Surface measurements on the 33-foot paraboloid at the Algonquin Radio Observatory 1960-1969

Breithaupt, R. W.; Harrison, R. D.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/21276275
Report (National Research Council of Canada. Radio and Electrical Engineering Division : ERB), 1969

ERB-831

UNCLASSIFIED

NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

SURFACE MEASUREMENTS ON THE 33-FOOT PARABOLOID AT THE ALGONQUIN RADIO OBSERVATORY 1960 - 1969

- R. W. BREITHAUPT AND R. D. HARRISON -

OTTAWA

OCTOBER 1969

ABSTRACT

This report is intended as a summary of surface measurements made on the 33-foot paraboloid at the Algonquin Radio Observatory in the period 1960–1969, including the modifications made to the surface in 1969. These modifications were based on survey data taken May 1968 and May 1969. The standard deviation from a best-fit paraboloid was thereby improved from 0.035 inch to about 0.021 inch.

CONTENTS

FIGURES

TABLES

SURFACE MEASUREMENTS ON THE 33-FOOT PARABOLOID AT THE ALGONQUIN RADIO OBSERVATORY 1960–1969

– R.W. Breithaupt and R.D. Harrison –

Introduction

A summary of all surface measurements made on the 33-foot paraboloid at the Algonquin Radio Observatory between 1960 and 1969 is presented, including those made after surface modifications in 1969. These modifications were based on survey data taken in 1968 and 1969. The standard deviation of the best-fit paraboloid changed from 0.025 inch in 1960 to 0.035 inch in1968 owing to various accidents and overloading, and finally to about 0.021 inch in 1969, after reworking the outer surface.

Gain deterioration due to surface roughness depends on both the magnitude of the error and the nature of the correlation between adjacent errors [1, 2]. If correlation regions are small with respect to the antenna diameter, and if the phase deviations are distributed randomly, then the gain loss is given by

$$\text{gain loss} = -4.34 \left(\frac{4\pi\epsilon}{\lambda}\right)^2 \text{ db} \tag{1}$$

where

ϵ = rms error (or standard deviation) on a shallow reflector which produces a phase front variance $\overline{\delta^2}$ [1],

λ = free space wavelength.

Note that the size of the correlation region for this antenna is probably much too large for the assumption in the above formula to hold, as a periodic variation or scalloping from rib to rib, is evident. However, results given by Vu [2] indicate that equation 1 can be considered a worst case. The gain loss versus ϵ for commonly used values of λ is given in Fig. 1.

The method of obtaining a theoretical best-fit paraboloid (BFP) from measured surface data is described in an earlier report [3]. Locations of the 2400 measurement stations (some inaccessible) are also given there.

Section 2 of this report describes measurements made on the template which was used to obtain surface data during 1967–1969. A summary of surface survey results of the antenna between 1960 and 1969 is tabulated in section 3. A final section describes the surface adjustment made in July 1969.

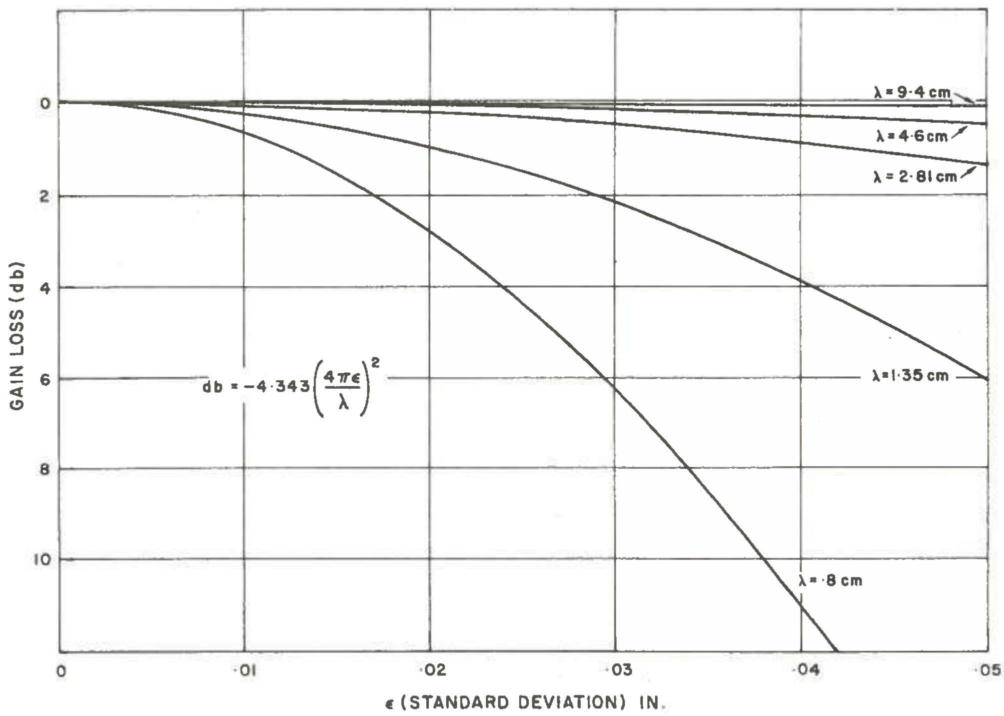


Figure 1 Gain loss due to surface roughness (worst case for small correlation regions)

2. Template Measurements

Antenna surveys taken in 1960–61 employed a template supplied by Philco [4] which was not measured by NRC. This template had a continuous blade attached for feeler gauge measurements, and seven or eight dial gauges were also attached at approximately uniform spacing, as shown in Fig. 2. There is some doubt as to the focal length (f.l.) of this template, as the quotation from Philco specifies an antenna f.l. of 169.4 inches, but the f.l. of the template does not seem to be explicitly stated. It is assumed to have been 169.4 inches.

A template was made in 1967 by NRC for further surface measurements, and this is shown in Fig. 3. The remaining discussion in this section concerns this template. A sweep blade was not originally provided in this case, and axial measurements are made by up to ten dial gauges attached, using locating pins, to the template at points whose (x, y) coordinates are known, and which lie nearly on a nominal parabola of f.l. 169.4 inches.

Each dial gauge consists of a spring loaded plunger and rack which rotates a helipot. A voltage is applied across the helipot so that a voltage change of 1 mV per 0.001 inch plunger movement is obtained. The voltage reading increases as the plunger moves upward into the dial gauge. Voltages or surface heights are then read conveniently and directly on a digital voltmeter by switching between all radial stations at a given azimuth

Figure 2 Philco template used for 1960–61 antenna surface measurements

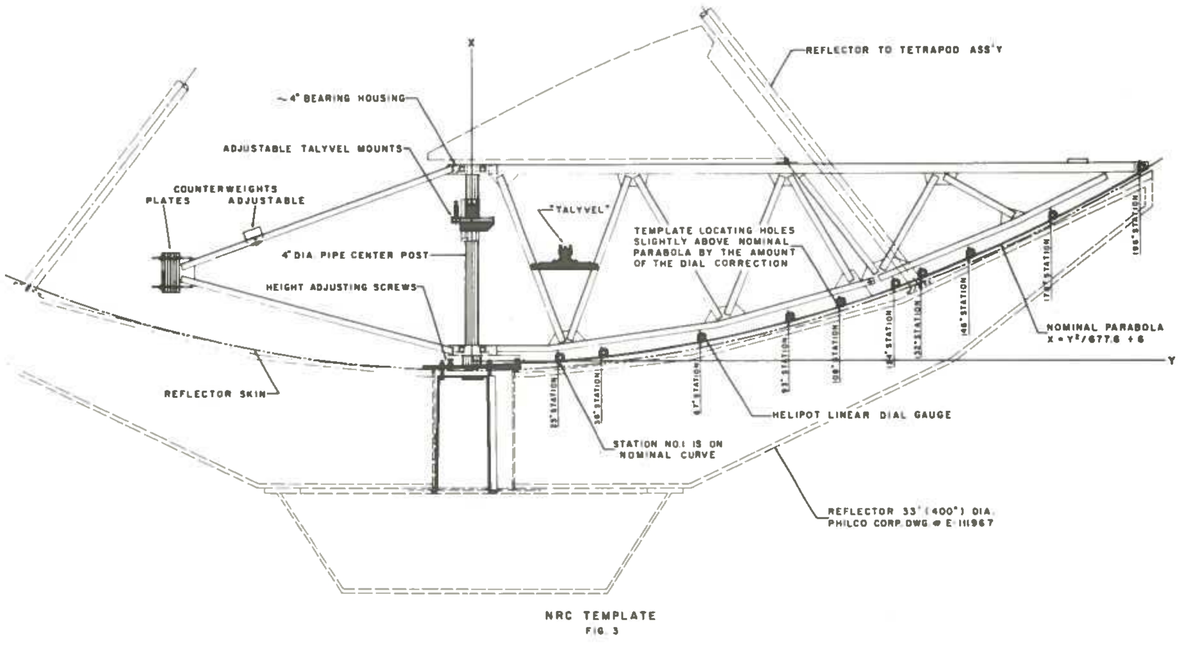
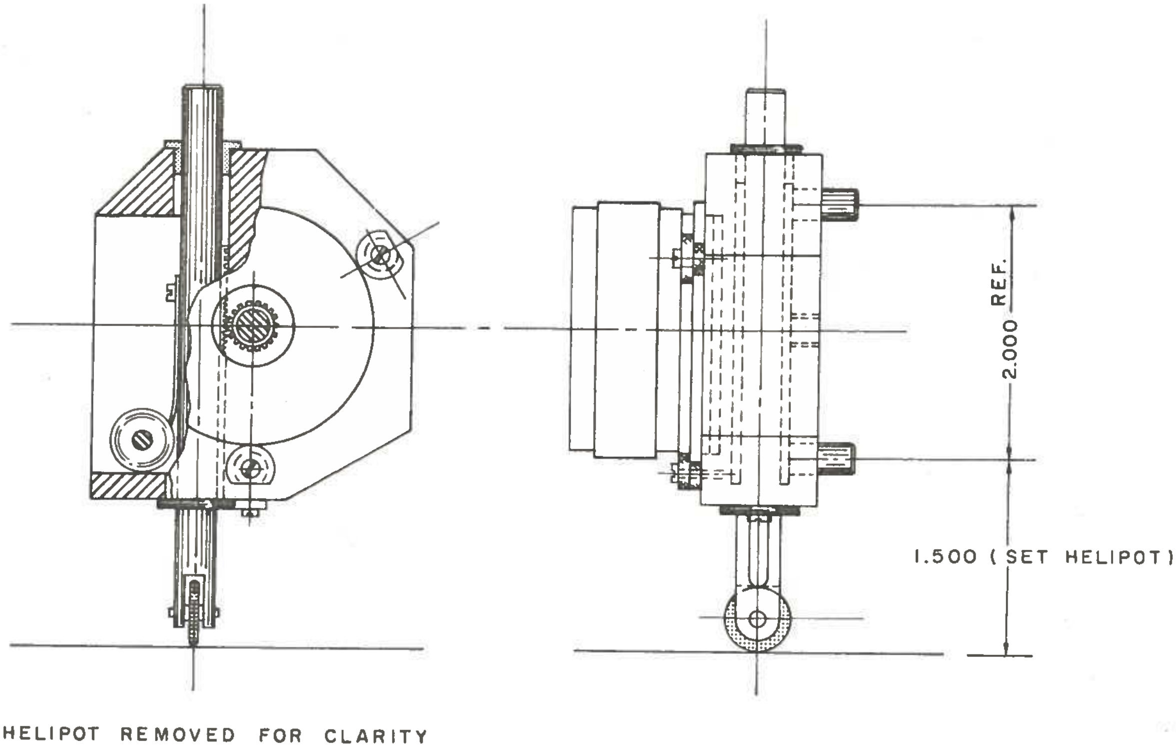
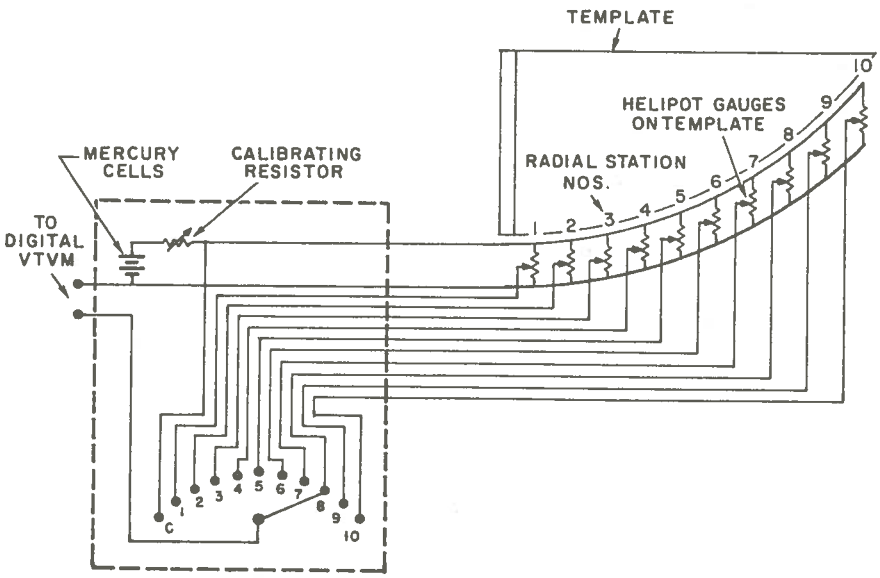


Figure 3 NRC template



(a)



(b)

Figure 4 Dial guages, (a) Assembly, (b) Electrical connections on template station. A dial gauge and its connections on the template are shown schematically in Fig. 4. Individual calibrations showed these gauges to be within ±1.5 mV of linear, excluding backlash, which was ∿2.5 mV.

The dial gauge locating holes on the template must be known very accurately, because a meaningful BFP can be obtained only if all survey points on the antenna are known in three dimensional space. Three measurements of these station locations on the template were made:

(*a*) 1967 original shop measurement

(*b*) April 19–21/69 and May 20–22/69 at Algonquin Radio Observatory.

Each of these measurements will now be briefly described.

a. 1967 Shop Measurement

This was done by setting the template post vertical by optical means, and then setting and reading a vertical height gauge at each station. The height differences from a horizontal optical datum were then determined. These are the x coordinates of the template holes in Fig. 3, and if $x = 0$ for station 1, then x for stations 2–10 was found to lie slightly above the nominal parabola $x = \frac{y^2}{677.6} + b$ which passes through station 1.

The radial or y coordinates were determined by first measuring interstation distances with a stick micrometer, and then using the Pythagorean theorem to obtain interstation radial increments. Unfortunately, the y coordinates obtained in this manner suffer both from accumulated error in the stick micrometer measurement and from error involved in the x measurements. Results for all template measurements are given in Table 1. Theoretical values of axial distance to the nominal parabola x_{th} were obtained using

$$x_{th} = \frac{y^2_{meas}}{677.6} + b.$$

The dial correction is defined as the axial distance between the measured station location and the nominal parabolic curves, or

$$\text{dial correction} = x_{meas} - x_{theor} .$$

Dial corrections, given in Table 1, are added to raw data to give the variation from the nominal paraboloid. Errors were estimated for the dial corrections and are included in Table 1. They are based on the following:

axial measurements

vertical setting of the template	$\pm r/25000$ inch (r = radius in inches)
instrumental levelling error	±0.00017 inch
height gauge error	±0.002 inch (per reading)

interstation measurements

stick micrometer	±0.001 inch

TABLE I

Station locations for dial gauges on template

	Shop Measurement 1967				ARO Measurement* April 19-21, 1969			ARO Measurement May 20-22, 1969		
Stn.No	$y_{meas.}$	$x_{meas.}$	dial corr.	est.error in dial corr.	$y_{meas.}$	$x_{meas.}$	dial corr.	$y_{meas.}$	$x_{meas.}$	dial corr.
Post	0	-	-	-	0	-	-	0	-	-
1	25.001	0	0	±.005	25.017	0	0	24.968	0	0
2	38.001	1.209	0	±.006	38.012	1.225	.017	37.953	1.220	.015
3	66.987	5.707	.007	±.007	67.007	5.715	.014	66.944	5.711	.019
4	92.982	11.852	.015	±.009	92.995	11.845	.010	92.927	11.832	.011
5	107.987	16.291	.004	±.010	108.027	16.301	.008	107.935	16.290	.021
6	123.985	21.783	.019	±.011	124.026	21.772	.002	123.930	21.772	.031
7	131.991	24.805	.017	±.012	132.010	24.808	.022	131.930	24.802	.041
8	145.994	30.537	.004	±.013	146.004	30.555	.030	145.920	30.551	.055
9	169.987	41.734	.012	±.015	170.016	41.736	.016	169.935	41.729	.042
10	196.002	55.784	.011	±.017	196.051	55.817	.036	195.448	55.786	.055

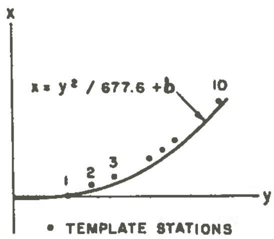
Nominal f.l. – 169.4 inch
All measurements corrected to 70°F
All dimensions in inches
Expansion coefficients:

$k = 13.5 \times 10^{-6}$ inch inch^{-1} °F^{-1} Aluminum 65S-T6Alloy (template, gauge bars)

$k = 6.45 \times 10^{-6}$ inch inch^{-1} °F^{-1} Lufkin White Banner Steel Tape

$k = 9 \times 10^{-6}$ inch inch^{-1} °F^{-1} Steel measurement instruments

All ARO measurements use gauge bar measurements made in June 3–6, 1969
Dial correction = $x_{meas} - x_{theor}$
*Error may have arisen in this case due to clamping the scale at both ends



b. April–May 1969 Algonquin Radio Observatory Measurements

Both of these measurements were made in the following manner. A set of ten gauge bars was constructed of aluminum channel, each with a dowel pin near one end to fit into the template dial gauge hole, and a transverse scribed line near the other, at a carefully measured distance from the dowel pin. The length of each bar is such that if the template is levelled (a difficult job), the dowel pin fitted into the dial gauge hole, and the bar positioned vertically, then a level may be used to ascertain the small elevation differences between scribed lines on various bars. This determines the axial (x) coordinates of the template stations, and the apparatus is shown schematically in Fig. 5. Original distances between scribe marks and dowel pins on the gauge bars were found to be in error owing to bent dowel pins, and template station locations were altered accordingly.

Radial (y) station distances were determined by positioning the levelled template nearly perpendicular to the line of sight from a transit, and reading a calibrated horizontal steel Lufkin tape placed along the top of the template, directly above each template dial gauge station. The tape was on edge, supported in several places, and held to a tension of 10 lb. Compensation for thermal expansion in the template, gauge bars, and steel tape was necessary as calibration temperatures usually differed considerably from template measurement temperatures. The template was assumed to expand freely in order to obtain the results at 70°F given in Table 1. This measurement method is good in that it avoids accumulated errors, but has the serious disadvantage that the template is difficult to level, and remains level for only a very short time unless there is no wind. A constant template

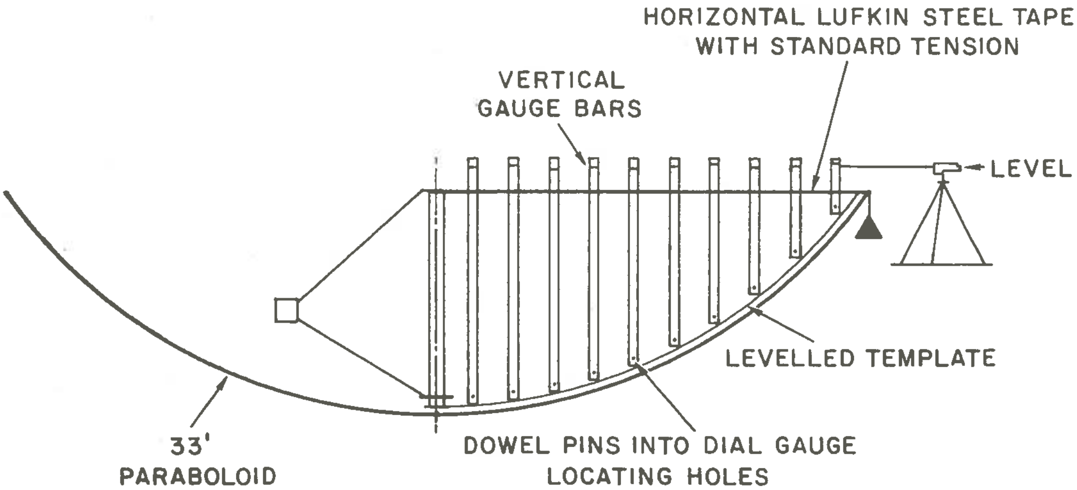


Figure 5 Template measurements using gauge bars

temperature is also required over the measurement period. Template tilt causes 0.00097-inch movement per second of tilt at the antenna rim.

Results for these two surveys of the template are given in Table 1 and agreement with shop measurements is seen to be rather poor. A plot of the dial correction-radius characteristic for each survey given in Fig. 6, suggests that template unbalance may be

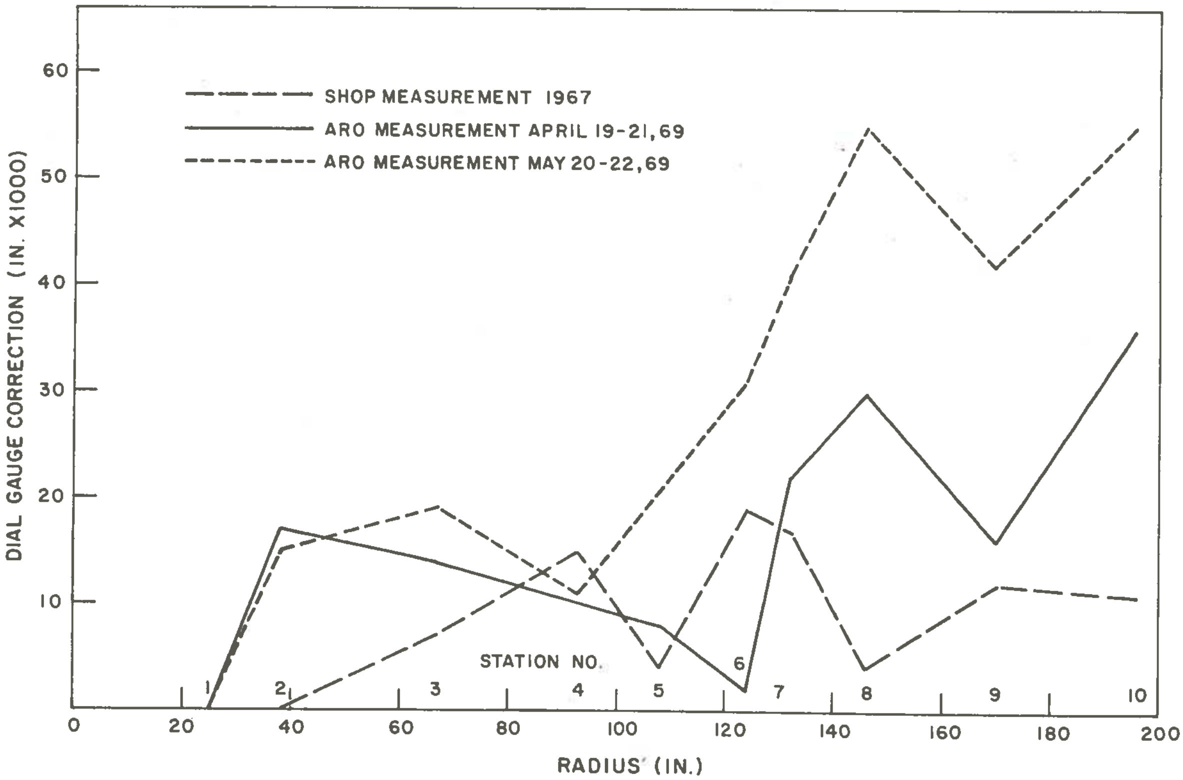


Figure 6 Dial gauge corrections versus radius for template surveys

a chief source of disagreement. The shop template measurements, corrected for survey temperature have been used in processing all antenna survey data because

- these measurements had best environmental conditions
- these radial (y) values lie between those obtained otherwise
- lowest standard deviation (SD) is obtained using these template data.

3. Antenna Surface Measurements

Results of all useful surveys of the surface of the 33-foot ARO paraboloid are summarized in this section. Statistical results for both raw and best-fit data were calculated using the method and program described in a previous report [3]. Shop template data were used in this program, except for the 1960–61 surveys which required no accurate template data. The survey temperature of the template was entered into the program for the 1968–69 measurements, to give suitable corrections for thermal expansion of the template. In addition, the subroutine FLYER was not called as it caused trouble elsewhere in the program, so that a full data set containing no gross errors had to be used. Any unnoticed gross errors were easily detected in the data plots, and the data were corrected and rerun. This was necessary because a large error, of $\gtrsim 0.1$ inch say, has a noticeable effect on standard deviation calculations.

A summary of results calculated for all useful antenna surveys taken from November 1960, to August 21, 1969, is presented in chronological order in Table 2. Skewness is not presented here because of an error in equation 4 of reference 3 in which $(\text{DATA (I, J)})^n$ should be replaced by $(\text{DATA (I,J)} - \text{mean})^n$ with an appropriate change being made in subroutine SKEW also. Important data regarding weather conditions, antenna protection, and time are also contained in Table 2. The antenna surface was modified just before the August 1969 surveys.

Each survey is also characterized by three additional figures (Figs. 7–30). These give azimuthal error distributions about the mean of each radial station for both raw and best-fit data, and also histograms showing the distribution of measured values for both raw and best-fit data. Note that the station numbering on the plots of azimuthal error distributions has no gaps, but reference to Table 2 shows which of the ten radial stations were actually omitted (i.e., Nos. 9 and 10 in Table 2 were never omitted).

The results of these surveys are largely self explanatory. Surveys taken in 1968–69 involved considerable trouble in achieving and maintaining a stable antenna pedestal and balanced template. The addition of a polythene shelter around the antenna, in July 1969, alleviated this problem to a large extent. This arrangement is shown in Fig. 31. Results of the two surveys of May 1969 do not agree particularly well with those of May 1968, probably owing to items listed under ‘other’ for those surveys in Table 2.

TABLE 2

Survey		November 3, 1960		July 1, 1961		May 15, 1968		May 16, 1968		May 21, 1969		May 22, 1969		August 20, 1969		August 21, 1969	
		raw	B.F.	raw	B.F.	raw	B.F.	raw	B.F.	raw	B.F.	raw	B.F.	raw	B.F.	raw	B.F.
Entire Antenna	mean S.D. median	316.35 26.65 316.05	304.50 24.99 305.18	325.45 23.83 323.77	317.80 23.11 316.55	714.62 80.26 719.41	790.32 35.98 792.06	720.45 70.76 725.30	785.54 35.28 786.24	466.12 65.52 464.55	523.11 38.31 523.77	583.66 68.18 591.52	633.28 40.72 632.79	625.94 101.30 646.80	740.09 21.13 740.70	629.23 99.99 649.38	741.91 21.12 742.43
Radial Stn. No. 1 ~25"	mean S.D. median					810.20 10.94 810.53	813.36 10.13 813.06	810.58 11.68 810.93	813.30 11.23 813.83	555.27 11.19 556.47	557.65 11.61 558.22	664.27 13.31 665.44	666.34 13.48 666.67	738.80 12.74 739.94	743.57 12.23 744.74	740.67 12.69 742.31	745.38 12.31 747.09
2 ~38"	mean S.D. median	323.15 14.70 322.50	322.13 13.89 321.47	325.29 14.82 326.80	324.61 14.63 324.82	806.67 17.33 806.61	814.00 15.31 814.21	791.82 15.38 791.85	798.12 15.55 798.54	537.59 15.08 537.94	543.10 16.26 544.78	649.27 17.43 648.50	654.07 18.33 654.32	723.67 15.44 724.35	734.73 14.75 735.18	725.61 15.41 725.70	736.52 14.90 736.69
3 ~67"	mean S.D. median	287.62 22.52 290.56	284.48 22.17 286.29	313.62 14.55 313.55	311.53 14.59 310.25	771.23 23.13 772.37	794.06 16.15 792.69	774.00 20.97 775.58	793.63 16.04 793.57	511.63 19.86 511.86	528.78 16.28 528.95	623.92 25.37 625.00	638.88 17.67 639.25	708.06 23.46 708.41	742.45 19.95 741.40	709.90 23.27 709.29	743.86 20.29 741.96
4 ~93"	mean S.D. median	316.05 22.15 317.73	310.01 21.87 310.60	327.97 18.11 329.29	323.95 18.31 325.36	718.42 29.11 721.54	762.43 21.32 763.95	723.90 24.06 727.00	761.75 18.03 763.08	459.32 26.01 461.88	492.39 21.36 492.07	576.80 34.73 579.09	605.62 23.08 605.81	667.12 31.40 669.41	733.40 26.87 733.33	669.80 31.42 671.11	735.25 27.41 735.79
5 ~108"	mean S.D. median			315.29* 24.57 311.25	309.35* 24.46 304.39												
6 ~124"	mean S.D. median	306.95 14.93 306.67	296.22 14.51 295.86	312.85 15.08 312.50	305.70 14.80 306.67	680.58 39.58 682.67	758.84 25.51 760.31	686.73 36.14 689.29	754.05 25.47 755.22	427.15 31.70 429.00	485.96 23.91 486.67	543.71 42.52 547.11	594.99 24.31 595.93	633.45 18.06 633.16	751.34 15.36 750.90	637.46 18.49 636.82	753.84 16.24 752.85
7 ~132"	mean S.D. median																
8 ~146"	mean S.D. median	317.61 27.09 314.53	302.73 27.06 301.45	336.32 24.95 334.69	326.42 24.85 324.35	663.32 47.14 663.33	771.84 28.59 769.48	672.45 42.84 675.48	765.79 28.56 763.29	413.61 39.02 413.57	495.16 27.87 491.94	533.78 50.32 534.13	604.89 27.60 601.67	573.74 19.86 573.89	737.19 18.10 737.07	577.75 18.79 578.56	739.12 17.62 739.29
9 ~170"	mean S.D. median	333.92 28.92 332.71	313.75 28.53 312.50	344.79 27.17 345.00	331.36 27.03 330.13	646.06 55.21 649.76	793.19 35.34 792.04	660.22 51.23 662.69	786.76 35.09 787.90	414.14 45.36 414.57	524.71 32.62 523.15	536.60 60.98 542.14	632.99 35.29 630.31	518.05 24.81 518.94	739.64 21.95 740.36	522.77 23.78 524.77	741.55 21.76 742.14
10 ~196"	mean S.D. median	329.16 23.06 331.00	302.35 23.41 301.75	327.48 26.19 328.71	309.62 26.04 311.00	620.44 68.66 628.85	816.06 52.00 809.50	643.89 62.28 654.09	812.13 51.60 809.50	410.26 55.43 410.56	557.26 48.06 550.77	540.89 78.78 551.67	669.05 58.59 661.55	444.62 28.19 446.28	739.24 28.49 737.16	449.89 26.77 451.77	740.77 27.28 738.94
Tilt for best fit	φ° θ°		.00267 153.		.00119 108.		.0162 171.		.0130 154.		.0122 171.		.0206 174.		.00676 167.		.00576 168.
Focal length		169.400	169.320	169.400	169.347	169.400	169.987	169.400	169.904	169.400	169.841	169.400	169.784	169.400	170.286	169.400	170.275
Temperature °F				72		64		72		42.5		48.0		40.0		47.5	
Survey Conditions wind/weather time				7:55 pm - 12:30 a.m.		gusty 10 am - 3 pm		quiet, overcast 9:30 a.m. - 12:30 p.m.		2 - 5 a.m.		7 - 11 p.m.		protected 3 - 7 a.m.		protected 1:30 - 5: 30 a.m.	
temperature variation										41 - 44°F		35 - 61°F		small		small	
other		measurement made inside enclosure with original template				no protection around antenna				levelling adjustment made at az. 4Aa,b				survey made inside roofless polythene enclosure. Some nos. on stn. 10 have been adjusted			

*radius was 113. in.

NOTES: Shop template data used throughout

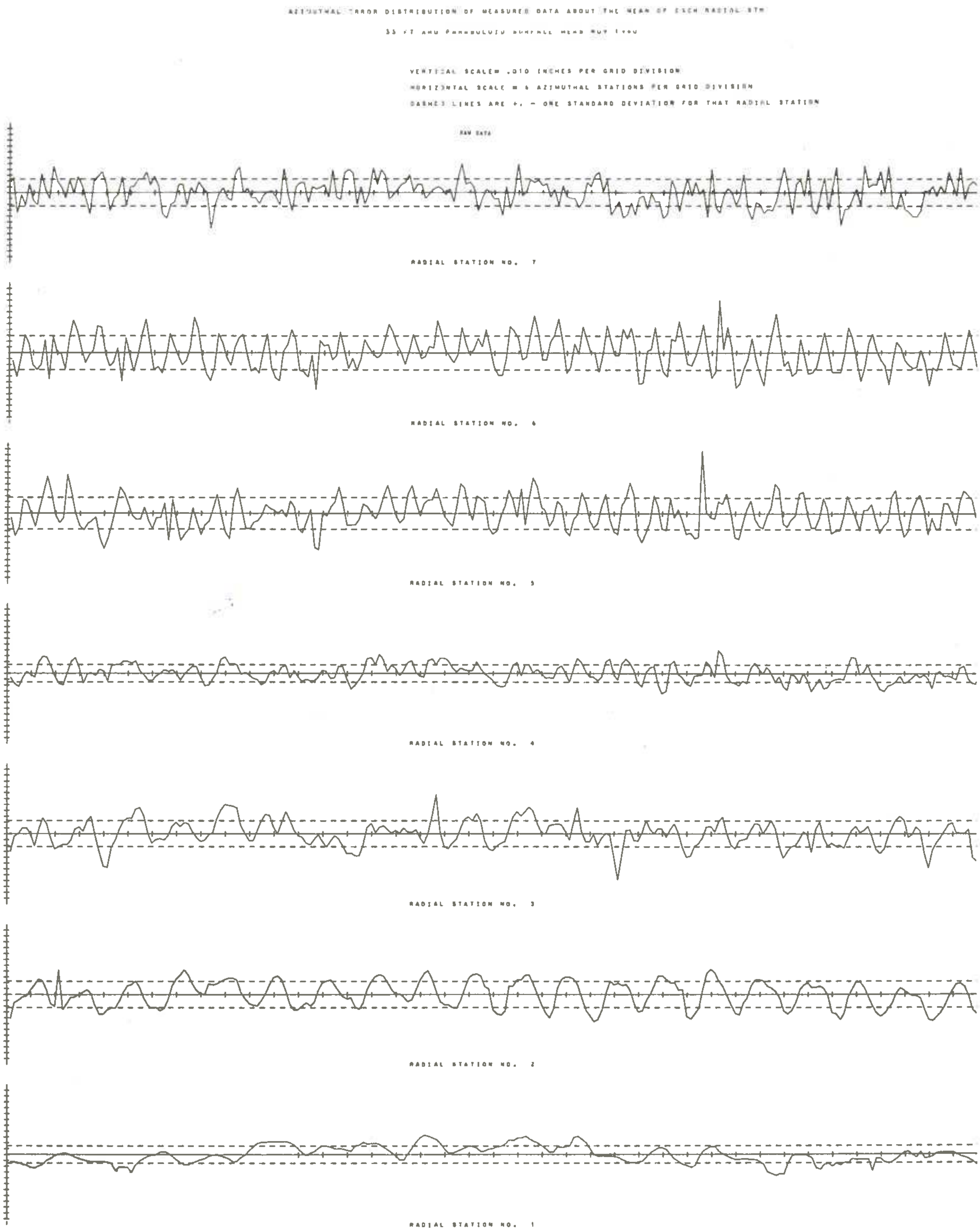


Figure 7 Azimuthal error distribution of raw data for November 1960 survey

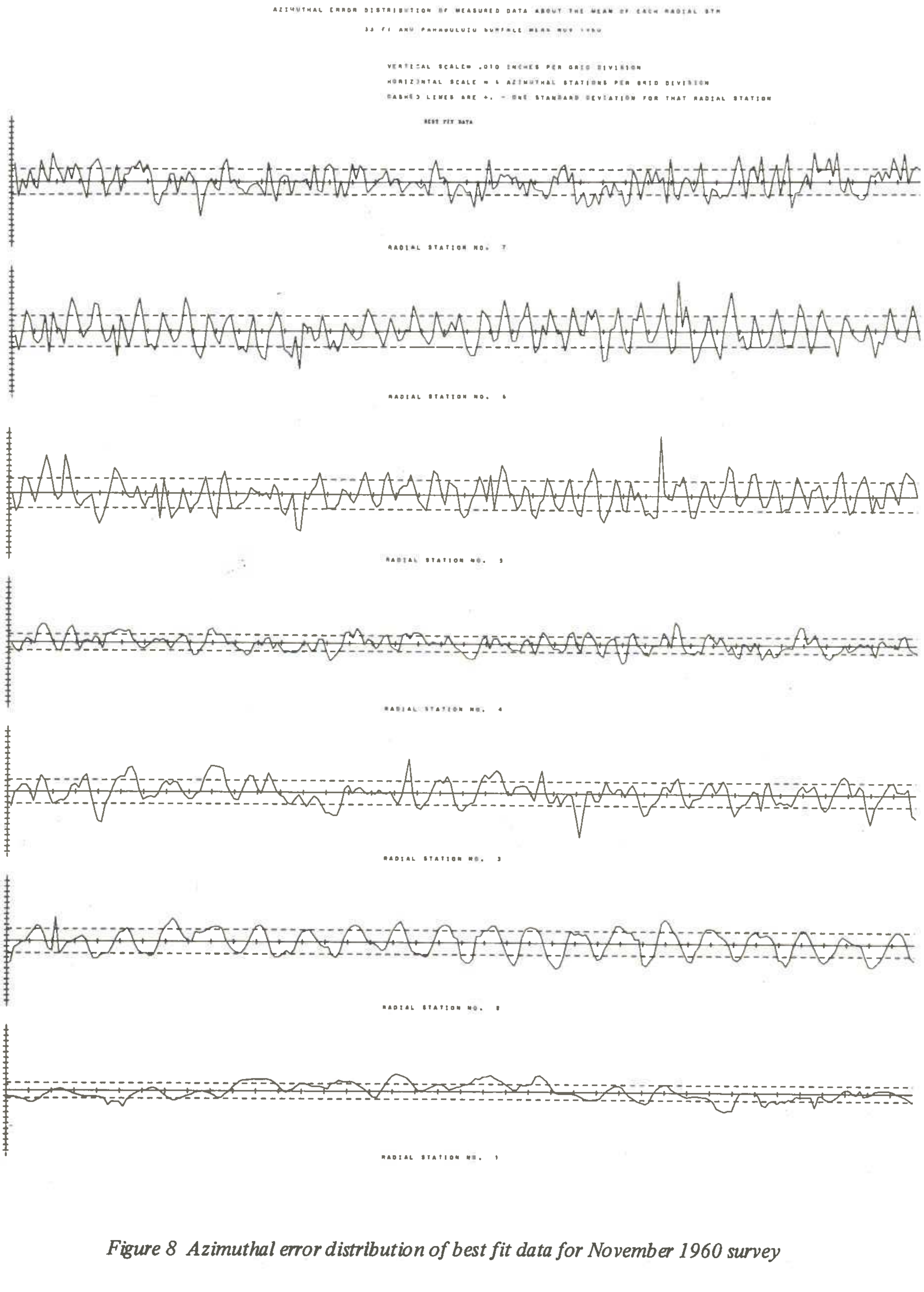
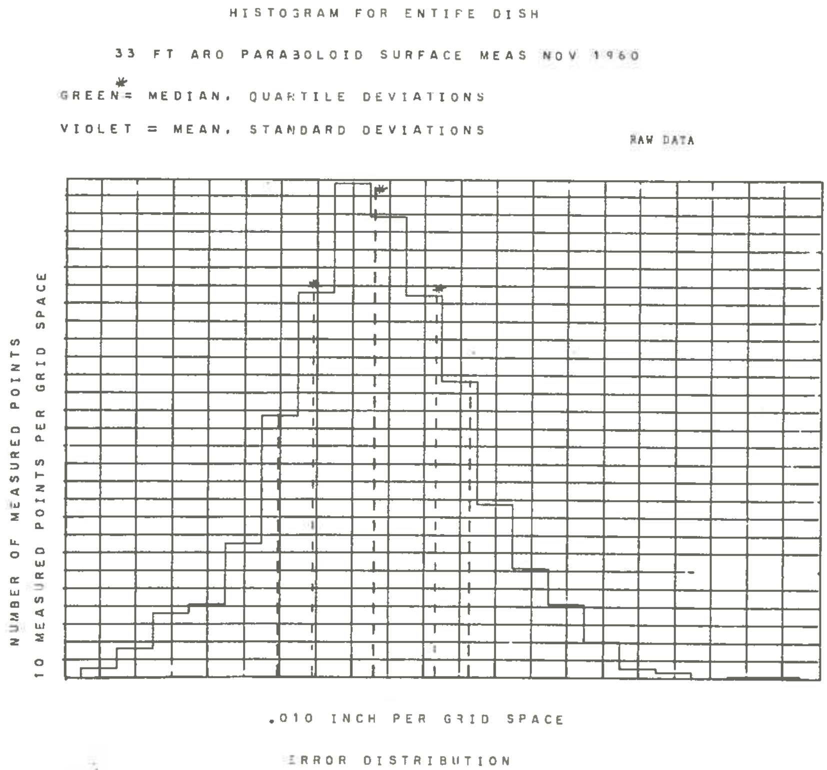


Figure 8 Azimuthal error distribution of best fit data for November 1960 survey



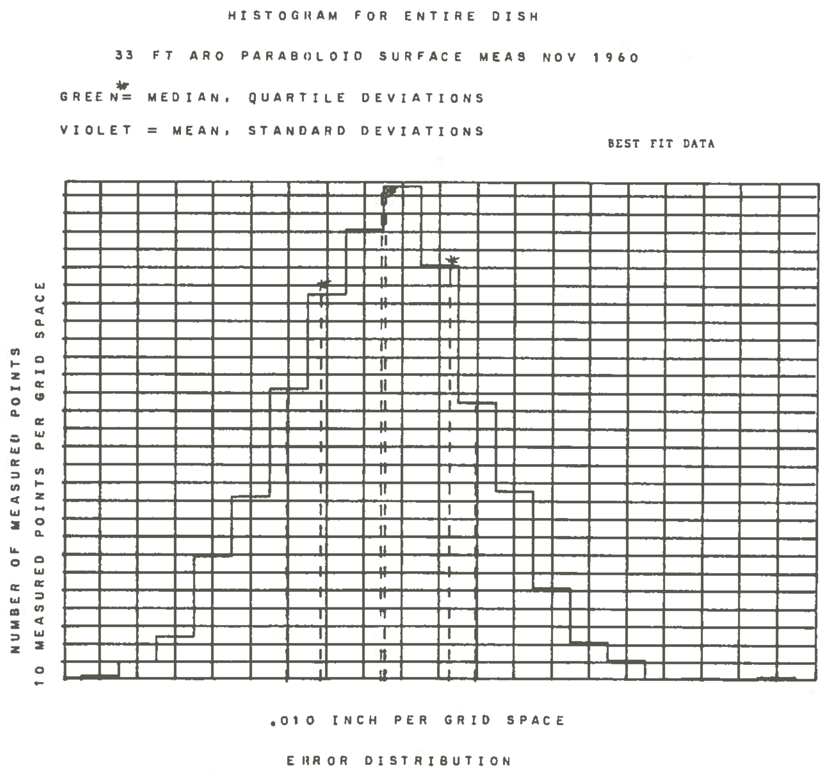


Figure 9 Histograms of raw and best fit data for November 1960 survey

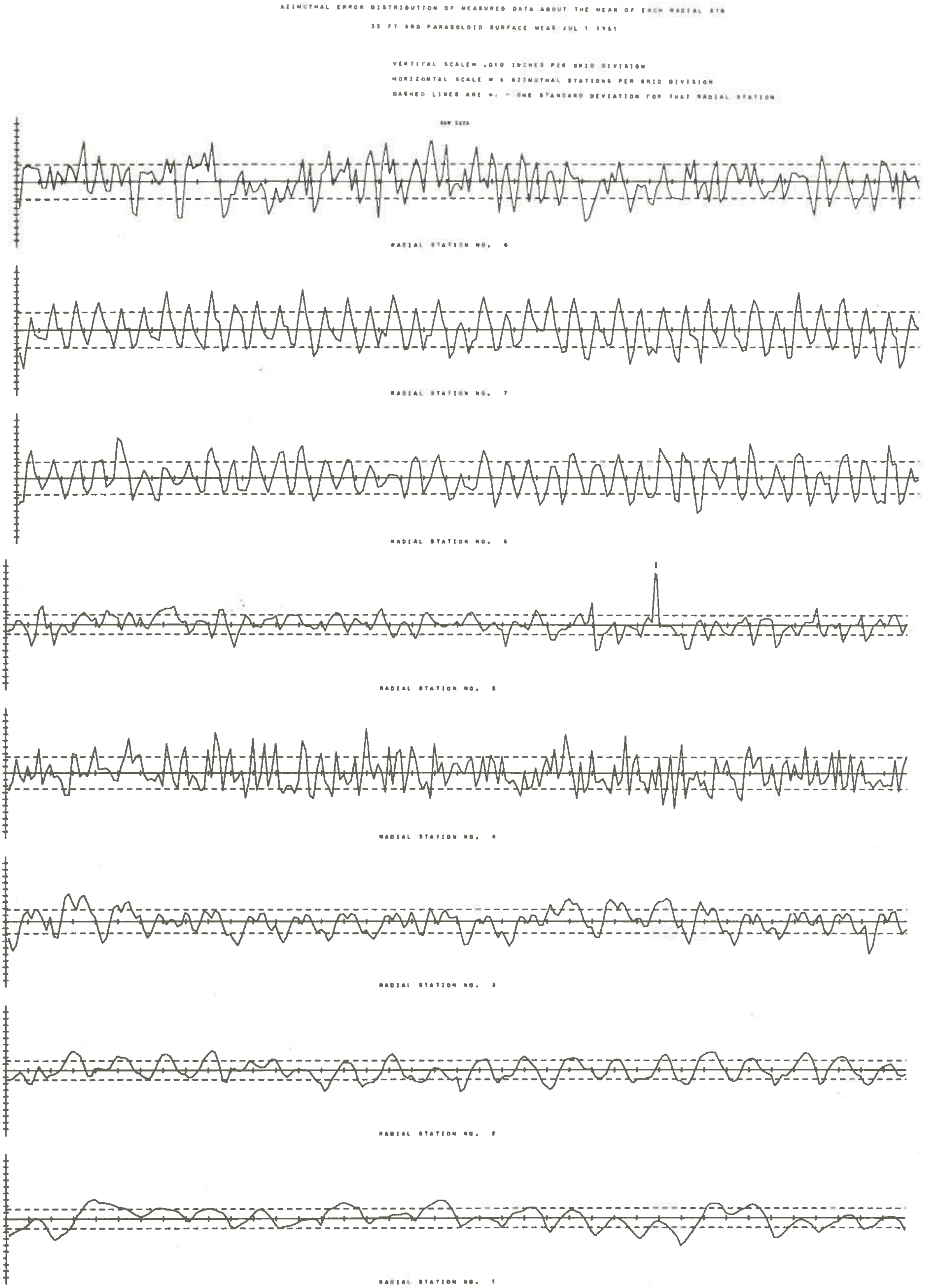


Figure 10 Azimuthal error distribution of raw data for July 1, 1961 survey

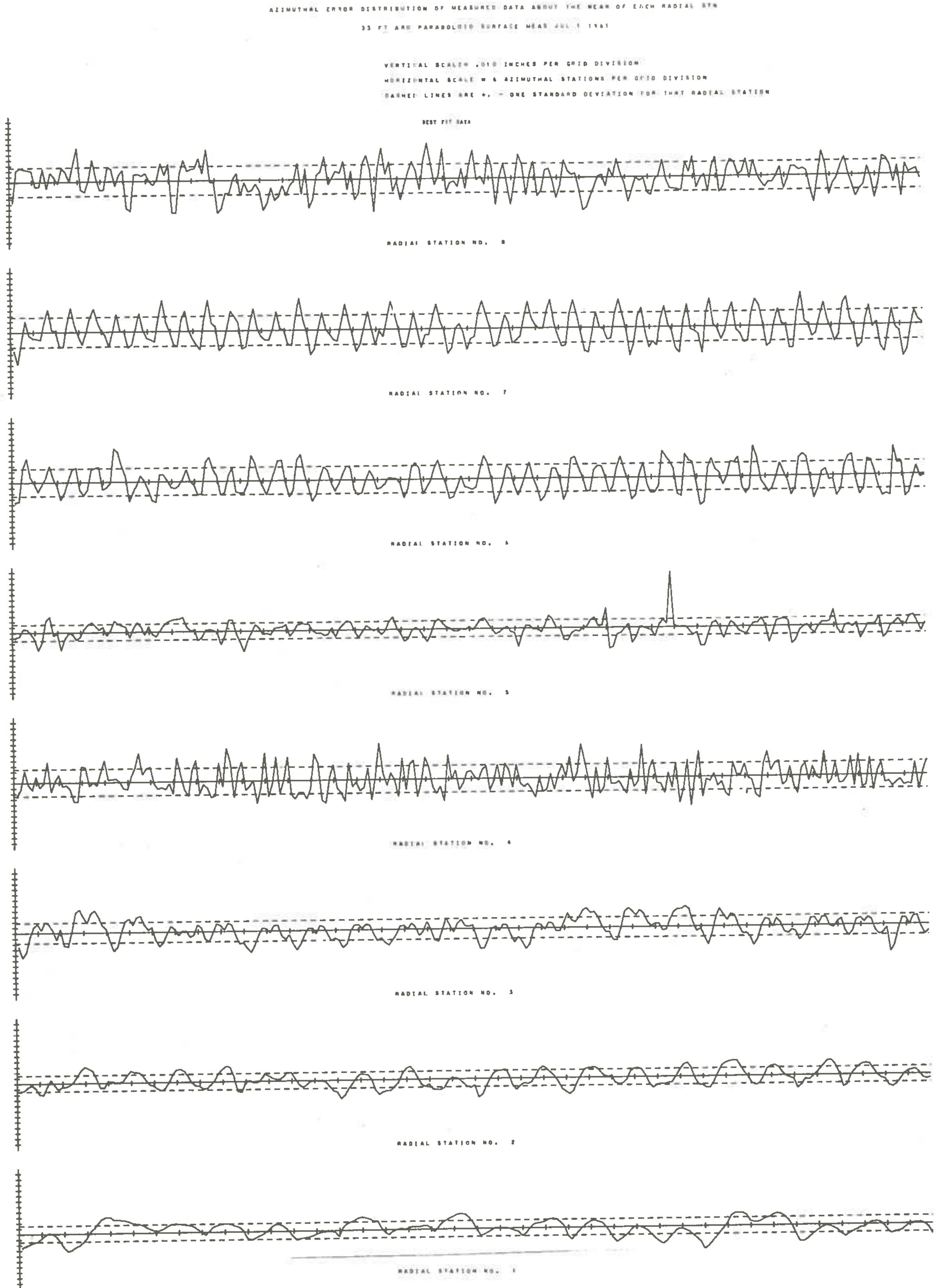
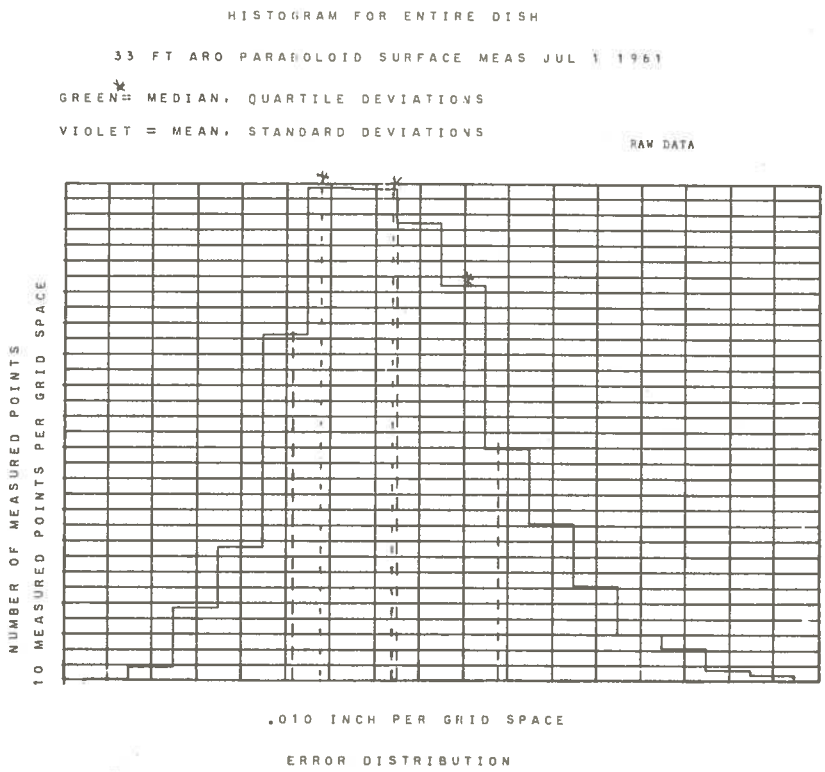


Figure 11 Azimuthal error distribution of best fit data for July 1 1961 survey



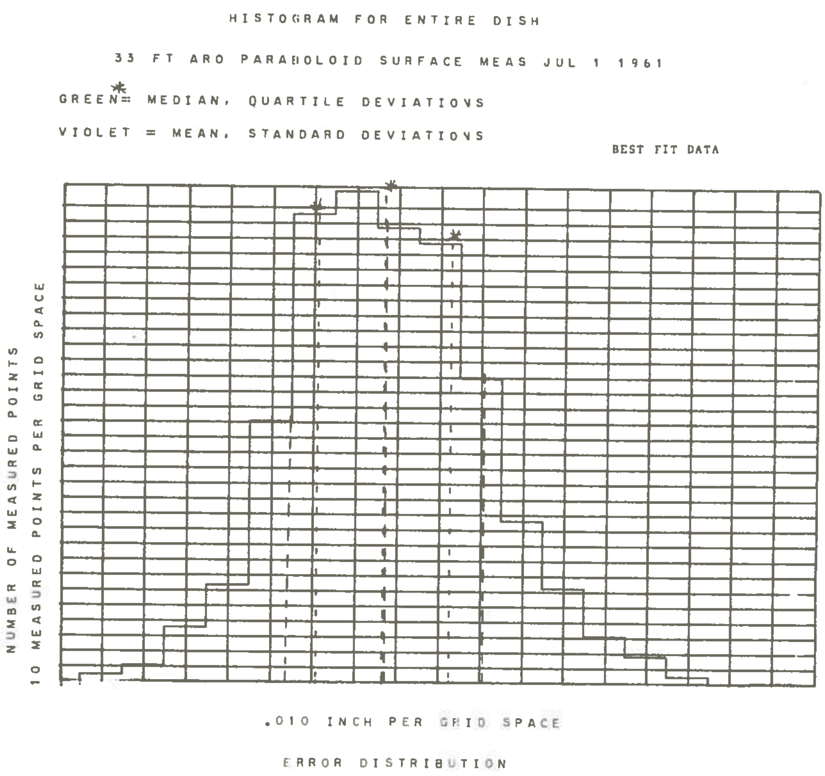


Figure 12 Histograms of raw and best fit data for July 1, 1961 survey

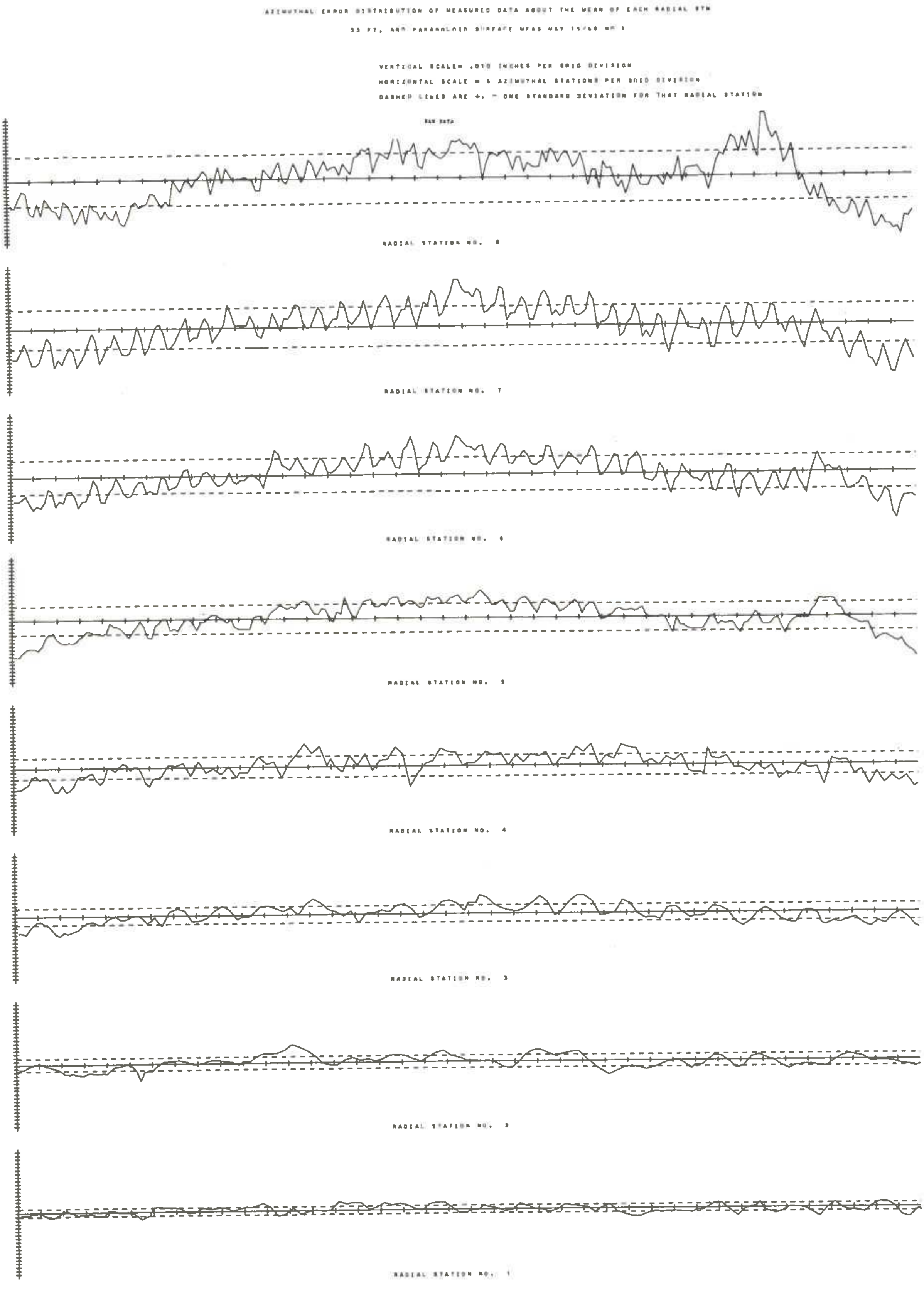


Figure 13 Azimuthal error distribution of raw data for May 15, 1968 survey

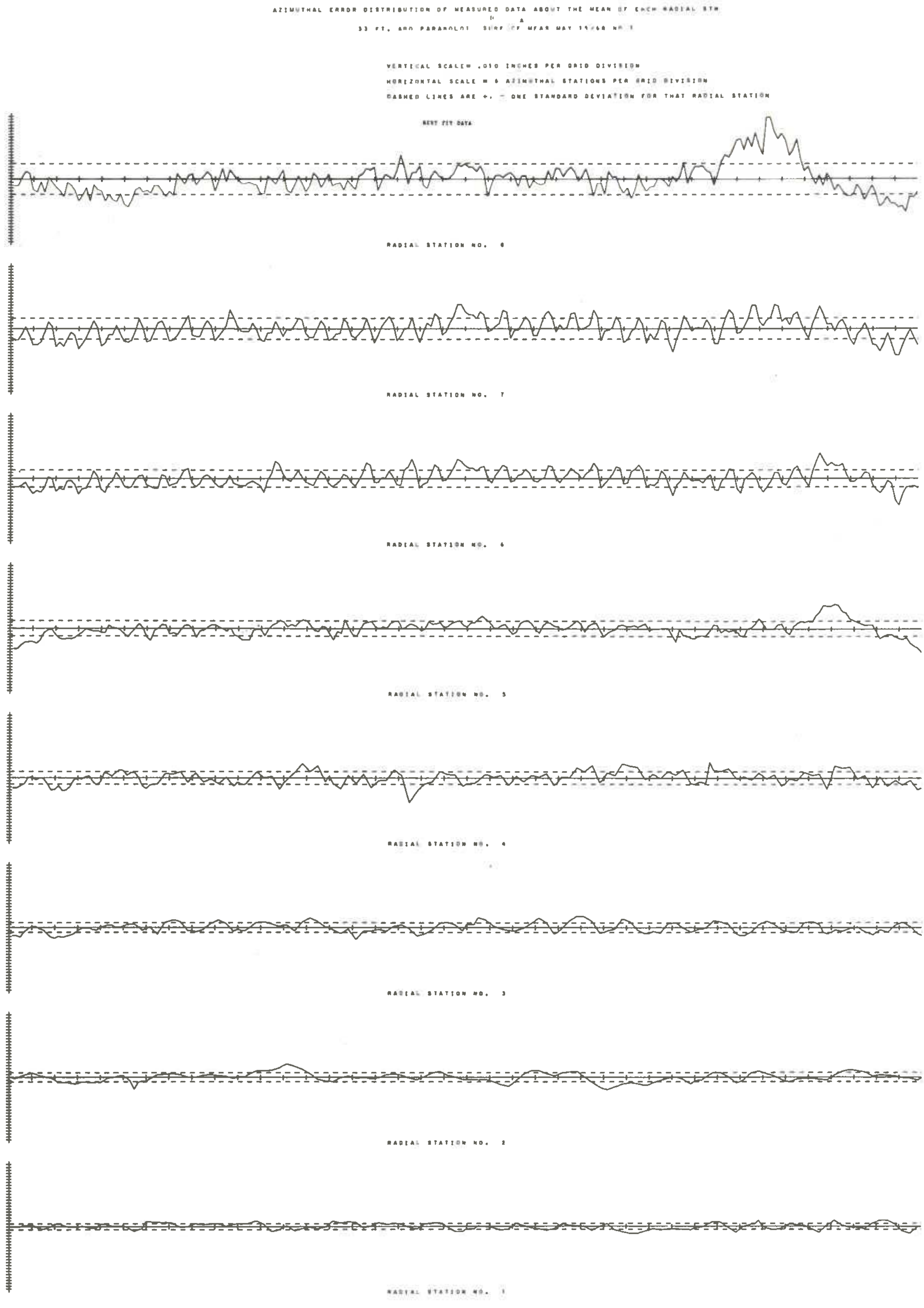


Figure 14 Azimuthal error distribution of best fit data for May 15, 1968 survey

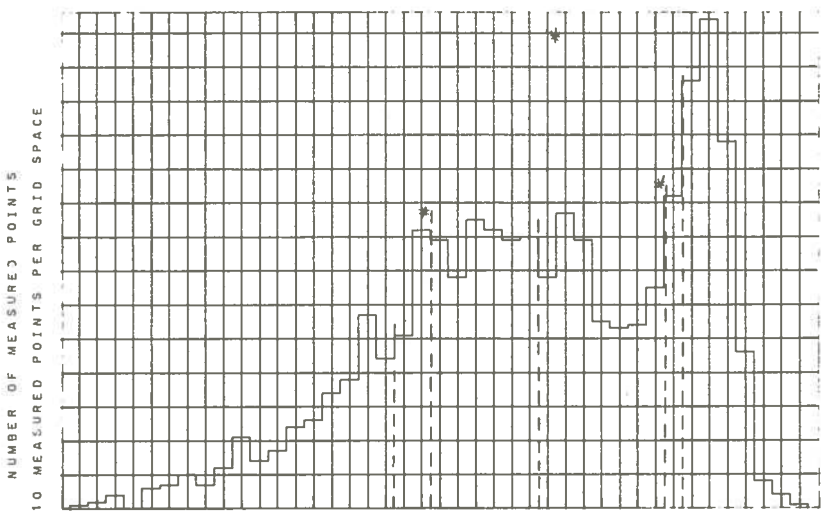
HISTOGRAM FOR ENTIRE DISH

33 FT. ARO PARABOLOID SURFACE MEAS MAY 15/68 NO 1

GREEN*= MEDIAN, QUARTILE DEVIATIONS

VIOLET = MEAN, STANDARD DEVIATIONS

RAW DATA



.010 INCH PER GRID SPACE

ERROR DISTRIBUTION

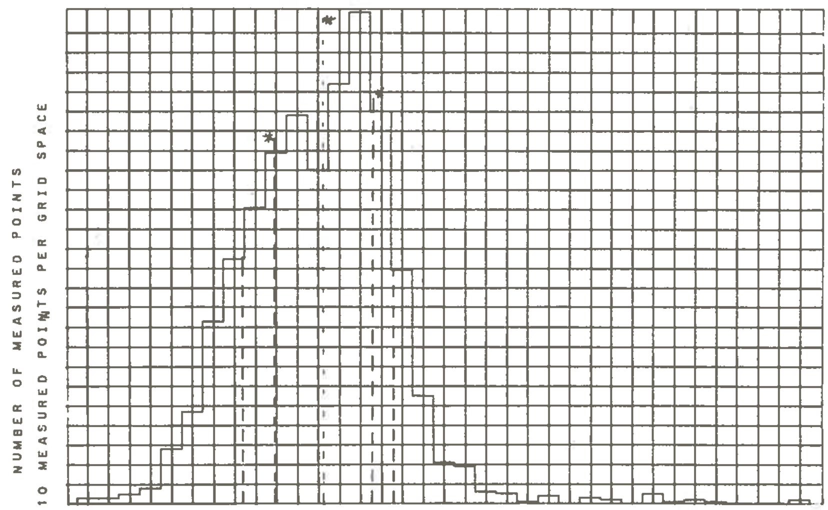
HISTOGRAM FOR ENTIRE DISH

33 FT. ARO PARABOLOID SURFACE MEAS MAY 15/68 NO 1

GREEN*= MEDIAN, QUARTILE DEVIATIONS

VIOLET = MEAN, STANDARD DEVIATIONS

BEST FIT DATA



.010 INCH PER GRID SPACE

ERROR DISTRIBUTION

Figure 15 Histograms of raw and best fit data for May 15, 1968 survey

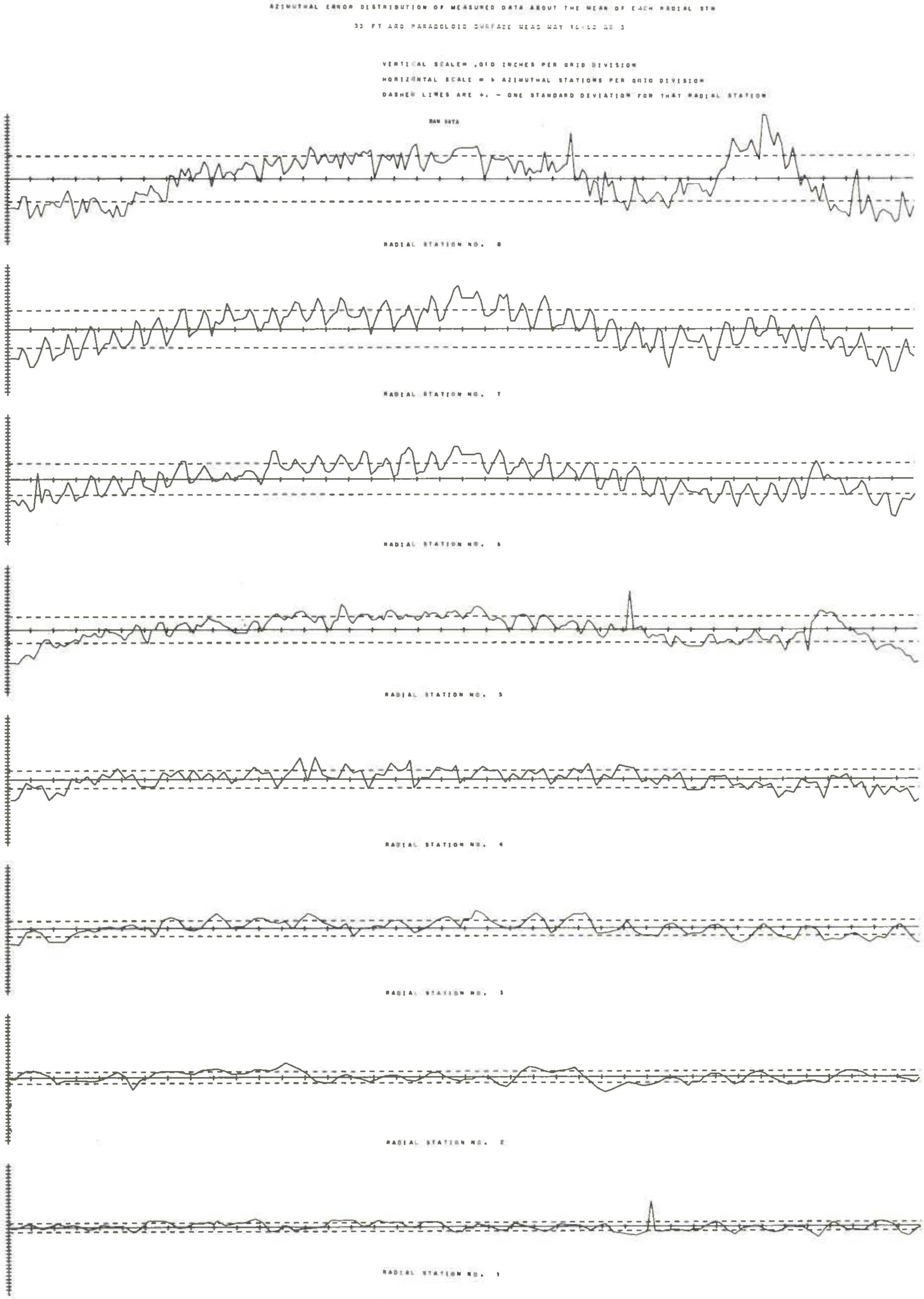


Figure 16 Azimuthal error distribution of raw data for May 16, 1968 survey

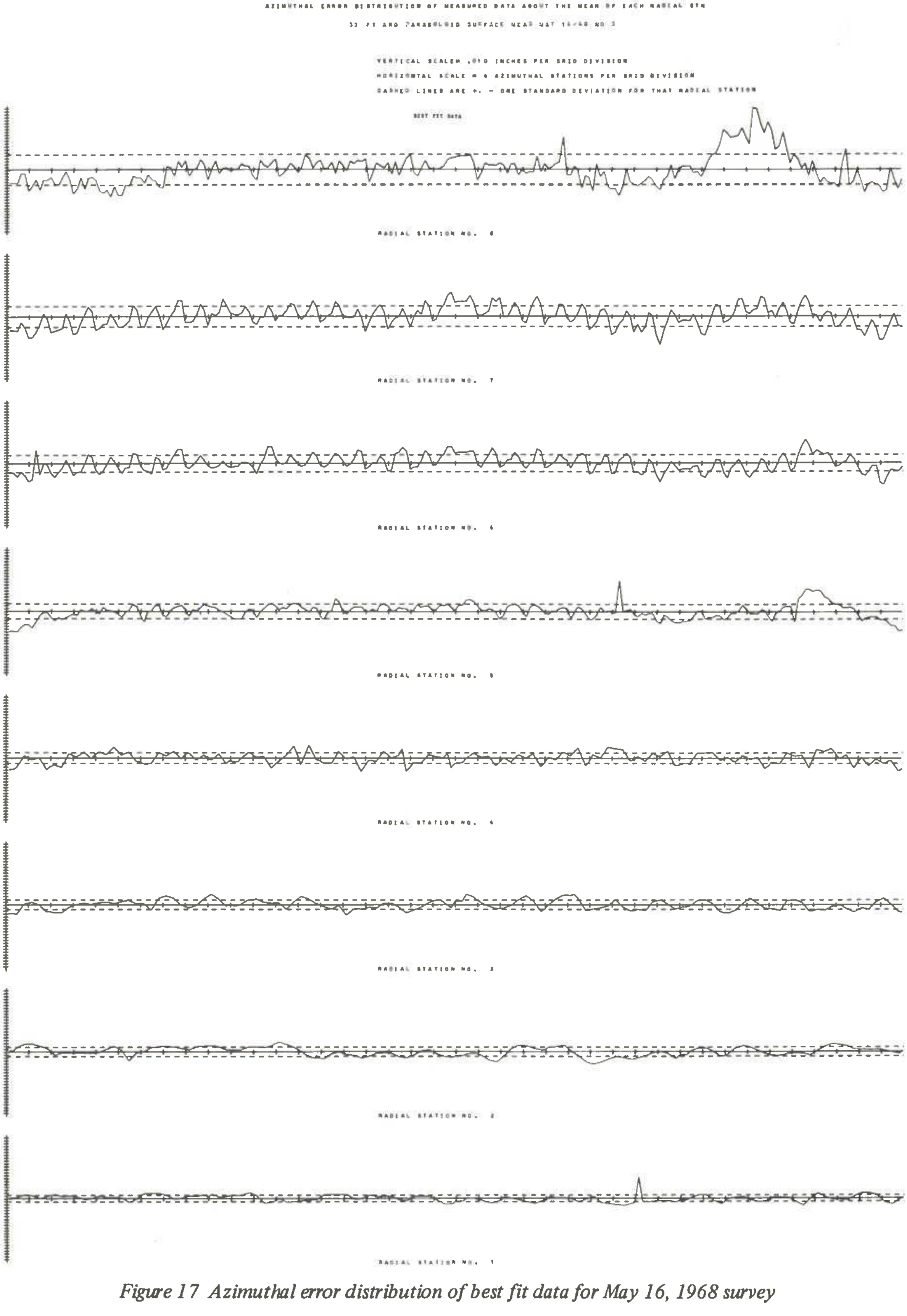


Figure 17 Azimuthal error distribution of best fit data for May 16, 1968 survey

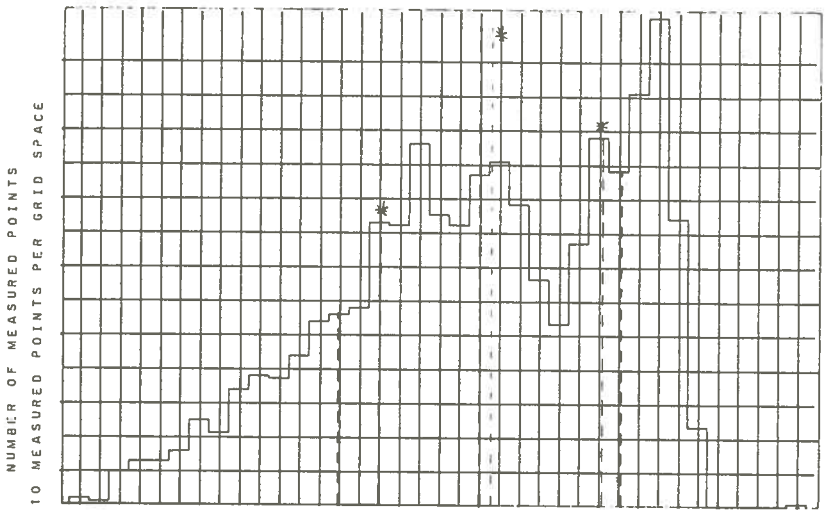
HISTOGRAM FOR ENTIRE DISH

33 FT ARO PARABOLOID SURFACE MEAS MAY 16/68 NO 3

GREEN*= MEDIAN, QUARTILE DEVIATIONS

VIOLET = MEAN, STANDARD DEVIATIONS

RAW DATA



HISTOGRAM FOR ENTIRE DISH

33 FT ARO PARABOLOID SURFACE MEAS MAY 16/68 NO 3

GREEN*= MEDIAN, QUARTILE DEVIATIONS

VIOLET = MEAN, STANDARD DEVIATIONS

BEST FIT DATA

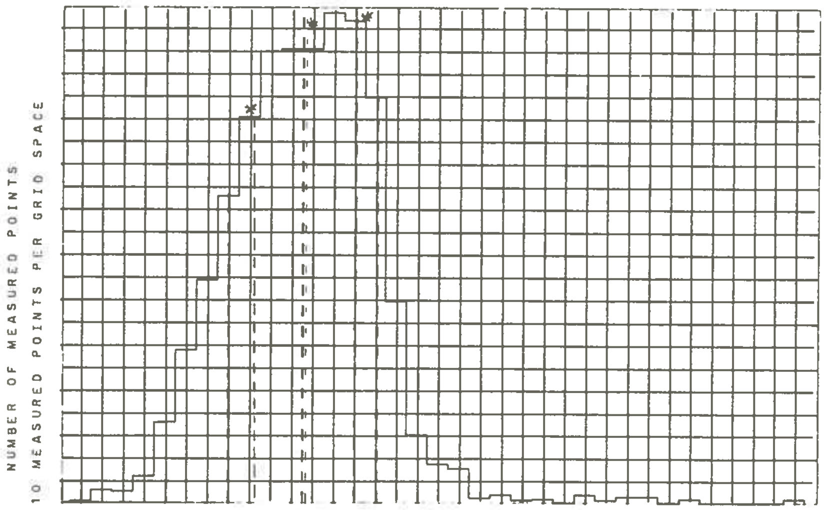


Figure 18 Histograms of raw and best fit data for May 16, 1968 survey

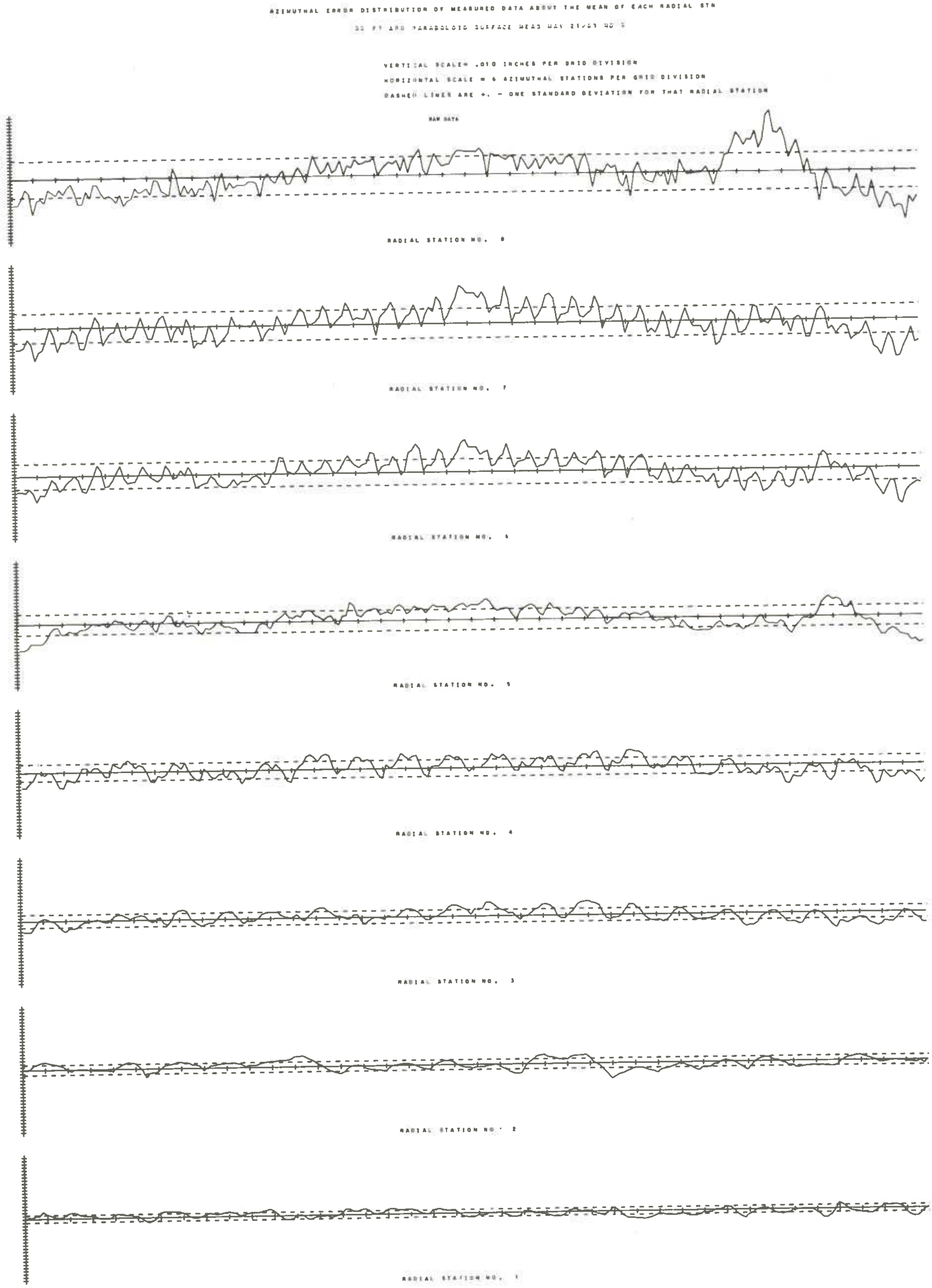


Figure 19 Azimuthal error distribution of raw data for May 21, 1969 survey

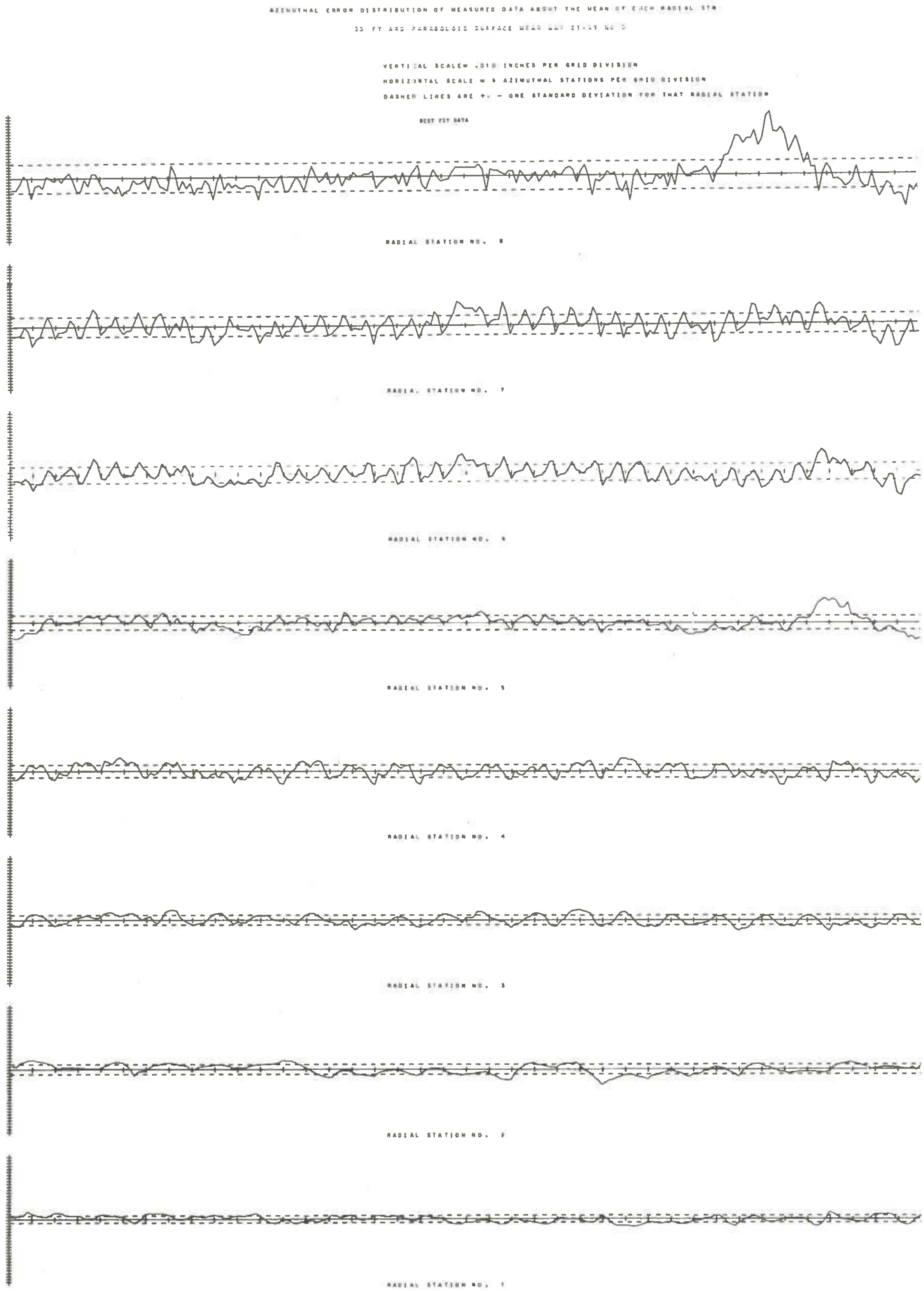


Figure 20 Azimuthal error distribution of best fit data for May 21, 1969 survey

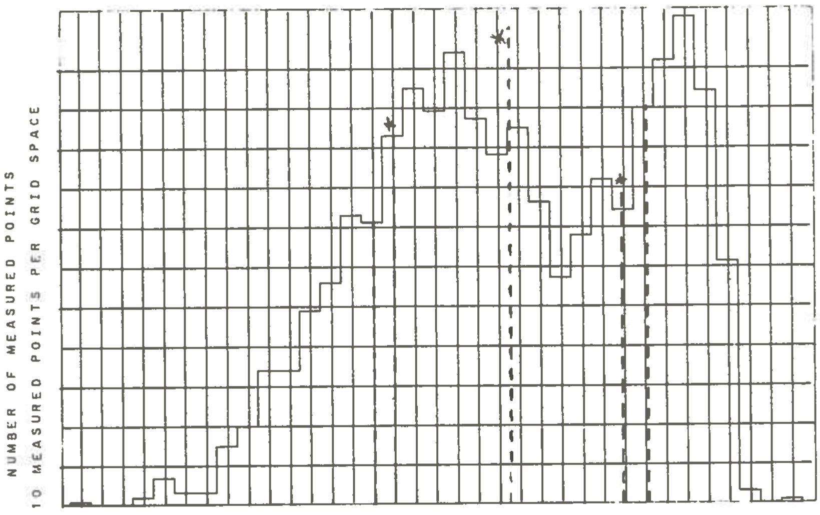
HISTOGRAM FOR ENTIFE DISH

33 FT ARO PARABOLOID SURFACE MEAS MAY 21/69 NO 5

GREEN*= MEDIAN, QUARTILE DEVIATIONS

VIOLET = MEAN, STANDARD DEVIATIONS

RAW DATA



.010 INCH PER GRID SPACE

ERROR DISTRIBUTION

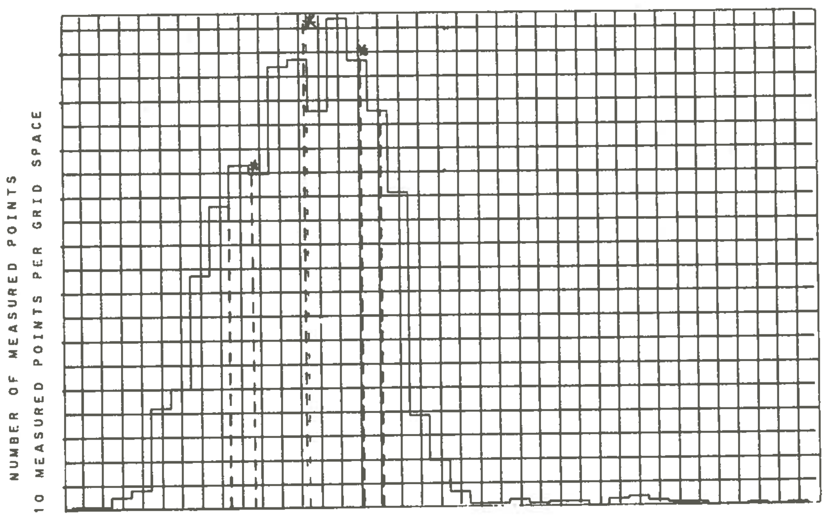
HISTOGRAM FOR ENTIFE DISH

33 FT ARO PARABOLOID SURFACE MEAS MAY 21/69 NO 5

GREEN*= MEDIAN, QUARTILE DEVIATIONS

VIOLET = MEAN, STANDARD DEVIATIONS

BEST FIT DATA



.010 INCH PER GRID SPACE

ERROR DISTRIBUTION

Figure 21 Histograms of raw and best fit data for May 21, 1969 survey

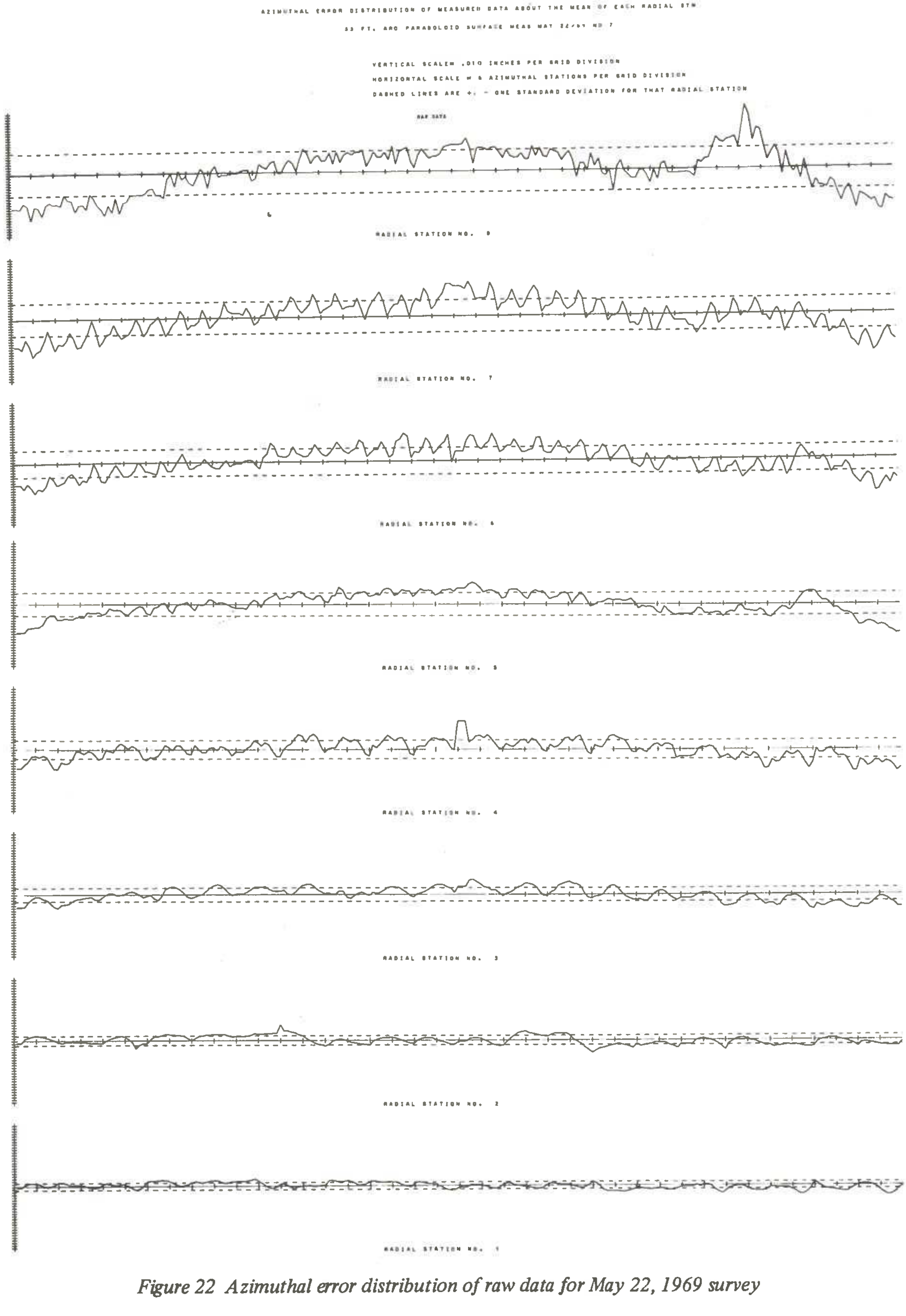


Figure 22 Azimuthal error distribution of raw data for May 22, 1969 survey

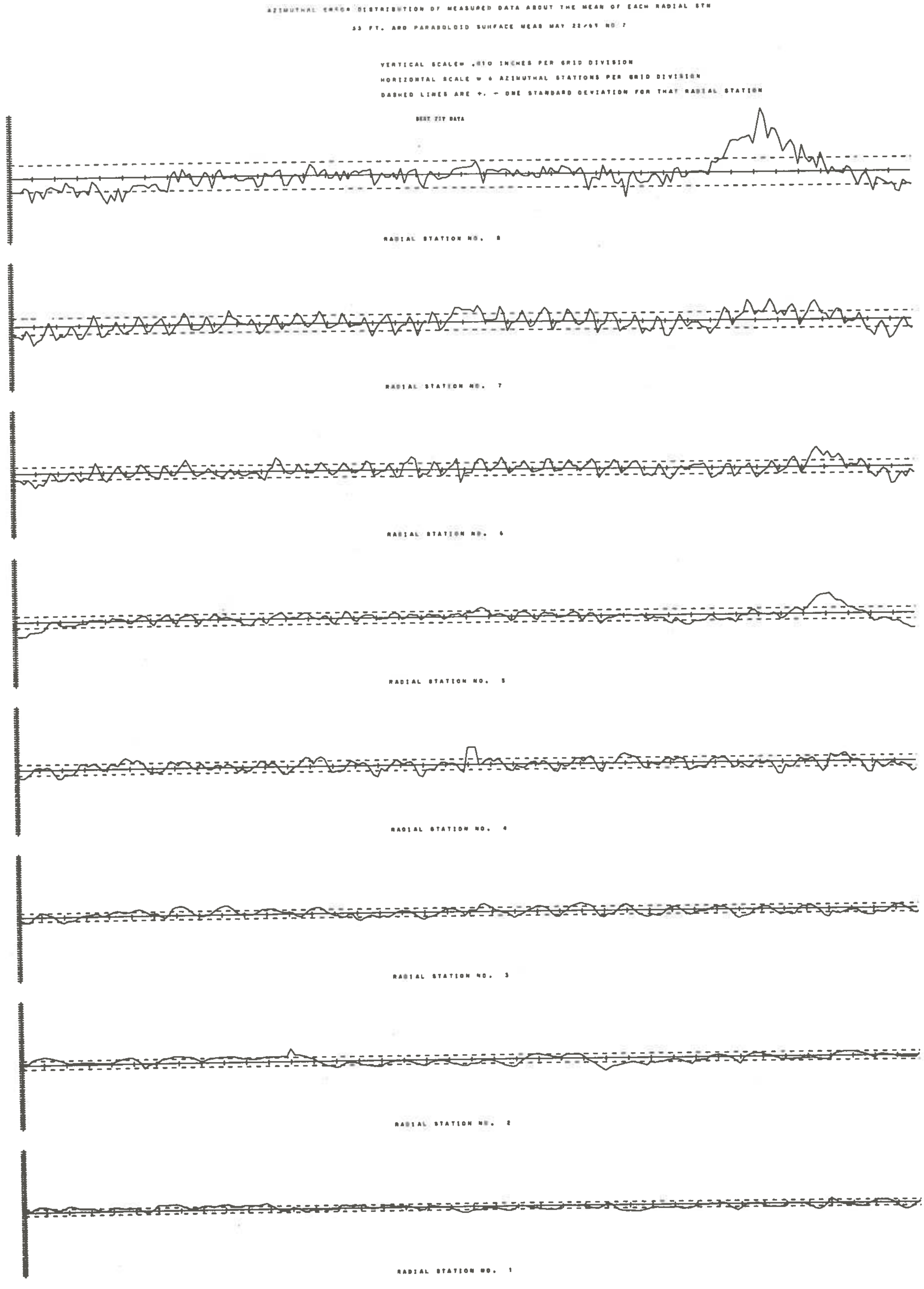
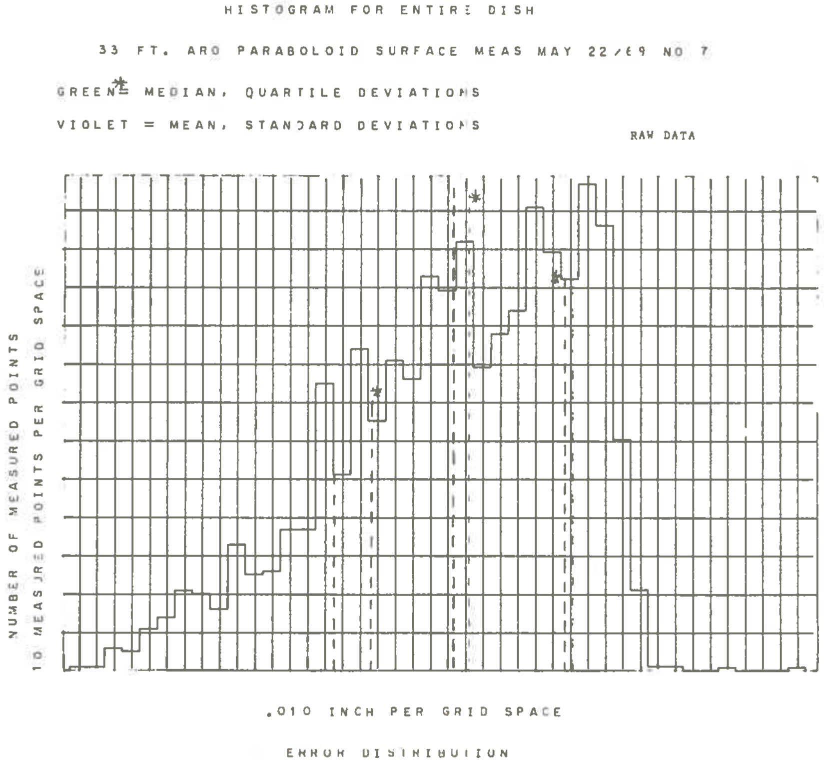


Figure 23 Azimuthal error distribution of best fit data for May 22, 1969 survey



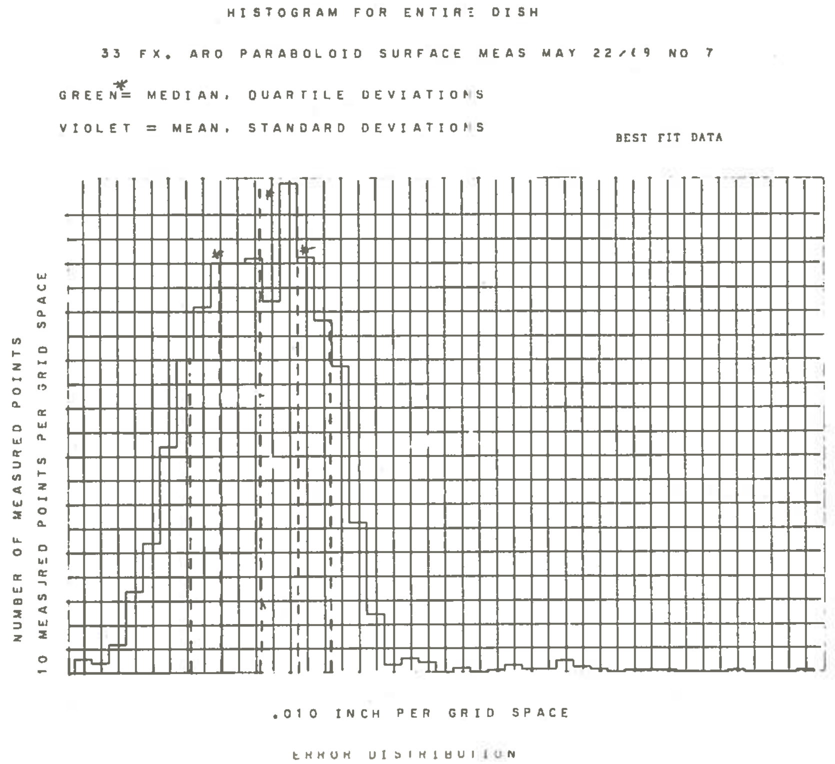


Figure 24 Histograms of raw and best fit data for May 22, 1969 survey

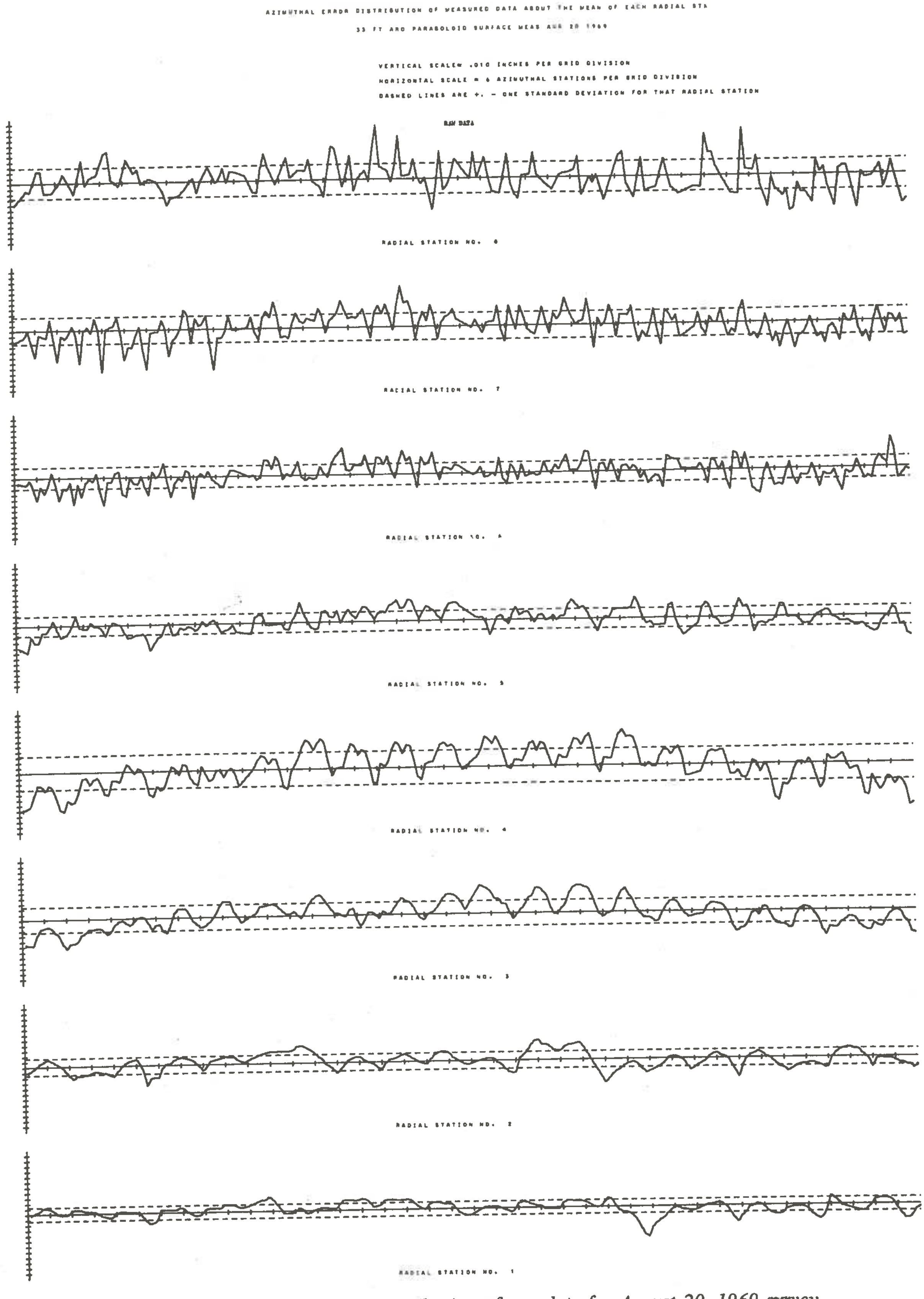


Figure 25 Azimuthal error distribution of raw data for August 20, 1969 survey

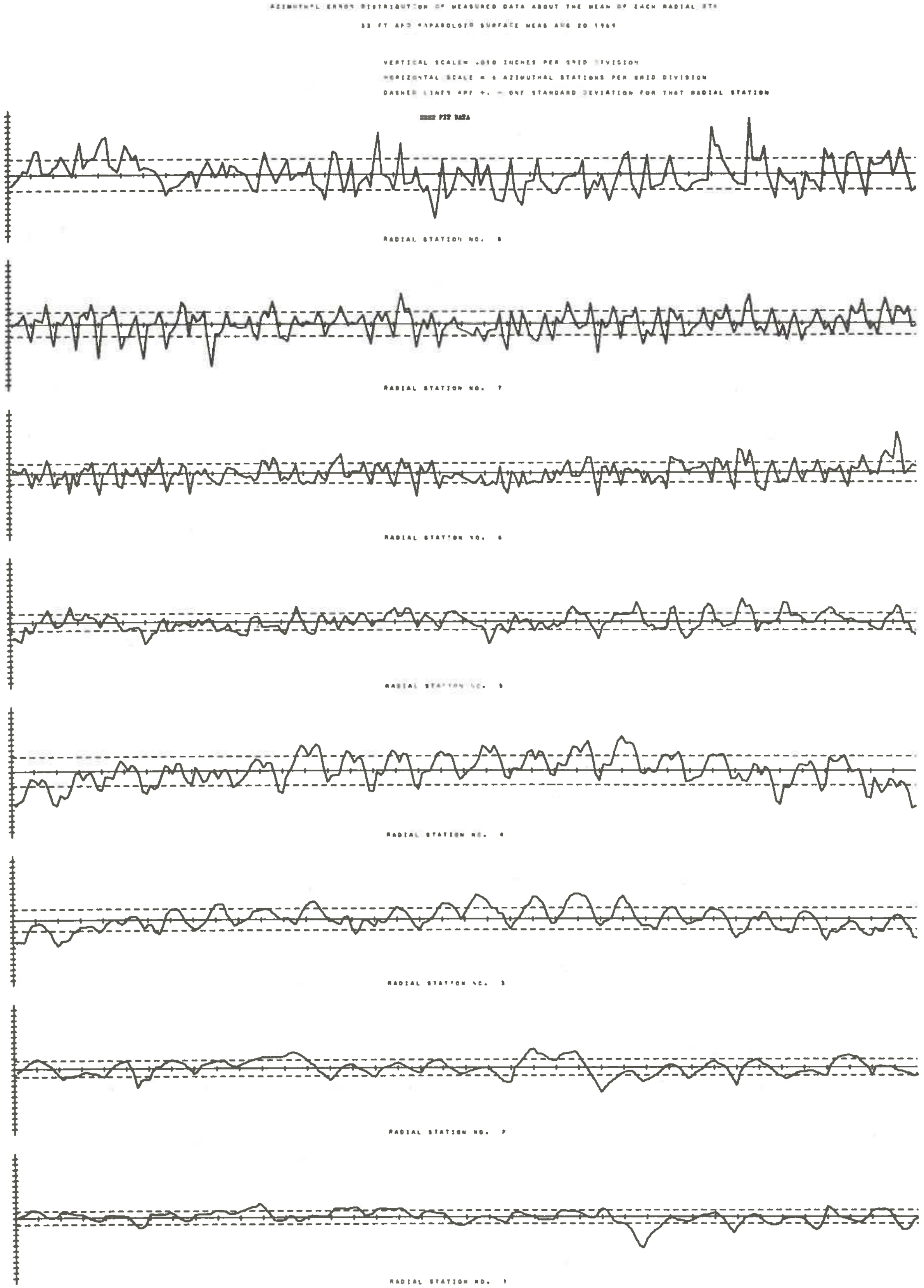
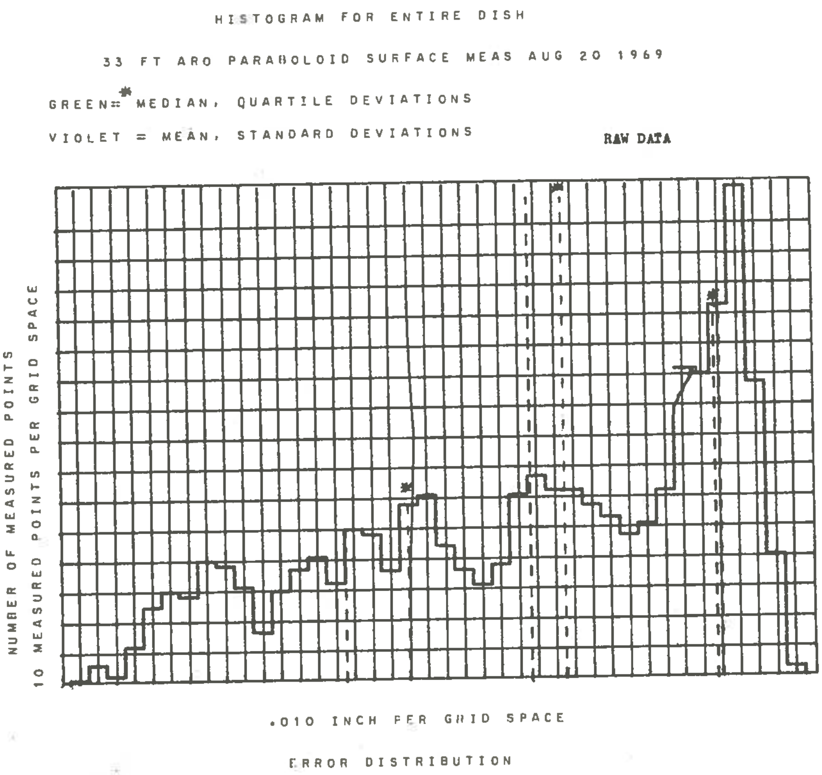


Figure 26 Azimuthal error distribution of best fit data for August 20, 1969 survey



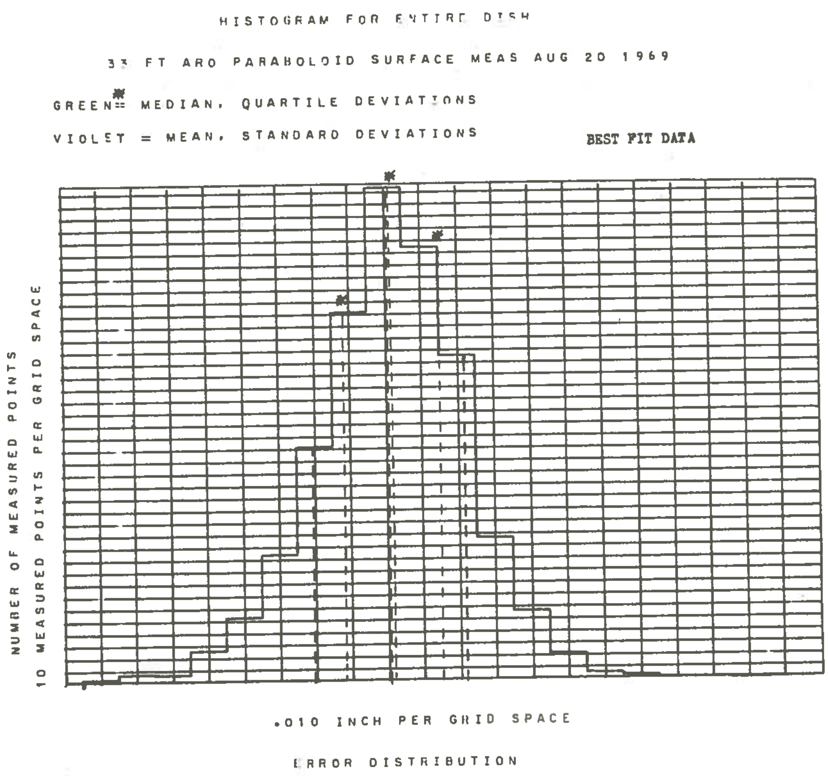


Figure 27 Histograms of raw and best fit data for August 20, 1969 survey

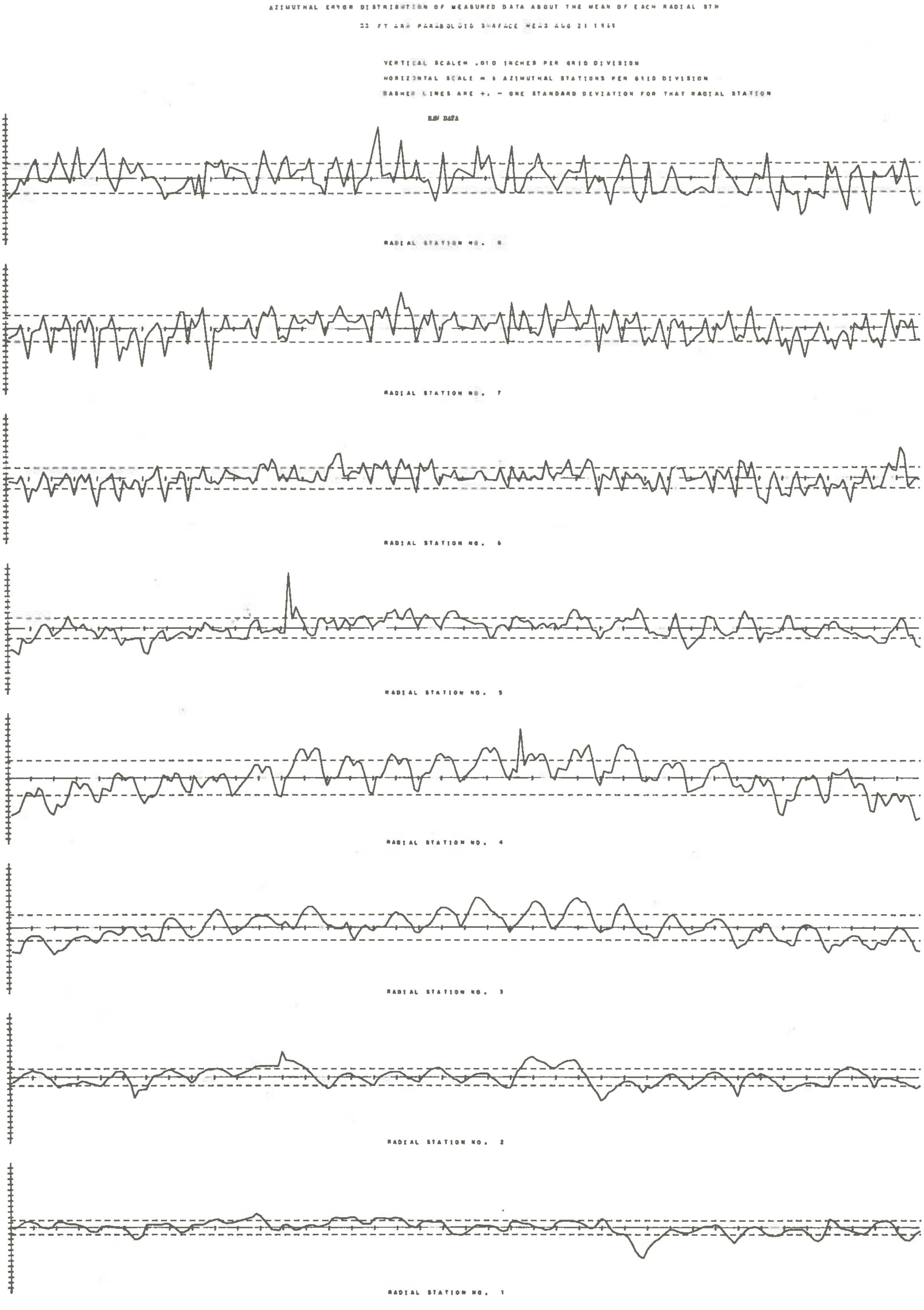


Figure 28 Azimuthal error distribution of raw data for August 21, 1969 survey

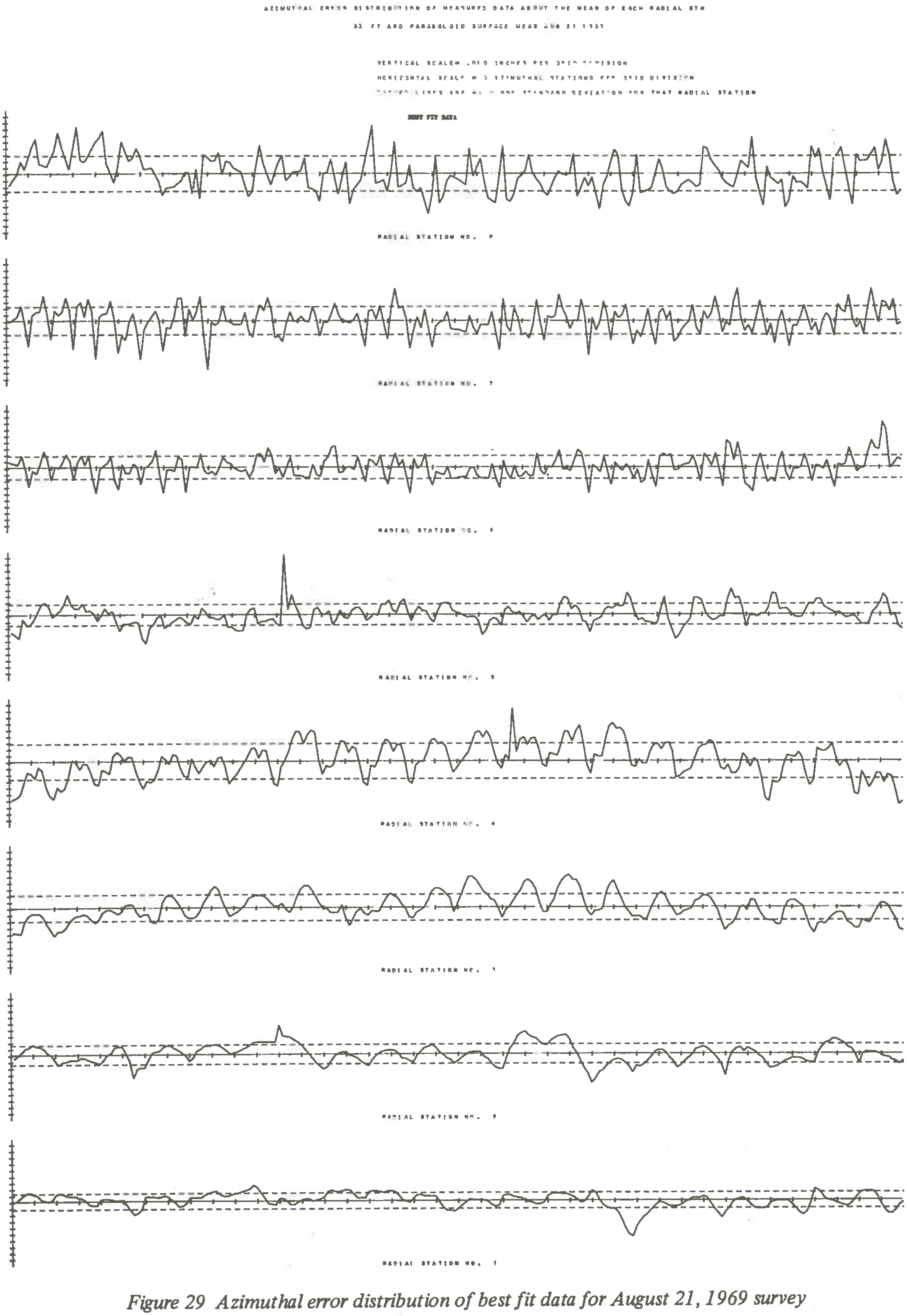
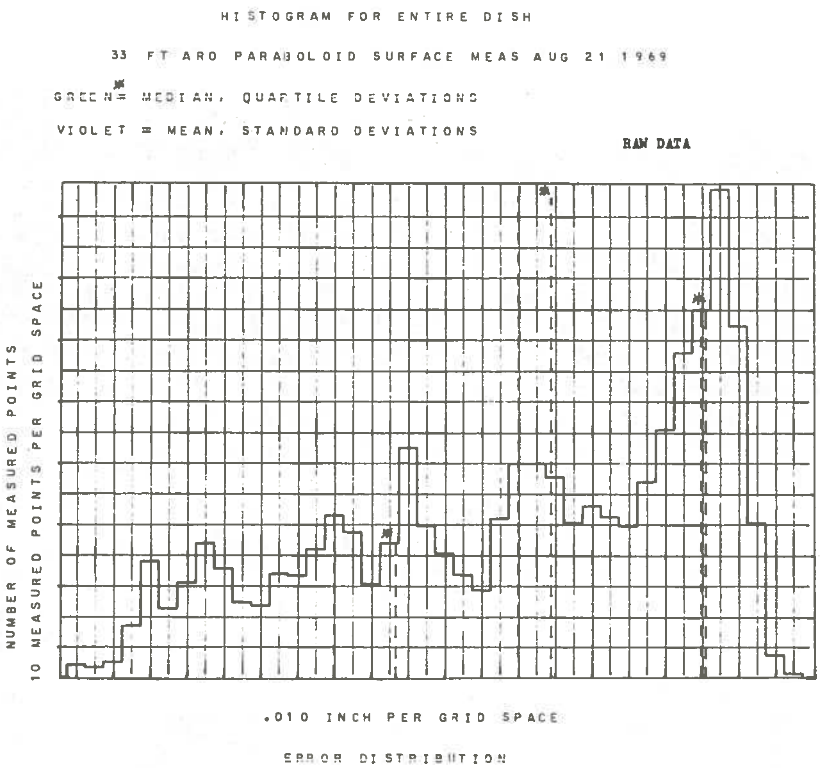


Figure 29 Azimuthal error distribution of best fit data for August 21, 1969 survey



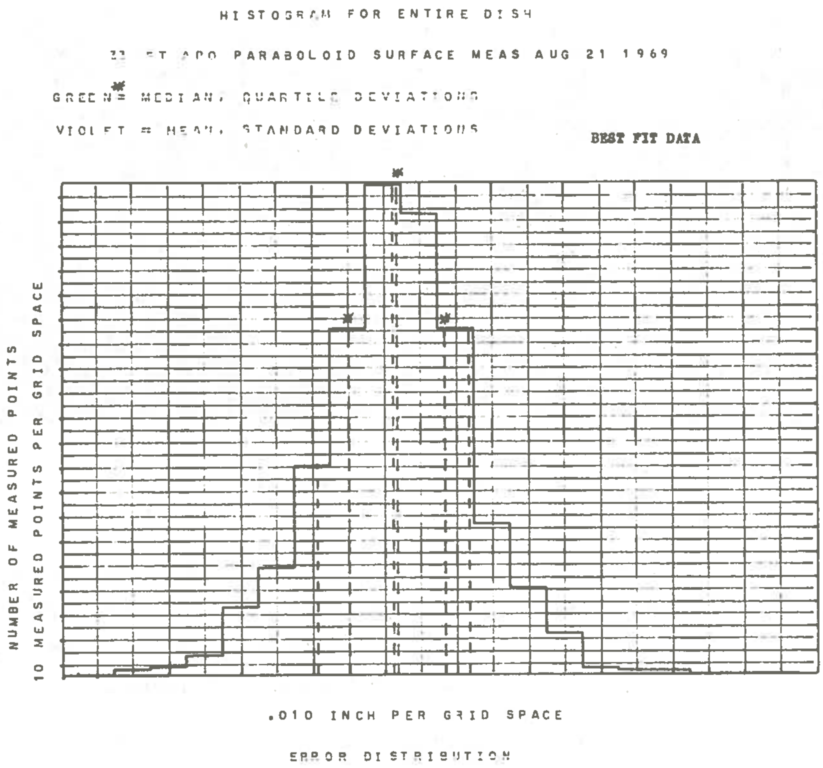


Figure 30 Histograms of raw and best fit data for August 21, 1969 survey

Figure 31 Polythene shelter used for surface modification and measurements in July–August 1969

It should also be noted that walking on the antenna surface was found to cause trouble in tilting the template, as well as in moving the surface itself, and all good surveys and surface adjustments were made without standing on the surface. *Therefore it is recommended that personnel not be allowed on the antenna surface.*

4. Antenna Surface Adjustment July 1969

The surveys of 1968–69 were necessitated by previously suspected reflector deformation. Results in Table 2 indicate that the best fit SD (standard deviation) did indeed deteriorate, from 0.025 inch in July 1961 to 0.035 inch in May 1968. Because of considerable interest in using this antenna at frequencies of ∿20 GHz, a decision was made to rework the outer surface area.

Agreement between the four surveys taken in May 1968 and May 1969 was examined by plotting the means of individual radial stations for best-fit data. Since the vertical height of the template varied between surveys, these four curves were superimposed for a best fit, as shown in Fig. 32. A slightly longer focal length seems to exist for the two surveys taken at a higher temperature, as expected. These means should ideally be horizontal lines, and the sag of some 0.060 inch indicates a corresponding sag in the antenna. A fifth curve was drawn on this figure to indicate the mean of the other four curves.

The May 16, 1968 survey was chosen as the basis for making corrections to the surface, as it was considered the best. These data were first modified so that its BF means would lie on the curve shown in Fig. 32. In order to find the expected improvement resulting from surface adjustment of various numbers of outer radial stations, several BFPs

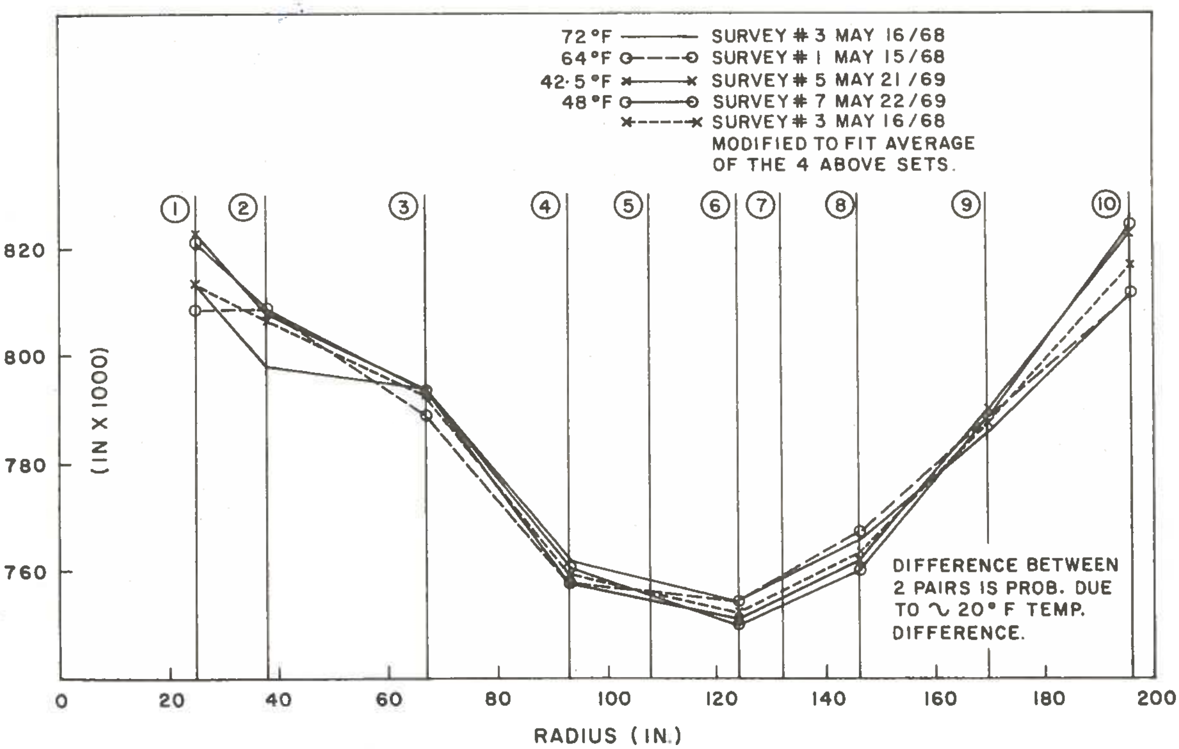


Figure 32 Mean plotted for each radial station for BFP

were calculated for this modified data set, based on radial stations:

(*i*) 1, 2, 3, 4, 6, 8, 9, 10 where no stations are changed
(*ii*) 1, 2, 3, 4, 6, 8, 9 where No. 10 would be adjusted to fit a BFP
(*iii*) 1, 2, 3, 4, 6, 8 where No. 9, 10 would be adjusted to fit a BFP
(*iv*) 1, 2, 3, 4, 6 where No. 8, 9, 10 would be adjusted to fit a BFP

TABLE 3

Estimation of Improvement for Various Surface Modifications
33 ft. ARO Paraboloid

Survey Used - Modified May 16, 1968. Shop template used

	raw	B.F.	raw	B.F.	raw	B.F.	raw	B.F.
Entire Antenna mean	721.22	786.22	731.69	795.44	743.44	804.47	758.11	811.53
SD	71.38	36.85	66.39	30.27	61.19	25.46	53.29	20.83
Radial Stn. 1 mean	810.58	813.28	810.58	814.02	810.58	814.97	810.58	816.02
SD	11.68	11.23	11.68	11.21	11.68	11.57	11.68	11.21
2 mean	800.69	806.98	800.69	808.65	800.69	810.87	800.69	813.20
SD	15.38	15.55	15.38	15.42	15.38	15.74	15.38	15.13
3 mean	773.07	792.63	773.07	797.86	773.07	804.73	773.07	812.27
SD	20.97	16.04	20.97	16.30	20.97	17.31	20.97	17.49
4 mean	721.35	759.05	721.35	769.13	721.35	782.38	721.35	796.91
SD	24.06	18.03	24.06	18.19	24.06	19.02	24.06	19.47
5 mean								
SD								
6 mean	684.06	751.93	684.86	769.85	684.86	793.39	684.86	819.22
SD	36.14	25.47	36.14	26.10	36.14	27.91	36.14	28.85
7 mean								
SD								
8 mean	670.22	763.22	670.22	788.08	670.22	820.73		
SD	42.84	28.56	42.84	29.54	42.84	32.26		
9 mean	661.43	787.50	661.43	821.20				
SD	51.23	35.09	51.23	36.18				
10 mean	648.72	816.34						
SD	62.28	51.60						
Tilt for B.F. $\phi°/\theta°$	.013	154.	.0116	154	.00914	171.	.00750	152.
Focal length template / B.F.	169.400	169.902	169.400	170.037	169.400	170.214	169.400	170.409
Survey Temp.	75° →							
BFP based on stns.	1,2,3,4,6,8,9,10		1,2,3,4,6,8,9		1,2,3,4,6,8		1,2,3,4,6	
Radial stns. to modify	none		10		9,10		8,9,10	
b for B.F. eqn.			795.6		804.5		812.	
$x = a y^2 + b$	Note: all units in inches x 1000 except f.l. which is in inches							

These calculations are summarized in Table 3. Over-all BFP standard deviations achievable vary from 0.037 inch for no adjustment to 0.021 inch for modification of the surface over the outer three stations. These results would apply if the tolerance of the modified portion is similar to that of the inner portion. The antenna surface was adjusted approximately, from radial station No. 7 to No. 10, to the BFP indicated in the last column of Table 3.

A sweep section of template blade was constructed and attached to the existing template from radial station No. 6 to No. 10. The curve of this blade is not quite parabolic, but a line drawn under it with a clearance of 0.125 inch is parabolic, with a f.l. of 170.409 inches. The antenna base was then tilted so that the axis of the BFP, calculated in Table 3, was vertical.

After damaged structural members of the antenna were either straightened or replaced, the huckbolt rivets which maintain the antenna skin position were all removed over the outer antenna surface. One aluminum panel section was replaced. A table of axial offsets (movement necessary to achieve a BFP for each survey station) had been prepared, but this was not used. Surface adjustment was made using a balanced template with a feeler gauge between the sweep blade and the antenna surface. It was necessary to adjust the template height so that a clearance of $\sim$0.125 inch would exist between the template blade and the antenna BFP. This was difficult to set precisely and a final value of 0.112 inch was used.

It was found that the base tilt varied $\sim$10–15 seconds due to heating of the concrete slab by the sun, so all observations and adjustments were made at night. Furthermore the reference surface on the antenna base provided for the Talyvel levels was not adequate, as a surface must be ground flat to $\sim 10^{-5}$ inch for use with a Talyvel level on its most sensitive scale (±50 sec full scale). Moisture and dirt also caused problems on these reference surfaces. In addition, the conical antenna base was suspected of slight flexing radially, and the triangular base supporting this was springy.

Two surveys were made on August 20 and 21, 1969, after the surface adjustment was completed. The outer edge of the antenna was found to be very flexible between supporting points, discernible movement extending inward from the rim perhaps 16 inches. Survey values obtained at radial station No. 10 consequently had a few large variations between supports. These points were arbitrarily suppressed in the calculations because of the tapered aperture distribution employed in radio observations, and the results are presented in Table 3.

The small difference between the predicted BFP SD of 0.0208 inch and the BFP SD of 0.0211 inch obtained indicates that good tolerances were maintained during the surface adjustment. It should be remembered that if the template station locations are much in error, then the so-called BFP which has been obtained will be better than the 'true' BFP.

Acknowledgment

Considerable effort in obtaining acceptable data by D. Hoey, J. Barnes, S. Gerylo, and F. Thayer under adverse conditions is acknowledged. A program was written by B. Clarke to obtain design data for the sweep template blade. Most of the credit for achieving a BFP SD of 0.021 inch after reworking the surface must go to Mr. C. Berlanda who made the surface adjustment.

References

1. Ruze, J. Antenna tolerance theory, a review. Proc. IEEE, 54: 633–640; 1966.
2. Vu, The Bao. Influence of correlation interval and illumination taper in antenna tolerance theory. Proc. IEE, 116 (2): 195–202; 1969.
3. Breithaupt, R.W. and Marks, R.O. Reflective surface analysis of the 33-foot and 150-foot paraboloid antennas of the Algonquin Radio Observatory. NRC Report ERB-786, June 1968.
4. Diether, P.A. and Henry, H.W. University of California 400-inch reflector reflective surface analysis. Philco WDL-TR-1267, February 29, 1960.