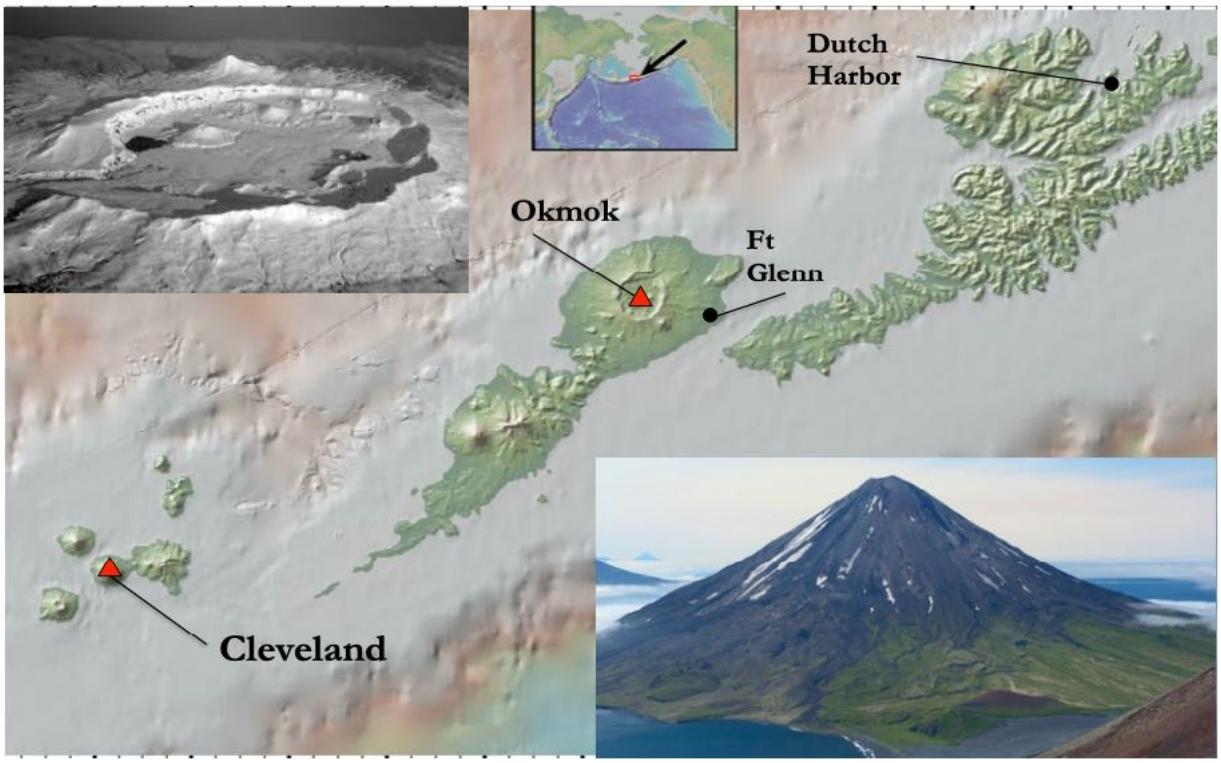
Project Report: AVERT in Alaska
2019 – 2024

Overview and Goals

The Anticipating Volcanic Eruptions in Real Time (AVERT) project lead by the Lamont-Doherty Earth Observatory of Columbia University was supported with funding from the Gordon and Betty Moore Foundation. In the years 2019–2024, AVERT worked in partnership with the Alaska Volcano Observatory (AVO) to install new instrumentation on two restless volcanoes in the Aleutian Islands: Okmok and Mount Cleveland. The over-arching goal of the project was to ***promote the collection of multi-sensor data on volcanoes, and provide that data openly and in near real time***. Such data streams are rarely available globally and yet are necessary to enable effective eruption forecasts. The specific goals of the AVERT-AVO partnership were:

- to install multi-sensor arrays on target volcanoes and test novel instrumentation;
- to explore satellite-based telemetry in order to provide robust real-time data;
- and to build a collaborative academic and observatory partnership.

Over the five-year timeline, all goals were met. The specific accomplishments are outlined below.



AVERT-AVO Volcano Targets

Okmok volcano occupies the northeastern half of Umnak Island and bears the scars of a caldera-forming eruption in BCE43. The last eruption of Okmok was in 2008, a VEI 4 eruption that created a new cone in the caldera. Combined GPS and InSAR data were used to develop a hindcast model for the 2008 eruption that identified tensile failure weeks before the eruption (Albright et al., 2019).

On the other hand, there was no increase in seismic activity until 5 hours prior to the eruption, with a swarm that extended to > 15 km depth (Garza-Giron et al., 2023). Since 2008, Okmok has been episodically inflating (Xue et al., 2020), and so one of our primary goals was to increase the continuous GNSS network on Okmok, filling in a number of near- and far-field azimuthal gaps. The other primary goal was to improve the telemetry both on and off the island.

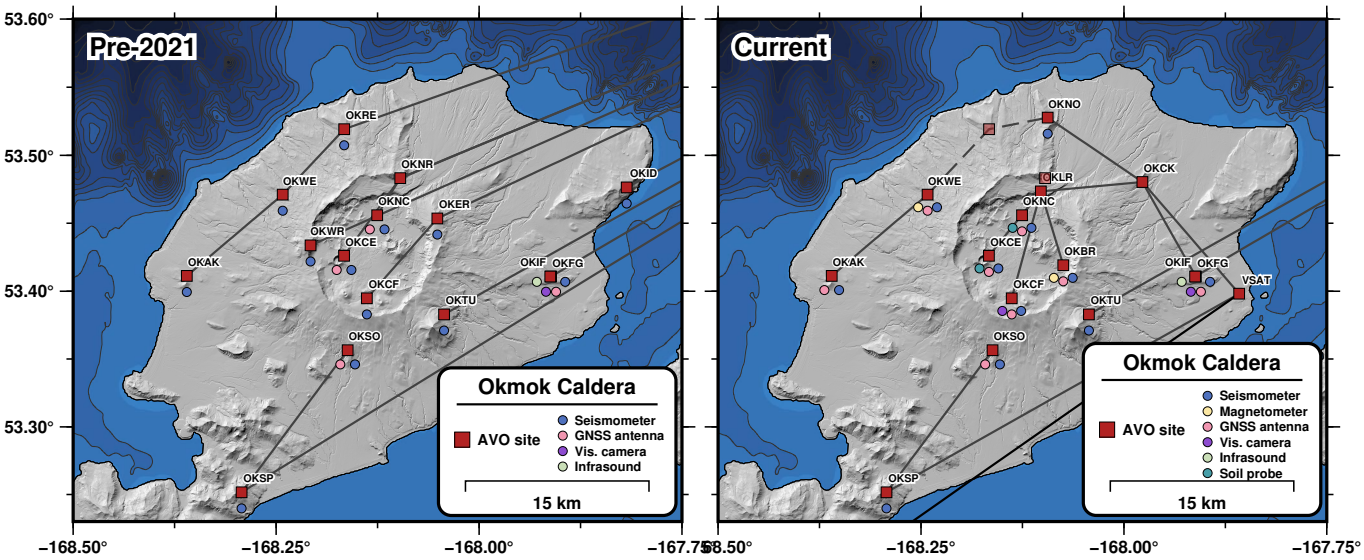
Cleveland volcano, located in the Islands of Four Mountains (IFM), is one of the most active volcanoes in the Aleutians. It erupted almost every year from 2005–2020. Cleveland is a classic stratovolcano with an open vent. Gas plumes with dome growth and destruction are common features of its activity. Due to its remote location, Cleveland has been a challenge to instrument, and at the start of the AVERT project, there were only two seismometers, one infrasound station, one infrasound array, and a camera on the IFM. AVO considers a minimum of 5 seismometers necessary to consider a volcano formally monitored, and so our primary goal was to increase the instrumentation on Cleveland to the level of monitoring. Another goal was to measure the chemistry, flux and appearance of the gas plume emanating from Cleveland's summit.

Timeline of the AVERT-AVO Project

Year	Where	Means	What
2019	LDEO	LDEO	The AVERT Project is funded in November.
	SFO	AGU	Project kicks-off with a lunch meeting with 15 project partners in San Francisco at the American Geophysical Union meeting and
2020	LDEO, AVO	AVO &Virtual	AVERT participation at the AVO annual gathering in Fairbanks, AK and start of joint field planning between AVO and AVERT in monthly zoom calls.
	LDEO	LDEO	COVID forces the cancellation of 2020 field work; efforts focus on testing instrumentation at Lamont and building a website.
2021	Okmok	R/V Steadfast	Installation of soil temperature and CO_2 probes; OKCE web cam; Fort Glenn VSAT; New site OKBR, seismometer. Camera surveys inside caldera. New telemetry for caldera sites.
	LDEO	Virtual	Novel Instrumentation Virtual Workshop (~450 registrants from 35 countries)
2022	LDEO	LDEO	Hired AVERT Post-doc Dr. Conor Bacon
	Cleveland	R/V Steadfast	New Sites CLNE; CLCL; CLSF, CLCO-2. 1 new GNSS, DOAS, IR-viz camera; 2 new magnetometers; 3 seismometers; BGAN; webcam; wind turbine; 5 campaign seismometers.
	Okmok	Bering Pacific Ranch	3 new GNSS, 2 magnetometers; BGAN
2023	Okmok	Nikolski	1 new GNSS; repoint BGAN
	Cleveland	Nikolski	2 new GNSS; new Scanning DOAS and web cam; 1 new campaign seismometer, summit gas flights, replace solar controller
2024	Okmok	Nikolski	Single board computer at OKFG; Maintenance and Hand-off to AVO
	Cleveland	Nikolski	Smart camera software on-site at CLNE; Maintenance and Hand-off to AVO

Accomplishments of AVERT-AVO partnership

Okmok Volcano. Maps below illustrate the stations, telemetry and instrumentation in place before and after the AVERT-AVO field campaigns at Okmok.



There were 3 primary accomplishments at Okmok as part of the AVERT Project:

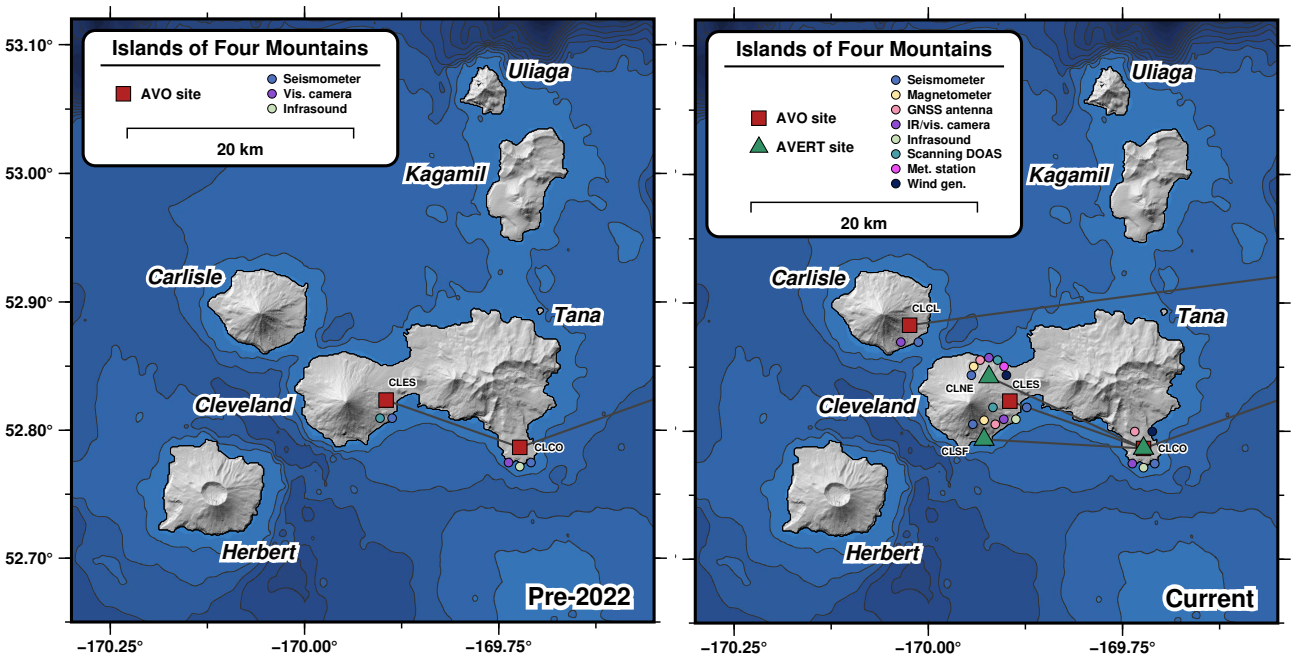
1. Telemetry. Although there were already many seismic stations on Okmok prior to 2021, all of the data were telemetered by radio to a repeater on adjacent Unalaska Island that was at high elevation, vulnerable to winter icing, and required a long shot over open water. Now almost all data are transmitted by VSAT satellite telemetry at the hub southeast of OKFG. Data at sites OKAK and OKWE on the western flank are currently recorded on-site, although the option exists to telemeter via AVERT BGAN instruments, now that satellite connection has improved and the cost is more competitive. Alternatively, an unused site at OKNR could be relocated to the old OKRE location, enabling a radio chain from the western side of the volcano to reach the Fort Glenn VSAT site.

2. Doubling of GNSS. The number of GNSS stations on Okmok was doubled as part of the AVERT project, from four to eight. The newly installed instruments at OKBR and OKCF join existing sites at OKNC and OKCE to now provide radial coverage of the active inflation source in the middle of the caldera. New GNSS instruments at OKAK and OKWE provide the first sensors to document deformation of the western flank, important for constraining deeper magma movement. The GNSS array is dramatically improved in number and geometry, and ready to document the on-going evolution of Okmok's deformation as it leads to the next eruption.

3. Novel Sensors. New instruments installed on Okmok represented the first of their kind deployed on any Alaskan volcano:

- First continuous magnetometers (at OKBR, inside the caldera, and OKWE, on the westernflank)
- First continuous temperature and CO_2 soil probes (at OKNC and OKCE). There is now a 3+ year continuous record to compare to seismicity and inflation at Okmok.
- First webcam inside Okmok caldera (at OKCF), which has been invaluable in assessing weather conditions for field work as well as for monitoring conditions within the caldera.

Cleveland/IFM. Maps below illustrate the stations, telemetry and instrumentation in place before and after the AVERT-AVO field campaigns at IFM.



There were 4 major accomplishments at Cleveland/IFM as a result of the AVERT Project:

1. Monitored Status. Three new permanent seismic stations were established on IFM: CLNE, CLSF and CLCL. With the total number of seismic stations increasing to five, this meant that from 2022, for the first time, Cleveland was considered monitored and could be designated at level Green. AVERT also contributed the first GNSS instruments (at CLNE, CLCO and CLSF) and continuous magnetometers (at CLNE and CLSF) to be deployed on IFM.
2. Novel Sensors. New instruments installed on Cleveland represented the first of their kind deployed on any Alaskan volcano: Two scanning DOAS (at CLNE and CLES) to measure continuous SO_2 flux degassing of the Cleveland plume. First dual-camera system with synchronized infrared and visible camera imagery. The system includes a single board computer that allows smart image capture and transmission.
3. Multi-parameter site. Site CLNE hosts two huts, two separate power systems, and seven distinct sensors: seismometer, GNSS, magnetometer, scanning DOAS, IR camera, visible camera and a met station. This site may host more different kinds of sensors than any other in Alaska
4. Technological innovation – Edge computing: The three dedicated AVERT sites at CLNE, CLSF, and CLCO were also distinguished from the standard AVO site designs by the incorporation of an on-site single-board computer (the embeddedTS TS-7970). These rugged, low-power systems allowed for scheduled power management of certain instruments—e.g., the dual camera system at CLNE, with intervals of 1 hour and 20 minutes for the visible and IR cameras, respectively–in order to greatly reduce the average power consumption of the sites, on-site redundant backup of instrument data, and also some edge computing capabilities. For example, by having on-site the redundant data storage,

the AVERT sites were able to catch up any data that was not telemetered during periods of telemetry disruption. Control software for these single-board computers were developed in-house. At the conclusion of the AVERT-AVO collaboration in summer 2024, all but one of the single-board computers were removed from the sites. A single device was left at the CLNE camera site in order to manage the acquisition of images from the dual-camera system, with a computer vision-based algorithm making *in situ* assessments of the visibility of the summit of Cleveland and adjusting the acquisition rate accordingly. Full details of the system design are being incorporated into a manuscript in preparation for publication, alongside an open release of the control software through GitHub.

Hand-off to AVO. A key guiding principle of the AVERT project was to assure legacy of all instrumentation and open archiving of all data. A total of 28 new sensors were deployed on Okmok and IFM as part of AVERT-AVO Project, with 21 sensors provided by AVERT for a total cost of ~$750,000 (including travel, shipping and supplies). All of these instruments have been handed-off to AVO for incorporation into their monitoring networks, with all data openly available in as real-time as possible. The chart below lists all sensors established in partnership with AVERT as well as the data streams and archives, as of Summer 2025.

New Instrumentation Installed as part of the AVERT-AVO Project.

Sensors in bold purchased by AVERT and donated to AVO.

Station	Instrument	Data Archive	Model
OKBR	**BB Seismometer**	EarthScope	Nanometrics Trillium Compact 120H
OKBR	**Magnetometer**	EarthScope	Bartington Mag-13 Three Axis Field Sensor
OKBR	**GNSS**	EarthScope	Reftek Resolute Polar w/ Tallysman Antenna
OKCF	Web camera	AVO AshCam	Stardot NetCam
OKCF	**GNSS**	EarthScope	Reftek Resolute Polar w/ Tallysman Antenna
OKCE	**Soil Probes, 2 temp, 1 CO_2**	AVERT	Vaisala
OKNC	**Soil Probes, 2 temp**	AVERT	Vaisala
OKWE	**Magnetometer**	EarthScope	Bartington Mag-13 Three Axis Field Sensor
OKWE	**GNSS**	EarthScope	Reftek Resolute Polar w/ Tallysman Antenna
OKAK	**GNSS**	EarthScope	Reftek Resolute Polar w/ Tallysman Antenna
CLNE	BB Seismometer	EarthScope	Nanometrics Trillium Compact 120H
CLNE	**Magnetometer**	EarthScope	Bartington Mag-13 Three Axis Field Sensor
CLNE	**Web camera**	AVERT	Stardot NetCam
CLNE	**Infrared camera**	AVERT	Teledyne DALSA Calibir GXM
CLNE	**Met Station**	AVERT	Vaisala WXT536
CLNE	**GNSS**	EarthScope	Reftek Resolute Polar w/ Tallysman Antenna
CLNE	Scanning DOAS	CVO/NOVAC	CVO Design
CLCO	**GNSS**	EarthScope	Reftek Resolute Polar w/ Tallysman Antenna

CLSF	**BB Seismometer**	EarthScope	Nanometrics Trillium Compact 120H
CLSF	**GNSS**	EarthScope	Reftek Resolute Polar w/ Tallysman Antenna
CLSF	**Magnetometer**	EarthScope	Bartington Mag-13 Three Axis Field Sensor
CLCL	BB Seismometer	EarthScope	Nanometrics Trillium Compact 120H
CLCL	Web camera	AVO AshCam	Stardot NetCam
CLES	Scanning DOAS	CVO/NOVAC	CVO Design
CLES	Web camera	AVO AshCam	Stardot NetCam

Participants in AVERT-AVO Field Deployments

More than 20 scientists, students and staff took part in the AVERT-AVO field deployments in Alaska. The cooperation and partnership in the field was a hallmark of this project that directly led to its success.

Field Team 2021
Max Kaufman (GI)
Skye Kushner (UAF)
Nick Frearson (LDEO)
Társilo Girona (UAF)
Jasper Baur (LDEO)
Pablo Saunders-Shultz (UAF)
Malcolm Herstand (DGGS)
Cora Siebert (DGGS)

Field Team 2022
Max Kaufman (GI)
Max Enders (USGS)
Malcolm Herstand (DGGS)
Cora Siebert (DGGS)
Skye Kushner (GI)
Pavel Izbekov (GI)
Nick Frearson (LDEO)
Conor Bacon (LDEO)
Jasper Baur (LDEO)
Diana Roman (Carnegie)
Allan Lerner (USGS)
John Power (USGS)
Einat Lev (LDEO)
Terry Plank (LDEO)
Mariah Graham (UAF)

Field Team 2023
Max Kaufman (GI)
Dane Ketner (AVO)
Skye Kushner (UAF)
Nick Frearson (LDEO)
Conor Bacon (LDEO)

Field Team 2024
Max Kaufman (GI)
Ellie Boyce (AVO)
Conor Bacon (LDEO)
Diana Roman (Carnegie)
Christoph Kern (CVO)