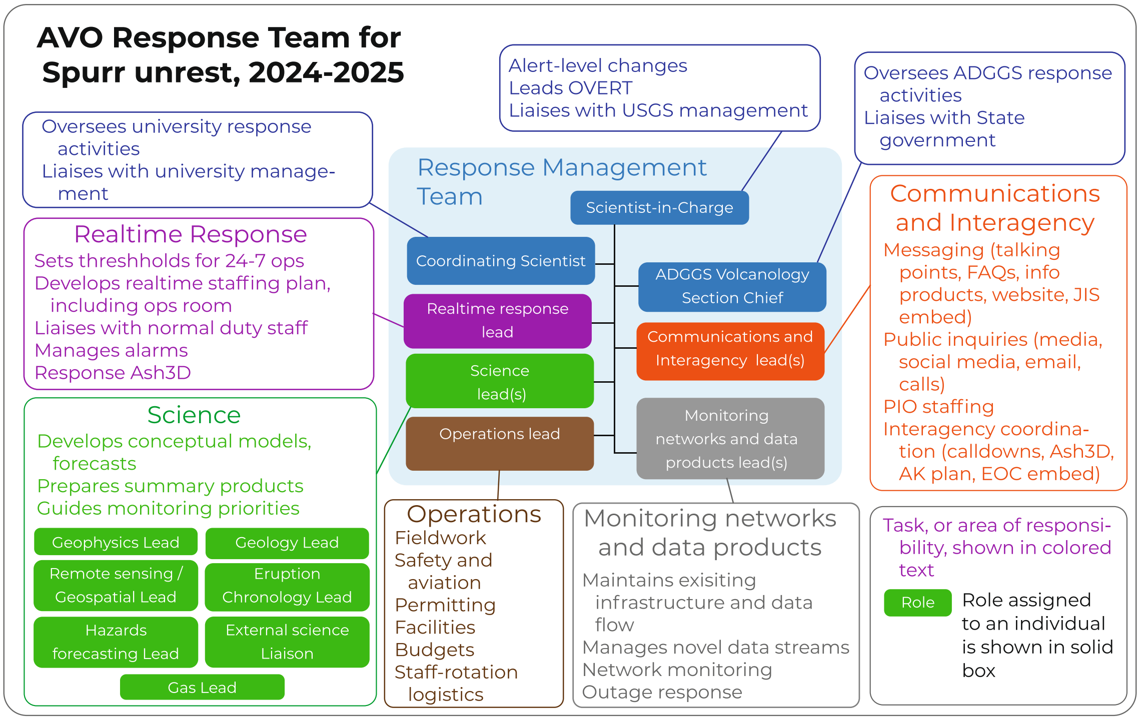

Fig. 9 Observatory volcanic event response team (OVERT) used by the Alaska Volcano Observatory (AVO) during the peak of the 2024–2025 unrest at Mount Spurr. *The response management team* (central light blue box) oversaw all observatory activities related to the response. The *science team* and *communications and interagency team* were activated specifically for the response, and roles that were assigned to individuals in those teams are shown in solid boxes. *Operations* and *real-time data and products* continued functioning mostly as they do during routine operations; response-specific duties covered by these positions are shown in colored text in the respective boxes. Finally, the *real-time response* was not fully activated during the response, but the *real-time response coordinators* developed plans to do so if unrest escalated. During the unrest, routine duty roles continued to be employed (Fig. 3E)

different phases of unrest and eruption, including thresholds for when the respective approaches should be used. These could include remote data watches, a primary response team, or 24/7 operations room staffing. If the response had proceeded to an eruption, the real-time response coordinator would have overseen the operations room, handled scheduling, and ensured response Ash3D duties are covered. The real-time response coordinator was also charged with liaising with routine duty staff and ensuring alarms are appropriate and operational. Ultimately, in this scheme, issuance of timely activity notices and warnings lies within the real-time response team and under the real-time response coordinator.

The two *science leads* oversaw a science team that had duties related to planning, forecasting, and coordinating with the scientific community. They met weekly, then monthly, over several months in 2025. The team consisted of leads for seismoacoustics, geodesy, gas, geology, remote sensing, eruption chronology, and hazards forecasting, and had an external science liaison. The external science liaison was chair of a Scientific Advisory Committee (SAC; (Cooper et al. 2023), implementing a coordinated response by the research community to maximize the scientific returns from volcanic unrest (National Academies of Sciences, Engineering, and Medicine, 2017). The hazards forecasting lead led expert elicitations (e.g.,Marzocchi et al. 2004; Tadini et al. 2022), a first for AVO to conduct these in this systematic and sustained way.

The *communications and interagency coordinators* were tasked with developing messaging, coordinating the response to media and public inquiries (mostly via social media and the AVO website), and interfacing with the USGS communication team. Importantly, they integrated with local and state emergency managers to ensure consistent messaging and ensure community preparedness. They also led the creation of new information products.

The *real-time data and products coordinators* ensured Spurr-specific data availability and developed protocols for dealing with data issues. Because AVO maintains real-time data and products continuously regardless of whether there is significant unrest, activities in this realm continued mostly as they do during routine operations. These include network state-of-health monitoring, maintenance and enhancement of monitoring infrastructure, data stewardship, data flow, and outage response. The real-time data and products coordinators also served as liaisons between the response management team and the permanent AVO field engineering and instrumentation team.

The *operations coordinator* was responsible for safety, all aspects of field operations, land-use permitting (important since Alaska volcanoes are on a variety of State and Federal lands), and facilities. Similarly to real-time data and products, much of this work was a continuation of normal observatory operations and did not require creation of a new team. Therefore, the operations coordinator ensured that Spurr-specific activities were completed and served as a conduit between the response management team and others involved in operations. These efforts are aligned closely with those of the real-time data and products team.

During the unrest, new instrumentation was installed to better monitor the volcano, including a station on Crater Peak with a multigas, seismometer, and infrasound sensor; new webcams; and improved telemetry systems. Maintenance of existing stations during a heavy snow year also was a priority, as was frequent gas-measurement flights. All work at Spurr required helicopter access. The RMT centralized decision-making for prioritization of tasks, use of resources, and safety, making such decision-making more efficient and transparent.

The Spurr OVERT was active throughout the unrest and was officially disbanded in September 2025.

Looking ahead

The recent unrest at Mount Spurr allowed AVO to organize for a significant eruption using the OVERT approach, though ultimately it did not erupt. This experience, combined with other responses since 2000, allows us to be more prepared for the next significant volcanic event. This could be another eruption or episode of significant unrest at one of the Cook Inlet volcanoes, where even a moderate eruption would lead to impacts to southcentral Alaska; an eruption of Akutan or Makushin, two very high threat volcanoes near Aleutian Island communities; an exceptionally large eruption in the more remote Aleutian Islands; or an eruption of Mount Edgecumbe, only 15 miles from Sitka in southeast Alaska. Any explosive eruption, especially if sustained, could have a significant impact on air travel, logistics, and global transport of goods.

On the extreme end, Alaska could also experience an eruption like Novarupta-Katmai 1912, the largest eruption on earth of the twentieth century (Hildreth and Fierstein 2012). This would require an unprecedented level of assistance from outside Alaska as well as significant engagement with other federal agencies such as Federal Emergency Management Agency (FEMA). During an event of that size, the full Volcano Science Center-wide response plan as described in Moran et al. (2024) would undoubtedly be used. A VSC-wide exercise focused on a hypothetical eruption of Newberry Volcano (Oregon, USA) in April 2023 was the first practice of this plan, and the VSC has plans to hold similar exercises in the coming years.

Future responses of any scale will encounter challenges, some unique to Alaska and some shared broadly by observatories worldwide. Physical responses in Alaska are expensive, due to generally high costs of operations combined with the extensive logistical requirements prompted by long distances, bad weather, and remote volcano locations. Continued development of remote sensing technologies and hardening of our data networks can mitigate these factors somewhat. Maintaining a trained and adequately sized staff also will be paramount. Cross-training between observatories will allow expansion during the largest responses, but even so, the need for observatory staff to be able to handle multiple operational and response tasks, sometimes simultaneously, will likely not diminish.

Lessons learned

Volcanic unrest and eruptions are prolonged, dynamic phenomena that require constant reevaluation of an observatory response. Knowing when to deviate from routine operations towards a more focused and deliberate response is challenging. Human decision-making is influenced by numerous factors. Having systems in place that are understood and practiced will minimize some of the friction that may be felt by the SIC and observatory staff related to implementing a well-defined, hierarchical structure with assigned roles and tasks. Below, we highlight a few additional specific lessons learned by AVO over the course of the last two decades of responses:

- *Document operational landmarks and actions during responses*. This is best done as part of maintaining an eruption chronology. Descriptions of the operational response can also be included in summaries of volcanic activity or other reports. Such documentation will be helpful for future responses, scientific analyses, and is an important part of the observatory record. As Artificial Intelligence tools mature, they may assist in summarizing response-team meetings, and compiling events from logs, chats, and other platforms, making this task easier, but ultimately a person has to verify the record in a timely fashion.
- *Conduct after-action reports, hot washes, or similar evaluations after a response is over*. The USGS Volcano Science Center does perform after-action reviews for larger responses (e.g., Williams et al. 2020), but it would also be beneficial to perform a review after smaller responses.

- *Acknowledge and evaluate the cost/benefit of using an OVERT*. It takes time and energy to manage the more complex structure, including additional meetings, generating required documentation, and getting people accustomed to operating in a new posture. Limiting the complexity of the response team to whatever is needed at a given juncture takes practice and judgement.
- *However, don't wait until it is too late to implement an OVERT.* Having the framework tested and in place during the unrest period allows for adequate planning and pre-eruption coordination, and many response activities (preparedness, forecasting) occur during unrest.
- *Take care when selecting individuals for formal roles within an OVERT.* Staff seniority or scientific/technical stature may not be a good predictor of how well a person will perform in a designated role, especially a role requiring one to work with outside groups, lead a team, or coordinate groups of scientists rather than conduct their individual research. Soliciting input from trusted colleagues can help prevent assigning someone to a role for which they are ill-suited. In particular, members of the response management team should be experienced members of the observatory or broader organization (in AVO's case, the USGS Volcano Science Center). After roles have been established, sticking with them to the extent possible will avoid confusion.
- *Between eruptions, build capacity for filling key roles*. Some roles are straightforward and allow staff to step in quickly with the proper training and documentation. Other roles may require longer-term preparation. For example, the interagency coordinator role should be filled by an experienced staff member who ideally has relationships with partners before a response begins. At AVO, there are two standing interagency coordinators who serve in that role continuously as an auxiliary duty. Providing opportunities for earlier career staff to gain familiarity with partners over the longer term will ease the transition into this role in the future.
- *Develop templates for OVERTs and duty rosters (including an organization chart-like graphic and written roles and responsibilities)*. Make sure these are accessible and ready to use as needed.
- *It is okay to have people fill multiple roles*. This does not follow ICS philosophy exactly; however, it acknowledges the reality of staffing shortages, and that some roles are not always going to take 100% of people's time. Such a situation should be monitored closely to guard against burnout. Additional staff could be brought in if roles expand as a response intensifies.
- *It is also acceptable to have more than one person in a role in some cases*. Dual leads for an effort can keep energy levels high, allow for a tag-team approach if someone is absent, and prevent burnout. This requires clear communication and may not be appropriate when rapid decision-making is a priority.
- *Finally, there is no one-size-fits-all approach*. Each eruption requires a specific approach to be handled effectively. While there are best practices and theoretical ideals in how a response should be organized, AVO's experience has been that there are unique aspects to individual responses that require situation-specific organizational structures. Starting from a common general principle and being transparent and flexible in how to deviate from it allows an observatory to mount effective and appropriate responses.

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Data availability The authors declare that the data supporting the findings of this study are currently available in published papers and data releases and the USGS Hazard Notification Service API (volcanoes.usgs.gov/hans-public/api/).

Declarations

Competing interests The authors declare no competing interests.

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