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GPS Measurements on the Island of Hawaii in 1992

by

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ABSTRACT

From mid-February through April 1992, the staff of the Hawaiian and Cascades Volcano Observatories measured a 58-station Global Positioning System (GPS) network on the island of Hawaii. The network extends across the entire island, with denser coverage around the summits of Kilauea and Mauna Loa Volcanoes and on the mobile south flank of Kilauea. Many of the stations had been previously surveyed with GPS during one or more of the 1987 - 1990 annual campaigns. Three Ashtech LD-XII and three MD-XII dual-frequency, codeless receivers were used in the survey. Most stations were occupied for three consecutive days and data was recorded for six hours each day. One station, located far from known areas of rapid deformation, served as a local reference and was occupied for 22 days. A total of 200 radial lines from this station were processed with Ashtech GPPS software using broadcast orbits. Repeat measurements indicate precision of about 5 mm in latitude, 15 mm in longitude and 35 mm in ellipsoid height. Line lengths were measured to within 10 mm over distances ranging from 34 km to 107 km. Selected lines were processed using the National Geodetic Survey's calculated satellite orbits, but comparison of these results with those using broadcast orbits showed differences of less than 5 mm in all components, and network adjustments of that subset showed no significant improvement in fit.

INTRODUCTION

Measurement of ground-surface deformation has been used to monitor the active volcanoes of Hawaii since the early 1900s. The measured movement of the ground surface has more recently been utilized in the study of fault systems on the island to model parameters such as dimensions, depth and amount of displacement on buried structures. For the most part, standard, high-precision surveying techniques have been used to quantify the motion, i.e., leveling to measure vertical motion, and triangulation and trilateration for horizontal control. Of these, leveling is the most time-consuming, although still the most accurate way to measure elevation change. Triangulation is no longer in use, and trilateration suffers from the limitations of line-of-sight and clear weather requirements. The Global Positioning System (GPS), on the other hand, provides three-dimensional positions relatively quickly in all weather conditions, with a wider choice of survey sites (although densely vegetated areas are still a problem).

GPS utilizes radio signals transmitted from U.S. Department of Defense satellites to receivers on the ground. A complete description of the system and the methods used to determine relative positions are given in Dixon (1991).

GPS has been used to monitor deformation in Hawaii since 1987. Surveys have been conducted on the island of Hawaii once each year in 1987, 1988, 1989 and 1990. In the early surveys, satellite coverage was much reduced from the present configuration and instruments were far less versatile. Nevertheless, these surveys showed the immense value of GPS as a tool for monitoring active volcanoes and fault systems (see Dvorak et al., 1993). During the 1992 survey, we occupied many of the existing GPS stations and expanded the network, primarily on Mauna Loa Volcano. Additional sites on Kilauea were measured during the time of our survey by a group led by Paul Segall from Stanford University.

EQUIPMENT AND PROCEDURES

Three Ashtech LD-XII and three MD-XII dual-frequency, codeless receivers were used in the 1992 survey. Power was supplied by 12-volt batteries, each of which provided about 40 hours of recording time. Antennas were set up on Wild tripods, centered on station marks with optical plummets that had been calibrated before starting the survey, and oriented to true north using a brunton compass. The height of the antenna relative to the survey mark was measured before and after the recording session. Antenna heights were recorded in the receiver and on a data sheet, along with other pertinent information. Each receiver was programmed to record data every 30 seconds. The minimum number of satellites was set to one, and the minimum recording elevation was set to 10 degrees. To conserve battery power, we used a timer designed by the Cascades Volcano Observatory to start and stop receivers left operating at remote sites.

Recording times were selected based on the best satellite geometry (position dilution of precision) and maximum number of satellites available. We planned to occupy each station for three consecutive days, recording over the same 6-hour period each day. Weather sometimes prevented the pick-up of stations that had been deployed by helicopter, so that some stations recorded data for up to six days.

Data from the receivers were downloaded in the field onto laptop computers upon breakdown of the setup, and later transferred to an IBM-compatible personal computer for processing. Initial checking of data quality was done immediately after each downloading by reviewing signal-to-noise ratio plots. The receivers performed without trouble throughout the duration of the survey. All Ashtech-format data were backed up on 3.5" floppies and QIC-80 data tapes. Data were converted to RINEX format using UNAVCO conversion software. Raw data are available from the authors in Ashtech format on QIC-80 data tapes or in RINEX format on a variety of media.

SURVEY SITES AND DATES

The 58-station GPS network on the island of Hawaii (Fig. 1) can be subdivided into two subnets: Kilauea (Fig. 2) and Mauna Loa (Fig. 3). The Mauna Loa network includes stations on the summit, the southwest and east rift zones, the southern flank in the Kaoiki seismic area, and three stations on the lower west flank spanning the Kealakekua fault system. Locations of these stations are described in Table 1. On Kilauea, stations are also concentrated in the summit and rift zone areas, although the coverage of the east rift zone is limited by dense vegetation and, on the middle east rift, by active lava flows. There is also a large number of stations on the south flank of Kilauea. Descriptions of stations on Kilauea are found in Table 2. Table 3 lists stations that are not part of either of these two networks but define the broader, island-wide network and provide long, relatively stable baselines. The station Lyman, in Hilo, (Fig. 1) was occupied almost continuously during the survey to provide a stable reference mark. While it is unlikely that any point on the island is truly stationary, Lyman is far removed from the most active sources of deformation. Local reference stations for each of the subnets were also occupied quite frequently. MLO was occupied during the entire time that stations on Mauna Loa were surveyed. Uwekahuna, at the summit of Kilauea, was occupied often for use as a reference for the Kilauea network.

Best satellite coverage was achieved starting at 1900 hours local time at the beginning of the survey. (Note that this was already the next day in UTM time.) Later in the campaign (starting on March 24, when only 3 receivers were used), we ran two sessions per day, one in the morning and one in the evening (see Table 4).

DATA PROCESSING

Data were processed using version 4.4.0 Ashtech GPPS software. GPPS calculates the relative positions of two sites from data collected simultaneously at those sites. Lines were processed radially from Lyman, fixing the position of Lyman to the position previously determined by J. Dvorak (pers. com.). During the last few weeks of the survey, only three receivers were available and Uwekahuna was sometimes used as the reference station. Its position fixed to the average of all 18 positions measured relative to Lyman during the survey. All independent baselines were then processed.

For processing, we set a 20-degree elevation mask, a maximum of 15 iterations, a convergence of 5 mm. All other parameters were left at default settings. We used the ionospheric free linear combination of L1 and L2 frequencies, with ambiguities fixed to the best-fitting integer.

Cycle slips were cleaned manually and the data reprocessed.

Initially, we processed data using both broadcast orbits and the National Geodetic Survey's (NGS) calculated orbits, but we found that positions never varied by more than 5 mm, and broadcast orbits were used for the rest of the processing. A network adjustment yielded a good fit of all the data. The subset of the data that had been processed with both broadcast and NGS orbits was also run through the adjustment program, and again it was found that use of NGS-improved orbits made insignificant difference in the fit of the adjustment.

RESULTS

GPS positions of all stations are listed in Tables 5, 6 and 7. A fairly good estimate of our repeatability is provided by the many repeat measurements of stations during the survey. We find an average standard deviation of 5 mm in latitude, 15 mm in longitude, 35 mm in ellipsoid height, and 10 mm in line length. Most of the repeats are not true reoccupations, because remote stations were set up only once and started by timers. However, on plots of line length *vs* repeatability (fig. 4), the stations that were set up prior to every recording session are indistinguishable. Also apparent from figure 4 is that repeatabilities are not proportional to line lengths at these distances. With the exception of very short lines, repeatability of line length measurements is less than 1 ppm - far better than expected errors of typical electronic distance measurements on Hawaii (Delaney et al., 1993).

Adjusted positions are listed in Table 3, along with standard deviations scaled by residuals from the network adjustment. Standard deviations are of the same magnitude as repeatabilities.

References

Delaney, P.T., Miklius. A., Arnodottir, T., Okamura, A.T., and Sako, M.K., 1993, Motion of Kilauea during sustained eruption from the Puu Oo and Kupaianaha vents, 1983-1991: Journal of Geophysical Research, v. 98, p. 17,801-17,820.

Dixon, T.H., 1991, An introduction to the Global Positioning System and some geological applications: Reviews of Geophysics, v. 29, p. 249-276.

Dvorak, J.D., Okamura, A.T., Lisowski, M., Prescott, W., and Svarc, J., 1994, GPS Measurements on the Island of Hawaii: 1987 to 1990: U.S. Geological Survey Bulletin, in press.

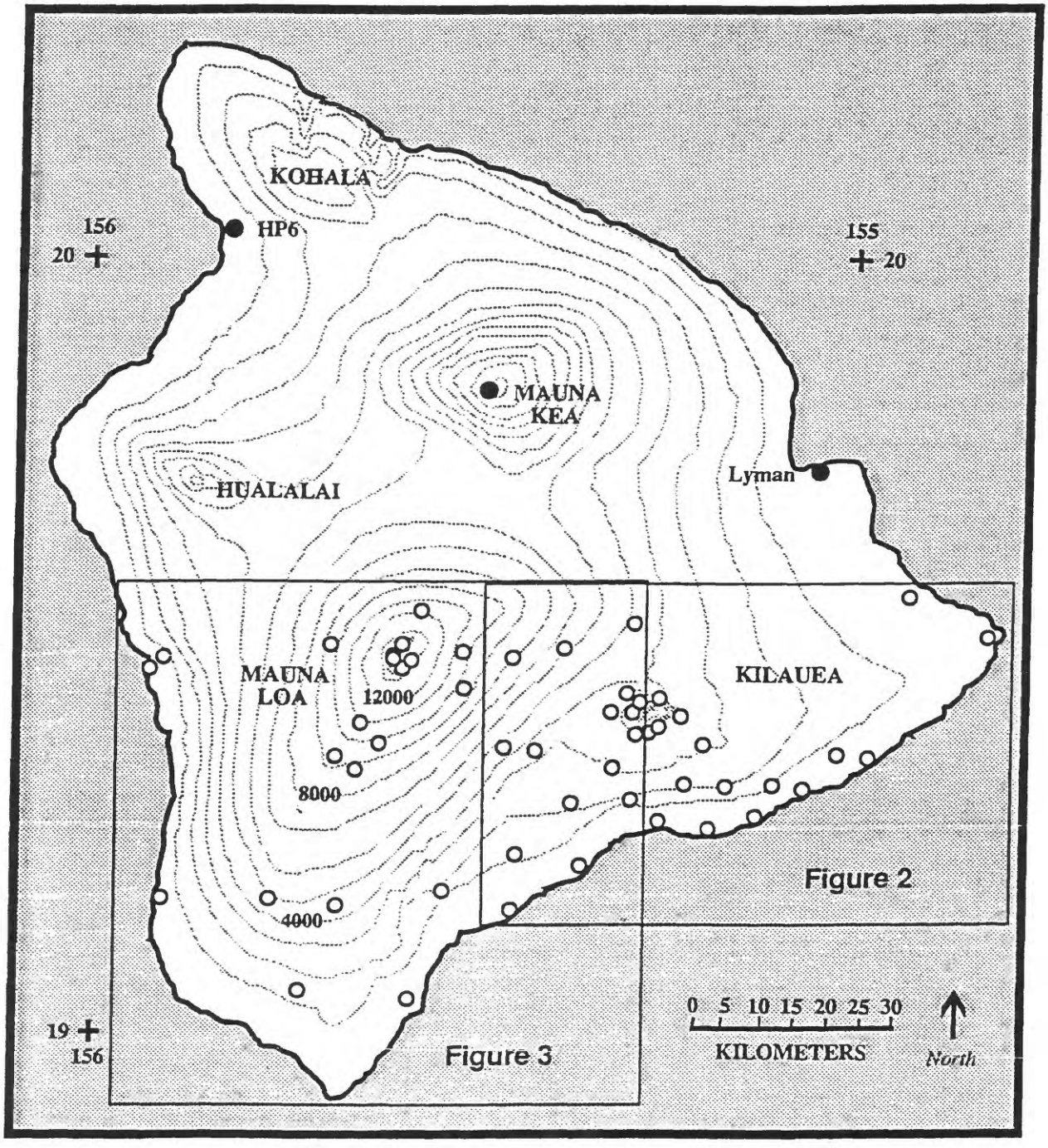

Figure 1. Map of stations occupied with GPS on the island of Hawaii in 1992.

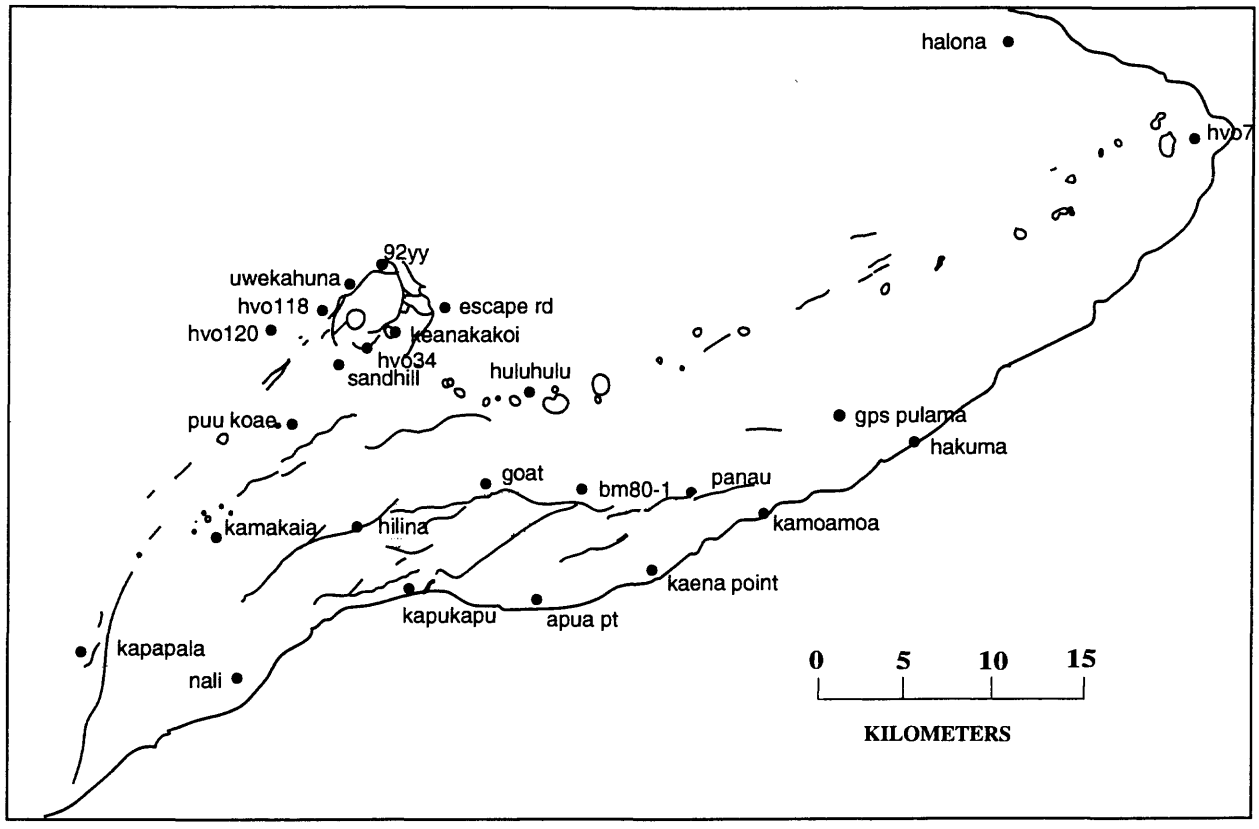

Figure 2. Map of stations on Kilauea Volcano occupied with GPS in 1992.

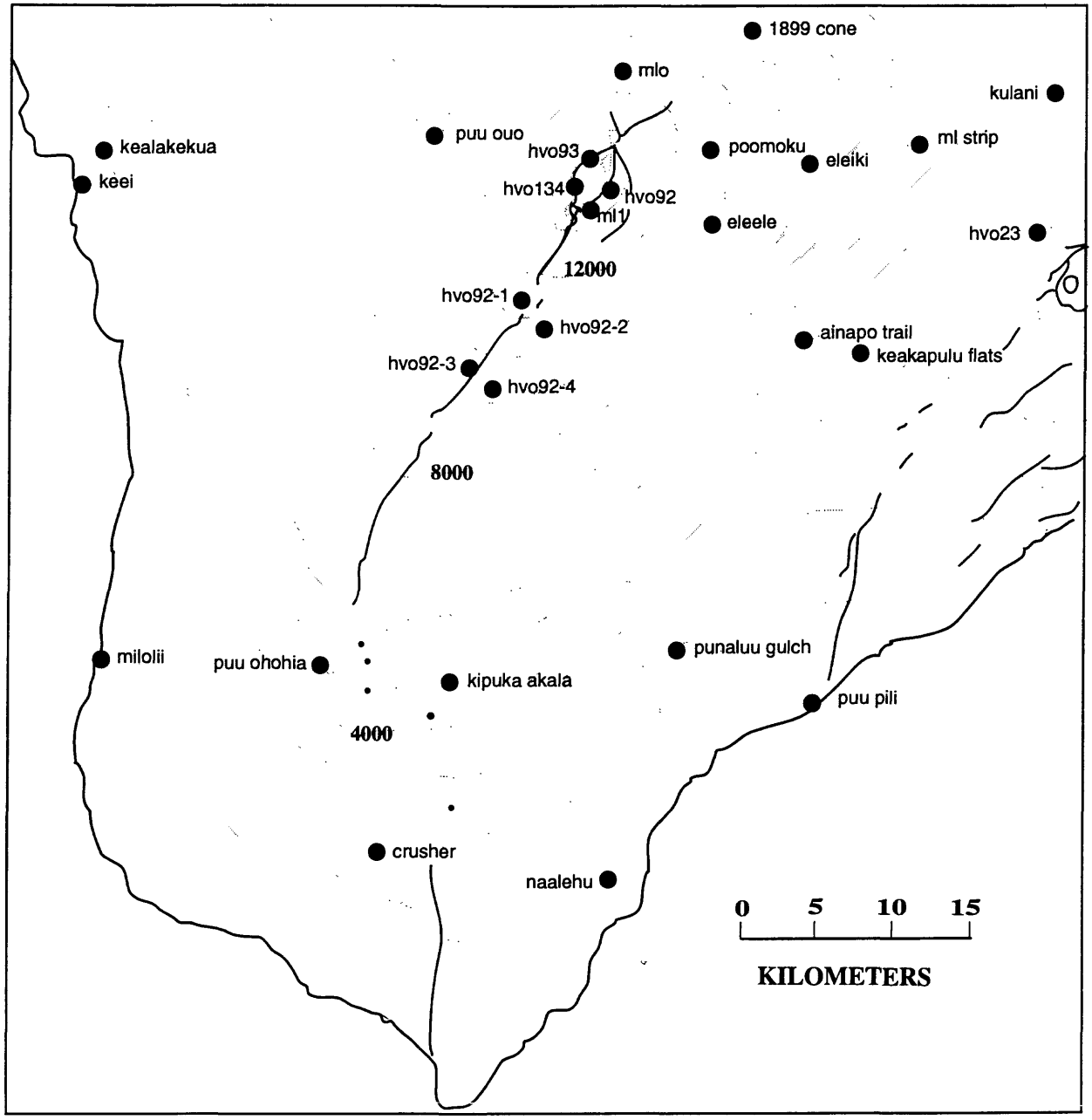

Figure 3. Map of stations on Mauna Loa Volcano occupied with GPS in 1992.

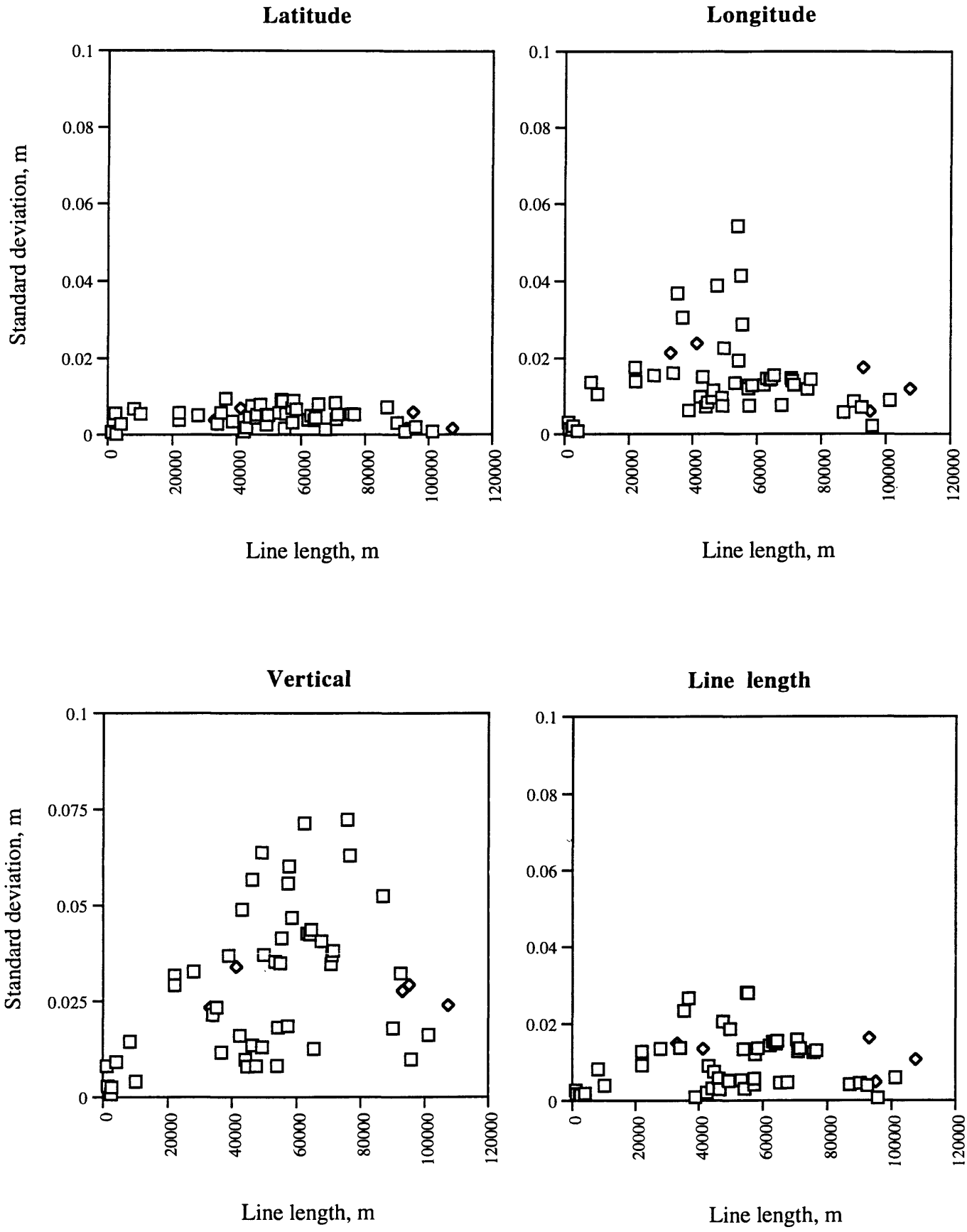

Figure 4. Plots of repeatability of 1992 GPS measurements. Squares represent stations that were set up only once and started with timers; diamonds represent stations that were set up each recording session. Note, however, that most positions are calculated relative to Lyman, which was set up prior to every recording session.

Table 1: Description of GPS stations on Mauna Loa occupied in 1992. Elevations and coordinates are WGS84 ellipsoid values. *'s next to quadrangle map names indicate that the station is not marked on the published map.

STATION NAME: **1899 CONE**
ELEVATION: 2905 m (9530')
LATITUDE: 19° 3.76'
LONGITUDE: 155° 29.52'

DESCRIPTION: Standard USGS aluminum disk stamped "1899" cemented in a solid cinder block
ACCESS: 4WD vehicle

The station is located on a small prehistoric cone on the north side of Mauna Loa's northeast rift zone. From the Saddle Road, drive 8.8 mi on the paved Mauna Loa Weather Observatory road to the switchback with the microwave dish. Stay on the paved road for another 2.5 mi. to a red cinder road on the left marked by a "cinder cone" sign . Drive to the end of the road, staying on the road to the left as you approach the cinder quarry. Drive onto a gravel road that heads toward the left of the cone. You can try driving up the cone or walk up the road. The station is on the left side of the road, ~15 m after the road starts to level off on top of the south rim of the cone. A cairn is located near the station. A helicopter can land on the top of the cone near the station. Sandbags are recommended to steady the tripod.

PUU ULAULA QUAD*

STATION NAME: **AINAPO TRAIL**
ELEVATION: 1570 m (5151')
LATITUDE: 19° 22.40'
LONGITUDE: 155° 27.48'

DESCRIPTION: Standard USGS benchmark stamped "HVO87-107"
ACCESS: 4WD vehicle. Contact Kapapala Ranch, Gordon Cran, (961-8403) for access; need GMX key from National Park or HVO.

See the description for Keakapulu Flats. Instead of turning right at the fence line, keep driving through the open gate. Several miles further, you will reach another, closed gate (forest reserve boundary), go 0.45 miles past this fence and the station will be on the right side of the road, on a pahoehoe tumulus about 15 m from the road. A helicopter can land in the road.

WOOD VALLEY S. QUAD*

STATION NAME: **CRUSHER**
ELEVATION: 626m (2054')
LATITUDE: 19° 4.11'
LONGITUDE: 155° 43.69'

DESCRIPTION: CRUSHER is a reference mark labelled "Kahuku SE base, 3 1948"
ACCESS: 2WD vehicle

The station is located on the 1887 aa lava flow, on the uphill side of Hwy 11, 2.9 mi. west of the Kahuku Ranch road. Climb the bank at the end of the guard rail on the southeast end of the first deep roadcut about 100 m beyond milepost 74. There is state bronze benchmark (labeled "survey mark") at the base of the power pole, 2 m from the bank. The reference mark is located 25 m N 50 W of the new state benchmark and is set in a concrete post on the top of a high point. Set up on the tick mark crossing the reference arrow.

KAHUKU RANCH QUAD

STATION NAME: **ELEELE**
ELEVATION: 3238 m (10623')
LATITUDE: 19° 26.65'
LONGITUDE: 155° 31.08'

DESCRIPTION: Aluminum disk stamped "Puu Eleele 1976"
ACCESS: Helicopter

The station is on a large conspicuous tumulus on the southeast flank of Mauna Loa, on the skyline if you approach the station by helicopter from the ENE. The benchmark is located ~20 m from a cairn on a high point on the tumulus in a S 50 E direction. The station is marked by white plastic strips. A helicopter can land just west of the station on top of the tumulus. If there are problems landing at the site, you can land on the southwest side at the base of the tumulus.

MAUNA LOA QUAD*

STATION NAME: **ELEIKI**
ELEVATION: 2623 m (8606')
LATITUDE: 19° 28.80'
LONGITUDE: 155° 27.24'

DESCRIPTION: Standard USGS aluminum disk stamped "1984 Eleiki Reset "
ACCESS: Helicopter

On the southern slope of Mauna Loa, the station is located about 150 m east of the Poomoku aa flow on pahoehoe lava. The station is 50 m southwest of a small black tumulus marked by a white plastic cross (Old Eleiki).

KIPUKA PAKEKAKE QUAD*

STATION NAME: **HVO134**
ELEVATION: 4136 m (13570')
LATITUDE: 19° 7.89'
LONGITUDE: 155° 36.28'

DESCRIPTION: PK nail with tag stamped "HVO134".
ACCESS: Helicopter

HVO134 is located on the west rim of Mokuaweoweo crater. It is ~250 m south of the last aa flow that lies south of the summit and ~30 m from the rim of the crater. Look for a cairn on a pahoehoe high point near some small collapsed tubes. Caution is required when landing a helicopter because of tricky winds. Tying the tripod down to nails and/or weighting with sandbags or rocks is recommended.

MAUNA LOA QUAD*

STATION NAME: **HVO23**
ELEVATION: 1215 m (3986')
LATITUDE: 19° 26.27'
LONGITUDE: 155° 18.31'

DESCRIPTION: Standard USGS bm stamped "HVO23"
ACCESS: 2WD vehicle

From the National Park entrance, drive southwest on Hwy 11, past the entrance to the golf course and take the next right onto the Mauna Loa road. Drive past the roundabout parking area for the Bird Park trail, through the stone pillars (gate should be unlocked, see observatory or National Park staff for combination if locked). The benchmark is 0.15 miles past the pillars, about 10 m to the left of the road, about 1.5 m above road level.

KILAUEA CRATER QUAD*

STATION NAME: **HVO92**
ELEVATION: 4075 m (13369')
LATITUDE: 19° 28.01'
LONGITUDE: 155° 34.89'

DESCRIPTION: Standard USGS aluminum disk stamped "HVO92"
ACCESS: Helicopter

HVO92 is located along the east rim of Mokuaweoweo Crater, 50 m from the NE corner of summit rest house in a N15E direction. The benchmark is 3 m south of the summit trail on an old pahoehoe outcrop flush with the general ground surface. A small rock cairn is next to the station. A helicopter can land near the station. Tying the tripod down to nails and/or weighting with sandbags or rocks is recommended.

MAUNA LOA QUAD*

STATION NAME: **HVO92-1**
ELEVATION: 3545 m (11631')
LATITUDE: 19° 23.93'
LONGITUDE: 155° 38.29'

DESCRIPTION: Standard USGS brass benchmark stamped "HVO92-1"
ACCESS: Helicopter, contact Kahuku Ranch, Carl Bredhoff (929-7413), for access.

Located on the upper southwest rift of Mauna Loa, to the west of Sulphur Cone. Use a helicopter with GPS navigation system.

SULPHUR CONE QUAD

STATION NAME: **HVO92-2**
ELEVATION: 3412 m (11194')
LATITUDE: 19° 23.01'
LONGITUDE: 155° 37.50'

DESCRIPTION: Standard USGS brass benchmark stamped "HVO92-2"
ACCESS: Helicopter, contact Kahuku Ranch, Carl Bredhoff (929-7413), for access.

Located on the upper southwest rift of Mauna Loa, to the east of Sulphur Cone, near a large lava tube below Red Cone. Use a helicopter with GPS navigation system.

SULPHUR CONE QUAD*

STATION NAME: **HVO92-3**
ELEVATION: 2961 m (9715')
LATITUDE: 19° 21.48'
LONGITUDE: 155° 40.49'

DESCRIPTION: Standard USGS brass benchmark stamped "HVO92-3"
ACCESS: Helicopter, contact Kahuku Ranch, Carl Bredhoff (929-7413), for access.

Located on the mid-upper southwest rift of Mauna Loa. Use a helicopter with GPS navigation system.

ALIKA CONE QUAD*

STATION NAME: **HVO92-4**
ELEVATION: 2961 m (9715')
LATITUDE: 19° 20.75'
LONGITUDE: 155° 39.40'

DESCRIPTION: Standard USGS brass benchmark stamped "HVO92-4"
ACCESS: Helicopter, contact Kahuku Ranch, Carl Bredhoff (929-7413), for access.

Located on the mid-upper southwest rift of Mauna Loa. Use a helicopter with GPS navigation system.

ALIKA CONE QUAD*

STATION NAME: **HVO93**
ELEVATION: 4164 m (13661')
LATITUDE: 19° 28.91'
LONGITUDE: 155° 28.91'

DESCRIPTION: Standard USGS aluminum disk stamped "HVO93"
ACCESS: Helicopter

HVO93 is located NW of the summit of Mauna Loa. It is 22 m from the rim of Mokuaweoweo in a westerly direction, 27 m from a weathered aa flow beheaded at the caldera rim, 50 m north of another beheaded aa flow, in weathered pahoehoe. It is easiest to fly to the station, but it can be reached by 4-wheel drive vehicle and on foot. From Saddle Road, drive up the Mauna Loa Observatory road ~15 mi. to the turnoff to the summit road. Drive until you get to ~40 m from the end of the road. Turn left at that point and follow the faded yellow paint marks to a flat pahoehoe area and park. Walk upslope towards the caldera (southwest) ~75 m looking for a rock cairn which marks the station.

MAUNA LOA QUADS*

STATION NAME: **KEAKAPULU FLATS**
ELEVATION: 1286 m (4219')
LATITUDE: 19° 22.09'
LONGITUDE: 155° 25.24'

DESCRIPTION: Standard USGS aluminum disk stamped "HVO146"
ACCESS: 4WD vehicle. Contact Kapapala Ranch: Gordon Cran (961-8403); need GMX key from National Park or HVO.

Drive down Hwy 11 towards Pahala to just past the National Park boundary sign to a metal gate located on the right side of the road. Go through the gate (GMX key), drive 100 m and turn left at a hardtop road. Drive about a mile and turn right just before a fence enclosing a corral. Enter the corral at the far end and immediately exit through the adjacent gate. Follow this road up into another corral. After entering the corral, turn right immediately and exit through the corner gate. From there, head toward the low terraced cliffs along a cow path which will turn into a dirt road as you progress. Go up the cliffs to a grove of eucalyptus trees surrounding an old house. Go past the grove and the road will take a sharp right turn and head uphill again. Follow this road until you reach a fence line. Turn right and follow the fence line about 0.3 mi. The station is located on a smooth pahoehoe slab next to the fence marked by a rock cairn. A helicopter can land on the north side of the fence with some clearing of brush.

WOOD VALLEY S. QUAD* (note that the benchmark labeled Keakapulu on the map is <u>not</u> the GPS site.)

STATION NAME: **KEALAKEKUA**
ELEVATION: 496 m (1627')
LATITUDE: 19° 29.21'
LONGITUDE: 155° 54.34'

DESCRIPTION: Standard USGS benchmark stamped "HVO88-12"
ACCESS: 2WD vehicle

Located on the west flank of Mauna Loa. From the Captain Cook Post Office, proceed 350 m SE along Hwy 11 to the SE entrance of the Kealakekua Ranch Center shopping complex. Station is located 4.5 m NW (to the left) of the edge of the road between the lower and middle parking lots, 17 m NE of the edge of the lower parking lot. Benchmark is set flush with the ground surface.

HONAUNAU QUAD*

STATION NAME: **KEEI**
ELEVATION: 33 m (108')
LATITUDE: 19° 27.93'
LONGITUDE: 155° 55.16'

DESCRIPTION: USC&GS benchmark stamped "KEEI NO BASE 1948"
ACCESS: 2WD vehicle

Take HWY 11 to the west side of the island and turn left onto HWY 160 which leads to Puuhonua O Honaunau (City of Refuge, National Historic Site). Instead of turning into the park, keeping going on the road, which will curve right and become one-lane wide. In a couple of miles, there will be a waste transfer station on the right. The station is ~10 m past the entrance to the dump, ~ 5 m to the left of the road. The benchmark is encircled by a 1 m high cylinder of aa, pushed up by a bulldozer. If driving from the north, drive down to Kealakekua Bay (turnoff before Captain Cook) and turn left, going through the village of Napoopoo to the transfer station.

HONAUNAU QUAD

STATION NAME: **KIPUKA AKALA**
ELEVATION: 1576 m (5171')
LATITUDE: 19° 10.23'
LONGITUDE: 155° 41.09'

DESCRIPTION: Standard USGS brass benchmark stamped "HVO92-8"
ACCESS: 4WD, contact Kahuku Ranch, Carl Bredhoff (929-7413) or Junior Molcilio (929 7227), for access.

From the observatory, take Hwy 11 toward the west side of the island. After passing South Point, take the Kahuku Ranch Road up about 10 miles (staying on the main road), passing water tanks and going through two gates until reaching a fork in the road in which the main road turns to the left and there is an old road paralleling a rock wall. The benchmark is in the middle of this old road along the rock wall, about 10 m from the fork.

PUU O KEOEKO QUAD*

STATION NAME: **KULANI**
ELEVATION: 1706 m (5597')
LATITUDE: 19° 31.23'
LONGITUDE: 155° 17.09'

DESCRIPTION: Unstamped spike

ACCESS: 4 WD vehicle. Contact Kulani Correctional Facility for access (935-3758) and key.

From the observatory, drive east on Hwy 11 to Mt.View and turn left onto North Kulani Road. Turn left at the stop sign at the intersection with Stainback Highway and drive until you get to a closed gate with a prison guard. State your business and he will give you instructions on how to get a key to get to the cone. After obtaining the key, drive between the gymnasium and the rear of the automotive shop to a locked gate. Follow the road about another 0.25 mile to an intersection with a cleared area directly ahead. Turn right at that intersection; this road will take you to the top of Kulani Cone. At the top of the cone, drive up a dirt road leading past two radio towers and a shack. The station is located at the edge of the cone, on a 18 cm x 18 cm x 15 cm cement block between two larger cement piers on a cement pad.

KULANI QUAD

STATION NAME: **MILOLII**
ELEVATION: 20 m (66')
LATITUDE: 19° 11.07'
LONGITUDE: 155° 54.43'

DESCRIPTION: USC&GS benchmark stamped "No. 3 1977"
ACCESS: 2WD vehicle

Take Hwy 11 to the west side of the island and turn down to the village of Milolii, following the road to the left to go along the coast. Just before the store and gas station, look for a pahoehoe peninsula in the middle of the cove. The benchmark is set in the pahoehoe, about 30 m WNW of telephone pole along a parking area that forms a break in the seawall.

MILOLII QUAD

STATION NAME: **MLO**
ELEVATION: 3420 m (11120')
LATITUDE: 19° 32.19'
LONGITUDE: 155° 34.54'

DESCRIPTION: Metal spike in a circular cement pad inscribed "Stair 1955"
ACCESS: 2WD vehicle. Observatory personnel should be informed of the survey; call 961-3788.

From Saddle Road, drive up the road to the Mauna Loa Weather Observatory until you get to the last switchback in the road about 75 m from the observatory. The station is located 20 m west of the switchback and about 10 m to the north and 3 m lower than the road.

KOKO'OLAU QUAD*

STATION NAME: **ML1**
ELEVATION: 4082 m (13392')
LATITUDE: 19° 27.11'
LONGITUDE: 155° 35.61'

DESCRIPTION: Standard USGS aluminum disk stamped "ML-1"
ACCESS: Helicopter

ML-1 is located on the SW rim of Mokuaweoweo Crater. The station is on a low, oval tumulus, about 15 m from the caldera rim. A large (1 m high) rock cairn is located about 30 m to the northeast on the nearby rim. Two smaller rock cairns are nearby. A permanent glass EDM reflector station (rebar with two reflectors attached to it), is also located nearby. A helicopter can land 15 m south of the station.

MAUNA LOA QUAD*

STATION NAME: **ML STRIP**
ELEVATION: 2061 m (6762')
LATITUDE: 19° 29.55'
LONGITUDE: 155° 23.14'

DESCRIPTION: Standard USGS brass disk stamped "HVO87-108"
ACCESS: 2WD vehicle

From the National Park entrance, drive southwest on Hwy 11, past the entrance to the golf course and take the next right onto the Mauna Loa Road (also called Strip Road). Drive 11.4 miles to the end of the road and park your vehicle on the left side of the parking area. Walk up the unpaved road about 5 m and turn left (before heading into the trees). The benchmark is about 5 m in, cemented in flat pahoehoe. A helicopter can land in the parking lot.

KIPUKA PAKEKAKE QUAD* (Note that the nearby benchmark on the map is <u>not</u> the GPS site.)

STATION NAME: **NAALEHU**
ELEVATION: 219 m (719')
LATITUDE: 19° 3.18'
LONGITUDE: 155° 34.86'

DESCRIPTION: Standard USGS brass benchmark stamped "HVO92-9"
ACCESS: 4WD vehicle. Contact Leighton Freitas at Kawaihae ranch (929-9941) for access.

From Hwy 11 in Na'alehu, take a left on the street just before Green Sands shopping center. Past the Na'alehu Coffee Shop, take the left fork in the road and go 0.6 miles to a red iron gate. Go through the gate and take an immediate right through a green gate. The station is 30 m further, on a pahoehoe pad on the left side of the road, marked by a rock cairn.

NAALEHU QUAD*

STATION NAME: **POOMOKU**
ELEVATION: 3439 m (11283')
LATITUDE: 19° 29.27'
LONGITUDE: 155° 31.12'

DESCRIPTION: Standard USGS aluminum disk stamped "BM77-503"
ACCESS: Helicopter

The station is located on a conspicuous pahoehoe tumulus, on the south side of the northeast rift of Mauna Loa, just north of the terminus of an aa flow lobe. It is about 0.35 mi south of the southern edge of the Ke A Poomoku lava flow. The station is marked by a white plastic cross. The helicopter can land ~25 m north of the tumulus.

MAUNA LOA QUAD*

STATION NAME: **PUNALUU GULCH**
ELEVATION: 677 m (2220')
LATITUDE: 19° 11.52'
LONGITUDE: 155° 32.34'

DESCRIPTION: Standard USGS brass benchmark, stamped "HVO92-18"
ACCESS: 4WD vehicle. Contact Ka'u Agribusiness for access (928-8311).

From the town of Pahala, go up Pikake St. to warning, "truck crossing" sign and take a sharp left into the cane fields. Take the first right turn (past the water tank on the left) and take the left fork at the bridge. In about 1.3 miles, the road will fork again, take the right fork and continue on the better road which will curve to the left. Go about 2 miles, passing two bridges and follow the better road to the right and uphill after the second bridge. Drive another mile and take a right. Continue about 1.3 miles and take a left and almost immediately, another left (this road leads to cinder quarry). The station is about 10 m past this last left turn, about 5 m to the right of the road and about 2 m above road level on a pahoehoe pad.

PUNALUU QUAD* (note that the nearby quarry is on the map)

STATION NAME: **PUU OHOHIA**
ELEVATION: 1627 m (5338')
LATITUDE: 19° 10.90'
LONGITUDE: 155° 46.00'

DESCRIPTION: Standard USGS brass benchmark stamped "HVO92-7"
ACCESS:4-wheel drive, contact Kahuku Ranch, Carl Bredhoff (929-7413) or Junior Molcilio (929 7227), for access and keys.

Located near the southwest rift of Mauna Loa. From Hwy 11, drive up Pineapple Parkway in Ocean View Estates and go through the locked gate onto the jeep trail. In about a quarter of a mile, there will be another locked gate to go through. Follow the jeep trail almost 3 miles, keeping to the west (left) trail. After passing through a kipuka, there will be another kipuka on the left and the road will start to take a turn to the right. The station is just past the curve, on the right side of the road.

PAPA QUAD*

STATION NAME: **PUU O UO**
ELEVATION: 2718 m (8917')
LATITUDE: 19° 29.86'
LONGITUDE: 155° 41.58'

DESCRIPTION: Nail with tag stamped "76-16"
ACCESS: Helicopter

The station is located on a prominent dark brown cinder cone that is the only large hill on Mauna Loa's west flank. Cinder is loose and unsuitable for pounding nails for tying down the tripod; sandbags are recommended for tripod stability in the often strong winds. A small helicopter can land on top of the cone near the station.

SULPHUR CONE QUAD (the map locates the mark on the opposite side of the cone)

STATION NAME: **PUU PILI**
ELEVATION: 36 m (118')
LATITUDE: 19° 8.85'
LONGITUDE: 155° 27.44'

DESCRIPTION: Standard USGS bm stamped "PUU PILI"
ACCESS: 4WD vehicle or helicopter. Contact Ka'u Agribusses (928-8311) for permission and also for keys to gates if driving.

This station is accessed through the Ka'u Agribusiness macadamia nut farm. Going southwest on Hwy 11, take a left turn about 1/4 mile past first turnoff into Pahala onto a dirt road. Drive down to the water tanks and take the road to the right. You will eventually reach a locked gate, keep going through the gate on the dirt-pahoehoe road all the way to the coast. The station is on a small littoral cone just to the left of where the road reaches the coast. This is another windy site; there are rocks near the station and the tripod can be tied down to nails. A helicopter can land near the site.

PAHALA QUAD

Table 2: Description of GPS stations on Kilauea occupied in 1992. Elevations and coordinates are WGS84 ellipsoid values. *'s next to quadrangle map names indicate that the station is not marked on the map.

STATION NAME: **92YY**
ELEVATION: 1224 m (4016')
LATITUDE: 19° 25.89'
LONGITUDE: 155° 16.00'

DESCRIPTION: Standard USGS bm stamped "92YY"
ACCESS: 2WD vehicle

Located just north of the summit caldera of Kilauea, the benchmark is on the east corner of the eastern entrance to the steam vents parking area on Crater Rim Drive in the National Park. It is cemented in an 8 inch square concrete pier, 40 feet south of the center line of Crater Rim Drive and 40 feet east of the road into the steam vent.

KILAUEA CRATER QUAD*

STATION NAME: **APUA PT**
ELEVATION: 24 m (78')
LATITUDE: 19° 15.59'
LONGITUDE: 155° 11.56'

DESCRIPTION: Standard USGS bm stamped "Apua Pt 2"
ACCESS: Helicopter or long hike

Located on the south coast of the island, this site is best flown to in a helicopter, but can be reached by a long, hot hike along the coast trail from Puu Loa to Apua Pt. The station is on a small tumulus, 100 -150 m back and slightly east of the palm grove at the bay. Look for a large, sun-bleached tree trunk just uphill of the station. A large rock cairn marks the site.

MAKAOPUHI QUAD*

STATION NAME: **BM80-1**
ELEVATION: 632 m (2073')
LATITUDE: 19° 9.02'
LONGITUDE: 155° 10.05'

DESCRIPTION: Standard USGS bm stamped "BM80-1"
ACCESS: 2WD vehicle

Drive down the Chain of Craters road in the National Park, past the Muli Wai a Pele pulloff, through a small forested area and about another half-mile to the pulloff just before the Kealakomo pavilion. The station is 0.5 miles past the 9 mile marker 10 to 20 m from the beginning of the pulloff, about 2.5 m to the right (ocean side) of the curb. There is painted mark on the curb. Windy conditions are common.

MAKAOPUHI QUAD*

STATION NAME: **ESCAPE RD** (HVO1140)
ELEVATION: 1199 m (3934')
LATITUDE: 19° 25.16'
LONGITUDE: 155° 14.43'

DESCRIPTION: Standard USGS bm stamped "HVO1140"
ACCESS: 2WD vehicle. GMX key from National Park or HVO is needed.

From the National Park entrance, drive towards Hilo and take the first road to the right , just outside the National Park (the first entrance to Volcano Village is directly opposite this road). Go through the gate and take the left road when it comes to a T. Continue 0.15 mile to a cleared area. The benchmark is located near the far end of the clearing about 5 m to the left of the road, on the left edge of an old, abandoned road. There are tall trees close to the station to the west and south, which makes this an unattractive GPS site.

VOLCANO QUAD*

STATION NAME: **GOAT**
ELEVATION: 830 m (2723')
LATITUDE: 19° 19.59'
LONGITUDE: 155° 13.69'

DESCRIPTION: Standard USGS bm, unstamped
ACCESS: Helicopter or 4WD vehicle and walking. GMX key from National Park or HVO is needed.

This station is best flown to, but it is possible to drive and walk to the site. If driving, take the Chain of Craters Road past the turnoff to Mauna Ulu and take the next road to the right. Go through the gate and drive about .9 miles, to a fork in the road, take the left road and continue roughly 1.5 to 1.75 miles past the old water tanks to some trail markers. Take the road to the right and drive about 0.5 mile. Looking uphill, you should see a prominent grove of ohia trees and a somewhat narrow ridge in front of it, the nose of the ridge pointing towards you. Hike to this ridge and follow it up to a small tumulus about 100 m before the tree grove. The station is on a small tumulus and is marked by a long wooden stake.

MAKAOPUHI QUAD

STATION NAME: **GPS PULAMA**
ELEVATION: 204 m (669')
LATITUDE: 19° 21.42'
LONGITUDE: 155° 01.75'

DESCRIPTION: Standard USGS brass bm stamped "HVO 92-10"
ACCESS: Helicopter

Located on the western edge of the 1991 Kupaianaha flow field, near the remnants of the Royal Gardens Subdivision, southeast of Plumeria St., this station is best reached by flying in a helicopter with a GPS navigation system.

KALAPANA QUAD*

STATION NAME: **HAKUMA**
ELEVATION: 33 m (108')
LATITUDE: 19° 20.75'
LONGITUDE: 154° 58.75'

DESCRIPTION: USC&GS bm, unstamped
ACCESS: Helicopter or 2WD vehicle and hiking

Located on the southeast coast of Kilauea, the station is on the Hakuma horst structure. From the eastern point of the horst, the station is about 400 m southwest along the top of the horst, directly seaward of the Hakuma triangulation station and about 8 m back from the sea cliff. A helicopter can land slightly east of the site. The station can be reached on foot by crossing the 1990-91 lava flows from the end of Hwy 130.

KALAPANA QUAD

STATION NAME: **HALONA**
ELEVATION: 115 m (377')
LATITUDE: 19° 33.32'
LONGITUDE: 154° 56.47'

DESCRIPTION: Standard USGS bm stamped "HALONA"
ACCESS: 4WD vehicle. Contact Glen Taguchi (933-4245) for permission and key to gate.

From the intersection with HWY 11, drive 6.7 miles on HWY 130 to Maku'u Drive, turn left. Go 1.85 miles to 17th ave, take a right. After about .25 miles, take a left onto Railroad Ave, which intersects 17th diagonally. From the cattle guard and old stone wall on Railroad, go 1.1 miles to a large mango tree on the left. Turn right onto jeep trail and drive about 1 mile. The station is to the right, on top of a low pahoehoe ridge about 15 m from the jeep trail.

PAHOA NORTH QUAD

STATION NAME: **HILINA**
ELEVATION: 706 m (2316')
LATITUDE: 19° 17.67'
LONGITUDE: 155° 18.44'

DESCRIPTION: Standard USGS benchmark stamped "HILINA RESET 1975"
ACCESS: 2WD drive vehicle and short walk or 4WD vehicle

Take Chain of Craters Road to the Hilina Pali Road Jct. Turn right and drive to the end of the road. Go 20 m on the hiking trail heading west, past the little pavilion, to a road leading off to the left (road may be hard to see because of tall grass). Follow the road to the left for 100 m. The station is on pahoehoe point to the left of the end of the road. A small plaque in memory of someone who died in the 1975 earthquake is near the station.

KAU DESERT QUAD

STATION NAME: **HVO7**
ELEVATION: 46 m (151')
LATITUDE: 19° 30.47'
LONGITUDE: 154° 50.08'

DESCRIPTION: Standard USGS aluminum leveling benchmark stamped "HVO7 1964"
ACCESS: 2WD vehicle

The benchmark is located on the lower east rift of Kilauea on the southeast corner of the intersection of Hwy 132 and 137, 18.6 m southeast of the center of the intersection, one foot below road level. The station is cemented in flat solid pahoehoe.

KAPOHO QUAD

STATION NAME: **HVO118**
ELEVATION: 1206 m (3957')
LATITUDE: 19° 24.91'
LONGITUDE: 155° 17.93'

DESCRIPTION: Standard USGS bm stamped "HVO118"
ACCESS:4WD or 2WD vehicle with high clearance

From the observatory, drive about .5 miles west on Crater Rim Drive. Just past several large boulders on the right, look for a dirt road on the right, at the top of a sharp curve to the left. Follow this road for about 250 m to an ash-covered pahoehoe mound. The benchmark is on top of this mound.

KILAUEA CRATER QUAD*

STATION NAME: **HVO120**
ELEVATION: 1130 m (3707')
LATITUDE: 19° 24.65'
LONGITUDE: 155° 19.42'

DESCRIPTION: Standard USGS bm stamped "HVO120"
ACCESS: 2WD vehicle

Take Hwy 11 southwest from the National Park entrance to mile marker 33. The benchmark is 0.6 miles further, on a high point to the left of the road and is marked by a red and white pole tied down with guide wires.

KILAUEA CRATER QUAD*

STATION NAME: **HVO34**
ELEVATION: 1105 m (3625')
LATITUDE: 19° 23.98'
LONGITUDE: 155° 16.69'

DESCRIPTION: Standard USGS bm stamped "HVO34 1964"
ACCESS: 2WD vehicle

Located on Crater Rim Drive, 0.15 miles east of Halemaumau parking lot. Cemented on a 1 foot square boulder, 12 m south of the center line, 10 m east of a large boulder.

KILAUEA CRATER QUAD*

STATION NAME: **KAENA POINT**
ELEVATION: 40 m (131')
LATITUDE: 19° 16.87'
LONGITUDE: 155° 7.29'

DESCRIPTION: Standard USGS benchmark stamped "Kaena Point"
ACCESS: 2WD vehicle and walking

Drive down the Chain of Craters road to the Puu Loa Petroglyph parking area. From the parking area, drive 0.7 mi and stop just at the beginning of a curve that bends to the left., less than 0.1 miles past the 17 mile marker. The station is 200 m SW from the right edge of the road on a pahoehoe tumulus. A rock cairn marking the station is visible on the skyline from the road.

MAKAOPUHI QUAD

STATION NAME: **KAMAKAIA**
ELEVATION: 803 m (2635')
LATITUDE: 19° 18.06'
LONGITUDE: 155° 22.28'

DESCRIPTION: Standard USGS bm stamped "HVO128"
ACCESS: Helicopter

Located on the southwest rift of Kilauea, this station is best flown to. The station is located on a triangular cement pad on top of the southwestern-most cinder cone of the Kamakaia Hills. One must be careful not to set up on another, nearby benchmark. A helicopter can land on top of the cone.

KA'U DESERT QUAD

STATION NAME: **KAMOAMOA**
ELEVATION: 43 m (141')
LATITUDE: 19° 19.08'
LONGITUDE: 155° 3.77'

DESCRIPTION: Standard USGS bm stamped "HVO158"
ACCESS: 2WD vehicle

Located on the south coast of Kilauea, on the first prominent tumulus east of Lae Apuki. The tumulus is marked by a large rock cairn and is visible on the skyline to the east from Lae Apuki. It is 15-20 m toward the coast from the road. A helicopter can land on the road or very near the station, but one must let the National Park Service know in advance. At this time, lava flows are crossing the Chain of Craters road at Lae Apuki, so that the station is stranded between these flows and the flows that overran Kamoamoa park to the east in late 1992. It is possible that the station will be destroyed if the eruption continues to send flows into this area.

KALAPANA QUAD*

STATION NAME: **KAPAPALA**
ELEVATION: 493 m (1617')
LATITUDE: 19° 14.27'
LONGITUDE: 155° 26.83'

DESCRIPTION: Standard USGS benchmark stamped "Kapapala 1949" cemented in bedrock
ACCESS: 2WD vehicle and walking. Contact Ken Fujiyama at the Volcano House for permission and leave a note in ranch mailbox.

From the Observatory, drive southwest on Highway 11 for 19 miles and stop at the ranch on the left side of the highway. Place a note in the mailbox describing your survey plans for the ranch personnel. From there, continue on the hwy for 0.8 miles, pulling off the road just before a curve to the right. The station is located about 200 m south (left) of the highway (you will need to cross a barbed-wire fence). It is on a pahoehoe tumulus about 2.5 m higher than the surrounding area. Remnants of a wooden trig flag may be around near the benchmark.

WOOD VALLEY QUAD SHEET

STATION NAME: **KEANAKAKOI**
ELEVATION: 1118 m (3668')
LATITUDE: 19° 24.11'
LONGITUDE: 155° 15.94'

DESCRIPTION: Standard USGS bm stamped "KEANAKAKOI RESET"
ACCESS: 2WD vehicle

Located along Crater Rim Drive, across from the western parking area for Keanakakoi Crater. The benchmark is cemented in pahoehoe, 10 m north of the center line of Crater Rim Drive, 1 m above road level. (Note that, for obscure reasons, this station, which is also a leveling and EDM site, is often called HVO10 Reset.)

KILAUEA CRATER QUAD*

STATION NAME: **NALI**
ELEVATION: 113 m (371')
LATITUDE: 19° 12.66'
LONGITUDE: 155° 21.97'

DESCRIPTION: Standard USGS bm stamped "NALI"
ACCESS: Helicopter

Located on the lower southwest rift of Kilauea on a prominent tumulus 2 km west of Naliikakani Point. The station is about 600 m east of a large aa flow and about 100 m WNW of a small kipuka of a aa with a pahoehoe flow through the middle. There are remnants of a wooden trig flag near the station. This station is best flown to in a helicopter with a GPS navigation system..

NALIIKAKANI QUAD

STATION NAME: **PANAU**
ELEVATION: 357 m (1171')
LATITUDE: 19° 19.17'
LONGITUDE: 155° 6.35'

DESCRIPTION: USC&GS bm, unstamped
ACCESS: Helicopter

Located 1.5 miles east of the hairpin turn on the Chain of Craters road, about .25 miles back from the cliff edge (Holei Pali), on the highest point of a large tumulus that is on a slight rise. There are few scattered ohia trees in the vicinity. When flying to the station from the west, the tumulus is prominent on the skyline and is marked by white paint. There are two reference marks near the main benchmark. The helicopter can land at the base of the tumulus.

KALAPANA QUAD

STATION NAME: **PUU HULUHULU**
ELEVATION: 1068 m (3503')
LATITUDE: 19° 22.29'
LONGITUDE: 155° 12.32'

DESCRIPTION: Standard USGS aluminum benchmark
ACCESS: 2WD vehicle and hike or 4WD drive vehicle, National Park GMX key, and shorter hike

Puu Huluhulu is a prehistoric cone located on the upper east rift of Kilauea volcano west and adjacent to Mauna Ulu. From the Chain of Craters Road, turn left on the Mauna Ulu access road and go 200 m to the Escape road located on the left. Go through the locked gate, drive onto the 1973, 1979 lava flows and turn right about 50 m before the far edge of the flow onto a road heading in the direction of the cone. Drive on this road until you intersect the hiking trail, then follow the trail as far as you can drive. Walk the rest of the way following the trail to the top of the cone. The station is located on the high point about 20 m west of the overlook, on a triangular cement pad. If a 2 wheel-drive vehicle is being used, park at the Mauna Ulu parking lot and follow the trail up to Puu Huluhulu.

MAKAOPUHI QUAD

STATION NAME: **PUU KAPUKAPU**
ELEVATION: 337 m (1106')
LATITUDE: 19° 16.544'
LONGITUDE: 155° 15.57'

DESCRIPTION: Standard USGS bm, unstamped
ACCESS: Helicopter

Located on top of a horst about .25 mile NW of Halape on the south coast of the island. The benchmark is cemented in a boulder on the western end of the hill. The site can get very windy; care should be taken landing the helicopter and the tripod should be weighted down. There are some rocks near the station, but sandbags would be handy.

KAU DESERT QUAD

STATION NAME: **PUU KOAE**
ELEVATION: 1009 m (3310')
LATITUDE: 19° 21.32'
LONGITUDE: 155° 19.34'

DESCRIPTION: Tagged rebar; stamped "PUU KOAE RESET"
ACCESS: 4WD vehicle

From the observatory, drive about 1.9 miles west on Crater Rim Drive to an unpaved road to the right, just past the southwest rift cracks and just before the left bend in the road at the ash-draped caldera faults. Follow the road up and to the left, taking the first right turn. From this point, the station is about 4.5 miles. The road will lead you past the Sandhill electronic tilt station. Keep following the road to the right and head toward the cinder cone. The road is marked by rock cairns and occasional ribbons and paint. It will go over pahoehoe and through sand washes, occasionally becoming quite rough. Drive to the west side of the cone and walk up the south-southeast side of the cone (trail is steep and on loose cinder) and follow the ridge to the left to the station. Center on the PK nail pounded into the top of the rebar. The site can be windy; the tripod should be weighted with sandbags. A helicopter can land at the base of the cone.

KAU DESERT QUAD

STATION NAME: **SANDHILL**
ELEVATION: 1149 m (3770')
LATITUDE: 19° 3.58'
LONGITUDE: 155° 17.49'

DESCRIPTION: Standard USGS bm stamped "HVO119"
ACCESS: 4WD vehicle

From the observatory, drive about 1.9 miles west on Crater Rim Drive to an unpaved road on the right just past the southwest rift cracks and just before the left bend in the road at the ash-draped caldera faults. Follow the road up, then to the left , past the first turnoff to the right and continue to the right where the road forks (0.2 miles from Crater Rim Drive). After about 0.1 miles, the road will turn right and lead directly to the station. There is a large rock cairn next to the benchmark.

KILAUEA CALDERA QUAD

STATION NAME: **UWEKAHUNA**
ELEVATION: 1269 m (4163')
LATITUDE: 19° 5.27'
LONGITUDE: 155° 17.21'

DESCRIPTION: Standard USGS aluminum bm stamped "HVO113", cemented in a rock outcrop
ACCESS: 2WD vehicle

The station is located on Uwekahuna Bluff, 300 m north of HVO at the base of the southwest corner of a large concrete pier (Uwekahuna triangulation station). Drive between the water tanks and the observatory building and head for the large concrete structure with an iron flag on it. The flag can be removed if no other survey party is using it.

KILAUEA CALDERA QUAD

Table 3: Description of miscellaneous stations occupied in 1992. Elevations and coordinates are WGS84 ellipsoid values. *'s next to quadrangle map names indicate that the station is not marked on the map.

STATION NAME: **HP6**
ELEVATION: 38 m (124')
LATITUDE: 20° 01.56'
LONGITUDE: 155° 49.26'

DESCRIPTION: NPS benchmark stamped "HP-6"
ACCESS: 2WD vehicle

The benchmark is located in Kawaihae, about 25 m west of the southwest corner of the Puukohola Heiau National Historic Monument visitors' center parking lot. The personnel at the visitors' center should be advised of the survey in advance. Also note that the park is closed with a gate across the access road in the evenings.

KAWAIHAE QUAD*

STATION NAME: **LYMAN**
ELEVATION: 8 m (26')
LATITUDE: 19°.43.55'
LONGITUDE: 155° 03.46'

DESCRIPTION: USC&GS benchmark stamped "REF LYMAN NO. 2." This a referernce mark, with an arrow pointing to the Lyman benchmark across the street, which is too close to the fence to be used for GPS.
ACCESS: 2WD vehicle. The Hilo Airport Authority would like to be notified, especially if observing at night; phone 935-0809.

From the Hwy 11 (Kanoelehua Avenue)-Hwy 19 (Kamehameha Avenue) intersection, at the Dairy Queen in Hilo, go 0.05 mi east to a fork in the road. Take the left fork (Kalanianaole Avenue) and drive 0.75 mi to the intersection with Silva St. (the pier will be on your left). Take a right onto Silva St.and drive about .2 miles. The road will curve to the right and turn into Kamehameha Ave. The station is located less than a hundred meters past this curve on the right side of the road, on a large, flat, pahoehoe rock outcrop, about 11 m from the centerline. This can be a heavy traffic area and cones or warning signs are recommended.

HILO QUAD * (The Lyman benchmark across the street is on the map.)

STATION NAME: **MAUNA KEA**
ELEVATION: 4167 m (13,671')
LATITUDE: 19° 49.37'
LONGITUDE: 155° 28.86'

DESCRIPTION: Standard USGS benchmark stamped "HVO88-14"
ACCESS: 4WD vehicle

The Mauna Kea GPS station is located near the summit of Mauna Kea. From Hilo, drive up Hiway 200 (Saddle Road), to the Mauna Kea road, which is on the right, across from a hunters check-in station. Follow this road until the astronomical observatories come into view. Take the road to the left, driving past the first, silver, dome-shaped observatory. Turn right onto a dirt road (may be paved later) that heads toward three observatories. After driving about 50 m, just before a curve to the right, turn left onto another dirt road which will take you up Poliahu Cone. Park at the edge of the ridge where the road makes a sharp left-hand turn and walk up to the right (northeasterly) about 50 meters. The station is marked with a large rock cairn. Extremely windy conditions are common, so the tripod must be stabilized with sandbags and/or tied down.

MAUNA KEA QUAD*

Table 4: Calendar of GPS occupations. In addition to Hawaii-time calendar dates, which are the dates listed on recording sheets, the UTM julian dates of occupation are listed below, since these are the dates included in data-file names. Also listed is the four-character site designation of each station that are used in RINEX filenames. The symbol * designates stations which were set up every evening; all others were set up only once and were started by timers. Station MLO was set up only once but was checked every 4 or 5 days (when batteries were replaced). The tripod occasionally needed very slight releveling, presumably due to contraction of the tripod legs from dehumidifying in the extremely dry conditions, which caused slight slipping. These slips never caused movements of more than two millimeters (usually less) from center. Other stations were found to be more seriously out of level on retrieval; these are marked with a †. §Station Nali was determined to have moved after the first three recording sessions, based on examination of reduced positions, and only the first three days of data are used to obtain the positions reported here.

2/12	044	Lyman*	Nali§	Apua Pt	Kamakaia	Hilina Pali	Uwekahuna
2/13	045	(RLYM)	(NALI)	(APUA)	(KAMK)	(HILI)	(UWEK)
2/14	046	"	"	"	"	"	"
2/15	047	"	"	"	"	Kapapala	"
2/16	048	"	"	"	"	(KAPA)	"
2/17	049	"	"	"	"	"	"
2/18	050	"	Poomoku	Eleiki	HVO92-1	HVO92-2	
2/19	051	"	(MOKU)	(LEKI)	(V921)	(O922)	MLO
2/20	052	"	"	"	"	"	(MLOO)
2/21	053	"	Eleele†	HVO92	HVO92-3	HVO92-4	"
2/22	054	"	(ELEL)	(VO92)	(V923)	(V924)	"
2/23	055	"	"	"	"	"	"
2/24	056	"	"	"	"	"	"
2/25	057	"	"	"	"	"	"
2/26	058	"	"	"	Puu Ouo		"
2/27	059	"	ML1	HVO134	(POUO)	HVO93	"
2/28	060	"	(ML11)	(V134)	"	(VO93)	"
2/29	061	"	"	"	"	"	"
3/01	062	"	"	"	"	"	"
3/02	063	"	"	"	"	"	"
3/03	064	"	ML Strip	Mauna Kea	1899 Cone	Uwekahuna	"
3/04	065	"	(MLST)	(MKEA)	(1899)	(UWEK)	"
3/05	066	"	"	"	"	"	"
3/07	068	Lyman*	Keei*	Kealakekua*	HP6	Mililii*	MLO
3/08	069	(RLYM)	(KEEI)	(KRCN)	(HP6K)	(MILL)	(MLOO)
3/09	070	"	"	"	"	"	"
3/10	071	"	Puu Ohohia	Kipuka Akala	Naalehu	Crusher	"
3/11	072	"	(V927)	(V928)	(V929)	(CRSH)	"
3/12	073	"	"	"	"	"	"
3/13	074	"	Sandhill	Kaena Point	Kamoamoa	BM80-1	Uwekahuna
3/14	075	"	(V119)	(KAEN)	(KAMO)	(M801)	(UWEK)
3/15	076	"	"	"	"	"	"
3/16	077	"	Keakapulu Flats	Goat	Escape Rd		"
3/17	078	"	(KFLT)	(GOAT)	(ESCP)		"
3/18	079	"	"	"	Kapukapu	Hakuma†	"
3/19	080	"	Ainapo Trail	Kulani	(KAPU)	(HAK)	"
3/20	081	"	(AINA)	(KULN)	"	"	"
3/21	082	"	"	"			"
3/22	083		"	"			"

3/24	085a		Puu Koae	Puu Huluhulu	"
3/25	085b		(KOAE)	(HULU)	"
3/25	086a		"	"	"
3/26	087a	Lyman*	HVO7*	Halona	
3/27	087b	(RLYM)	(HVO7)	(HLON)	
3/27	088a	"	"	"	
3/31	092a		HVO23	HVO118	Uwekahuna
4/1	092b		(VO23)	(V118)	(UWEK)
4/1	093a		92YY	HVO120	"
4/2	093b		(92YY)	(V120)	"
4/2	094a		HVO34	Keanakakoi	"
4/2	094b		(VO34)	(KNKK)	"
4/22	114a		Panau	GPS Pulama	Uwekahuna
4/23	114b		(PANA)	(PULM)	(UWEK)
4/23	115a		"	"	"
4/24	115b		"	"	"
4/28	120a		Puu Pili	Punaluu Gulch	Uwekahuna
4/29	120b		(PILI)	(9218)	(UWEK)
4/29	121a		"	"	"
4/30	121b		"	"	"

Table 5: Average WGS84 coordinates and ellipsoid heights determined with Ashtech GPPS software, using broadcast orbits, along with standard deviations, in meters, based on differences from the mean position and number of sessions (n). Table 5a lists positions relative to Lyman, positions in Table 5b are relative to Uwekahuna

Table 5a

	Latitude	s.d.(m)	Longitude	s.d.(m)	Ellipsoid height		n
lyman	19° 43' 21.90783"		155° 03' 17.26675"		26.0300		Ref
1899 cone	19° 03' 45.58056"	.0026	155° 29' 31.01655"	.0095	2905.0385	.0637	3
ainapo trail	19° 22' 24.01298"	.0031	155° 27' 28.90688"	.0119	1570.0188	.0557	3
apua pt	19° 15' 35.47944"	.0057	155° 11' 33.52220"	.0133	24.3966	.0352	6
bm80-1	19° 09' 01.12902"	.0052	155° 10' 02.69580"	.0114	632.3594	.0135	3
crusher	19° 04' 06.88674"	.0008	155° 43' 41.21493"	.0088	626.2536	.0162	3
eleele	19° 26' 38.74018"	.0089	155° 31' 04.78706"	.0074	3238.0352	.0601	7
eleiki	19° 28' 48.14579"	.0051	155° 27' 14.23423"	.0226	2623.0935	.0370	3
escape rd	19° 25' 09.56412"	.0034	155° 14' 25.64225"	.0062	1199.7765	.0368	2
goat	19° 19' 35.30299"	.0078	155° 13' 41.10341"	.0389	829.6760	.0081	3
hakuma	19° 20' 45.26422"	.0008	154° 58' 44.87352"	.0098	33.4269	.0160	3
halona	19° 33' 19.18076"	.0037	154° 56' 28.23897"	.0176	114.7813	.0317	2
hilina pali	19° 17' 40.24893"	.0088	155° 18' 26.32725"	.0192	706.4363	.0182	3
hp6	20° 01' 33.92208"	.0071	155° 49' 13.92226"	.0057	59.0208	.0524	3
hvo7	19° 30' 28.21614"	.0037	154° 50' 04.71086"	.0214	46.1411	.0233	3
hvo92	19° 28' 00.81215"	.0039	155° 34' 53.29906"	.0129	4075.1759	.0714	7
hvo92-1	19° 03' 55.84155"	.0040	155° 38' 17.19132"	.0139	3545.1970	.0369	3
hvo92-2	19° 03' 00.97465"	.0083	155° 37' 30.22192"	.0147	3412.1598	.0346	3
hvo92-3	19° 01' 28.59473"	.0052	155° 40' 29.43054"	.0143	2961.2732	.0630	6
hvo92-4	19° 00' 45.71832"	.0053	155° 39' 24.02625"	.0118	2961.1016	.0723	6
hvo93	19° 28' 54.58321"	.0049	155° 35' 56.32351"	.0145	4164.3972	.0427	4
hvo134	19° 07' 53.16395"	.0043	155° 36' 16.61695"	.0144	4136.6866	.0437	4
kaena point	19° 16' 52.23438"	.0052	155° 07' 17.34408"	.0074	40.4827	.0131	3
kamakaia	19° 18' 03.53367"	.0070	155° 22' 16.57372"	.0128	824.5666	.0186	6
kamoamoa	19° 19' 04.79547"	.0075	155° 03' 46.45848"	.0083	43.3098	.0080	3
kapapala	19° 14' 16.12969"	.0013	155° 26' 49.92448"	.0075	493.7970	.0407	3
kapukapu	19° 16' 32.51099"	.0091	155° 15' 34.47187"	.0543	337.7175	.0081	3
keakapulu flts	19° 22' 05.54798"	.0016	155° 25' 14.29708"	.0416	1286.6132	.0349	3
kealakekua	19° 29' 12.57463"	.0016	155° 54' 20.32381"	.0174	495.8519	.0277	3
keei	19° 27' 55.56590"	.0058	155° 55' 09.39351"	.0059	32.8443	.0293	3
kipuka akala	19° 10' 13.79162"	.0030	155° 41' 05.16202"	.0085	1576.0482	.0180	3
kulani	19° 31' 13.73628"	.0028	155° 17' 56.29882"	.0160	1706.4465	.0214	3
mauna kea	19° 49' 22.06438"	.0043	155° 28' 51.58738"	.0095	4163.6969	.0566	3
milolii	19° 11' 04.37116"	.0015	155° 54' 25.70074"	.0119	19.6523	.0240	3
ml strip	19° 29' 32.74724"	.0018	155° 23' 08.42223"	.0150	2060.5611	.0488	3
ml1	19° 27' 06.36386"	.0037	155° 35' 36.75320'	.0142	4082.4262	.0425	4
mlo	19° 32' 11.32371"	.0066	155° 34' 32.55853"	.0127	3419.6502	.0468	22
naalehu	19° 03' 10.84952"	.0008	155° 34' 51.60216"	.0070	218.5669	.0323	3
nali	19° 12' 39.38517"	.0080	155° 21' 58.17659"	.0154	113.2909	.0126	3
poomoku	19° 29' 16.12531"	.0054	155° 31' 07.21773"	.0288	3438.6713	.0414	3
puu ohohia	19° 10' 54.13693"	.0020	155° 46' 00.12015"	.0021	1626.7390	.0098	3
puu ouo	19° 29' 51.44384"	.0052	155° 41' 34.56375"	.0129	2717.5080	.0381	5
sandhill	19° 23' 34.55340"	.0046	155° 17' 29.17610"	.0071	1149.6010	.0098	3
uwekahuna	19° 25' 15.99438"	.0069	155° 17' 12.47092"	.0239	1269.1319	.0339	18

Table 5b

92yy	19° 25' 53.52915"	.0055	155° 16' 00.22969"	.0011	1224.8225	.0008	2
gps pulama	19° 21' 25.18299"	.0049	155° 01' 45.28362"	.0154	204.5373	.0226	4
huluhulu	19° 22' 17.38299"	.0054	155° 12' 19.51810"	.0105	1068.9104	.0041	4
hvo23	19° 26' 16.37726"	.0001	155° 18' 18.75973"	.0021	1215.0182	.0026	2
hvo34	19° 23' 58.81072"	.0048	155° 16' 41.46307"	.0013	1128.1562	.0053	2
hvo118	19° 24' 54.58328"	.0006	155° 17' 55.68387"	.0014	1206.1754	.0028	2
hvo120	19° 24' 39.26010"	.0028	155° 19' 25.05819"	.0007	1130.0833	.0092	2
keanakakoi	19° 24' 06.61934"	.0082	155° 15' 56.65563"	.0006	1140.5940	.0051	2
panau	19° 19' 10.39436"	.0057	155° 06' 21.28346"	.0138	357.0515	.0291	4
punaluu gulch	19° 11' 31.75382"	.0094	155° 32' 20.47391"	.0306	691.0166	.0116	4
puu koae	19° 21' 19.41268"	.0067	155° 19' 20.69153"	.0136	1009.1505	.0145	4
puu pili	19° 08' 51.16851"	.0057	155° 27' 26.64312"	.0369	36.1223	.0234	4

Table 6: Adjusted WGS84 coordinates and elevations, with standard deviations, in meters, based on the least-squares network adjustment. 6a: Relative to Lyman; 6b: relative to Uwekahuna

Table 6a

	Latitude	s.d.(m)	Longitude	s.d.(m)	Ellipsoid Height	
lyman	19° 43' 21.90783"		155° 03' 17.26675"		26.0300	
1899cone	19° 33' 45.58045"	.0018	155° 29' 31.01649"	.0052	2905.0494	.0052
ainapo trail	19° 22' 24.01316"	.0024	155° 27' 28.90637"	.0069	1570.0293	.0068
apua pt	19° 15' 35.47939"	.0014	155° 11' 33.52242"	.0042	24.3943	.0043
bm80-1	19° 19' 01.12902"	.0018	155° 10' 02.69608"	.0054	632.3667	.0056
crusher	19° 04' 06.88676"	.0025	155° 43' 41.21502"	.0072	626.2541	.0067
eleele	19° 26' 38.74022"	.0011	155° 31' 04.78692"	.0031	3238.0459	.0033
eleiki	19° 28' 48.14581"	.0020	155° 27' 14.23387"	.0060	2623.0992	.0062
escape rd	19° 25' 09.56416"	.0037	155° 14' 25.64165"	.0123	1199.7965	.0133
goat	19° 19' 35.30291"	.0021	155° 13' 41.10293"	.0062	829.6796	.0063
hakuma	19° 20' 45.26427"	.0025	154° 58' 44.87243"	.0072	33.4398	.0072
halona	19° 33' 19.18074'	.0034	154° 56' 28.23910"	.0085	114.7792	.0097
hilina pali	19° 17' 40.24895"	.0018	155° 18' 26.32749"	.0055	706.4268	.0056
hp6	20° 01' 33.92197"	.0023	155° 49' 13.92259"	.0066	59.0305	.0067
hvo7	19° 30' 28.21610"	.0032	154° 50' 04.71066"	.0083	46.1436	.0092
hvo92	19° 28' 00.81226"	.0010	155° 34' 53.29909"	.0030	4075.1849	.0032
hvo92-1	19° 23' 55.84157"	.0020	155° 38' 17.19111"	.0060	3545.2024	.0063
hvo92-2	19° 23' 00.97478"	.0020	155° 37' 30.22171"	.0060	3412.1664	.0062
hvo92-3	19° 21' 28.59484"	.0012	155° 40' 29.43050"	.0035	2961.2806	.0037
hvo92-4	19° 20' 45.71843"	.0011	155° 39' 24.02627"	.0033	2961.1150	.0034
hvo93	19° 28' 54.58317"	.0013	155° 35' 56.32360"	.0038	4164.3863	.0039
hvo134	19° 27' 53.16392"	.0013	155° 36' 16.61705"	.0037	4136.6769	.0038
kaena point	19° 16' 52.23439"	.0019	155° 07' 17.34428"	.0058	40.4880	.0059
kamakaia	19° 18' 03.53362"	.0013	155° 22' 16.57387"	.0040	824.5660	.0041
kamoamoa	19° 19' 04.79551"	.0018	155° 03' 46.45862"	.0054	43.3150	.0056
kapapala	19° 14' 16.12955"	.0018	155° 26' 49.92465"	.0054	493.8032	.0055
kapukapu	19° 16' 32.51113"	.0025	155° 15' 34.47136"	.0072	337.7208	.0073
keakapulu flts	19° 22' 05.54794"	.0021	155° 25' 14.29655"	.0062	1286.6149	.0063
kealekekua	19° 29' 12.57444"	.0020	155° 54' 20.32419"	.0061	495.8462	.0062
keei	19° 27' 55.56572"	.0021	155° 55' 09.39392"	.0063	32.8359	.0064
kipuka akala	19° 10' 13.79166"	.0024	155° 41' 05.16217'	.0068	1576.0529	.0063
kulani	19° 31' 13.73638"	.0031	155° 17' 56.29844"	.0093	1706.4453	.0099
mauna kea	19° 49' 22.06426"	.0018	155° 28' 51.58727"	.0052	4163.7070	.0051
milolii	19° 11' 04.37100"	.0022	155° 54' 25.70087"	.0066	19.6471	.0065
ml strip	19° 29' 32.74713"	.0020	155° 23' 08.42207"	.0057	2060.5705	.0057
ml1	19° 27' 06.36383"	.0013	155° 35' 36.75334"	.0037	4082.4165	.0038
mlo	19° 32' 11.32370"	.0008	155° 34' 32.55862"	.0023	3419.6529	.0024
naalehu	19° 03' 10.84956"	.0024	155° 34' 51.60238"	.0067	218.5625	.0062
nali	19° 12' 39.38522"	.0017	155° 21' 58.17684"	.0051	113.2837	.0053
poomoku	19° 29' 16.12539"	.0019	155° 31' 07.21725"	.0057	3438.6722	.0060
puu ohohia	19° 10' 54.13693"	.0023	155° 46' 00.12028"	.0065	1626.7400	.0061
puu ouo	19° 29' 51.44383"	.0012	155° 41' 34.56385"	.0036	2717.4998	.0036
sandhill	19° 23' 34.55341"	.0017	155° 17' 29.17635"	.0052	1149.6096	.0054
uwekahuna	19° 25' 15.99442"	.0010	155 17' 12.47097"	.0030	1269.1308	.0032

Table 6b

uwekahuna	19°	25' 15.99445"		155°	17' 12.47098"	1269.1222	
92yy	19°	25' 53.52912"	.0018	155°	16' 00.22970"	.0019	1224.8237	.0055
gps pulama	19°	21' 25.18298"	.0018	155°	01' 45.28346"	.0028	204.5381	.0054
huluhulu	19°	22' 17.38294"	.0022	155°	12' 19.51796"	.0058	1068.9185	.0067
hvo23	19°	26' 16.37725"	.0022	155°	18' 18.75974"	.0024	1215.0186	.0069
hvo34	19°	23' 58.81073"	.0022	155°	16' 41.46314"	.0022	1128.1658	.0067
hvo118	19°	24' 54.58328"	.0020	155°	17' 55.68387"	.0022	1206.1763	.0064
hvo120	19°	24' 39.26010"	.0018	155°	19' 25.05820"	.0020	1130.0823	.0058
keanakakoi	19°	24' 06.61935"	.0023	155°	15' 56.65568"	.0023	1140.5934	.0070
panau	19°	19' 10.39436"	.0019	155°	06' 21.28353"	.0029	357.0485	.0054
puu koae	19°	21' 19.41263"	.0022	155°	19' 20.69173"	.0059	1009.1544	.0063
punaluu gulch	19°	11' 31.75383"	.0026	155°	32' 20.47397"	.0064	691.0196	.0067
puu pili	19°	08' 51.16840"	.0024	155°	27' 26.64284"	.0060	36.1360	.0066

Table 7: Adjusted cartesian GPS positions; a: relative to Lyman, b: relative to Uwekahuna.

Table 7a

lyman	-5445971.0602	-2533159.9104	2138839.1987
1899 cone	-5473028.7727	-2495131.7376	2123112.3908
ainapo trail	-5476761.7226	-2500750.7899	2102900.9324
apua pt	-5467568.3029	-2527222.9904	2090533.3938
bm80-1	-5465079.9686	-2528994.0515	2096703.0509
crusher	-5497802.7033	-2479106.0346	2070730.2491
eleele	-5478438.1288	-2494590.2599	2110845.5538
eleiki	-5473912.4374	-2499920.3564	2114394.1762
escape rd	-5465373.3522	-2520675.5819	2107580.6550
goat	-5467608.1098	-2523138.1661	2097760.0729
gps lyman	-5445634.1200	-2534241.4961	2138424.2756
hakuma	-5455267.0641	-2546252.2366	2099526.4572
halona	-5446655.5967	-2546628.1591	2121413.1492
hilina pali	-5472049.2656	-2516015.2984	2094380.1691
hp6	-5468952.3510	-2455489.1462	2170430.8136
hvo7	-5443443.2237	-2557471.1376	2116435.5554
hvo92	-5481151.3317	-2488498.0193	2113505.3154
hvo92-1	-5485437.5913	-2483906.9410	2106221.1788
hvo92-2	-5485268.0224	-2485335.5005	2104584.7345
hvo92-3	-5487896.6394	-2480781.8795	2101754.0443
hvo92-4	-5487507.8179	-2482702.0081	2100509.4921
hvo93	-5481485.7115	-2486630.0013	2115094.8980
hvo134	-5482280.3031	-2486340.1151	2113303.9251
kaena point	-5463732.4630	-2533690.3936	2092766.5980
kamakaia	-5474740.6416	-2509853.3191	2095095.0406
kamoamoa	-5459919.9832	-2538708.3212	2096614.5899
kapapala	-5479877.1185	-2503424.9810	2088384.5525
kapukapu	-5470259.8074	-2520715.9061	2092292.2572
keakapulu flats	-5475056.7037	-2504291.5670	2102271.1625
kealekekua	-5491390.7918	-2455768.4765	2114392.9914
keei	-5492297.1631	-2454606.0678	2112006.0469
kipuka akala	-5493375.3285	-2482112.4993	2081702.5317
kulani	-5464987.1127	-2513732.0498	2118309.6697
mauna kea	-5464796.1420	-2492640.3847	2150664.3725
milolii	-5501158.8976	-2459964.7320	2082660.3692
ml strip	-5470031.1271	-2506030.5033	2115499.9149
ml1	-5482189.9172	-2487576.6729	2111928.0926
mlo	-5477995.6424	-2487729.7011	2120551.9491
naalehu	-5491580.6722	-2493287.5298	2068968.4379
nali	-5476894.4997	-2511431.9206	2085450.2603
poomoku	-5477171.1475	-2493935.4283	2115477.6797
puu ohohia	-5496591.1065	-2474106.8060	2082891.1948
puu ouo	-5483781.0143	-2476836.2284	2116261.3067
sandhill	-5468453.0817	-2516197.5337	2104807.9477
uwekahuna	-5467409.9831	-2516254.1489	2107790.2204

Table 7b

uwekahuna	-5467409.9756	-2516254.1451	2107790.2184
92yy	-5466141.6918	-2517990.7535	2108864.1545
gps pulama	-5457269.6972	-2541376.2153	2100741.2868
huluhulu	-5465315.3656	-2524702.6853	2102542.3402
hvo23	-5467610.7448	-2514217.5110	2109523.5513
hvo34	-5467627.4673	-2517350.3566	2105504.5103
hvo118	-5468081.9769	-2515175.3349	2107148.2441
hvo120	-5469248.4045	-2512841.2163	2106678.4829
keanakakoi	-5467018.6881	-2518509.5717	2105735.1532
panau	-5462040.9264	-2534709.9755	2096880.8500
punaluu gulch	-5485565.7325	-2495405.9664	2083676.2781
puu koae	-5470945.0711	-2513761.0133	2100840.5495
puu pili	-5482917.6935	-2503634.3895	2078797.0289