Geodetic Studies in the Novarupta Area, Katmai National Park, Alaska, 1990 to 1995

By Jack W. Kleinman, Eugene Y. Iwatsubo, John A. Power, *and* Elliot T. Endo

Note. - Jack W. Kleinman (1961-1994), a member of the geodesy group at the Cascades Volcano Observatory, Vancouver, Washington, died in a kayaking accident on the White Salmon River, Washington, on February 12, 1994. Jack started employment with the U.S. Geological Survey in the summer of 1985. In the spring of 1986, he began his career in volcano studies by participating in geodetic monitoring at Mount St. Helens. In the following years Jack worked on projects that took him to Yellowstone National Park, Long Valley, most of the Cascades volcanoes, the South Pole, Stromboli, Italy, and Alaska. Jack especially liked working in Alaska. He helped establish the first geodetic network near Novarupta, Katmai National Park, Alaska, in 1989, and served as crew chief for additional surveys there in 1990 and 1993. The job entailed long days of hard work in the face of unforgiving weather, logistical complexities, and a skin-tight budget. As in his kayaking, Jack relished the challenges of working in Alaska. For Jack, the colder and wetter, the more he liked field work. The physically demanding field work at Katmai National Park and on Augustine Island was perfect for Jack. He is missed by his colleagues and friends.

ABSTRACT

A five-station electronic distance meter (EDM) network centered around the Novarupta dome in Katmai National Park, Alaska, was established in 1990 and resurveyed in 1993 and 1995. Both EDM and Global Positioning System (GPS) measurements were made in 1993. The 1995 survey was restricted to the more accurate GPS surveying method. Analysis of EDM data in 1993 suggested an average increase of 22.5 mm in slope distances between stations from 1990 to 1993. Those changes were about 2-3 times the expected error for lines of this length (1.5 to 4.7 km) and suggested that ground deformation was taking place in the Novarupta area. Loss of data from one of five GPS receivers in 1993 precluded complete comparison of GPS data with EDM results. In July 1995, the network was occupied with five P-code GPS receivers. Two 12-15 hour observations were made simultaneously at all five stations,

which were located relative to a reference GPS station in Fairbanks. For final L1-only solutions and EDM line lengths between stations, one station was held fixed using these new coordinates. The 1995 GPS results, when compared with recomputed EDM line lengths for 1990 and 1993 and available 1993 GPS line lengths, indicate that the Novarupta site moved about 15-20 mm to the west and the Mainstreet station moved a similar distance to the northwest during the interval from 1990 to 1993. There is a suggestion that the Mainstreet station also moved from 1993 to 1995. The movement at both stations is thought to be a result of a deformation source to the southeast outside the network or associated with the stability of the sites. The movement is not a result of volcano deformation centered at Novarupta. To further evaluate ground deformation in the Katmai area, extension of the network with GPS observations beyond the immediate vicinity of Novarupta is recommended.

INTRODUCTION

Novarupta dome, located at the head of the Valley of Ten Thousand Smokes in Katmai National Park, Alaska (fig. 1), is the site of the largest volcanic eruption world-wide this century. During the 1912 eruption, approximately

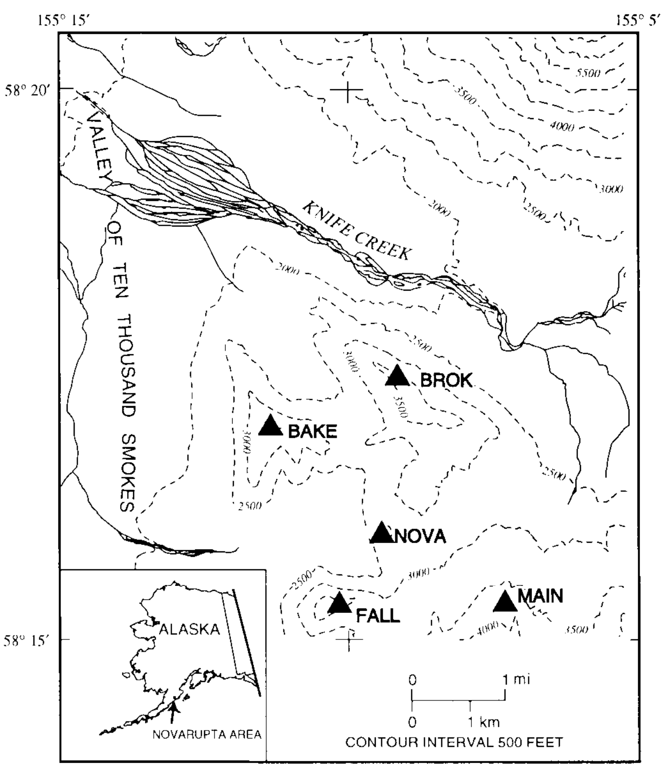

Figure 1. The braced quadrilateral geodetic network in the Novarupta area of the Valley of Ten Thousand Smokes. Benchmark locations are indicated by triangles and abbreviated names used in the text.

15 km³ of compositionally mingled magma (Hildreth, 1983) erupted from the Novarupta vent area, which collapsed to form a 2-km-wide depression. The summit of nearby Mt. Katmai synchronously collapsed, presumably a result of a complex connection with the venting magma system (Hildreth, 1983, 1987). The eruptive sequence ended with the extrusion of the Novarupta rhyolite dome within the vent depression.

In conjunction with other geophysical studies initiated under the Continental Scientific Drilling Program (Eichelberger and Hildreth, 1986; Eichelberger and others, 1991), a geodetic network was established during 1989-90 to monitor ground deformation in the Novarupta area (Kleinman and Iwatsubo, 1991). The geodetic network consists of three stations from which measurements of slope distance and zenith angle can be made to each of the other stations. This technique was first used by the U.S. Geological Survey (USGS) in 1965 at the volcanoes Kilauea and Mauna Loa on the island of Hawaii. It was later used successfully to monitor ground deformation at Mount St. Helens both before and after the May 18, 1980, eruption (Lipman and others, 1981). Similar networks have been established at many of the other volcanoes in the Cascades Range to provide baseline geodetic information (Chadwick and others, 1985; Iwatsubo and others, 1988). A comparison of measurements of a three-station Novarupta electronic distance meter (EDM) network in 1989 and 1990 revealed no changes in slope distance larger than the expected measurement error (Kleinman and Iwatsubo, 1991). In 1990, part of the network was reestablished with more permanent marks and two stations were added to form the geodetic network resurveyed in 1993 and 1995.

The first opportunity to remeasure the network came in 1993. Following the Redoubt eruptions in 1990, the USGS Volcano Hazards Program began experimenting with Global Positioning System (GPS) receivers acquired for the purpose of monitoring geodetic networks on silicic volcanoes. With the availability of GPS equipment, a decision was made to occupy the Katmai network with both EDM and GPS receivers. GPS surveying does not require intervisibility between stations and thus could be accomplished in inclement weather. Dvorak and others (1994) describe the GPS surveying technique that was first applied in Hawaii and subsequently used at Novarupta.

THE NOVARUPTA GEODETIC NETWORK

The geodetic network in the Novarupta area consists of one benchmark located on Novarupta (NOVA) and four additional benchmarks located on surrounding topographic highs (fig. 1). These four stations (Baked Mountain, BAKE; Broken Mountain, BROK; Falling Mountain, FALL; and Mainstreet, MAIN) formed a 2 km by 4 km braced quadrilateral approximately centered around Novarupta. The Falling Mountain, Broken Mountain, and Mainstreet benchmarks are fixed on 1.25-cm diameter copperweld rods driven 10.7 m into tephra at BROK and MAIN. The rod at FALL was driven to a depth of 2.4 m (Kleinman and Iwatsubo, 1991) into tephra. The benchmark on Novarupta, stamped 1989 K-2, is fixed in a hole drilled into a large rhyolite boulder and has a punch mark enclosed by a small rectangle for a centering target. The Baked Mountain benchmark is a brass disk approximately 7.6 cm in diameter cemented in shale. The brass disk is stamped BAKED and has a punch mark located about 2 cm from the center of the disk that was used as a target for centering. Benchmarks at other sites have small + marks enclosed by a triangle for centering targets. Broken Mountain is stamped K-3, Mainstreet K-4, and Falling Mountain K-5. An older benchmark at Falling Mountain, K-1, has been abandoned. Owing to the topography and the weight of surveying equipment and batteries, all sites require helicopter support out of King Salmon. Baked Mountain, Novarupta, and Falling Mountain require short hikes from helicopter landing sites.

GEODETIC FIELD WORK AND DATA ANALYSIS

EDM MEASUREMENTS AND CORRECTIONS

The 10 lines of the braced quadrilateral network at Novarupta were measured in July 1990 and in June 1993. A Wild DI-5 EDM and a Wild T-2000 theodolite were used for the 1990 survey. In 1993, a Geodimeter 6000 EDM and a Wild T-2 theodolite were used. Prism sets mounted onto tripods and centered over permanent benchmarks were used for both surveys. Both the Wild DI-5 EDM and the Geodimeter 6000 EDM automatically measure distance. Hundreds of measurements at several different modulation frequencies are performed automatically by the EDM instruments with the push of a button. A mean distance and standard deviation is given for each set of measurements to a reflector. In 1990, as many as eight triangular clusters of three retro-reflectors were used because the DI-5 has a relatively weak laser source; vertical clusters of three retro-reflectors were used in 1993. Retroreflectors used in 1993 could be tilted, but it is not known if the any clusters were tilted. Vertical angles were measured with a theodelite from each EDM setup to reflector sites. These vertical angles, along with instrument and reflector heights measured at each site, were used for conversion of slope distances to mark-to-mark distances. Mark-to-mark measured distances were corrected for atmospheric refraction (temperature, pressure, and humidity). The 1990 and 1993 EDM data were first reduced in 1993 with a hand calculator. The average change in line length was +22.5 mm (where + represents extension).

To gauge the validity of these changes, it was necessary to evaluate all likely sources of error in the measurements. One error source is the EDM instrument itself. Manufacturer specifications are 3 mm ±2 parts per million (ppm) for the Wild DI-5 used in 1990 and 5 mm ±1 ppm for the Geodimeter 6000 used in 1993. Because different EDM's and reflector sets were used for the two surveys, we checked the equipment sets against each other on a 1-km-long National Geodetic Survey calibration line. The two EDM's agreed with each other within manufacturer's specifications, but the two different types of reflector sets differed by a constant factor of 0.0056 m. This difference was accounted for in the 1993 analysis results that indicated an average line-length change of 22.5 mm.

Atmospheric factors can cause line-length changes, which introduces another potential source of error. Temperature, pressure, and relative humidity were measured at each endpoint so that the appropriate atmospheric corrections could be applied to the line-length measurements. Temperature corrections, the largest of the atmospheric corrections, are about 1 ppm for every 1.0°C change in temperature. Temperatures were measured 7.6 m above ground level at the top of a telescoping survey rod to minimize the effect of ground radiation.

Errors can also be introduced by instrument or reflector setup inaccuracies. Tribrach circular level bubbles and optical plummets can be out of true or height measurements can be made incorrectly. We attempted to minimize these potential sources of error by calibrating optical plummet tribrachs and by making redundant height measurements. High winds can also introduce error. The highest winds were encountered in 1990 while measuring the line from Baked Mountain to Novarupta, which shortened by 15 mm from 1990 to 1993. Benchmark instabilities as a result of slope creep or unstable rock are also possible sources of error.

To ensure consistently analyzed mark-to-mark slope distances, 1990 and 1993 EDM measurements were reduced in 1995 with a computer program written by Cascades Volcano Observatory staff for routine reduction of EDM data. The results of the analysis of EDM data are shown in table 1, including baseline lengths and differences between the 1993 and 1990 EDM surveys. There is no standard deviation record for EDM field measurements, and errors indicated in the table 1 explanation are based on manufacturers' specifications.

GPS OBSERVATIONS AND ANALYSIS

OBSERVATIONS DURING 1993

The 1993 Alaska field season was the first opportunity to utilize GPS receivers as a volcano deformation monitoring tool in the Novarupta area at Katmai. Five Ashtech

Table 1. Line lengths from repeated EDM measurements of the Novarupta geodetic network in 1990 and 1993

[Manufacturer's specification for the EDM used in the 1990 survey is 3 mm +2 ppm. Manufacturer's specification for the EDM used in 1993 is 5 mm +l ppm]

Line	Distance-meters		Changes
	1990	1993	1993-1990
BAKE-NOVA	2566.0758	2566.0611	-0.015
BROK-NOVA	2795.7467	2795.7548	+0.008
MAIN-NOVA	2197.3964	2197.3972	+0.001
FALL-NOVA	1497.4217	1497.4070	-0.015
FALL-BAKE	3105.6921	3105.6878	-0.004
FALL-BROK	4070.6871	4070.6866	-0.001
FALL-MAIN	2663.3693	2663.3660	-0.003
MAIN-BAKE	4700.0450	4700.0297	-0.015
MAIN-BROK	4356.1728	4356.1608	-0.012
BROK-BAKE	2151.1032	2151.1045	+0.001

Table 2. Line lengths from GPS measurements of the Novarupta geodetic network in 1993

[Root-mean-square errors enclosed by parentheses. There were two 6-h observation sessions in 1993]

Station pair	Distance (meters)
BAKE-NOVA	2566.0555 (.009) 2566.0552 (.014)
BROK-NOVA	2795.7487 (.013) 2795.7534 (.015)
FALL-NOVA	1497.4040 (.006) 1497.4030 (.008)
FALL-BAKE	3105.6806 (.008) 3105.6809 (.013)
FALL-BROK	4070.6801 (.015) 4070.6783 (.012)
BROK-BAKE	2151.1062 (.008) 2151.1064 (.009)

dual-frequency receivers (no P-code capability) were deployed shortly after the completion of the EDM survey. Two 6-h observation sessions were made overnight. For unknown reasons, the receiver at MAIN failed and all data were lost. The loss of data from one receiver resulted in the loss of data for 4 baselines out of the 10 in the network around Novarupta. Using 1995 updated coordinates relative to Fairbanks, 1993 GPS data were processed using Ashtech GPS Post-Processing System (GPPS™) software and broadcast orbits (predicted satellite orbits). Precise orbits (computed from actual satellite orbits) from the same source for orbits used in 1995 were not available for July 1993, and this lack of precise-orbit data was one reason for using GPPS software. We saw no advantage in processing 1993 GPS data with geodetic-grade software. BAKE, BROK and FALL were fixed to obtain all possible baselines distances. Root-mean-square (RMS) errors (Bevington, 1969) for baseline-length solutions varied from 6 mm to 15 mm. GPPS-determined baseline lengths are shown in table 2. Seeber (1993) and Hofmann-Wellenhof and others (1992)

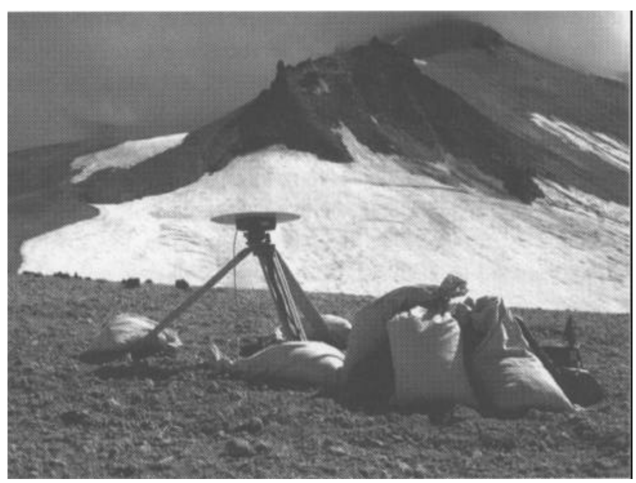

Figure 2. The Mainstreet GPS station located on the northwest slope of Trident Mountain. The GPS receiver and battery are located under a plastic tarpaulin weighted down by tephra filled sample bags in the left foreground.

Table 3. World Geodetic System (WGS)-84 latitude, longitude, height, and X, Y, and Z coordinates from repeated GPS observations

[Root-mean-square errors for X, Y, and Z coordinates are enclosed by parentheses. There were three 12-h solutions for BAKE and MAIN,and two 12-h solutions for BROK, FALL, and NOVA]

Station	North latitude	West longitude	Height (meters)	X (meters)	Y (meters)	Z (meters)
BAKE	58° 16' 51.814832"	155° 11' 29.228658"	1141.8988	-3051806.0133 (.0037)	-1410684.8700 (.0018)	5403232.7216 (.0061)
	58° 16' 51.814127"	155° 11' 29.225605"	1141.9129	-3051806.0160 (.0027)	-1410684.9261 (.0014)	5403232.7221 (.0044)
	58° 16' 51.817122"	155° 11' 29.222761"	1141.8514	-3051805.8956 (.0100)	-1410684.9215 (.0069)	5403232.7185 (.0148)
BROK	58° 17' 24.871796"	155° 9' 33.149105"	1097.2164	-3050200.6339 (.0028)	-1412026.6719 (.0014)	5403732.4601 (.0045)
	58° 17' 24.877422"	155° 9' 33.143637"	1097.0376	-3050200.3768 (.0101)	-1412026.6511 (.0072)	5403732.3996 (.0152)
FALL	58° 15' 16.652979"	155° 10' 28.750913"	1171.2769	-3053679.4393 (.0029)	-1412637.6641 (.0014)	5401708.8943 (.0046)
	58° 15' 16.656674"	155° 10' 28.746263"	1171.0427	-3053679.2074 (.0106)	-1412637.6404 (.0071)	5401708.7554 (.0154)
MAIN	58° 15' 16.079094"	155° 7' 45.486891"	1197.9303	-3052586.7675 (.0037)	-1415066.5384 (.0018)	5401722.2164 (.0060)
	58° 15' 16.079319"	155° 7' 45.487474"	1197.9186	-3052586.7606 (.0028)	-1415066.5247 (.0014)	5401722.2102 (.0045)
	58° 15' 16.083213"	155° 7' 45.482769"	1198.2440	-3052586.7906 (.0100)	-1415066.6232 (.0068)	5401722.5502 (.0146)
NOVA	58° 15' 54.906988"	155° 9' 36.201614"	845.0910	-3052250.1535 (.0031)	-1412920.6042 (.0015)	5402054.2212 (.0051)
	58° 15' 54.911162"	155° 9' 36.193736"	844.9653	-3052249.9399 (.0111)	-1412920.6469 (.0076)	5402054.1823 (.0167)

present thorough discussions of the GPS surveying technique and data analysis.

OBSERVATIONS DURING 1995

In late July 1995, five Trimble SSE receivers (dual-frequency P-code receivers) were borrowed from the Hawaiian Volcano Observatory to occupy the Novarupta network. On July 22, receivers were set up at MAIN (fig. 2) and at BAKE. Receivers were programmed to record for 16-h (30-s epochs) during the best NAVSTAR (NAVigation Satellite Time And Ranging) satellite configuration for the day. On July 23, additional receivers were installed at BROK, FALL, and NOVA. The receiver at NOVA was programmed to record for two 12-h sessions because of a battery limitation. The goal of the survey was to obtain at least two simultaneous 12-16 h observations for all stations. These long observations, although not required for short-baseline GPS surveys, were used to establish precise locations for each station relative to known GPS sites in Kodiak and Fairbanks. On July 24, all five GPS receivers were retrieved without incident.

The 1995 Novarupta GPS data were processed with Bernese (version 3.5) geodetic-grade software (Rothacher and others, 1993). Precise orbits and pole data were obtained from CODE (Center for Orbit Determination Europe). All five Novarupta stations were first located relative to Fairbanks and Kodiak using L1 frequency and L2 frequency observations (table 3). ITRF93 (International Terrestrial Reference Frame) coordinates corrected for continental plate velocity were used for Fairbanks and Kodiak. These Bernese-determined locations for the Novarupta network were used as a priori station coordinates (initial locations required for data processing) for 1993 GPS data processing with GPPS. For final baseline calculations, BAKE was held fixed and data were processed for L1-only relative-coordinate solutions for BROK, FALL, MAIN, NOVA, and all baseline lengths. RMS errors for relative-coordinate solutions were 0.1-0.3 mm. Repeatabilities and scatter as defined by Dixon (1991) for observations are shown in figure 3. Computed baseline lengths and RMS errors are shown in table 4.

RESULTS

To determine if ground deformation had taken place in the Novarupta area from 1990 to 1995, we compared baseline lengths from the 1990 and 1993 EDM surveys with GPS-measured baselines in 1993 and 1995. As a check on consistency of the two surveying methods, we also compared 1993 GPS line lengths with 1993 EDM line lengths. All line-length data were placed in a spreadsheet to facilitate comparison of data and then plotted on geodetic-network diagrams.

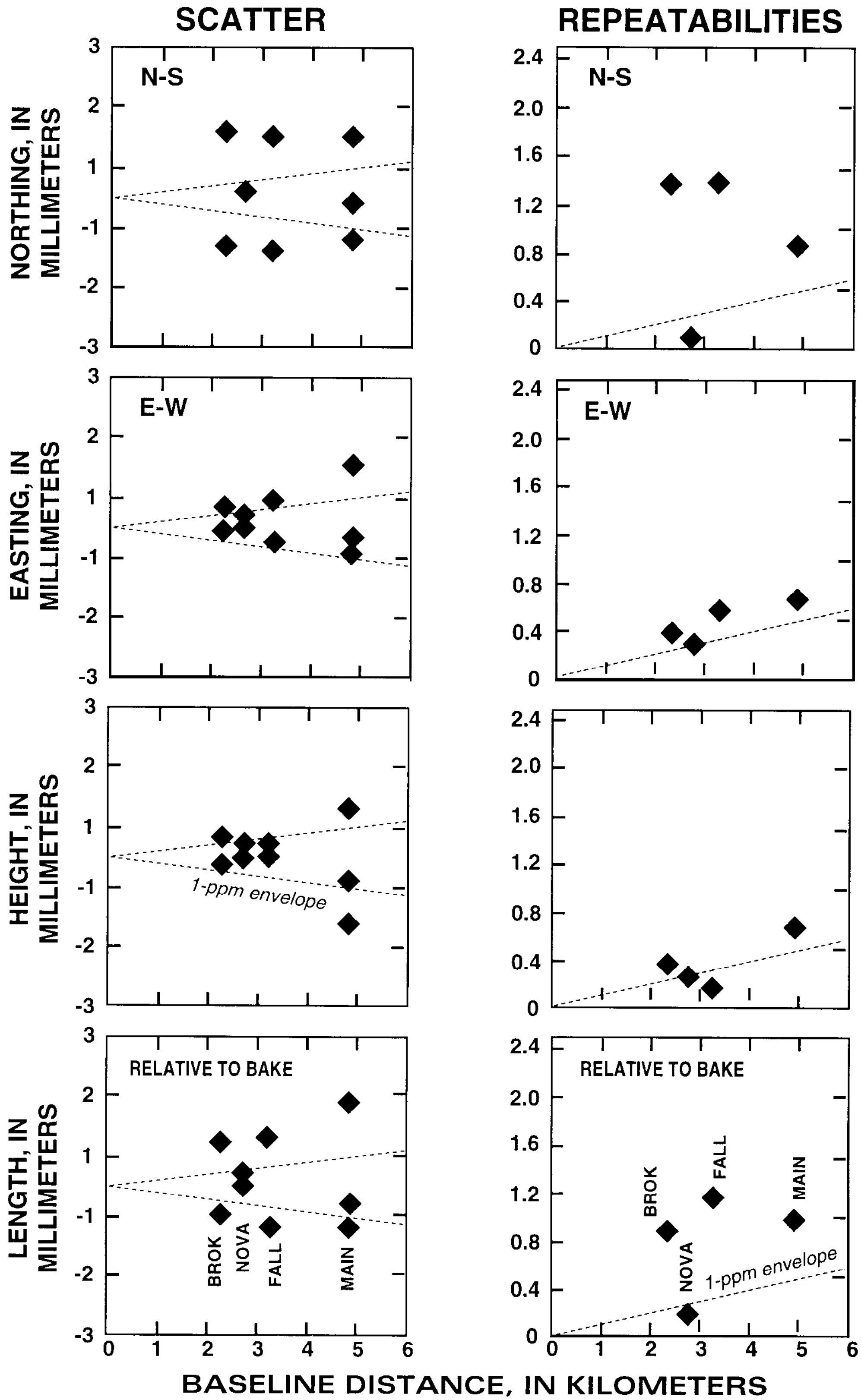

Figure 3. Plots of scatter and repeatability for L1-frequency-only Bernese-determined solutions for the 1995 GPS survey. The 1-ppm envelope is indicated by sloping dashed lines. Scatter plots show solutions plotted about a calculated mean. Repeatability is a statistical measure of the similarity of solutions.

Table 4. Line lengths from GPS measurements of the Novarupta geodetic network in 1995

[Root-mean-square errors enclosed by parentheses]

Station pair	Distance (meters)	Distance (meters)
BAKE-NOVA	2566.0545 (.0001)	2566.0544 (.0001)
BROK-NOVA	2795.7595 (.0002)	2795.7614 (.0002)
MAIN-NOVA	2197.3976 (.0001)	2197.3962 (.0001)
FALL-NOVA	1497.3951 (.0002)	1497.3966 (.0002)
FALL-BAKE	3105.6773 (.0001)	3105.6787 (.0001)
FALL-BROK	4070.6784 (.0002)	4070.6821 (.0002)
FALL-MAIN	2663.3618 (.0001)	2663.3609 (0001)
MAIN-BAKE	4700.0227 (.0001)	4700.0210 (.0001)
MAIN-BROK	4356.1407 (.0001)	4356.1409 (.0001)
BROK-BAKE	2151.1101 (.0001)	2151.1113 (.0001)

Calculated line-length differences between the 1993 GPS (six baselines) and the 1993 EDM survey varied from 2 to 7 mm (fig. 4). The differences between the 1993 EDM and 1993 GPS surveys may be a result of unknown phase eccentricities of the Ashtech GPS antenna.

We have no way to evaluate GPS setup errors because there were no repeat surveys in 1993 and 1995. As part of the preparation effort for the 1995 field season, all optical tribrachs used for the Novarupta GPS survey were calibrated by a Wild service center. Kern self-centering tripods were used in 1990. We assume that antenna slant heights were measured correctly and baseline length errors that result from setup are comparable to the 5-mm-or-less errors encountered by other investigators (Larson, 1990) for repeat GPS surveys.

The 1993 GPS line-length differences relative to 1990 EDM line lengths for the six baselines measured by both techniques are similar to 1993 EDM and 1990 EDM line-length differences. No similar comparison could be made for four baselines from MAIN because of the loss of data. Line-length differences from NOVA to FALL and from NOVA to BAKE for 1993 and 1990 EDM measurements (fig. 5A) are nearly identical to line-length differences for 1993 GPS data and 1990 EDM data (fig. 5B). These data suggest that NOVA moved about 15-20 mm to the west or northwest during the interval between 1990 and 1993. Although length differences obtained by EDM surveys of lines from the MAIN station are close to the error limits for this surveying technique, the data suggest that MAIN may also have moved 15-20 mm to the northwest. Data also indicate that MAIN continued to move from 1993 through 1995 (fig. 6). The 1995 GPS line lengths relative to 1990 EDM line lengths show displacement similar to that suggested for NOVA during the 1990 to 1993 interval (fig. 7).

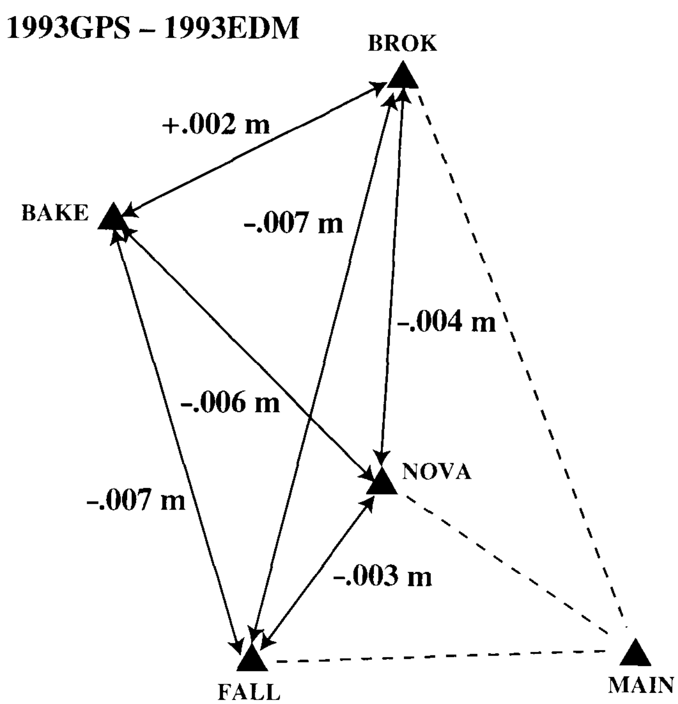

Figure 4. Novarupta line-length differences for 1993 GPS and 1993 EDM surveys.

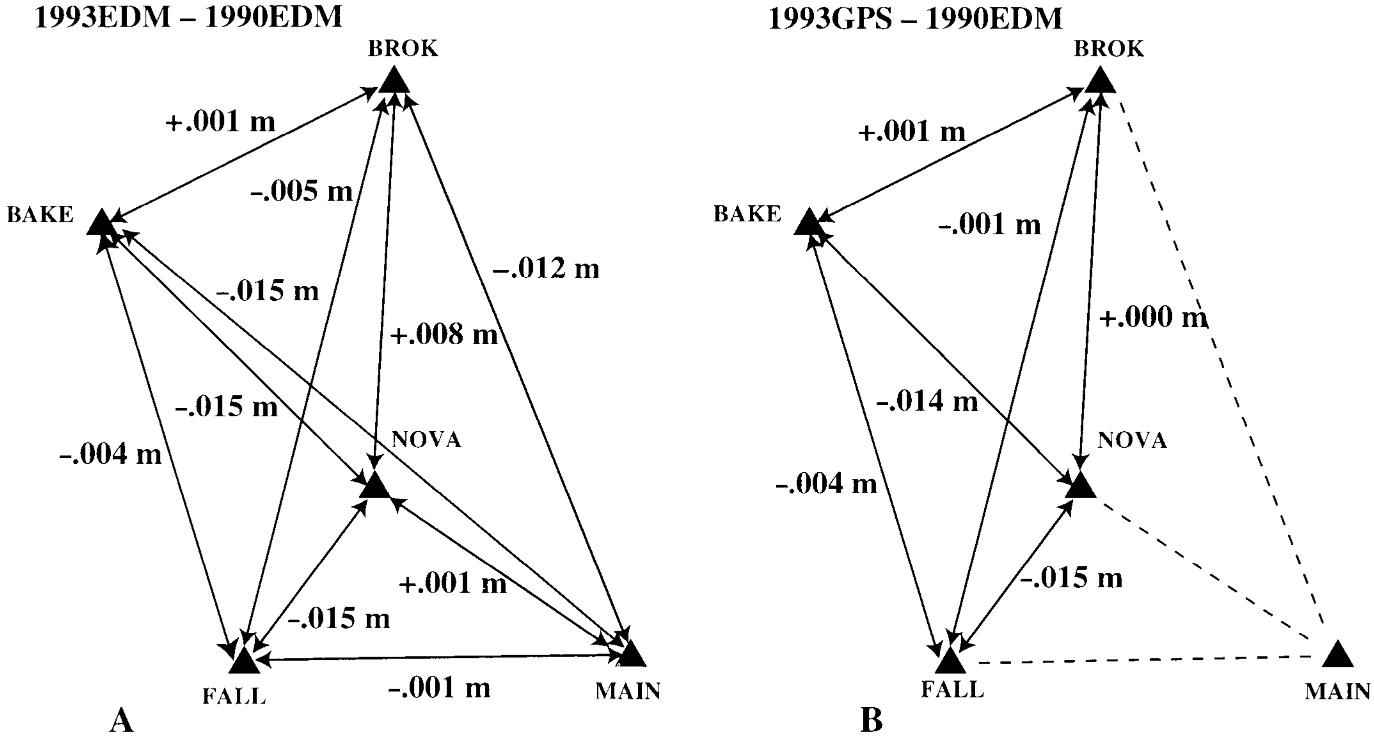

Figure 5. *A*, Novarupta line-length differences for 1993 EDM and 1990 EDM surveys. *B*, Novarupta line-length differences for 1993 GPS and 1990 EDM surveys.

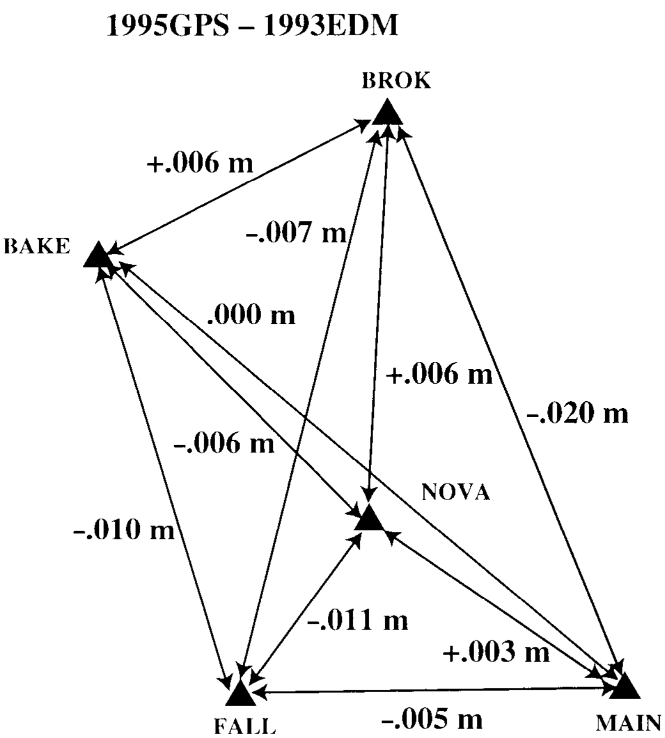

Figure 6. Novarupta line-length differences for 1995 GPS and 1993 EDM surveys.

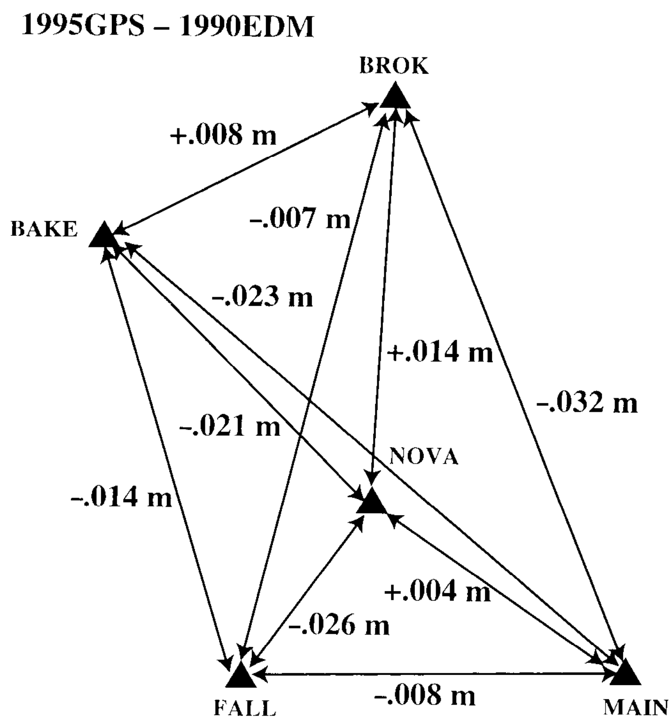

Figure 7. Novarupta line-length differences for 1995 GPS and 1990 EDM surveys.

DISCUSSION

It is not possible to definitively assess the magnitude of possible systematic errors in the Novarupta EDM surveys or the errors associated in comparing results from two surveying techniques and the use of different instruments. We tried to minimize such errors, and all appropriate corrections were applied to reduce any residual errors. Nevertheless, the lack of redundancy in the early measurements raises the possibility of larger-than-expected systematic errors.

Another approach to error assessment for the Novarupta EDM surveys is to compare them with similar repeated trilateration and distance-measurement networks elsewhere. An analysis of such surveys at 12 volcanoes in the Cascades Range indicated that repeatability was 2.46 mm ±2.26 ppm (Iwatsubo and Swanson, 1992). For the analysis, it was assumed that no real changes occurred at any of the volcanoes during the periods between surveys. For EDM surveys at Mount St. Helens during 1980, a period that included real ground displacements associated with eruptive activity, accuracies are believed to be ±10 mm over 2-4 km-long lines (Lipman and others, 1981). These line lengths are similar to those in the Novarupta network. By comparison with these earlier results, the l- to 15-mm average line-length change in the Novarupta network from 1990 to 1993 is close to the probable total error in the measurements.

Unlike continuous GPS measurements of the type being made in California along the Hayward fault (King and others, 1995), errors associated with repeated GPS measurements like that at Novarupta in 1995 are difficult to assess because of few observations. For continuous measurements, a few parts per million RMS scatter in baseline length was observed for single-frequency measurements. The accuracy of results of the 1995 GPS survey near Novarupta cannot be any better than that achieved for continuous monitoring. We have to assume that satellite-signal multipath errors and random setup errors are possible sources of error for any GPS survey of the type done in 1993 and 1995. The 1995 GPS results are only slightly better than the EDM surveys of 1990 and 1993, and changes of less than 10 mm are probably due to some observation error.

The possibility that a nearby shallow magma body exists south of the Novarupta area has been suggested by Ward and others (1991) on the basis of P-wave travel-time residuals and a negative Bouguer gravity anomaly. In late 1992-early 1993 increased seismic activity was observed (Peter Ward, USGS, oral commun., 1993) in the area southwest of Baked Mountain (slightly west of the geodetic network). The relatively small geodetic network in this study does not well constrain the location of a hypothetical magma body. Expanding the size of the geodetic network to include the epicenters of seismic activity would be helpful in ascertaining the aerial extent of crustal deformation. The Novarupta network was tied to a regional GPS network in 1995, but the GPS network (Lisowski and others, 1993) is too regional in scope to help constrain a localized area of crustal deformation. To further evaluate ground deformation in the Katmai area, extension of the network with GPS observations beyond the immediate vicinity of Novarupta is recommended.

While the geodetic work in 1990, 1993, and 1995 did not result in evidence for volcano-related ground deformation centered at Novarupta, we now have a network that is tied into a worldwide coordinate system and locations for five stations that are accurate enough for future differential (real-time kinematic) GPS surveying for mapping or grid-type geophysical exploration in the Valley of Ten Thousand Smokes.

Acknowledgments.- The Katmai geodetic studies were supported by the Alaska Volcano Observatory and the USGS Volcano Hazards Program. Geodetic studies in the Valley of Ten Thousand Smokes were made possible with support and cooperation from Katmai National Park personnel and the National Park Service. We also thank the U.S. Fish and Wildlife Service for the generous use of their facilities in King Salmon. Our special thanks to the helicopter pilots for field support to and from King Salmon and Art Jolly for his help in 1995.

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