Interagency Collaboration on an Active Volcano: A Case Study at Hawai'i Volcanoes National Park

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Introduction

Hawai'i Volcanoes National Park (HVNP) includes two active Hawai'i shield volcanoes: Mauna Loa, the largest active volcano on earth, which most recently erupted for three weeks in 1984, and Kīlauea, which has been erupting continuously for more than 31 years. Unlike the steep-sided volcanoes around the rim of the Pacific Ocean, all Hawai'ian volcanoes have gentle-sloped flanks that result from copious eruptions of fluid lavas with infrequent interludes of explosive activity. Each of the Hawai'ian volcanoes erupts from its summit area—Kīlauea and Mauna Loa both have summit calderas (large subsided craters)—and from one or more rift zones (a sequence of vents aligned radially away from the summit).

Because Kīlauea and Mauna Loa are included within the national park, there is a natural intersection of missions for the National Park Service (NPS) and the US Geological Survey (USGS). HVNP staff and the USGS Hawai'ian Volcano Observatory (HVO) scientists have worked closely together to monitor and forecast multiple eruptions from each of these volcanoes since HVNP's founding in 1916.

The US Geological Survey's Hawai'ian Volcano Observatory

HVO was founded in 1912 by Massachusetts Institute of Technology professor Thomas A. Jaggar, Jr., to study the Kīlauea volcano. After being managed by academic institutions and various federal agencies (including NPS), HVO was permanently transferred to USGS in 1947.

HVO's current mission is to provide timely and accurate warnings of volcanic and earthquake activity. To achieve that goal, the observatory operates a large network of monitoring instruments and researches volcanic and earthquake processes to better understand the workings of both phenomena.

Hawai'i Volcanoes National Park

HVNP was established on August 1, 1916. Today the park protects and manages approx-

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Figure 1. Kamoamoa fissure erupting on March 6, 2011, just west of the Pu'u 'Ō'ō vent. USGS photo.

imately 135,000 ha (333,000 acres) of public land that includes some of the most unique geological, biological, and cultural landscapes in the world, while educating and keeping safe 1.6 million visitors during their visits. Extending from sea level to the summit of Mauna Loa at 4,169 m (13, 677 ft) (the most voluminous volcano in the world measured from its base on the ocean floor), the volcanic topography also supports one of the most fascinating biological landscapes in the world, with diverse populations of plant and animal communities across seven ecological life zones. The park also plays a unique role in the history of human development on the Hawai'ian Islands and remains an important place for living cultures in Hawai'i. Just as the biological and geological features of the park have shaped the landscape, so too has the Native Hawai'ian culture.

Named as an international biosphere reserve in 1980 and a World Heritage site in 1987, the outstanding universal values by which these designations occur transcend national boundaries. In fact, HVNP is a model for other protected areas around the world for management of active volcanic sites.

Eruption responses within HVNP

Kīlauea's most recent and ongoing eruption started in early 1983 along the volcano's east rift zone about 19 km (12 mi) from its summit and near the eastern boundary of the national park. The eruption began with episodic lava fountains that quickly built a 255-m-(835-ft-) tall cinder-and-spatter cone later named "Pu'u 'Ō'ō." Since 1986, the eruption site has peri-

odically moved from vents at Puʻu ʻŌʻō to vents downrift and uprift of the cone. Each shift in the eruption site has resulted in dramatic changes at Puʻu ʻŌʻō, changes in the lava flows that were active prior to and after the shift, and changes in the hazards posed to the public within and outside HVNP. As of 2014, the eruption has covered 127.2 sq km (49.1 sq mi) and added about 202.5 ha (500 acres) of new land along the southeast coast of Kīlauea. In early 2008, a second eruption started at a new location within the volcano's summit caldera and, for the first time in recorded history, Kīlauea was simultaneously erupting persistently from two locations. Every development in these two ongoing eruptions requires the focused attention of both agencies until public safety is achieved.

Kamoamoa eruption, March 5–9, 2011

The Kamoamoa fissure eruption in March 2011 is a good example of a short, but dramatic, eruptive event during the Kīlauea volcano's continuous east rift zone eruption and the joint work of NPS and USGS in monitoring and mitigating the hazards posed by volcanic activity.

From 2007 through early 2011, lava continuously erupted from a vent east of Puʻu ʻŌʻō flowed southeast to the coast, where it destroyed several homes in a nearby community. Interestingly, HVO instruments measured inflation (increased storage of magma below the surface) of Kīlauea's summit even as lava continued to erupt from the Puʻu ʻŌʻō vent.

HVO scientists also recorded an increasing number of earthquakes along the rift zone between the summit and Puʻu ʻŌʻō starting in late January 2011 and continuing into the first

Figure 2. Low lava fountains from the west Kamoamoa fissure fed a lava flow to the south on March 9, 2011. USGS photo.

few days of March 2011. On March 5, at 1:42 pm HST, Kīlauea's summit lava lake began to drop, indicating that magma pressure beneath the summit was rapidly decreasing. At 1:56 pm, HVO's automated data alarms were triggered and scientists began watching webcams positioned at the Puʻu ʻŌʻō vent to see what changes might happen. At 2:16 pm, the crater floor within Puʻu ʻŌʻō started to collapse dramatically. At that point, HVO contracted with a helicopter for aerial reconnaissance of the area and first-hand observation of the activity by HVO geologists.

After discussions among HVO scientists based on all available monitoring data, the HVO scientist-in-charge (SIC) began calling contacts on the emergency-manager call-down list, the first being HVNP dispatch for NPS personnel. At 2:49 pm, the SIC spoke with the HVNP duty ranger to explain what was happening and the possible future outcomes. A few minutes later, the HVO SIC had the same conversation with the director of the Hawaiʻi County Civil Defense agency. HVO then issued a public volcanic activity notice, raising the alert level code to its highest level ("WARNING") and instituted continuous personnel rotations at HVO to assure that staff was on duty to monitor the activity at all times.

At 5:15 pm, an HVO geologist who was inspecting, from a helicopter, the collapsing floor of Puʻu ʻŌʻō crater, witnessed the start of a fissure eruption west of the Puʻu ʻŌʻō cone. This outbreak of lava was relayed to HVNP rangers, who responded with evacuations of park visitors and closure of park areas near the eruption site. A small crew of HVO geologists was also dispatched to the site on foot to monitor the eruption overnight.

HVNP response to the eruption

No other place in Hawaiʻi, nor elsewhere in the world, has as dynamic a landscape and one so approachable during volcanic activity. As mentioned above, HVO operates within the park and is mandated to provide timely and accurate warnings of volcanic or seismic activity within the park boundary, as well as within the entire state. Additionally, HVNP relies on USGS science to inform park management decisions relative to visitation, closed areas, research and permitting, and access to wilderness. It is a unique partnership and relationship within the National Park Service. At HVNP, volcanic research is equal in importance to the conservation and public use aspects of the area. Working closely with USGS scientists in 2011, the park had a unique opportunity to showcase, in real time, the dynamic eruptive events as a part of its interpretive and educational programs.

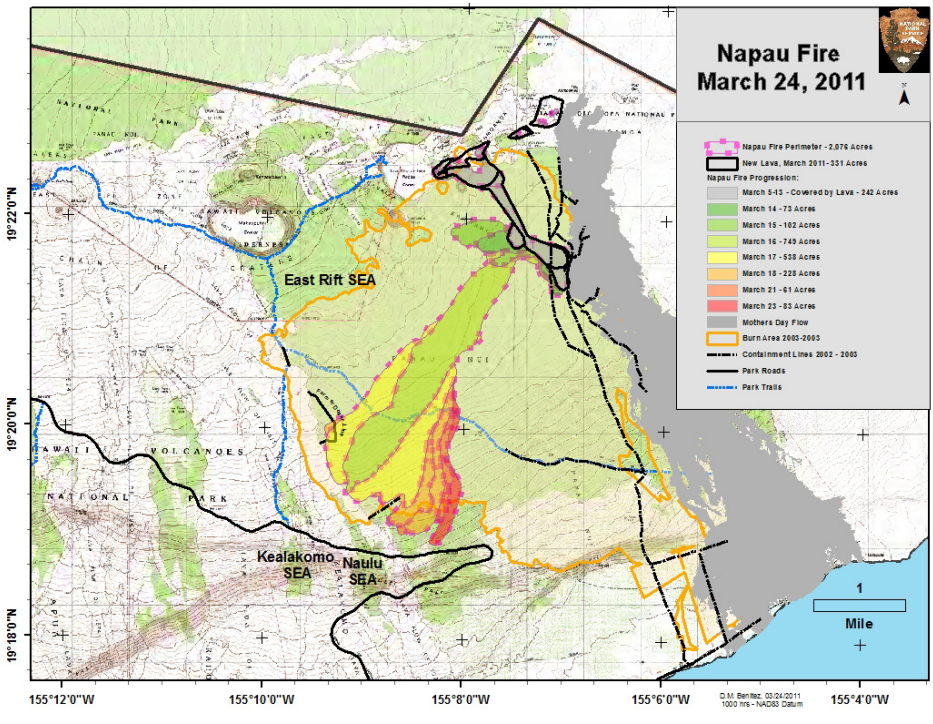
Providing real-time eruption information and education was a top priority for the park and of critical importance to this messaging effort was the collaboration that took place between NPS and USGS. Unlike previous eruptive events, HVNP interpretive staff went to the fissure eruption site to collect photos and videos that were posted on the NPS website and on computer monitors and exhibits in both park visitor centers, on the same day. This on-site coverage by interpretive staff, the first in park history, allowed the eruption to become real for park visitors, who otherwise would not have witnessed the event. HVNP did not have a social media plan during the 2011 event but West Hawaiʻi parks did a great job covering the Kamoamoa fissure eruption on the Pacific Island blog, an unofficial but popular site.

HVNP safety concerns

HVNP manages for all-risk. Incidents within incidents happen regularly, and this event was no exception. For example, when HVO notified HVNP of increased earthquake hazards and gas emissions (measured at almost 10 times normal rates) along Chain of Craters Road near Kealakomo, all NPS response personnel were directed to have respirators with them while in this area. HVO webcams also alerted HVNP to fire creeping into the park and, later on March 5, the expectation of a lava-ignited wildfire was realized, adding a layer of complexity to the eruptive response and messaging efforts. The resources at risk included the park's East Rift Special Ecological Area (SEA), which has been intensively managed to exclude invasive species and to protect and restore highly valued native plant and animal communities. Resource values include remnant native rainforest and mesic forest that contain some of the only known populations of threatened and endangered species such as the Hawai'ian jewel orchid, rare endemic lobeliads and mints, as well as rare endemic bird species such as the Hawai'ian hawk, honeycreeper, and Hawai'i's only endemic terrestrial mammal, the Hawai'ian hoary bat.

A major problem with the fire, located 11 km (7 mi) east of Kīlauea Visitor Center on Kīlauea volcano's east rift zone, was access, which required long hikes over deep earth cracks,

Figure 3. Map showing the western Kamoamoa lava flow (gray with black outlines) and the progression of the lava-induced fire (multiple colors, each with pink outlines; HVNP 2011).



fissures, and areas of high potential for exposure to volcanic gases. Helicopter access was also necessary. Trade winds pushed the fire to the southwest towards the SEA, and over a 13-day period it grew to over 2,000 acres. Early during the fire the volcanic activity paused, which allowed NPS to reopen Chain of Craters Road to the public. NPS also began to focus on exploring all suppression points, continuing to coordinate with USGS on eruption activity and air quality. Earlier NPS fire reconnaissance flights also sent GIS map files of the lava flow to HVO geologists. Access to the fire remained a problem as intensified trade winds and the radiant heat generated from the lava flow caused the fire to burn actively. By day two, the Chain of Craters Road was closed again, this time due to smoke impacts. Portions of fence lines also burned, causing numerous snags to fall across and significantly damage the fence. By day three of the fire, the lava flow had subsided, though the fire was not contained until April 5, 2011. The fire continued to be monitored by helicopter until April 21, 2011, to detect hot spots and verify that the fire was contained and extinguished (HVNP 2011).

In addition to minimizing loss or damage to natural and cultural resources, staff at both HVNP and HVO have safety in their mission. With fire, the management objective always focuses on the safety of firefighters and park personnel, visitors, and cooperators. During this already complex response, two other unforeseen issues compromised employee safety. Both required close corroboration between NPS and USGS and daily risk assessment exercises.

Media flight poses danger to scientists on the ground

Because the eruption started late on March 5, there was time overnight for word to spread about the new volcanic activity and, as the sun rose on the eruption's second day (March 6, 2011), a small fleet of helicopters bearing members of the media converged on the Kamoamoa fissure eruption. The fissure erupted through a thick blanket of tephra (cinders) produced during lava fountaining in the early 1980s. HVO had sent a small crew on foot to monitor the eruption during the first night, so when the helicopters converged on the eruption area, HVO scientists were already on the ground.

As in other US areas, the Federal Aviation Administration (FAA) regulates aircraft flight paths in Hawai'i that are used by a mixture of commercial airliners, air tour operators, media, USGS, and other agencies. Air tours are restricted to pre-approved paths at minimum altitudes of 500 to 1500 ft above ground level (agl). Media flights, used by independent videographers and photographers, as well as news media, have no such restrictions and are allowed to fly at any altitude as long as they do not land and do not endanger people on the ground. The exception is when a temporary flight restriction (TFR) is in effect. In that instance, approval for access must be granted by the land manager.

On the morning of March 6, 2011, one particular media flight with an independent videographer onboard was flying low and just upwind of the erupting fissure. With the videographer focused on shooting footage of the spectacular sight and the pilot focused on steering clear of the eruption, neither noticed the two HVO scientists who were standing in a field of cinder observing the lava fountaining. The helicopter was flying so low that the rotor wash (downward airflow from the spinning helicopter rotor blades) blew cinder into the scientists' eyes, thereby endangering their safety on the ground.

The incident was reported to FAA, including video footage (provided by the videographer) in which the two scientists can be clearly seen. According to the report, the pilot was not looking for people on the ground and inadvertently flew low over the scientists while trying to position the videographer for dramatic footage. Along with reporting the incident, HVNP officially requested a TFR to keep all aircraft, other than those used by HVO and HVNP to perform their official duties, out of an area within a 5.6-km (3.5-mi) radius of the vent and 1,220 m (4,000 ft) agl. FAA immediately instituted this restriction and there were no additional such incidents during the Kamoamoa eruption. On March 7, the TFR was reduced to a 2.4 km (1.5 mi) radius and 460 m (1,500 ft) agl.

Another safety issue centered on air tour congestion while HVO and HVNP monitored the eruptive and fire activity, both on the ground and in the air. The film captured by the previously mentioned videographer aired nationally and internationally on major television networks. Because the area was closed to visitors on the ground for safety reasons, the only way this short-lived eruption could be personally witnessed was by air tour. Thus, airspace and radio communication around the lava flow and wildfire became a concern for the park. The park and regional aviation manager met with FAA and the Hawai'i Helicopter Tour Operators Association to discuss the aviation operations and related concerns. An aviation safety communiqué (SAFECOM) was also issued.

Once these measures were put in place, operations supporting eruption monitoring and science, park interpretation and safety, and fire containment proceeded without interference.

The science of the Kamoamoa eruption

Throughout the eruption, HVO scientists made on-site measurements and documented as much of the eruptive behavior as possible. This documentation included a webcam set up by HVO to record details of lava fountains along the western fissure. These images were shared with the public via HVO's webcam webpage and were accessed several million times during the eruption. For months afterward, the fissure itself was studied because it was constructed from lava spatter ejected by low fountains. Understanding the processes that built the Kamoamoa spatter ramparts allow HVO scientists to approximate the conditions of unwitnessed fissure eruptions through their remaining spatter deposits. Three-dimensional representations of the spatter ramparts built along the Kamoamoa fissure were made to document the result of this eruption and lava samples were acquired during the course of the eruption to determine if magma feeding the fissure was changing. In addition, geophysical data, including radar satellite coverage, were interpreted to understand why the eruption occurred.

The results will help forecast the next change in the ongoing eruption of Kīlauea and will improve the information provided to land and emergency managers. According to the eruption studies, the Kamoamoa eruption resulted from overpressure of the volcano's magmatic system (Lundgren et al. 2013). More magma was being injected into the subsurface plumbing than was being erupted at the surface. The overpressure caused an increase in the number of earthquakes recorded between the summit and Pu'u 'Ō'ō prior to the outbreak. The lava that was erupted contained traces of older un-erupted lava that had been stored below the ground surface. As the magma rose to be erupted, it mixed with magma from storage areas on the way to the surface.

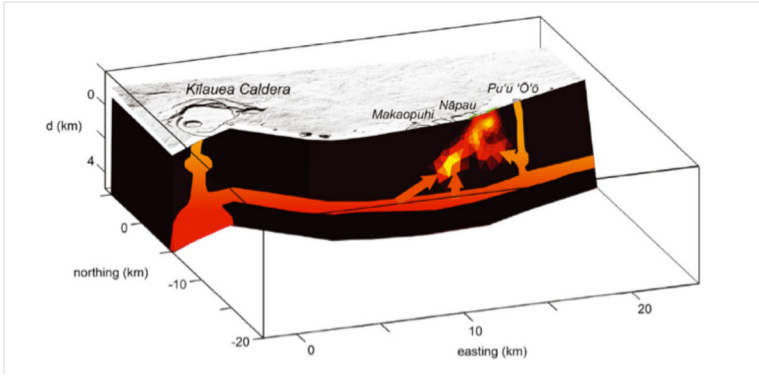


Figure 4. The geophysical model of the subsurface magma plumbing and its connection between the summit (Kīlauea Caldera) an the Kamoamoa fissure eruption between Nāpau Crater and Pu'u 'Ō'ō (orange arrows; Lundgren et al. 2013).

The Kamoamoa eruption was the first of three such events in 2011. The sequence was the same for each event: the crater of Pu'u 'Ō'ō filled with lava slowly and then collapsed quickly while lava issued from its crater or flank. The lava flow from an event in August continued for several days and also induced a fire, while the lava flow from an event in September continued for several months in the opposite direction and outside HVNP. The lessons learned by HVO and HVNP during the Kamoamoa eruption helped minimize the negative effects of these two later 2011 eruptions.

Conclusion

The Kamoamoa eruption started on March 5, 2011, and was over by March 9, after having erupted almost 3 million cubic m (almost 4 million cubic yds) of lava and several tens of thousands of tons of sulfur dioxide gas. Lava returned to the long-lived vent at Pu'u 'Ō'ō two weeks later and Kīlauea volcano's ongoing east rift zone eruption resumed. HVNP wrapped up the lava-induced fire response by April 21, 2011. HVO continues to monitor volcanic activity on Kīlauea.

For future responses by HVO and HVNP personnel, a TFR request will be made immediately to extend for the duration of the entire eruption and fire incident. Otherwise, this incident was typical of joint HVO and HVNP responses to an eruption with the national park.

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