NBS REPORT

5579

HOURLY CORRELATION OF RADIO PATH LENGTHS AND SURFACE REFRACTIVITY INDEX FROM MAUI, T. H., PHASE STABILITY PROGRAM

by

M. C. Thompson, Jr. and Frank E. Freethey

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
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HOURLY CORRELATION OF RADIO PATH LENGTHS AND SURFACE REFRACTIVITY INDEX FROM MAUI, T. H., PHASE STABILITY PROGRAM

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I. Introduction:

This report describes refractive index measurements made during the NBS phase stability experiments [1-2] conducted on the island of Maui, T. H., during November 1956 and their correlation with the phase measurements. The object of these measurements was to determine to what extent it might be feasible to predict phase variability from ordinary meteorological observations.

II. Terrain:

A map of the island of Maui, T. H., is shown in Figure 1. The lower station of the propagation path was located at the old naval airport at Puunene at an elevation above mean sea level of 110 feet, and the upper station on the top of Haleakala peak, 10,025 feet above mean sea level and approximately 81,608 feet distant by line of sight from the Puunene location. The surface profile beneath the propagation path is shown in Figure 2. The radio path elevation angle was 6.8°. Meteorological instrument stations were maintained at three intermediate points on the slope of Haleakala. No. 1, at an elevation of about 3000 feet, was situated about 3 miles NE of the propagation path and was generally under the influence of the NE trade wind. Station No. 2 was about 7000 feet above sea level and 3 miles NE of the path. This location was sometimes influenced by an upslope condition deriving from the trade winds, but more often was swept by a return, or SW wind, resulting from the circulation of the trade winds about Haleakala from the west Maui mountains. Station No. 3 was about 2 miles NE of the path at an elevation of 8,600 feet and was usually influenced by the SW circulation wind.

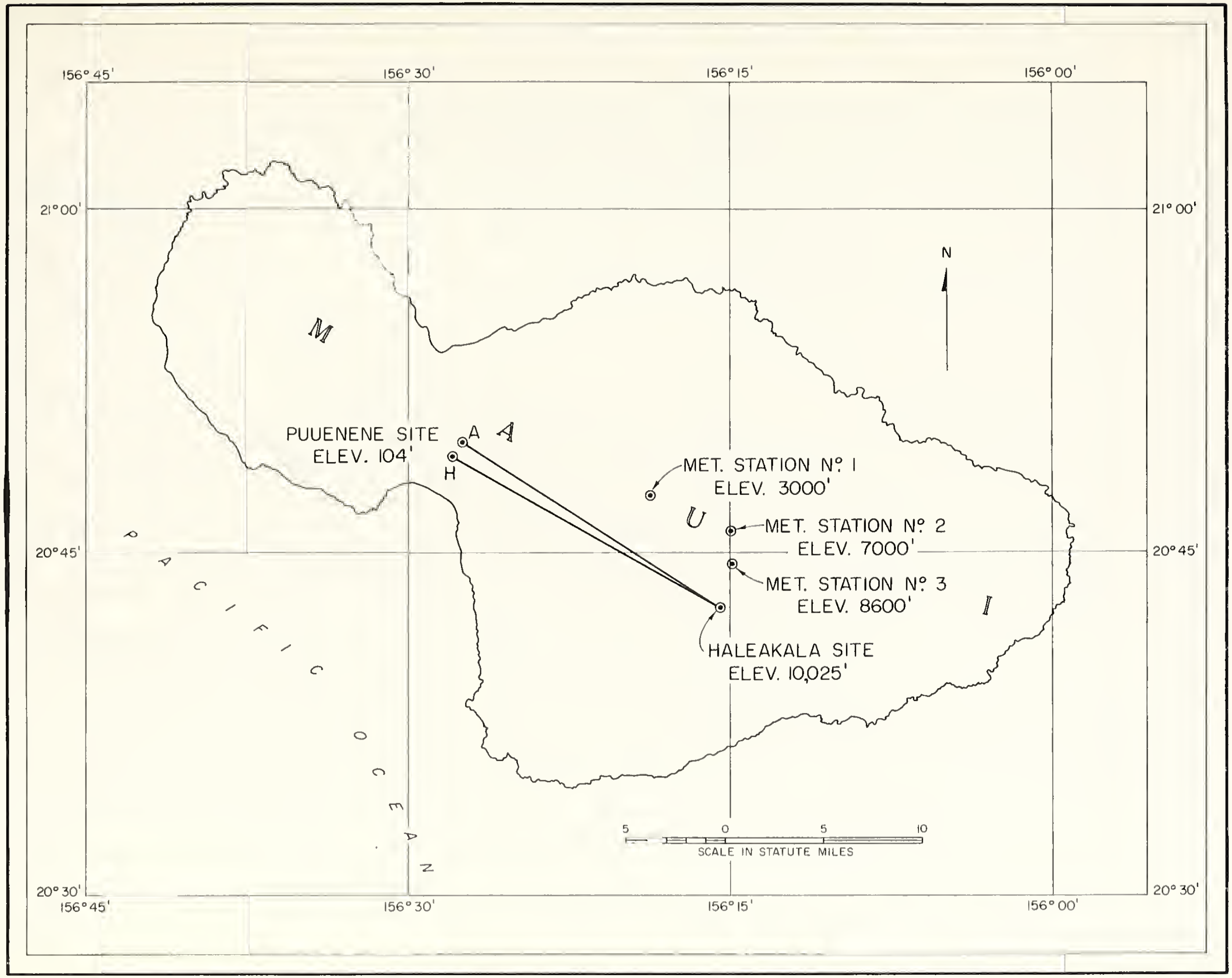
We feel that the most serious weaknesses in this analysis are:

1. The discontinuities in the phase recordings due to interruptions in radio signals and equipment performance.
2. The fact that, except for the end points, the surface meteorological stations could not be located closer to the radio path, especially in an area having such unusual wind circulation characteristics. 3 /

III. Airborne Index Measurements:

The airborne measurements were made using an NBS Model 2 microwave refractometer built for the Arizona Electronic Proving Grounds, Ft. Huachuca, Arizona, 4 / and on loan from that organization. The refractometer was installed in an L-20 aircraft rented from the U. S. Army installation at Wheeler AFB, Oahu, T. H.

The normal flight patterns were to climb to about 11,000 feet in the vicinity of Puunene, proceed to the upper site at Haleakala Summit, turn 180° and descend along a line approximately parallel to and 1000 feet above the actual radio path. The indicated air speed during this descent usually varied between 90 and 120 mph with the rate of descent approximately 1,500 ft/min. Since the region near the path included the local commercial airlanes, radio path descents were feasible



LOCATION OF PROPAGATION PATHS USED IN MAUI EXPERIMENT

Figure 1

TERRAIN PROFILE FOR MAUI PHASE MEASUREMENTS

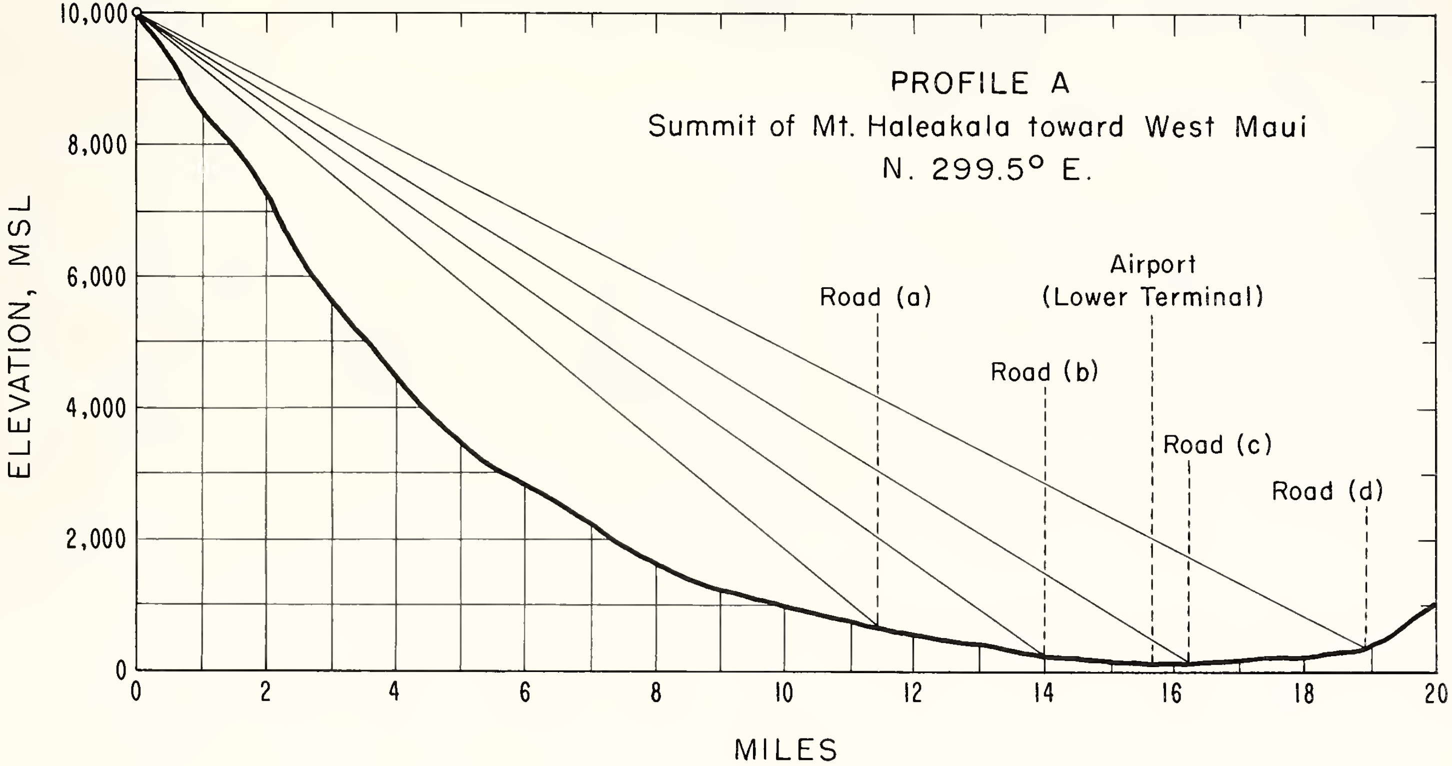


Figure 2

only during the few hours of each day when clouds were not present in the area.

Figures 3 and 4 represent the type of data obtained from these flights. The variations in index roughness (as indicated by RMS values of the fluctuations in a band width of approximately .05 to 30 cps.) with altitude are shown in Figure 3. The power density spectrum of a sample of data obtained in level flight at approximately 3,800 altitude is shown in Figure 4. This level was normally found to be characterized by larger index variations. The flight pattern was again along the line between the terminals of the radio path but at constant altitude. Because of the rising terrain this flight path extended along only about half of the extent of the radio path.

IV. Ground Measurements:

Surface observations of meterological data were taken at five ground stations. These recordings are summarized in the following :

Station	Altitude (MSL)	Instruments
Puunene	110 ft.	Microbarograph Hygrothermograph Aerovane wind recorder
1	3000	Microbarograph Hygrothermograph
2	7000	Microbarograph Hygrothermograph
3	8,600	Microbarograph Hygrothermograph
Haleakala	10,000	Mercury barometer Hygrothermograph Aerovane wind recorder

The station at Haleakala was in operation from 1000, November 5 to 1800, November 9. All others were operated from 1000, November 5 to 0800, November 10. The pressure record at Haleakala consists of barometer readings at 30 minute intervals. All other records were continuous. The radio phase records were made at 9,414 MC between Puunene and Haleakala and the analysis of these records covers the period from 0200, November 6 to 1800, November 9.

V. Data Reduction and Presentation:

a. Hourly N_s values at each station throughout operating period were computed from records of pressure, temperature and relative humidity.

b. These hourly N_s values were plotted as ordinates against time of day and date for the entire operating period, as a family of curves representing each station, simple average of hourly N_s for all stations, and simple average of hourly N_s for upper and lower stations only (see Figure 5).

c. For daily comparison of hourly N_s variations at each station, the curves of b, above were replotted as a series of families representing each day's fluctuations at each of the five stations. (See Figures 6a, 6b, 6c, 6d, and 6e).

d. Average values of hourly N_s for the entire path, weighted for altitude differences (Δh) between the recording stations were computed and plotted versus time of day in a family of curves representing each day's fluctuations (See Figure 7).

e. Equal N_s contours at 5N intervals were plotted as a family of curves on a graph having altitude as ordinate versus time for the entire period of the run as abscissa. Since only five determinations of N for any one hour were actually made at the respective altitudes of

REFRACTOMETER DATA

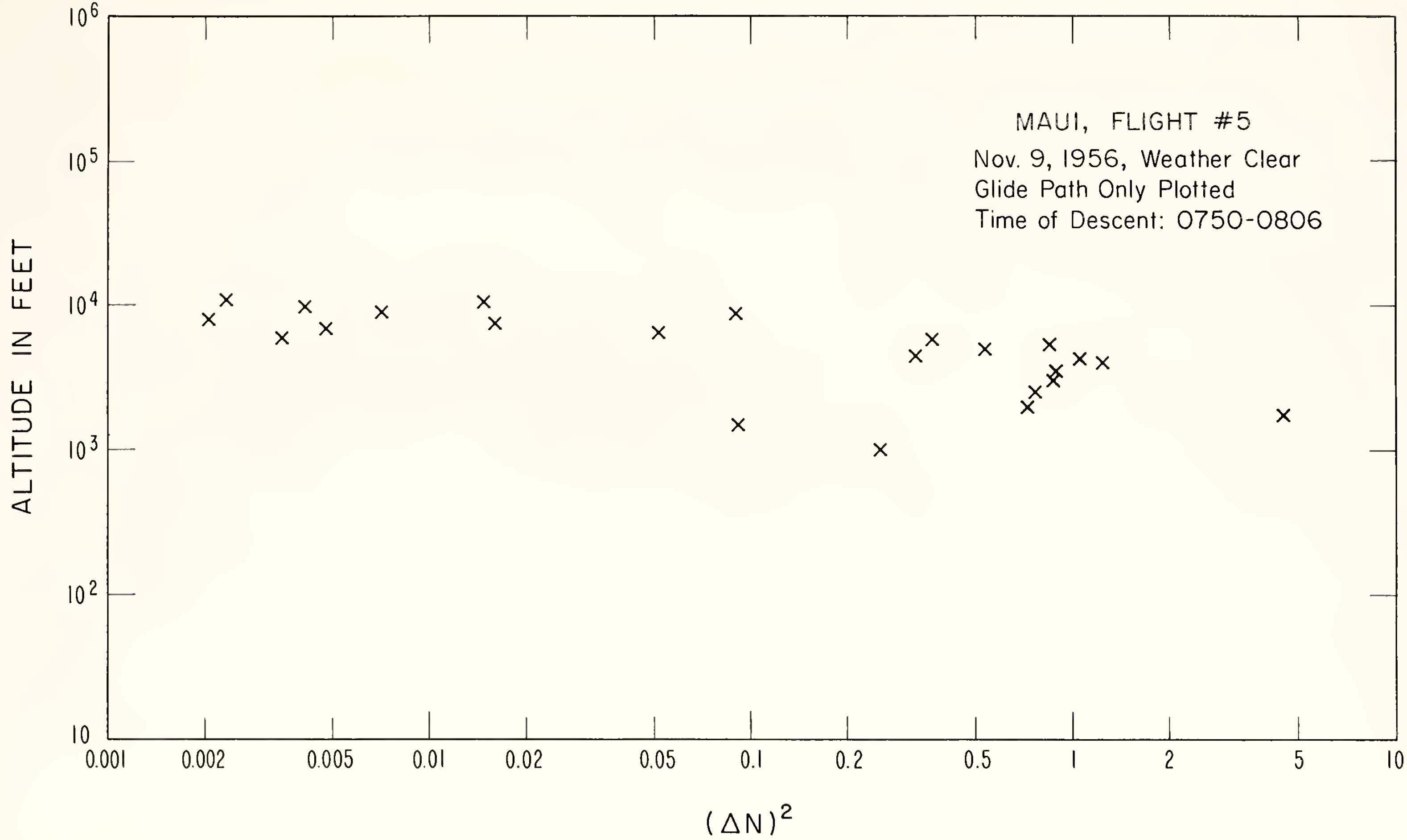


Figure 3

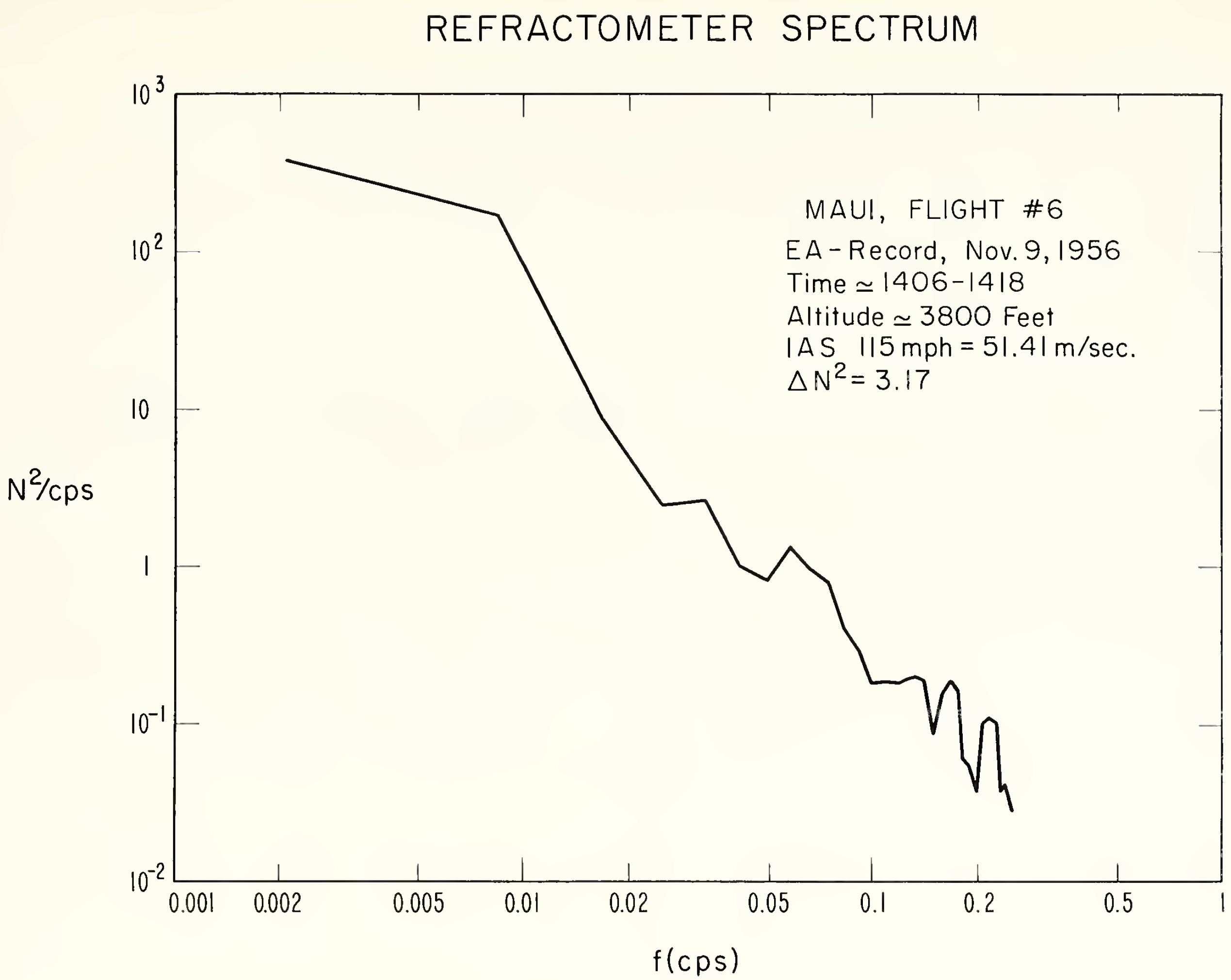

REFRACTOMETER SPECTRUM
MAUI, FLIGHT #6
EA-Record, Nov. 9, 1956
Time ≃ 1406-1418
Altitude ≃ 3800 Feet
IAS 115 mph = 51.41 m/sec.
ΔN² = 3.17
N²/cps
10³
10²
10
1
10⁻¹
10⁻²
0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
f(cps)

Figure 4

HOURLY VALUES OF SURFACE REFRACTIVITY FOR FIVE STATIONS AND AVERAGES

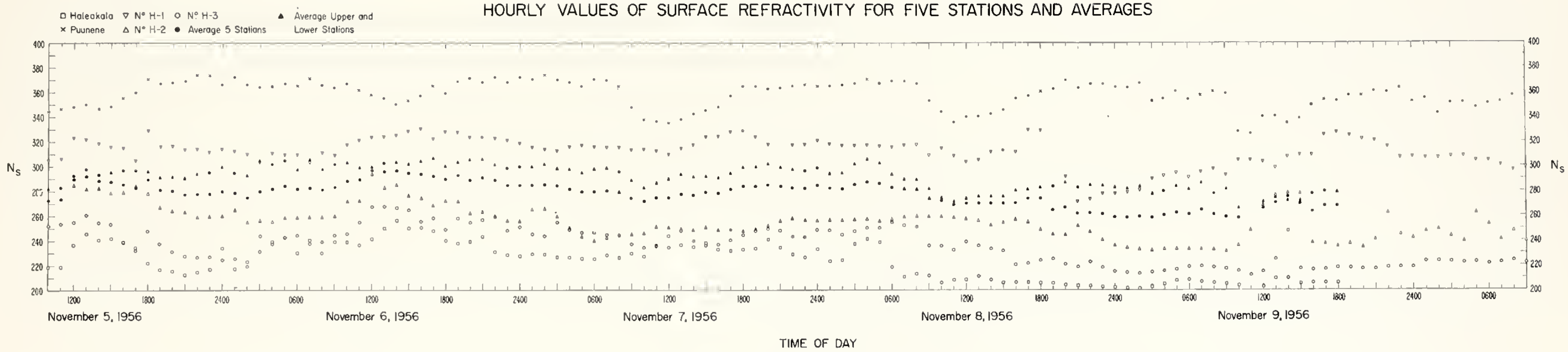


Figure 5

DAILY COMPARISON OF HOURLY VALUES OF SURFACE REFRACTIVITY FOR PUUNENE STATION, ELEVATION 110 FEET MSL

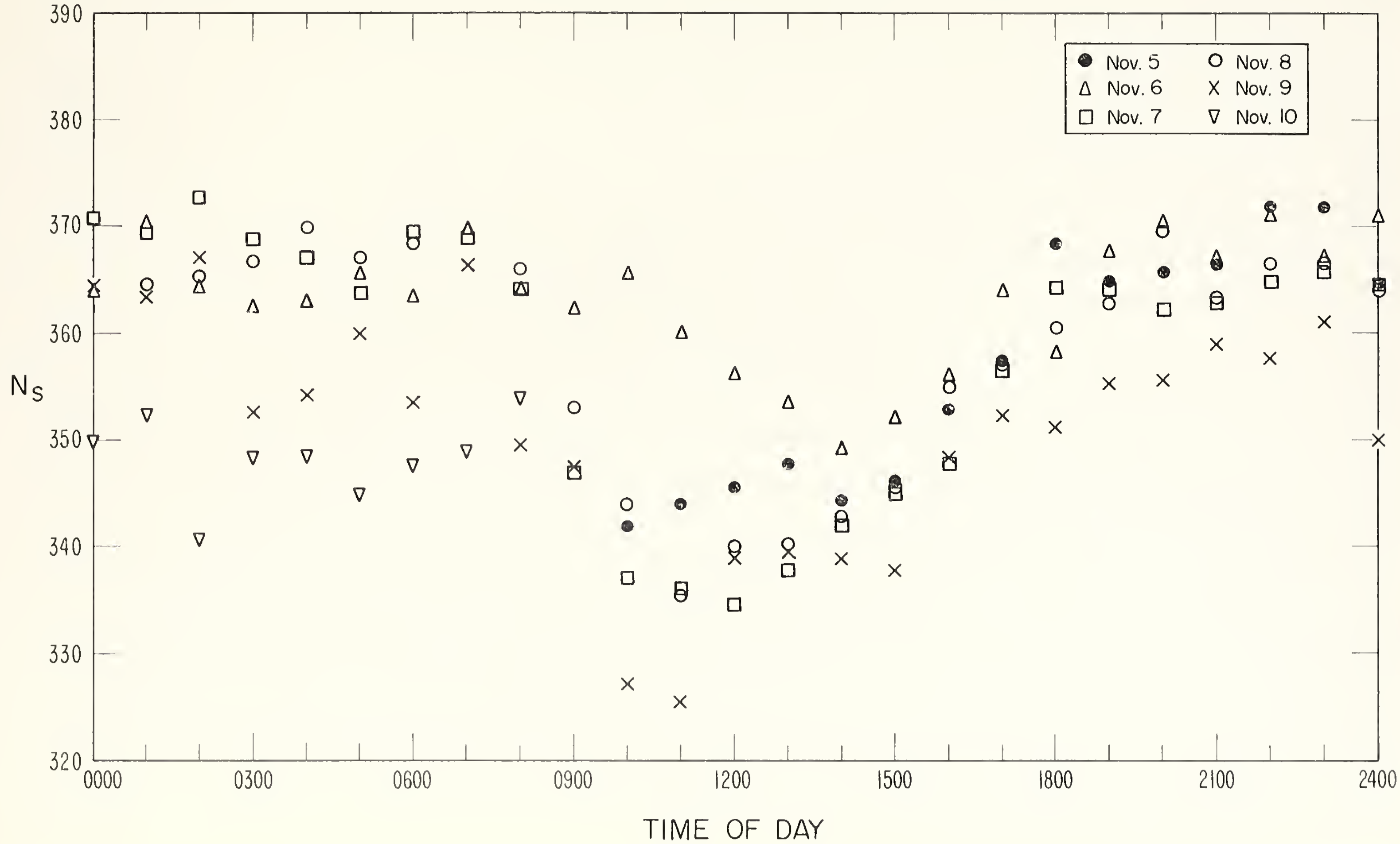


Figure 6a

DAILY COMPARISON OF HOURLY VALUES OF SURFACE REFRACTIVITY FOR STATION Nº 1, ELEVATION 3,000 FEET MSL

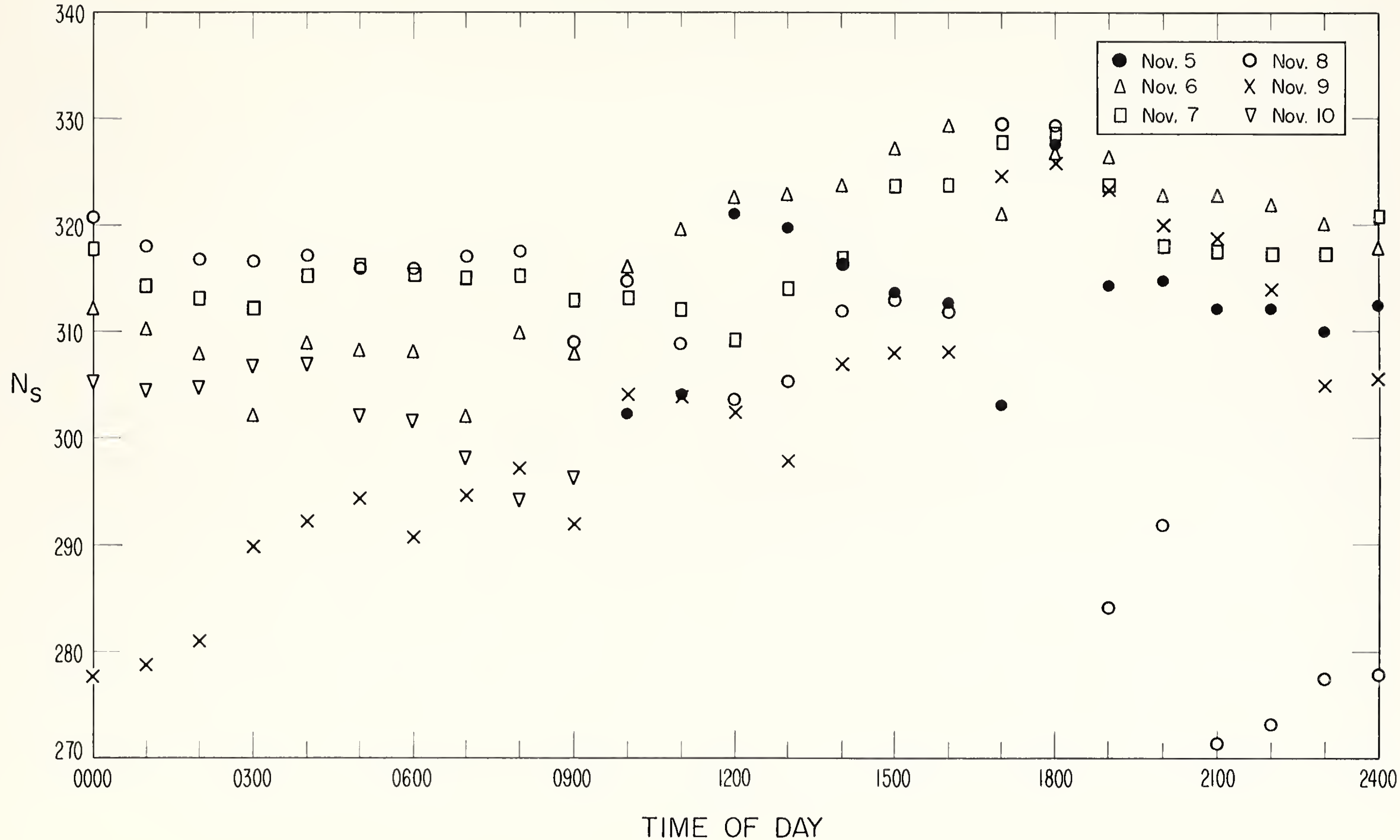


Figure 6b

DAILY COMPARISON OF HOURLY VALUES OF SURFACE REFRACTIVITY
FOR STATION N° 2, ELEVATION 7,000 FEET MSL

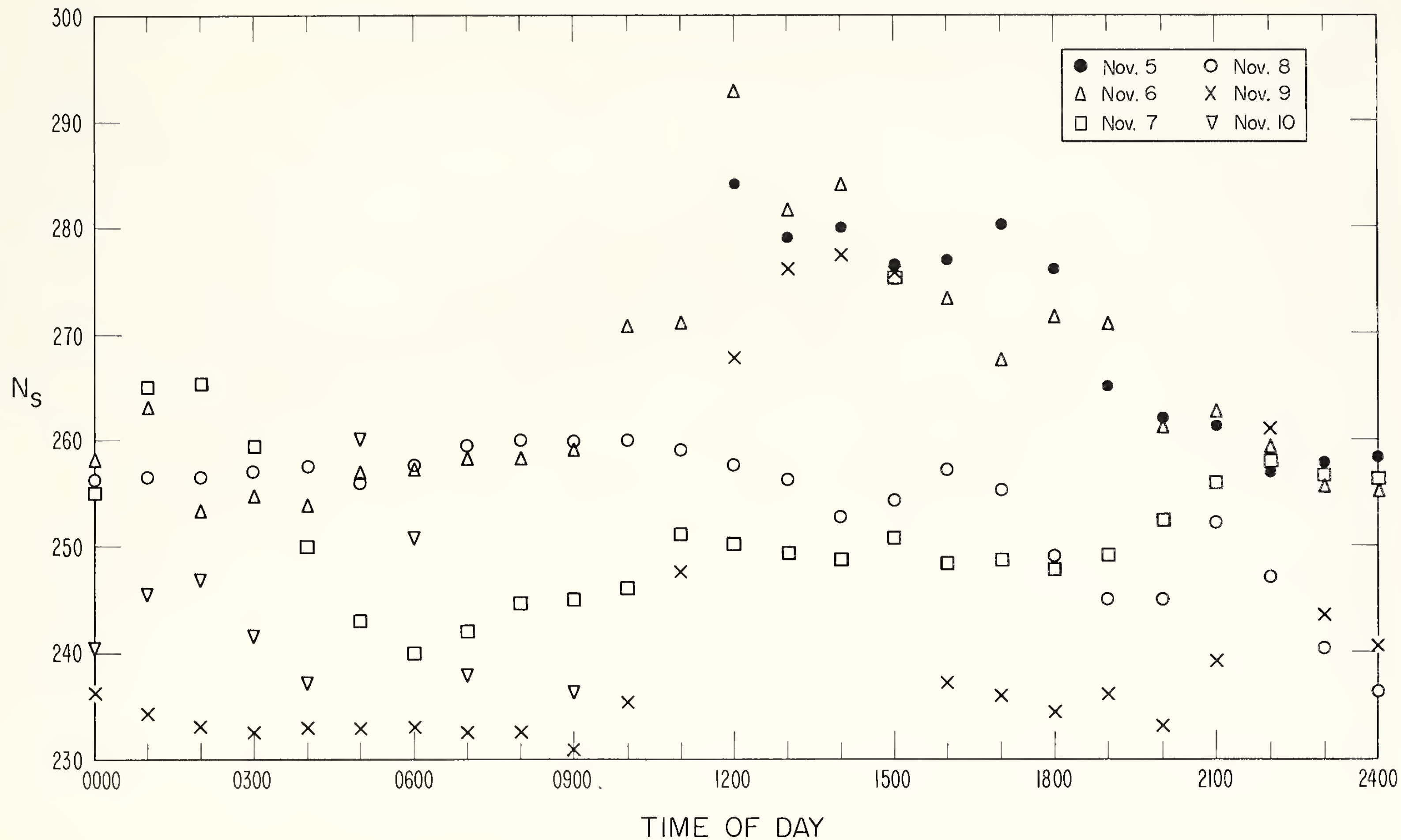


Figure 6c

DAILY COMPARISON OF HOURLY VALUES OF SURFACE REFRACTIVITY
FOR STATION N° 3, ELEVATION 8,600 FEET MSL

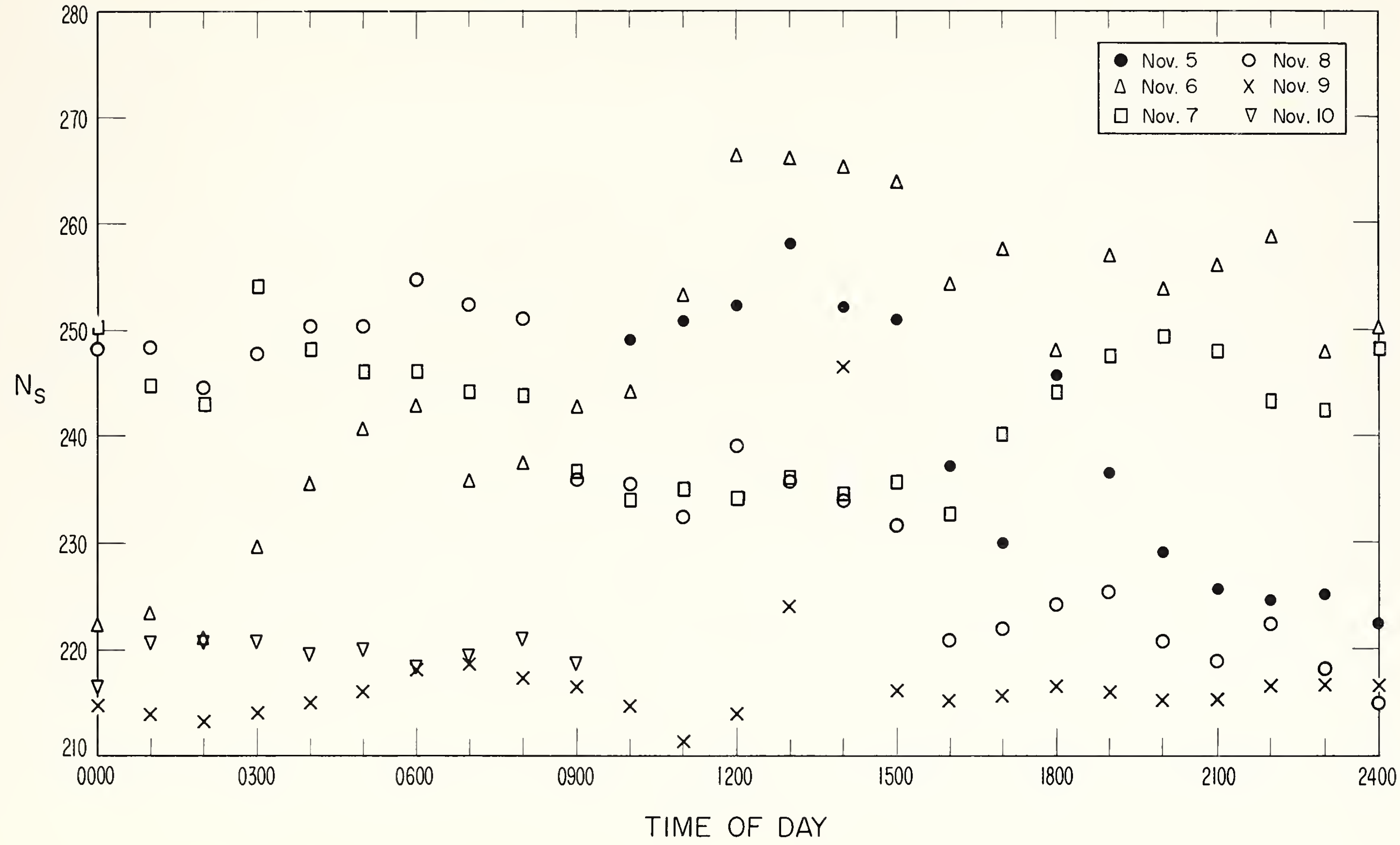


Figure 6d

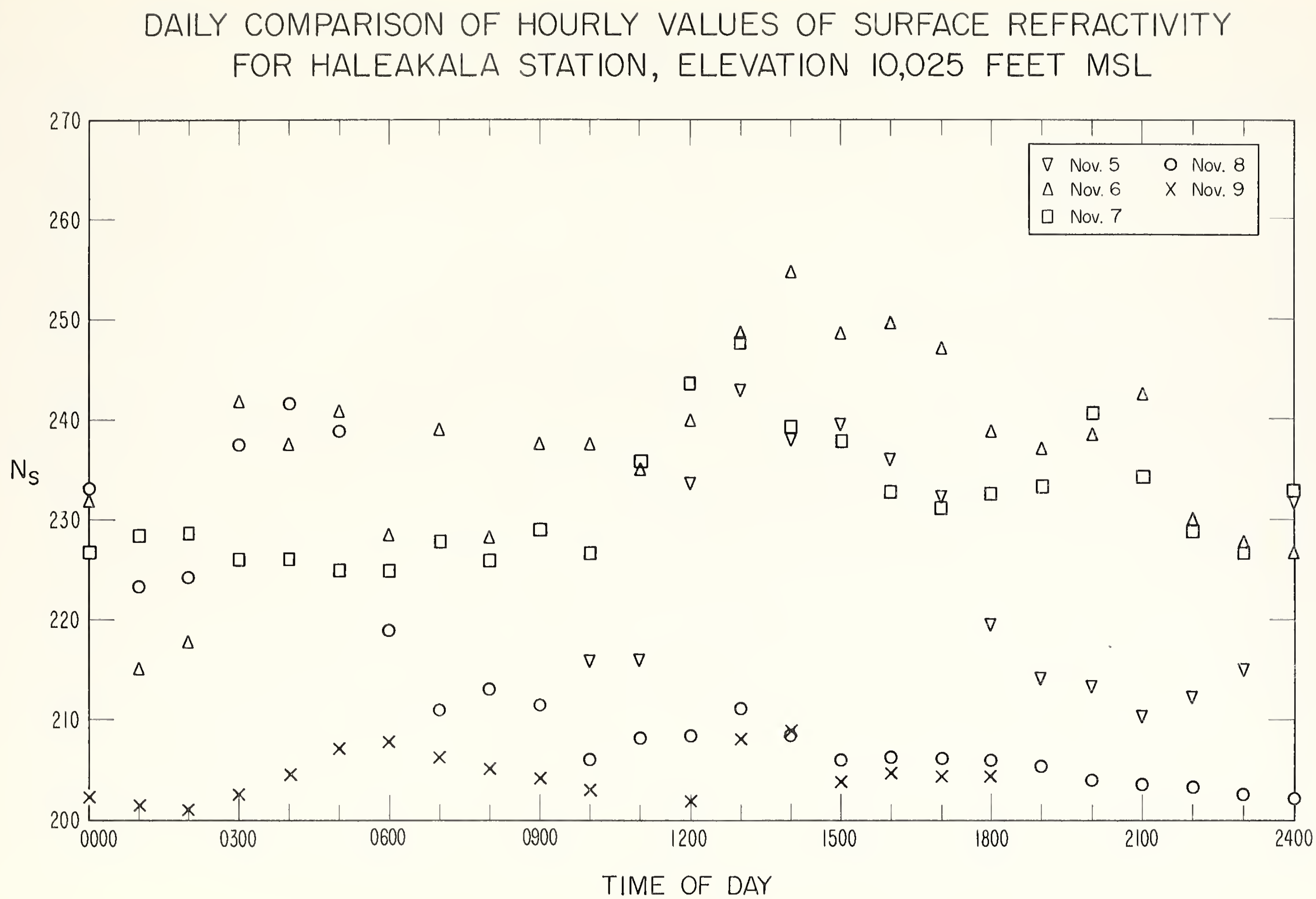

DAILY COMPARISON OF HOURLY VALUES OF SURFACE REFRACTIVITY
FOR HALEAKALA STATION, ELEVATION 10,025 FEET MSL
Nov. 5
Nov. 6
Nov. 7
Nov. 8
Nov. 9
N_S
270
260
250
240
230
220
210
200
0000
0300
0600
0900
1200
1500
1800
2100
2400
TIME OF DAY

Figure 6e

DAILY COMPARISON OF WEIGHTED AVERAGE SURFACE REFRACTIVITY FOR FIVE STATIONS

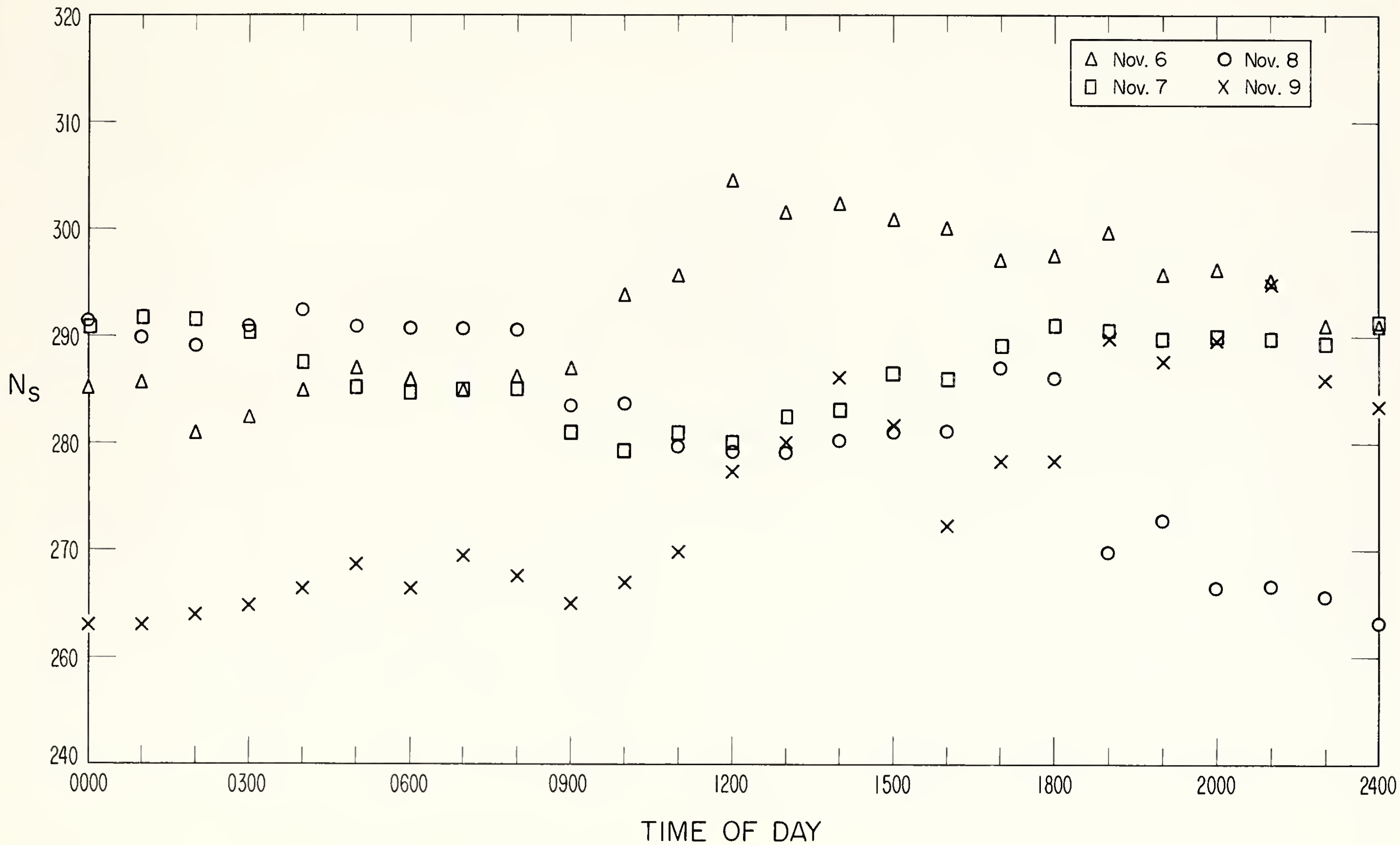


Figure 7

the five recording stations, the spacing of the 5N intervals between stations was done by linear interpolation. Each 5N change, therefore, was assumed to occur at equally spaced altitude intervals between any two stations (See Figure 8).

f. From the records of variations in the phase of the signal over the round trip path between Puunene and Haleakala, the phase changes were read off for the time interval from 0130, November 6 to 1815, November 9, at intervals of approximately 15 minutes. Using only those cumulative shifts corresponding to the full hour intervals, these phase changes in terms of equivalent $\Delta N \phi$, were plotted against the known N_s value for the respective hour and day as a point array for:

1. Puunene (Figure 9)
2. Station #1 (Figure 10)
3. Station #2 (Figure 11)
4. Station #3 (Figure 12)
5. Haleakala (Figure 13)
6. Weighted average N_s for entire path (Figure 14)
7. Simple average N_s for five stations (Figure 15)
8. Simple average N_s for upper and lower stations (Figure 16)

The scales on these graphs were so chosen as to make the theoretical line determined by the point array have a slope of unity.

g. Each single composite graph described in paragraph f above, was replotted as six separate graphs, each covering a four hour period of the day, e.g. 0100 - 0400 inclusive, 0500 - 0800 inclusive, etc. (See Figures 9a, 9b, 9c, 9d, 9e, 9f, etc. through Figures 16a, 16b, 16c, 16d, 16e, 16f).

For each of the point arrays plotted as described in paragraphs f and g, a regression line (indicated by a broken line on the graphs) was calculated and drawn and the following information computed and noted on the graph concerned:

n = number of points
b = slope of regression line
γ = correlation coefficient of points about regression line
$\% > t_0$ = A percentage figure which is a measure of how well the observed slope b agrees with the expected value of unity. Specifically, this number answers the question: What is the percent probability that in repeated samplings the quantity 1-b will be larger than that obtained in the sample plotted?

h. The relative phase variation versus time of day and date was plotted at 15 minute intervals for the period from 0130, November 7 to 1800, November 9 with gross weather conditions as noted in the Haleakala log, chronologically indicated (See Figure 17).

VI. General Weather:

From 2000 to about 0900 daily weather in the path was clear. During the middle of the day, from 0900 to 1700 clouds or fog was the rule, sometimes in the path, sometimes above it. It usually began to break up to light scattered clouds by 1800. The sun at this season rose about 0600 on the peak and about an hour later on Puunene in the valley, when it first illuminated the path. Sunset occurred about 1730.

Summary:

Because of the limited period covered by the records described above, as well as discontinuities that exist in some of them, it is difficult, if not impossible, to analyze conclusively the information they may contain. Well established diurnal variations in refractive index

ALTITUDE-TIME CONTOURS OF EQUAL INDEX FOR MAUI EXPERIMENTS

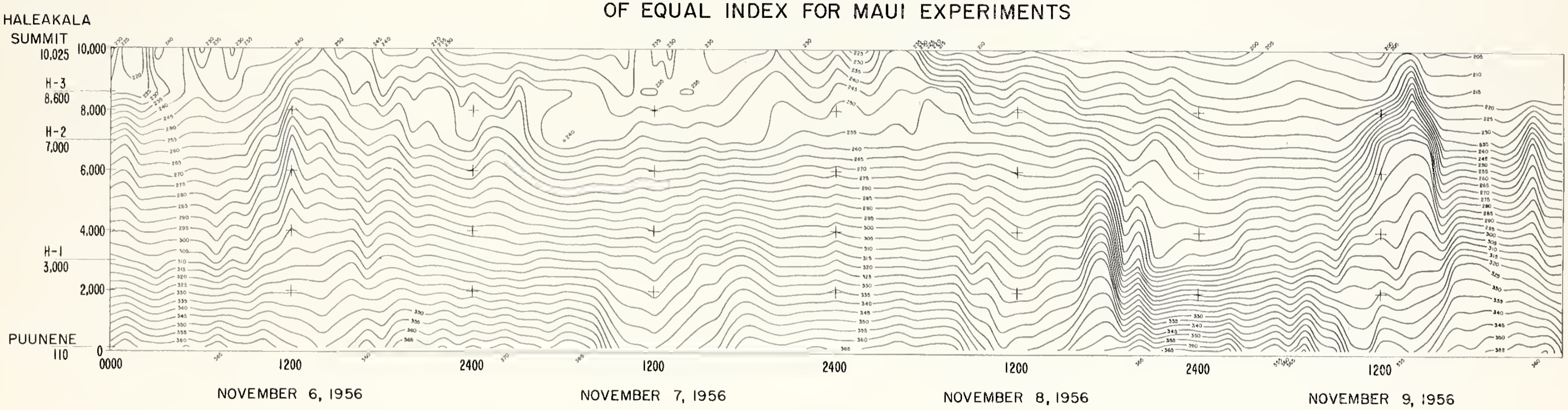


Figure 8

RELATIVE RADIO PATH INDEX VERSUS SURFACE INDEX AT PUUNENE, ELEVATION 110 FEET

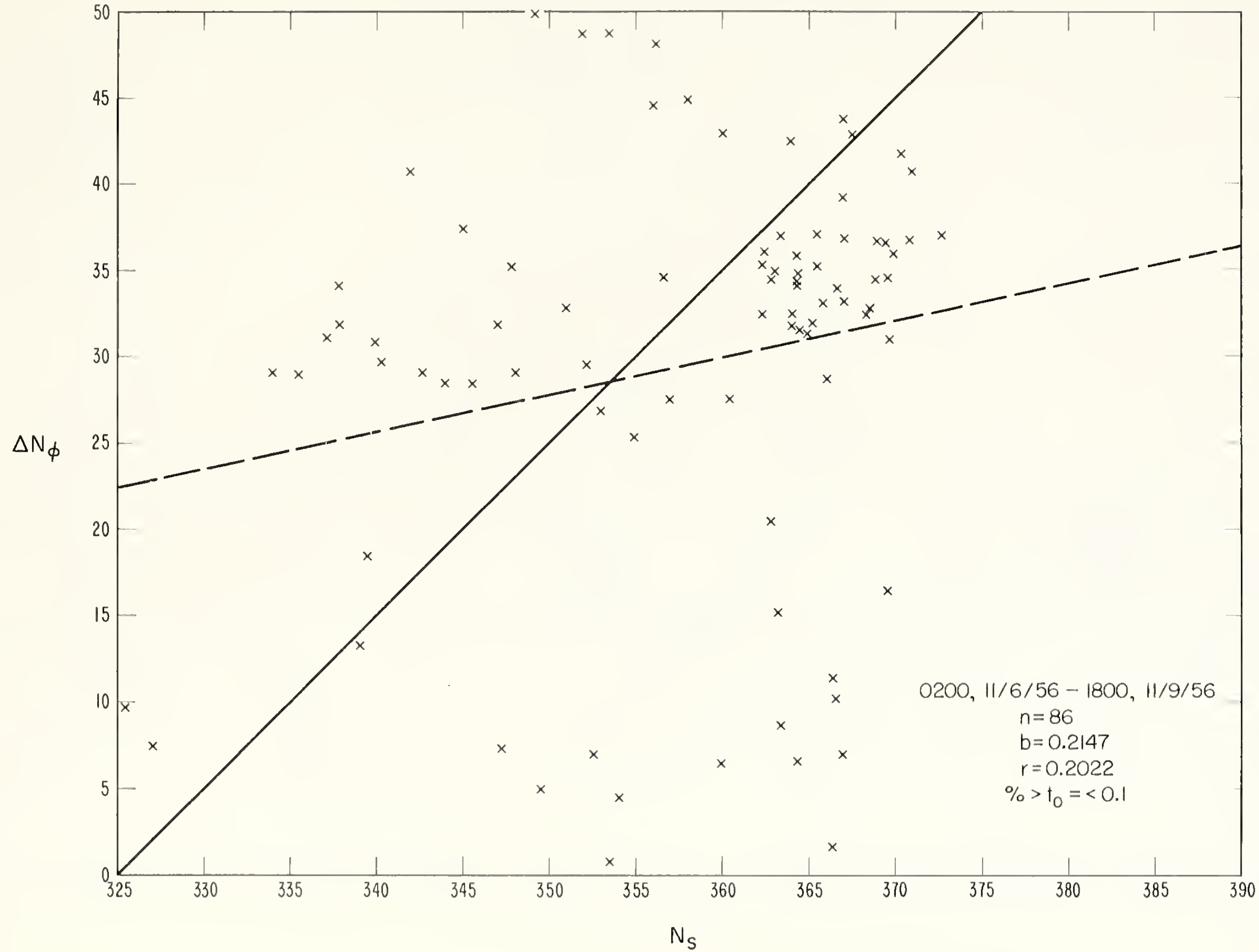
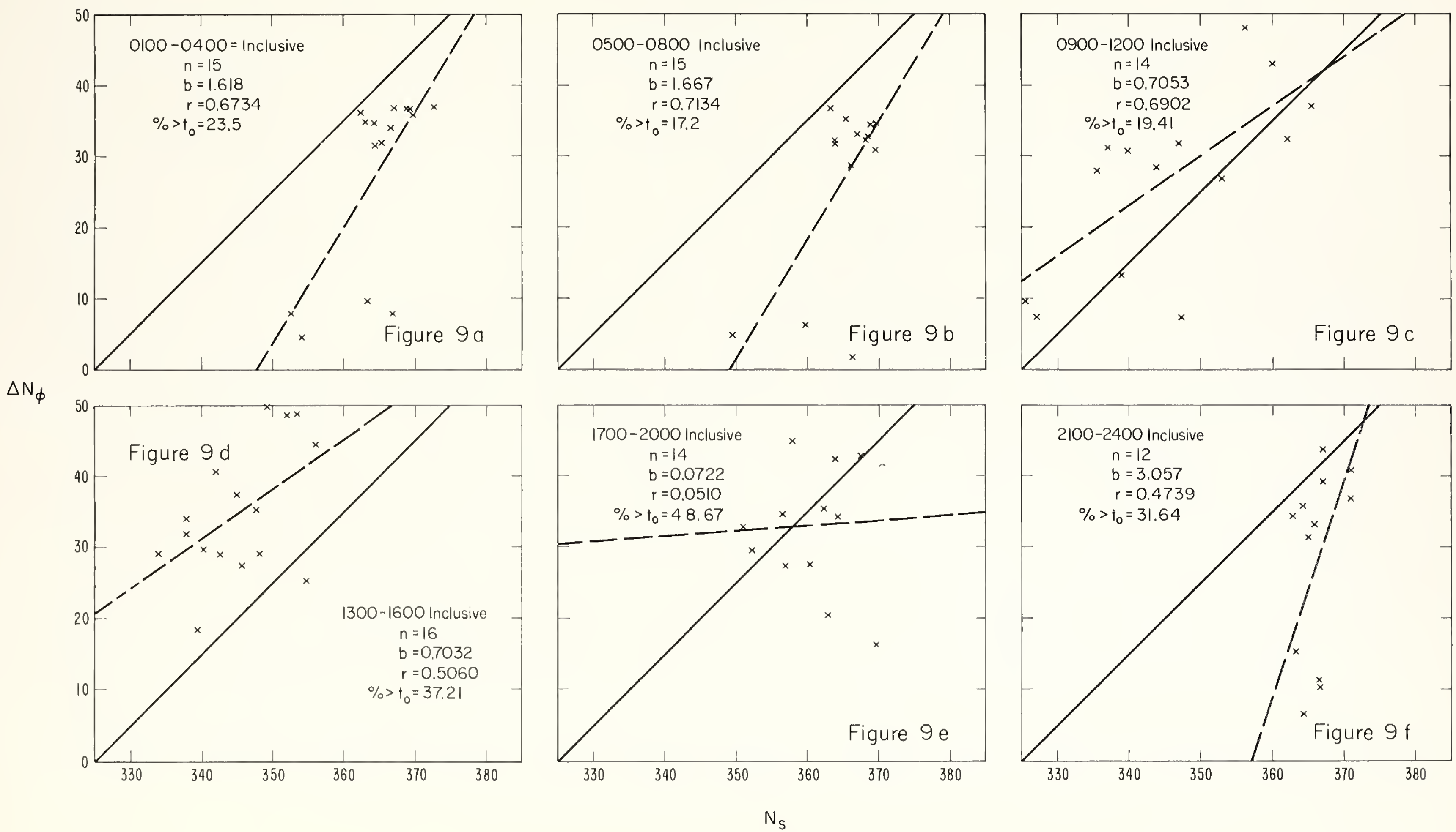


Figure 9

RELATIVE RADIO PATH INDEX VERSUS SURFACE INDEX AT PUUNENE, ELEVATION 110 FEET



RELATIVE RADIO PATH INDEX VERSUS SURFACE INDEX
AT STATION Nº 1, ELEVATION ~ 3,000 FEET

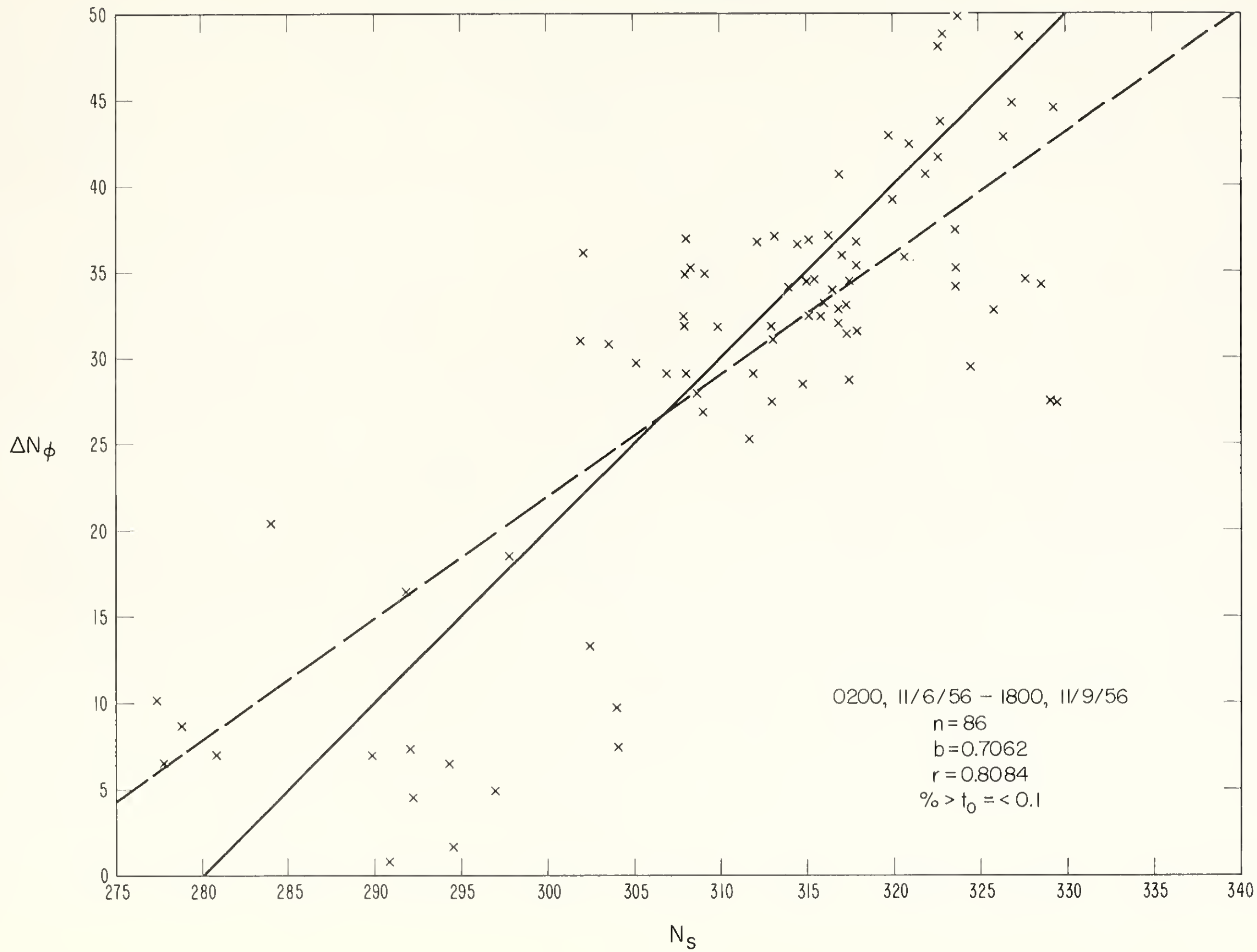
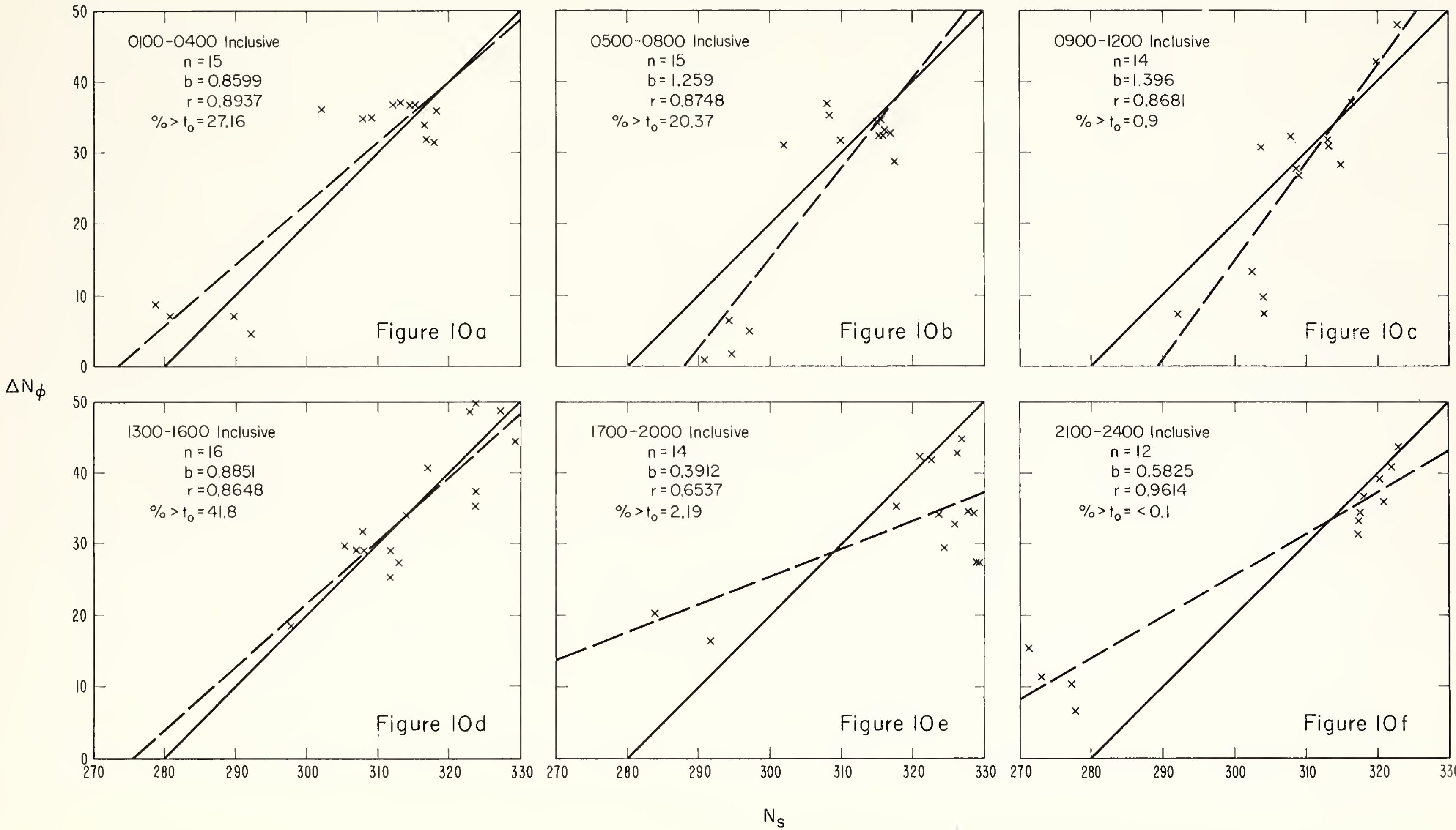


Figure 10

RELATIVE RADIO PATH INDEX VERSUS SURFACE INDEX AT STATION #1, ELEVATION 3,000 FEET



RELATIVE RADIO PATH INDEX VERSUS SURFACE INDEX AT STATION Nº 2, ELEVATION ~ 7,000 FEET

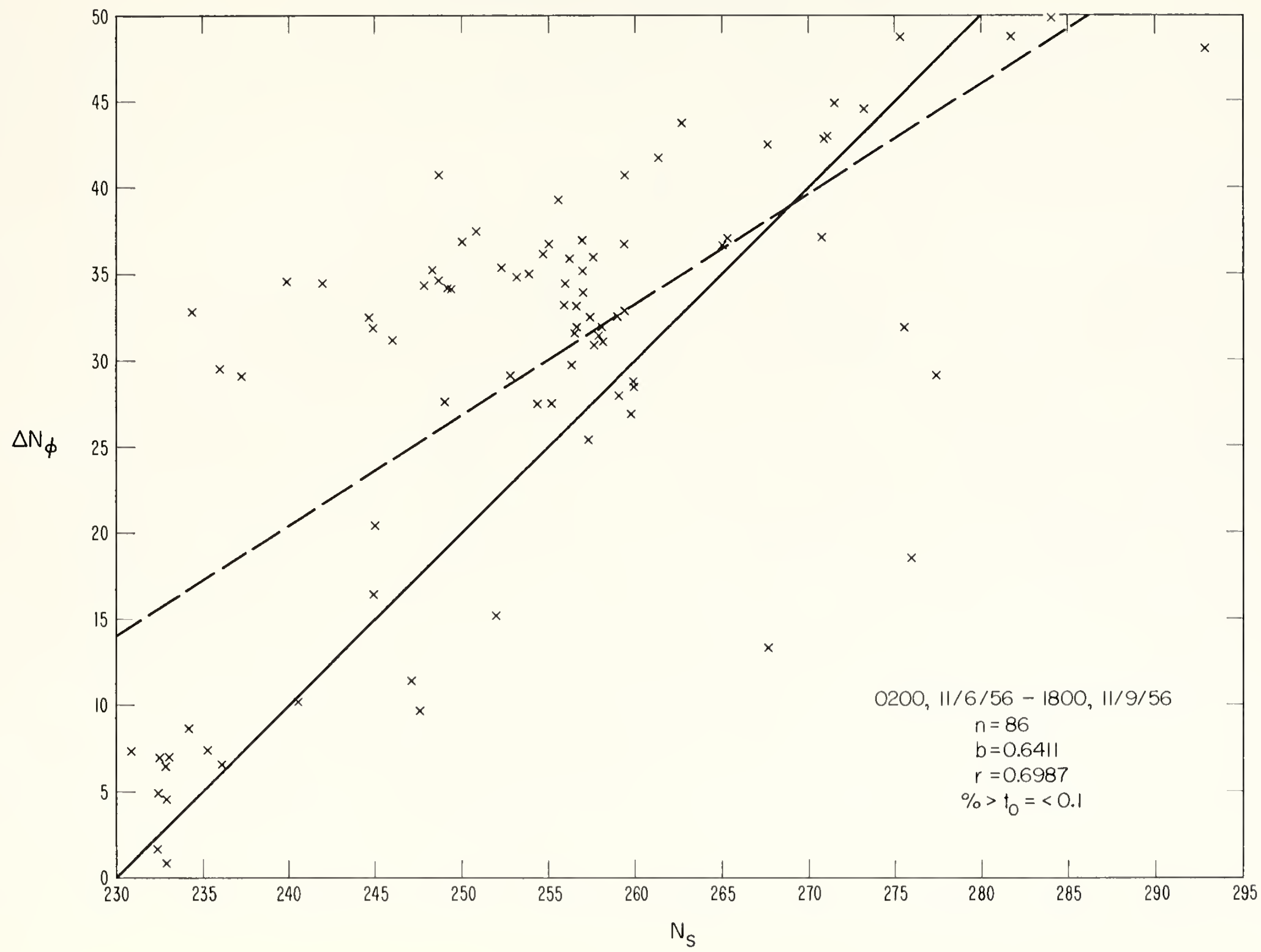
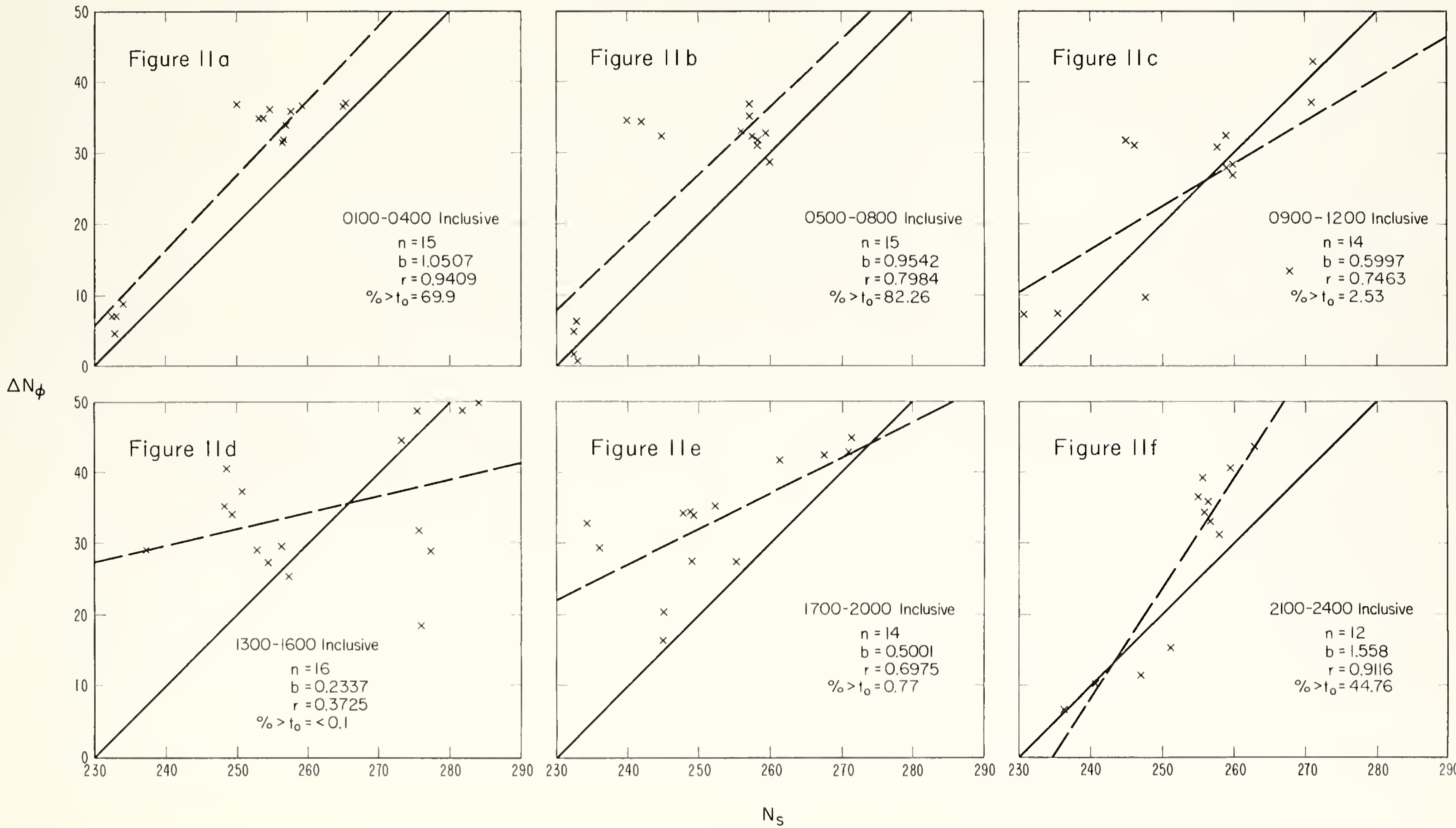


Figure 11

RELATIVE RADIO PATH INDEX VERSUS SURFACE INDEX AT STATION #2, ELEVATION 7,000 FEET



RELATIVE RADIO PATH INDEX VERSUS SURFACE INDEX
AT STATION N° 3, ELEVATION ~ 8,600 FEET

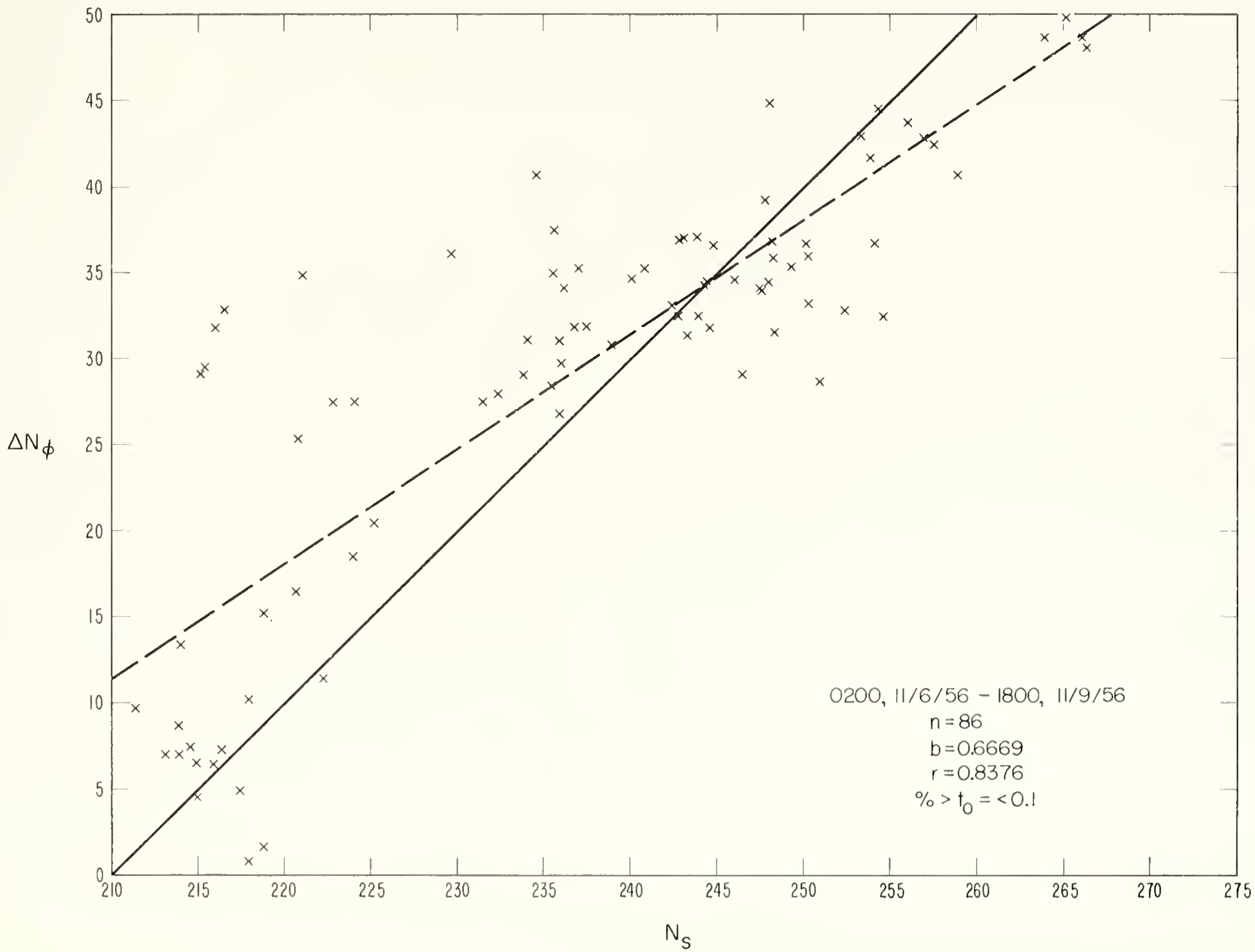
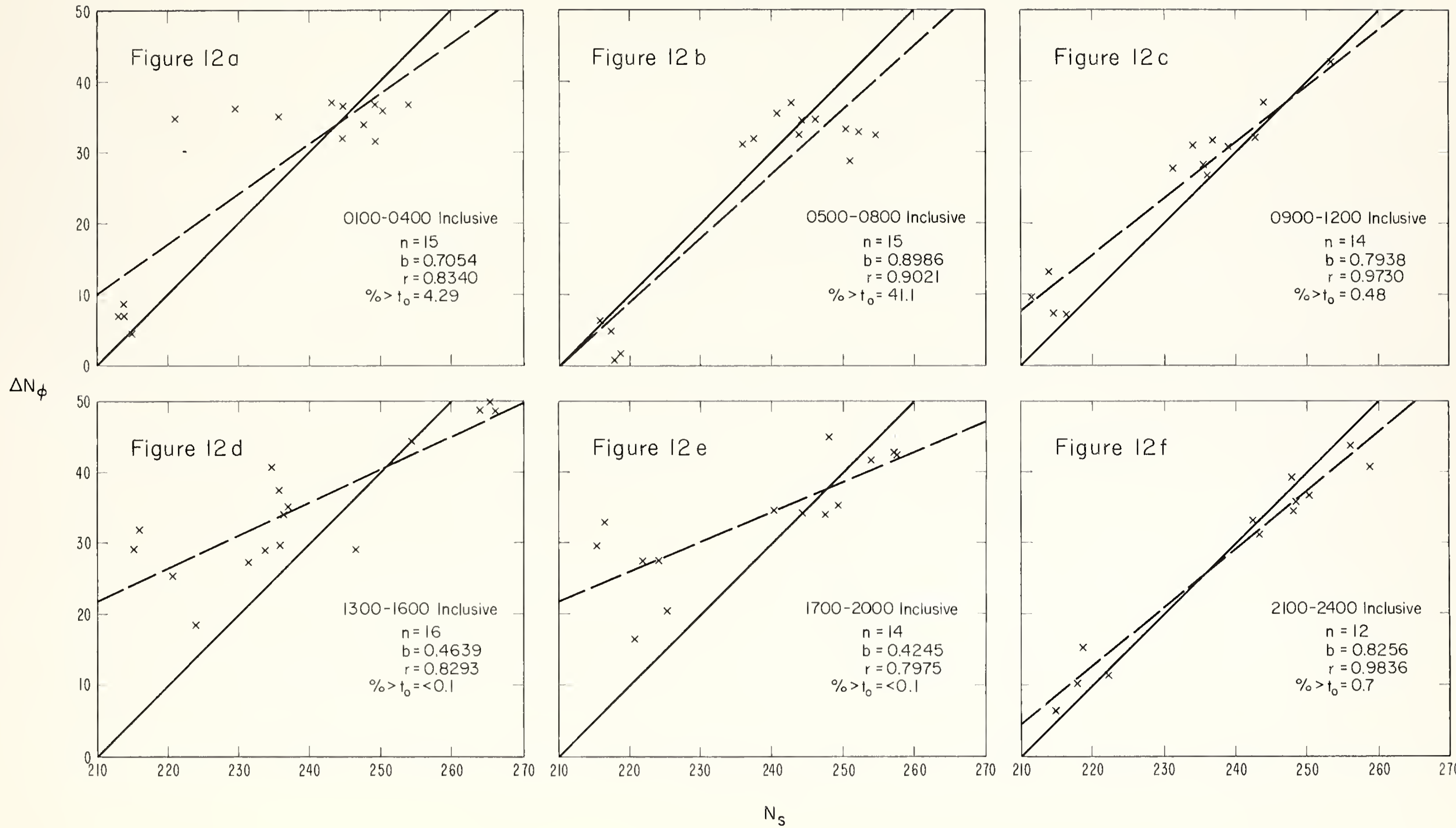


Figure 12

RELATIVE RADIO PATH INDEX VERSUS SURFACE INDEX
AT STATION #3, ELEVATION 8,600 FEET



RELATIVE RADIO PATH INDEX VERSUS SURFACE INDEX
AT HALEAKALA, ELEVATION 10,025 FEET

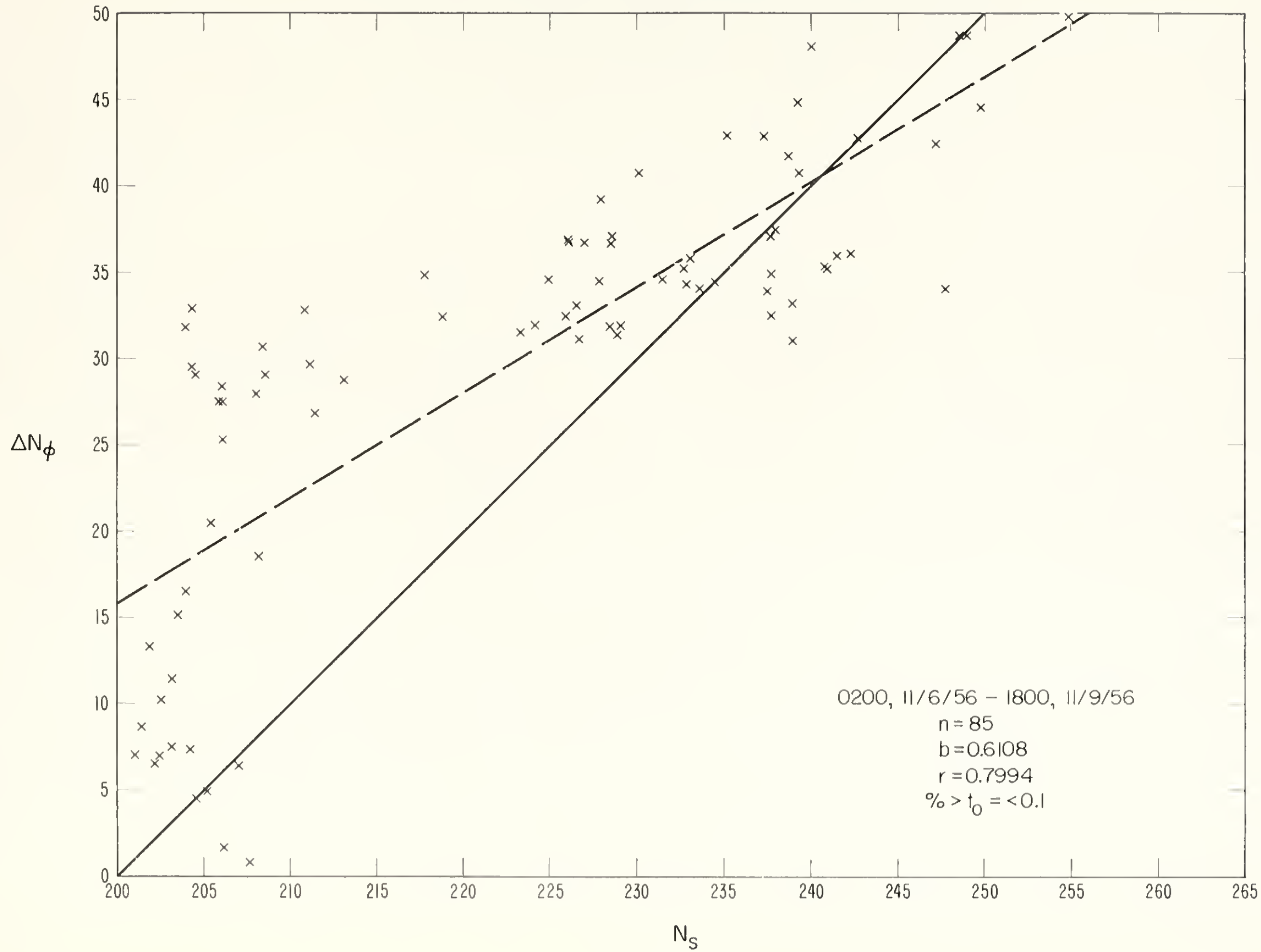
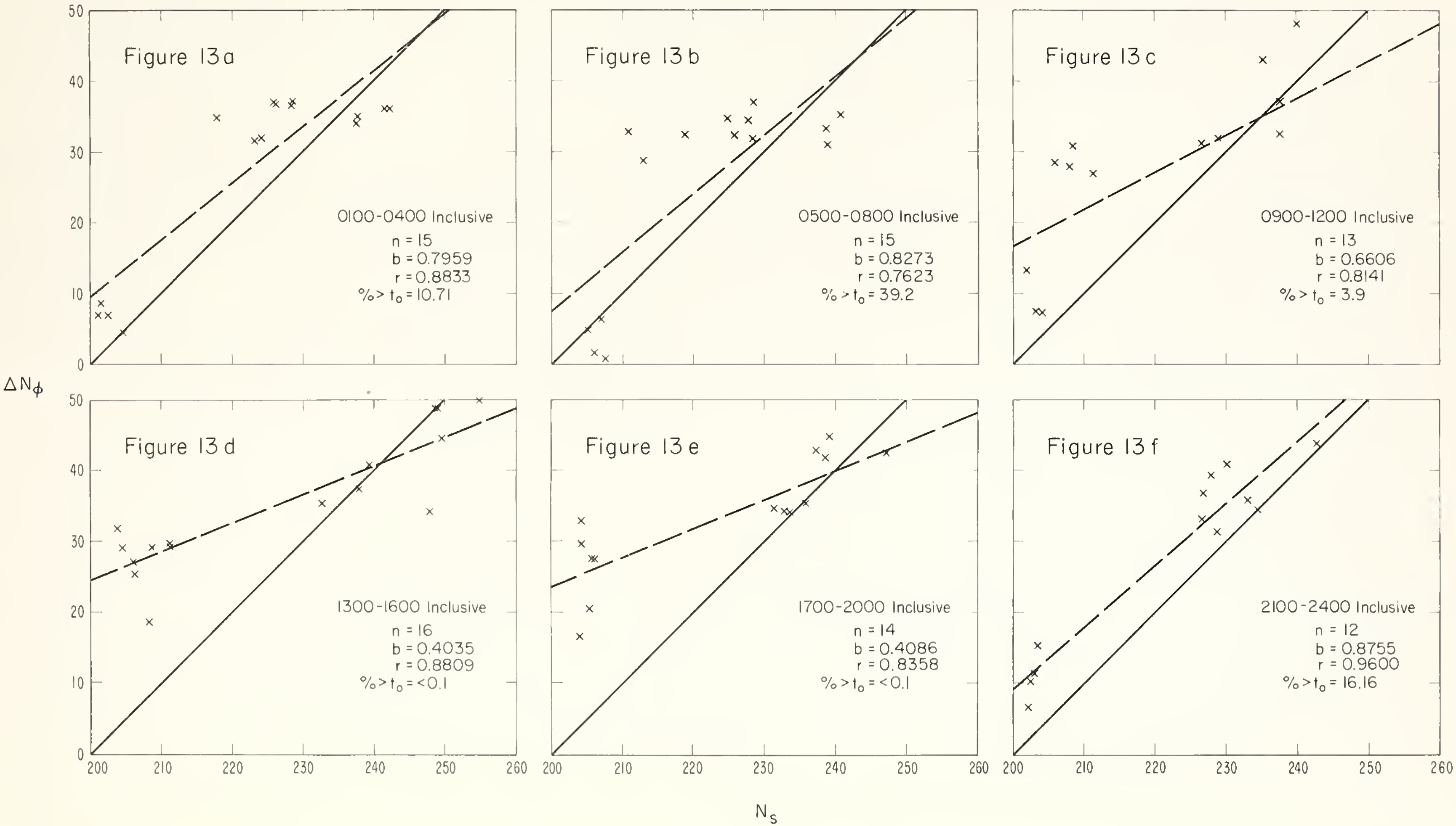


Figure 13

RELATIVE RADIO PATH INDEX VERSUS SURFACE INDEX AT HALEAKALA, ELEVATION 10,025 FEET



RELATIVE RADIO PATH INDEX
VERSUS WEIGHTED AVERAGE SURFACE INDEX AT FIVE STATIONS

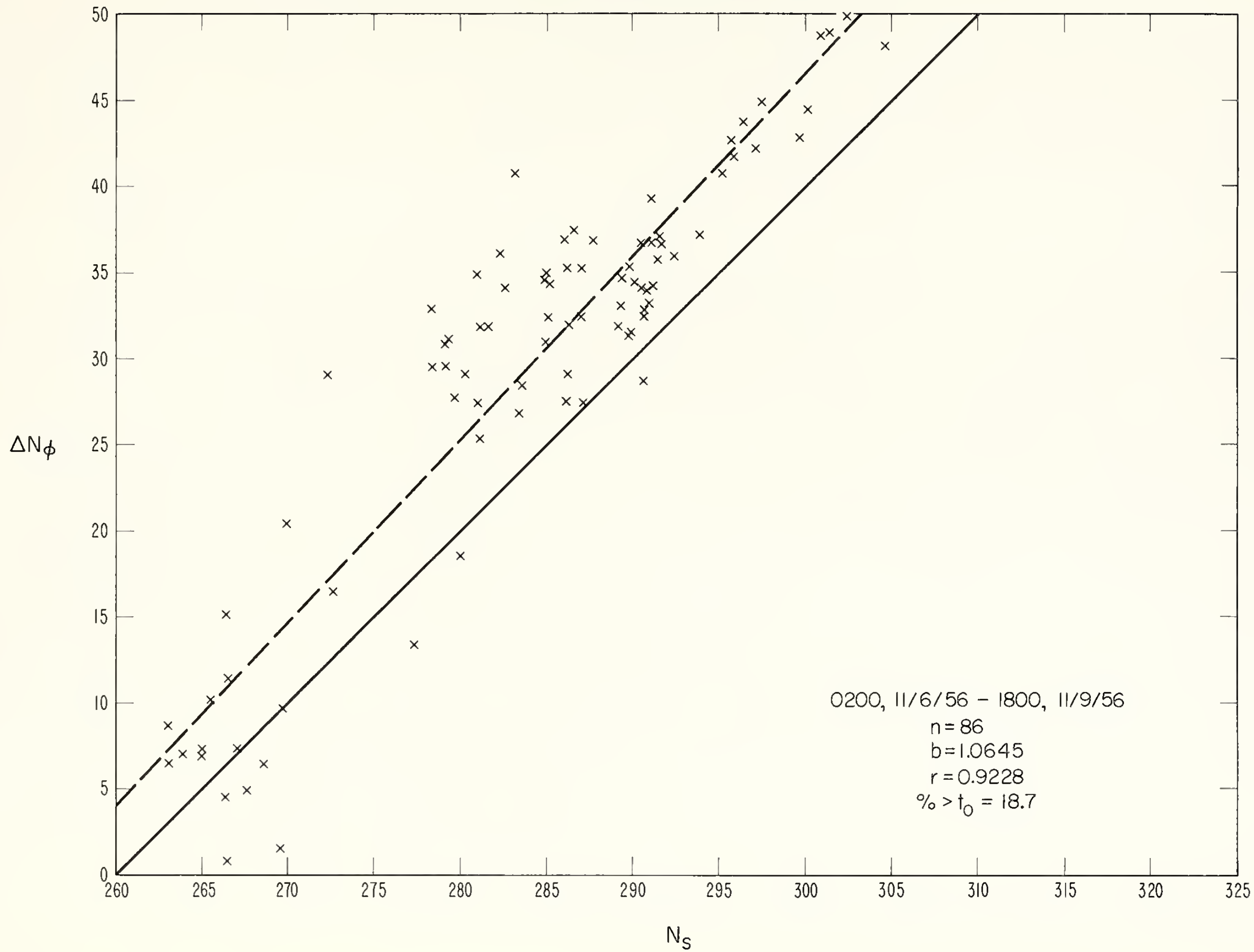
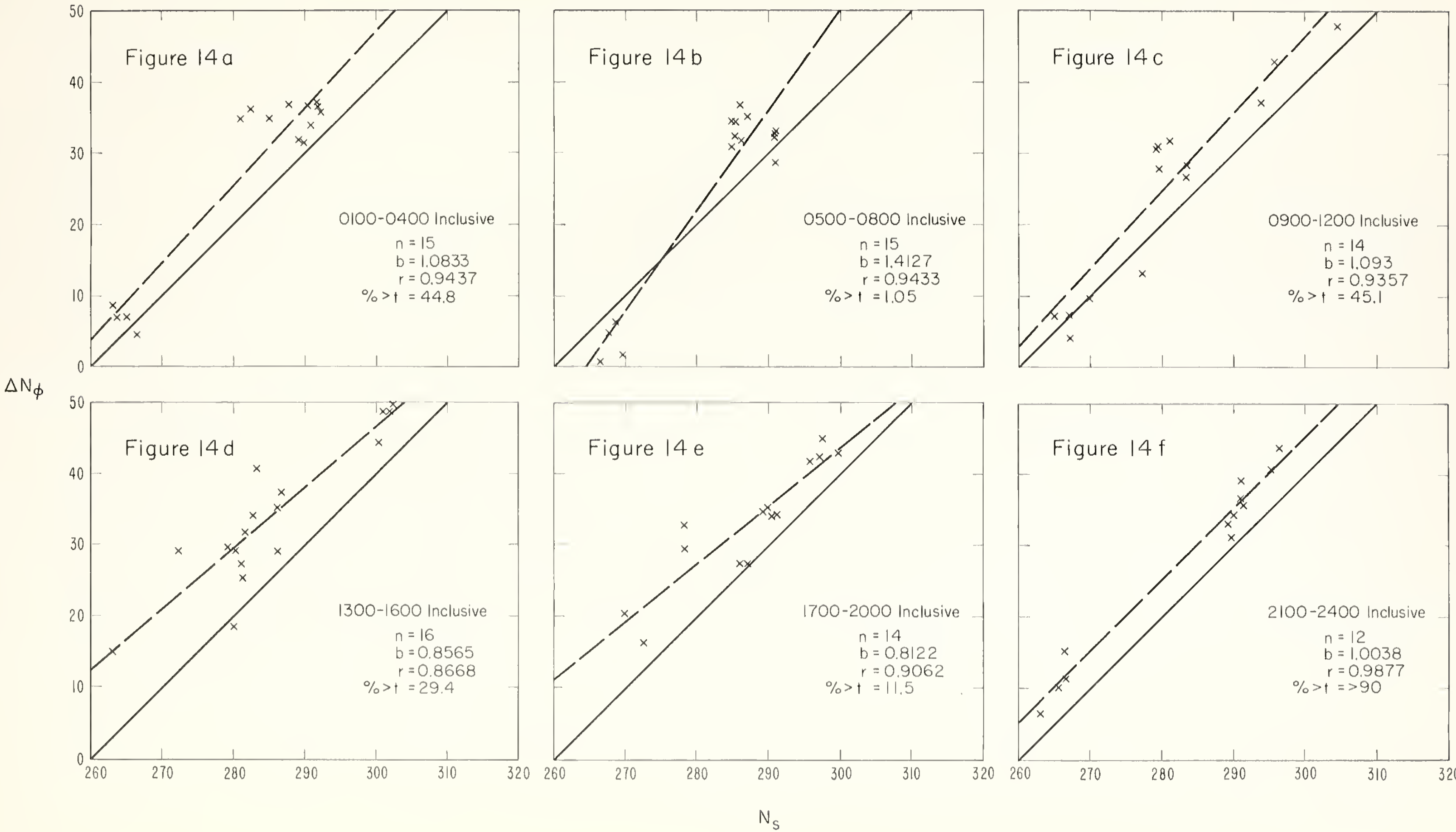


Figure 14

RELATIVE RADIO PATH INDEX VERSUS WEIGHTED AVERAGE SURFACE INDEX AT FIVE STATIONS



RELATIVE RADIO PATH INDEX
VERSUS SIMPLE AVERAGE SURFACE INDEX AT FIVE STATIONS

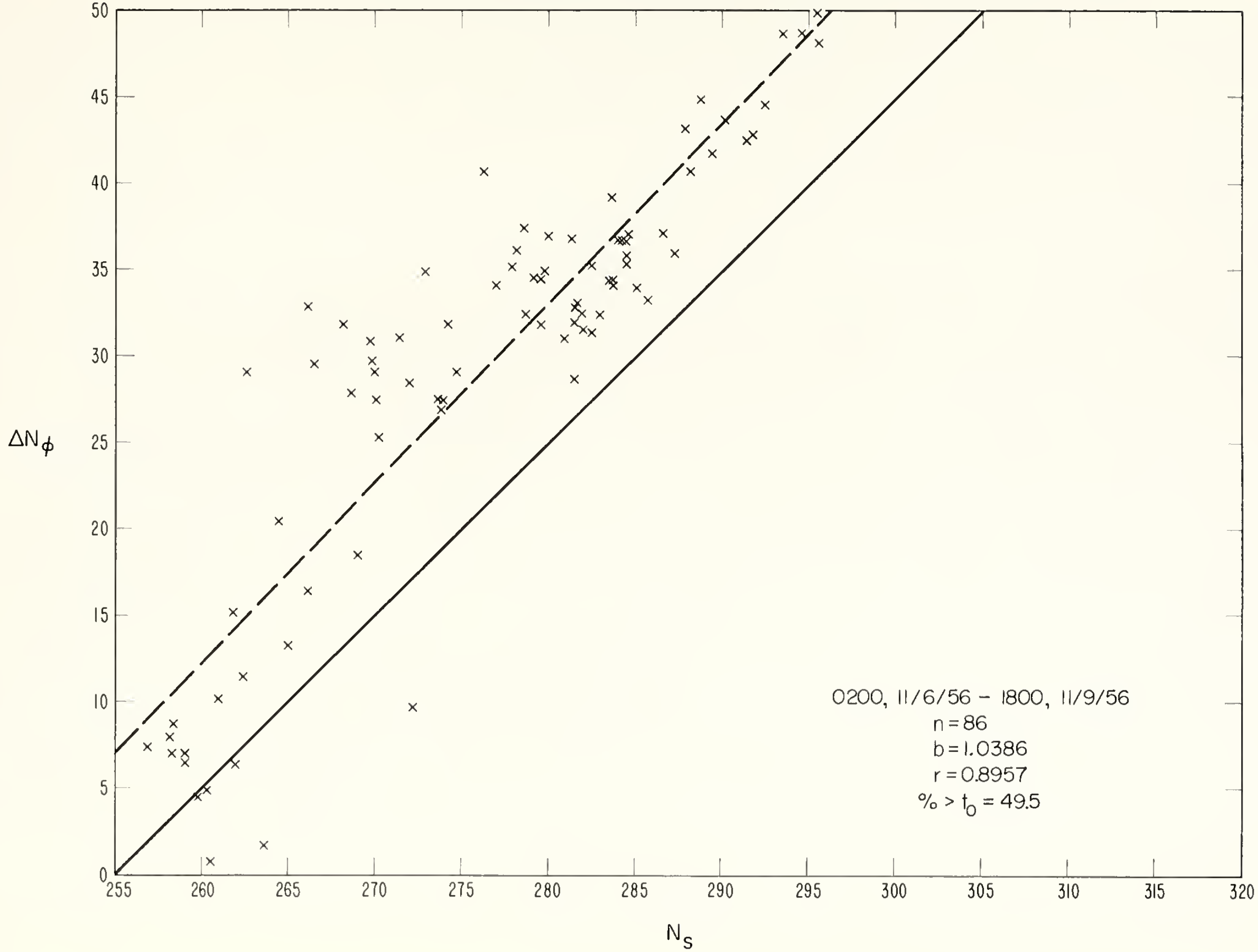
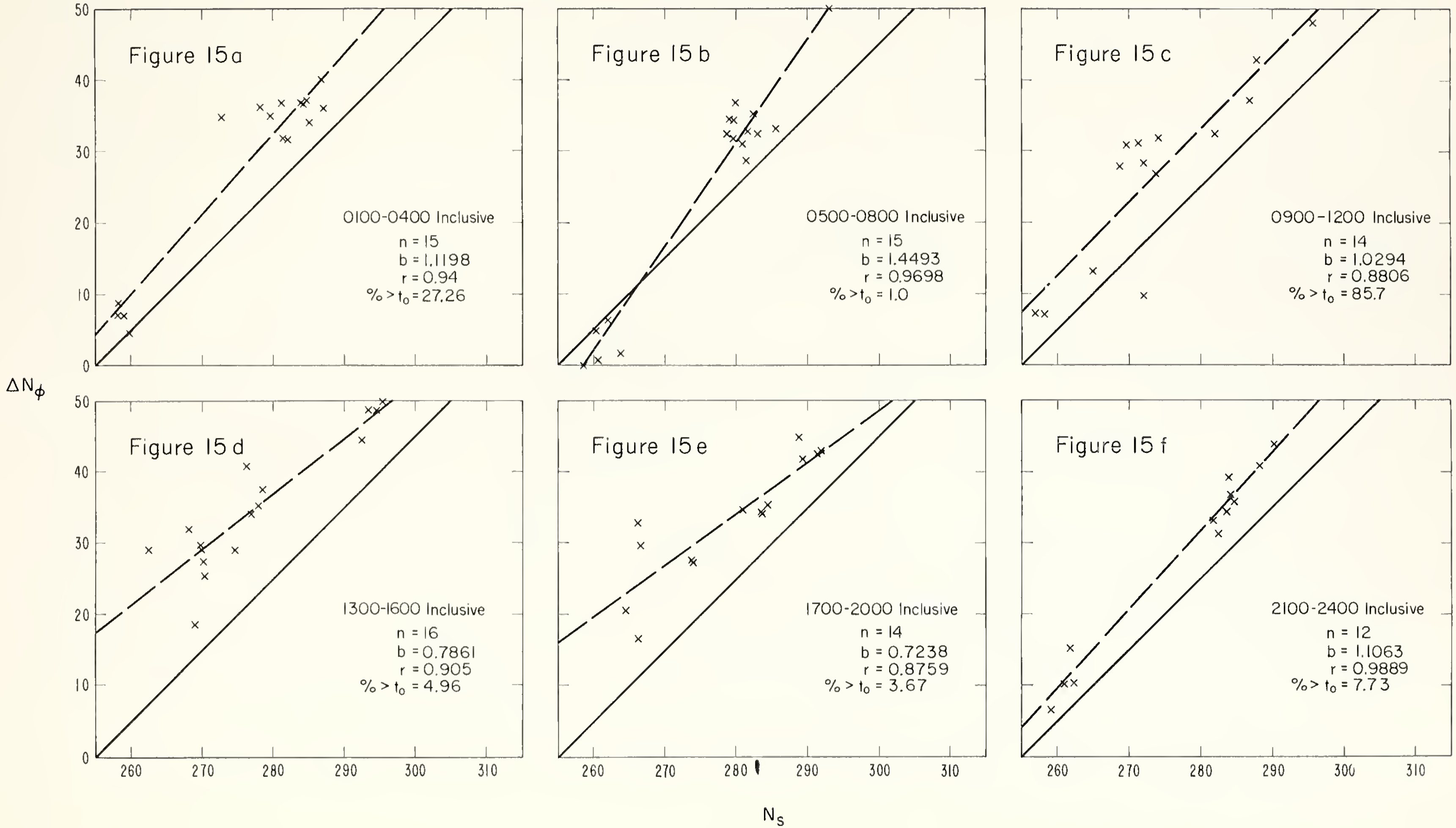


Figure 15

RELATIVE RADIO PATH INDEX
VERSUS SIMPLE AVERAGE SURFACE INDEX AT FIVE STATIONS



RELATIVE RADIO PATH INDEX
VERSUS END POINT AVERAGE SURFACE INDEX

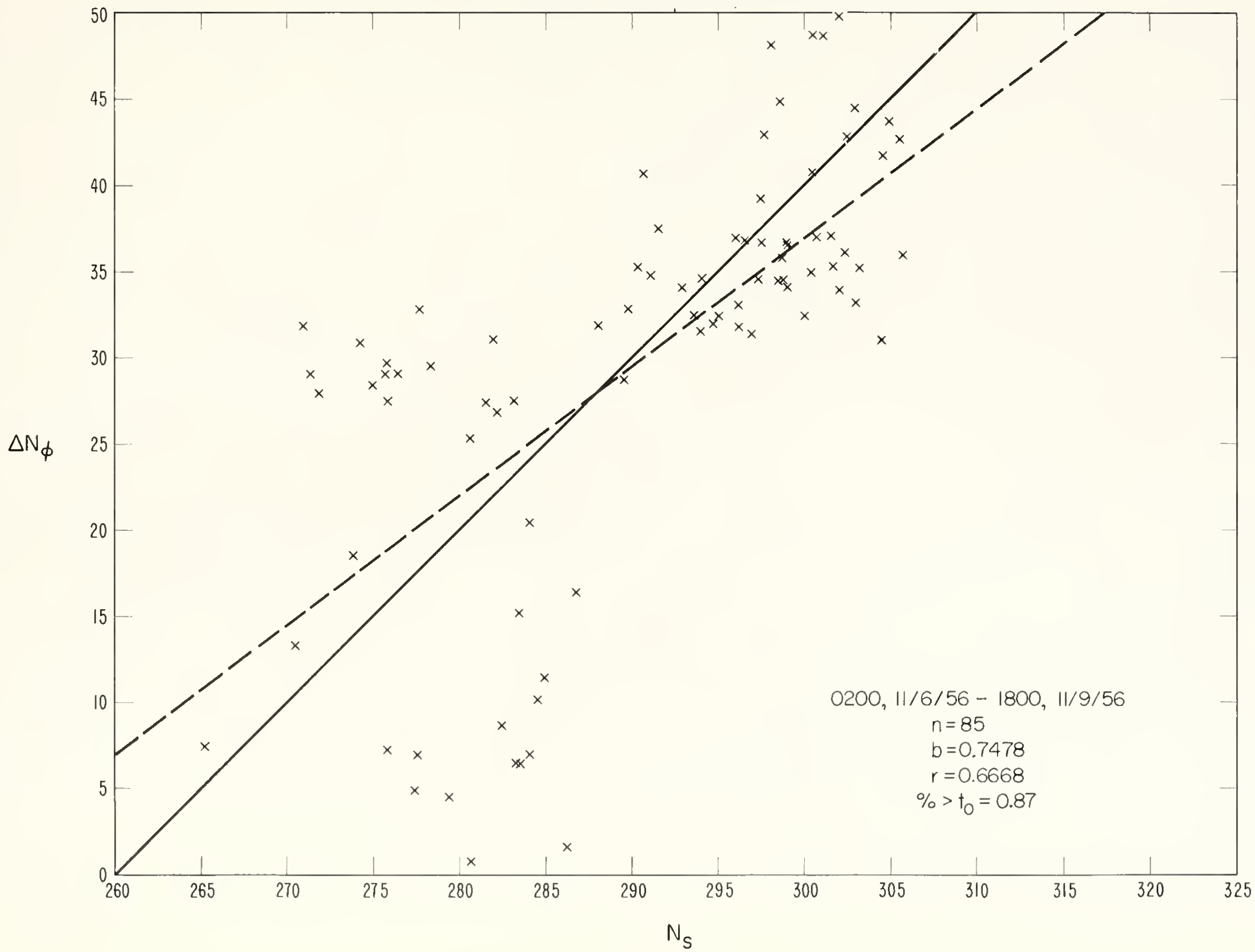
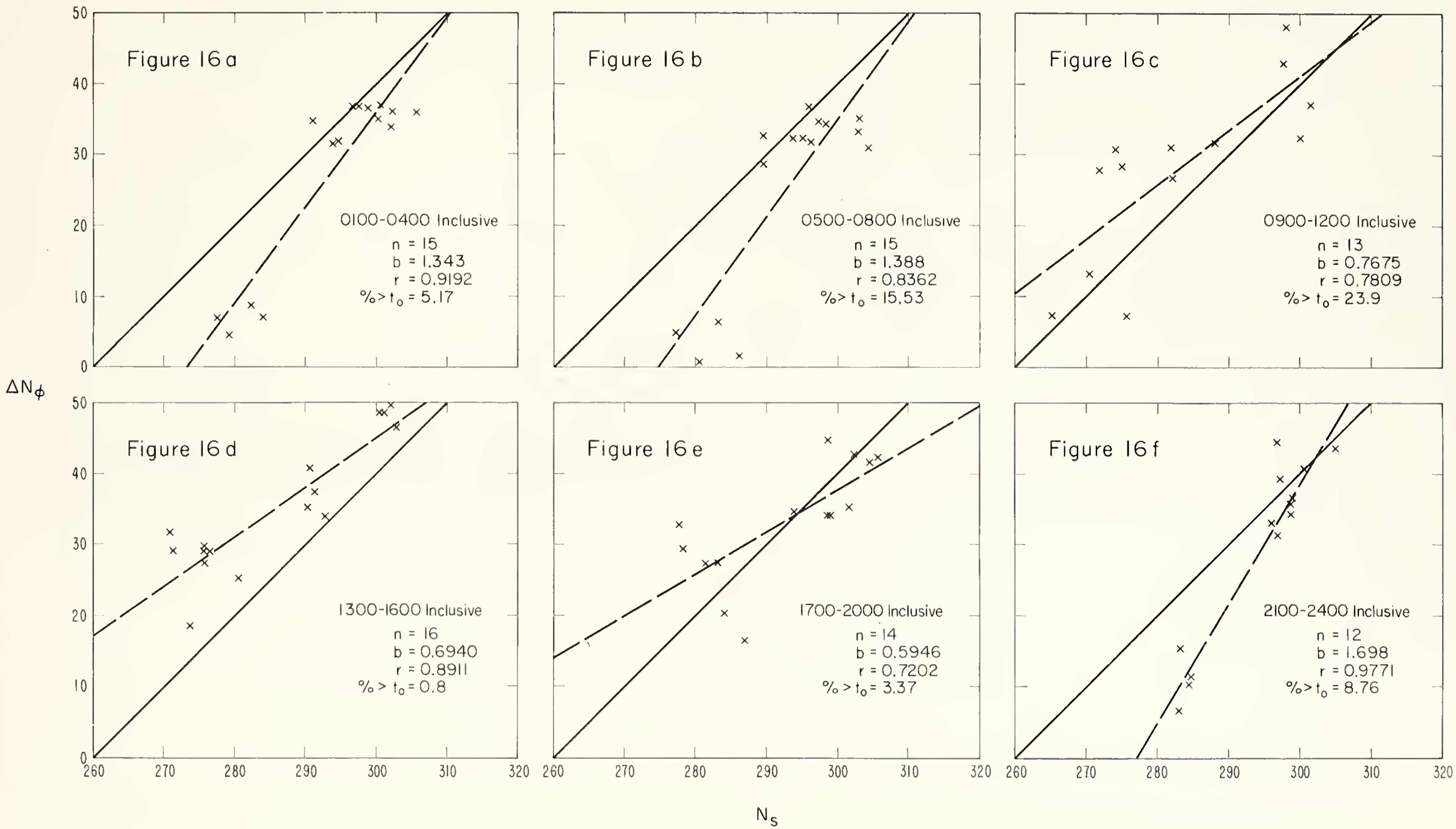


Figure 16

RELATIVE RADIO PATH INDEX VERSUS END POINT AVERAGE SURFACE INDEX



SUMMARY OF PHASE RECORD WITH METEOROLOGICAL NOTES

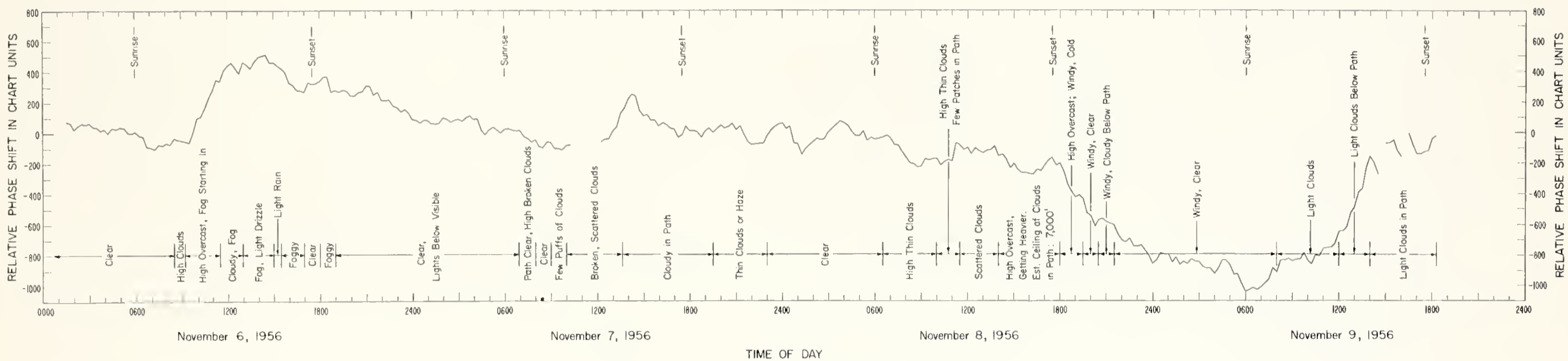


Figure 17

appeared consistently, but the equable weather which prevailed during most of the run provided no dramatic front phenomena to be studied, nor, of necessity, any seasonal variations. The main analytic effort, therefore, of this study was aimed at (1) determining the simplest reliable way to average the index over the propagation path from records taken at five stations covering a vertical distance of 10,000 feet; and (2) to learn if any particular period of the day appeared most favorable for correlating phase measurements with surface index variations. A comparison of the plots of Figures 9 through 16 seems to indicate that either the weighted or the simple average index of all five stations give the best average N_s for the path at any particular time; and those of Figures 9a, b, c, etc. through 16a, b, c, etc., (though of doubtful validity because of the small number of points in each array) suggest that the daily period from 2100 to 0400 is the time when the atmosphere is normally most stable, in this sense, and measurements of this nature most reliably made.

Acknowledgments:

As described in (1) and (2) the Maui experiments were conducted as a joint effort of several sections of the Radio Propagation Engineering Division. In the preparation of this report of a relatively small part of the experiment, the assistance of the following persons is gratefully acknowledged: H. B. Janes, A. W. Kirkpatrick, J. W. Herbstreit, and B. R. Bean.

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4. M. C. Thompson, Jr. and M. J. Vetter, "Compact Microwave Refractometer for Use in Small Aircraft," The Review of Scientific Instruments, December 1958.

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