U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

HAWAIIAN VOLCANO OBSERVATORY SUMMARY 90 PART II DEFORMATION DATA, JANUARY TO DECEMBER 1990

BY

MAURICE SAKO[1], PAUL DELANEY[2],
ALLAN LARGO[1], ASTA MIKLIUS[1], ARNOLD OKAMURA[1]

U.S. Geological Survey
Hawaiian Volcano Observatory
Hawaii Volcanoes National Park, Hawaii 96718

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[1] U.S. Geological Survey, Hawaiian Volcano Observatory, Hawaii Volcanoes National Park, Hawaii 96718
[2] U.S. Geological Survey, Flagstaff, Arizona 86001

1990 HAWAIIAN VOLCANO OBSERVATORY STAFF

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GARY HONZAKI (Seismic Electronic Technician)
ZOE JACOBI (Seismic record changer)
JAMES KAGIMOTO (Seismic record changer)
AKIRA YAMAMOTO (Seismic record changer)

* Left 1990
\+ Arrived 1990

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INTRODUCTION

The measurement of ground surface deformation is an integral component in understanding how volcanoes work. Since the founding of the Hawaiian Volcano Observatory (HVO) in 1912, these measurements have been instrumental in understanding how Kilauea and Mauna Loa deform before, during, and after eruptions and earthquakes. With these data, one can model the magma storage and transport system of a volcano.

This report is a part of HVO Summary 90 and covers leveling, tilt (spirit-level, short base water-tube, and electronic), and Electronic Distance Measurement (EDM) data acquired at HVO between January and December 1990. Data acquired prior to 1987 (1978-1986) will be written up in separate Open-File Reports. Open-File Report 88-237 for tilt data is already published and contains data through 1986. This yearly summary also includes other pertinent data, such as, descriptions of new or reset leveling bench marks, tilt stations, EDM stations, and instrument calibrations. A bibliography of all publications written by present HVO personnel, alumni, and affiliates pertaining to Hawaiian volcanism can be found in the HVO Summary 90, Part I Seismic Data and is not included in this report.

CHRONOLOGICAL SUMMARY OF DEFORMATION SURVEYS FOR KILAUEA AND MAUNA LOA ON THE ISLAND OF HAWAII.

Kilauea

Leveling, EDM, and tilt surveys of Kilauea were conducted during 1990. The surveys were conducted to monitor post-seismic deformation from the June 1989, M6.1 south flank earthquake as well as deformation associated with the continuing east rift eruption. Leveling and EDM measurements during the early months of the year were done to complete surveys that were started in 1989.

With the exception of a few lines, all of the south flank EDM trilateration network was occupied (fig. CS-1). The EDM survey started in the latter part of 1989 and continued into January of 1990. The January EDM survey was tied into baseline shots on the northeast slope of Mauna Loa (Kulani and Keaau) and southeast slope of Mauna Kea (Kaiwiki New). The survey covered an area between the upper east rift (Puu Huluhulu) to Kapoho on the lower east rift of Kilauea (fig. CS-2).

Figure CS-1. Location map of the entire Kilauea south flank EDM trilateration network occupied during the 1989-90 survey.

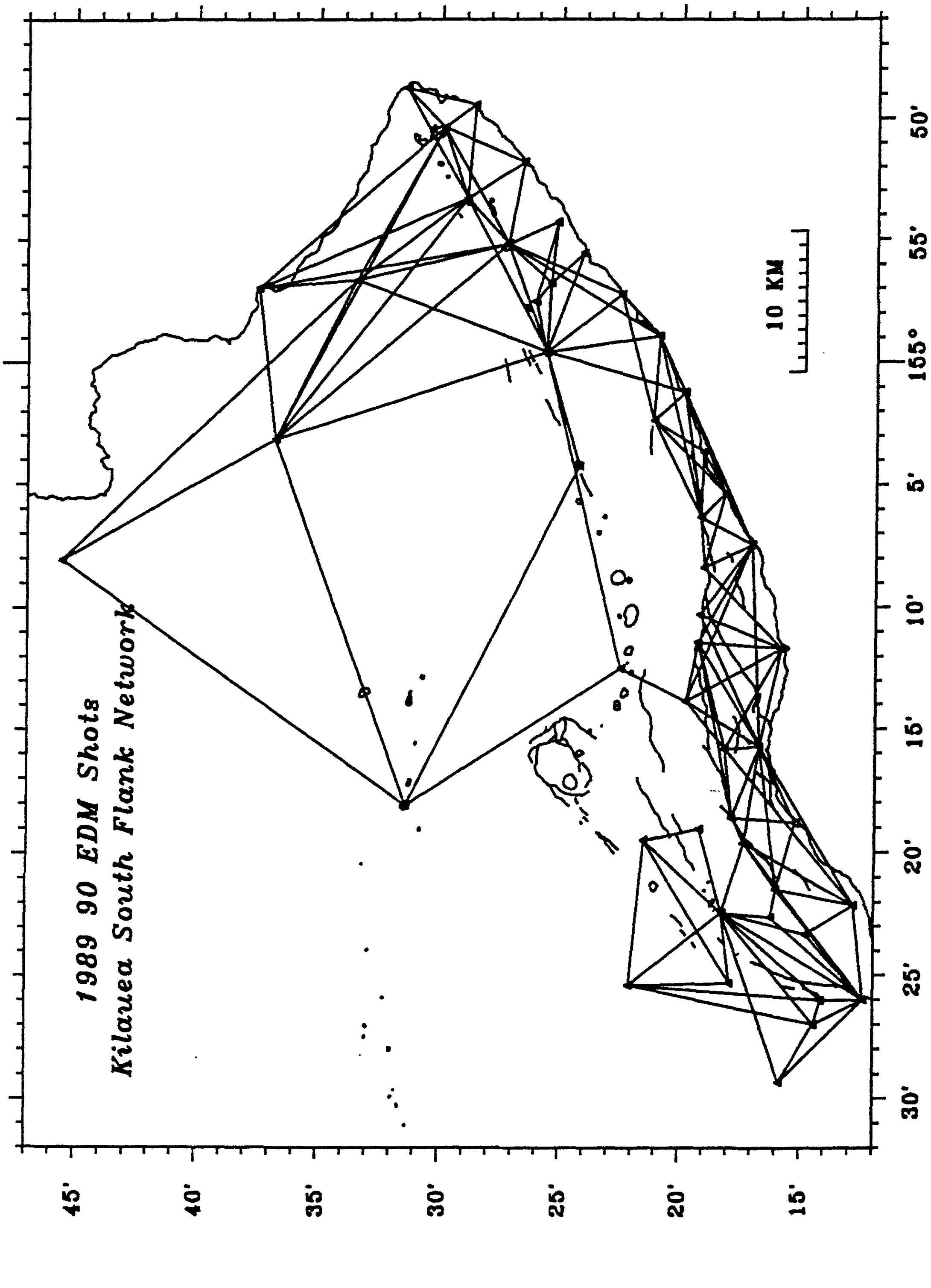


Figure CS-2. Location map of stations in the south flank EDM trilateration network that were occupied during the 1990 portion of the survey.

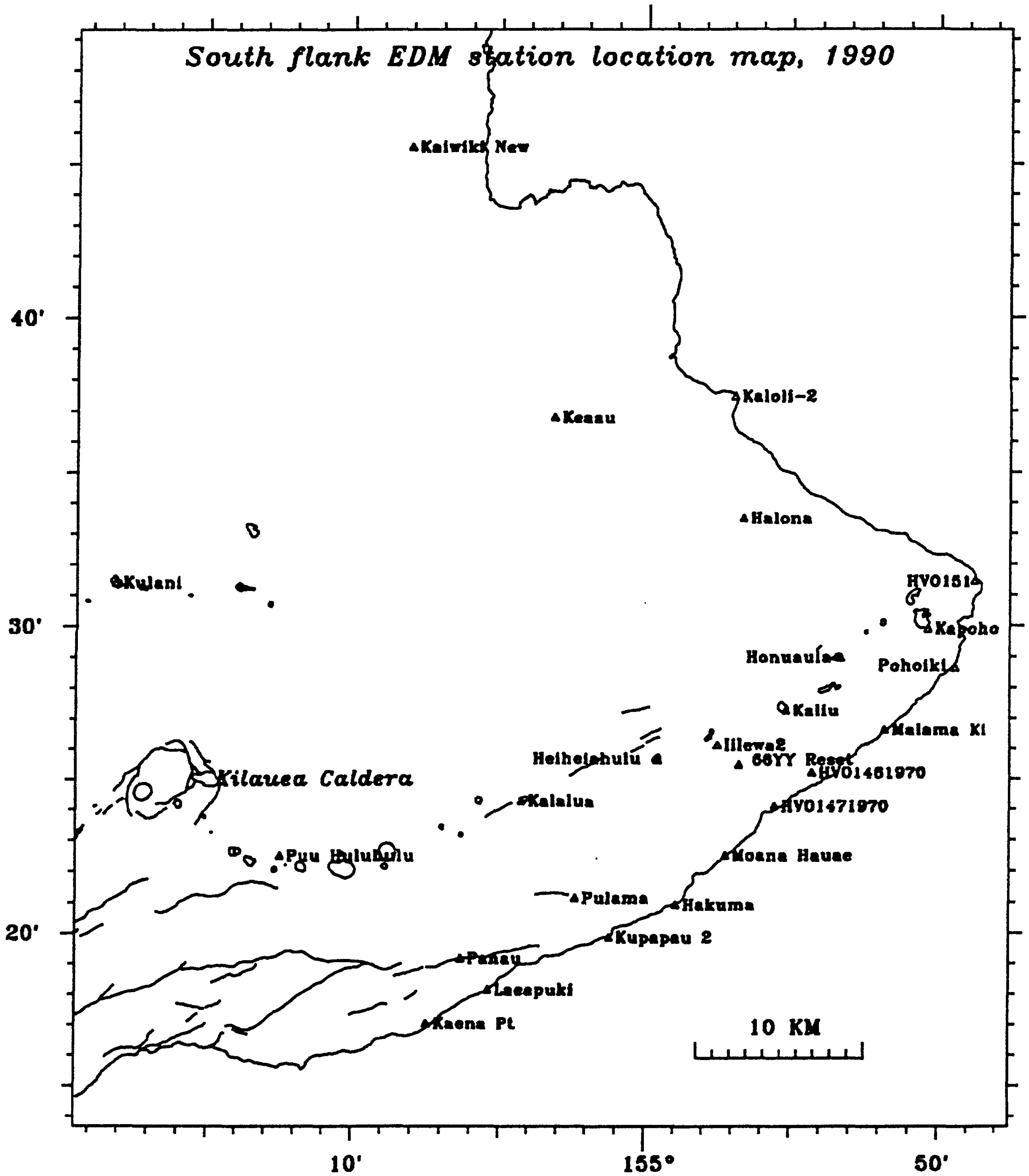
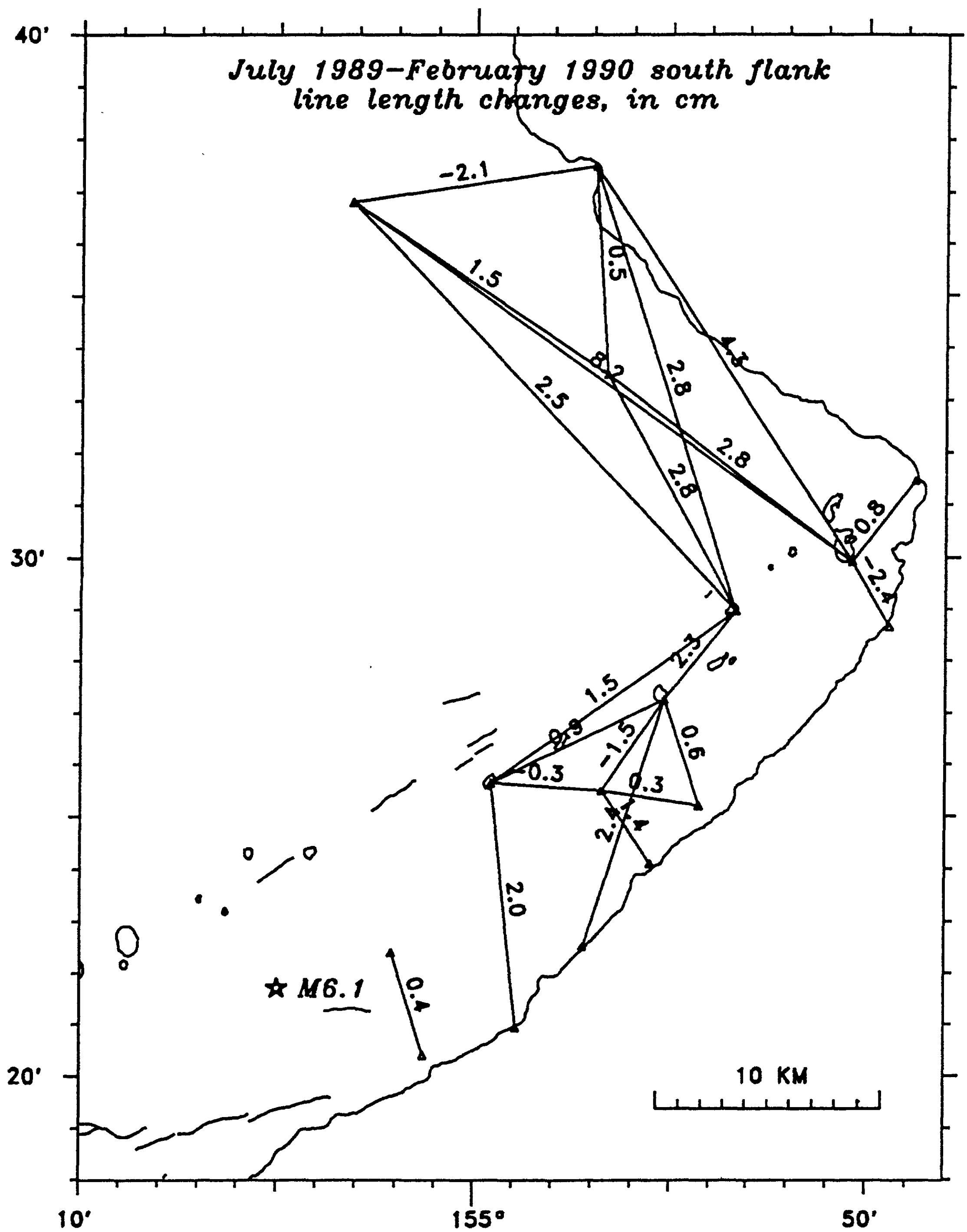


Figure CS-3. Map of line length changes between July 1989 and February 1990 on the south flank and lower east rift of Kilauea, in cm.



The surveys measured between July 1989 (post June M6.1 earthquake) and January 1990, show relatively small extensions of line lengths on all lines with the exception of three that showed contraction (fig. CS-3 and Table CS-1). These results are in contrast to the pre- and post-earthquake survey results which showed contractions on lines south of the rift zone and extensions to the north of the rift. The exception would be lines that spanned the area of cracks as the results of the June 1989 M6.1 earthquake (See Deformation Summary 1989).

Table CS-1. Table of line length differences between 1989 and 1990 surveys.

Ins.	Instr. Stn. Name	Refl. Stn. Name	Date	Line Length in (m)	Date	Line length in (m)	Diff. in (m)
RM	HALONA	KAPOHO	01/11/90	12478.587	07/27/89	12478.559	0.028
RM	HALONA	HONUAULA	01/11/90	9980.995	07/27/89	9980.967	0.028
RM	HALONA	KALOLI-2	01/11/90	7382.252	07/27/89	7382.247	0.005
HP	KALIU	HONUAULA	01/11/90	4426.746	09/21/89	4426.723	0.023
RM	KALOLI-2	KAPOHO	01/11/90	17777.285	07/27/89	17777.242	0.043
RM	KALOLI-2	HONUAULA	01/11/90	16805.477	07/27/89	16805.448	0.029
HP	KAPOHO	HVO151	01/11/90	3728.043	07/27/89	3728.034	0.009
HP	KAPOHO	POHOIKI	01/11/90	2906.932	07/27/89	2906.956	-0.024
RM	KEAAU	HONUAULA	01/11/90	22230.819	07/27/89	22230.772	0.047
RM	KEAAU	KAPOHO	01/11/90	25399.774	07/27/89	25399.692	0.082
RM	KEAAU	HALONA	01/11/90	12928.351	07/27/89	12928.336	0.015
RM	KEAAU	KALOLI-2	01/11/90	10931.481	07/27/89	10931.502	-0.021
HP	66YY RESET	KALIU	01/12/90	4162.636	09/21/89	4162.651	-0.015
HP	66YY RESET	HVO1461970	01/12/90	4473.819	09/21/89	4473.816	0.003
HP	KALIU	HVO1461970	01/12/90	4212.688	09/21/89	4212.682	0.006
RM	MOANA HAUAE	KALIU	01/12/90	9485.298	09/21/89	9485.273	0.025
RM	HEIHEIAHULU	HONUAULA	02/21/90	12347.293	09/21/89	12347.278	0.015
HP	KALIU	HEIHEIAHULU	02/21/90	8115.768	09/21/89	8115.759	0.009

The leveling survey, started in July 1989, in Keaau (G20), went through Pahoa, down to Kaimu, west along the coast via the Chain of Craters Road and ended up on Holei Pali at HVO64 (see details in Deformation Summary 89). The traverse, measured to assess the amount of vertical displacement from the June M6.1 south flank earthquake, was continued in 1990 from bench mark HVO64, up through the eastern section of the summit, and down to Keaau, closing the loop (fig.CS-4). Although the time span in closing of the loop was several months, the closure was exceptionally good (-1 mm). The remainder of the Kilauea summit level network began in the latter part of January, after the completion of the loop mentioned above, and ended in early February (fig. CS-5).

Comparison of the 1988 and 1990 level surveys (figure CS-4) shows that the greatest vertical displacements occurred on the summit. The lower east rift along the Pahoa-Kaimu Highway also showed large vertical displacements (see Summary 89 for a more detailed report on the lower east rift). While the vertical changes on the lower east rift can most likely be attributed to co-seismic motion as the result of the June 1989 M6.1 earthquake, the subsidence of the summit area is consistent with subsidence due to the on-going Puu Oo eruption.

The maximum vertical changes continue to occur in the area south of Halemaumau which subsided ~22 cm at Rebar4 (fig. CS-5 and CS-6) from 1988 to 1990, compared to -12 cm between 1986 and 1988. Previously detected uplift from the Kalanaokuaiki Pali to the end of the Hilina Pali road relative to the bench mark at Birdpark (HVO23) continues to occur (fig. CS-6). This coincides with Global Positioning System (GPS) data reduced and analyzed by John Dvorak (USGS Bulletin, in prep.), that also show steady uplift of the Hilina Pali bench mark from 1987 to 1990.

Subsidence was measured on the upper the southwest rift with the maximum vertical change occurring on, or slightly south of, the axis of the rift (fig. CS-6a). The upper east rift also subsided from 1988 to 1990 (Fig. CS-6b). Table CS-2 lists all of the vertical changes from 1988 and 1990.

Figure CS-4. Vertical changes between 1988 and 1990 at selected bench marks along the routes leveled in January-March 1990, in cm. Bench mark A100 in Hilo is used as the datum. Also shown is the epicenter of the M6.1 June 1989 earthquake.

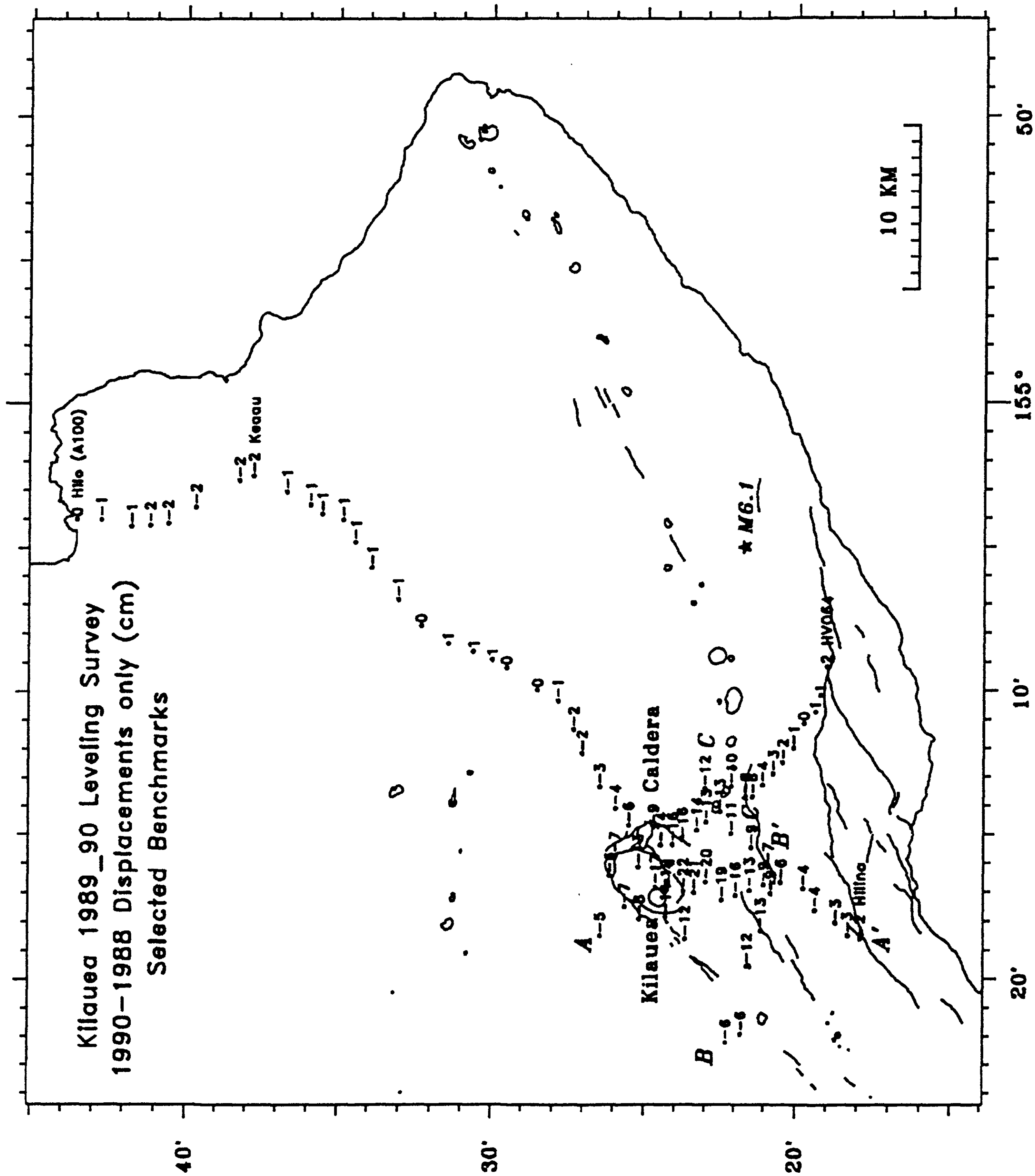


Figure CS-5. Map of selected bench marks with vertical changes of Kilauea summit leveling network between 1988 and 1990 surveys, in cm. Also shown are locations for profiles A-A', B-B', and C-C' in fig. CS-6.

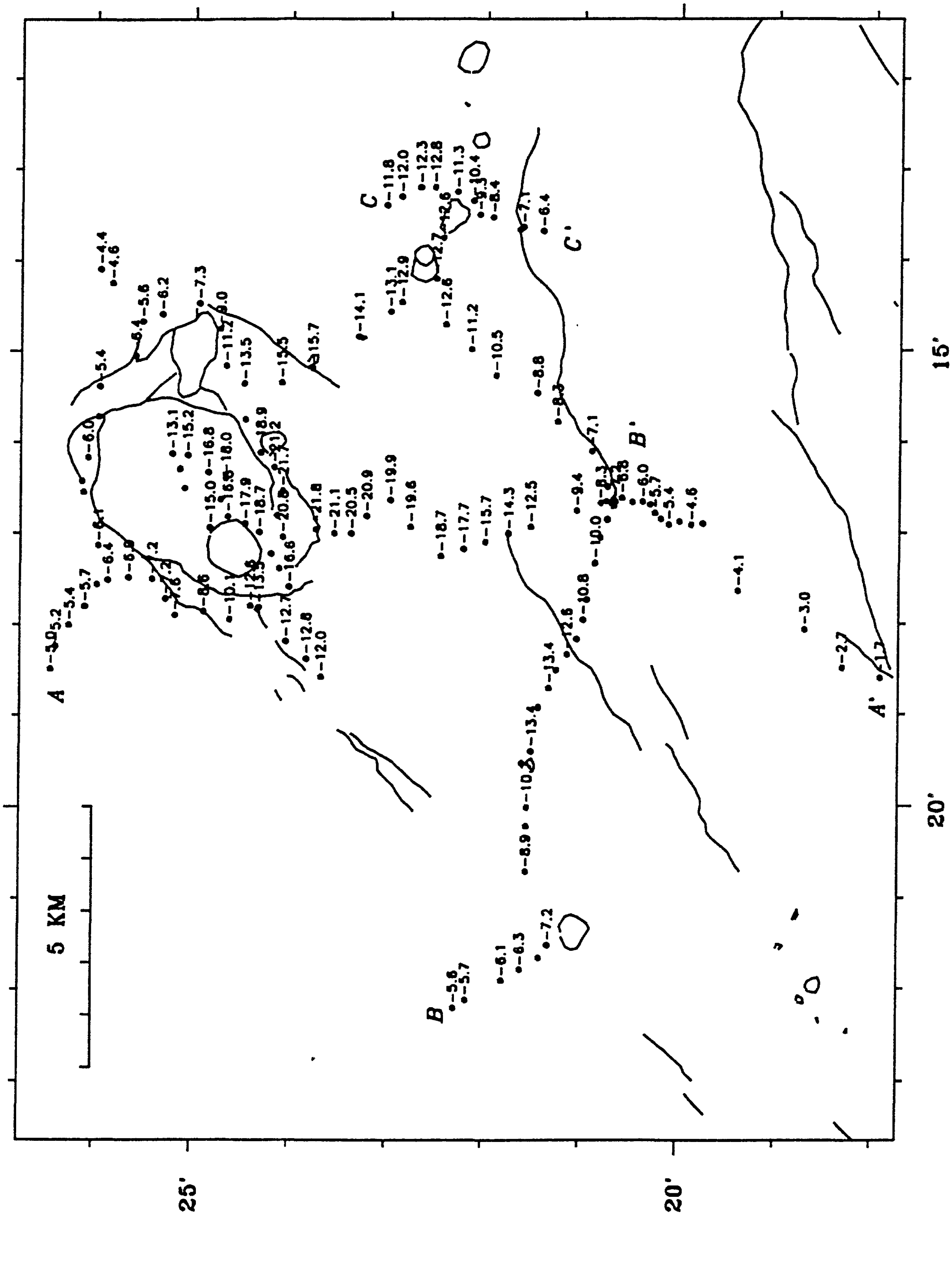


Figure CS-6a, CS-6b, and CS-6c. A-A' = Vertical displacement profile from Bird Park (HVO23), skirting the west side of Kilauea caldera, across the Koae fault zone and down to the end of the Hilina Pali road; B-B' = Profile along the Mauna Iki-Footprints Trail across the upper southwest rift of Kilauea between Hwy 11 and Hilina Pali road; C-C' = Profile across the upper east rift along the Ainahou-Escape road.

Figure CS-6a.

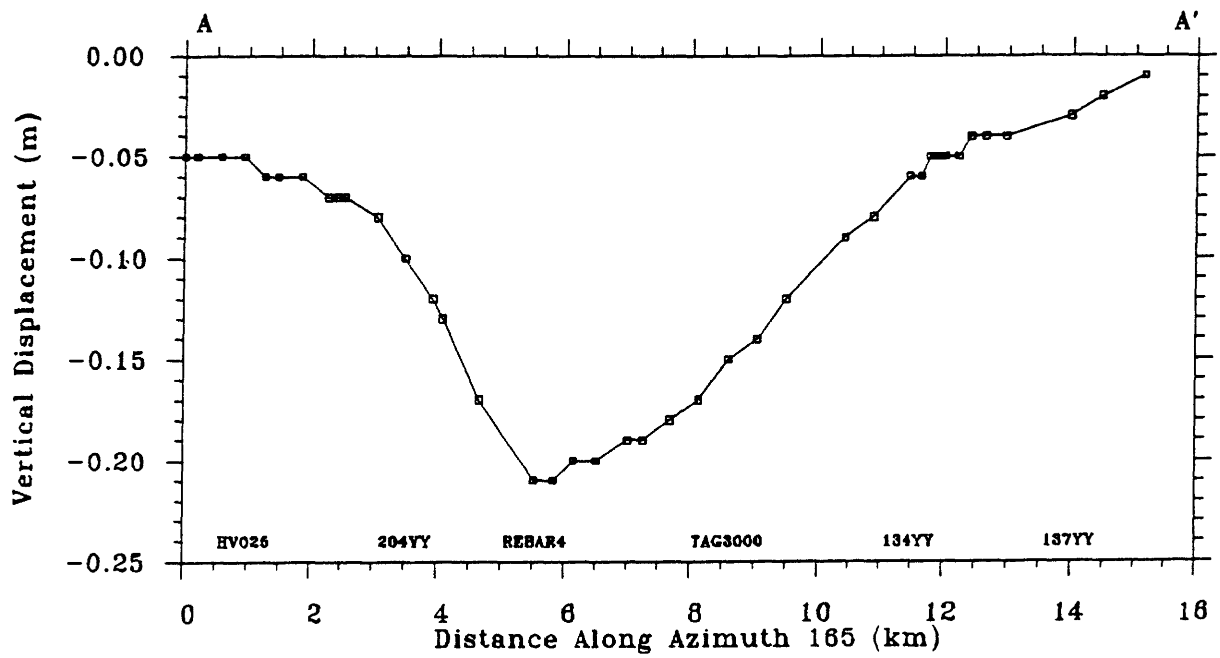


Figure CS-6b.

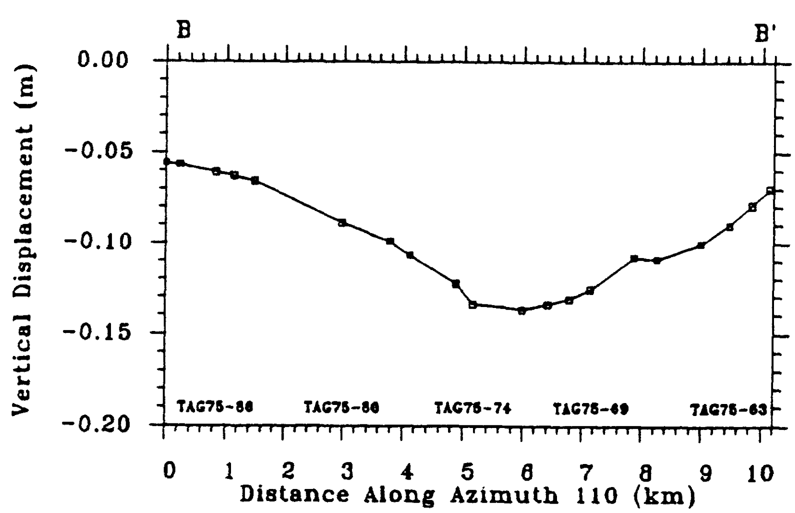


Figure CS-6c.

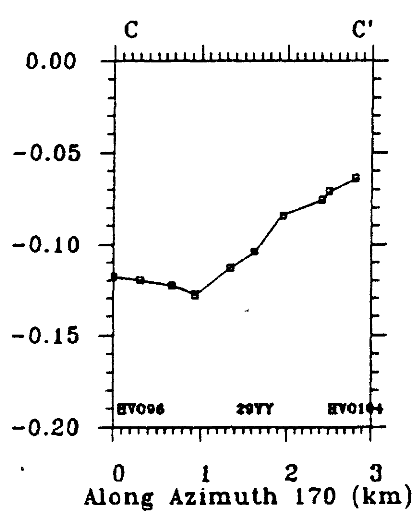


Table CS-2. Table of elevation differences for 1988-1990 survey of bench marks located on the south flank and summit of Kilauea and on Hwy. 11 between Volcano and Keaau (bench mark A100 located in Hilo is used as the datum). Data for 1989 measurements (Hilo through lower Puna and south flank) can be found in Summary 89.

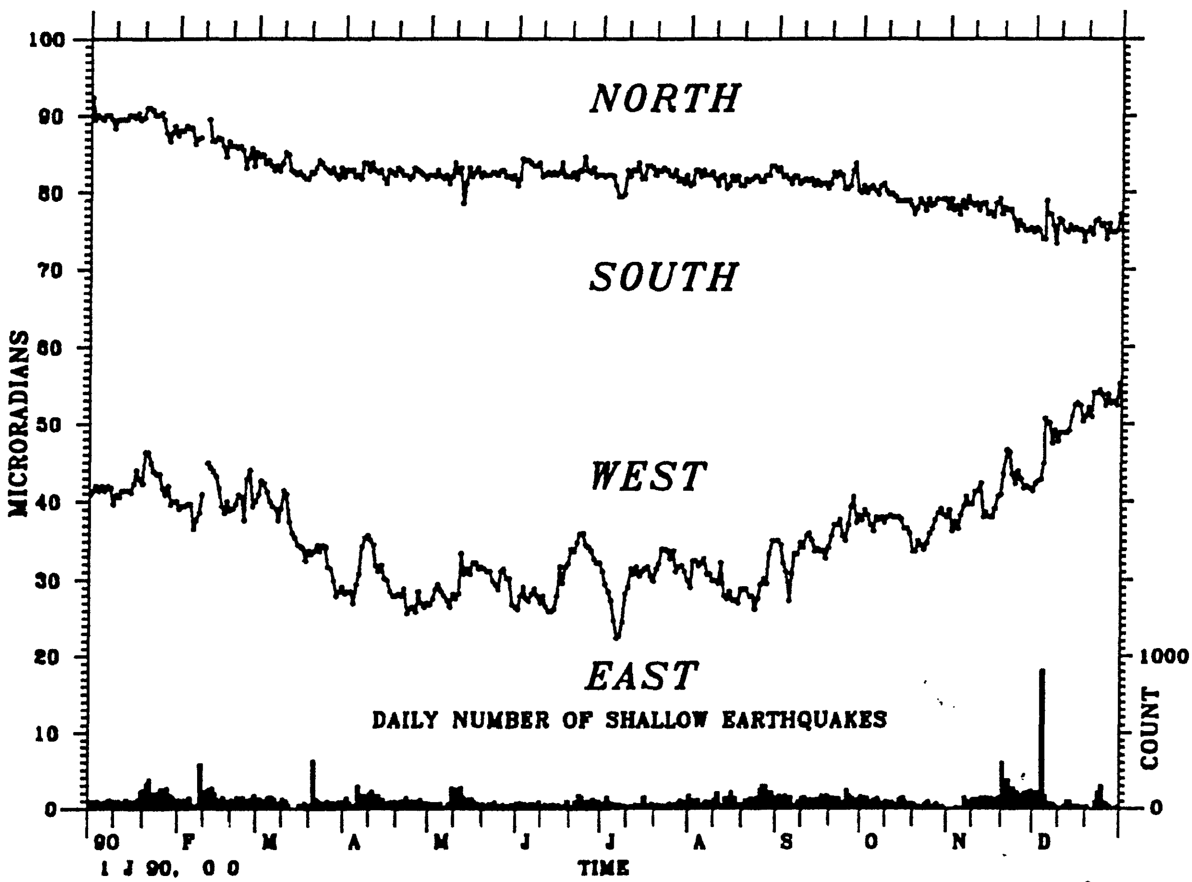
Bench mark	1990 elev. (m)	Δ 88-90 (m)	s.d. (m)	Bench mark	1990 elev. (m)	Δ 88-90 (m)	s.d. (m)
HVO63	466.048	0.013	0.023	R20	698.219	0.004	0.018
HVO77-13	517.430	0.015	0.023	7YYRESET	678.176	0.008	0.017
BM79-503	582.481	0.015	0.024	Q20	671.639	0.009	0.017
BM79-502	619.676	0.012	0.024	6YYRESET	657.069	0.010	0.017
BM80-1	613.649	0.012	0.024	P20	648.626	0.012	0.017
HVO77-10	665.112	0.007	0.023	V1RESET	646.063	0.007	0.016
HVO77-7	720.432	0.001	0.023	HVO86-102	596.773	0.002	0.016
BM79-507	743.886	-0.004	0.023	N20	560.733	0.002	0.016
BM79-506	774.839	-0.009	0.024	5YY	525.487	-0.006	0.016
HVO77-4	824.851	-0.018	0.024	M20	506.658	-0.006	0.016
HVO77-3	866.832	-0.028	0.024	HVO86-103	466.928	-0.007	0.015
HVO77-2	908.647	-0.038	0.024	HVO87-101	453.135	-0.010	0.015
BM79-501	971.227	-0.072	0.024	4YY	426.100	-0.012	0.015
HVO101	971.837	-0.076	0.024	T20	386.360	-0.013	0.015
KF5	973.654	-0.085	0.024	HVO86-104	372.742	-0.013	0.015
BM79-500	977.231	-0.094	0.024	K20	348.157	-0.016	0.015
29YY	984.189	-0.104	0.024	3YY	318.077	-0.012	0.014
28YYRESET	999.235	-0.126	0.024	L20	277.459	-0.012	0.014
27YYR	998.825	-0.127	0.024	2YY	268.762	-0.014	0.014
BM79-511	1032.620	-0.130	0.024	Y1	210.437	-0.008	0.014
26YYR	1044.372	-0.132	0.024	1YY	198.439	-0.008	0.014
25YY	1072.015	-0.142	0.024	HVO86-105	182.065	-0.015	0.014
BM79-510	1102.517	-0.158	0.024	8YYY	171.036	-0.014	0.014
24YY	1102.495	-0.158	0.024	H20	154.391	-0.012	0.014
BM79-509	1106.767	-0.156	0.024	HVO86-106	131.139	-0.017	0.014
22YY	1132.906	-0.135	0.024	G20	90.750	-0.019	0.014
REBAR2	1136.101	-0.113	0.023	BM79-514	1017.001	-0.127	0.024
20YY	1167.975	-0.090	0.023	131YY	1005.927	-0.112	0.024
19YY	1193.368	-0.074	0.023	BM79-515	1008.850	-0.105	0.024
HVO1140	1177.311	-0.062	0.023	132YY	996.855	-0.088	0.024
17YYRESET	1162.939	-0.056	0.023	BM79-516	984.124	-0.083	0.024
X20	1141.960	-0.046	0.023	133YY	980.309	-0.071	0.024
16YYRESET	1134.479	-0.044	0.023	BM79-517	965.694	-0.071	0.025
S20	1109.722	-0.039	0.022	BM79-518	964.068	-0.075	0.025
BM3565	1086.727	-0.031	0.022	TAG10500	966.855	-0.083	0.025
S1	1073.382	-0.028	0.022	TAG9000	985.515	-0.093	0.025
14YY	1041.591	-0.024	0.021	TAG7500	994.351	-0.108	0.024
15YY	1040.393	-0.024	0.021	TAG6000	1015.096	-0.125	0.024
V20	1003.445	-0.022	0.021	TAG4500	1010.135	-0.143	0.024
13YY	962.276	-0.020	0.021	TAG3000N	1026.516	-0.157	0.024
W20	913.707	-0.017	0.020	TAG1500	1031.049	-0.178	0.024
12YY	881.781	-0.016	0.020	BM79-115	1035.732	-0.187	0.024
HVO86-100	847.478	-0.014	0.019	BM79-114	1048.274	-0.196	0.024
11YY	838.658	-0.014	0.019	113YY	1063.307	-0.199	0.024
10YY	817.242	-0.012	0.019	BM83-500	1071.116	-0.209	0.024
U20	796.138	-0.008	0.019	112YY	1083.959	-0.208	0.024
HVO87-106	796.007	-0.008	0.019	HVO37	1095.672	-0.212	0.024
9YY	758.053	-0.004	0.018	REBAR4	1106.961	-0.213	0.024
8YY	754.430	-0.003	0.018	SPIT	1110.101	-0.202	0.024
HVO86-101	715.430	0.001	0.018	205YYRESET	1107.192	-0.182	0.024

Table CS-2. (continued)

Bench mark	1990 elev. (m)	Δ 88-90 (m)	s.d. (m)	Bench mark	1990 elev. (m)	Δ 88-90 (m)	s.d. (m)
BM79-519	969.090	-0.076	0.025	HVO25	1208.495	-0.054	0.024
IRONPOLE	969.383	-0.076	0.025	HVO24	1209.146	-0.052	0.025
BM79-520	970.779	-0.071	0.025	P1	1204.049	-0.049	0.025
HVO86-51	972.113	-0.072	0.025	HVO23	1190.989	-0.047	0.025
HVO86-52	967.814	-0.068	0.025	HVO104	960.485	-0.065	0.024
134YY	961.013	-0.063	0.025	KF45	988.425	-0.114	0.024
HVO86-53	950.931	-0.060	0.025	KF46	991.216	-0.129	0.024
HVO86-54	942.197	-0.057	0.025	BM3269	994.879	-0.123	0.024
HVO86-55	930.128	-0.057	0.025	HVO96	1013.998	-0.121	0.025
HVO86-56	914.284	-0.056	0.025	HVO95	1033.076	-0.118	0.025
HVO86-57	904.620	-0.054	0.025	TAG75-57	970.926	-0.070	0.025
HVO86-58	901.602	-0.050	0.025	TAG75-62	971.618	-0.079	0.025
HVO86-59	898.504	-0.045	0.025	TAG75-63	967.379	-0.090	0.025
135YY	892.321	-0.040	0.025	TAG75-64	970.328	-0.100	0.025
136YY	862.329	-0.041	0.025	TAG75-66	959.619	-0.109	0.025
137YY	800.892	-0.030	0.026	TAG75-67	957.598	-0.108	0.025
138YY	751.616	-0.027	0.026	TAG75-68N	955.891	-0.117	0.025
139YY	695.742	-0.017	0.027	TAG75-69	945.028	-0.126	0.025
REBAR1	1139.847	-0.155	0.024	TAG75-70N	933.085	-0.131	0.025
HVO10R	1117.924	-0.186	0.024	TAG75-71N	944.861	-0.133	0.025
BM79-508	1113.729	-0.206	0.024	TAG75-72	947.895	-0.137	0.025
HVO35	1106.274	-0.210	0.024	TAG75-74	949.726	-0.134	0.025
HVO34	1105.315	-0.203	0.024	TAG75-75	951.273	-0.123	0.025
HVO33	1117.446	-0.173	0.024	TAG75-77	935.860	-0.107	0.026
HVO32	1109.752	-0.173	0.024	TAG75-78	930.934	-0.099	0.026
HVO31	1112.554	-0.161	0.024	TAG75-80	922.568	-0.089	0.026
118YY	1138.063	-0.130	0.024	TAG75-83A	897.734	-0.071	0.027
117YY	1140.106	-0.122	0.024	TAG75-84	890.747	-0.065	0.027
204YY	1151.166	-0.097	0.024	TAG75-85	896.833	-0.063	0.027
HVO29	1182.185	-0.082	0.024	TAG75-86	907.593	-0.061	0.027
203YY	1201.618	-0.073	0.024	TAG75-88	927.883	-0.057	0.028
HVO28	1221.051	-0.068	0.024	TAG75-89	929.478	-0.056	0.028
HVO27	1242.961	-0.069	0.024	KF43	1125.944	-0.123	0.024
HVO26	1227.031	-0.066	0.024	KF44	1109.074	-0.123	0.025
Z20	1228.567	-0.058	0.024	CONEPEAKRESET	1112.778	-0.116	0.025
93YY	1218.857	-0.055	0.024				
HVO143	1214.159	-0.055	0.024				
92YY	1201.625	-0.058	0.024				
BM3973	1210.390	-0.066	0.024				
Y20	1201.486	-0.053	0.024				
90YY	1180.400	-0.063	0.023				
HVO41	1101.846	-0.174	0.024				
BM82-501	1102.197	-0.163	0.024				
BM82-500	1094.322	-0.171	0.024				
HVO44	1080.074	-0.175	0.024				
110YY	1080.379	-0.163	0.024				
HVO45	1076.958	-0.147	0.024				
109YY	1073.149	-0.126	0.024				
HVO46	1074.696	-0.141	0.024				
HVO47	1078.837	-0.156	0.024				
HVO49	1093.355	-0.145	0.024				
95YY	1219.217	-0.061	0.024				
96YY	1216.726	-0.057	0.024				

As indicated by the Uwekahuna water-tube tiltmeter located on the NW side of the caldera, (fig. CS-7) Kilauea's summit continued to gradually tilt in a SSE direction in the early months of the year, consistent with the pattern of the summit subsidence. This trend of tilt continued into mid August when the direction changed towards WSW possibly indicating a period of reinflation of the north caldera area. This tilt pattern has continued to the end of this reporting period.

Figure CS-7. Plot of the Uwekahuna Vault water-tube tilt and Kilauea summit shallow earthquake counts between January 1990 and December 1990.



In October, the Kilauea summit EDM network was measured. There are relatively small changes between the October 1989 and the October 1990 surveys, the largest change being about five centimeters. Lines crossing the area of greatest subsidence in general showed contraction, while the longer baselines from the summit area to Mauna Loa all extended (Table CS-3).

Figure CS-8 Horizontal line length displacement vectors of stations in the Kilauea summit EDM trilateration network between October of 1989 and October of 1990. The error ellipses represent 2σ of actual error.

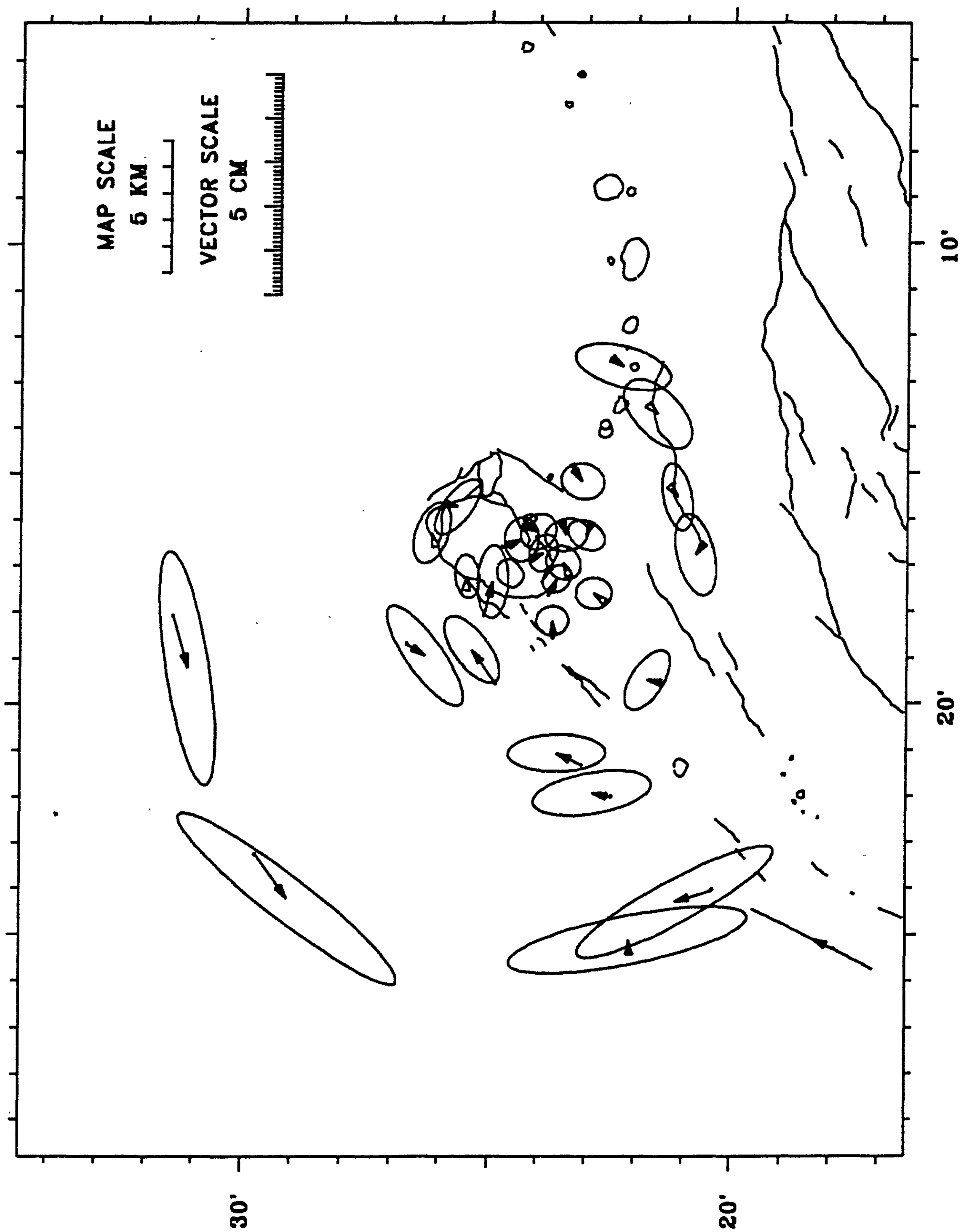


Table CS-3. Table of horizontal line length changes for Kilauea summit EDM network between October 1989 and October 1990.

Ins. Stn.	Refl. Stn.	1st survey line length, (m)	date	2nd survey line length, (m)	date	diff. (m)
HVO132	68-24	1593.053	10/16/89	1593.024	10/17/90	-0.029
HVO132	HVO113	3787.638	10/16/89	3787.619	10/17/90	-0.018
HVO118	97YY	3048.399	10/16/89	3048.415	10/17/90	0.016
HVO118	HVO119	2580.558	10/16/89	2580.548	10/17/90	-0.010
HVO118	HVO119	2580.565	10/16/89	2580.548	10/17/90	-0.017
HVO118	HVO120	2651.341	10/16/89	2651.327	10/17/90	-0.014
HVO113	97YY	3224.470	10/16/89	3224.473	10/17/90	0.003
HVO114	HVO109	4343.711	10/17/89	4343.701	10/17/90	-0.010
HVO114	HVO119	3071.033	10/16/89	3070.973	10/17/90	-0.060
HVO114	HVO119	3071.029	10/17/89	3070.973	10/17/90	-0.056
HVO114	HVO113	5135.188	10/16/89	5135.185	10/17/90	-0.002
HVO114	HVO113	5135.203	10/17/89	5135.185	10/17/90	-0.018
HVO114	68-24	982.282	10/17/89	982.262	10/17/90	-0.020
HVO114	HVO144	2835.983	10/17/89	2835.948	10/17/90	-0.034
CONE PEAK	HVO120	2774.103	10/17/89	2774.119	10/17/90	0.016
HVO114	HVO132	1919.995	10/16/89	1919.946	10/17/90	-0.049
CONE PEAK	HVO119	1627.748	10/16/89	1627.739	10/17/90	-0.009
CONE PEAK	HVO119	1627.742	10/17/89	1627.739	10/17/90	-0.003
CONE PEAK	HVO113	3895.272	10/17/89	3895.263	10/17/90	-0.009
CONE PEAK	HVO118	2749.128	10/16/89	2749.120	10/17/90	-0.008
CONE PEAK	HVO144	2279.160	10/17/89	2279.134	10/17/90	-0.026
CONE PEAK	HVO145	4992.973	10/17/89	4992.972	10/17/90	-0.001
HVO136	HVO135	4377.718	10/16/89	4377.710	10/18/90	-0.008
HVO136	HVO145	2731.167	10/16/89	2731.191	10/18/90	0.024
PUU KOAE RESET	HVO144	3843.295	10/16/89	3843.296	10/18/90	0.001
PUU KOAE RESET	CONE PEAK	4325.541	10/16/89	4325.536	10/18/90	-0.005
PUU KOAE RESET	HVO109	5486.230	10/16/89	5486.204	10/18/90	-0.026
PUU KOAE RESET	HVO135	8510.274	10/16/89	8510.290	10/18/90	0.016
HVO119	KEAKAPULU	13943.212	10/19/89	13943.211	10/18/90	-0.001
HVO113	KEAKAPULU	15384.988	10/19/89	15384.974	10/18/90	-0.015
HVO111	KEAKAPULU	17593.805	10/19/89	17593.777	10/18/90	-0.027
HVO111	KEAKAPULU	17593.805	10/19/89	17593.764	10/18/90	-0.041
HVO119	HVO34	1579.860	10/16/89	1579.834	10/18/90	-0.026
HVO111	HVO114	3403.230	10/17/89	3403.263	10/18/90	0.032
HVO119	HVO113	3159.835	10/16/89	3159.846	10/18/90	0.011
HVO119	HVO113	3159.847	10/16/89	3159.846	10/18/90	-0.001
PUU KOAE RESET	HVO136	5299.500	10/16/89	5299.504	10/18/90	0.004
PUU KOAE RESET	HVO136	5299.504	10/16/89	5299.504	10/18/90	0.000
PUU KOAE RESET	HVO145	4326.486	10/16/89	4326.489	10/18/90	0.003
PUU KOAE RESET	HVO120	6148.667	10/16/89	6148.692	10/18/90	0.026
HVO111	ML STRIP	20921.355	10/19/89	20921.373	10/18/90	0.018
HVO119	ML STRIP	14815.538	10/19/89	14815.589	10/18/90	0.051
HVO113	ML STRIP	13038.115	10/19/89	13038.159	10/18/90	0.044
HVO113	HVO34	2544.111	10/16/89	2544.131	10/18/90	0.020
HVO113	HVO10 RESET	3076.138	10/16/89	3076.127	10/18/90	-0.011
PUU KOAE RESET	HVO113	8185.995	10/16/89	8185.959	10/18/90	-0.035
HVO110	HVO113	5863.000	10/17/89	5862.978	10/19/90	-0.022
HVO110	HVO119	4883.198	10/17/89	4883.136	10/19/90	-0.062
HVO110	PUU HULUHULU	4497.233	10/17/89	4497.250	10/19/90	0.017
HVO143	HVO10 RESET	3401.491	10/16/89	3401.518	10/19/90	0.027
HVO119	HVO144	1900.352	10/16/89	1900.319	10/19/90	-0.033
HVO119	HVO10 RESET	2874.556	10/16/89	2874.502	10/19/90	-0.054

Table CS-3 (continued)

Ins. Stn.	Refl. Stn.	1st survey line length, (m)	date	2nd survey line length, (m)	date	diff. (m)
HVO113	PUU HULUHULU	10163.857	10/17/89	10163.836	10/19/90	-0.021
HVO111	HVO113	8534.495	10/17/89	8534.478	10/19/90	-0.018
HVO111	HVO113	8534.495	10/17/89	8534.467	10/19/90	-0.028
HVO111	HVO110	3960.623	10/17/89	3960.598	10/19/90	-0.025
HVO111	HVO110	3960.625	10/17/89	3960.598	10/19/90	-0.027
HVO111	HVO119	6111.381	10/17/89	6111.334	10/19/90	-0.047
HVO119	68-24	2614.323	10/16/89	2614.250	10/19/90	-0.073
HVO111	PUU HULUHULU	5628.337	10/17/89	5628.316	10/19/90	-0.021
HVO117	PUU HULUHULU	2513.233	10/17/89	2513.210	10/19/90	-0.023
HVO117	HVO110	3794.148	10/17/89	3794.148	10/19/90	0.000
BM84-50	HVO143	1401.627	10/16/89	1401.618	10/22/90	-0.009
BM84-50	BM82-500	2741.385	10/16/89	2741.384	10/22/90	-0.001
BM84-50	HVO34	3799.985	10/16/89	3799.978	10/22/90	-0.006
BM84-50	HVO119	5244.080	10/16/89	5244.040	10/22/90	-0.040
BM84-50	HVO10 RESET	3032.372	10/16/89	3032.387	10/22/90	0.015
HVO160	HVO135	3652.507	10/25/89	3652.519	10/22/90	0.012
HVO113	HVO10 RESET	3076.138	10/16/89	3076.153	10/22/90	0.014
HVO113	HVO119	3159.835	10/16/89	3159.865	10/22/90	0.030
HVO113	HVO119	3159.847	10/16/89	3159.865	10/22/90	0.018
HVO113	HVO34	2544.111	10/16/89	2544.144	10/22/90	0.033
HVO113	HVO143	2069.979	10/16/89	2069.986	10/22/90	0.007
HVO113	BM84-50	3106.507	10/16/89	3106.477	10/22/90	-0.030
HVO113	BM84-50	3106.503	10/16/89	3106.477	10/22/90	-0.026
HVO113	BM82-500	1864.414	10/16/89	1864.447	10/22/90	0.033
KULANI	HVO111	19407.450	10/19/89	19407.432	10/02/90	-0.018
KULANI	HVO119	14155.786	10/19/89	14155.744	10/02/90	-0.042
KULANI	HVO113	11085.629	10/19/89	11085.645	10/02/90	0.016

Spirit-level tilt stations were measured on the lower east rift of Kilauea in July. Selected tilt stations were also measured on the summit after an earthquake swarm occurred in the summit caldera region and upper east rift on December 4-5, 1990.

Stations located on the south flank of the lower east rift in general tilted in a northerly direction while stations located to the north tilted in a southerly direction. This pattern holds true as far down rift as the Pohoiki road (fig. CS-9). Most of this survey's tilt (compared to previous survey taken in 1986) can be attributed to the June 1989 M6.1 south flank earthquake but time-series plots of stations with a long history show that there has been gradual subsidence taking place since 1976. These results are consistent with level data from 1975-1989 that also show rift subsidence.

Results of the summit tilt survey after the earthquake swarm are difficult to interpret because of the long time span between surveys (November 1988 to December 1990. The subsidence of the summit and upper east rift (figure CS-10 and 10a) due to the current Puu Oo eruption tend to overwhelm the changes resulting from the intrusion. Tiltmeters (short base water-tube and Ideal Aerosmith) in the Uwekahuna vault showed small changes in a northwesterly direction (< 8 µrads), which indicates inflation of the summit caldera area, associated with the swarm (fig. CS-7).

Figure CS-9. Vector plot of Kilauea lower east rift spirit-level tilt between June 1986 and January 1989.

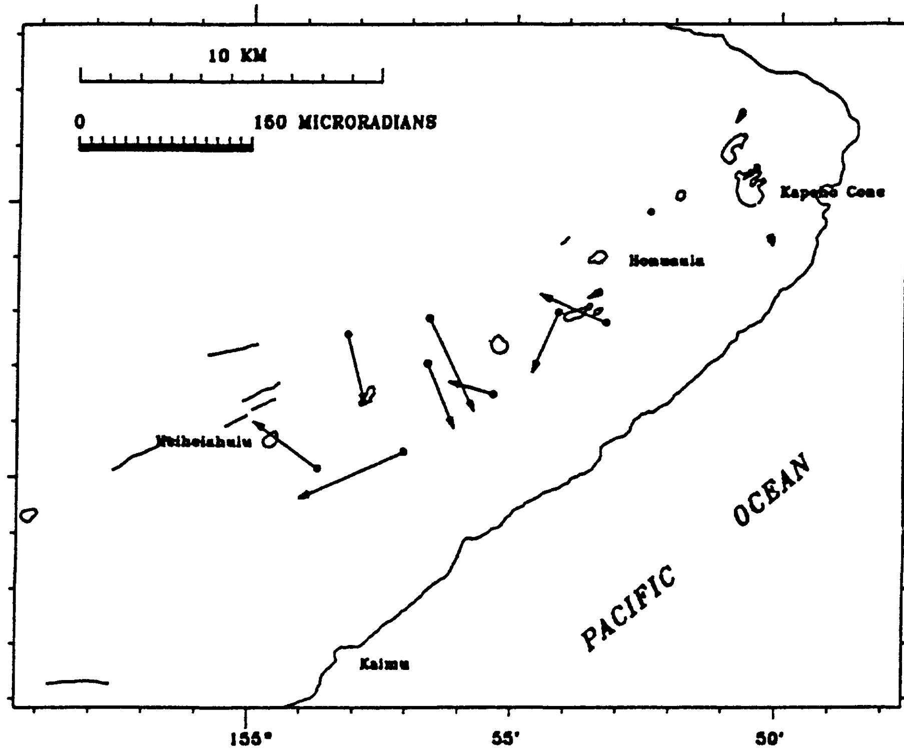


Figure CS-10. Plot of tilt vectors at selected spirit-level tilt sites on the summit and upper east rift zone of Kilauea between 1986 and 1990. The 1990 survey was measured after a summit-upper east rift zone earthquake swarm.

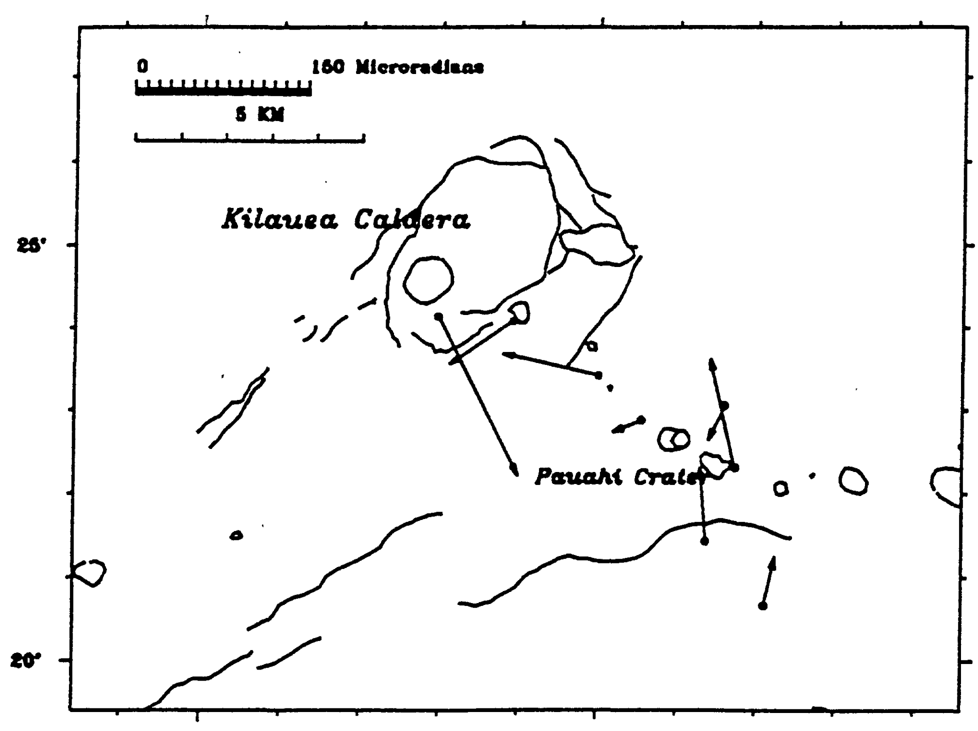
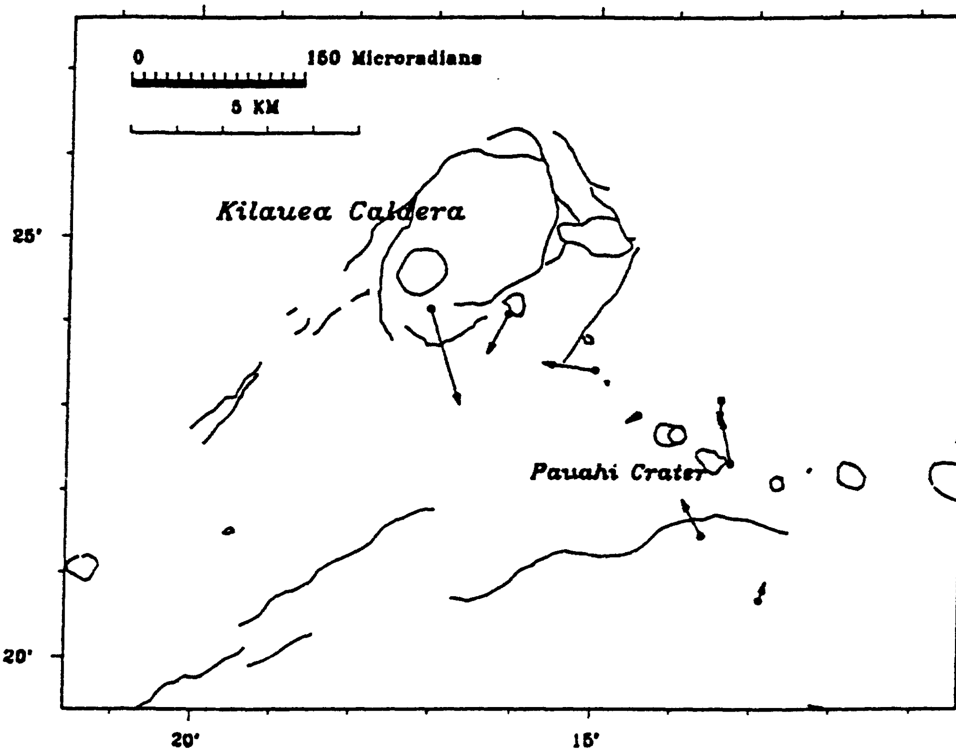
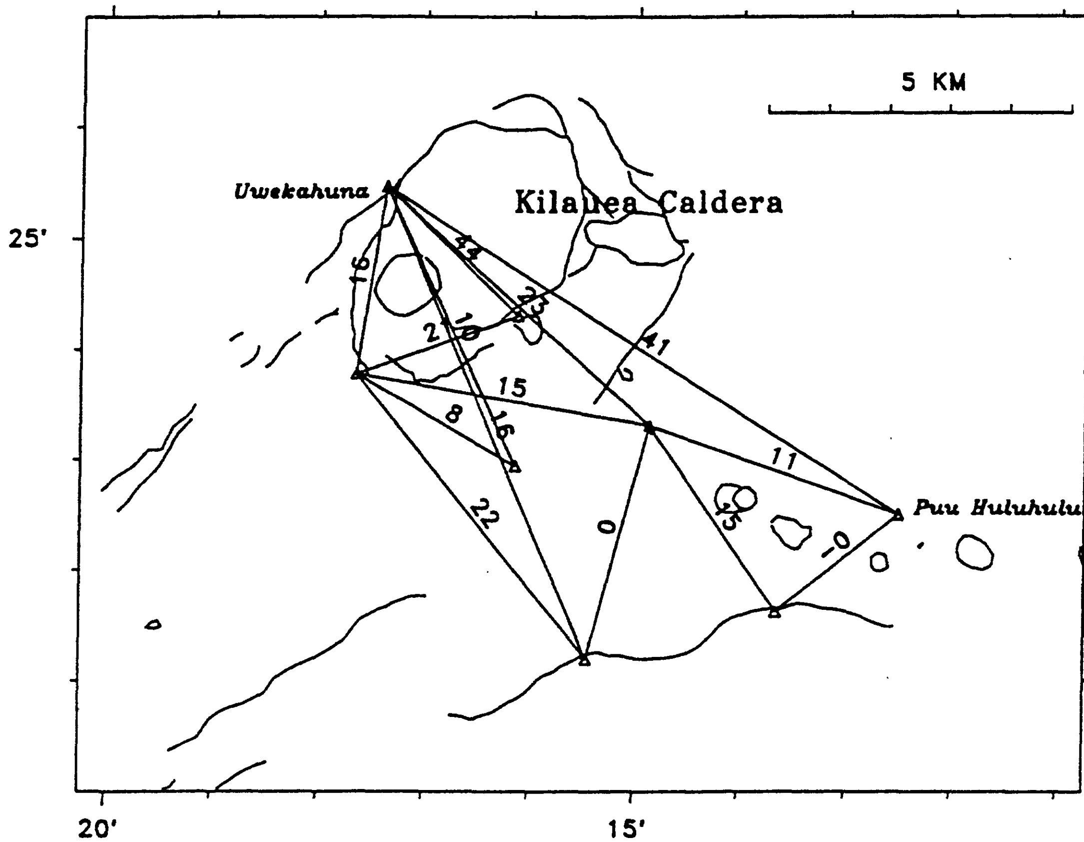


Figure CS-10a. Plot of tilt vectors at selected spirit-level tilt sites on the summit and upper east rift zone of Kilauea between 1988 and 1990. The 1990 survey was done after a summit-upper east rift zone earthquake swarm.



All line lengths except those that spanned the area of the earthquake swarm showed negligible changes (fig. CS-11). The largest change (4.4 cm) occurred between Uwekahuna (HVO113) and Keanakakoi (HVO10RESET) and between HVO113 and Puu Huluhulu (4.1 cm). These changes in line lengths fit the location of the main body of located earthquakes during the swarm.

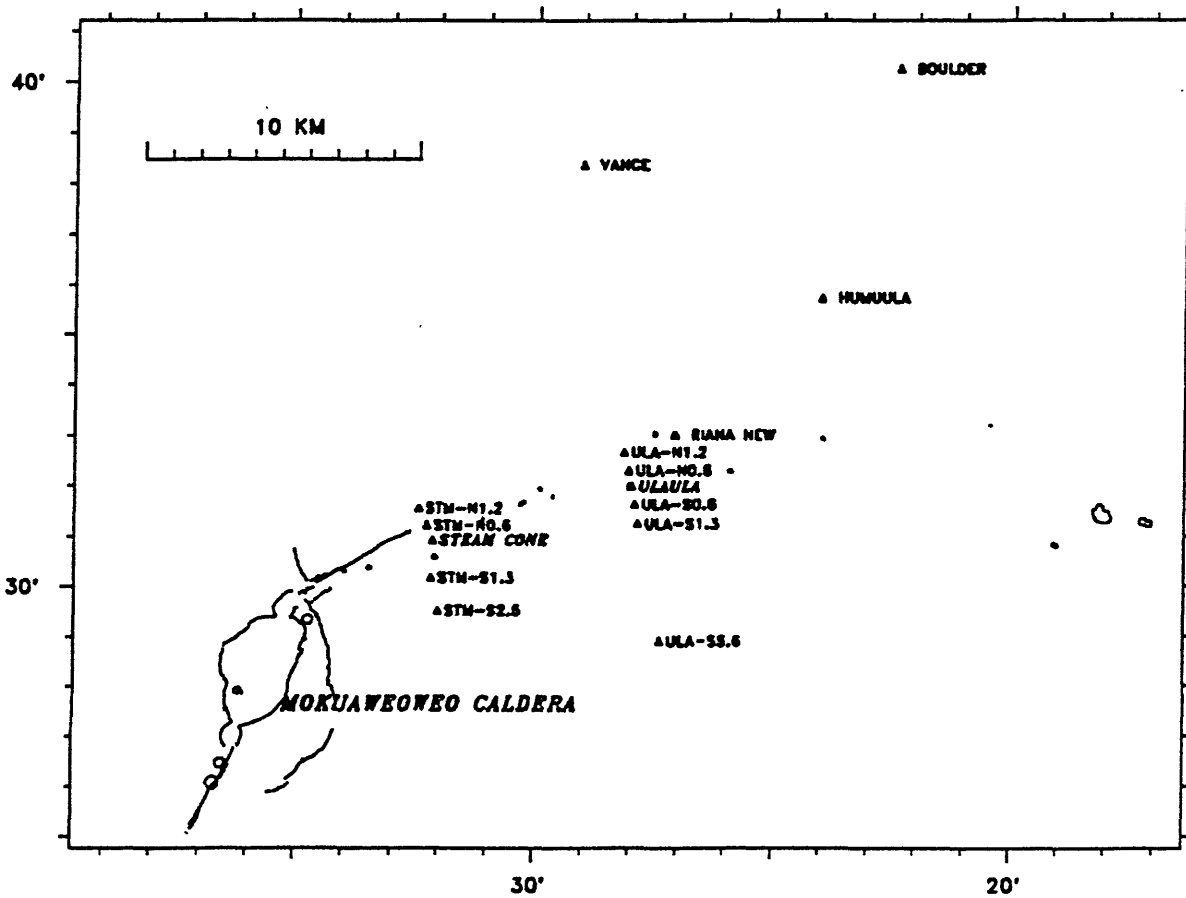
Figure CS-11. Location map and line length changes between October 1990 and December 1990 of selected EDM lines over the area affected by the December earthquake swarm on the summit and upper east rift zone of Kilauea.



Mauna Loa

During April of 1990, the Mauna Loa northeast rift permanent-glass monitors and a few selected lines to the north and north-northeast of the rift were measured in response to an increase in earthquake activity during late March-early April (fig. CS-12). Initial reports put the swarm in close proximity to the rift zone. Further examination showed that the earthquakes occurred further south and may have been related more to the Kaoiki fault rather than the northeast rift. The swarm included a several quakes that registered >M4.0.

Figure CS-12. Location map of Mauna Loa northeast rift zone permanent-glass and selected EDM lines measured in response to an earthquake swarm in March-April.



Permanent-glass EDM monitors shot from Steam Cone and Puu Ulaula to the north and south of the rift all showed contractions (fig. CS-12a and 12b). The Steam Cone monitor showed small changes since 1989 while the changes on the Puu Ulaula monitor showed changes in the 3-4 cm range. Line lengths measured at greater distances from the rift, Riana to Humuula and Boulder, both in a north-northeasterly direction, contracted 3 and 4 cm respectively since 1988. Line lengths between Riana and Vance to the north showed negligible changes.

The northeast rift spirit-level tilt network was measured during May and compared to the November 1988 survey. Stations located closer to the rift continue to tilt toward the rift (fig. CS-13), the largest tilts being ~20 µrads. Tilt vectors plotted from post-eruption 1984 also show the same results but at a slightly larger magnitude (fig. CS-13a). A possible mechanism for this pattern could be the cooling contraction of the the 1984 eruption dike.

Figure CS-12a and 12b. Time-series plot of Puu Ulaula and Steam Cone permanent-glass monitors located along the northeast rift zone of Mauna Loa.

Figure CS-12a.

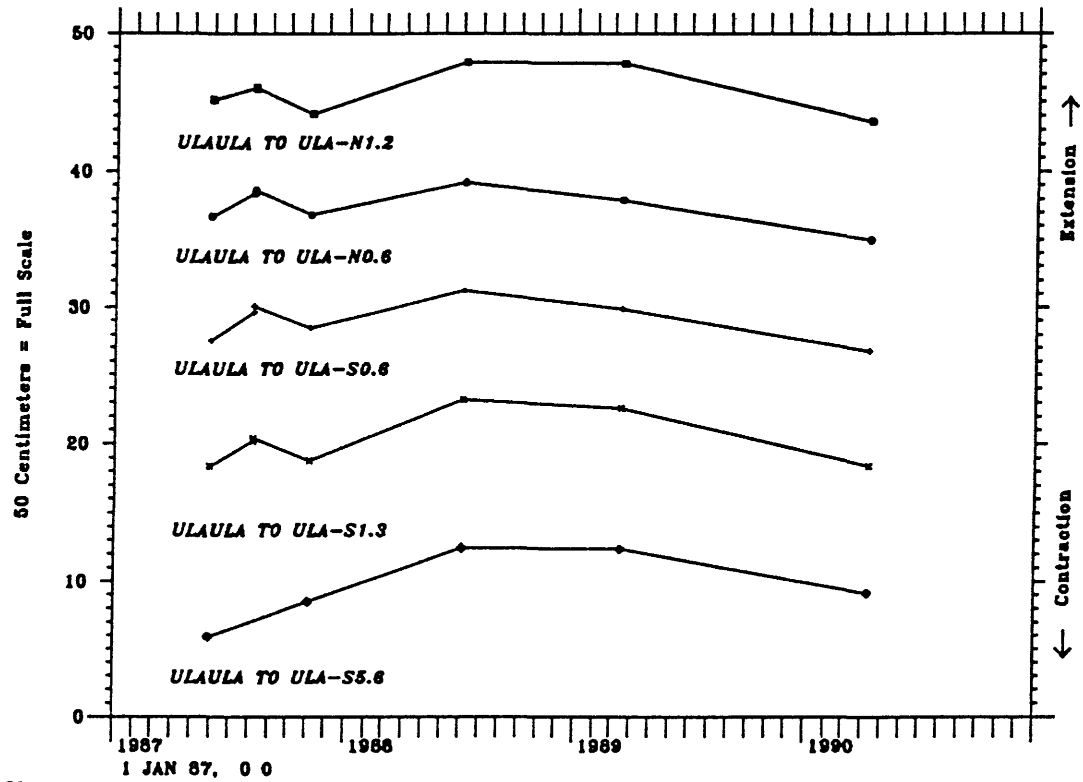


Figure CS-12b.

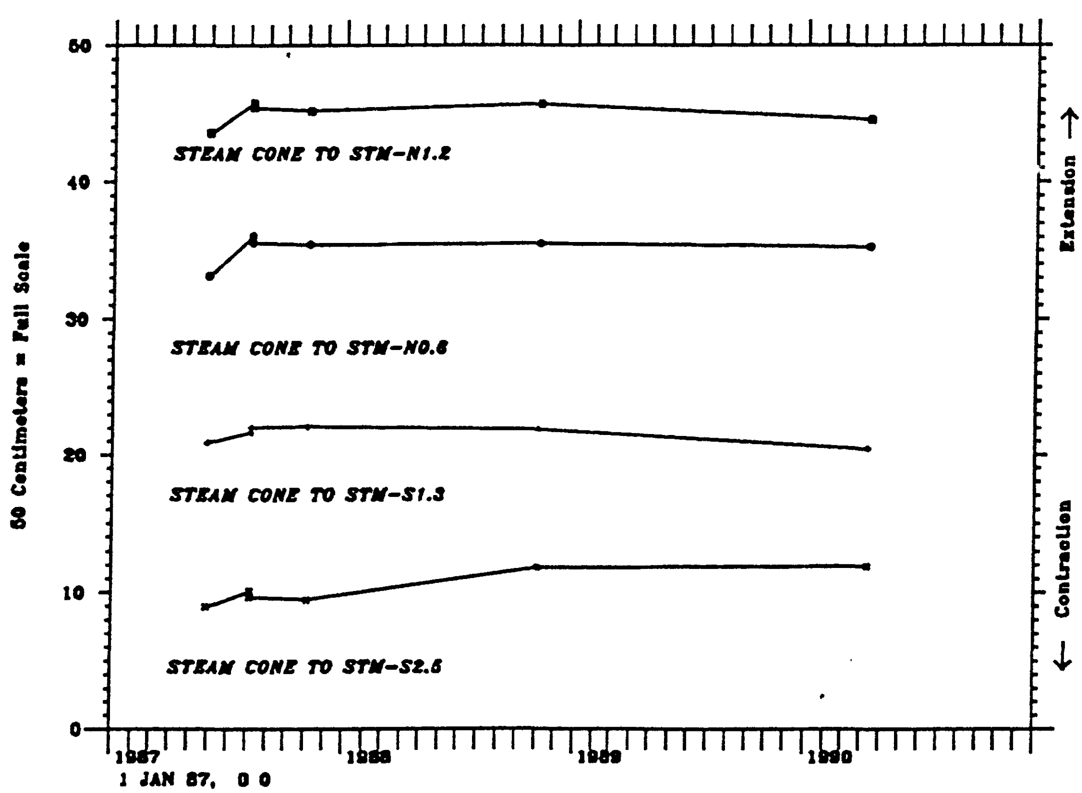


Figure CS-13. Plot of Mauna Loa northeast rift zone spirit-level tilt network with tilt vectors for November 1988 to May 1990 surveys.

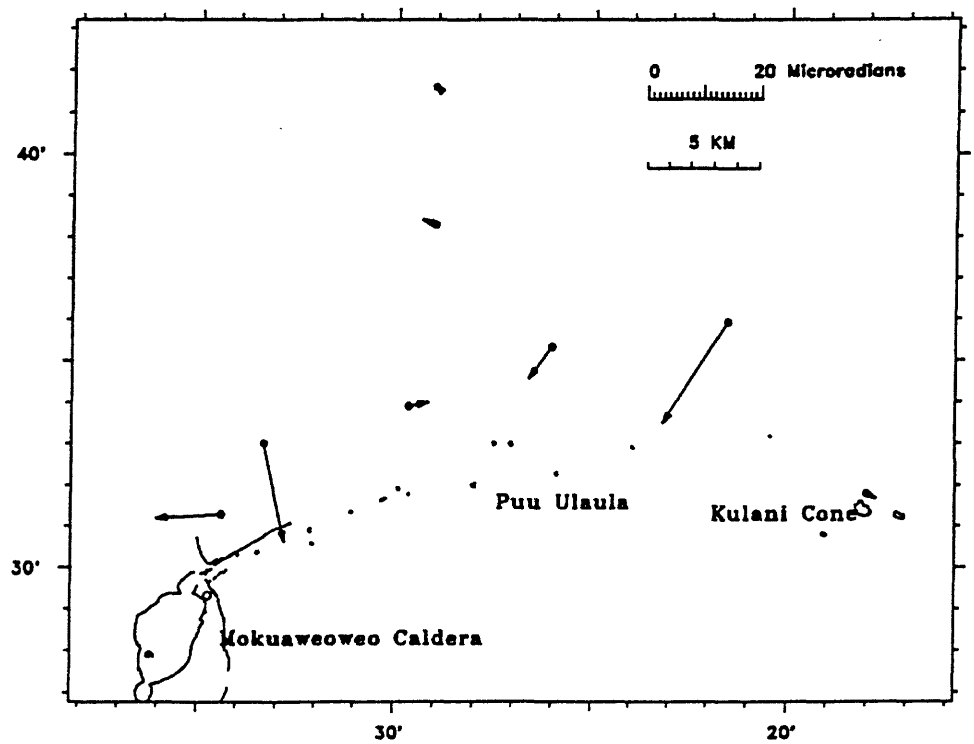
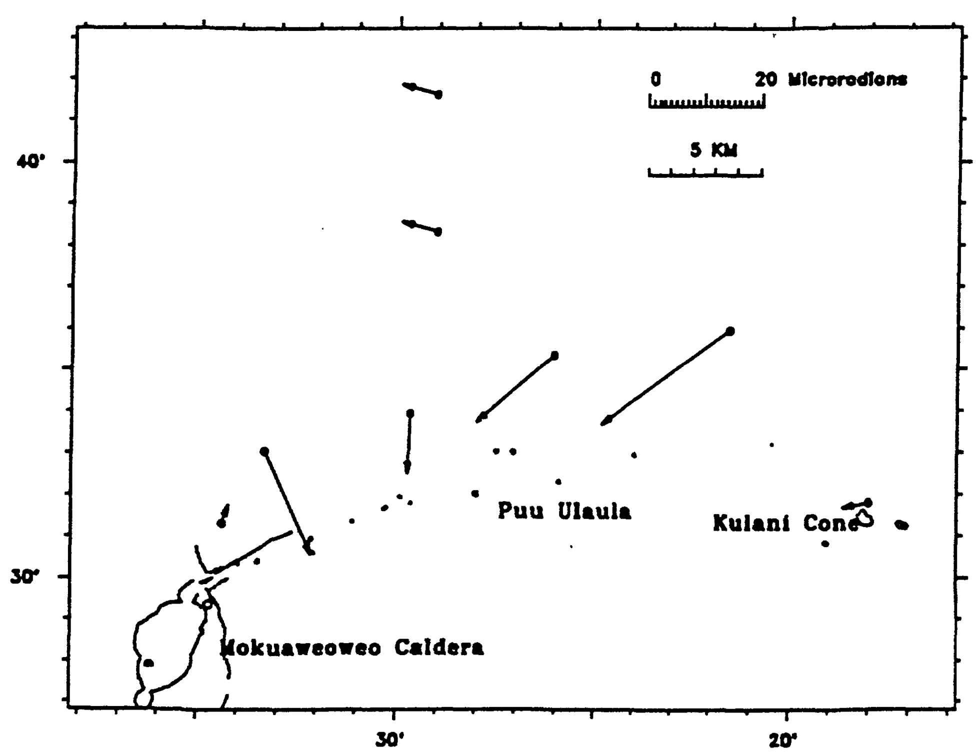


Figure CS-13a. Plot of tilt vectors for Mauna Loa northeast rift zone spirit-level tilt between post-eruption 1984 and May 1990 surveys.



The summit and southwest rift permanent-glass EDM monitors were measured during July and August (fig. CS-14). All three summit lines show contractions, the largest about 52 mm and the smallest about 19 mm (fig. CS-15 and 15a). The difference in deformation pattern during 1989-90 from long-term (post '84 eruption) trends may be reflecting a change in the inflation pattern (see Mauna Loa spirit-level tilt section of this report) and may be a short-lived adjustment. Although a fraction of the change in line length can be attributed to the difference between the K & E Rangemaster III (used in previous years) and the HP 3808A used this year, the changes exceed the largest amount of inter-instrument discrepancy we could estimate from repeated measurements between instruments.

Figure CS-14. Location map of permanent-glass EDM monitors on Mauna Loa summit and southwest rift zone.

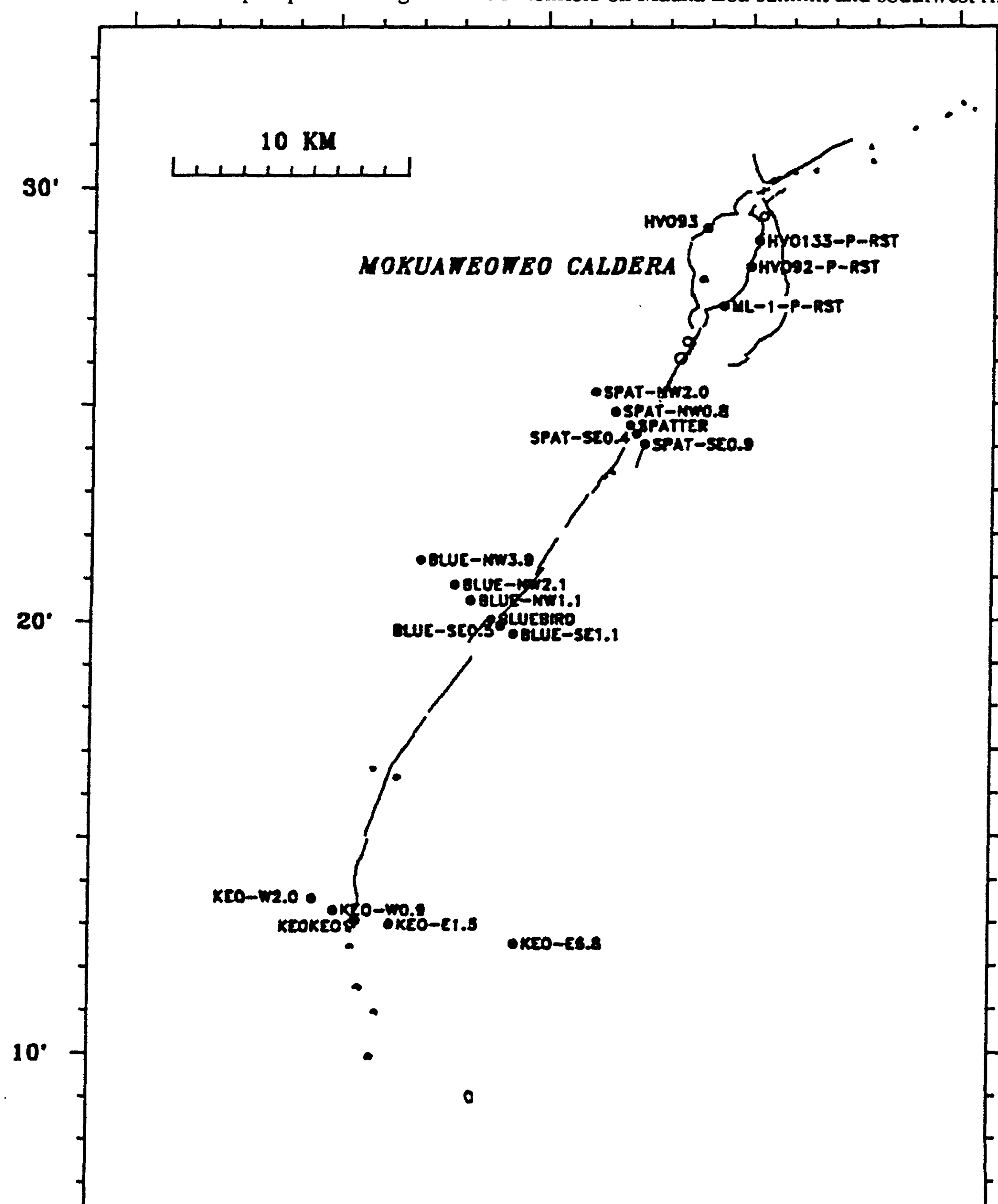


Figure CS-15. Plot of permanent-glass EDM monitor line length changes on Mauna Loa summit between 1989 and 1990.

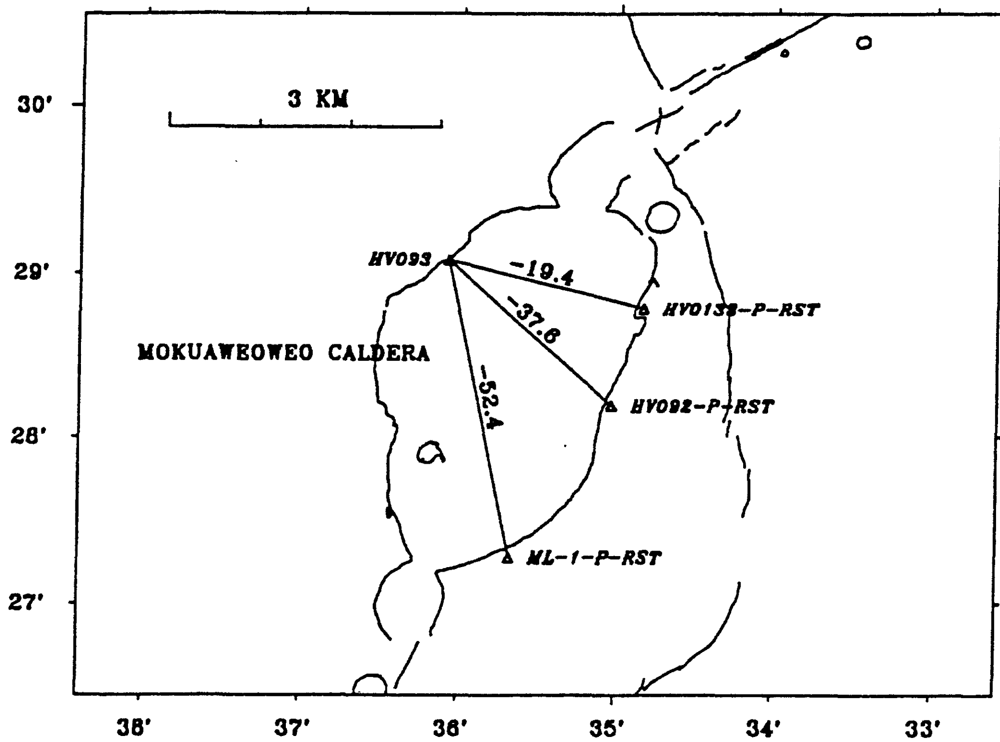
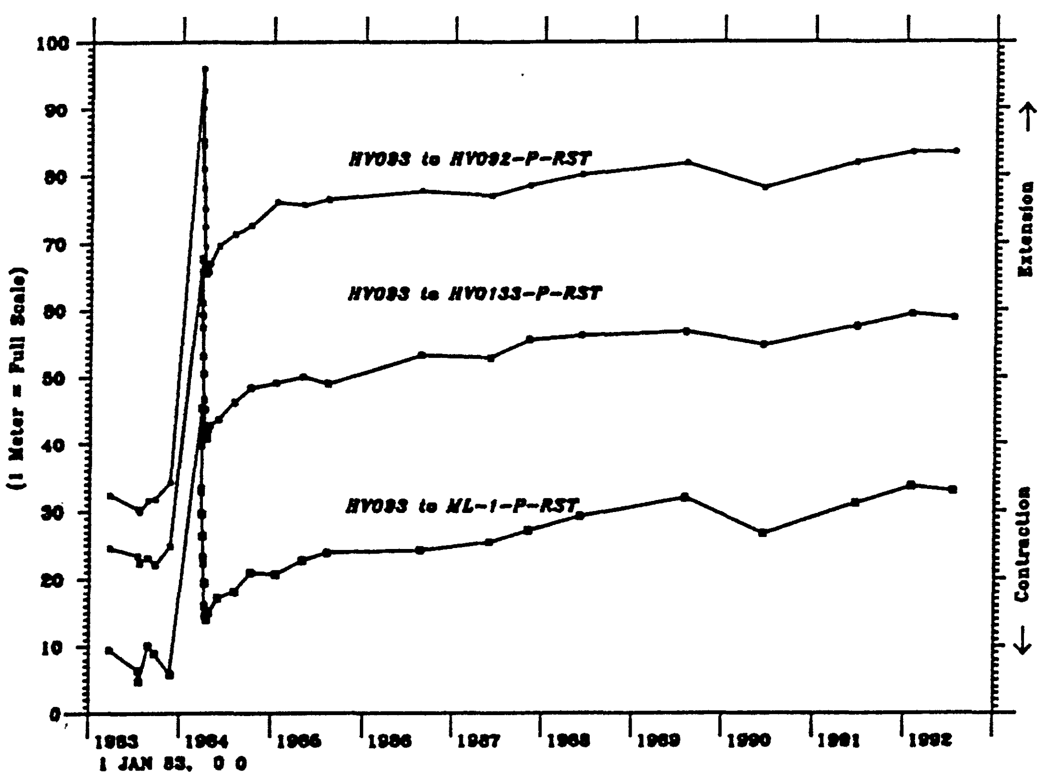


Figure CS-15a. Time-series plot of the EDM permanent-glass lines spanning Mauna Loa summit caldera.



Permanent-glass monitors on the southwest rift show contractions on all lines measured on the Spatter and Bluebird monitors (fig. CS-15b and 17c). Only two of four lines on the Keokeo monitor were measurable, so interpretation of any changes is not possible (fig. CS-15d).

Figure CS-15b, c, and d. Time-series plot of Spatter, Bluebird, and Keokeo EDM permanent-glass monitors located along southwest rift zone of Mauna Loa .

Figure CS-15b.

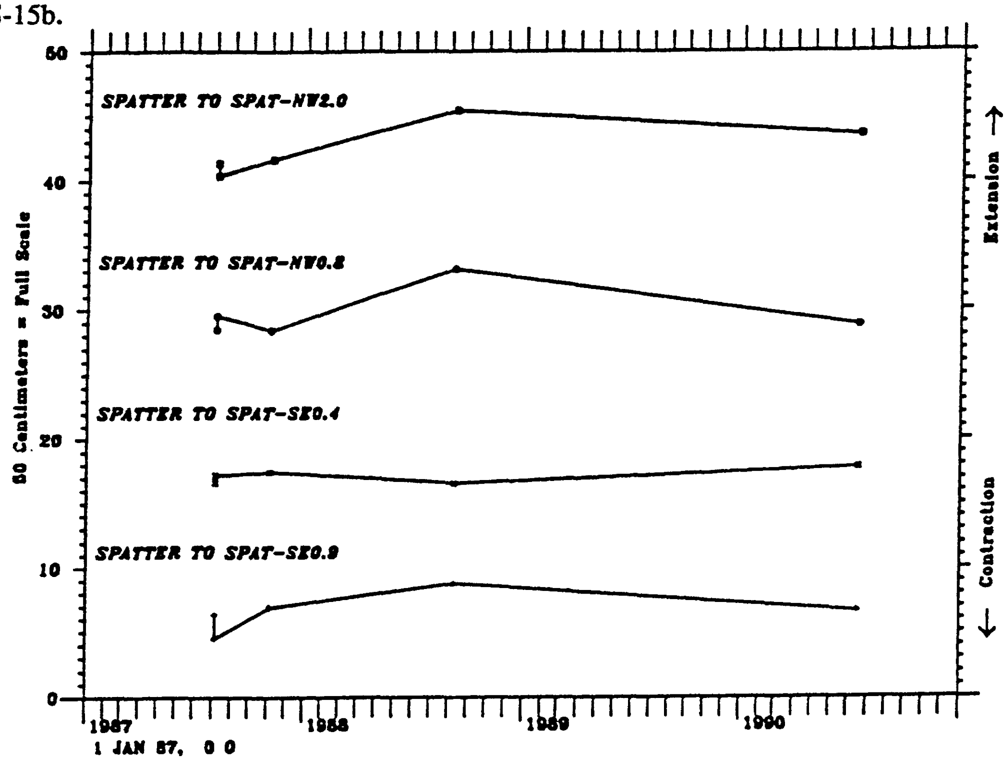


Figure CS-15c.

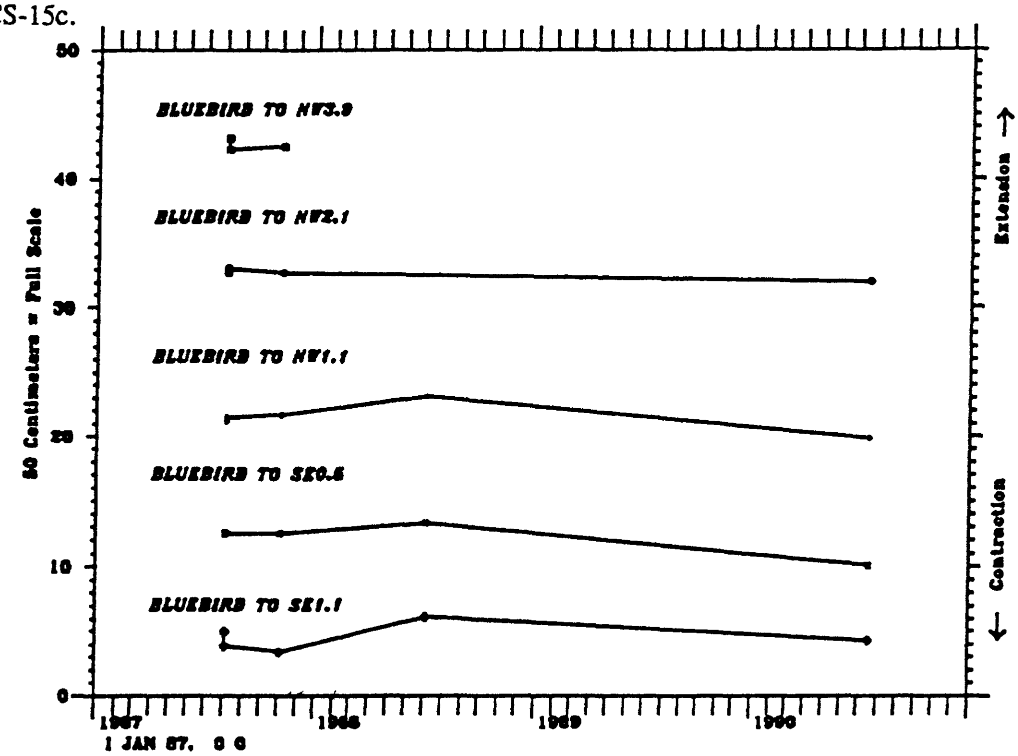
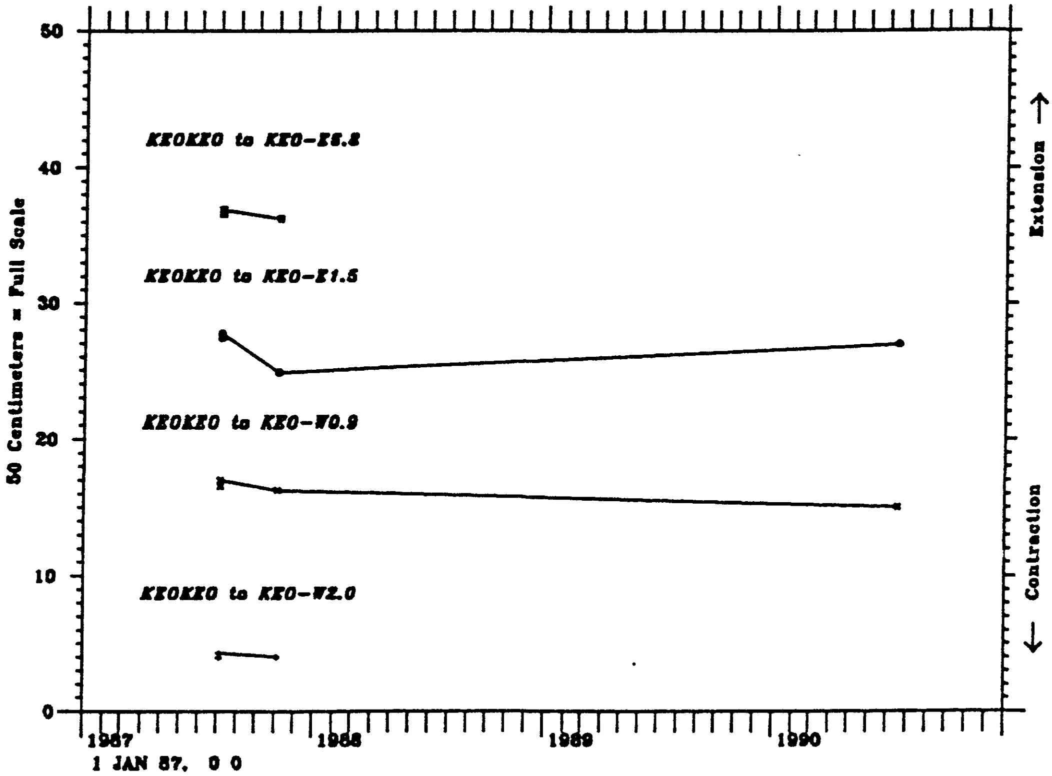
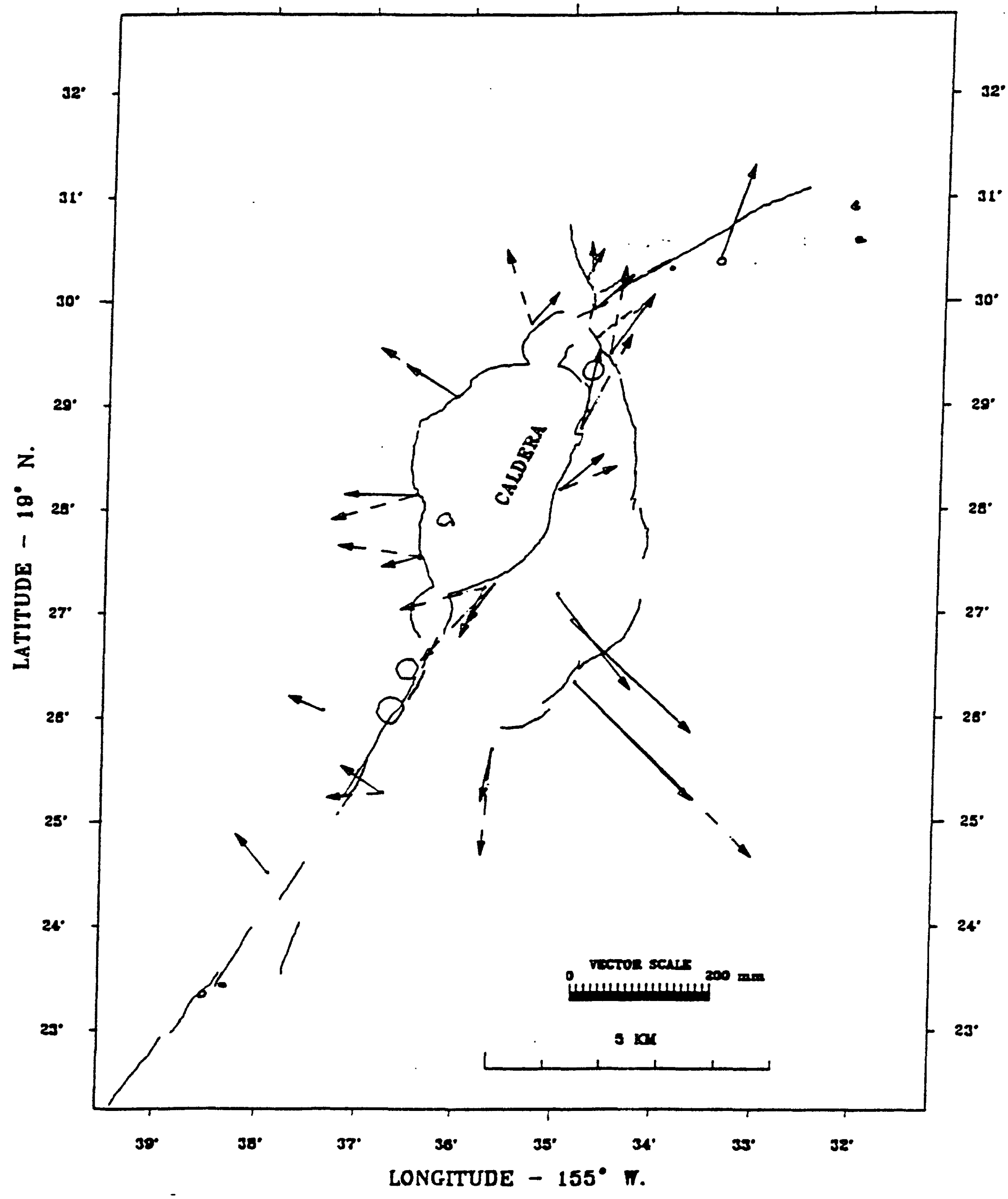


Figure CS-15d.



Line length changes in the summit trilateration network were small and modelling the changes for horizontal displacements produced error ellipses of the same magnitude as the displacements. Comparison with 1984 post-eruption line lengths show displacements radiating away from the southeastern caldera, the area of greatest vertical changes and tilt (fig. CS-16).

Figure CS-16. Horizontal displacement vectors calculated from EDM line length changes in the Mauna Loa summit network. Dashed vectors represent data from 1976 to 1983 and solid vectors post eruption-1984 to 1990. Note that six of the stations have only post-eruption 1984 to 1990 data.



Tilts of stations on the summit from 1989 to 1990 (fig. CS-17) show a pattern of inflation slightly different from the long-term trend (fig. CS-18). Tilt vectors, especially on the west side of the caldera, radiate from an area west of the caldera, rather than the usual center in the south-eastern section of the caldera. This tilt pattern is consistent with what was seen on the cross-caldera permanent-glass lines.

Figure CS-17. Vector plot of the Mauna Loa summit spirit-level tilt network between August 1989 and June-July 1990 surveys.

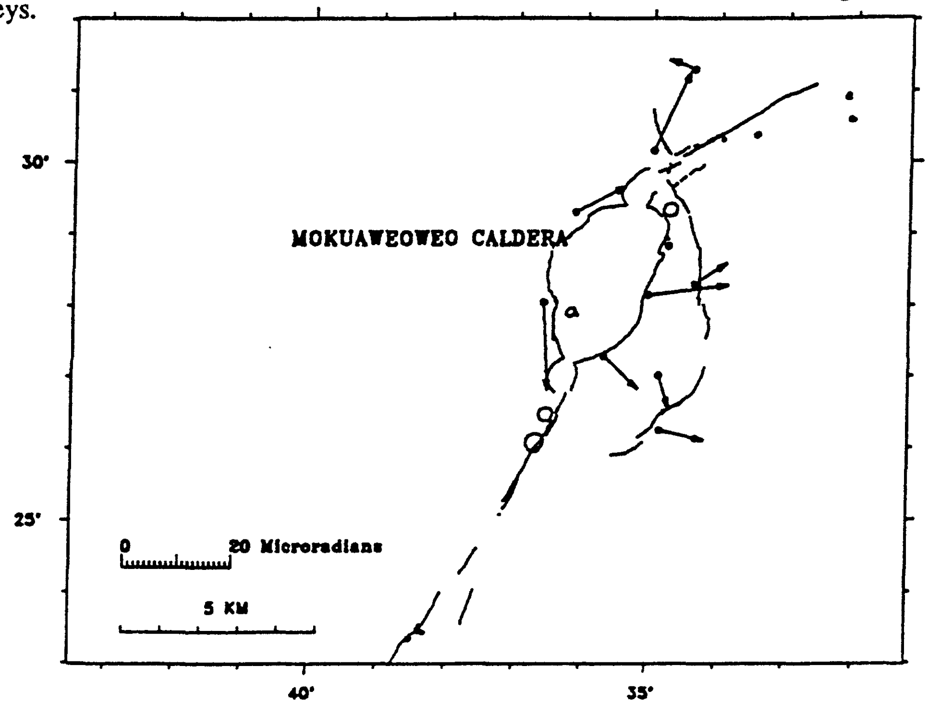
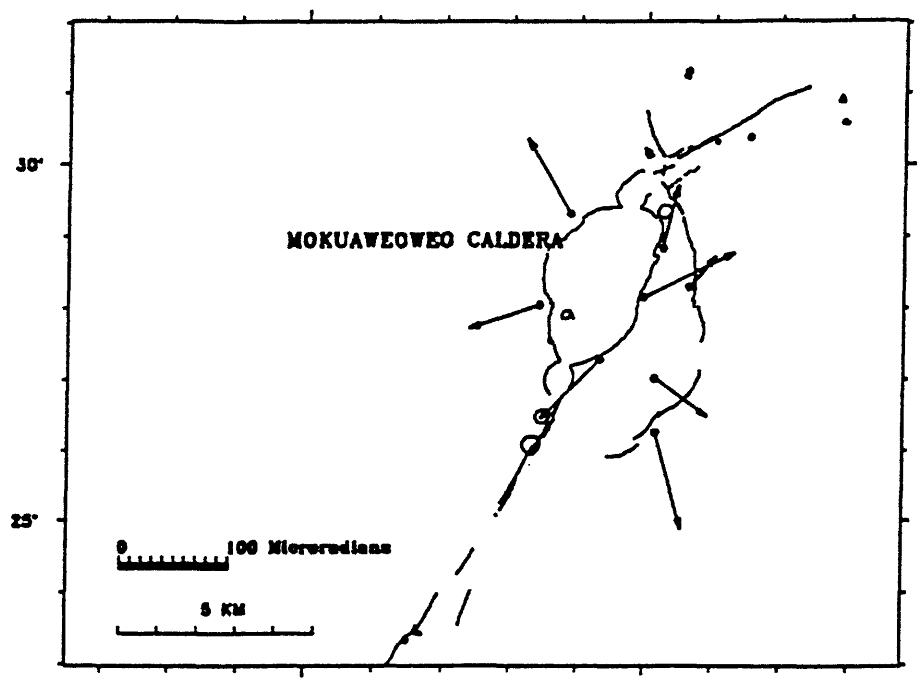


Figure CS-18. Long-term tilt vector plot (post-1984 eruption to current survey) of Mauna Loa summit monitor network.



The calculations listed in Table CS-4 indicate that the summit of Mauna Loa has regained an average of approximately 43% of the subsidence measured during the the 1984 eruption. Stations HVO 133 (pahoehoe block with "Y" nail possibly moved to give anomalous tilt), New Crk Stnre (re-established because of disturbed nail) and Fissure (new station established in 1988) were not included as part of the average. The average tilt rate per month between 1989 and 1990 is ~1.0 μrads, about 0.5 μrads less than between 1988 and 1989. The average rate of inflation per month since the end of the 1984 eruption excluding HVO 133, New Crk Stnre, and Fissure is ~0.9 μrads, down 0.3 μrads. The post-1984-eruption/present reinflation cycle on the summit represents, on average, ~84% of the post 1975 eruption/pre 1984 eruption inflation, as measured by spirit level tilt.

Comparison of changes in tilt and horizontal displacements on Mauna Loa's summit in the period since the 1984 eruption and between the 1975 and 1984 eruptions shows a relatively close coincidence of directions of tilt and horizontal displacement between these two time periods, with both data revealing a center of inflation located south-southeast of the caldera. The magnitudes of tilt and EDM displacements are very similar for stations located west of the caldera, while stations to the east show magnitudes for the period from 1984 to now that are, on average, about 50% of those between 1975 and 1983.

Table CS-4. Table of tilt changes, percentage and rate of recovery for Mauna Loa summit. **Bold numbers** indicate the summit subsidence measured during the 1984 Mauna Loa eruption. The average exclude stations that do not have data prior to and after the 1984 eruption and those that had suspected busts because of individual block movement.

Station Name	Date from	to	N-S µrads	E-W µrads	µrads	% Recovery/ µrads/month
NEW CRK STNRE						
	10/21/86		500.00	500.00		
	10/21/86	7/17/90	528.67	524.48	37.70	*%/0.8
MOK 2						
	12/ 9/76		500.00	500.00		
	12/ 9/76	11/22/83	558.42	471.84	64.85	
	11/22/83	4/26/84	409.86	530.73	**-159.81**	
	4/26/84	6/12/90	479.56	490.10	80.68	50%/1.1
LAVA TUBE						
	9/11/75		500.00	500.00		
	9/11/75	7/13/83	474.14	429.47	75.12	
	7/13/83	4/23/84	531.10	578.78	**-159.81**	
	4/23/84	7/17/90	509.28	513.55	68.78	43%/0.9
NEW HVO 135						
	7/26/77		500.00	500.00		
	7/26/77	7/12/83	478.30	375.62	126.26	
	7/12/83	4/23/84	558.33	638.91	**-275.18**	
	4/23/84	7/17/90	502.92	583.58	78.31	28%/1.0
NEW AINAPO TRAIL 1						
	7/13/83		500.00	500.00		
	7/13/83	4/23/84	582.21	396.08	**-132.51**	
	4/23/84	7/17/90	546.37	444.68	60.39	46%/0.8
AINAPO TRAIL 2						
	9/11/75		500.00	500.00		
	9/11/75	7/13/83	348.75	547.02	158.39	
	7/13/83	4/23/84	528.29	469.25	**-195.66**	
	4/23/84	7/17/90	438.19	494.11	93.47	48%/1.3
SUMMIT CABIN						
	7/16/75		500.00	500.00		
	7/16/75	7/12/83	597.38	559.37	114.05	
	7/12/83	4/27/84	467.80	452.77	**-167.79**	
	4/27/84	7/17/90	509.10	536.47	93.33	56%/1.2
HVO 133						
	7/16/75		500.00	500.00		
	7/16/75	7/13/83	641.97	503.36	142.01	
	7/13/83	4/27/84	467.22	456.61	**-180.90**	
	4/27/84	7/17/90	524.93	470.58	59.38	!33%/0.8
FISSURE						
	11/17/88		500.00	500.00		
	11/17/88	6/12/90	504.59	497.41	5.27	* %/0.3
					Average	43%/0.9

* Denotes changes from when station was first read and not immediately after the end of the March-April 1984 eruption. No percentage of recovery was calculated.

! Denotes an anomalous reading because of suspected individual block movement where one of the rods was located and thus may not represent the regional tilt.

Mauna Loa summit was leveled during July (fig. CS-19). Figure CS-20 plots elevation changes along the level line from Vent to Ml-1 from 1983 to post-eruption 1984 and post-eruption-1984 to the 1990 Measured vertical changes between 1983 and post-eruption-1984 shows ~65 cm of subsidence, with the maximum change at ML-106. From post-1984-eruption to the present, ~25 cm of uplift has occurred, ML-106 again being the bench mark with the maximum recorded vertical displacement. This is also the area that tilt vectors indicate as the center of uplift. The total post-eruption inflation represents about 40% recovery of the measured deflation associated with the eruption.

Figure CS-19. Location map of Mauna Loa summit leveling bench marks surveyed in July 1990.

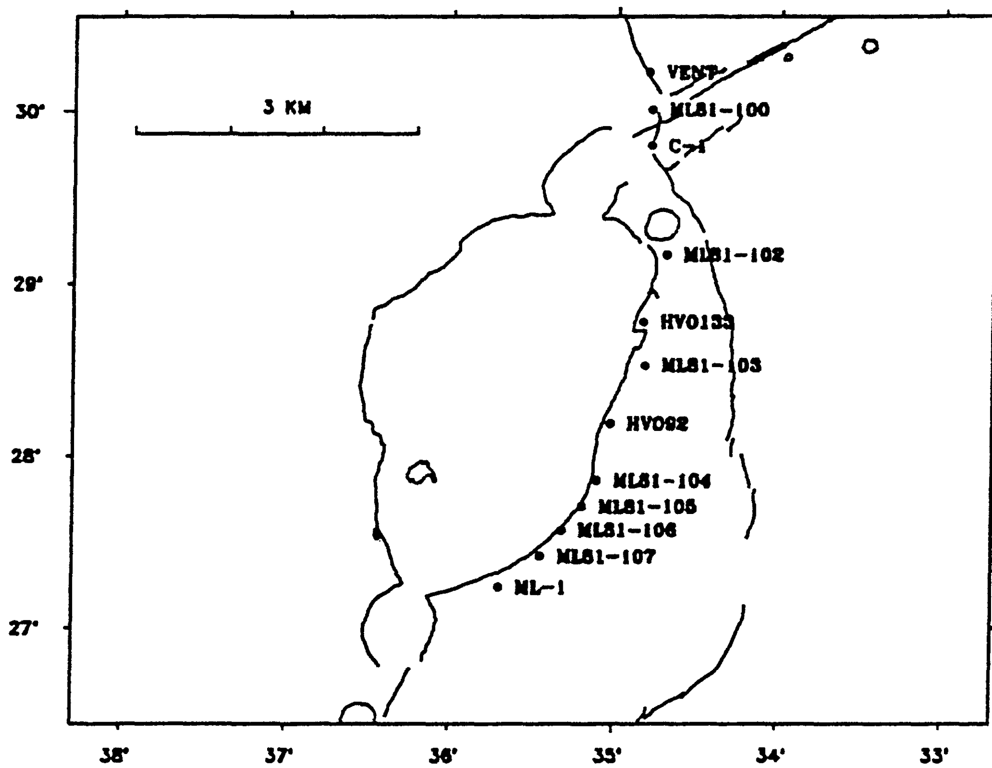
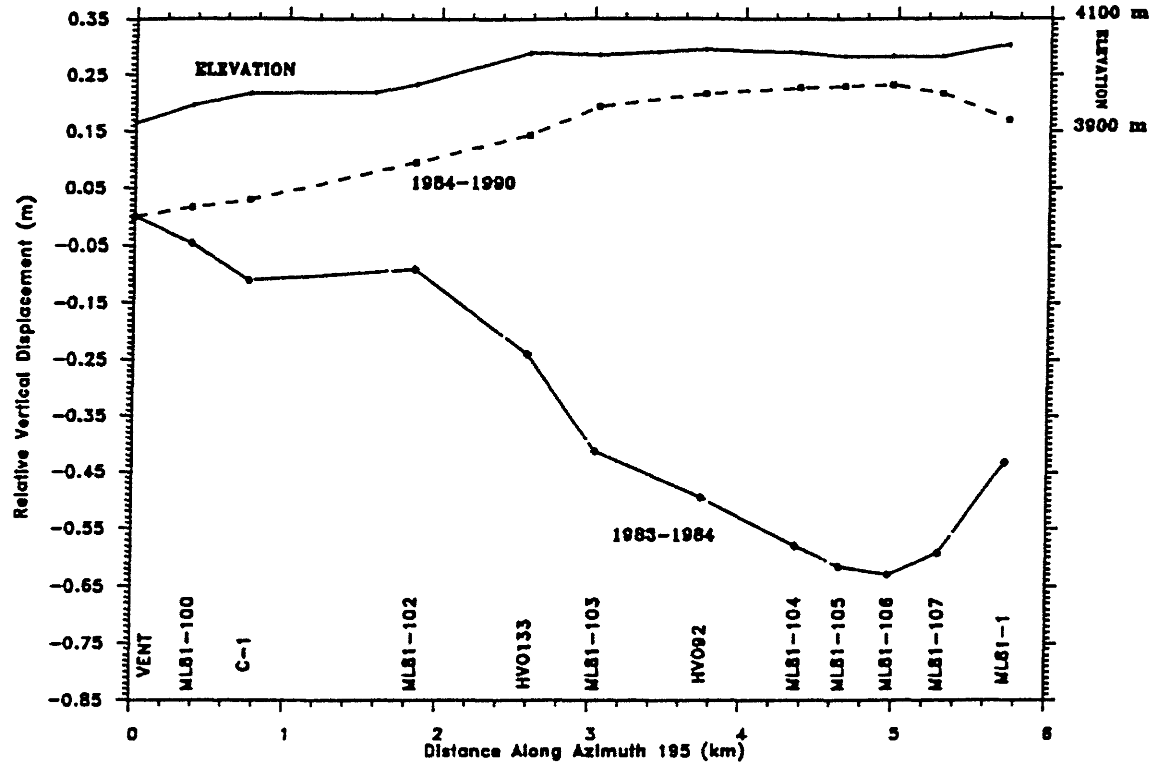
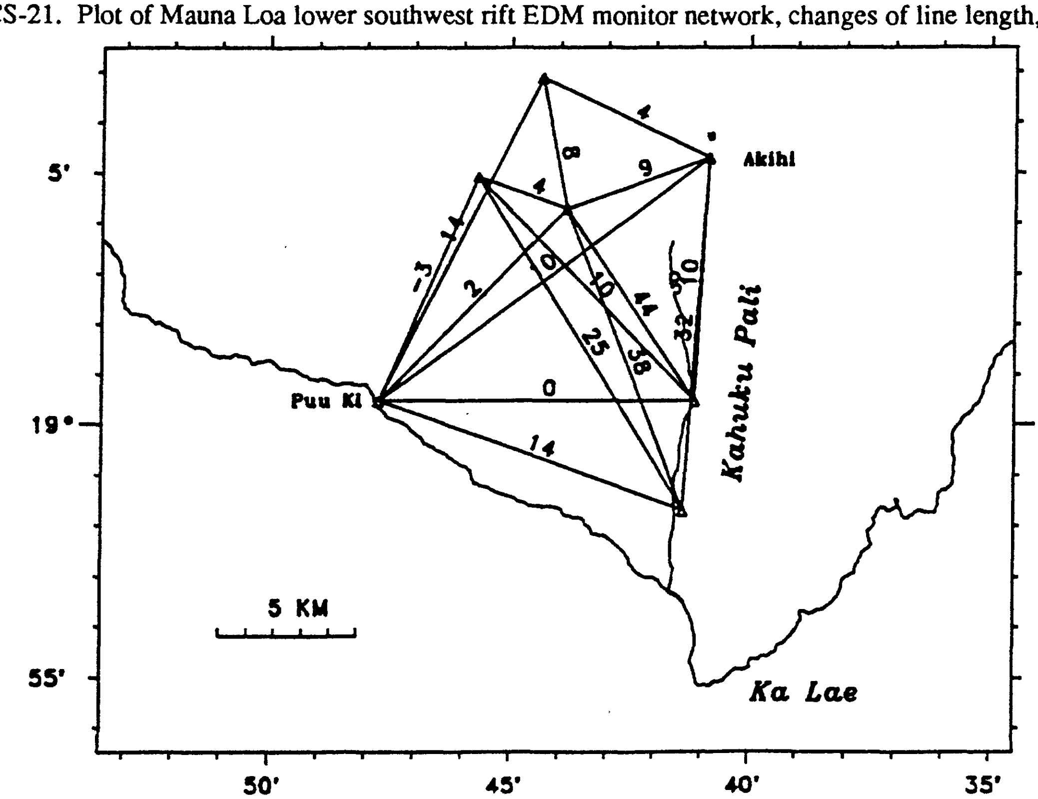


Figure CS-20. Profiles of ground elevation and elevation difference at leveling bench marks on Mauna Loa summit



The Mauna Loa lower southwest rift of EDM monitor net was reoccupied in November. Since last measured in 1984, most of the line lengths (fig. CS-21) have extended, with the largest changes on lines that cross the Kahuku Pali. However, most changes are within the expected error and displacement solutions yield uncertainties much larger than actual displacements.

Figure CS-21. Plot of Mauna Loa lower southwest rift EDM monitor network, changes of line length, in mm.

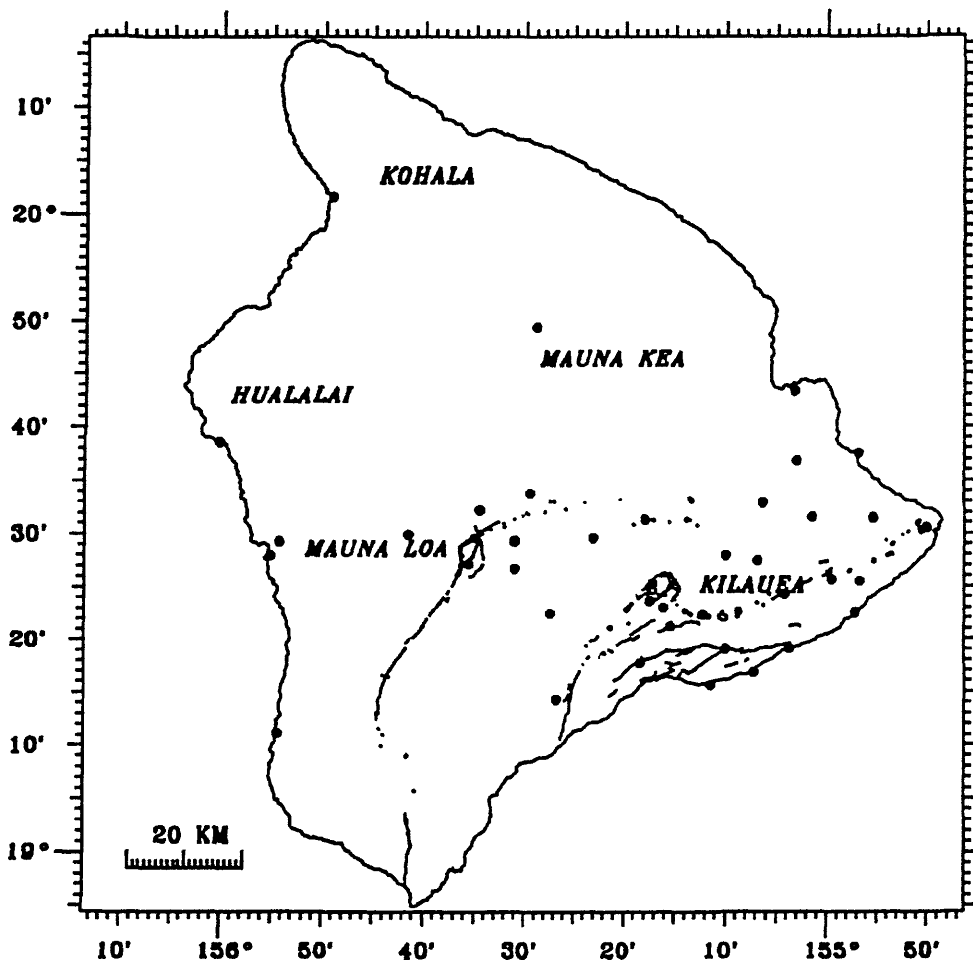


A fourth GPS survey was conducted on the Island of Hawaii from the 8th to the 25th of August 1990 (fig. CS-22). Measurements were made at 39 stations using four TI4100 receivers loaned to us by Will Prescott of the Branch of Tectonophysics in Menlo Park. Of these stations, fourteen were located on Mauna Loa, the rest on Kilauea. The base station, Lyman, located at the Hilo Airport, was occupied every day and is used as the fuducial station for data is processing.

Because of the timing of NAVSTAR satellites passing over Hawaii during August the initial observations began at about 6:00 am local time and lasted about five hours. Five people operated the four receivers on a rotating schedule.

All of the GPS data gathered on the island of Hawaii from 1987-90 is in being written up by John Dvorak in a USGS Bulletin.

Figure CS-22. Location map of stations occupied during the 1990 Global Positioning System survey.

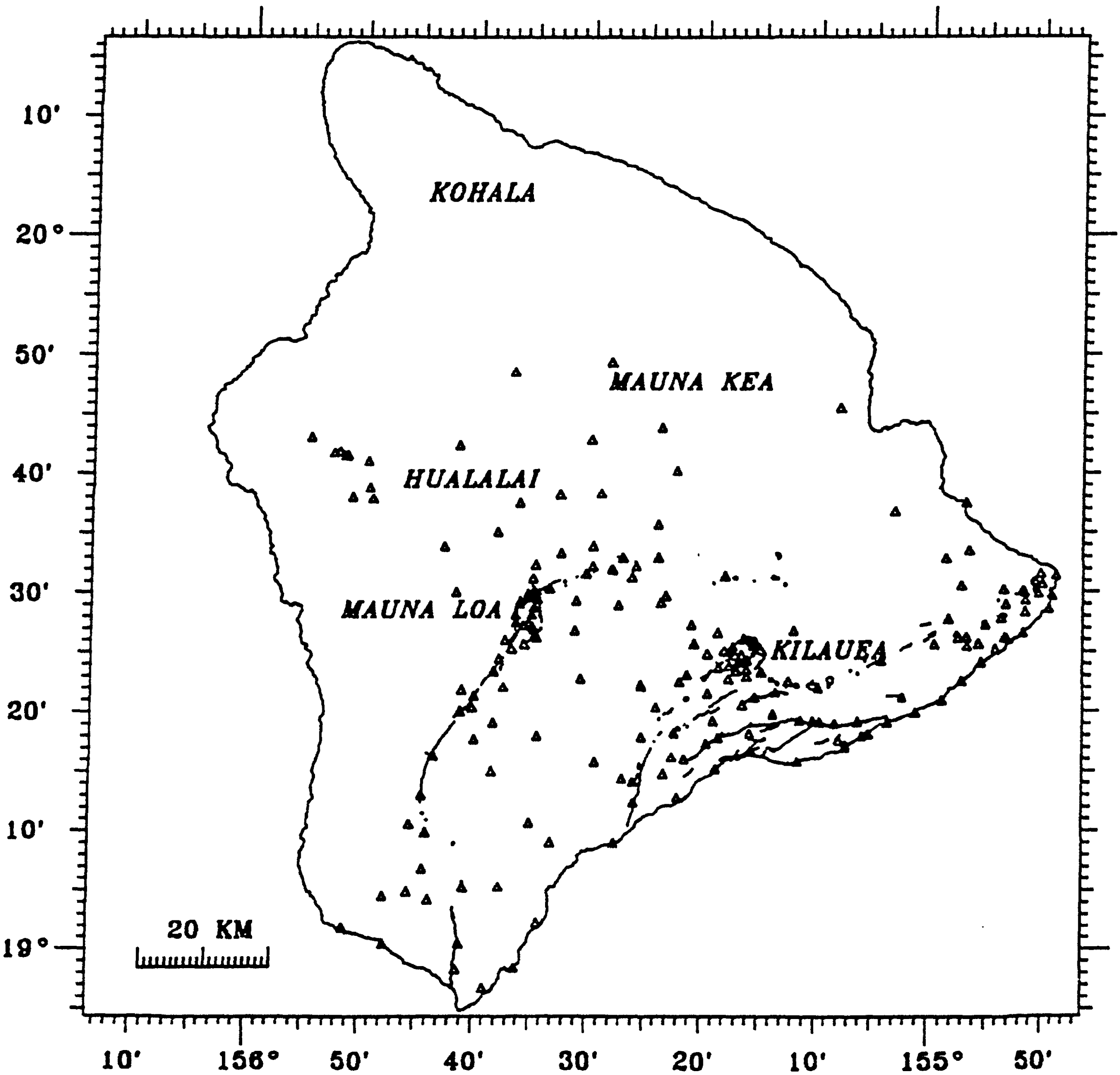


ACKNOWLEDGEMENTS

We thank the staff of HVO for all their support in the gathering of the data. We also thank all of the volunteers who helped with the clearing of the survey lines and with the actual gathering of the data throughout the year.

EDM SECTION

Figure EDM-1. Location map of all HVO EDM stations on the island of Hawaii (excluding permanent glass monitors



EDM INTRODUCTION

EDM surveys at HVO are presently measured using two types of EDM instruments, the K&E Rangemaster III (**RM**) and the Hewlett-Packard HP3808A (**HP**) is the other instrument. We periodically use a K&E Ranger V-A (**RV**) instrument also.

The **RM** uses a ruby-red laser beam, whereas the **HP** uses an infrared beam. The approximate range of the **RM** is 60 km; **HP**, 10 km. The manufacturers' listed accuracies for the electronic components of each instrument are as follows: **RM,** ±5 mm and ±1 ppm (RMS) between -28°C and +49°C; **HP,** ±5 mm and ±1 mm/km (RMS) between -20°C and +55°C. The accuracy and the precision of the instruments depend greatly on atmospheric conditions but cannot be less than these values.

With a few exceptions, only end-point temperatures are taken on our shot lines, with the probes shielded from the sun and at least 7 m above the ground. For our permanent-glass monitors, temperatures are taken only at the instrument site so that the precision of these measurements tends to be less. These monitors are intended to indicate areas where thorough surveys should be conducted.

All EDM instruments are periodically calibrated on a National Geodetic Survey (NGS) calibration line. These lines are located along Highway 11 near Hilo on relatively flat area and presumed stable area in Panaewa. The most recent calibration was conducted in September of 1989. The instrument offset constants measured during that calibration session are:

Rangemaster III	=	0.172 m	±	0.001 m
Hewlett-Packard	=	0.014 m	±	0.001 m

See Summary 89 Part II for description of the calibration procedure.

Table EDMKI-1. Table of line length and standard deviation for 1990 surveys of Kilauea summit and upper southwest rift zone.

Instr.	Instr. Stn.	Refl. Stn.	Date	Line Length in (m)	Std. Dev. in (m)
HP	BM84-50	BM82-500	10/22/90	2741.3836	0.0011
HP	BM84-50	HVO10 RESET	10/22/90	3032.3874	0.0012
HP	BM84-50	HVO34	10/22/90	3799.9782	0.0012
HP	BM84-50	HVO119	10/22/90	5244.0394	0.0015
HP	BM84-50	HVO143	10/22/90	1401.6179	0.0029
HP	HVO110	HVO111	12/06/90	3960.5990	0.0010
HP	HVO110	HVO113	10/19/90	5862.9773	0.0019
HP	HVO110	HVO113	12/06/90	5863.0003	0.0015
HP	HVO110	HVO117	12/06/90	3794.1640	0.0018
HP	HVO110	HVO119	10/19/90	4883.1362	0.0036
HP	HVO110	HVO119	12/06/90	4883.1512	0.0018
HP	HVO110	PUU HULUHULU	10/19/90	4497.2497	0.0012
HP	HVO110	PUU HULUHULU	12/06/90	4497.2614	0.0020
HP	HVO118	97YY	10/17/90	3048.4150	0.0013
HP	HVO118	HVO119	10/17/90	2580.5481	0.0035
HP	HVO118	HVO120	10/17/90	2651.3274	0.0012
HP	HVO132	68-24	10/17/90	1593.0239	0.0013
HP	HVO132	HVO113	10/17/90	3787.6193	0.0013
HP	HVO136	HVO135	10/18/90	4377.7102	0.0024
HP	HVO136	HVO145	10/18/90	2731.1914	0.0014
HP	HVO143	HVO10 RESET	10/19/90	3401.5181	0.0007
HP	HVO160	HVO135	10/22/90	3652.5190	0.0012
RM	CONE PEAK	HVO113	10/17/90	3895.2632	0.0048
RM	CONE PEAK	HVO118	10/17/90	2749.1202	0.0051
RM	CONE PEAK	HVO119	10/17/90	1627.7390	0.0030
RM	CONE PEAK	HVO120	10/17/90	2774.1188	0.0031
RM	CONE PEAK	HVO144	10/17/90	2279.1339	0.0037
RM	CONE PEAK	HVO145	10/17/90	4992.9715	0.0042
RM	HVO111	HVO110	10/19/90	3960.5982	0.0037
RM	HVO111	HVO113	10/19/90	8534.4669	0.0046
RM	HVO111	HVO113	10/19/90	8534.4771	0.0021
RM	HVO111	HVO114	10/18/90	3403.2630	0.0042
RM	HVO111	HVO119	10/19/90	6111.3344	0.0034
RM	HVO111	KEAKAPULU	10/18/90	17593.7631	0.0030
RM	HVO111	KEAKAPULU	10/18/90	17593.7769	0.0041
RM	HVO111	ML STRIP	10/18/90	20921.3736	0.0043
RM	HVO111	PUU HULUHULU	10/19/90	5628.3158	0.0031
HP	HVO113	97YY	10/17/90	3224.4727	0.0016
RM	HVO113	BM82-500	10/22/90	1864.4467	0.0036
RM	HVO113	BM84-50	10/22/90	3106.4770	0.0025
RM	HVO113	HVO10 RESET	10/18/90	3076.1270	0.0051
RM	HVO113	HVO10 RESET	10/22/90	3076.1528	0.0039
RM	HVO113	HVO10 RESET	12/05/90	3076.1841	0.0032
RM	HVO113	HVO34	10/18/90	2544.1309	0.0032
RM	HVO113	HVO34	10/22/90	2544.1442	0.0031
RM	HVO113	HVO111	10/02/90	8534.4888	0.0029
RM	HVO113	HVO111	12/05/90	8534.4885	0.0027
RM	HVO113	HVO114	10/02/90	5135.1879	0.0029

Table EDMKI-1. (Continued)

Instr.	Instr. Stn.	Refl. Stn.	Date	Line Length in (m)	Std. Dev. in (m)
RM	HVO113	HVO114	12/05/90	5135.1950	0.0034
RM	HVO113	HVO119	10/02/90	3159.8558	0.0019
RM	HVO113	HVO119	10/22/90	3159.8647	0.0043
RM	HVO113	HVO119	12/05/90	3159.8716	0.0073
RM	HVO113	HVO143	10/22/90	2069.9860	0.0035
RM	HVO113	KEAKAPULU	10/18/90	15384.9740	0.0043
RM	HVO113	ML STRIP	10/18/90	13038.1588	0.0056
RM	HVO113	PUU HULUHULU	10/19/90	10163.8355	0.0025
RM	HVO113	PUU HULUHULU	12/06/90	10163.8772	0.0035
RM	HVO114	68-24	10/17/90	982.2622	0.0036
RM	HVO114	HVO109	10/17/90	4343.7013	0.0045
RM	HVO114	HVO113	10/17/90	5135.1849	0.0059
RM	HVO114	HVO119	10/17/90	3070.9731	0.0030
RM	HVO114	HVO132	10/17/90	1919.9457	0.0036
RM	HVO114	HVO144	10/17/90	2835.9486	0.0038
RM	HVO117	HVO110	10/19/90	3794.1482	0.0033
RM	HVO117	PUU HULUHULU	10/19/90	2513.2103	0.0022
HP	HVO117	PUU HULUHULU	12/06/90	2513.2096	0.0013
RM	HVO119	68-24	10/19/90	2614.2504	0.0023
RM	HVO119	HVO10 RESET	10/19/90	2874.5025	0.0034
RM	HVO119	HVO10 RESET	12/05/90	2874.5235	0.0023
RM	HVO119	HVO34	10/18/90	1579.8339	0.0048
RM	HVO119	HVO111	12/05/90	6111.3571	0.0047
RM	HVO119	HVO113	10/18/90	3159.8460	0.0046
RM	HVO119	HVO114	12/05/90	3070.9816	0.0034
RM	HVO119	HVO144	10/19/90	1900.3187	0.0021
RM	HVO119	KEAKAPULU	10/18/90	13943.2107	0.0027
RM	HVO119	ML STRIP	10/18/90	14815.5893	0.0044
RM	KULANI	HVO111	10/02/90	19407.4315	0.0036
RM	KULANI	HVO113	10/02/90	11085.6446	0.0035
RM	KULANI	HVO119	10/02/90	14155.7440	0.0030
RM	KULANI	ML STRIP	10/02/90	9567.8806	0.0027
RM	PUU KOAE RESET	CONE PEAK	10/18/90	4325.5362	0.0024
RM	PUU KOAE RESET	HVO109	10/18/90	5486.2037	0.0015
RM	PUU KOAE RESET	HVO113	10/18/90	8185.9595	0.0036
RM	PUU KOAE RESET	HVO120	10/18/90	6148.6925	0.0042
RM	PUU KOAE RESET	HVO135	10/18/90	8510.2899	0.0047
RM	PUU KOAE RESET	HVO136	10/18/90	5299.5046	0.0055
RM	PUU KOAE RESET	HVO144	10/18/90	3843.2959	0.0039
RM	PUU KOAE RESET	HVO145	10/18/90	4326.4894	0.0018

Table EDMSF-1. Table of line length and standard deviation of 1990 surveys for Kilauea south flank, middle and lower east rift stations.

Instr.	Instr. Stn.	Refl. Stn.	Date	Line Length in (m)	Std. Dev. in (m)
RM	66YY RESET	HVO1461970	01/12/90	4473.8192	0.0016
RM	66YY RESET	HVO1471970	01/12/90	3602.9114	0.0028
RM	HALONA	HEIHEIAHULU	01/17/90	15407.8367	0.0046
RM	HALONA	HONUAULA	01/11/90	9980.9947	0.0041
RM	HALONA	KAIWIKI NEW	01/17/90	29882.0413	0.0057
RM	HALONA	KALIU	01/11/90	11621.0281	0.0052
RM	HALONA	KAPOHO	01/11/90	12478.5865	0.0048
RM	HEIHEIAHULU	66YY RESET	02/21/90	4799.0808	0.0026
RM	HEIHEIAHULU	HAKUMA	02/21/90	8758.3744	0.0030
RM	HEIHEIAHULU	HONUAULA	02/21/90	12347.2926	0.0042
RM	HEIHEIAHULU	IILEWA2	02/21/90	3679.7177	0.0060
RM	HEIHEIAHULU	KALALUA	02/21/90	8272.4382	0.0043
RM	HEIHEIAHULU	KALIU	02/21/90	8115.7680	0.0033
RM	HEIHEIAHULU	KUPAPAU 2	02/21/90	11024.0643	0.0022
RM	HEIHEIAHULU	PUU HULUHULU	02/21/90	23357.2267	0.0029
HP	HONUAULA	MALAMA KI	01/11/90	5062.6165	0.0014
RM	IILEWA2	66YY RESET	02/21/90	1580.3782	0.0021
RM	IILEWA2	HVO1461970	02/21/90	5896.8477	0.0050
RM	KALIU	66YY RESET	01/12/90	4162.6361	0.0043
RM	KALIU	HVO1461970	01/12/90	4212.6881	0.0025
RM	KALIU	KAPOHO	01/12/90	9737.1273	0.0042
RM	KALIU	MALAMA KI	01/12/90	5938.5046	0.0030
RM	KALIU	MOANA HAUAE	01/12/90	9485.2977	0.0035
RM	KALOLI-2	HONUAULA	01/11/90	16805.4765	0.0052
RM	KALOLI-2	KALIU	01/11/90	18965.0141	0.0047
RM	KALOLI-2	KAPOHO	01/11/90	17777.2845	0.0051
HP	KAPOHO	MALAMA KI	01/12/90	6746.5874	0.0028
RM	KAPOHO	HVO151	01/11/90	3728.0425	0.0039
RM	KAPOHO	POHOIKI	01/11/90	2906.9318	0.0028
RM	KEAAU	HALONA	01/11/90	12928.3510	0.0029
RM	KEAAU	HEIHEIAHULU	01/17/90	21556.3078	0.0043
RM	KEAAU	HONUAULA	01/11/90	22230.8190	0.0044
RM	KEAAU	KAIWIKI NEW	01/17/90	18256.1597	0.0037
RM	KEAAU	KALIU	01/11/90	22237.8124	0.0051
RM	KEAAU	KALOLI-2	01/11/90	10931.4809	0.0026
RM	KEAAU	KAPOHO	01/11/90	25399.7743	0.0042
RM	KULANI	KAIWIKI NEW	01/17/90	31456.0411	0.0048
RM	KULANI	KALALUA	01/17/90	27789.2636	0.0051
RM	KULANI	KEAAU	01/17/90	28028.7247	0.0042
RM	KULANI	PUU HULUHULU	01/17/90	19211.1757	0.0044
RM	KUPAPAU 2	HAKUMA	02/21/90	4483.0871	0.0022
RM	KUPAPAU 2	KAENA PT	02/21/90	12105.0074	0.0020
RM	KUPAPAU 2	LAEAPUKI	02/21/90	7942.3199	0.0016
RM	KUPAPAU 2	PANAU	02/21/90	9348.4776	0.0022
RM	KUPAPAU 2	PULAMA	02/21/90	3617.5387	0.0041
RM	PUU KOAE	HVO160	10/18 90	11143.2876	0.0038

Table EDMML-1. Table of line length and standard deviation of 1990 surveys for Mauna Loa summit, north flank, northeast rift, and lower southwest rift zone.

Instr.	Instr. Stn.	Refl. Stn.	Date	Line Length in (m)	Std. Dev. in (m)
HP	1949 AA	1949 CONE RESET	08/24/90	3419.8446	0.0024
HP	1949 AA	SKELETONS	08/24/90	2497.4263	0.0016
HP	1949 CONE RESET	HVO92	08/25/90	2706.7014	0.0011
HP	1949 CONE RESET	HVO134	08/25/90	953.0217	0.0005
HP	1949 CONE RESET	ML-1	08/25/90	1261.8782	0.0004
HP	1949 CONE RESET	POHAKU HANALEI S	08/25/90	3205.2085	0.0005
HP	1949 CONE RESET	SKELETONS	08/25/90	1353.4159	0.0012
HP	BM82-100	BM82-101	08/25/90	540.6728	0.0012
HP	BM82-100	SKELETONS	08/25/90	1654.8883	0.0008
RM	CRUSH RM	AHUAUMI	11/06/90	11875.3264	0.0055
RM	CRUSH RM	ML75-1	11/06/90	8465.2644	0.0055
RM	CRUSH RM	ML75-3	11/06/90	5752.1606	0.0032
HP	HVO92	HVO93	08/25/90	2475.4588	0.0012
HP	HVO92	HVO134	08/25/90	2443.6317	0.0008
HP	HVO92	NORTH PIT	08/25/90	3052.0168	0.0040
HP	HVO133	HVO93	08/25/90	2290.9848	0.0017
HP	HVO133	JAGGAR	08/25/90	1828.9630	0.0024
HP	HVO133	LUA POHOLO	08/25/90	1385.0286	0.0010
HP	HVO133	NORTH PIT	08/25/90	2012.4271	0.0021
RM	KAMAOA	AHUAUMI	11/06/90	14361.2022	0.0053
RM	KAMAOA	CRUSH RM	11/06/90	3434.1304	0.0030
RM	KAMAOA	ML75-1	11/06/90	11429.5045	0.0025
HP	LUA POHOLO	HVO93	08/25/90	2685.5975	0.0040
HP	LUA POHOLO	JAGGAR	08/25/90	501.4319	0.0017
HP	ML-1	HVO92	08/25/90	2101.1710	0.0030
HP	ML-1	HVO93	08/25/90	3379.4264	0.0019
HP	ML-1	HVO134	08/25/90	1852.0516	0.0007
RM	ML75-2	AHUAUMI	11/06/90	13616.1371	0.0045
RM	ML75-2	CRUSH RM	11/06/90	5819.3797	0.0019
RM	ML75-2	ML75-1	11/06/90	9497.5138	0.0048
RM	ML75-2	ML75-3	11/06/90	6916.7145	0.0045
RM	ML75-2	PUU KI	11/06/90	15421.0935	0.0028
RM	ML75-2	PUU KI	11/06/90	15421.0954	0.0028
RM	ML75-2	PUU KI	11/06/90	15421.1010	0.0028
RM	ML75-2	PUU KI	11/06/90	15421.1047	0.0028
HP	NORTH PIT	HVO93	08/25/90	1903.0434	0.0005
HP	NORTH PIT	JAGGAR	08/25/90	1010.5371	0.0014
HP	NORTH PIT	LUA POHOLO	08/25/90	1265.1125	0.0009
HP	POND	1949 AA	08/24/90	2258.5939	0.0015
HP	POND	1949 CONE RESET	08/24/90	4309.4385	0.0033
HP	POND	POHAKU HANALEI S	08/24/90	1701.2835	0.0015
HP	POND	SKELETONS	08/24/90	4037.5494	0.0016
HP	POND	TRAIL	08/24/90	4109.7604	0.0019
RM	PUU KI	AHUAUMI	11/06/90	11861.3748	0.0046
RM	PUU KI	CRUSH RM	11/06/90	9827.4978	0.0041
RM	PUU KI	KAMAOA	11/06/90	8963.5465	0.0058
RM	PUU KI	ML75-1	11/06/90	11655.8594	0.0042
RM	PUU KI	ML75-3	11/06/90	14045.3535	0.0030

Table EDMML-1. (Continued)

Instr.	Instr. Stn.	Refl. Stn.	Date	Line Length in (m)	Std. Dev. in (m)
RM	RIANA NEW	BOULDER	04/10/90	15710.7276	0.0027
RM	RIANA NEW	HUMUULA	04/10/90	7421.6161	0.0052
RM	RIANA NEW	VANCE	04/10/90	10485.4869	0.0021
HP	SPATTER	POHAKU HANALEI S	08/24/90	3062.2580	0.0016
HP	SPATTER	POND	08/24/90	2294.8921	0.0006
HP	TRAIL	1949 AA	08/25/90	1852.2519	0.0009
HP	TRAIL	BM82-100	08/25/90	1096.5038	0.0004
HP	TRAIL	BM82-101	08/25/90	1586.5073	0.0005
HP	TRAIL	SKELETONS	08/25/90	2286.4269	0.0007

EDM PERMANENT-GLASS SECTION

Figure EDM-2. Location map of all Mauna Loa permanent-glass EDM monitors on the island of Hawaii

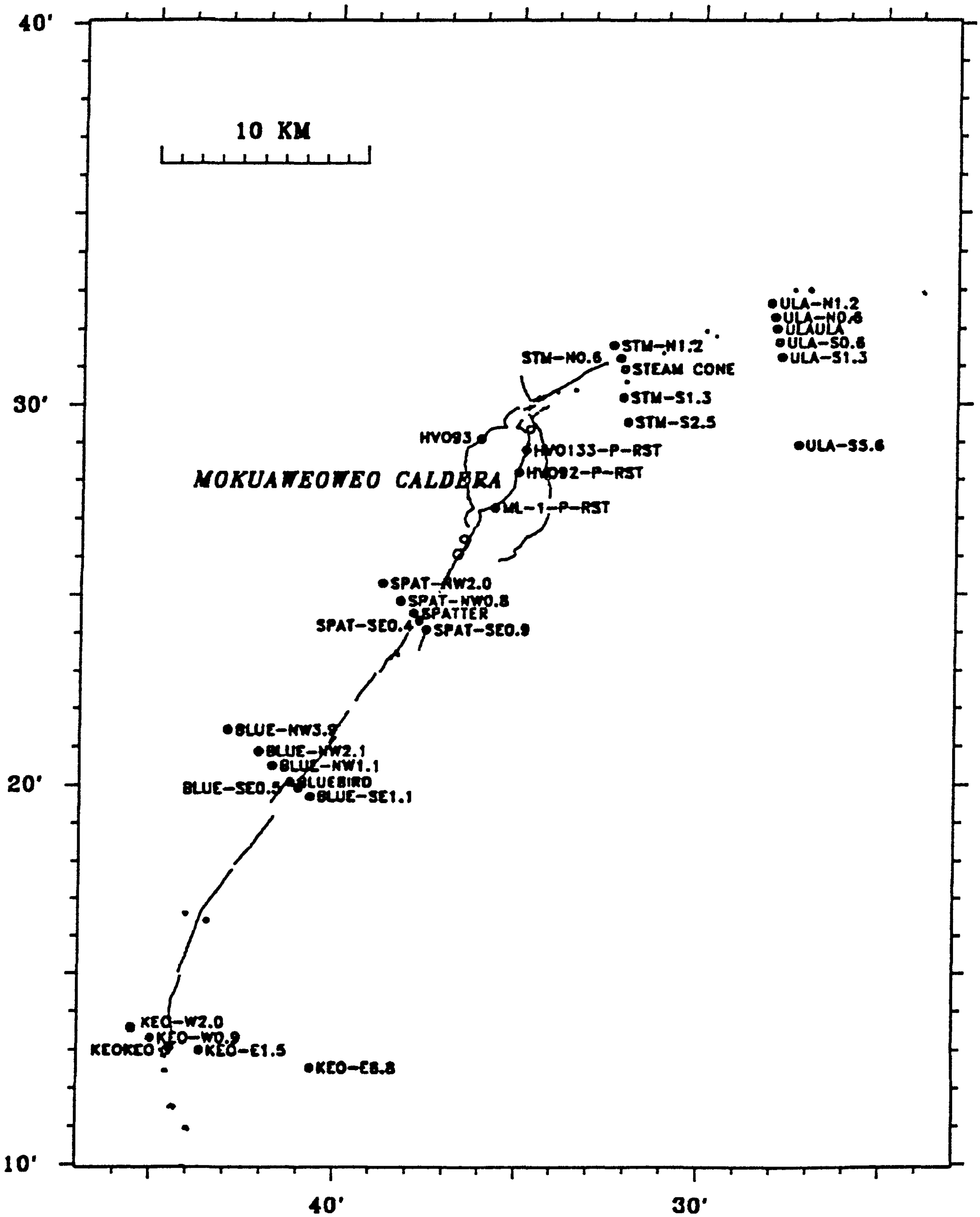
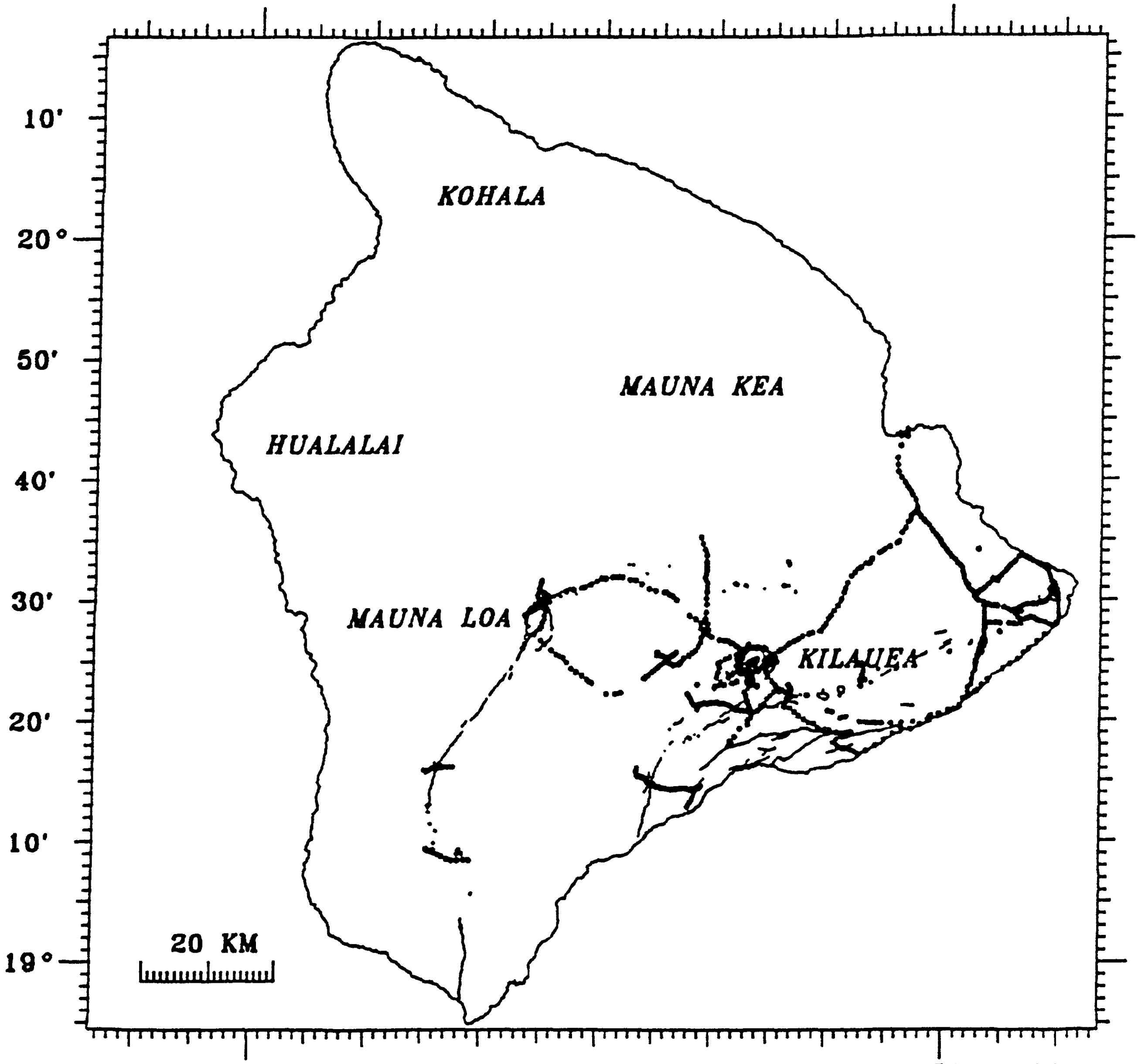


Table EDMMLPM-1. Table of line length and standard deviation of 1990 surveys for Mauna Loa summit, northeast rift zone, and southwest rift zone permanent-glass monitors.

Instr.	Instr. Stn.	Refl. Stn.	Date	Line Length in (m)	Std. Dev. in (m)
RM	BLUEBIRD	BLUE-NW1.1	07/17/90	1188.5282	0.0028
RM	BLUEBIRD	BLUE-NW2.1	07/17/90	2136.7798	0.0038
RM	BLUEBIRD	BLUE-SE0.5	07/17/90	527.5409	0.0016
RM	BLUEBIRD	BLUE-SE1.1	07/17/90	1140.7329	0.0031
HP	HVO93	HVO92-P-RST	06/12/90	2527.7301	0.0027
HP	HVO93	HVO133-P-RST	06/12/90	2292.5472	0.0015
HP	HVO93	ML-1-P-RST	06/12/90	3375.8168	0.0046
RM	KEOKEO	KEO-E1.5	07/17/90	1509.1395	0.0039
RM	KEOKEO	KEO-W0.9	07/17/90	970.5704	0.0038
RM	SPATTER	SPAT-NW0.8	07/17/90	877.6381	0.0029
RM	SPATTER	SPAT-NW2.0	07/17/90	2080.8656	0.0043
RM	SPATTER	SPAT-SE0.4	07/17/90	436.6480	0.0039
RM	SPATTER	SPAT-SE0.9	07/17/90	981.4464	0.0027
RM	STEAM CONE	STM-N0.6	04/10/90	601.2725	0.0038
RM	STEAM CONE	STM-N1.2	04/10/90	1240.4958	0.0055
RM	STEAM CONE	STM-S1.3	04/10/90	1384.1442	0.0030
RM	STEAM CONE	STM-S2.5	04/10/90	2532.7190	0.0041
RM	ULAULA	ULA-N0.6	04/10/90	671.5198	0.0016
RM	ULAULA	ULA-N1.2	04/10/90	1277.2360	0.0040
RM	ULAULA	ULA-S0.6	04/10/90	683.4373	0.0022
RM	ULAULA	ULA-S1.3	04/10/90	1392.1941	0.0023
RM	ULAULA	ULA-S5.6	04/10/90	5663.4914	0.0057

LEVELING SECTION

Figure LEV-1. Location map of HVO leveling bench marks for the island of Hawaii.



LEVELING INTRODUCTION

Our primary leveling method utilizes a pair of Wild three-meter double-scale invar rods and Wild NA-2 levels fitted with a micrometer plate. Unlike the Ziess NI-1 levels, the self-leveling compensator in the NA-2 instrument is fitted with magnetic shields and is not influenced by the Earth's magnetic field. A data-logging procedure is provided for our HP-71b calculators, and at various times during the day, data from the calculator is dumped to a printer and tape drive. At the end of each day, the data are uploaded to our computer for final reduction. Unlike the now defunct HVO three-wire method, the reading sequence of backsight low scale, foresight low scale, foresight high scale, and backsight high scale provides a check against blunders caused by both reading errors and instability of the rod or instrument. The method requires that foresight-backsight distance imbalance be less than 5 m per setup and less than 10 m per section; our imbalance was less than 2 m per setup. Although the maximum allowable distance of sight is 60 m, we found that sighting was considerably easier if less than 50 m, and so sightings never approached the maximum allowable distance. Because air temperature gradients and, therefore, refraction errors are particularily severe near the ground, we avoided use of the lower 0.5 m of the rods. Exception to the rule was if a bench mark was situated on the edge of a road cut high off the ground surface or if the instrument was close enough to a rod so refraction was not a factor in the reading. We hammered two-inch PK nails with washers into the roadbed to serve as pins for rod setups. Although the three-meter rods are considerably lighter than the four-yard rods used previously, the washers provided additional support to inhibit systematic errors due to pin settling. Additionally, we removed the rods from the pins after the foresight shot and while waiting for the backsight. Many, but not all, systematic errors accumulate with the run direction of the leveling; this direction was reversed at least once each half day to randomize and minimize such errors.

Data reduction employed a look-up table to apply a small correction to the height of the graduations on each of the rods. Rod calibration was performed by the Institute of Standards and Technology.

The method meets or exceeds the standards for Second-Order, Class-I leveling, as outlined by Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys (Federal Geodetic Control Committee, NOAA, 1980). We can expect that random error propagates as $\sigma^1 = 2.0\ \text{mm/km}^{1/2} \times L^{1/2}$, where L is distance of traverse, in kilometers, and this σ is used whenever errors meet or are less than 2.0 mm/km$^{1/2}$. When observed errors exceed this figure, actual error is used to calculate standard deviations.

Table KILV-1. Table of elevations for bench marks located on the south flank, summit and upper southwest rift of Kilauea, plus bench marks along Hwy 11 between Volcano village and Keaau (bench mark A100 located in Hilo is used as the datum). The date shown is the median date of the survey.

Bench mark	Elev. (m)	Std. dev. (m)	Date
HVO63	466.048	0.019	10/25/89
HVO77-13	517.430	0.020	10/25/89
BM79-503	582.481	0.020	10/25/89
BM79-502	619.676	0.020	10/25/89
BM80-1	613.649	0.020	10/25/89
HVO77-10	665.112	0.020	10/25/89
HVO77-7	720.432	0.020	10/25/89
BM79-507	743.886	0.020	10/25/89
BM79-506	774.839	0.021	10/25/89
HVO77-4	824.851	0.021	10/25/89
HVO77-3	866.832	0.021	10/25/89
HVO77-2	908.647	0.021	10/25/89
BM79-501	971.227	0.021	10/25/89
HVO101	971.837	0.021	10/25/89
AR3	971.818	0.021	10/25/89
KF5	973.654	0.021	10/25/89
BM79-500	977.231	0.021	10/25/89
29YY	984.189	0.021	10/25/89
28YYRESET	999.235	0.021	10/25/89
27YYR	998.825	0.021	10/25/89
BM79-511	1032.620	0.021	10/25/89
26YYR	1044.372	0.021	10/25/89
25YY	1072.015	0.021	10/25/89
BM79-510	1102.517	0.021	10/25/89
BM79-509	1106.767	0.021	10/25/89
22YY	1132.906	0.021	10/25/89
REBAR2	1136.101	0.021	10/25/89
20YY	1167.975	0.021	10/25/89
19YY	1193.368	0.020	10/25/89
HVO1140	1177.311	0.020	10/25/89
17YYRESET	1162.939	0.020	10/25/89
X20	1141.960	0.020	10/25/89
16YYRESET	1134.479	0.020	10/25/89
S20	1109.722	0.020	10/25/89
BM3565	1086.727	0.019	10/25/89
S1	1073.382	0.019	10/25/89
14YY	1041.591	0.019	10/25/89
15YY	1040.393	0.019	10/25/89
V20	1003.445	0.019	10/25/89
13YY	962.276	0.018	10/25/89
W20	913.707	0.018	10/25/89
12YY	881.781	0.018	10/25/89
HVO86-100	847.478	0.017	10/25/89
11YY	838.658	0.017	10/25/89
10YY	817.242	0.017	10/25/89
U20	796.138	0.017	10/25/89
HVO87-106	796.007	0.017	10/25/89
9YY	758.053	0.016	10/25/89
8YY	754.430	0.016	10/25/89
HVO86-101	715.565	0.016	10/25/89

Bench mark	Elev. (m)	Std. dev. (m)	Date
R20	698.219	0.016	10/25/89
7YYRESET	678.176	0.015	10/25/89
Q20	671.639	0.015	10/25/89
6YYRESET	657.069	0.015	10/25/89
P20	648.626	0.015	10/25/89
V1RESET	646.063	0.014	10/25/89
HVO86-102	596.773	0.014	10/25/89
N20	560.733	0.014	10/25/89
5YY	525.487	0.014	10/25/89
M20	506.658	0.014	10/25/89
HVO86-103	466.928	0.013	10/25/89
HVO87-101	453.135	0.013	10/25/89
4YY	426.100	0.013	10/25/89
T20	386.360	0.013	10/25/89
BM1268	386.012	0.013	10/25/89
HVO86-104	372.742	0.013	10/25/89
K20	348.157	0.013	10/25/89
3YY	318.077	0.012	10/25/89
L20	277.459	0.012	10/25/89
2YY	268.762	0.012	10/25/89
Y1	210.437	0.012	10/25/89
1YY	198.439	0.012	10/25/89
HVO86-105	182.065	0.012	10/25/89
8YYY	171.036	0.012	10/25/89
H20	154.391	0.012	10/25/89
HVO86-106	131.139	0.012	10/25/89
G20	90.750	0.012	10/25/89
BM79-514	1017.001	0.021	10/25/89
131YY	1005.927	0.021	10/25/89
BM79-515	1008.850	0.021	10/25/89
132YY	996.855	0.021	10/25/89
BM79-516	984.124	0.021	10/25/89
133YY	980.309	0.021	10/25/89
BM79-517	965.694	0.022	10/25/89
BM79-518	964.068	0.022	10/25/89
TAG10500	966.855	0.022	10/25/89
TAG9000	985.515	0.022	10/25/89
TAG7500	994.351	0.021	10/25/89
TAG6000	1015.096	0.021	10/25/89
TAG4500	1010.135	0.021	10/25/89
TAG3000	1026.536	0.021	10/25/89
TAG1500	1031.049	0.021	10/25/89
BM79-115	1035.732	0.021	10/25/89
BM79-114	1048.274	0.021	10/25/89
113YY	1063.307	0.021	10/25/89
BM83-500	1071.116	0.021	10/25/89
112YY	1083.959	0.021	10/25/89
HVO37	1095.672	0.021	10/25/89
REBAR4	1106.961	0.021	10/25/89
SPIT	1110.101	0.021	10/25/89

Table KILV-1 Continue

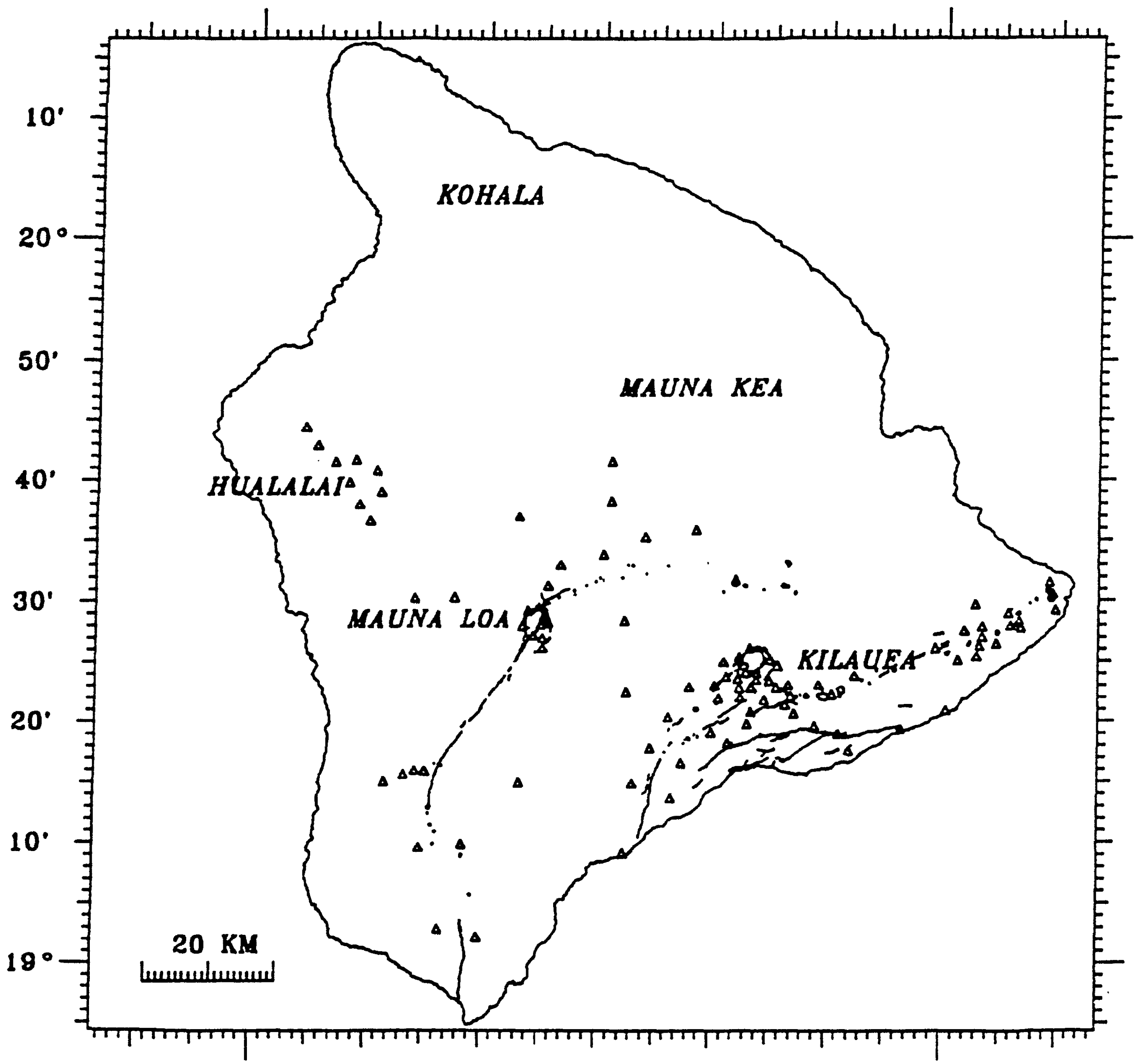
Bench mark	Elev. (m)	Std. dev. (m)	Date	Bench mark	Elev. (m)	Std. dev. (m)	Date
205YYRESET	1107.192	0.021	10/25/89	95YY	1219.217	0.021	10/25/89
BM79-519	969.090	0.022	10/25/89	96YY	1216.726	0.021	10/25/89
IRONPOLE	969.383	0.022	10/25/89	HVO25	1208.495	0.021	10/25/89
BM79-520	970.779	0.022	10/25/89	HVO24	1209.146	0.022	10/25/89
HVO86-51	972.113	0.022	10/25/89	P1	1204.049	0.022	10/25/89
HVO86-52	967.814	0.022	10/25/89	HVO23	1190.989	0.022	10/25/89
134YY	961.013	0.022	10/25/89	HVO104	960.485	0.021	10/25/89
HVO86-53	950.931	0.022	10/25/89	KF45	988.425	0.021	10/25/89
HVO86-54	942.197	0.022	10/25/89	KF46	991.216	0.021	10/25/89
HVO86-55	930.128	0.022	10/25/89	BM3269	994.879	0.021	10/25/89
HVO86-56	914.284	0.022	10/25/89	HVO96	1013.998	0.022	10/25/89
HVO86-57	904.620	0.022	10/25/89	HVO95	1033.076	0.022	10/25/89
HVO86-58	901.602	0.022	10/25/89	TAG75-57	970.926	0.022	10/25/89
HVO86-59	898.504	0.022	10/25/89	TAG75-62	971.618	0.022	10/25/89
135YY	892.321	0.022	10/25/89	TAG75-63	967.379	0.022	10/25/89
136YY	862.329	0.022	10/25/89	TAG75-64	970.328	0.022	10/25/89
137YY	800.892	0.023	10/25/89	TAG75-66	959.619	0.022	10/25/89
138YY	751.616	0.023	10/25/89	TAG75-67	957.598	0.022	10/25/89
139YY	695.742	0.024	10/25/89	TAG75-68N	955.891	0.022	10/25/89
REBAR1	1139.847	0.021	10/25/89	TAG75-69	945.028	0.022	10/25/89
HVO10R	1117.924	0.021	10/25/89	TAG75-70N	933.085	0.022	10/25/89
BM79-508	1113.729	0.021	10/25/89	TAG75-71N	944.861	0.022	10/25/89
HVO35	1106.274	0.021	10/25/89	TAG75-72A	947.895	0.022	10/25/89
HVO34	1105.315	0.021	10/25/89	TAG75-74	949.726	0.022	10/25/89
HVO33	1117.446	0.021	10/25/89	TAG75-75	951.273	0.022	10/25/89
HVO32	1109.752	0.021	10/25/89	TAG75-76N90	943.518	0.023	10/25/89
HVO31	1112.554	0.021	10/25/89	TAG75-77	935.860	0.023	10/25/89
118YY	1138.063	0.021	10/25/89	TAG75-78	930.934	0.023	10/25/89
117YY	1140.106	0.021	10/25/89	TAG75-79N90	927.843	0.023	10/25/89
204YY	1151.166	0.021	10/25/89	TAG75-80	922.568	0.023	10/25/89
HVO29	1182.185	0.021	10/25/89	TAG75-81N90	917.153	0.023	10/25/89
203YY	1201.618	0.021	10/25/89	TAG75-83A	897.734	0.024	10/25/89
HVO28	1221.051	0.021	10/25/89	TAG75-84	890.747	0.024	10/25/89
HVO27	1242.961	0.021	10/25/89	TAG75-85	896.833	0.024	10/25/89
HVO26	1227.031	0.021	10/25/89	TAG75-86	907.593	0.024	10/25/89
Z20	1228.567	0.021	10/25/89	TAG75-87	920.605	0.024	10/25/89
93YY	1218.857	0.021	10/25/89	TAG75-88	927.883	0.025	10/25/89
HVO143	1214.159	0.021	10/25/89	TAG75-89	929.478	0.025	10/25/89
92YY	1201.625	0.021	10/25/89	KF43	1125.944	0.021	10/25/89
BM3973	1210.390	0.021	10/25/89	KF44	1109.074	0.022	10/25/89
Y20	1201.486	0.021	10/25/89	CONEPEAKRESET	1112.778	0.022	10/25/89
90YY	1180.400	0.020	10/25/89				
HVO41	1101.846	0.021	10/25/89				
BM82-501	1102.197	0.021	10/25/89				
BM82-500	1094.322	0.021	10/25/89				
HVO44	1080.074	0.021	10/25/89				
110YY	1080.379	0.021	10/25/89				
HVO45	1076.958	0.021	10/25/89				
109YY	1073.149	0.021	10/25/89				
HVO46	1074.696	0.021	10/25/89				
HVO47	1078.837	0.021	10/25/89				
HVO48	1085.763	0.021	10/25/89				
HVO49	1093.355	0.021	10/25/89				

Table MLLV-1. Table of elevations for bench marks on Mauna Loa summit level line. Vent is used as an arbitrary datum.

Bench mark	Elev. (m)	Std. dev. (m)	Date
VENT	3915.253	0.000	7/07/90
ML81-100	3947.162	0.000	7/07/90
C-1	3968.059	0.001	7/07/90
ML81-102	3984.207	0.002	7/07/90
HVO133	4040.487	0.002	7/07/90
ML81-103	4036.382	0.003	7/07/90
HVO92	4045.659	0.003	7/07/90
ML81-104	4039.746	0.004	7/07/90
ML81-105	4033.065	0.004	7/07/90
ML81-106	4034.151	0.004	7/07/90
ML81-107	4033.460	0.005	7/07/90
ML-1	4053.009	0.005	7/07/90

TILT SECTION

Figure DT-1. Location map of all spirit level tilt stations on the island of Hawaii.



TILT INTRODUCTION

Three methods are presently being used to gather tilt data on Kilauea, Mauna Loa, and Hualalai. These methods are as follows:

1. Water-tube or "wet" tilt: A single short-base water-tube tiltmeter is located in the Uwekahuna Vault near the rim of Kilauea Caldera. This is a closed three-pot system connected by two tubes (one for water and one for air), with the pots aligned along magnetic N-S and E-W directions. Readings are taken once daily except during periods of rapid change accompanying intrusive or extrusive episodes. At these times, measurements are taken at least once per hour. Of the three methods, this has the longest continuous record.

2. Electronic tilt: An Ideal Aerosmith tiltmeter oriented in a E-W direction and a two-component Westphal tiltmeter are located in Uwekahuna Vault, where data can be compared with the water-tube system. Additional continuously recording electronic tiltmeters (borehole or platform type), are located at strategic points on Kilauea summit and east rift zone and Mauna Loa summit and northeast rift zone. Data from all electronic instruments are telemetered back to the observatory and give us real-time information of any unusual activity that occurs in the close proximity of these instruments. A detailed description of this type of monitoring will be made available in an Open-File Report by Allan Largo in 1992.

3. The Spirit level tilt: The spirit-level method, which forms the backbone of the HVO tilt network, uses three 3 m rods set up on benchmarks with hubs in a 40 m equilateral triangle whenever possible. A Nak2 precise level gun with a micrometer plate is set up in the middle of the triangle to measure all three rods. Stations cover the summit and parts of the rift zones of all three volcanoes.

We present, in this report, data and time-series plots from all of the "spirit level" surveys done in 1990, along with selected wet and electronic tilt data. Acquisition and plotting procedures for electronic tilt data have been modified and plots of these data are included.

Table KIDT-1. 1990 Kilauea spirit-level tilt data. All stations are assigned 500.00 μrads as the arbitrary starting point for the N-S and E-W components of tilt, with the exceptions being stations that were converted from nails to bench marks (station names ending with a "V").

Station. Name	Date	(y-x) in cm	(x-z) in cm	(z-y) in cm	Closure in cm	N-S μrads	E-W μrads
NEW HEIHEIAHULU							
	1/21/85	2.199	69.191	-71.391	-0.001	500.00	500.00
	11/29/90	2.269	68.875	-71.144	0.000	541.46	427.78
TELEPHONE POLE							
	2/ 1/71	57.672	0.665	-58.338	-0.001	500.00	500.00
	11/29/90	58.222	0.197	-58.420	-0.001	648.18	521.25
OPIHIKAO ROAD							
	10/17/80	-67.379	131.240	-63.859	0.002	500.00	500.00
	12/11/90	-67.301	130.940	-63.640	-0.001	537.71	438.41
NEW PUNA FLOWER FARM							
	1/21/85	0.301	-4.940	4.640	0.001	500.00	500.00
	11/29/90	0.093	-4.784	4.690	-0.001	444.89	517.87
NEW LEILANI JUNCTION							
	1/23/85	180.635	-40.721	-139.909	0.005	500.00	500.00
	12/ 4/90	180.373	-40.564	-139.809	0.000	443.67	483.90
TANGERINE							
	7/28/77	73.639	-140.471	66.830	-0.002	500.00	500.00
	1/23/85	73.738	-140.354	66.617	0.001	453.31	550.64
TANGERINE V							
	1/23/85	77.542	-139.533	61.994	0.003	453.31	550.64
	12/ 4/90	77.539	-139.340	61.799	-0.002	381.15	565.49
LEILANI ESTATES							
	8/28/73	-39.855	49.101	-9.245	0.001	500.00	500.00
	12/28/82	-39.881	49.110	-9.229	0.000	498.39	494.74
LEILANI ESTATES V							
	12/28/82	-40.675	47.656	-6.981	0.000	498.39	497.74
	12/ 4/90	-40.797	47.776	-6.980	-0.001	463.61	478.05
NEW BM 197YY							
	1/23/85	89.961	70.952	-160.909	0.004	500.00	500.00
	12/ 4/90	89.932	70.910	-160.843	-0.001	487.58	485.03
UH EXPERIMENT FARM							
	10/17/80	-37.607	145.485	-107.881	-0.003	500.00	500.00
	12/11/90	-37.905	145.460	-107.553	0.002	540.39	426.25
NEW PUUA							
	1/22/85	-93.367	28.937	64.431	0.001	500.00	500.00
	12/11/90	-93.348	28.897	64.453	0.002	499.18	490.13
KAPOHO CONE							
	8/28/73	-13.904	16.150	-2.246	0.000	500.00	500.00
	12/28/82	-14.389	16.460	-2.070	0.001	421.09	405.88
KAPOHO CONE V							
	12/28/82	-16.830	17.400	-0.570	0.000	421.09	405.88
	12/11/90	-16.891	17.428	-0.540	-0.003	413.63	392.86
NEW PUU KII FLOW							
	1/23/85	-19.111	-38.021	57.133	0.001	500.00	500.00
	12/11/90	-19.128	-38.050	57.179	0.001	497.85	489.41
SANDSPIT							
	6/25/69	52.889	10.535	-63.427	-0.003	500.00	500.00
	12/ 7/90	55.773	10.368	-66.141	0.000	130.66	1222.50

Table KIDT-1. (Continued)

Station. Name	Date	(y-x) in cm	(x-z) in cm	(z-y) in cm	Closure in cm	N-S µrads	E-W µrads
RE KEANAKAKOI							
	6/27/84	0.622	-11.120	10.498	0.000	500.00	500.00
	12/ 7/90	0.271	-10.822	10.551	0.000	441.73	425.56
PUHIMAU HOT AREA							
	8/16/71	-122.101	234.505	-112.406	-0.002	500.00	500.00
	12/ 7/90	-121.538	232.711	-111.173	0.000	783.97	138.38
DEVIL'S THROAT							
	11/24/71	-77.335	95.537	-18.203	-0.001	500.00	500.00
	12/ 7/90	-77.750	93.575	-15.825	0.000	452.79	-134.09
HVO 104							
	9/24/73	-138.886	104.741	34.145	0.000	500.00	500.00
	12/ 7/90	-137.853	104.078	33.775	0.000	718.15	351.25
KAHALII							
	7/11/79	-197.459	224.365	-26.906	0.000	500.00	500.00
	12/20/84	-197.372	224.303	-26.932	-0.001	524.10	498.49
KAHALII V							
	12/20/84	-197.320	231.439	-34.119	0.000	524.10	498.49
	12/ 7/90	-196.970	231.302	-34.332	0.000	610.83	522.78
ESCAPE ROAD 4							
	6/27/84	-62.113	41.842	20.271	0.000	500.00	500.00
	12/ 7/90	-61.805	41.302	20.502	-0.001	645.47	455.66
HVO 95B							
	7/ 2/84	-132.740	119.776	12.964	0.000	500.00	500.00
	12/ 7/90	-132.879	119.745	13.135	0.001	465.17	470.88

Table MLDT-1. 1990 Mauna Loa spirit-level tilt data. All stations are assigned 500.00 µrads as the arbitrary starting point for the N-S and E-W components of tilt, with the exceptions being stations that were converted from nails to bench marks (station names ending with a "V").

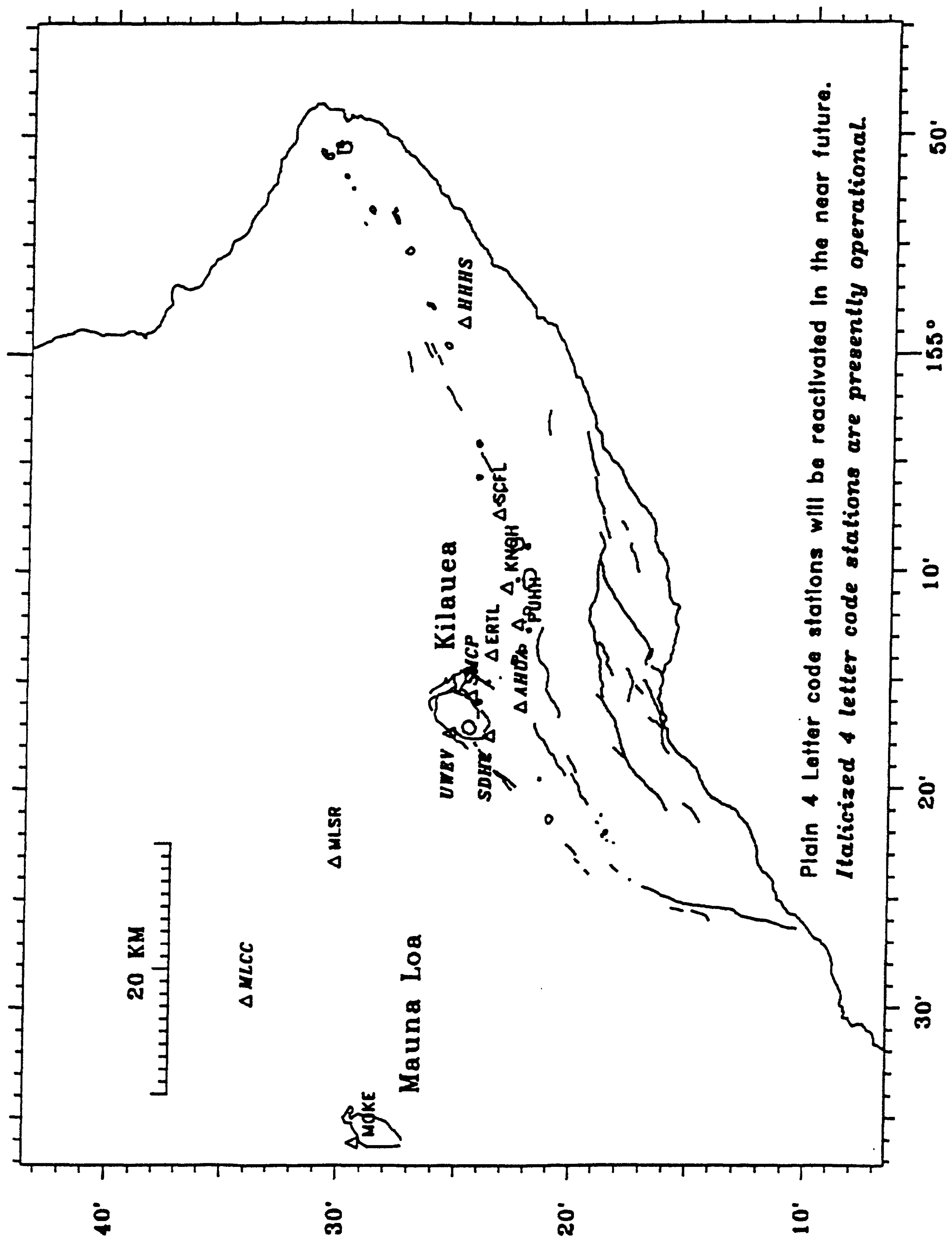
Station. Name	Date	(y-x) in cm	(x-z) in cm	(z-y) in cm	Closure in cm	N-S µrads	E-W µrads
MOK 2							
	12/ 9/76	192.219	-79.899	-112.323	-0.003	500.00	500.00
	8/12/87	192.075	-79.835	-112.241	-0.001	461.93	496.62
MOK 2V							
	8/12/87	188.390	-79.589	-108.800	0.001	461.93	496.62
	6/12/90	188.441	-79.639	-108.803	-0.001	479.56	490.10
LAVA TUBE							
	9/11/75	-90.852	49.554	41.293	-0.005	500.00	500.00
	8/14/87	-90.702	49.550	41.151	-0.001	519.50	538.74
LAVA TUBE V							
	8/14/87	-90.466	49.597	40.869	0.000	519.50	538.74
	7/17/90	-90.552	49.600	40.949	-0.003	509.28	513.55
NEW HVO 135							
	7/26/77	-32.250	43.703	-11.449	0.004	500.00	500.00
	8/ 7/87	-32.240	44.010	-11.770	0.000	513.89	602.65
NEW HVO 135V							
	8/ 7/87	-41.281	31.720	9.561	0.000	513.89	602.65
	7/17/90	-41.319	31.679	9.641	0.001	452.58	473.67
NEW AINAPO TRAIL 1							
	7/13/83	-36.343	-8.011	44.355	0.001	500.00	500.00
	8/ 7/87	-36.229	-8.315	44.542	-0.002	553.91	431.20
NEW AINAPO TRAIL 1V							
	8/ 7/87	-30.480	-8.727	39.207	0.000	553.91	431.20
	7/17/90	-30.497	-8.673	39.170	0.000	546.37	444.68
AINAPO TRAIL 2							
	9/11/75	37.175	21.507	-58.678	0.004	500.00	500.00
	8/14/87	37.100	21.643	-58.743	0.000	467.36	487.28
AINAPO TRAIL 2V							
	8/14/87	47.351	31.810	-79.161	0.000	467.36	487.28
	7/17/90	47.351	31.903	-79.253	0.001	438.19	494.11
SUMMIT CABIN							
	7/16/75	57.984	51.502	-109.486	0.000	500.00	500.00
	8/ 7/87	57.974	51.526	-109.501	-0.001	494.51	506.05
SUMMIT CABIN V							
	8/ 7/87	43.986	63.833	-107.816	0.003	494.51	506.05
	7/17/90	44.050	63.864	-107.911	0.003	509.10	536.47
NEW CRK STNRE							
	10/21/86	19.404	107.816	-127.219	0.001	500.00	500.00
	8/14/87	19.423	107.798	-127.222	-0.001	506.81	502.24
NEW CRK STNRE V							
	8/14/87	18.659	113.623	-132.282	0.000	506.81	502.24
	7/17/90	18.745	113.585	-132.331	-0.001	528.67	524.48
HVO 133							
	7/16/75	93.230	-139.293	46.064	0.001	500.00	500.00
	7/17/90	93.175	-139.355	46.180	0.000	524.93	470.58
HVO 133V							
	7/17/90	18.575	46.676	-65.252	-0.001	524.93	470.58

Table MLDT-1. (Continued)

Station. Name	Date	(y-x) in cm	(x-z) in cm	(z-y) in cm	Closure in cm	N-S µrads	E-W µrads
FISSURE							
	11/17/88	2.952	-247.800	244.848	0.000	500.00	500.00
	6/12/90	2.944	-247.809	244.867	0.002	504.59	497.41
STATION 12000							
	6/ 5/75	85.324	-158.791	73.466	-0.001	500.00	500.00
	6/12/90	85.251	-158.800	73.547	-0.002	509.62	481.27
KULANI							
	3/24/76	-98.020	262.769	-164.746	0.003	500.00	500.00
	6/ 1/90	-97.871	262.658	-164.789	-0.002	538.45	473.64
HUMUULA							
	1/ 7/81	55.187	31.600	-86.786	0.001	500.00	500.00
	5/31/90	55.187	31.573	-86.761	-0.001	500.34	492.12
HUMUULA V							
	5/31/90	50.572	30.678	-81.248	0.002	500.34	492.12
VANCE							
	1/ 4/77	134.090	-59.657	-74.435	-0.002	500.00	500.00
	5/31/90	134.279	-59.768	-74.506	0.005	539.91	473.37
VANCE V							
	5/31/90	130.790	-58.816	-71.975	-0.001	539.91	473.37
POLE 103							
	6/ 5/75	230.994	-186.857	-44.140	-0.003	500.00	500.00
	5/31/90	231.420	-187.088	-44.331	0.001	565.92	628.23
CINDER CONE							
	6/ 5/75	209.263	-239.986	30.723	0.000	500.00	500.00
	5/31/90	209.079	-240.265	31.188	0.002	592.97	406.64
POLE 285							
	6/26/75	246.326	-267.908	21.581	-0.001	500.00	500.00
	5/31/90	246.299	-267.888	21.589	0.000	496.54	496.85
POLE 1							
	7/10/75	55.585	134.607	-190.192	0.000	500.00	500.00
	5/31/90	58.170	135.495	-193.663	0.002	650.19	1283.68

ELECTRONIC TILT SECTION

Figure ET-1. Location map of all Elctronic tilt stations on the island of Hawaii.



Status of HVO Electronic Tiltmeter Network, 1990

Introduction

Electronic tilt monitoring is one of the methods used by the Hawaiian Volcano Observatory (HVO) to monitor volcanic related activity on the Island of Hawaii. It is the only method of measuring tilt that allows remote observation of real time changes. We initially occupied 14 electronic tilt sites with either platform or borehole tiltmeters. Five stations were located on Mauna Loa and nine on Kilauea. Beginning in 1989, due to a re-evaluation of the accuracy and precision of the tiltmeters and elctronic problems with some of the stations, we had reduced the array to four stations. As of this reporting period, seven instruments located in key areas, are being used for hazard assessment and monitoring on Mauna Loa (1) and Kilauea (6).

Each site is sampled every 10 minutes on a rotating basis by an Apple computer at HVO (Puniwai and others, 1990; English and others, 1987) and is telemetered, either by direct line of sight or via repeater stations, to the receiving system. Data is then processed through the acquisition system and dumped into our VAX computer system. Data is stored in files for use in plotting of graphs to analyze tilt changes utilizing the BOB program (Tom Murray, 1989).

Types of Electronic Tiltmeters

There are two basic types of electronic tiltmeters employed by HVO's deformation program. These are borehole (manufactured by Autonetics, Kinemetrics) and platform (Ideal Aerosmith, Westphal, Kinemetrics, and Applied Geomechanics) tiltmeters with either single or dual axes, using spirit level bubble sensors. The spirit level bubble or electrode contains a highly conductive fluid which acts as a variable capacitor or resistor and responds to changes in fluid level due to the angle of tilt. The perpendicular axes are labeled the X and Y vector components, X being the north component and Y being the west component. The voltage standard used by HVO (there are exceptions) is that positive voltage change respresents north- and west-down vectors, and negative voltage change represents south- and east-down vectors.

Ideal Aerosmith (IDAE)

The IDAE (Table ETM-2) is a single-axis, mercury-sensor, platform tiltmeter which is installed in the Uwekahuna vault on northwest side of Kilauea's summit caldera to measure east-west tilt on the volcano. This unit is the most sensitive instrument in our network.

The method for tracking the tilt utilizes mercury housed within two cisterns spaced a meter apart. This operates on a capacitance principle, where the mercury and the cistern's top housing cover act as capacity plates, leaving an air gap to serve as a dielectric between the mercury and the housing. This capacitance is then measured through an electronic wein bridge circuit similar to a LC bridge meter used to measure capacitance and inductance. The output voltage is then calibrated to measure values in microradians.

Autonetics (ATO) and Kinemetrics (KIN) Tiltmeters

The ATO (from Table ETM-2) tiltmeters were the first borehole instruments employed by HVO. The KIN (Table ETM-2) tiltmeters are of both borehole and platform types. The sensor contains a single bubble connected to four electrical leads, which correspond to the four components of tilt. As ATO and KIN tiltmeters are no longer marketed, the deterioration of the electrode sensors are the biggest problem that exists with this system because of the unavailability of repair and spare parts.

Westphal Tiltmeters (WES)

HVO was given three complementary WES (Table ETM-2) platform tiltmeters (Westphal and others, 1981) to use for our studies of tilt changes on Kilauea. We were granted the right to modify the tiltmeter to HVO's own specifications. The design of this tiltmeter is also a dual axis type but uses two separate bubble sensors for the X and Y components.

Applied Geomechanics Tiltmeter (AGM)

The AGM (Table ETM-2) is a platform type, dual axis tiltmeter utilizing two separate bubble sensors for X and Y components. As far as what can be purchased on the market today, this type of tiltmeter seems to show the best performance in tracking the tilt.

Electronics tiltmeter performances and data quality

Seven electronic tilt instruments are presently in operation for the monitoring of ground deformation. Time-series plots for five of these stations can be found in this report. One of two instruments (Ideal Aerosmith) located in the Uwekahuna vault and Summer Camp which was re-installed in early December has no time-series plot. Stations in need of servicing due to instrumentation problems and others that were being tested and calibrated at the Sandhill site also have no time-series plots (see fig. ET-1). Overhaul and testing of tiltmeter performances at the Sandhill site is expected to be completed by the end of 1991.

Ahua, Uwekahuna Vault, Summer Camp, and Sandhill (SDH2) are the four tiltmeter sites located on the summit of Kilauea. The AHUA, IDAE, and UWEV tilt stations seem to be free of any major problems. Until March 1989, the SDH2 station consisted only of a borehole tiltmeter (KIN), but anomalous readings resulted from rain-induced instability of the site. As a test, an additional borehole tiltmeter (ATO, 6/89) and four platform tiltmeters (two Kinemetrics, one Wesphal, and one Applied Geomechanics 3/89) were installed. The borehole tiltmeters produced much more stable results as compared with the platform tiltmeter. The borehole system has not been abandoned, but we are continuing to try and find ways to correct the instability problem.

As part of this test, a grid of 16 benchmarks aligned in a N-S direction, four to a side, set 35.4 m apart, was set up around the Sandhill (SDH2) electronic tilt site to test how accurately the electronic tiltmeters are tracking the summit tilt. As also mentioned in Summary 89, this grid was set up to determine an accurate evaluation and uncertainty involved in the measurement of tilt. Measurements were taken on each benchmark using a 3 m rod with stays and a NI-2 leveling instrument with a micrometer plate. The survey was done to 1st class-1st order specifications excluding temperature corrections.

We now have preliminary results for all three surveys listed in Table ETM-1. Measurement error is estimated to be, on average, 0.18 mm per 50 m shot, based on network adjustment of height differences between bench marks. This measurement error accounts for 90% of the error in fitting the network to a plane; the rest assumed to be the result of non-planar tilt of the network. The tilt shows an east-southeast vector at a annual rate of ~ 25 µrads/year.

Table ETM-1. Preliminary results of the Sandhill spirit-level tilt station stability, precision and accuracy experiment data.

Survey date	Tilt angle and direction	
6/89 to 10/89	10.0 +/- 1.0 µrad,	S39.3E +/- 6.0°
10/89 to 9/90	20.5 +/- 1.0 µrad,	S29.6E +/- 3.0°
6/89 to 9/90	30.4 +/- 1.2 µrad,	S32.8E +/- 2.3°

SMCP borehole tiltmeter was reinstalled on December 4, 1990, just prior to an earthquake swarm in the summit and upper east rift of Kilauea. The station seemed to have responded to the intrusion fairly well. Also, the AHUA tiltmeter was discontinued on the same day because it was deemed that the site was too unstable to furnish reasonable data.

The HHHS (borehole) station, located on the lower east rift, was reinstalled in June 1989 with a new tiltmeter because of low-gain response in the older unit's east-west vector. The number of offsets seen on the record were due to battery changes.

The MLCC tilt station, located on the northeast rift of Mauna Loa is working very well but MOKE (borehole) tilt station which is located on the summit was not in service as of this reporting period due to a defect in the tiltmeter electronics. As soon as there is a part available, the system will be put back into operation.

A more technical and complete report on these electronic tiltmeters utilized by HVO is being written in an Open-file report by Allan Largo. Also a detailed report on the electronic tilt experiment at SDH2 site will be covered in another report.

Table ETM-2. Electronic tiltmeter specifications and type.

AGM = Applied Geomechanics, ATO = Autonetics, HVO = HVO-TM, IDA = Ideal Aerosmith,
KIN = Kinemetrics, WES = Wesphal, I = Initial Installation, RI = Reinstalled, D = Discontinued, RL = Relocated

Kilauea Summit	Status	Volt/μrad	Type	Installation Date
1. AHU	I	20 mv	ATO-Borehole	10/03/73
AHUA		0008 X=37.2 mv, Y=35.7 mv	ATO-Borehole	10/19/89
	D			12/ 4/90
2. SDH		20 mv	ATO-Borehole	05/08/75
SDH	RI	20 mv	KIN-Borehole	07/30/75
SDH2 (SDH)	I	331 X=19.81 mv, Y=19.28 mv	KIN-Platforrn	03/28/89
SDH2 (Test)	I	330 X=25.9 mv, Y=26.12 mv	KIN-Platforrn	03/28/89
SDH2 (Test)	I	ZL-608 X=20.1 mv, Y=19.96 mv	WES-Platform	03/28/89
SDH2 (Test)	I	X=18.69 mv, Y=18.95 mv	AGM-Platform	03/28/89
SDH	D			06/01/89
SDH2 (Test)	I	0096B X=20.2 mv, Y=20.1 mv	ATO-Borehole	06/01/89
3. SMC (land line)	I			11/05/73
SMC	RI	20 mv	ATO-Borehole	12/13/83
SMCP	D			06/02/89
	RI			12/ 4/90
4. UWE	I	10 mv	WES-Platform	08/12/81
UWEV		10 mv	WES-Platform	08/12/81
IDAE	I	100 mv	IDA-Platform	? / ? /66
Kilauea East Rift				
1. ESR	I	20 mv	ATO-Borehole	06/02/75
ERTL	D			06/02/89
2. HHH	I	20 mv	KIN-Borehole	No Ref.
HHHS	RI	0107b X=18.75 Y=20.67	ATO-Borehole	06/07/89
3. KNO	I	20 mv	ATO-Borehole	07/03/84
KNO	D			No Ref.
4. PHH	I	20 mv	ATO-Borhole	No Ref.
PHH	RI	20 mv	HVO-Platform	06/06/75
PUHH	D			12/01/88
5. PUK	I	20 mv	KIN-Borehole	11/03/80
KMM (PUK)	RL	20 mv	KIN-Borehole	07/03/84
KMM	D			06/ ? /85
SFL (KMM)	RI	20 mv	KIN-Borehole	10/08/86
SCFL (SFL)	D			
Mauna Loa				
1. AIN	I	20 mv	ATO-Borehole	10/18/82
	D			10/08/85
2. CRK	I	20 mv	KIN-Borehole	07/19/83
	D			
3. MCC	I	40 mv	ATO-Borehole	07/14/75
MLCC	RI	0003 X=30 mv, Y=35 mv	ATO-Borehole	10/17/89
4. MLO	I	20 mv	WES-Platform	02/22/83
	D			10/27/86
	RI	20 mv	WES-Platform	
MLSR	D			01/11/89
5. MLS	I	40 mv	ATO-Borehole	06/26/75
MOKE		0108B X=36 mv,.1 Y=42.3 mv	ATO-Borehole	07/12/89

Table ETM-3. Table for electronic tiltmeter site location, ID (new and old), coordinates (in decimal degrees), and status of station for the island of Hawaii.

	Old ID	New ID	Coordinates		Status 1990
Kilauea Summit			Latitude	Longitude	
1. Ahua	AHU	AHUA	19.3729°	155.2701°	In operation
2. Sandhill	SDH	SDH2	19.3879°	155.2981°	In operation
3. Summer Camp	SMC	SMCP	19.4002°	155.2700°	In operation
4. Uwekahuna	UWE	UWEV	19.4239°	155.2839°	In operation
5. Uwekahuna	IDA	IDAE	19.4239°	155.2839°	In operation
Kilauea East Rift					
1. Escape Road	ESR	ERTL	19.3943°	155.2304°	Discontinued
2. Heiheiahulu	HHH	HHHS	19.4170°	154.9757°	In operation
3. Kane Nui O Hamo	KNO	NA	19.3843°	155.1791°	Pulled out
4. Puu Huluhulu	PHH	PUHH	19.3762°	155.2068°	Pulled out
6. Steam Crack Forestline	SFL	SCFL	19.3886°	155.1238°	Disconnected
Mauna Loa					
1. Ainapo	AIN	NA	19.4341°	155.5530°	Discontinued
2. Crack	CRK	NA	19.4573°	155.5698°	Discontinued
3. Mauna Loa Cinder Cone	MCC	MLCC	19.5661°	155.4949°	In operation
4. Mauna Loa Strip Road	MLO	MLSR	19.5036°	155.3886°	Discontinued
5. Mauna Loa Summit	MLS	MOKE	19.4980°	155.5866°	Disconnected
Repeater Stations					
1. Mauna Kea	MKR	MKR			

Discontinued = Site abandoned.
Disconnected = Instrument in place and will be operational after some maintenance and servicing.
Pulled out = Intrument will be reinstalled after maintenance and servicing.

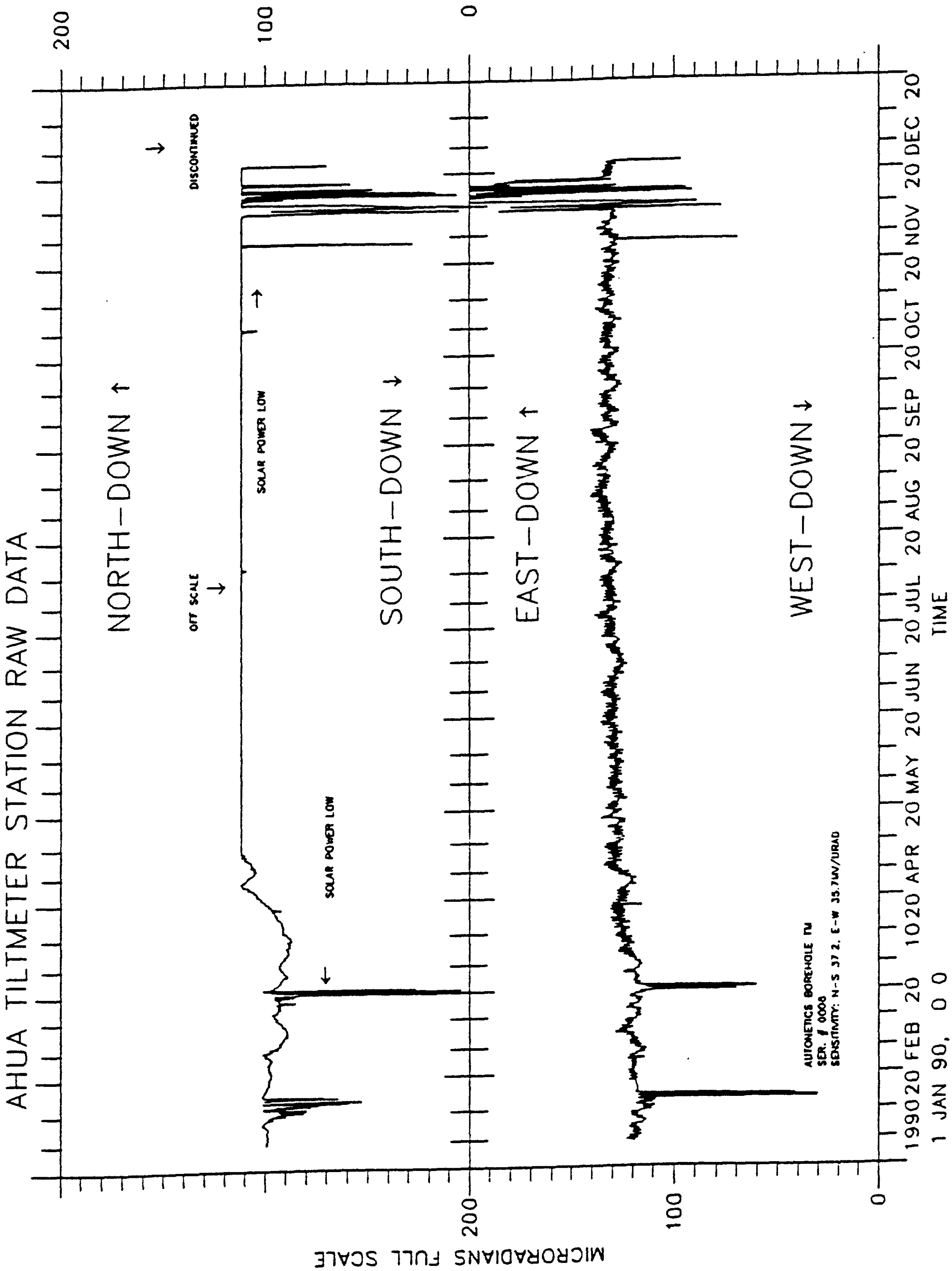
TIME SERIES PLOTS

FOR

ELECTRONIC TILT STATIONS

ENDING DECEMBER 1990

Figure ET-2.



AHUA TILTMETER STATION RAW DATA
NORTH—DOWN ↑
SOUTH—DOWN ↓
EAST—DOWN ↑
WEST—DOWN ↓
DISCONTINUED
OFF SCALE
SOLAR POWER LOW
SOLAR POWER LOW
AUTONETICS BOREHOLE TM
MICRORADIANS FULL SCALE
TIME
1 JAN 90, 0 0

Figure ET-3.

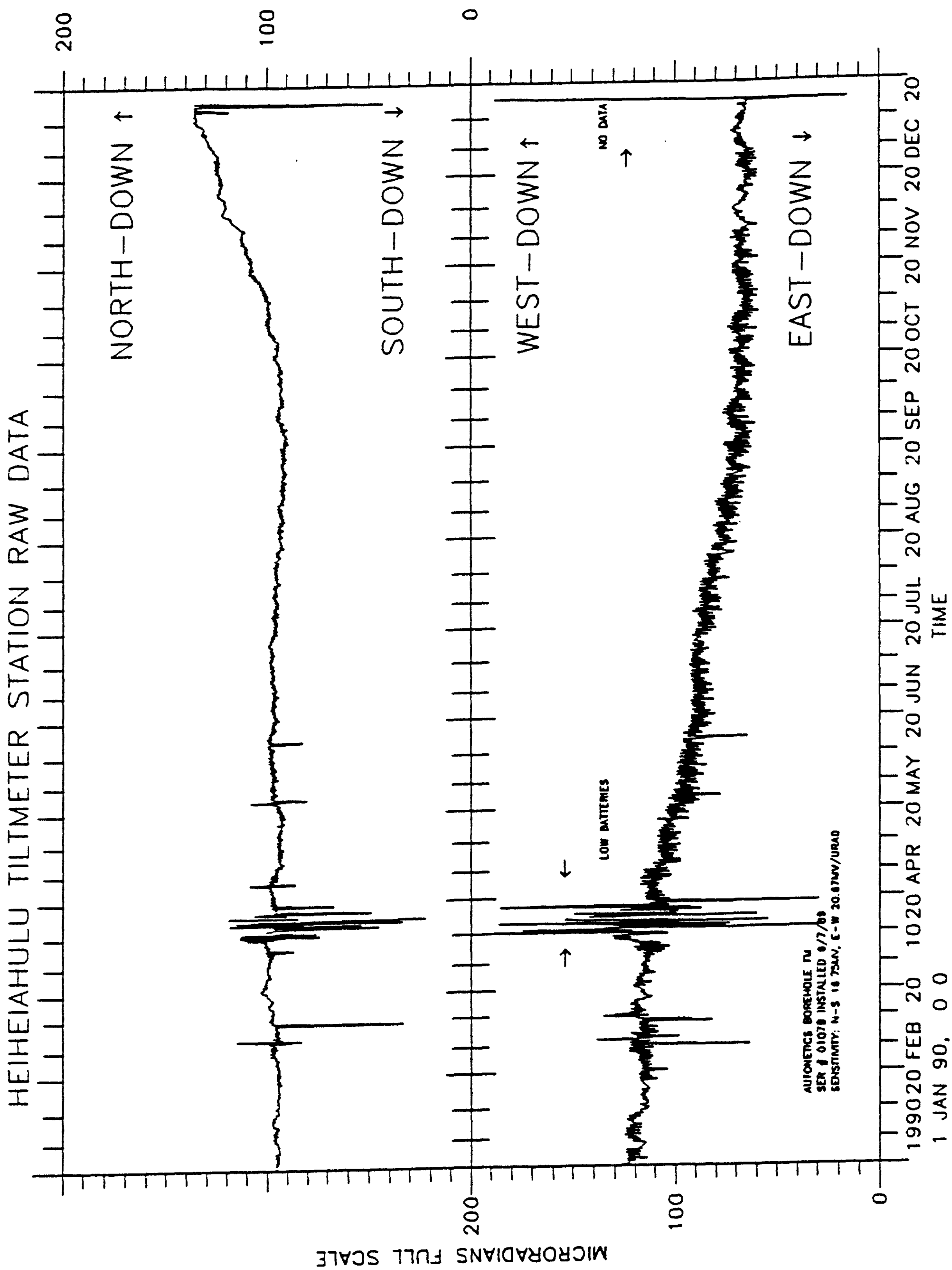

HEIHEIAHULU TILTMETER STATION RAW DATA
NORTH-DOWN
SOUTH-DOWN
WEST-DOWN
EAST-DOWN
LOW BATTERIES
NO DATA
TIME
MICRORADIANS FULL SCALE
1 JAN 90, 0 0
1990
20 FEB 20
10 20 APR 20 MAY 20 JUN 20 JUL 20 AUG 20 SEP 20 OCT 20 NOV 20 DEC 20
200
100
0

Figure ET-4.

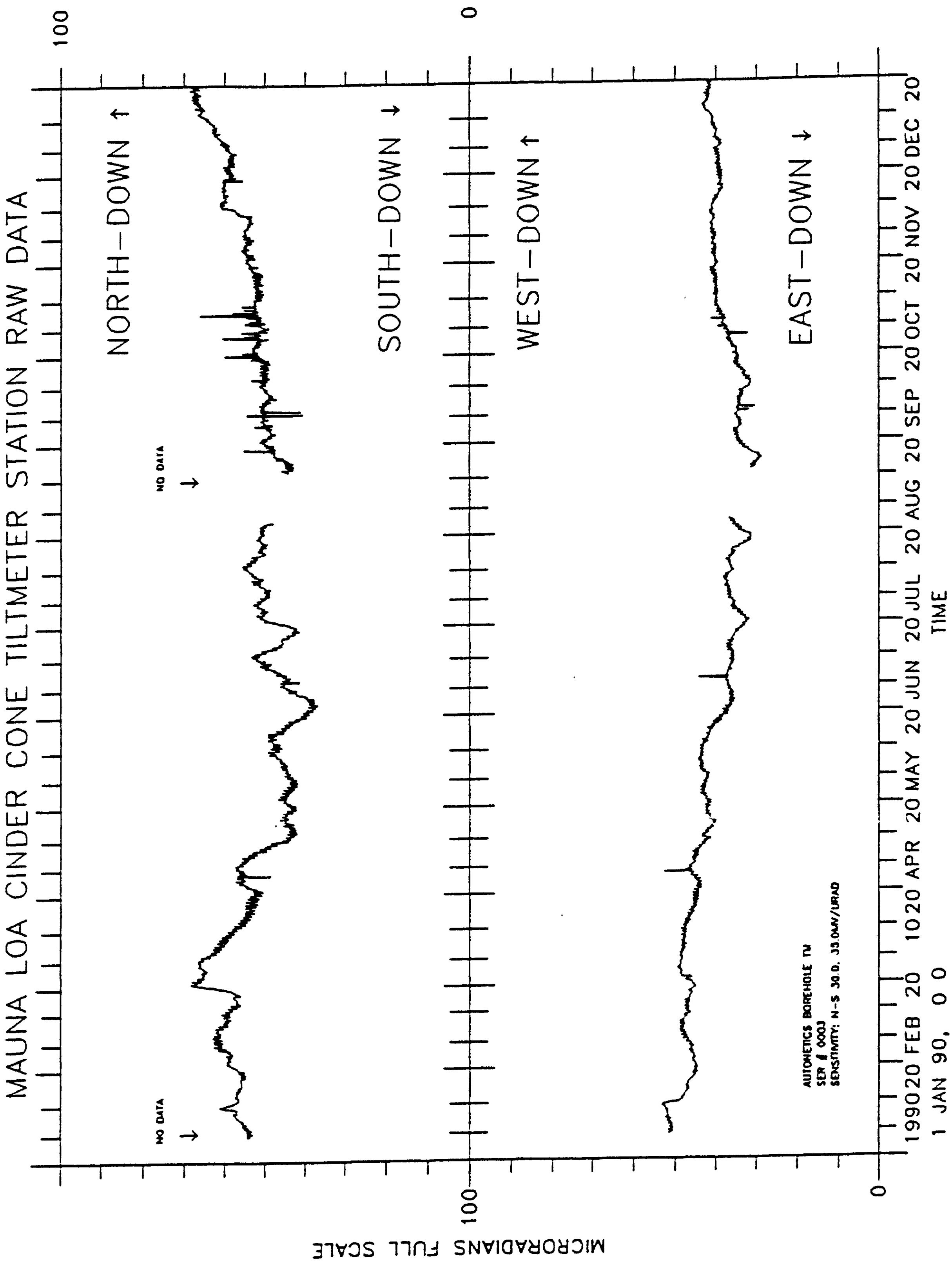

MAUNA LOA CINDER CONE TILTMETER STATION RAW DATA
NORTH—DOWN
SOUTH—DOWN
WEST—DOWN
EAST—DOWN
NO DATA
NO DATA
1 JAN 90, 0 0
1990 20 FEB 20 10 20 APR 20 MAY 20 JUN 20 JUL 20 AUG 20 SEP 20 OCT 20 NOV 20 DEC 20
TIME
MICRORADIANS FULL SCALE
100
0
100
0

Figure ET-5.

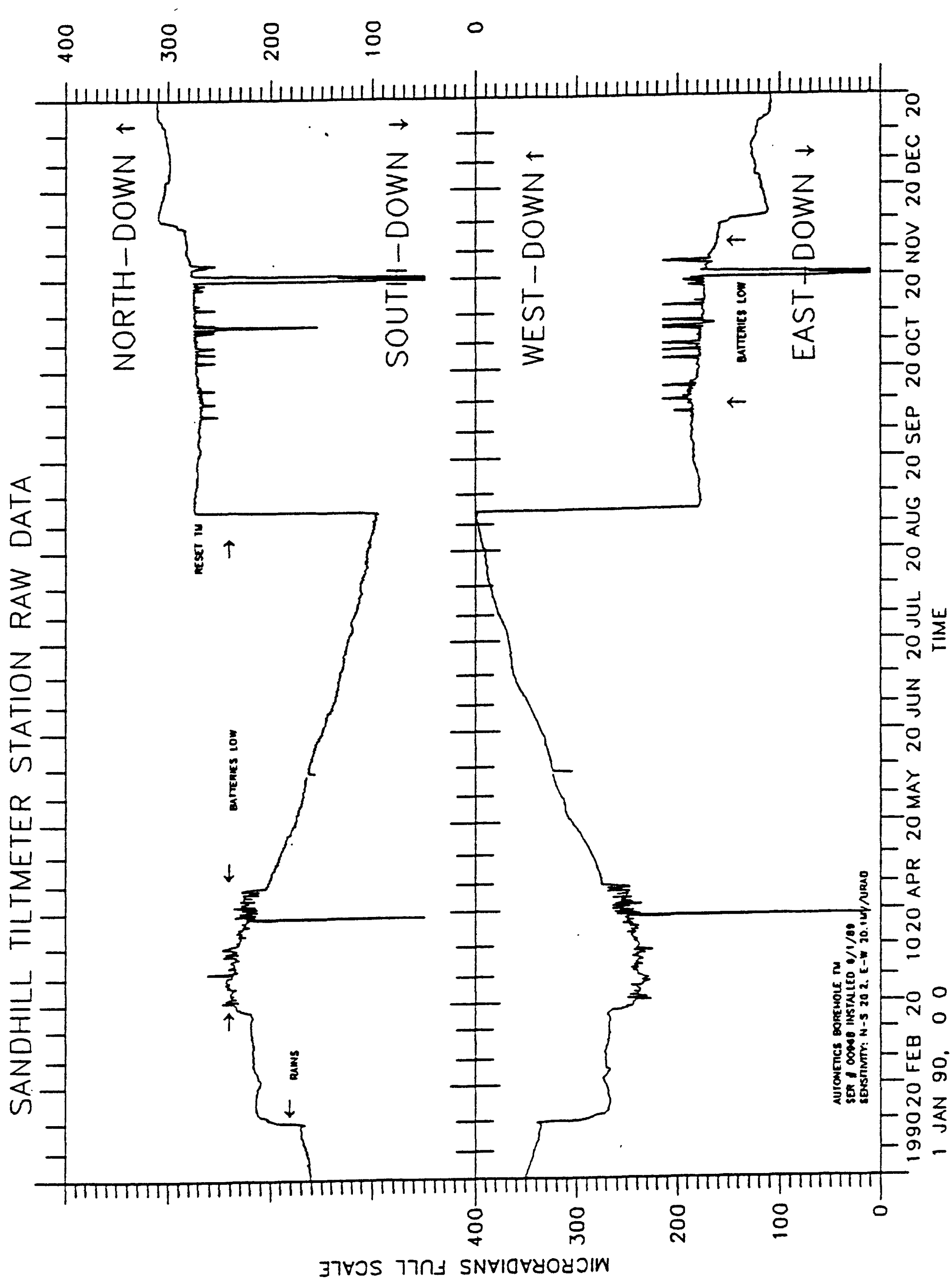
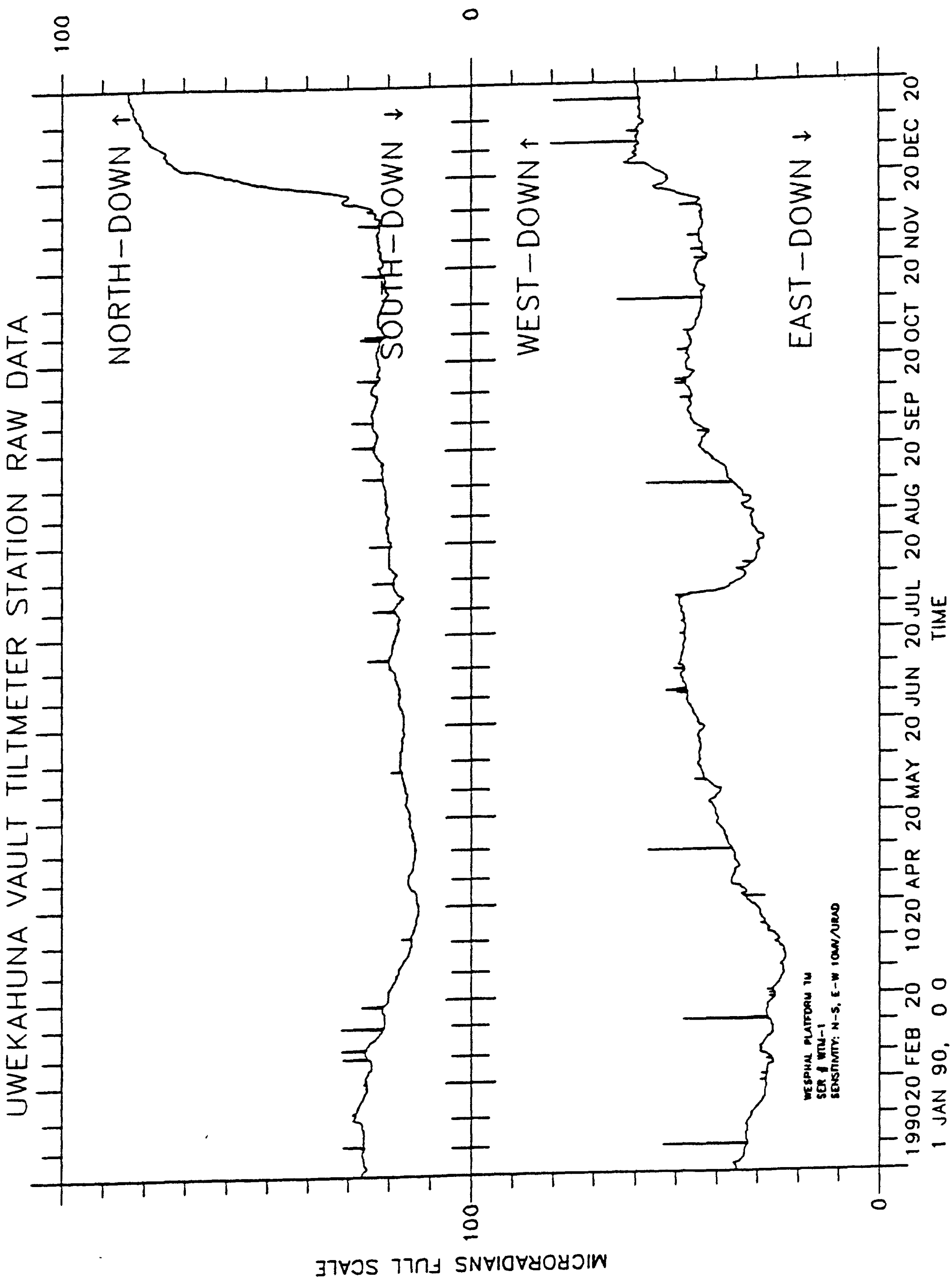

SANDHILL TILTMETER STATION RAW DATA
NORTH—DOWN ↑
SOUTH—DOWN ↓
WEST—DOWN ↑
EAST—DOWN ↓
RAINS
BATTERIES LOW
RESET TM
BATTERIES LOW
AUTONETICS BOREHOLE TM
1 JAN 90, 0 0
1990 20 FEB 20 10 20 APR 20 MAY 20 JUN 20 JUL 20 AUG 20 SEP 20 OCT 20 NOV 20 DEC 20
TIME
MICRORADIANS FULL SCALE
400
300
200
100
0

Figure ET-6.


UWEKAHUNA VAULT TILTMETER STATION RAW DATA
NORTH-DOWN ↑
SOUTH-DOWN ↓
WEST-DOWN ↑
EAST-DOWN ↓
100
0
100
0
1990 20 FEB 20 10 20 APR 20 MAY 20 JUN 20 JUL 20 AUG 20 SEP 20 OCT 20 NOV 20 DEC 20
1 JAN 90, 0 0
TIME
MICRORADIANS FULL SCALE

APPENDIX

New tilt station

The following is a description of a new spirit-level tilt station that was installed during this reporting period.

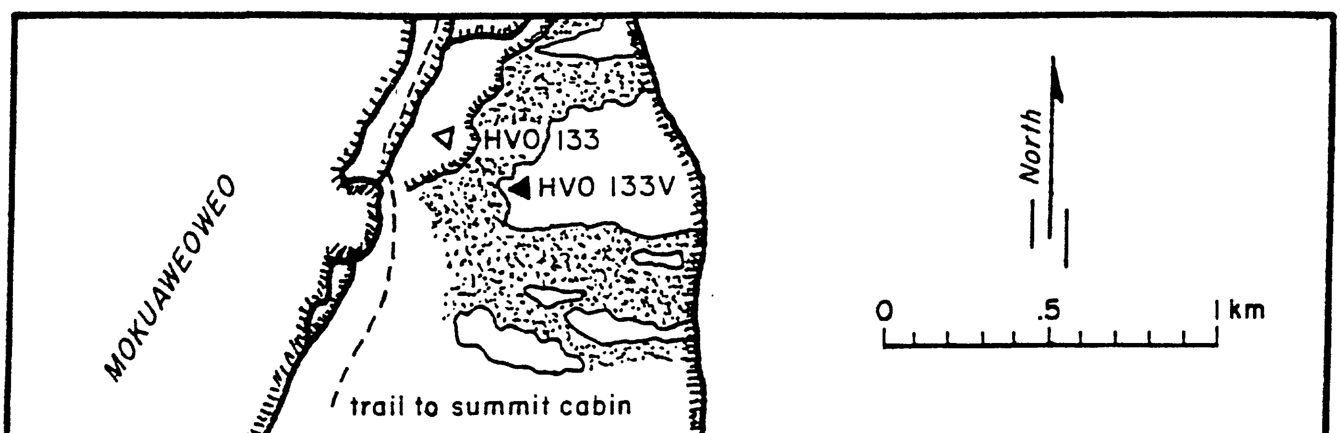
Station Name:	**HVO 133V**
Previous Name:	HVO 133
Latitude:	19° 28.76'
Longitude:	155° 34.57'
Station Data:	Ly = 38.62 m, Lz = 35.88 m, $\theta = 75°$ $\phi = 140°$
Station Coefficients:	$\tau(N) = 0.219\ d(y-x) - 0.080\ d(x-z) =$
	$\tau(E) = 0.184\ d(y-x) + 0.297\ d(x-z) =$

Description: **HVO 133V** is a spirit-level tilt station installed to replace HVO 133 tilt station as part of the Mauna Loa summit network. HVO 133 was set up with PK nails for the tilt rod locations and one nail was driven into an unstable pahoehoe block, resulting in some anomalous readings.

HVO 133V is located ~200 m S60°E of HVO 133, on a pahoehoe flow, surrounded by aa/semi-hoe lava flows on the northeast end of Mokuaweoweo caldera about halfway between the inner main caldera wall (~550 m east of the edge) and the outer caldera fault scarps.

The station is located towards the caldera edge of the boundary between the pahoehoe and the aa/semi-hoe flow. Ahus (rock cairns) mark the sites of the "X", "Y", and "Z" bench mark w/nipples. The bench marks are cemented into solid pahoehoe lava. The instrument site is located in the middle of the triangle and is marked by a PK nail painted with a yellow circle and an ahu built next to it. There is a excellent area to land a helicopter right at the station site. Three one-meter long portable invar strips labeled "X", "Y", and "Z" with one centimeter markings used for making the measurements, is attached to a corresponding stainless steel rod by a steel spring .

Figure APP-1. Location map of HVO 133V spirit-level tilt station on Mauna Loa summit.



Ammendment to Deformation Summary 1989 for Kupapau 2 coordinates (APPENDIX: New bench mark section)

CHANGE Old Lat: N19.7128° Lon: W155.0669°

to New Lat: N19.3312° Lon: W155.0201