The 2006 Eruption of Augustine Volcano, Alaska
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Chapter 19

The Plate Boundary Observatory Permanent Global Positioning System Network on Augustine Volcano Before and After the 2006 Eruption

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Abstract

In September of 2004, UNAVCO and the National Science Foundation (NSF) funded EarthScope Plate Boundary Observatory (PBO) installed five permanent Continuous Global Positioning System (CGPS) stations on Augustine Volcano, supplementing one existing CGPS station operated by the Alaska Volcano Observatory. All six CGPS stations proved crucial to scientists for detecting and monitoring the precursory deformation of the volcano beginning in early May 2005, as well as for monitoring the many subsequent small inflationary and deflationary episodes that characterized the 2006 eruption. Following the eruption, in September of 2006, PBO added six additional permanent CGPS stations. The 2006 eruption and its precursors were the first significant activity of the volcano in 20 years and the PBO CGPS network provided an unprecedented opportunity to monitor and detect volcanic ground deformation on an erupting Alaskan stratovolcano. Data from the new CGPS stations coupled with the existing seismic stations provided scientists with the first real opportunity to use geodetic data and real time seismic data to assess the volcanic hazards before, during, and after an Alaskan eruption.

Introduction

This paper describes the development and expansion of the Continuous Global Positioning System (CGPS) before and after the 2006 eruption of Augustine Volcano. In September of 2004, the EarthScope Plate Boundary Observatory (PBO) installed five permanent CGPS stations on Augustine Volcano. In planning for the installation of the stations, staff from the PBO Alaska regional office worked closely with staff from the Alaska Volcano Observatory (AVO) and the PBO Magmatic Systems Site Selection Committee to install CGPS stations at strategic locations around the volcano. The goal was to provide a good spatial distribution of stations to monitor and detect both short- and long-term volcanic deformation in response to magmatic intrusions at depth and magma migration through the volcanic edifice.

Owing to its frequent eruptive activity, Augustine was a relatively well instrumented volcano prior to the 2006 eruption (Power and others, 2006). In 1992, AVO installed a three-station GPS network on the volcano consisting of dual-frequency, high-power-consumption Ashtech LD-XII receivers (Murray and others, 1992). These receivers were located on the base of the volcano (station AUGL), on the flank of the volcano, and on the top of the 1986 volcanic dome. Due to the high power consumption of the receivers, they were operated for only a few hours a day. A telemetered network of tiltmeters was installed in 1993 and 1994 to extend the coverage of deformational monitoring on the volcano (Dzurisin and others, 1994). In 1996, the Ashtech LD-XII receivers were replaced with lower power L1-only Ashtech SCA-12 receivers (Murray and others, 1996). In 2000, AVO replaced station AUGL with a dual frequency Trimble 4700 GPS receiver and dual frequency choke ring antenna, and the remaining two stations were no longer maintained. The continuous instrumentation deployed in the 1990s and repeated Electronic Distance Measurement (EDM) and GPS measurements of the volcano for the period 1988 to 2000 suggested no discernible pattern of displacement that could be attributed to magmatic activity on Augustine Volcano (Power and others, 1998; Pauk and others,

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2001). Prior to the installation of the five PBO CGPS stations in 2004, AVO operated only the one dual frequency CGPS station (AUGL) located on the east quadrant of the volcano. AUGL was incorporated into the PBO network in 2006 and subsequently renamed AV21 to comply with the PBO volcanic station naming scheme.

All five of the PBO CGPS stations and the one AVO CGPS on the volcano were operating normally at the onset of the eruption, but half of the network went offline shortly thereafter due to volcanic activity. Pyroclastic flows generated by the eruption completely destroyed two of the original five PBO stations and severely damaged a third, but spared the remaining three CGPS stations. These stations continued to operate throughout the explosive and effusive phases of the 2006 eruption.

In 2006, PBO installed six additional CGPS stations on the volcano at the request of the PBO Magmatic Systems Site Selection Committee to improve ongoing geodetic monitoring of the volcano. The Committee requested new locations to strengthen the existing network geometry and to improve the detection of subtle ongoing volcanic deformation signals at the volcano. The new stations were installed on the lower western and northern flanks of the volcano, on the southwest flank of the volcano, and on the upper flanks on the north and south side of the volcano (fig. 1; table 1). The spatial distribution of the new stations was dictated by the availability of competent bedrock on the volcano, line of site between stations and the AVO data communication facility in Homer, and attempts to fill gaps in the original network geometry and strengthen the geodetic monitoring of the volcano.

2004 CGPS Station Installations

PBO installed short drilled-braced monuments (SDBM) as the primary monument type for all the PBO CGPS stations on Augustine during both the 2004 and 2006 installations (fig. 2). The SDBM is a very stable, inexpensive, and durable monument that can be installed in exposed competent bedrock with off-the-shelf construction tools. The monument is constructed of 1-inch diameter Type 316 stainless steel rods that are welded into a stable tripod structure. The SDBM consists of a vertical leg braced by three diagonal legs inclined at approximately 55 degrees to the ground. All the legs extend approximate 2 m into the bedrock and converge with the center leg approximately 1.5 m above the ground surface. An electric hand held drill is used to drill all four 3.5 cm holes into the rock and each leg is grouted in place and the angled legs are welded to the central leg. The UNAVCO Web site (http://facility.unavco.org/project_support/permanent/monumentation/sdbm.htm, accessed September 28, 2009) provides detailed instructions and equipment lists for the construction of the SDBM. A stainless steel leveling mount is welded onto a threaded adaptor on the top of the center leg. A dual-frequency choke ring GPS antenna is attached to the leveling mount and a protective radome is put over the antenna.

For the Augustine network, PBO used the Trimble NetRS geodetic grade GPS receiver, Trimble part number 48164, and a radome covered Trimble dual frequency (L1/L2) choke ring antenna, model number TRM 26959.00, at each station. The NetRS is a low-power (3 Watt) rugged GPS receiver that allows for remote operation, status monitoring, and programming using Internet Protocol (IP) (fig. 3). Utilizing a standard internet browser, a user can access NetRS data and change data recording parameters. This proved helpful during times of volcanic unrest when conditions prohibited site access. The choke ring antenna is a reliable, low-power, multipath-resistant geodetic antenna that maintains millimeter precision (fig. 4).

The five CPGS stations were installed in competent bedrock outcrops with excellent sky view and clear telemetry paths to the AVO communications facility in Homer (fig. 1 and appendix 1). Unfortunately, the lack of competent bedrock in each quadrant prevented an ideal distribution of the stations; however, the final station distribution was sufficient to capture deformation on the upper and lower flanks of the volcano prior to and after the eruption. The network was concentrated within 5 km of the volcano's summit to ensure detection of shallow magmatic sources.

Each CGPS station on Augustine consisted of a Plaschem fiberglass hut or enclosure that houses the GPS receiver, a charge controller, surge protector, and 24 rechargeable 12 volt, 110 amp hour, sealed lead-acid batteries (fig 2). The 24 battery bank provides sufficient continuous power to all equipment throughout the long winter when there is limited daylight and the solar panels are encased in ice or snow and are not charging the batteries. The fiberglass huts are 5 ft square, 5 ft high, and weigh approximately 650 lbs. Due to the size and weight of the hut, a helicopter is required to sling the hut from an established base of operations to the designated remote station location on the volcano. One 64-watt solar panel was mounted to the angled south face of the hut to recharge the batteries. Three additional solar panels are mounted to an aluminum solar panel mounting structure or "swing set" located adjacent to the hut. The swing set is constructed of 2-inch-diameter, schedule-80 aluminum pipe that is coupled to the ground on the corners with rock bolts cemented into the bedrock or set in cement when installed in soil (fig. 5). Solar panels on the swing set recharge the batteries that supply the primary power source for the GPS receiver and digital radio components at each station. The swing sets used at the Augustine stations are a modified version of the swing set developed and utilized by AVO at many seismic stations on other Alaskan volcanoes. Complete metadata information including all equipment types, equipment serial numbers, data products, and photos for each Augustine station can be found on the PBO Web site at (http://pboweb.unavco.org/shared/scripts/gmap/, accessed September 28, 2009).

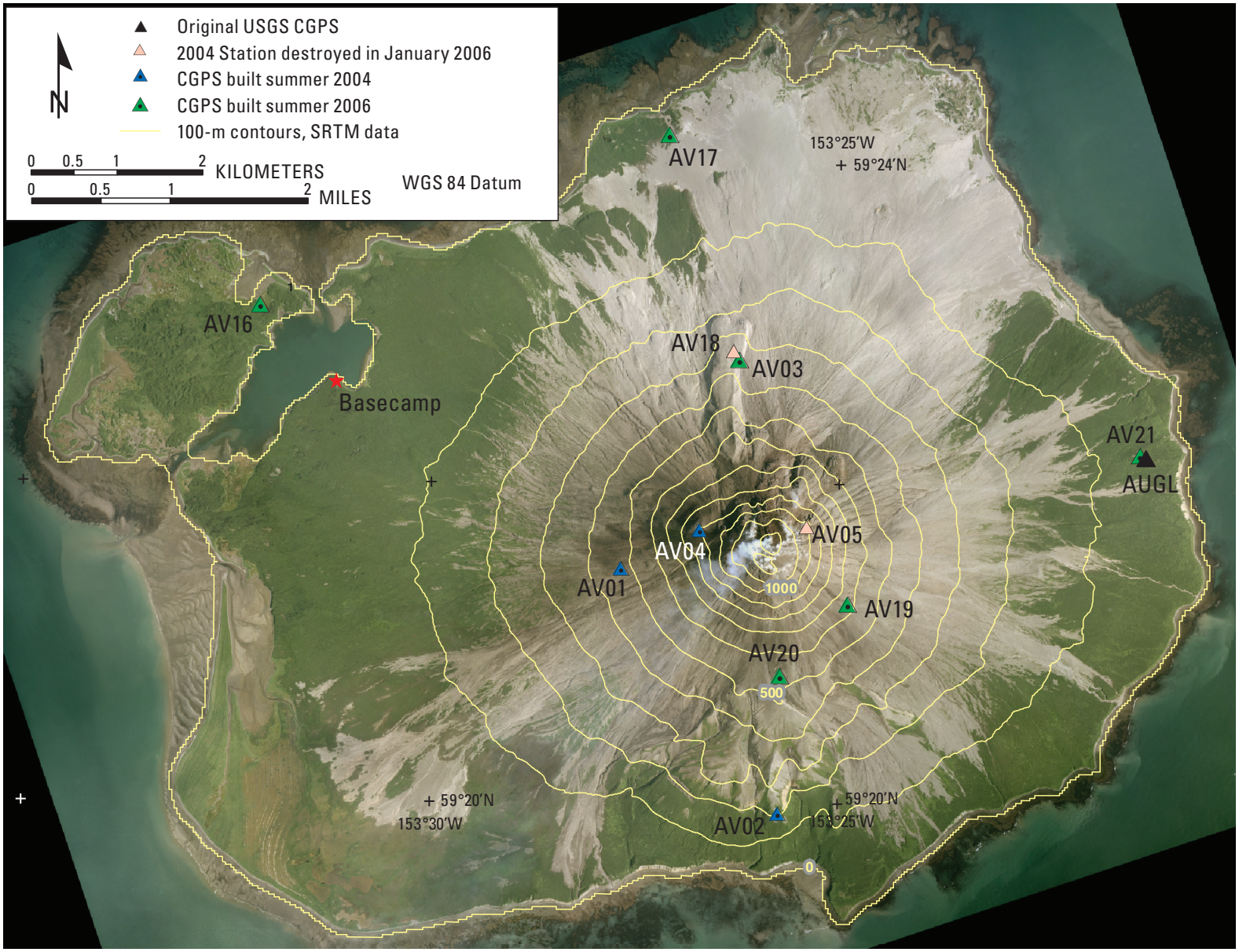

Figure 1. Map of Augustine Volcano showing Plate Boundary Observatory (PBO) Continuous Global Positioning System (CGPS) stations installed in 2004 and 2006, stations destroyed in the 2006 eruption, and Alaska Volcano Observatory (AVO) station on the volcano before the 2004 PBO installations. Note that station AV21 is in the same location as station AUGL. Base map from U.S. Geological Survey (USGS), orthophoto taken on July 12, 2006. Shuttle Radar Topography Mission (SRTM) contours.

Table 1. Geodetic coordinates of the Augustine GPS network and nearby regional Plate Boundary Observatory (PBO) GPS stations as of October 2006, including stations installed in 2004 and destroyed during the 2006 eruption of Augustine Volcano.

Station ID	PBO formal name	Longitude (degrees W)	Latitude (degrees N)	Elevation (meters)	Install date	Removal date
AC27	AC27MNEILAK2004	154.1630	59.2525	420.0	09/17/2004	Active
AC59	AC59URSUSAK2004	153.5852	59.5672	308.8	09/11/2004	Active
AUGL[1]	N/A	153.3539	59.3702	104.0	06/01/1996	01/09/2006
AV01	AV01AUGST_AK2004	153.4608	59.3585	47.9	09/10/2004	Active
AV02	AV02AUGST_AK2004	153.4284	59.3329	231.1	09/11/2004	Active
AV03	AV03AUGST_AK2004	153.4377	59.3812	360.2	09/08/2004	1/28/2006
AV04	AV04AUGST_AK2004	153.4447	59.3626	915.9	09/08/2004	Active
AV05	AV05AUGST_AK2004	153.2521	59.2146	1036.6	09/16/2004	1/13/2006
AV11	AUGS_MOUNAK2006	153.3546	59.3706	114.4	09/10/2006	Active
AV16	AUGLAGOONAK2006	153.5350	59.3859	26.5	09/04/2006	Active
AV17	AUGSTINNWAK2006	153.4510	59.4040	30.0	09/05/2006	Active
AV18	AUGVNORTHAK2006	153.4370	59.3800	370.0	09/03/2006	Active
AV19	AUGSTINSEAK2006	153.4140	59.3550	650.0	09/06/2006	Active
AV20	AUGS_SOUTHAK2006	153.4280	59.3470	540.0	09/11/2006	Active
AV21[1]	AV21AUGST_AK2006	153.3539	59.3702	104.0	01/09/2006	07/18/2008

[1] Sites AUGL and AV21 represent the same physical location. Only the name was changed.

2006 Augustine Eruption

All six CGPS stations on Augustine were operating prior to the 2006 eruption and proved useful in detecting inflation of the volcano before the eruption and subsequent deflation after the eruption (Cervelli and others, 2006; Cervelli and others, this volume). Unfortunately, pyroclastic flows damaged three of the stations early in the eruption. Station AV05 was destroyed on January 13 during the explosive stage of the eruption. Station AV04 was heavily damaged and stopped transmitting data on January 17 as the result of a large pyroclastic flow (fig. 6). Station AV03 continued to collect data until it was destroyed by a pyroclastic flow generated by an explosion on January 28 (fig. 7). Stations AV01, AV02, and AUGL were not damaged and remained operational throughout the entire eruption and subsequent debris flows generated on the volcano. Unfortunately, because of weather constraints and concern for crew safety, no attempt was made to repair AV04 until several months after the eruption had stopped and seismic activity had subsided. As a result of the station being offline, any deformation on the western flank of the volcano was not thoroughly recorded in the months that immediately followed the eruption.

2006 GPS Installations and Network Maintenance

In October of 2005, the PBO Magmatics Systems Site Selection Committee requested that the Alaska PBO regional office install an additional five to six permanent CGPS stations on Augustine in response to the precursory deformation of the volcano observed in the GPS data time series. The Alaska regional staff immediately began initial planning for the installation; however, severe winter conditions in Cook Inlet and concern about crew safety working on a restless volcano led to the decision to delay the installations until activity subsided and weather conditions were more favorable. However, in December of 2005, AVO staff upgraded the GPS station AUGL with a NSF-purchased NetRS GPS receiver, and the station was renamed AV21 and incorporated into the PBO network. Because of continued activity on the volcano after the 2006 eruption began, and because of other regional commitments, the Alaska regional office was unable to install the new stations until September of 2006.

During September of 2006, PBO installed an additional six new GPS stations on Augustine (fig. 1) and repaired AV04. At each new station, PBO built SDBM monuments and

Figure 2. Photo of Plate Boundary Observatory (PBO) station AV03, located on north side of Augustine Volcano. Station includes a standard PBO Short Drilled Braced Monument (SDBM) geodetic monument with GPS antenna enclosed in a plastic radome. Note that the original PBO style gray fiberglass enclosure and aluminum solar panel "swing set" installed in 2004. The station was completely destroyed by the 2006 eruption. Photo by Benjamin Pauk, September 12, 2004.

installed Trimble NetRS GPS receivers, Trimble choke ring antennas, and Intuicom digital radios. All data collected at the new stations were incorporated into the existing digital radio network telemetered to Homer.

The fiberglass enclosure huts deployed in 2006 are a larger and remodeled version of those installed in 2004. One key advantage of the new huts is that they were designed to accommodate two 64 watt solar panels (fig. 8). In addition, a new equipment mounting plate or back panel was developed and incorporated in the design for the interior of the enclosure. The new back panel is made of noncorrosive stainless steel and mounts to one of two sets of four bolts on either of the interior sides (east or west side) of the hut (fig. 9). The NetRS, Intuicom radio, charge controller, surge protector, and other associated equipment is mounted on to a single panel allowing rapid modular replacement of equipment.

The six stations installed in September of 2006 completed a robust network. Stations AV16 and AV17 were installed on the lower northwestern and western flanks of the volcano. Stations AV18 was installed within 300 m of the destroyed station AV03 on the north side of the volcano.

Figure 3. Photo of Trimble NetRS and Intuicom EB1 radio mounted inside an older style Plate Boundary Observatory (PBO) fiberglass enclosure installed on the volcano in 2004. Photo by Benjamin Pauk, September 9, 2004.

Station AV19 was installed on the southwestern flank of the volcano on a small spine of bedrock at an altitude of about 650 m. AV20 was installed in a bedrock outcrop approximately 1 km due north of station AV02 at a higher elevation on the volcano's southern flank. Due to concerns about the monumentation at AV21, a SDBM monument was built approximately 200 m west of AV21 and was designated as AV11, and AV21 was deactivated from the PBO network after the 2 stations recorded in parallel for almost two years. The heavily damaged station AV04 was repaired in 2006 and routine maintenance was performed at stations AV01, AV02, AC27, and AC59.

In addition to the 2006 hut modifications, a more rigid and durable swing set was designed and installed at three of the six new stations. No swing sets were needed at stations AV18, AV19, and AV20 as they have good southern exposure and are located on wind swept ridges where snow accumulations have historically been minimal. The new swing set was designed to withstand greater ice, snow, and wind loads commonly experienced by solar mounts on Augustine and other remote Alaskan volcanoes. Additional aluminum angled bar was bolted to the sides across the back of the panels to minimize flexure of the solar panels. The new hut and swing sets used the same 64-W solar panels deployed in 2004. As on the 2004 swing sets, all external connecting wires were enclosed in ½-inch-diameter Liquitite conduit, securely clamped to the aluminum poles and fed into the hut's power panel through a watertight plastic pass-through connection mounted to the side of the hut. In addition to the corners of the swing sets

Figure 5. Photo of solar panel "swing set" structure with three 64 watt panels installed in 2004 Plate Boundary Observatory (PBO) GPS stations on Augustine Volcano. Photo by Karl Feaux, September 11, 2004.

Figure 4. Photo of PBO station AV02 located on the south side of Augustine Volcano. Photo shows a Trimble L1/L2 choke ring dual frequency GPS antenna on a Plate Boundary Observatory (PBO) Short Drilled Braced Monument (SDBM). Plastic radome is removed to expose radome base, Southern California Integrated GPS Network (SCIGN) adapter and antenna. Monument is made of Type 316 1-inch diameter stainless steel rods. Photo by Karl Feaux, September 11, 2004.

Figure 6. Photo of damaged Continuous Global Positioning System (CGPS) station AV04, located on the upper west flank, after the 2006 eruption of Augustine volcano. The station was damaged by passing pyroclastic flow that ripped off the plastic radome, melted the coax antenna cable, conduit, and the middle of the L1/L2 choke ring antenna. Photo by Benjamin Pauk, September 2, 2006.

being set in concrete, it was further coupled to the ground using a minimum of four 3/16-inch diameter guy wires connected to 0.5×6 inch-long galvanized eyebolts on the swing set connected to another nongalvanized eyebolt cemented into available bedrock adjacent to the base of the swing set.

To minimize the time to install a complete station during the 2006 project, all swing sets were built at the base camp during weather delays and slung to each station by helicopter. Preconstruction of all equipment and programming of radios and receivers in the PBO warehouse before deployment to the island reduced the average site installation time from two days to one. During the 2006 installation period, Augustine was at Aviation Color Code Yellow and Volcano Alert Level Advisory indicating signs of elevated unrest and increased seismic activity at the volcano. Consequently, it was critical to minimize the amount of time spent working on the island in the event that volcanic activity increased, thereby necessitating a crew evacuation.

Network Installation Logistics

All operations for the 2004 and 2006 installations were based out of a camp established on the west side of the island adjacent to the informally named West Lagoon (fig.1). All gear, including huts, swing set materials, batteries, tools, and associated installation and camping equipment was transported to Augustine Island from Homer, Alaska, by the M/V *Maritime Maid* in 2004 and by the M/V *Kittiwake* in 2006. A Bell Long Ranger helicopter was used to sling all gear from the ships to the base camp staging area because no docks or landing areas are present on the island. Additional support, including equipment and crew transport to and from the island, was completed with float planes based in Homer. These support aircraft were able to take off and land in the lagoon. The lack of road and trails on the island required that a helicopter be used during both installations in order to provide logistical support and sling external loads of gear as well as transport internal loads of equipment and crew to and from each location on the island.

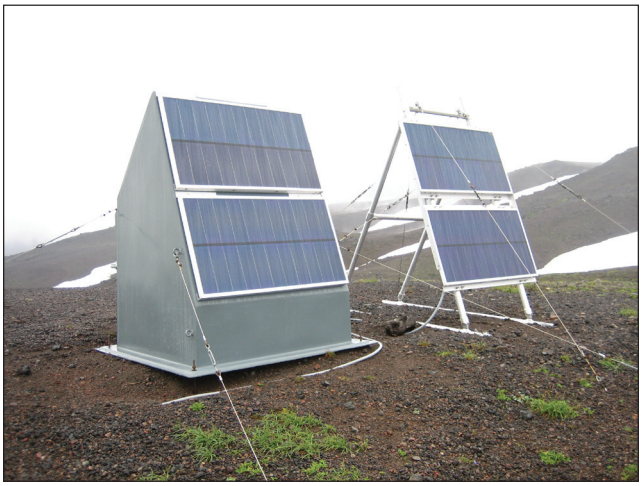

Figure 8. Photo of modified fiberglass enclosure and solar panel structure deployed on Augustine Volcano during the 2006 installations. The new enclosure can accommodate two 64 watt solar panels, and both the enclosure and swing set use guy wires for added anchoring to the ground. Photo by Dave Mencin, September 4, 2006.

Figure 7. Photo of deformed and decapitated Continuous Global Positioning System (CGPS) monument AV03 after the 2006 eruption. Trimble antenna, plastic radome, and leveling mount were ripped off and monument was deformed in direction of pyroclastic flow that swept over the monument. The swing set and fiberglass enclosures were completely destroyed and buried by flow deposits. Photo by Benjamin Pauk, September 3, 2006.

Current PBO Augustine Radio Network and Telemetry

Data from each existing GPS station in the Augustine network (except for AV20) are transmitted in real time through a point-to-multipoint, spread-spectrum 900 MHz ISM-band Ethernet radio network to a master radio located at the AVO communications facility in Homer (fig. 10). The radios are connected to an appropriate Yagi directional antenna mounted to vertical poles inside of each fiberglass hut. In some cases, an external mount on a 2-inch-diameter aluminum pole is used. The huts are transparent to frequencies in this 900 MHz range and protect the antenna from the elements. Stations AV04, AV16, AV17, and AV18 are stand-alone stations with only one slave radio located within the hut and transmit data to Homer through a repeater radio at PBO station AC59 16 km northwest of the volcano on the Alaska Peninsula at Ursus

Head. The slave radio connects to the NetRS GPS receiver through a standard CAT5 Ethernet patch cable. Station AV01, which serves as a slave repeater station, has two radios located in its hut. One is a slave radio that transmits data collected at AV01 to station AC59, whereas the second radio in the hut repeats data from AC27, located on the Alaskan Peninsula west of Augustine Island, to station AC59 and then to Homer (fig. 10). Data from stations AV02, AV11, and AV19 are routed directly to Homer. Station AV20 has no line of site to any other PBO station on the volcano or in the Cook Inlet region. As of this writing, the station is manually downloaded on a biannual basis and will be incorporated in to the existing radio telemetry at a later date.

PBO Augustine GPS Data Collection

The Trimble NetRS has 1 GB of internal memory for storing data and the standard operating procedures for all PBO CPGS is to split the data space on the receiver into two separate ring buffers, a 800 MB partition for data collection at 1 Hz to be used only during events such as a volcanic eruption, earthquakes, or other events of great scientific interest, and a 200 MB partition for daily data files with a 15 second data collection rate. The size of daily files sampled at the 15 seconds averages about 1 MB and it typically takes about six months to completely fill the 200 MB partition, at which point the receiver will overwrite older data.

Prior to the eruption, AVO requested PBO to set up three separate data partitions on each GPS receiver for simultaneous collection of three different sample rates. The three partitions stored daily and hourly files, both sampled at 15 seconds, and also hourly files sampled at 1 Hz. Prior to the eruption and request for additional sample rates, PBO only collected hourly and daily 15-second data files. Before, during, and after the eruption, all hourly 15-second data files were downloaded hourly whereas the 15-second daily files continued to be downloaded daily. During the explosive phase of the 2006 eruption, PBO collected and downloaded hourly 1-Hz data files from stations AV01 and AV02 on the volcano. Due to the large size of the 1-Hz data files and larger bandwidth requirements, the 1-Hz files were only collected for a few weeks during the explosive phases of the eruption and were no longer collected after the onset of the effusive phase of the eruption.

All raw data collected from the CGPS network on Augustine are available for download from the UNAVCO Data Archive Facility, with raw receiver files converted to standard Receiver Independent Exchange (RINEX) format for easy processing, analysis, and interpretation. In addition to raw data, PBO provides higher-level data products consisting of station position and velocity solutions in the Stable North America Reference Frame (SNARF), along with their related Solution Independent Exchange (SINEX) files. PBO's data analysis occurs at two analysis centers, one at the New Mexico Institute of Mining and Technology using the GAMIT processing package and the other at Central Washington University using the GIPSY processing package, with combined solutions generated at the Massachusetts Institute of Technology. These data products and the specific PBO Augustine data products collected before, during, and after the eruption can be accessed from the UNAVCO Archive Facility through the UNAVCO Web page at (http://www.unavco.org, accessed September 28, 2009) as well as directly from the PBO Web site at (http://pboweb.unavco.org, accessed September 28, 2009).

Figure 9. Photo of stainless steel back panel mounting system developed for new huts deployed during the 2006 Augustine Volcano installations. Trimble NetRS and Intuicom EB1 spread spectrum radio mounted on to upper portion of panel. Photo by Benjamin Pauk, September 4, 2006.

Conclusions

The original PBO CGPS network on Augustine Volcano was designed to follow the existing telemetry paths of the AVO seismic network, minimizing the need for extensive radio testing in the field. Extensive planning, organization, radio network development, and bench testing of the GPS and digital radio network in the laboratory prior to deployment proved extremely valuable in minimizing the amount of time spent in the field

troubleshooting the radio network. Additionally, the original radio network design was implemented to allow for expansion. Consequently, the PBO engineers in 2006 were able to incorporate the radios for the new stations without having to significantly alter the existing radio telemetry paths.

The destruction of three of the original six stations early in the eruption severely affected AVO's ability to use GPS as a key monitoring tool during the entire eruption. Had field conditions permitted, PBO field crews could have redeployed new equipment shortly after the eruption began to ensure continued data collection. This would have provided invaluable information about flank deformation of the volcano after the onset of the eruption. Unfortunately, severe winter weather and hazardous conditions on the volcano prevented access and work during the eruption.

The interval between the original 2004 network deployment and the 2006 eruption response deployment provided PBO engineers ample experience to make marked improvements to GPS monument construction and enclosure and electronics design. One fundamental lesson learned from the 2004 installations was the need for well-defined logistics for this type of operation. The 2004 installations on Augustine were the first large-scale deployment for PBO field engineers in Alaska and many logistical items, such as scheduling of boats, helicopter contracts, and equipment transport, was conducted late in the planning process. As a result, additional float plane charters were required to bring some tools and equipment not available at time of shipping to the island after the 2004 installations began. In 2004, all construction, including assembly of the huts and swing sets, was done on site, adding significantly to construction time at a site. Logistics and construction of the 2006 installations were streamlined by effective planning that began in October of 2005 and included a thorough organization of equipment and materials, additional acquisition of tools, and construction of the enclosures in the warehouse prior to shipment to the volcano.

Another valuable lesson learned during the time between the two installations was the need for a larger enclosure with an accessible and standardized equipment panel for easy access and rapid replacement of equipment. Between the 2004 and 2006 installations, enclosures were redesigned to accommodate more solar panels, which in some cases during the 2006 installations, removed the need for swing sets in areas of good southern exposure and historically low snow accumulation. These modifications allowed for efficient installation of the new CGPS stations at the request of the PBO Magmatic Systems Site Selection Committee in 2006. As a result of the streamlined construction procedures, PBO field engineers were able to reduce site construction time by about 50 percent from two days to one. In the future, these procedures will allow for stations to be built quickly, efficiently, and safely in remote volcanic settings before the onset of volcanic unrest. The lessons learned from the 2004 and 2006 installations, combined with the hut and swing set improvements and streamlined construction procedures, proved extremely valuable to PBO volcanic network installations on Unimak Island in 2008 and contributed to their success.

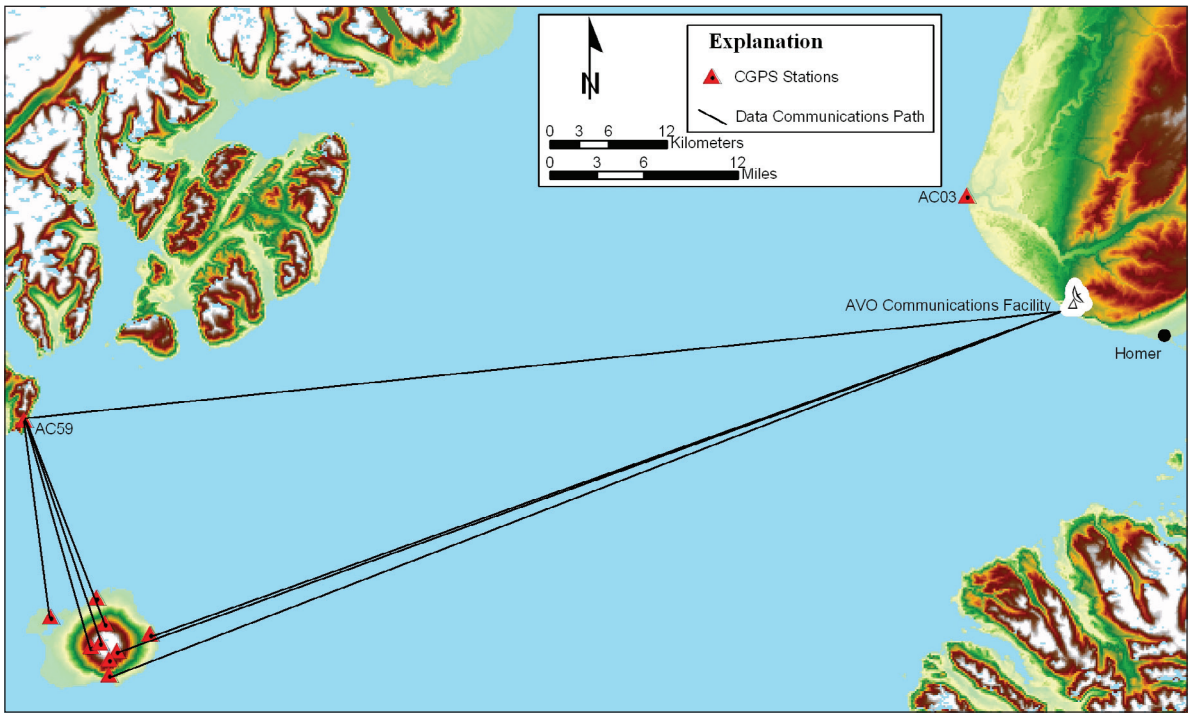

Figure 10. Regional map showing radio telemetry links of the Plate Boundary Observatory (PBO) Augustine Volcano GPS network. Map projection is Universal Transverse Mercator Projection, Zone 5, North American Datum of 1983 (NAD 83). CGPS, Continuous Global Positioning System.

Acknowledgments

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Appendix 1. Station and telemetry description of existing Plate Boundary Observatory (PBO) Augustine GPS network.

AV01: Station is located on the western flank of volcano on a prominent andesite outcrop. Radio telemetry path for the station is to PBO station AC59 located at Ursus Head, about 15 miles to the northwest, and is repeated to the AVO communications facility in Homer. AV01 also host a repeater radio that repeats data from PBO regional station AC27 located in McNeil River State Refuge. AV01 consists of an original style PBO fiberglass enclosure, swing set, and SDBM.

AV02: Station is located on the southern flank of the volcano on a prominent outcrop of sedimentary rock. The radio telemetry path is from the station directly to the AVO communications facility located in Homer. The station consists of an original style PBO fiberglass enclosure, swing set, and SDBM.

AV04: Station is located on the upper western flank of the volcano on a prominent flat spot. The radio telemetry path is to Homer through a radio repeater located at PBO station AC59. The station consists of an original style PBO fiberglass enclosure and SDBM.

AV11: Station is located in bedrock on the western end of a low lying east-west trending ridge on the northeastern side of the volcano. The radio telemetry path is directly to the AVO communications facility in Homer. The station is near the old AVO GPS station AUGL and consists of an older style AVO fiberglass enclosure, swing set, and SDBM.

AV16: Station is located on a large rock outcrop west of the main lagoon on the west side of the island. The radio telemetery path is to Homer through a repeater radio located at PBO station AC59. Station consists of a newer style fiberglass enclosure, newer style swing, set and SDBM.

AV17: Station is located on a 20 foot diameter rock outcrop on the northern base of the volcano. The radio telemetry path is to Homer through a repeater radio located at PBO station AC59. The station consists of a newer style fiberglass enclosure and SDBM.

AV18: Station is located in bedrock on the prominent lava flow on the north side of the volcano within 100 feet of location of the destroyed PBO station AV03. The radio telemetry path is to Homer through a repeater radio located at PBO station AC59. The station consists of a newer style fiberglass enclosure, newer style swing set, and SDBM.

AV19: Station is located on a bedrock spine on the southwest flank of volcano. The radio telemetry is directly to the AVO communications facility in Homer. The station consists of a newer style fiberglass enclosure and SDBM.

AV20: Station is located on the southern flank of the volcano about 0.5 miles north of station AV02. The station is manually downloaded once every three months and is not currently part of the existing telemetry network. The station consists of a newer style fiberglass enclosure and SDBM.