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U.S. GEOLOGICAL SURVEY

HAWAIIAN VOLCANO OBSERVATORY
SUMMARY 92, PART III
ELECTRONIC TILT DATA, JANUARY TO DECEMBER 1992

BY
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U.S. GEOLOGICAL SURVEY
HAWAIIAN VOLCANO OBSERVATORY
HAWAII VOLCANOES NATIONAL PARK, HAWAII 96718

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+ Arrived during 1992
* Left during 1992

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TIME-SERIES PLOTS FOR THE YEAR 1992

FEBRUARY 17 EVENT, TIME-SERIES PLOTS

MARCH 3 EVENT, TIME-SERIES PLOTS

ELECTRONIC TILT VECTORS

INTRODUCTION

Electronic tiltmeters are used by the Hawaiian Volcano Observatory (HVO) to measure ground deformation on the island of Hawaii in real time. This report includes the measurements recorded by all the tiltmeters operating during 1992. The station locations are depicted in Figure 1. This report also includes the rainfall record and the watertube tilt data at Uwekahuna which have a bearing on some of the events measured by the electronic tiltmeters.

INSTRUMENTATION

There are two basic styles of electronic tiltmeters used by HVO: borehole and platform models. The borehole tiltmeters used at HVO consist of an electrolytic bubble sensor mounted at the bottom of a buried, vertically oriented pipe about 1 m long. The platform tiltmeters consist of a sensor mounted on a rectangular or triangular-shaped platform designed for surface mounting.

A detailed description of each type of electronic tiltmeter used at HVO follows under the manufacturer's heading.

ROCKWELL AUTONETICS AND KINEMETRICS

These borehole tiltmeters were originally built by Rockwell Autonetics, then, subsequently, by Kinemetrics, Inc. These tiltmeters have a single sensor with four electrodes mounted orthogonally, forming a dual-axis sensor. The sensor contains a conductive fluid with a small air bubble to indicate the vertical pole. The electrodes indicate the position of the bubble, and, hence any change in tilt. The sensor is mounted at the bottom end of a buried, vertically oriented, meter long pipe. HVO had six of this type of meters operating at the beginning of 1992.

WESTPHAL

This platform tiltmeter was built by J. A. Westphal of Caltech in 1984 (Westphal, 1983). It utilizes two single-axis electrolytic bubble transducers mounted orthogonally, forming a dual-axis instrument. Each bubble contains conductive fluid, two opposing electrodes, and a small air bubble to indicate the vertical pole. The bubbles are mounted in holders fastened on an 20.3 cm. square invar plate. HVO currently operates one of this type of instrument.

IDEAL AEROSMITH

This platform tiltmeter is built by the Ideal Aerosmith Corporation. This single-axis tiltmeter utilizes two interconnected cisterns spaced a meter apart filled with mercury. The mercury and the cistern cover act as capacitance plates, with an air gap for a dielectric. The capacitance is measured through

ELECTRONIC TILTMETER STATION LOCATIONS

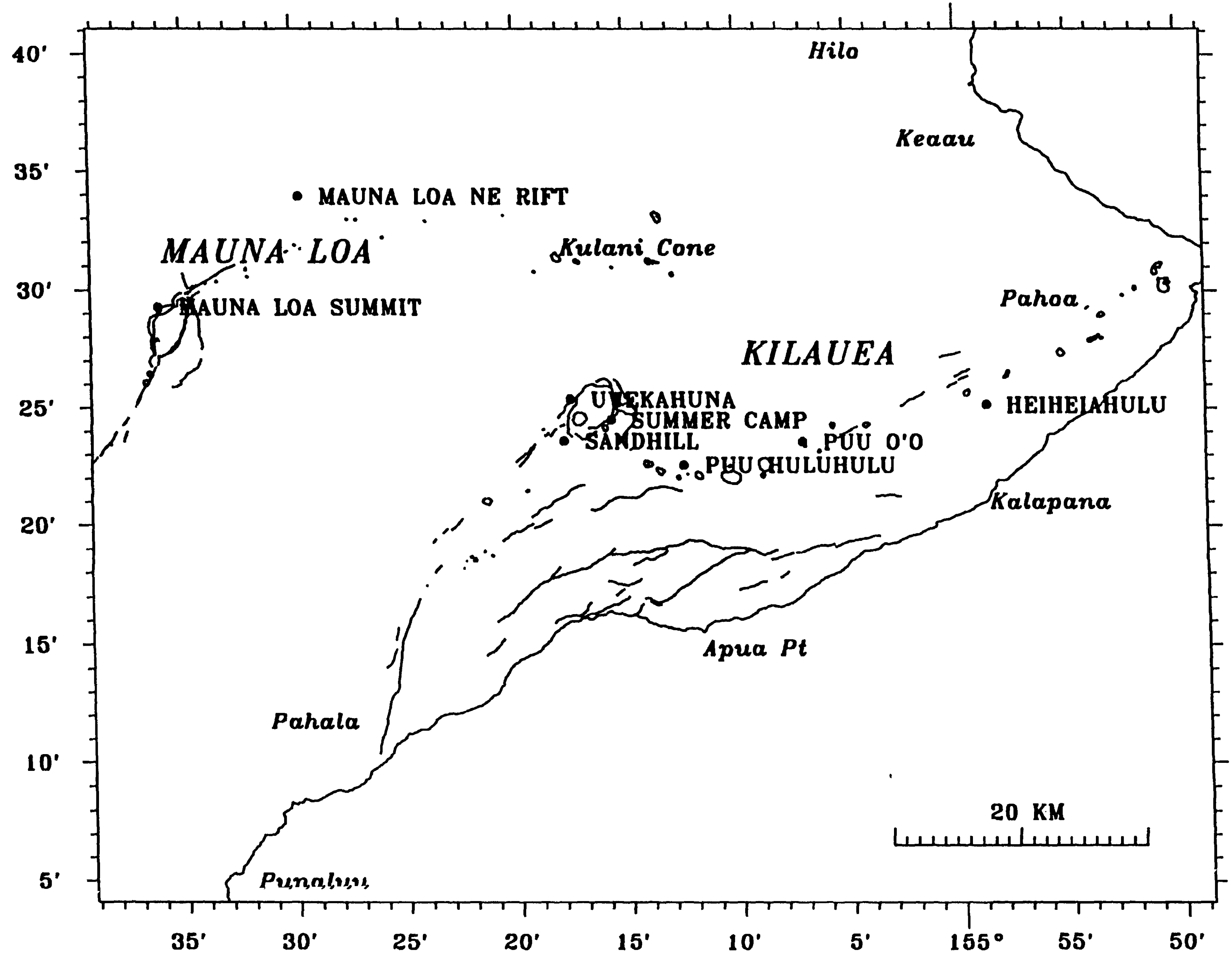


Fig. 1

a wein bridge and converted to a voltage output calibrated in microradians. HVO operates has one of this type of instrument.

APPLIED GEOMECHANICS

HVO operates one tiltmeter from Applied Geomechanics. It is a .85-m-long borehole model with biaxial output. This model uses two electrolytic bubble transducers oriented orthogonally in the bottom of the sensor tube.

DATA COLLECTION & PROCESSING

All tiltmeters present their output signals expressed as a voltage. These voltage signals are collected by the HVO Polling Telemetry System for Low Frequency Data Acquisition (Puniwai, 1990) every 10 minutes. The polling system converts the voltage into digital form, collects the information in the central polling computer, and then passes the data to the HVO minicomputers for storage, retrieval and analysis.

The tilt information is stored as 12-bit data values (0 to 4096 bits), converted back to voltage (2.44 mv/bit), translated into microradians (per tiltmeter calibration values), then plotted. All the time-series plots presented in this paper have been produced with BOB, an interactive program for accessing, processing, and displaying time-series data (Murray, 1986). Both the year-long data plots and the event plots have been cleaned (noise spikes removed/earthquake and instrumental offsets removed).

The station location and vector plots were produced with QPLOT (Klein, 1980). The data for the vector plots were taken from the BOB data files for the corresponding period.

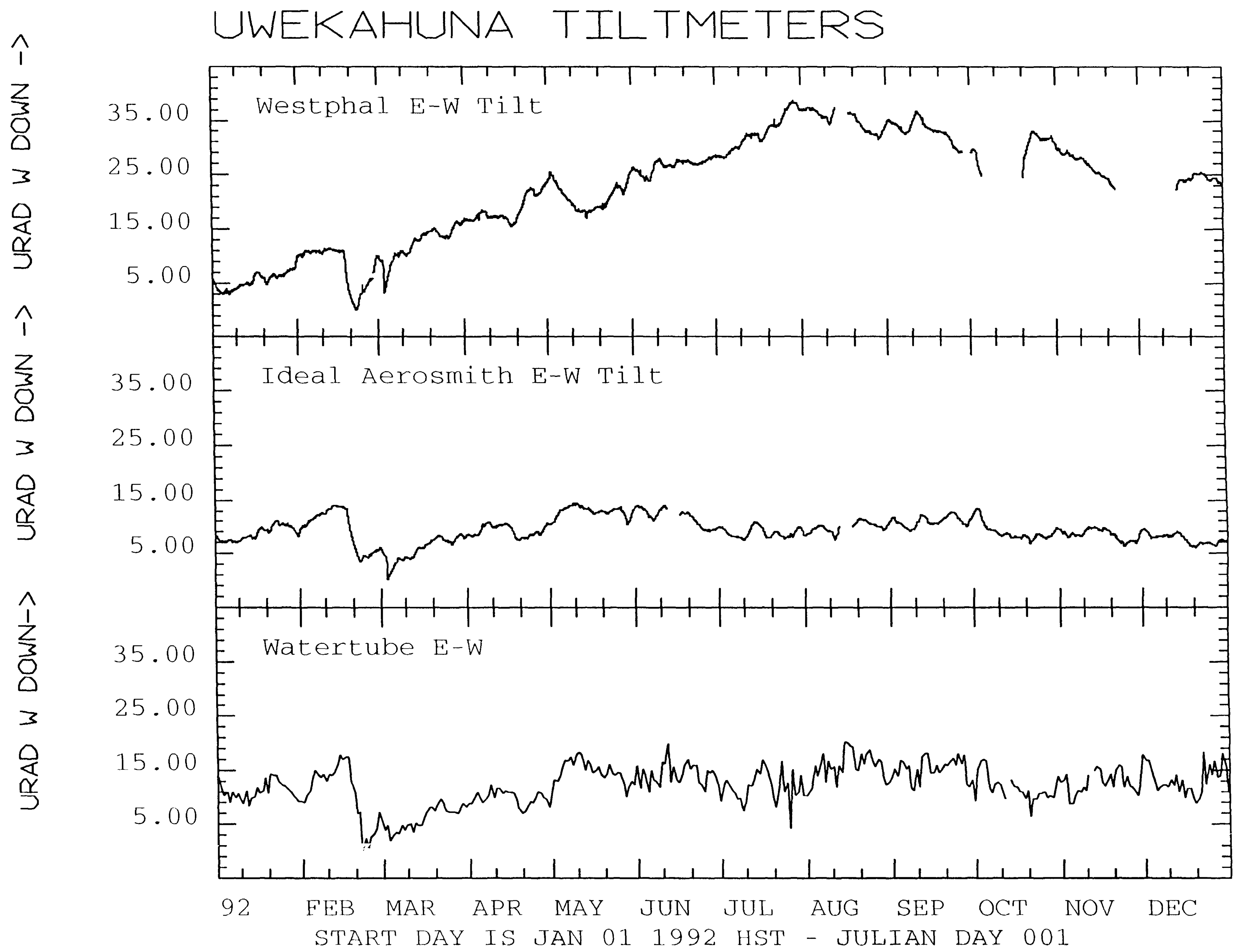
STATION INFORMATION & DISCUSSION

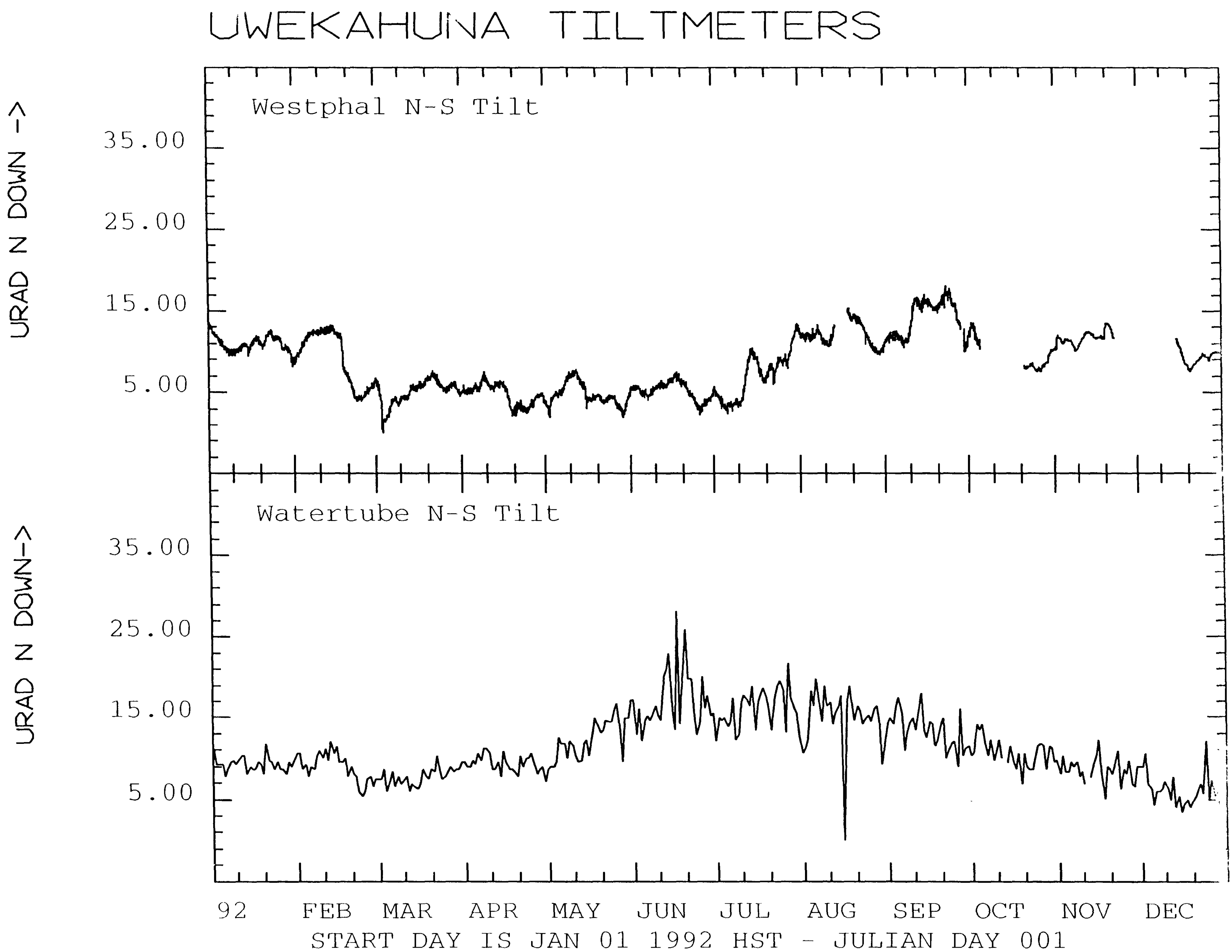
1. **UWEV** (Uwekahuna) Latitude 19.4239° Longitude 155.2839°

The UWEV station (labelled "UWEKAHUNA" in the data plots) is located in the Uwekahuna Vault operated by HVO at Kilauea's summit. This station is used to monitor Kilauea's summit magma chamber. The vault was constructed in 1948. The single-wall, concrete vault is located 360 m west of the Hawaiian Volcano Observatory. It is 6 m long, 3.6 m wide, with a 2.4-m-high ceiling and is divided into three rooms: two entrance chambers and a large instrument room. The instrument room is supplied with 120 VAC uninterruptible power, is dehumidified, and has less than 0.5°C daily temperature variation. The vault has approximately .5 m of ash overburden, and rests on bedrock.

INSTRUMENTATION

Three independent tilt instruments are housed within the vault: an Ideal Aerosmith tiltmeter, a Westphal tiltmeter, and a


UWEKAHUNA TILTMETERS
Westphal E-W Tilt
Ideal Aerosmith E-W Tilt
Watertube E-W
URAD W DOWN ->
URAD W DOWN ->
URAD W DOWN->
35.00
25.00
15.00
5.00
92
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
START DAY IS JAN 01 1992 HST - JULIAN DAY 001


UWEKAHUNA TILTMETERS
Westphal N-S Tilt
Watertube N-S Tilt
URAD N DOWN ->
URAD N DOWN->
35.00
25.00
15.00
5.00
92
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
START DAY IS JAN 01 1992 HST - JULIAN DAY 001

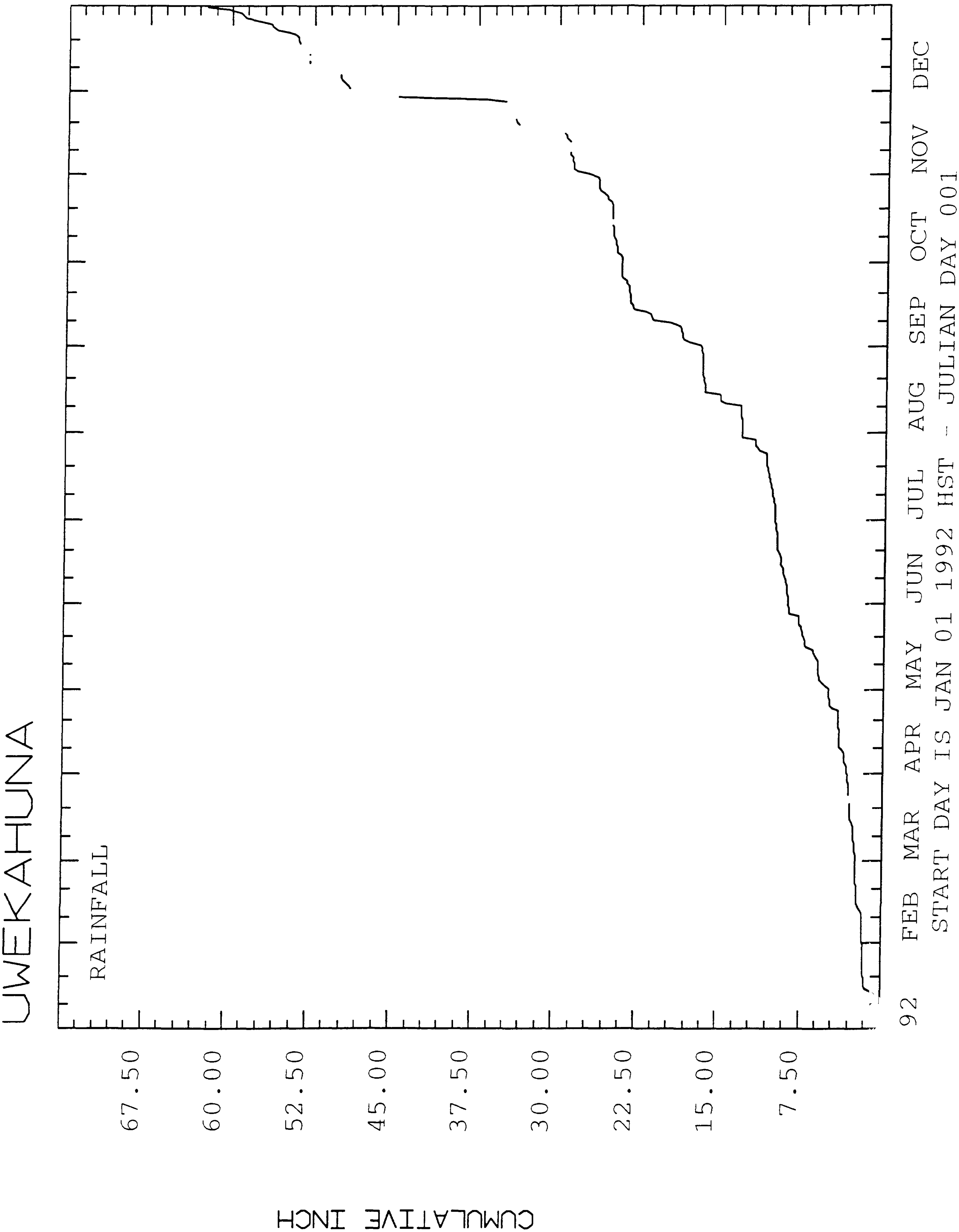

UWEKAHUNA
RAINFALL
CUMULATIVE INCH
67.50
60.00
52.50
45.00
37.50
30.00
22.50
15.00
7.50
92
FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
START DAY IS JAN 01 1992 HST - JULIAN DAY 001

Fig. 4

watertube tiltmeter.

The Ideal Aerosmith tiltmeter was installed in 1968 and is aligned E-W. It has been operating since 1968 with occasional down time for repairs and calibration. The instrument is relatively insensitive to small temperature fluctuations.

The Westphal Tiltmeter was installed in 1984. It has been operating since then with occasional down time for repairs and calibration. The instrument is relatively insensitive to daily temperature diurnal.

The two electronic instruments in the Uwekahuna vault are the only tiltmeters in the HVO network whose output can be easily verified by alternate means. HVO has a 3-m-long biaxial watertube tiltmeter, installed in the Uwekahuna vault, which is usually read on a daily basis. This provides a convenient check for the electronic tiltmeters, and the data have been plotted in this report with the electronic data. The watertube was installed in 1956 and provides a long-term record of Kilauea summit tilt changes.

DISCUSSION

The Ideal Aerosmith and the Westphal tiltmeters agree on short-term tilt changes but disagree on long-term trends during the year (fig. 2). The Westphal E-W component showed a slow, positive drift from March to August which was not confirmed by the Ideal Aerosmith or the watertube tiltmeters, and a slow, negative drift from September to December which was also not confirmed. Short-term events or changes on the order of a month or less were corroborated by all E-W tilt components. The Westphal N-S component depicted short-term events that were similiar in signature to the Uwekahuna N-S watertube component (fig. 3). The Westphal N-S component also showed some long-term drift as compared with the Uwekahuna watertube, but not on the order of the E-W component. The Westphal N-S component showed a slightly negative drift from January thru June as compared to the watertube, and then a slightly positive drift from July to October. The Westphal tiltmeter then underwent repairs in October.

Analysis of the Westphal tiltmeter data shows good short-term measurements, but the tiltmeter is hampered by long-term instrumental drift. The Westphal tiltmeter was periodically down for repairs during the months of October, November, and December, as reflected by missing data points.

The Ideal Aerosmith tiltmeter record over-all closely resembles the watertube record, which indicates good stability of this electronic tiltmeter. The Ideal Aerosmith and the Westphal tiltmeters are rather closely matched in amplitude for tilt events (such as the February 7 event discussed later), but both show a slightly lower amplitude signal than the watertube for specific events.

The Uwekahuna rainfall record is introduced here (fig. 4) because of the instrument location and its use as a gener[illegible] indicator for rainfall over Kilauea volcano as a whole. T[illegible] standard National Weather Service raingauge is usually read daily, and the data are plotted as a cumulative record for ease of interpretation. The intent in including these data is an attempt to correlate any specific tilt event with rainfall. High levels of rainfall can cause tilt events at a specific site or affect the mountain as a whole.

2. **SDH2** (Sandhill) Latitude 19.3879° Longitude 155.2981°

The SDH2 station (labelled "SANDHILL" in the data plots) is located 400 m SW of the Sandhill benchmark (HVO 119) at Kilauea summit. This station is used to monitor Kilauea's summit magma chamber and is much closer to the assummed epicenter of the chamber than the UWEV station, which may account for the large tilt changes recorded at this site. The geology of this site consists of ash, approximately 3 m thick, underlain by pahoehoe. The tiltmeter is installed in a meter-long pipe, the top of which is .5 m below surface level.

The Sandhill site was established in 1974, and a series of tiltmeters has occupied this site over time. The current tiltmeter, an Autonetics borehole (serial no. 0096B), has occupied this site since June 1, 1989.

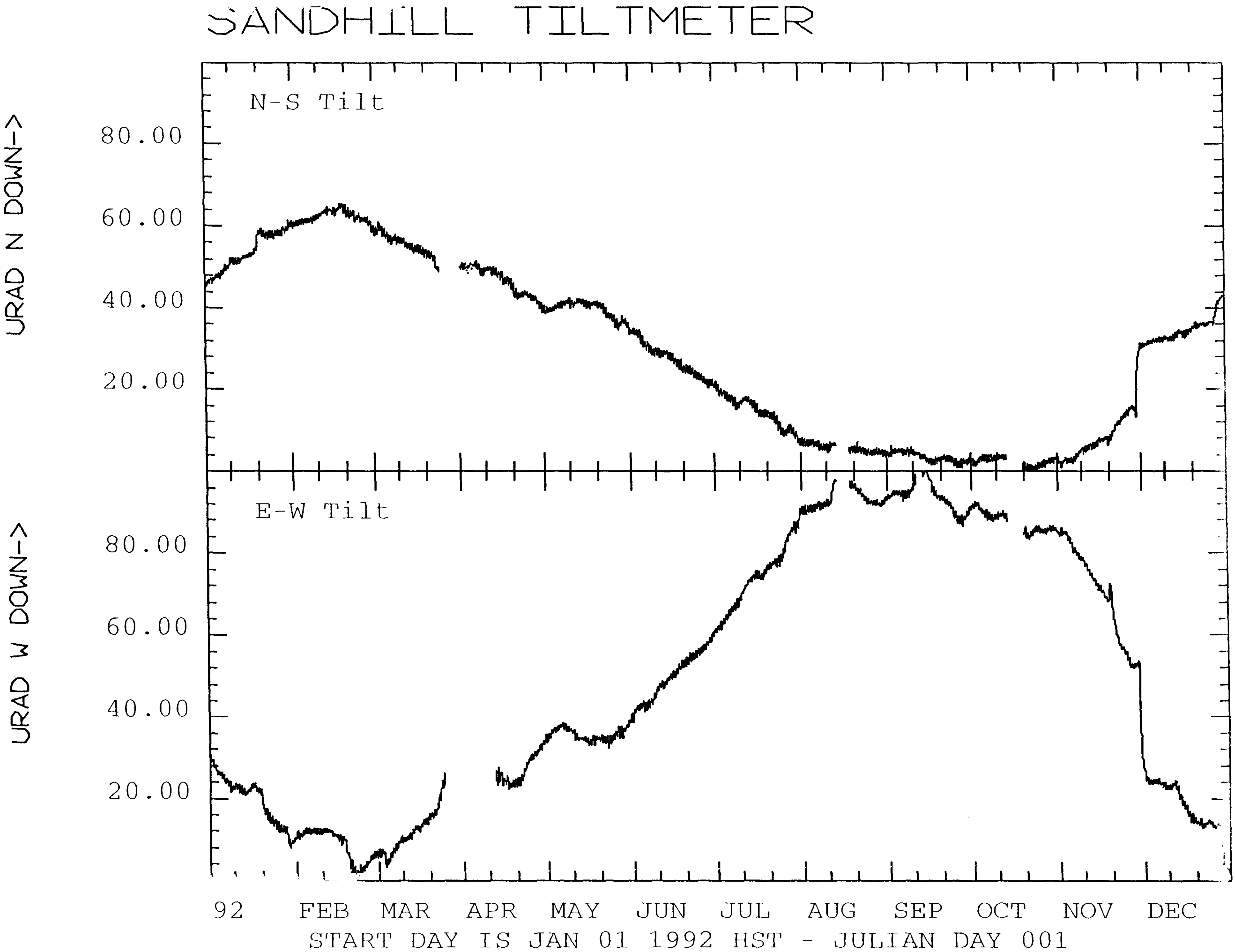
DISCUSSION

The Sandhill tiltmeter showed large tilt changes throughout the year (fig. 5). The tiltmeter showed a NE down vector of 36 microradians from the beginning of the year to mid-February, indicating summit deflation. From mid-February to August, the tiltmeter indicated summit inflation of 119 microradians. For the rest of the year, the tiltmeter indicated some summit deflation but experienced large disturbances from weather events. The timing of changes in direction of tilt, indicating volcanic movement at Sandhill, is confirmed by tiltmeter changes at other stations. The magnitude of the tilt changes are not cross-checked by other methods, but the general indication of inflation or deflation of the mountain is confirmed by the Uwekahuna tiltmeters.

The station is in an excellent position to monitor volcanic changes of Kilauea summit, but is very sensitive to the effects of heavy rain. Sharp increases or decreases in tilt caused by heavy rain occurred in mid-August, early September, late November (two events), and late December (one event).

3. **SMCP** (Summer Camp) Latitude 19.4086° Longitude 155.2623°

The SMCP station (labelled "SUMMER CAMP" in the data plots) is located on the eastern edge of Kilauea caldera, between Crater Rim Drive and the caldera's edge. This site is used to monitor Kilauea's summit magma chamber and the upper East Rift Zone (ERZ).


SANDHILL TILTMETER
N-S Tilt
E-W Tilt
URAD N DOWN->
URAD W DOWN->
80.00
60.00
40.00
20.00
92
FEB
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JUN
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START DAY IS JAN 01 1992 HST - JULIAN DAY 001

Fig. 5

The site is composed of unconsolidated tephra from the 1960 Kilauea Iki eruption. A 15-cm-diameter, 1.5-m-long pipe is installed at the site, filled with silica sand. The top of the pipe is 2 m below ground level.

The Summer Camp site was established in 1973, and a series of tiltmeters have occupied this site over time. The current tiltmeter, a Kinemetrics borehole (serial no. 355), was installed on December 3, 1990, and the site dismantled on March 5, 1992. The top of the tiltmeter is even with the top of the pipe.

DISCUSSION

The tiltmeter indicated summit deflation of about 25 microradians from the beginning of the year to mid-February (fig. 6). From mid-February to early March, the tiltmeter indicated summit inflation of about 18 microradians. This station has responded well to changes in Kilauea's summit magma chamber.

4. **PUHH** (Pu'u Huluhulu) Latitude 19.3762° Longitude 155.2068°

The PUHH station is located on the north-facing slope of Pu'u Huluhulu, a forested, consolidated cinder cone on Kilauea's ERZ. This site is intended to monitor Kilauea's upper ERZ. The geology of the site consists of very thin pahoehoe flows and welded pyroclastics. A meter-long pipe is cemented in place, the top of which is about 20 cm below ground level.

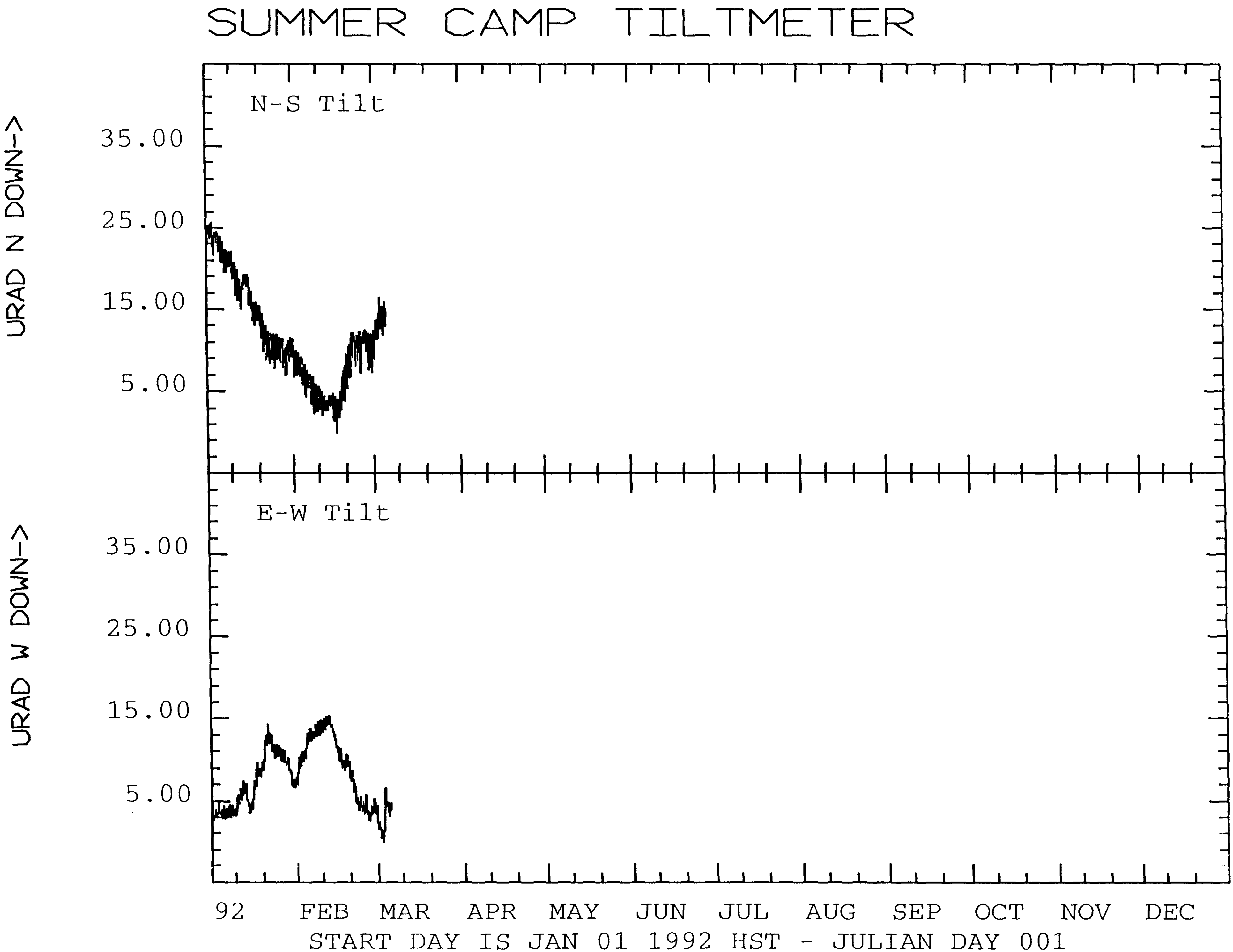
The Pu'u Huluhulu site was established in 1974, and a series of tiltmeters has occupied this site over time. An Autonetics borehole tiltmeter (serial no. 008b), has occupied this site since March 1, 1991.

DISCUSSION

The tiltmeter did not show strong regional changes for the first half of this year (fig. 7), but did respond well to the seismic events of February and March. The tiltmeter did show a north-down vector of about 20 microradians from June until November, then a west-down vector of 12 microradians for the rest of the year.

This site responds well to horizontally propogating dikes that pass the station. The site appears insensitive to rainfall and seems very stable when the long-term record is analyzed. The tiltmeter's N-S component has a large diurnal signature, but both components show an excellent response to events. The very low diurnal component on the E-W channel makes it valuable in discerning small events.

5. **SCFL** (Steaming Crack Forest Line)
Latitude 19.3886° Longitude 155.1238°


SUMMER CAMP TILTMETER
N-S Tilt
URAD N DOWN->
35.00
25.00
15.00
5.00
E-W Tilt
URAD W DOWN->
35.00
25.00
15.00
5.00
92
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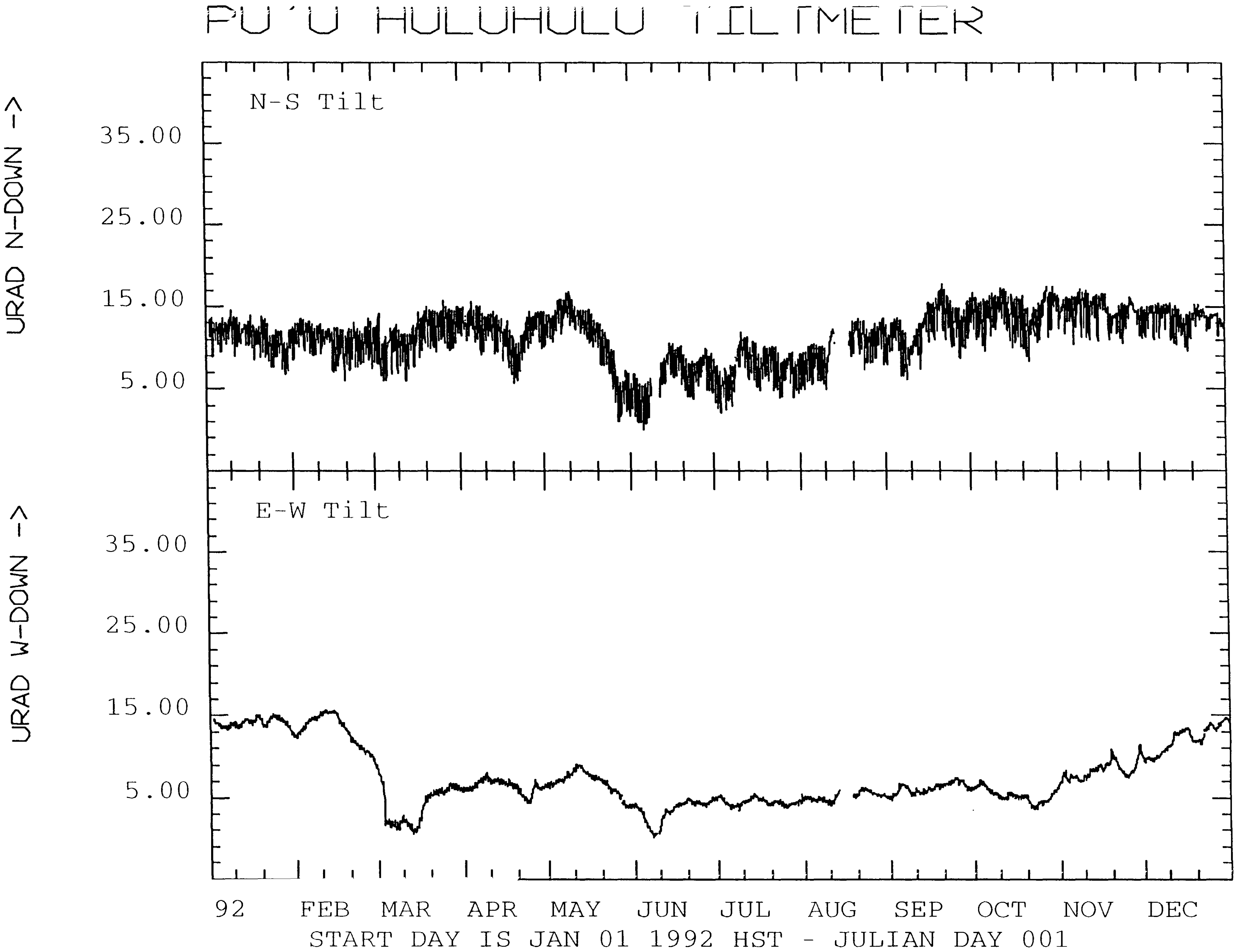
START DAY IS JAN 01 1992 HST - JULIAN DAY 001

Fig. 6


PU'U HULUHULU TILTMETER
N-S Tilt
URAD N-DOWN ->
35.00
25.00
15.00
5.00
E-W Tilt
URAD W-DOWN ->
35.00
25.00
15.00
5.00
92
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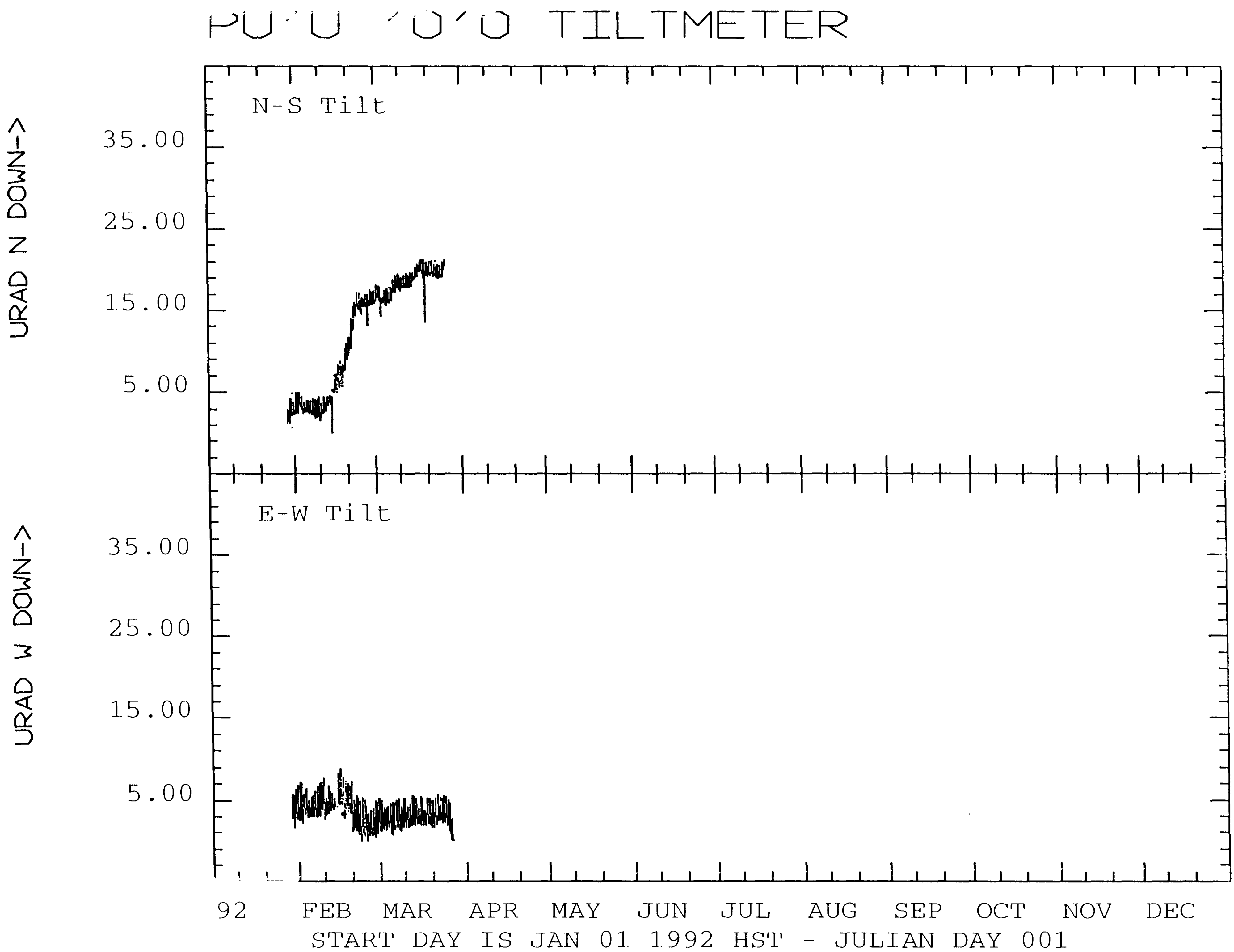
START DAY IS JAN 01 1992 HST - JULIAN DAY 001

Fig. 7


PU'U 'O'O TILTMETER
N-S Tilt
URAD N DOWN->
35.00
25.00
15.00
5.00
E-W Tilt
URAD W DOWN->
35.00
25.00
15.00
5.00
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START DAY IS JAN 01 1992 HST - JULIAN DAY 001

Fig. 8

The SCFL station (labeled "PU'U 'O'O" in the data plots) is located 1.5 km west of Pu'u 'O'o on Kilauea's ERZ. This site is intended to monitor changes in the Pu'u 'O'o area of the ERZ. The geology of the site consists of 2 m of tephra underlain by pahoehoe. A 1.5-m-long pipe containing the tiltmeter is installed in the unconsolidated tephra.

This site was originally established in January 1991. The tiltmeter was not operating at the beginning of this year. An Applied Geomechanics borehole tiltmeter (serial no. 0519) was installed on January 29. The site was dismantled on March 27 due to danger from advancing lava flows.

DISCUSSION

The station responded well to events this year, although it was only operating for two months. The tiltmeter displayed a north-down vector of about 5 microradians for the month of March (fig. 8). The data also showed a moderate diurnal effect (4 microradians), which makes it hard to discern small events.

6. **HHHS** (Heiheiahulu) Latitude 19.4170° Longitude 154.9757°

The HHHS station (labelled "HEIHEIAHULU" in the data plots) is located 1.8 km SE of Heiheiahulu cinder cone on Kilauea's ERZ. This site is intended to monitor changes near Heiheiahulu in the middle ERZ. The geology of the site consists of thick pahoehoe flows. The tiltmeter is installed in a 1.5-m-deep borehole.

This site was established in 1977, and a series of tiltmeters has occupied this site over time. An Autonetics borehole tiltmeter (serial no. 0107B), has occupied this site since June 7, 1989.

DISCUSSION

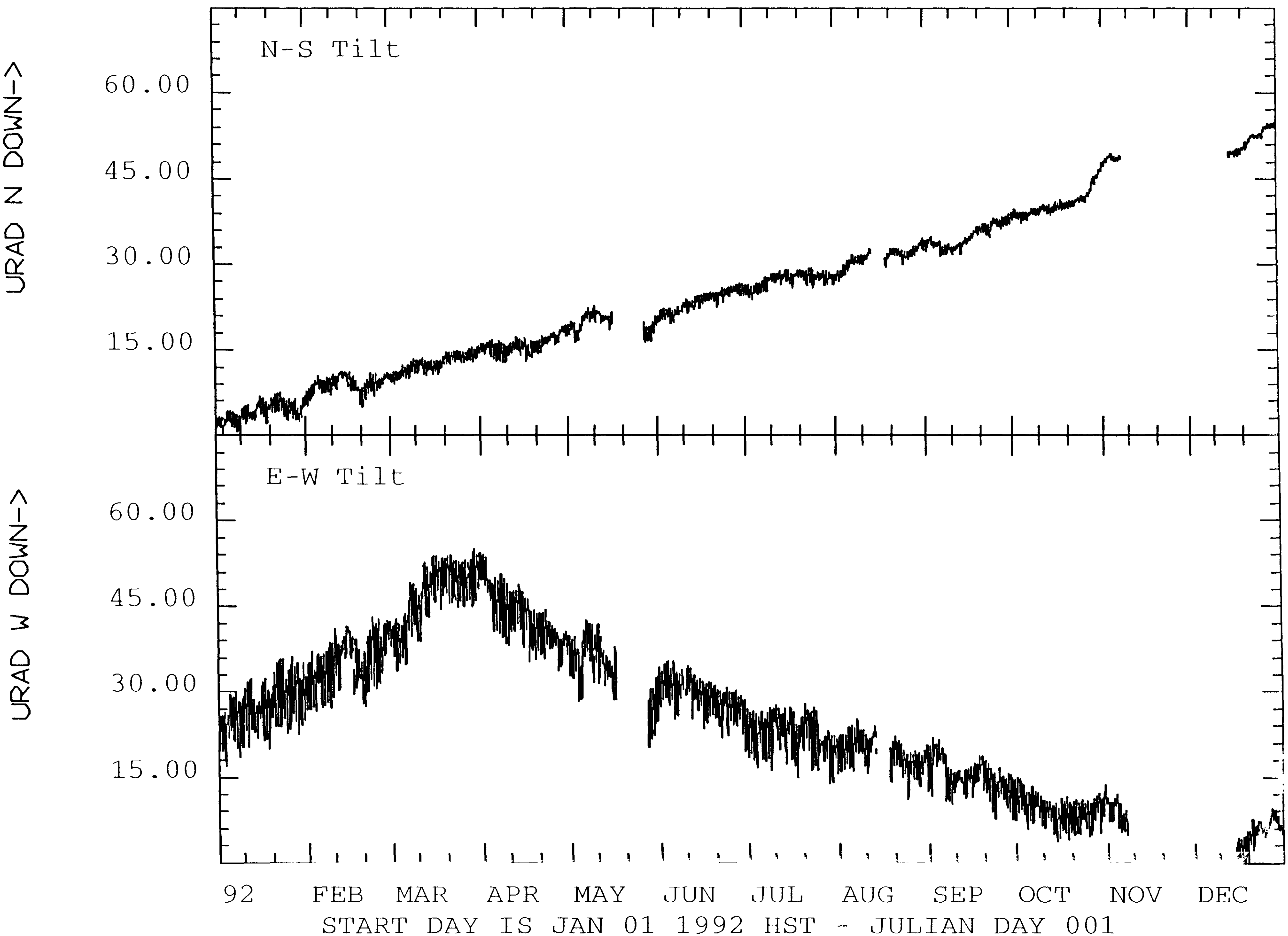
For the first three months of the year, the tiltmeter showed a NW down vector of 34 microradians, then a NE down vector of 74 microradians for the rest of the year (fig. 9).

This site did not respond to the two events affecting Kilauea summit and upper ERZ, and does not appear to be sensitive to Kiluaea rainfall events.

7. **MOKE** (Mokuaweoweo) Latitude 19.4980° Longitude 155.5866°

The MOKE station (labelled "MAUNA LOA SUMMIT" in the data plots) is located on the NW side of Mokuaweoweo, Mauna Loa's summit caldera. It is situated about 300 m from the caldera's edge, at the end of the summit access road. The geology of the site consists of pahoehoe flows. A 1.5-m-deep hole was drilled within a 1-m-deep partially collapsed lava bubble for the tiltmeter.

This site was established in 1975, and a series of tiltmeters has occupied this site over time. An Autonetics borehole


N-S Tilt
E-W Tilt
URAD N DOWN->
URAD W DOWN->
60.00
45.00
30.00
15.00
60.00
45.00
30.00
15.00
92
FEB
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START DAY IS JAN 01 1992 HST - JULIAN DAY 001

Fig. 9

tiltmeter (serial no. 0008B), has occupied this site since July 23, 1991.

DISCUSSION

The tiltmeter has shown no dramatic changes for the year (fig. 10); most small events recorded were related to weather effects (rain or snow). The N-S component has shown no over-all changes for the year, while the E-W component showed a generally East-down tilt vector for the first half of the year and a West-down tilt vector for the last half of the year. It is uncertain whether the E-W signal is seasonal changes, or reflecting true tilt of the ground surface.

8. **MLCC** (Mauna Loa Cinder Cone)
Latitude 19.5661° Longitude 155.4949°

The MLCC station (labelled "MAUNA LOA NE RIFT" in the data plots), is located about 4 km N of Mauna Loa's NE rift zone, and 4.5 km NW of Puu Ulaula. The station is located on an unconsolidated cinder cone. A 1.5-m-long pipe installed in the cinder houses the tiltmeter.

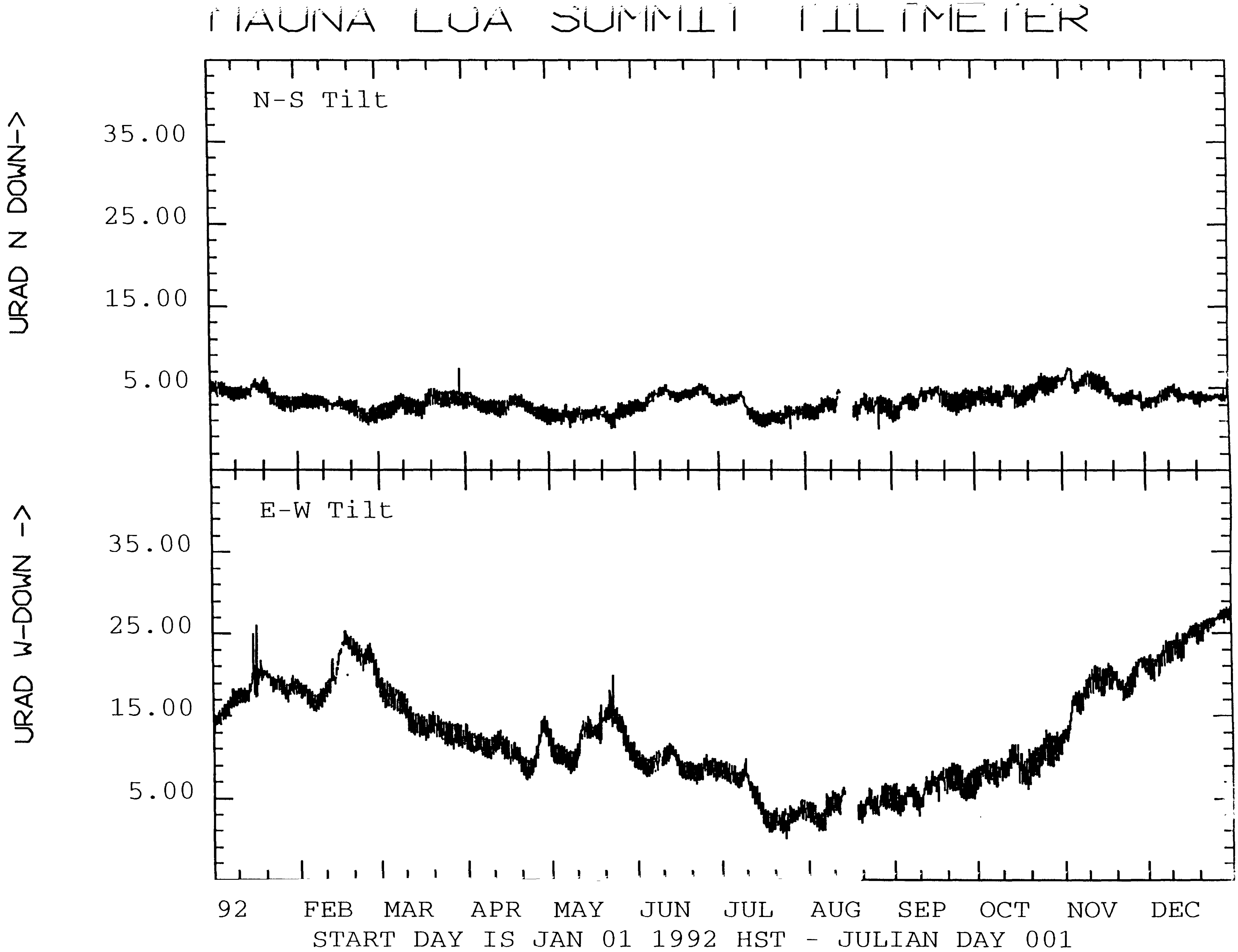
This site was established in 1975, and a series of tilt-meters has occupied this site over time. An Autonetics borehole tiltmeter (serial no. 0003), has occupied this site since October 17, 1989. The top of the tiltmeter is a few centimeters below ground level.

DISCUSSION

This station has shown no over-all changes for the year (fig. 11). Both components showed a long-period sine-wave pattern which is possibly seasonal changes experienced by this site or true tilt signals. The long-term data pattern experienced at this site is corroborated by changes at the MOKE instrument, posing a question as to whether the changes are truly magma related or seasonal adjustments. Several small-amplitude/short-duration tilt events can also be correlated with the MOKE instrument data, most likely related to weather events.

EVENT OF FEBRUARY 17, 1992

The eruptive level on Kilauea's ERZ declined from the beginning of the year through the middle of February, when all flows then ceased. There still was an active lava pond within Pu'u 'O'o. On February 17, at about 1930 hrs, a fissure opened on the uprift flank of Pu'u 'O'o, signaling a restart of the lava flows and the beginning of Episode 50. At approximately 2020 on February 17 the summit tilt began to show a slow but steady deflation (see fig. 12, 13, 14, and 19). All summit stations clearly depicted the summit deflation, which lasted until February 22. The Pu'u



MAUNA LOA SUMMIT TILTMETER
N-S Tilt
URAD N DOWN->
35.00
25.00
15.00
5.00
E-W Tilt
URAD W-DOWN ->
35.00
25.00
15.00
5.00
92
FEB
MAR
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JUN
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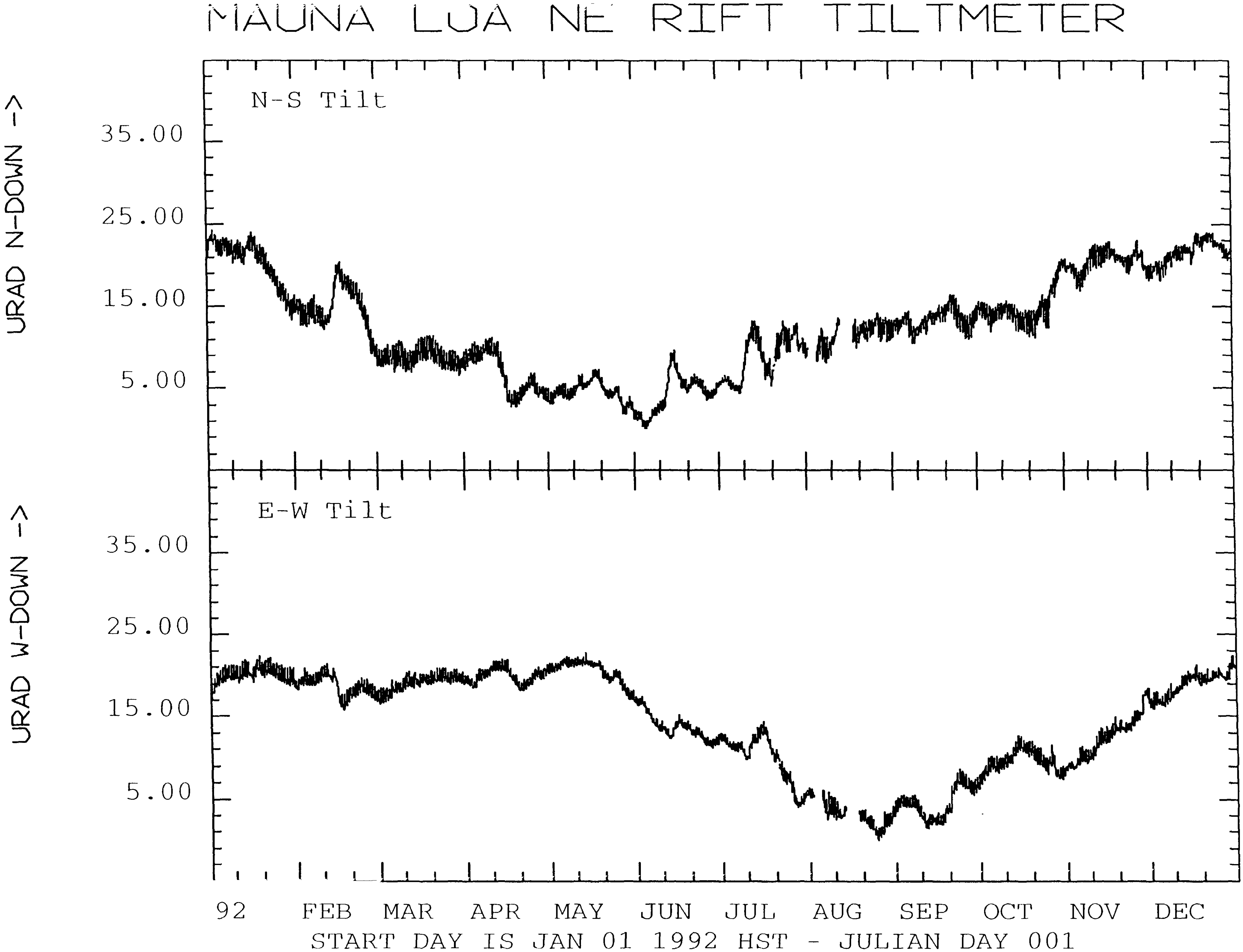
AUG
SEP
OCT
NOV
DEC
START DAY IS JAN 01 1992 HST - JULIAN DAY 001

Fig. 10


MAUNA LOA NE RIFT TILTMETER
N-S Tilt
URAD N-DOWN ->
35.00
25.00
15.00
5.00
E-W Tilt
URAD W-DOWN ->
35.00
25.00
15.00
5.00
92
FEB
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JUN
JUL
AUG
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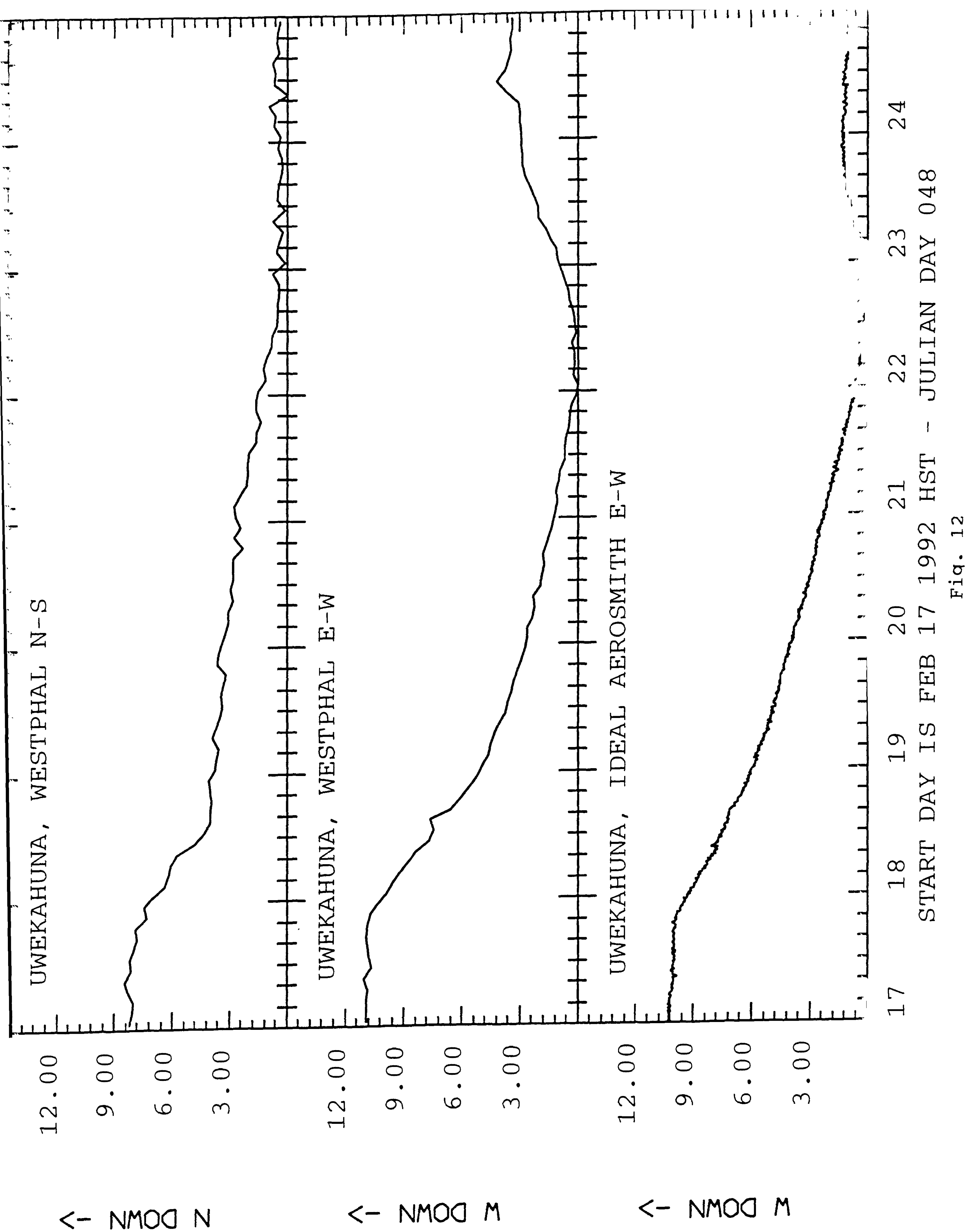
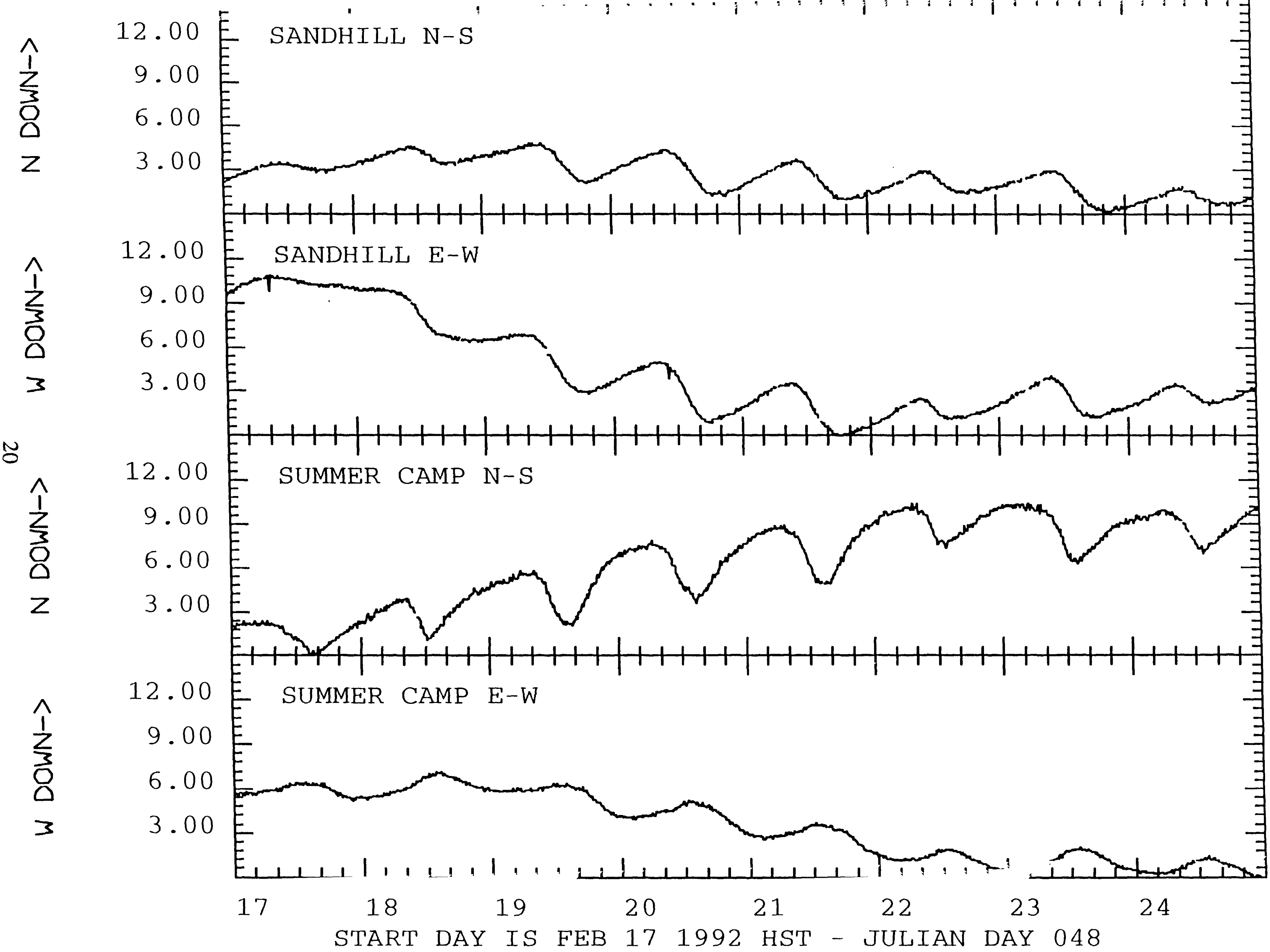
OCT
NOV
DEC
START DAY IS JAN 01 1992 HST - JULIAN DAY 001

Fig. 11



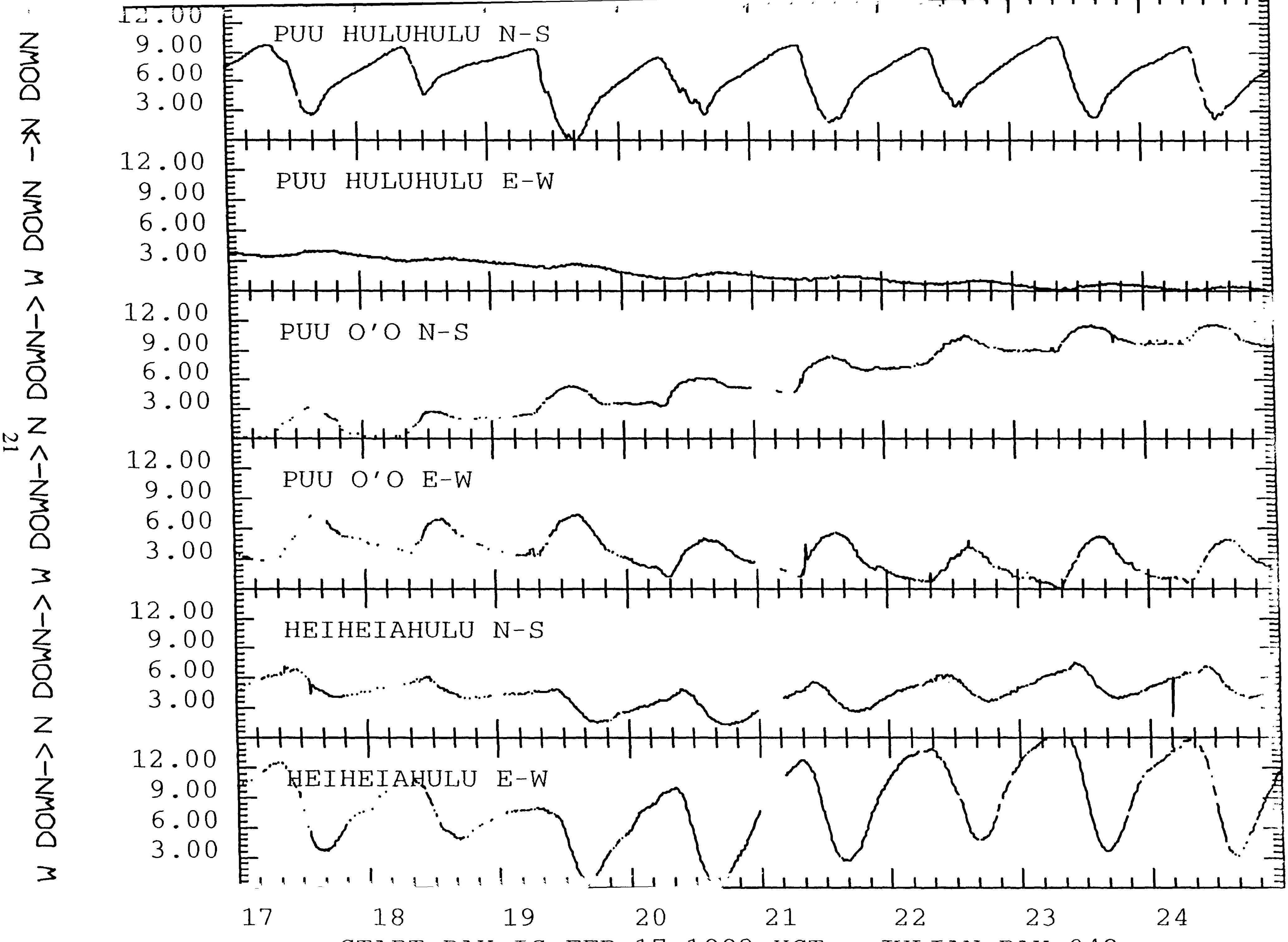
UWEKAHUNA, WESTPHAL N-S
UWEKAHUNA, WESTPHAL E-W
UWEKAHUNA, IDEAL AEROSMITH E-W
N DOWN ->
W DOWN ->
W DOWN ->
12.00
9.00
6.00
3.00
17
18
19
20
21
22
23
24
START DAY IS FEB 17 1992 HST - JULIAN DAY 048

Fig. 12



SANDHILL N-S
SANDHILL E-W
SUMMER CAMP N-S
SUMMER CAMP E-W
N DOWN->
W DOWN->
N DOWN->
W DOWN->
12.00
9.00
6.00
3.00
17
18
19
20
21
22
23
24
START DAY IS FEB 17 1992 HST - JULIAN DAY 048

Fig. 13



PUU HULUHULU N-S
PUU HULUHULU E-W
PUU O'O N-S
PUU O'O E-W
HEIHEIAHULU N-S
HEIHEIAHULU E-W
12.00
9.00
6.00
3.00
17
18
19
20
21
22
23
24
START DAY IS FEB 17 1992 HST - JULIAN DAY 048
W DOWN-> N DOWN-> W DOWN-> N DOWN-> W DOWN -N DOWN

Fig. 14

Huluhulu tiltmeter vaguely responded to the event, displaying a 4 microradian vector down to the east between February 17 and the 22. The Pu'u 'O'o tiltmeter shows a tiny, abrupt change at about 2000 hrs, and a 12 microradian NNE-down vector over the next seven days. The Heiheiahulu tiltmeter did not appear to respond to this event.

The start of the summit deflation nearly an hour after the fissure opening indicates that the fissure eruption depressurized the summit area, and that the summit did not initiate rift events for this episode. The Pu'u 'O'o tiltmeter recorded a tiny deflation or depressurization of the rift at the start of this event, then an increase of pressure over the next five days.

EVENT OF MARCH 3, 1992

A seismic swarm began at 0045 hrs on March 3, 1992, in Kilauea's upper ERZ between Devil's Throat and Pauahi Crater. The Pu'u Huluhulu tiltmeter indicated movement at 0050, showing a vector down to the NE. This continued until 0230 hrs, when the vector rotated to SE down. Kilauea's summit tiltmeters began to show summit subsidence at 0100 hrs on March 3 (See fig. 15, 16, 17, 20, and 21). The Pu'u 'O'o tiltmeter showed a south-down vector begining at 0110 hrs, slowed to a stop about 0600 hrs, then showed a north-down vector until 1000 hrs. The Heiheiahulu tiltmeter showed no response. All tiltmeter signals returned to background levels by 1000 hrs.

The tilt record indicates that magma 1) first began to pressurize (rise or intrude into) the Pauahi Crater area, and 2) then subsequently the summit and Pu'u 'O'o areas depressurized or subsided. During this event, activity within Pu'u 'O'o ceased. This event began to wane after 0230 hours, and buildup of pressure which the Pu'u 'O'o tiltmeter documented was a prelude to the resumption of activity at Pu'u 'O'o later in the day.

CONCLUSION

The tiltmeters provided important clues in discerning the nature of the events of February and March. They can also provide information on the timing of events in different parts of the volcano.

The information from the various tiltmeters generally corroborated with each other about events that occurred, even over long time periods. Some of the vectors for some time periods are hard to interpret which leads to dismissal of the data or attributing the change to site instability.

The electronic tiltmeters can be a very good tool in the remote monitoring of volcanoes. Care must be given to installation of the tiltmeters, and the history and the quality of the data from each site must be understood. The data are generally good in the short term but must be critically questioned in the long term due to uncertainties of instrument and site stability.

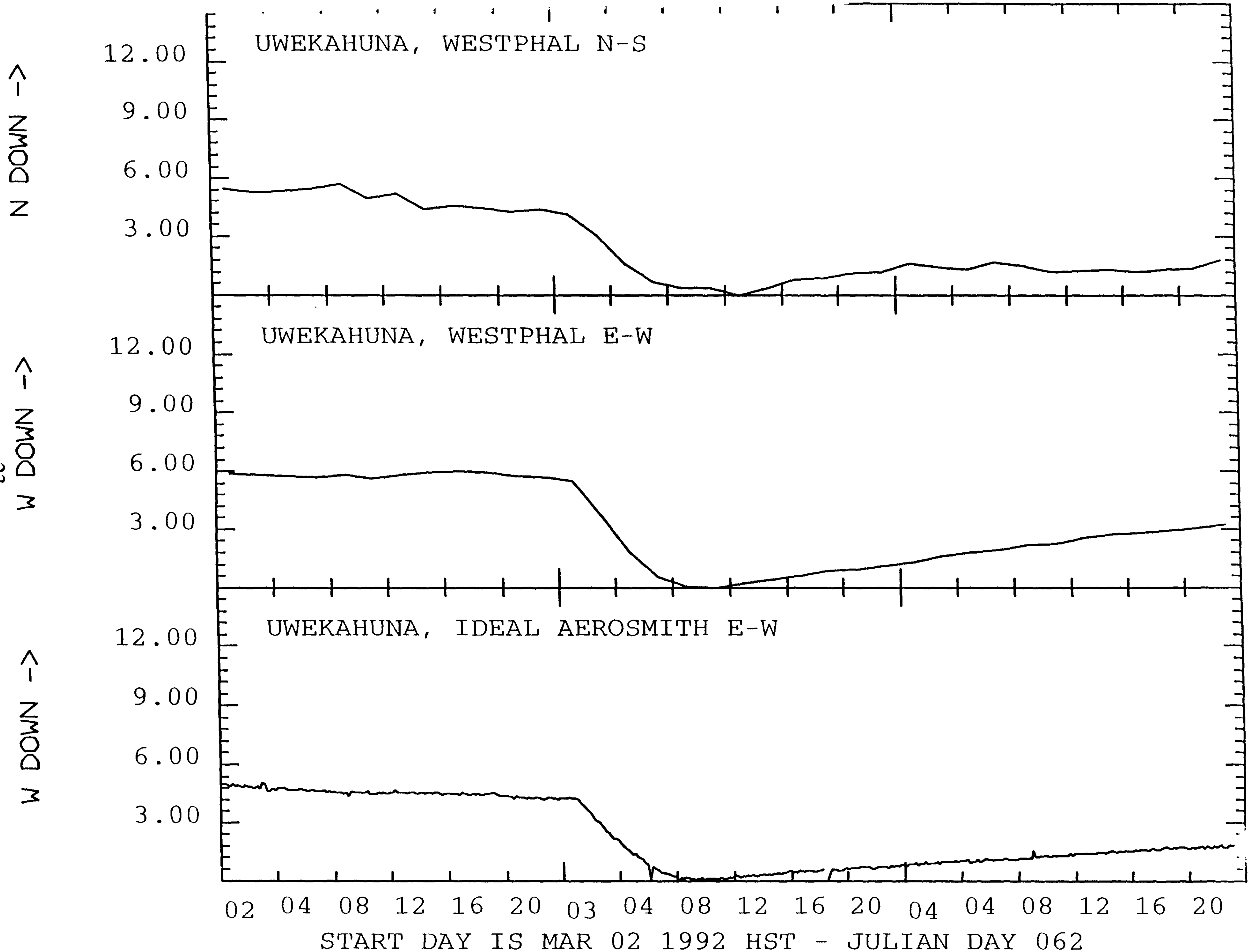

UWEKAHUNA, WESTPHAL N-S
UWEKAHUNA, WESTPHAL E-W
UWEKAHUNA, IDEAL AEROSMITH E-W
N DOWN ->
W DOWN ->
W DOWN ->
12.00
9.00
6.00
3.00
02 04 08 12 16 20 03 04 08 12 16 20 04 04 08 12 16 20
START DAY IS MAR 02 1992 HST - JULIAN DAY 062

Fig. 15

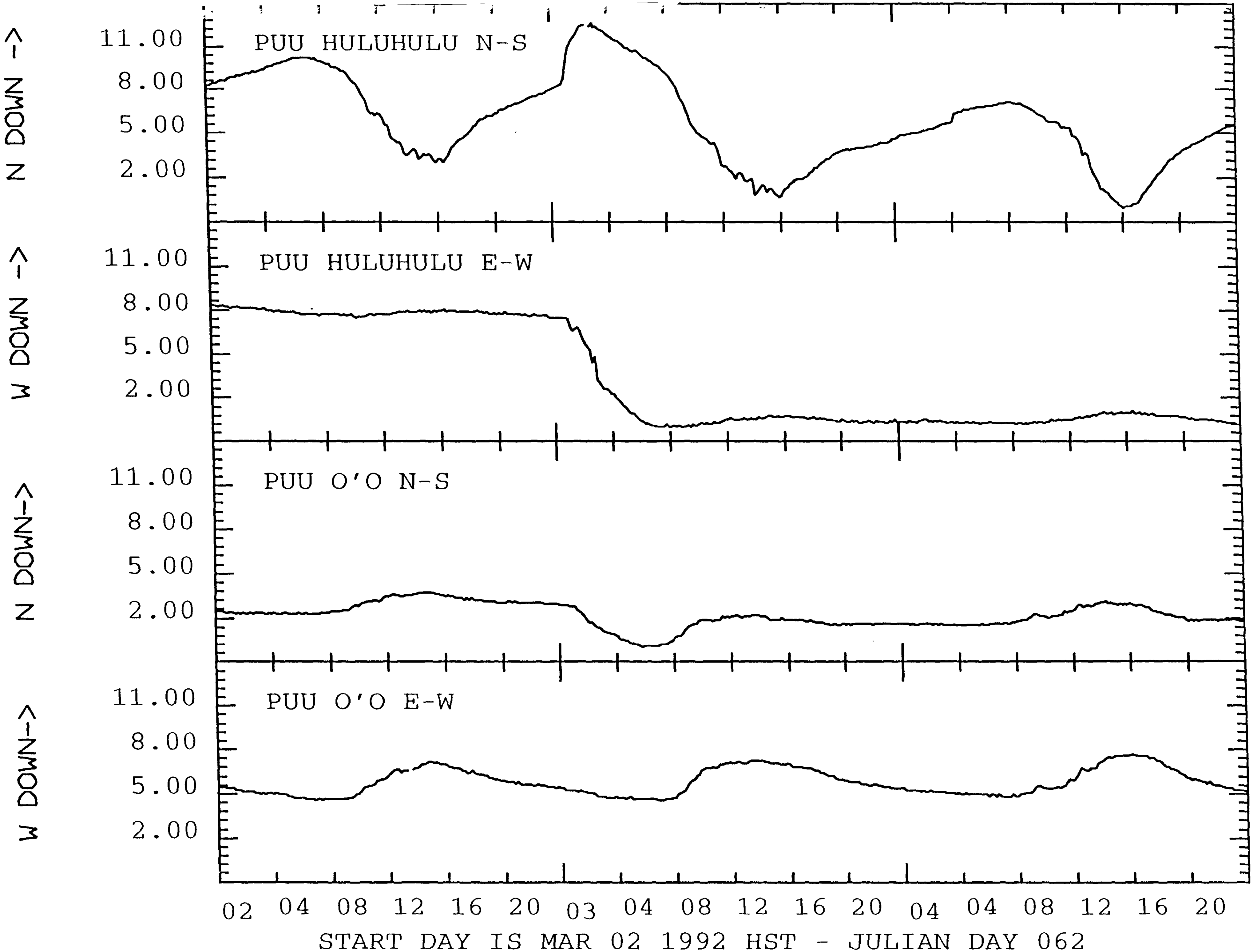
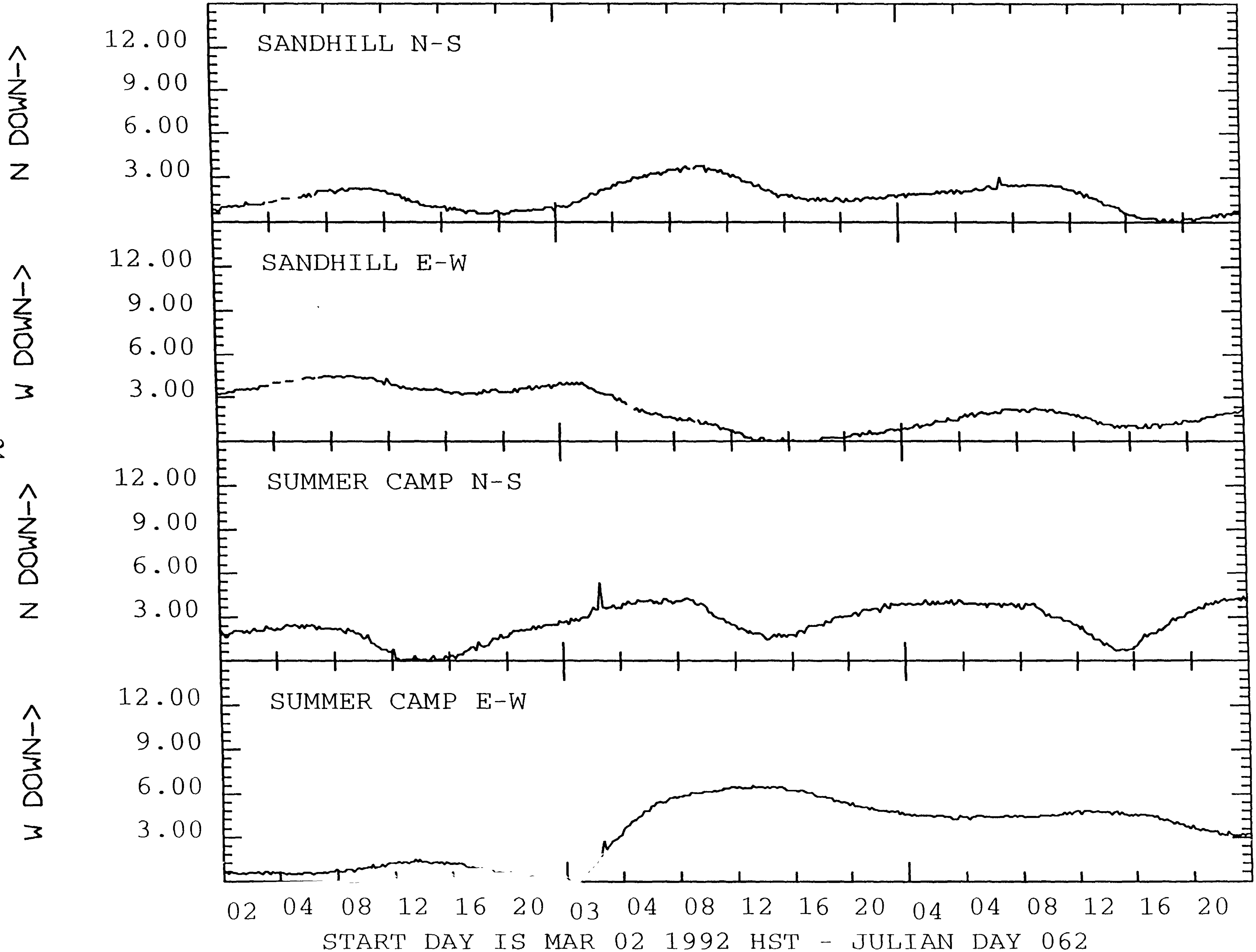

N DOWN ->
W DOWN ->
N DOWN->
W DOWN->
11.00
8.00
5.00
2.00
PUU HULUHULU N-S
PUU HULUHULU E-W
PUU O'O N-S
PUU O'O E-W
02 04 08 12 16 20 03 04 08 12 16 20 04 04 08 12 16 20
START DAY IS MAR 02 1992 HST - JULIAN DAY 062

Fig. 17



SANDHILL N-S
SANDHILL E-W
SUMMER CAMP N-S
SUMMER CAMP E-W
N DOWN->
W DOWN->
N DOWN->
W DOWN->
12.00
9.00
6.00
3.00
02 04 08 12 16 20 03 04 08 12 16 20 04 04 08 12 16 20
START DAY IS MAR 02 1992 HST - JULIAN DAY 062

Fig. 16

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APPENDIX I.

VECTOR PLOTS

The time periods were chosen by looking at all stations and delineating periods by change in direction of tilt. A plot of vectors for Kilauea for October to the end of the year was not done because only one tiltmeter worked without interruption through this period.

KILAUEA SUMMIT AND EAST RIFT ELECTRONIC TILT VECTORS
January 1 to February 17, 1992

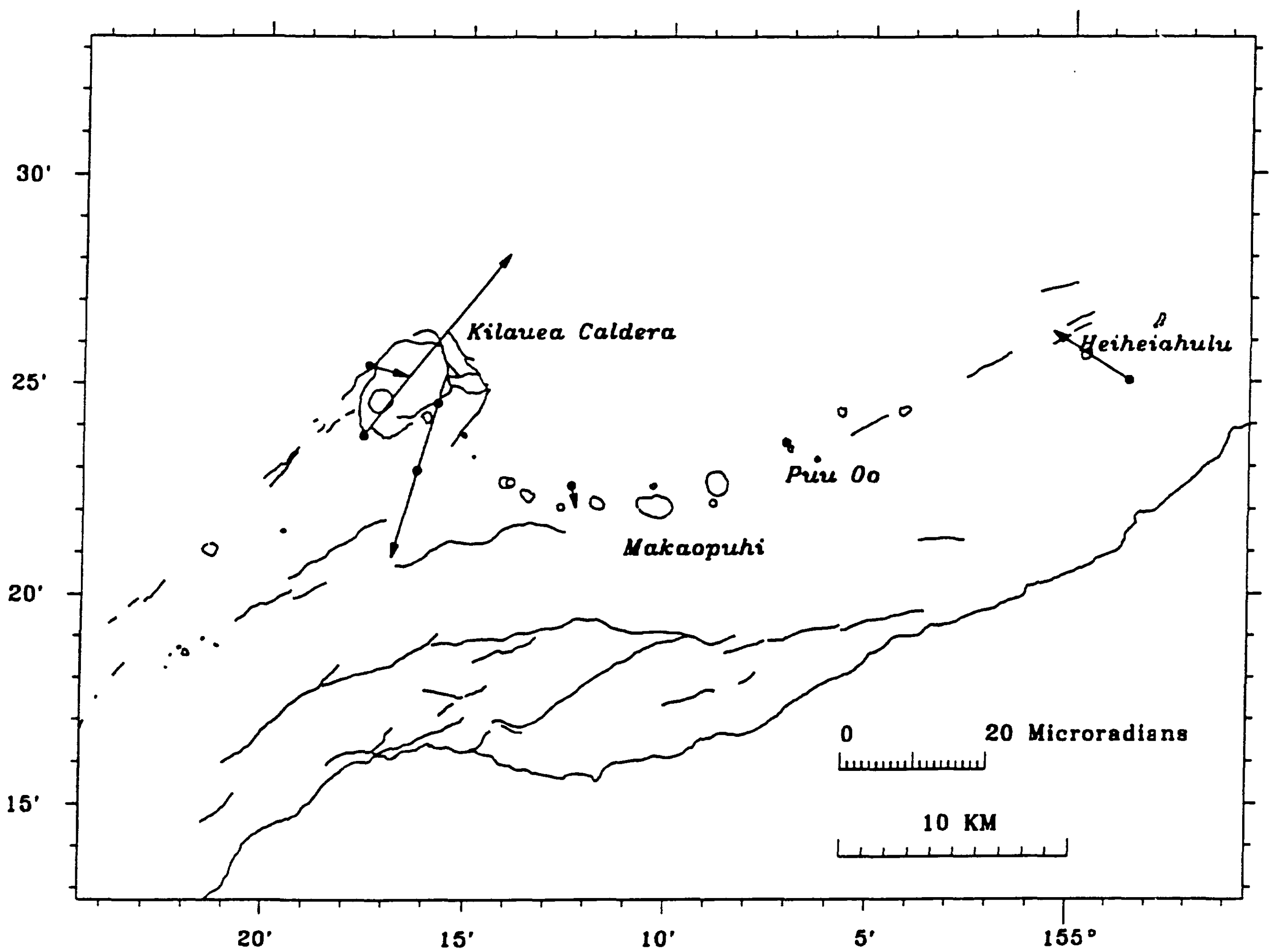

Figure 18. Kilauea summit and east rift electronic tilt vectors, January 1 to February 17, 1992. All tiltmeters show subsidence of the summit and ERZ.

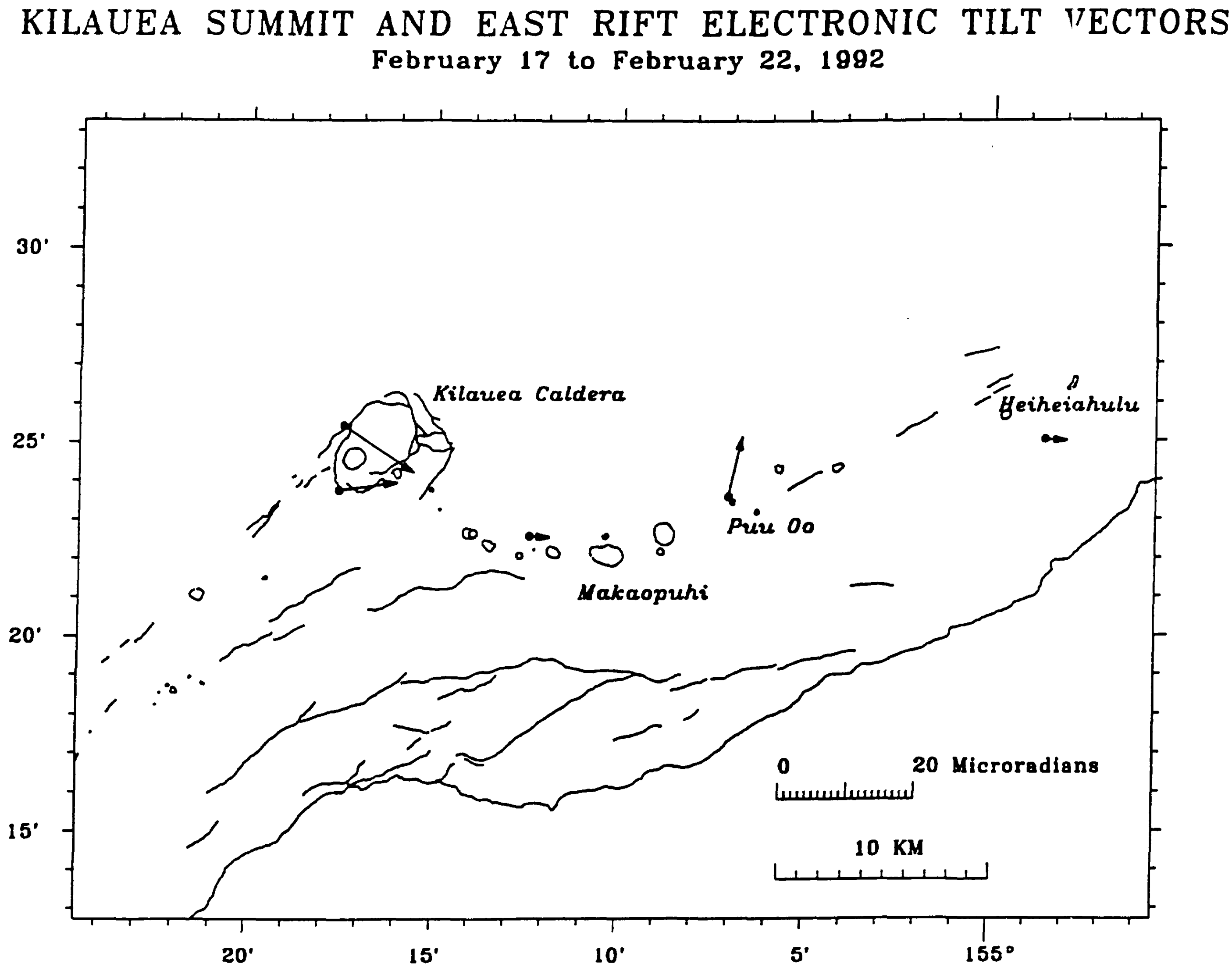

Figure 19. Kilauea summit and east rift electronic tilt vectors, February 17 to February 22, 1992. The cumulative effects of the Feb. 17 event: the summit and upper ERZ tiltmeters show subsidence and lower ERZ tiltmeters seem to indicate inflation of their respective areas.

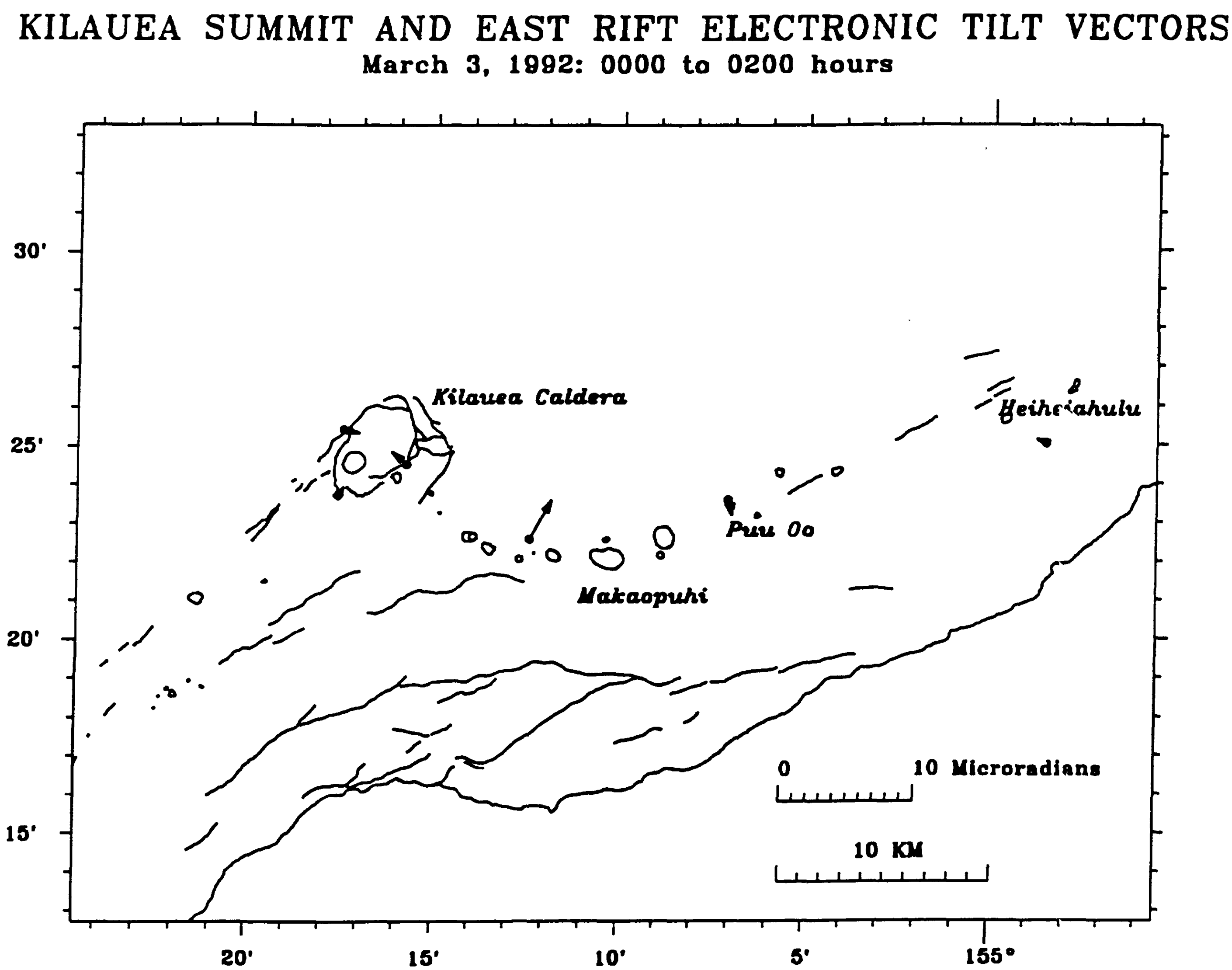

Figure 20. Kilauea summit and east rift electronic tilt vectors, March 3, 1992: 0000 to 0200 hours. Ther first phase of the March 3 event: summit tiltmeters indicate summit subsidence, the Pu'u Huluhulu tiltmeter indicates inflation, the Pu'u 'O'o tiltmeter indicates deflation, and the Heiheiahulu meter shows no response.

KILAUEA SUMMIT AND EAST RIFT ELECTRONIC TILT VECTORS
March 3, 1992: 0200 to 0800 hours

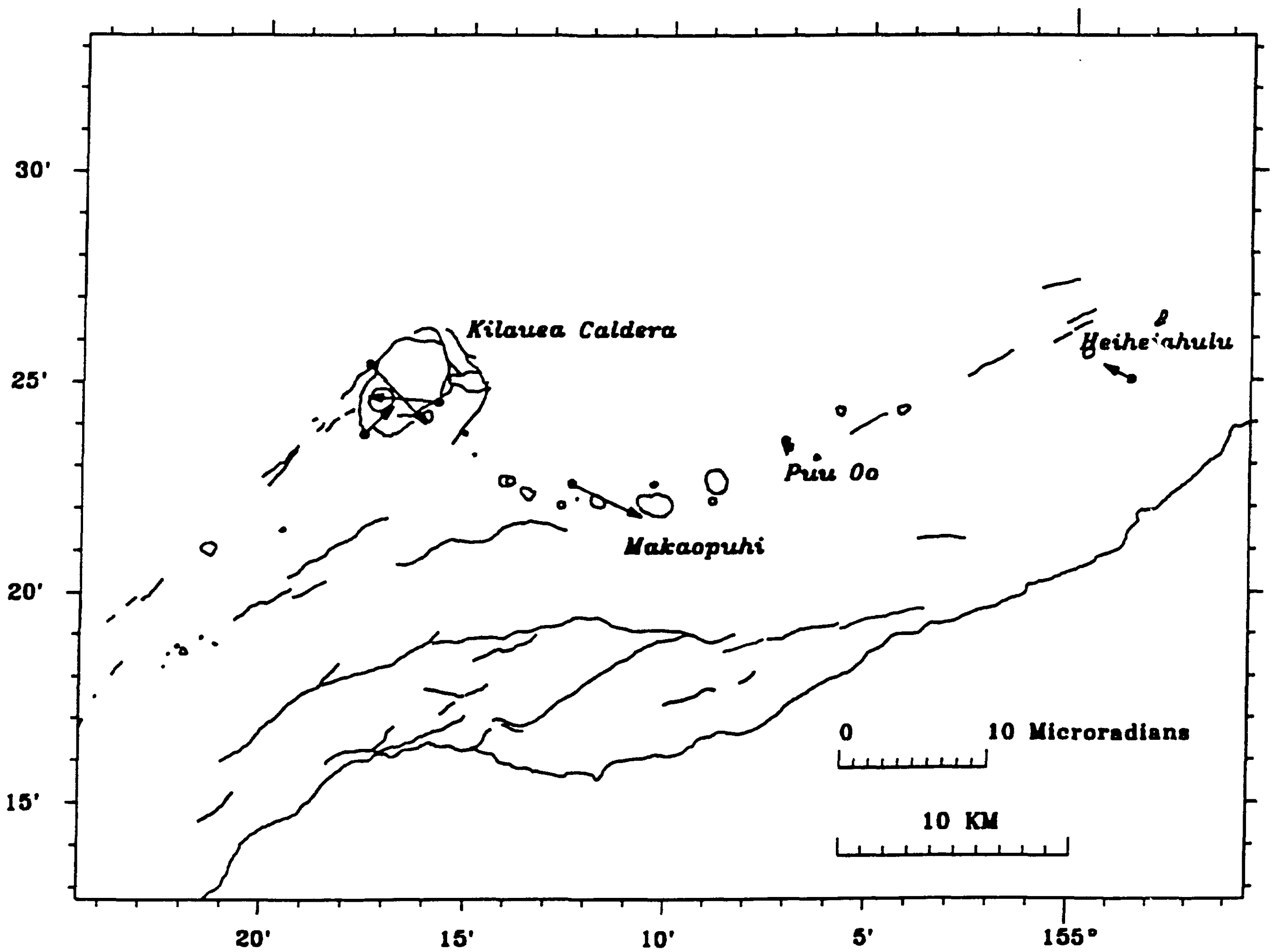

Figure 21. Kilauea summit and east rift electronic tilt vectors, March 3, 1992: 0200 to 0800 hours. The second phase of the March 3 event: summit tiltmeters show continued subsidence, the Puu Huluhulu tiltmeter depicts subsidence, the Pu'u 'O'o tiltmeter indicates no change, and the Heiheiahulu meter indicates subsidence.

KILAUEA SUMMIT AND EAST RIFT ELECTRONIC TILT VECTORS

March 4 to August 1, 1992

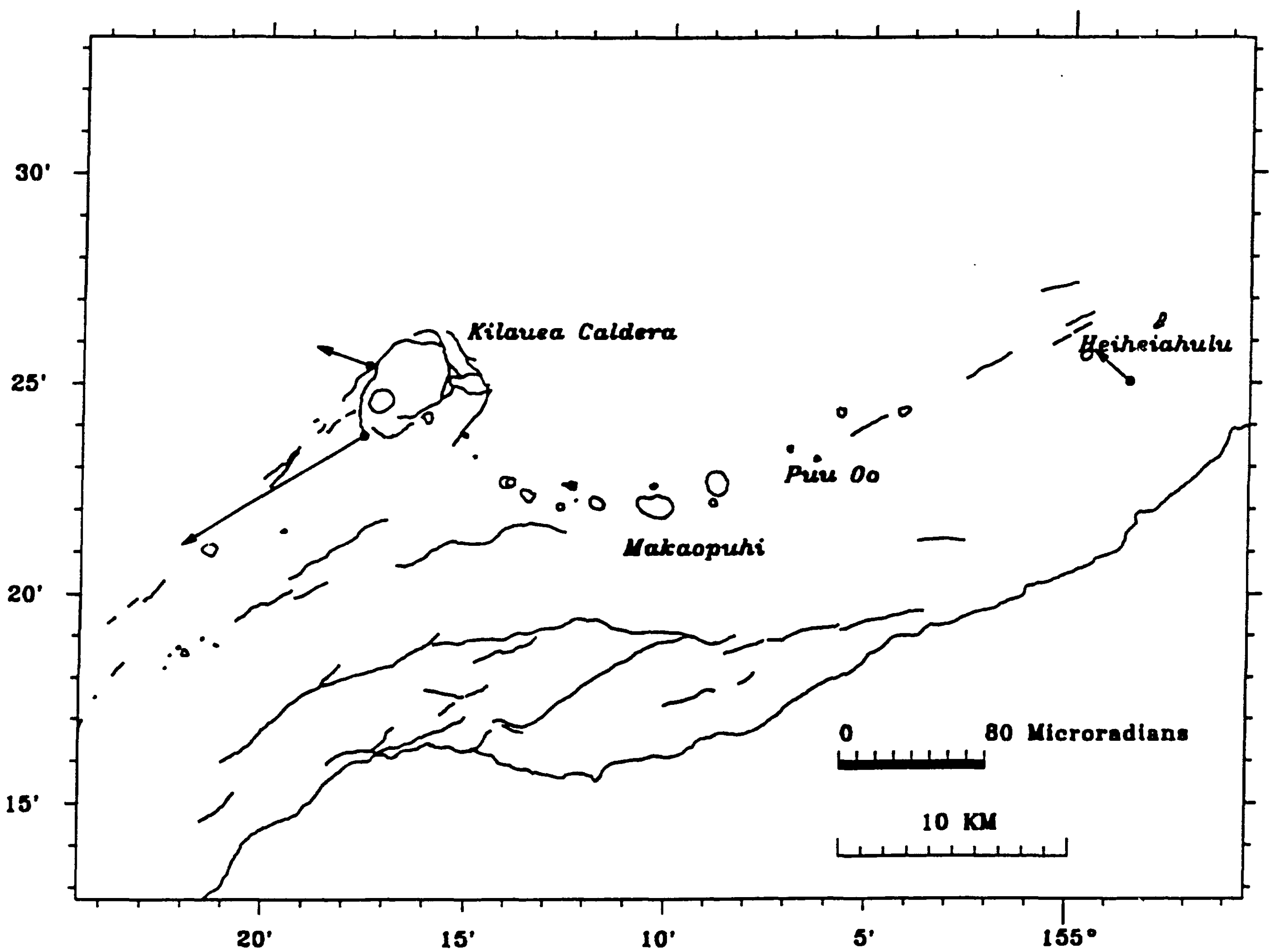

Figure 22. Kilauea summit and east rift electronic tilt vectors, March 4 to August 1, 1992. The summit tiltmeters indicate inflation, the upper and middle ERZ tiltmeters show no change, and the Heiheiahulu meter indicates subsidence.

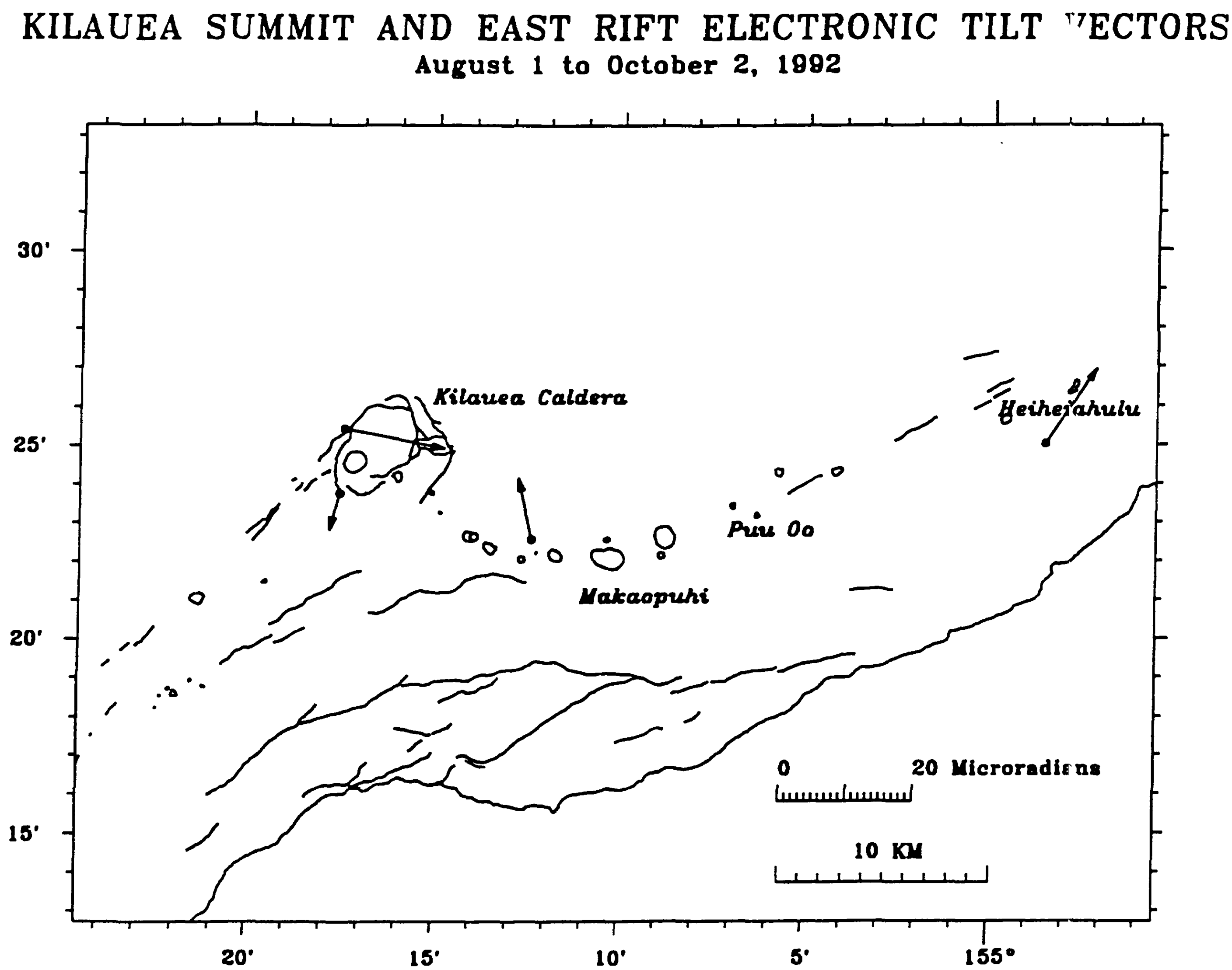

Figure 23. Kilauea summit and east rift electronic tilt vectors, August 1 to October 2, 1992. Tiltmeters displayed an incoherent tilt record for this period.

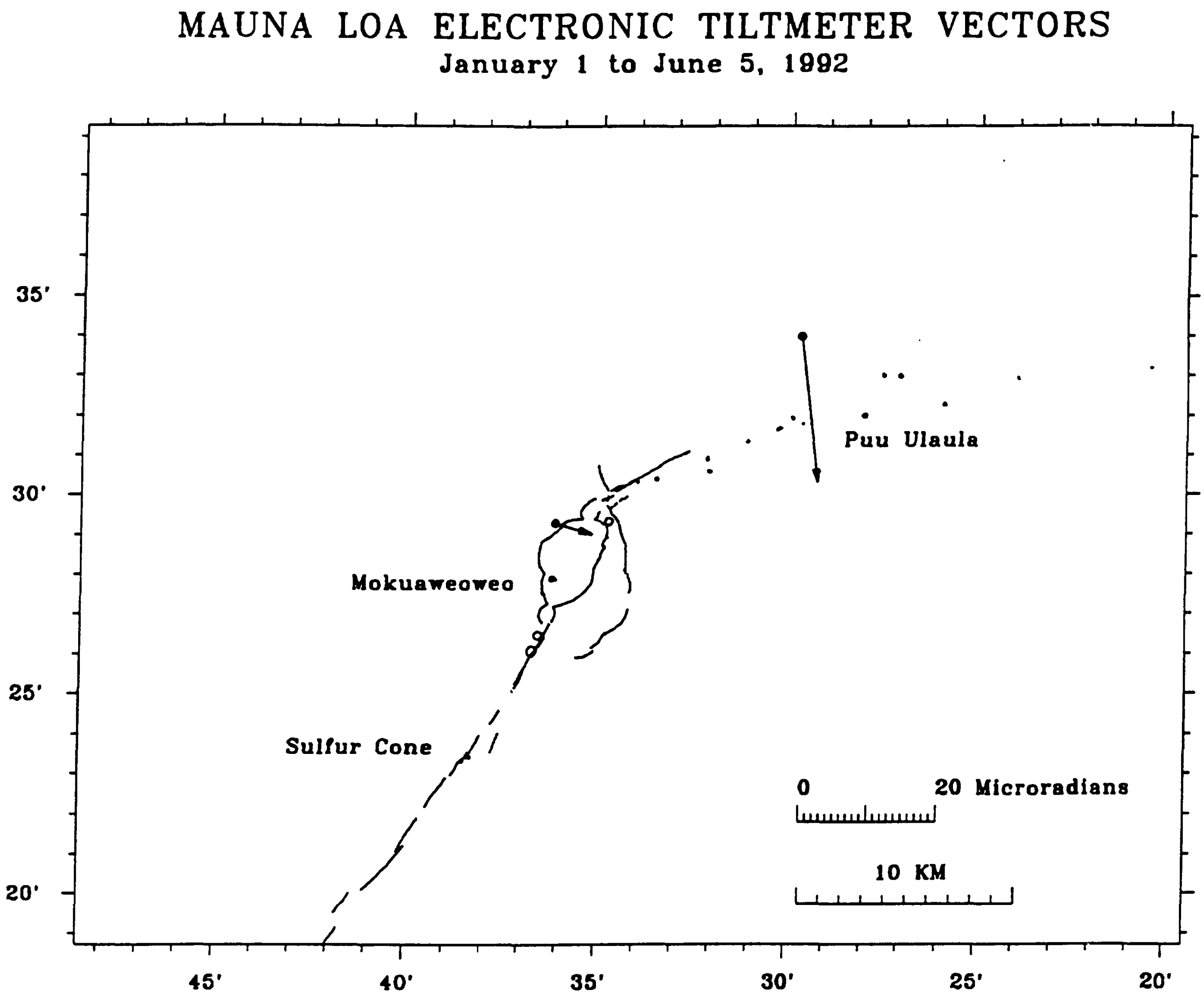

Figure 24. Mauna Loa electronic tilt vectors, January 1 to June 5, 1992. The tiltmeters either indicate subsidence of the summit and NE rift zone areas or seasonal changes.

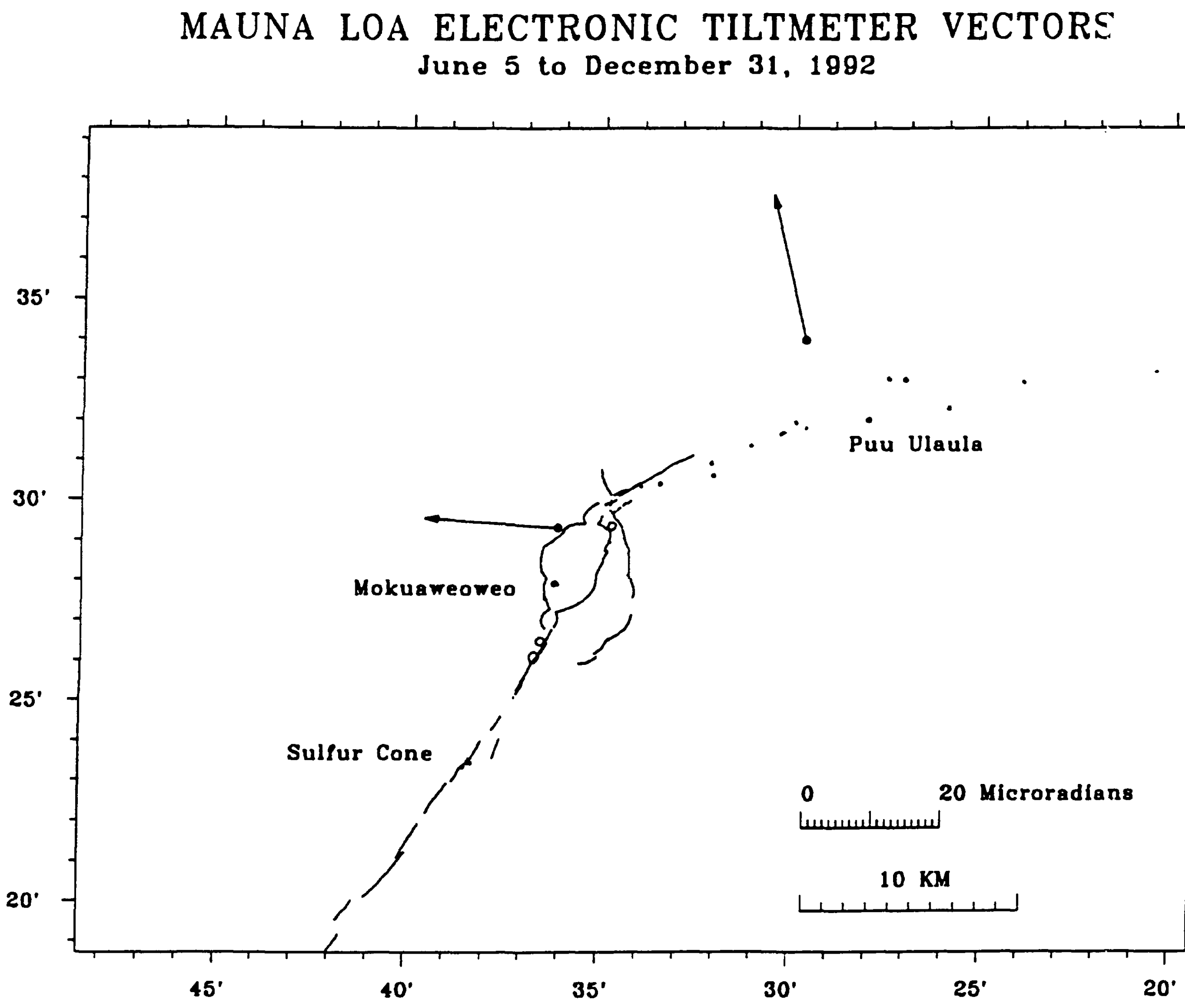

Figure 25. Mauna Loa electronic tilt vectors, June 5 to December 31, 1992. The tiltmeters either indicate inflation of the summit and NE rift zone areas or seasonal changes.

APPENDIX II. MAINTENANCE LOG

****
UWEV (UWEKAHUNA)

Tiltmeter: Westphal, WTM-1
  Calibration factors: X (NS) = 10.0 mv/microradian
                       Y (EW) = 10.0 mv/microradian
Tiltmeter: Ideal Aerosmith, serial no: 10567
  Calibration factor: 100.0 mv/microradian

Digital system inputs:
1: Westphal Tiltmeter, X component
2: Westphal Tiltmeter, Y component
3: Temperature
4: Ideal Aerosmith
5:
6:
7: Short
8: Battery

02/18/92
0906 Remarks: Replaced Harris chip with upgraded Maxim chip.

Before:		After:
	Batt= 13.06	
	X= 2.569	X= 2.776
	Y= -0.505	Y= -0.499
	Temp= 2.948	Temp= 2.948
	IDAE= -1.460	IDAE= -1.452
	IDAF= -1.439	IDAF= -1.439

02/24/92
0913 Symptom: Noisy X channel.
Remarks: Scoped channels- no signs of large spikes. Increased filter of tiltmeter from 10 sec to 100 sec. Spikes are still visible; may be an inherited problem of the tiltmeter.

Before:	After:
X= 2.527	X= 2.511
Y= -0.552	Y= -0.513
Temp= 2.959	Temp= 2.953
IDAE= -0.763	IDAE= -0.767
IDAF= -0.760	IDAF= -0.763

02/28/92
0834 Remarks: Removed Westphal tiltmeter for service.
X= 2.53
Y= -0.527
Temp= 2.95
1335 Remarks: Reinstalled Westphal tiltmeter
Remarks: Added shields to signal lines to see if this will eliminate the noise problem.
X= 2.493
Y= -0.510

Temp= 2.954

09/28/92
1130 Remarks: Removed tiltmeter for service due to noise problems.
X= 2.57
Y= 0.412
Temp=2.99

9/28-29/92
Remarks: Serviced tiltmeter, EW channel showing square wave on output. Replaced IC chip LF 347. Looks ok after changing IC chip on EW channel.

09/29/92
0836 Remarks: Reinstalled tiltmeter after repair. Still found noise present on digital channel inputs. Cleaned up loose wiring at the front door area to see if I can reduce the noise problem. Noise problem seems to be coming from inside of the vault. Replaced old four conductor wire with individual shielded wire for X and Y channels. Noise seems to be reduced. May have to wait a few days to see the results on data recording. Modifications complete 1220.
1356 X= 2.57
Y= -0.471

10/05/92
1030 Remarks: Removed tiltmeter for service, the noise problem is coming from within the tiltmeter unit.

10/20/92
0959 Remarks: Serviced Westphal tiltmeter, found noise problem coming from the power supply. Added high frequency capacitor filters to reduce the noise. Reinstalled tiltmeter temporarily to see if noise problem still exists. The noise seems to be well within 5mv.
X= 2.42
Y= -0.528
IDAE =-1.117

12/11/92
0900 Problem: Noisy traces.
Remarks: Westphal tiltmeter blown by electrical storm. Removed tiltmeter for repairs.

12/14/92
1025 Remarks: Westphal tiltmeter power supply went bad. Replaced power supply.
1028 Reinstalled tiltmeter.
X= 2.542
Y= -0.781
Temp= 2.961

****

SDH2 (SANDHILL)

Tiltmeter: Autonetics, serial no: 0096B
  Calibration factors: X (NS) = 18.4 mv/microradian
                       Y (EW) = 20.5 mv/microradian

Digital system inputs:
- 1: Tiltmeter, X component
- 2: Tiltmeter, Y component
- 3: Temperature
- 4:
- 5:
- 6:
- 7: Short
- 8: Battery

01/10/92

0756 Remarks: Reinstalled Kinemetrics tiltmeter by cementing the legs directly on the pad. Fine threaded rods 12" long were inserted into the cement pad.

0812 Reset complete

X= 0.303 Leads not connected
Y= 0.318
X= 0.233 Leads connected
Y= 0.381

Calibration offset
X= 0.314
Y= 0.584

Normal
X= 0.136
Y= 0.499

Remarks: TST1 was discontinued to save power. Kinemetrics tiltmeter 330 is connected to SDH2 digital box system, channels TL1N (X), TL1E (Y) and Temperature, borehole container (TMP1), outside (TMP2).

0852 Final readings on digital box channels.

0=borehole	X= 0.5326
1=	Y= -2.058
2=borehole temp	TMP1= 2.839
3=platform	X= 0.258
4=	Y= 1.386
5=Out temp	TMP2= 3.062

04/01/92

1433 Symptom: Station not reporting.

Remarks: Bad batteries. One bad cell replaced with used battery.

X= 0.510
Y= -2.167
X2= -2.260
Y2= 3.326
Temp= 2.904

04/06/92
1422 Symptoms: Station reporting intermittent.
Remarks: Station antenna fell down. Propped antenna up.

04/14/92
0833 Symptom: Data noisy.
Remarks: The voltage of the old batteries were low, replaced with good used batteries.
Before: Batt= 11.64
X= 0.524
Y= -1.959
X2= -1.558
Y2= 3.21
Temp= 2.90
After: Batt= 12.80
X= 0.520
Y= -1.937
X2= -1.534
Y2= 3.24
Temp= 2.90

06/03/92
1345 Remarks: Converted to solar power. Disconnected air cell @ 1346
Before: X= 0.207
Y= -1.644
Temp= 2.94
X2= -1.838
Y2= 3.16
Temp= 3.63
After: Solar= 13.25
X= 0.203
Y= -1.595
Temp= 2.94
X2= -1.829
Y2= 3.16

06/16/92
0932 Remarks: Installed voltage controlled circuit.
Before: X= 0.1087
Y= -1.443
Temp= 2.96
0948 After: Solar= 13.43
X= 0.0965
Y= -1.401
Temp= 2.95

10/19/92
0906 Problem: Station offset with noisy data.
Remarks: Found breakage in power wire. Repaired break temporarily.
Before: Solar= 13.05
X=0

```
                 X2=0
                 Y=0
                 Y2=0
                 Temp=0
                 Temp2=0
         After: Solar= 12.41
                X= -0.448
                X2= -1.957
                Y= -0.800
                Y2= 3.11
                Temp= 2.94
                Temp2= 2.96
```

10/20/92

```
    0906 Remarks: Replaced broken power cable with a new one.
         Before: Solar= 13.05    X= -0.499       X2=-2.02
                                 Y= -0.756       Y2=3.15
                                 Temp= 2.89      Temp 2=2.95
         After: Solar= 13.12     X= -0.455       X2= -1.957
                                 Y= -0.763       Y2= 3.11
                                 Temp= 2.90      Temp2= 2.96
```

****

SMCP (SUMMER CAMP)

```
    Tiltmeter: Kinemetrics, serial no: 355B
      Calibration factors: X (NS) =  20.63 mv/microradian
                           Y (EW) =  21.75 mv/microradian
    Digital system inputs:
       1:  Tiltmeter, X component
       2:  Tiltmeter, Y component
       3:  Temperature
       4:
       5:
       6:
       7:  Short
       8:  Battery
```

03/06/92

```
    1040 Remarks: Discontinued station.  Removed polling box #8 ard
              transceiver F1 #003.
         Batt= 13.04
         X= -2.600
         Y= 0.221
         Temp= 2.971
         FX= -2.595
         FY= 0.219
```

****
PUHH (PU'U HULUHULU)

```
     Tiltmeter: Autonetics, serial no: 0008B
       Calibration factors: X (NS) = 58.68 mv/microradian
                            Y (EW) = 47.28 mv/microradian
     Digital system inputs:
        1:  Tiltmeter, X component
        2:  Tiltmeter, Y component
        3:  Temperature
        4:  THTN
        5:  THTE
        6:  Battery
        7:  None
        8:  Solar Battery

01/10/92
     1039 Remarks: Converted to solar power.
            Before: X=1.318        0=X         3=Open      6=Short
                    Y=-3.024       1=Y         4=Open      7=Digital Batt
                    Temp=NA        2=TEMP      5=TM Batt
          TM batt input readings    1.164        Actual      13.10
            Correction=0.146
          Digital batt                  13.66
     1052 Disconnected tiltmeter power
     1123 Installation completed
     1124 X= 1.384
          Y= -3.008
          Temp= 2.98
          TM batt= 1.160, Actually= 12.93 volts
               Correction factor= 0.133

02/11/92
     1048 Symptom: Noisy east-west channel.
          Remarks: Noise is caused by the loading effects of the Harris
              chip due to the voltage level nearing off-scale.  Shorted the
              output resistor of the tiltmeter for increased current to the
              Harris inputs.  Voltage seems to be much more stable.
            Before: Radio batt= 14.07V     Tm= 14.32
                    X= 1.286
                    Y= -2.943
                    Temp= 1.340     triggered= 3.012
                    Tm batt mon= 1.211
          Cal Check on tm           X= 1.294         1.530          1.289
                                    Y=-2.928        -2.730         -2.922
     1123 After: X= 1.226
                 Y= -3.197
                 Temp= 1.297      triggered= 3.053
                 Tm batt= 1.233   triggered= 1.300
                 Radio bat= 15.54
                 Tm batt= 13.77
```

11/04/92

1016 Problem: The station not transmitting.

Remarks: Solar battery water dried out although battery voltages read 12.68V. The Z of the battery was high, which means the battery could not power the radio.

Before: Radio batt= 12.68 Tilt batt = 13.54
X= 1.692
Y= -3.57
Temp= 3.01

Remarks: Replaced DC converter with new one and modified the system so that it runs from one power system.

After: X= 1.645
Y= 3.52
Temp=3.07

****

SCFL (PU'U 'O'O)

Tiltmeter: Applied Geomechanics, serial no: 519
Calibration factors: X (NS) = 25.54 mv/microradian
Y (EW) = 23.12 mv/microradian

Digital system inputs:
1: Tiltmeter, X component
2: Tiltmeter, Y component
3: Temperature
4:
5:
6:
7: Short
8: Battery

01/29/92

0916 Remarks: Replaced borehole tiltmeter. Installed Applied Geomechanics borehole tiltmeter, temperature probe, and replaced batteries.

Before: reset unfiltered: X= -2.811
Y= -0.230
Temp= 2.899

Disconnected system

1030 Batt= 13.6
X= 0.170
Y= 0.300

Second reading, unfiltered final
X= 0.155 X= 0.298
Y= 0.335 Y= 0.417
Temp= 2.926
Batt= 12.56
Conv= +11.62, - 11.63

02/21/92

0820 Symptom: Station not reporting.

Remarks: Found problems with original box #23. The system seems to cut off during transmissions. Replaced with box #10 that

includes the new Maxim chip.
Before: Batt= 12.89
X= 0.613
Y= 0.456
Temp= 2.879
0828 After: X= 0.623
Y= 0.470
Temp= 2.926

03/27/92
1038 Remarks: Discontinued station due to danger from lava. Lava is approximately 50 feet from the station. All components of the station were removed.

****

HHHS (HEIHEIAHULU)

Tiltmeter: Autonetics, serial no: 0107B
Calibration factors: X (NS) = 18.75 mv/microradian
Y (EW) = 20.67 mv/microradian
Digital system inputs:
1: Tiltmeter, X component
2: Tiltmeter, Y component
3: Temperature
4: Short
5: None
6: None
7: None
8: Battery

2/12/92
1236 Remarks: Converting to solar power. Partially installed solar, still connected to primary battery and not connected to polling system. Installed styrofoam insulation around borehole sensor and a tarp covering. Solar panel will be connected later.

Batt= 12.89 V.	Batt= 12.85
0= X= 1.941	X= 1.957
1= Y= 0.928	Y= 0.988
2= Temp= 2.93	
3= short	
4= open	
5= batt	
6= open	
7= open	

Solar readings= 12.85 Volts @ 549ma, overcast skies.

2/26/92
1156 Remarks: Continuing solar installation and increased insulation around borehole sensor. Connected solar power to the polling system. Added more insulation around sensor by filling sensor section with more sand and the packing of more foam.
1230 Solar on NO LOAD= 15.84 V.

Solar with LOAD= 15.73 V.
Power, before: 12.75 volt with air cells
after: Solar=15.73 V.

1237 Final: Solar= 15.68 V.

X=1.930	X= 1.921	X= 1.942
Y=0.937	Y= 0.903	Y= 0.936
Temp=3.037	Temp= 3.074	Temp= 3.115

5/27/92

1036 Remarks: A problem with the station digital box #9. Replaced box with #23.

Before: Solar=15.45	After: Solar= 15.60
X=2.08	X= 2.08
Y=1.57	Y= 1.547
Temp=3.09	Temp= 3.09

6/8/92

1047 Remarks: Installed clamper circuit to reduce voltage power under 14 volts

Before: Solar=15.92
X=2.12
Y=1.612
Temp=3.04

1102 After: Solar=13.86
X=2.10
Y=1.597
Temp=3.06

6/9/92

1236 Remarks: Stations was locked on caused by the clamper circuit that was installed. The battery voltage dropped too low causing the digital box to lock on. Removed clamper for further modifications.

1243 Solar= 13.60
X= 2.08
Y= 1.593
Temp= 3.03

9/24/92

1203 Remarks: Installed Datel DC converter #BWR-12/4155-D12

Before: Solar= 13.62
X= 2.37
Y= 1.419
Temp= 3.04

1209 X= 2.29
Y= 1.401
Temp= 3.07

1217 X= 2.38
Y= 1.426
Temp= 3.04

10/2/92

1009 Remarks: Added silica sand in housing container to see if the tiltmeter electronics is causing the large diurnal. Buried the electronics in an insulated container to see if it reduces the diurnal.

11/5/92

1037 Problem: Offset on X channel

Before: Batt= 13.46
X= 2.822
Y= 1.318
Temp= 3.016

After: X= 2.80
Y= 1.309
Temp= 3.085

Remarks: Could not find any problems related to the offset on the X channel. Somehow the tilt sensor has physically moved. Open channels were not shorted. Shorted open channels to reduce cross talk.

11/10/93

1042 Problem: The station is out.

Remarks: The station was vandalized. Two deep cycle batteries were stolen.

12/15/92

0956 Problem: Tilt traces look flat.

Remarks: Tiltmeter power was not connected after the station was vandalized.

Before: Batt= ?
X= 0.003
Y= 0.003
Temp= 2.95

1006 X= 3.04
Y= 1.172
Temp= 2.95

****

MOKE (MAUNA LOA SUMMIT)

Tiltmeter: Autonetics, serial no: 0097B

Calibration factors: X (NS) = 24.23 mv/microradian
Y (EW) = 25.40 mv/microradian

Digital system inputs:

1: Tiltmeter, X component
2: Tiltmeter, Y component
3: Temperature
4: Short
5: None
6: Battery
7: None
8: None

07/28/92

1138 Remarks: Converted to solar power.

1141 Before: Batt= 12.57, -13.12
X= 0.593
Y= 0.878
Temp= 2.94

1219 After: Solar=12.65v, Conv. out=+ /- 11.9v
X= 0.581
Y= 0.856
Temp= 3.09

****

MLCC (MAUNA LOA NE RIFT)

Tiltmeter: Autonetics, serial no: 0003B
Calibration factors: X (NS) = 30.0 mv/microradian
Y (EW) = 35.0 mv/microradian

Digital system inputs:
1: Tiltmeter, X component
2: Tiltmeter, Y component
3: Temperature
4: Short
5: Battery

10/27/92

1052 Remarks: Replaced old DC converter with new Datel type.