JOURNAL OF RESEARCH of the National Bureau of Standards—D. Radio Propagation,
Vol. 65D, No. 1, January–February 1961

Observation of *F*-Layer and Sporadic-*E* Scatter at VHF in the Far East[1]

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(April 26, 1960)

This paper describes properties of sporadic-*E* scatter and *F*-layer scatter observed over the Okinawa-to-Tokyo path (1480 kilometers) and the Philippines-to-Tokyo path (2850 kilometers) operating at frequencies of about 50 megacycles per second.

Sporadic-*E* scatter is often observed on the Okinawa signal in the evening hours and has the closest correlation (0.94 in correlation ratio) with the occurrence of sporadic *E* characterized by the descriptive symbol "M" of all ionospheric factors. Bearing of the *E*s scatter shows a regular diurnal variation similar to that of the normal *E*-layer scatter.

F-layer scatter generally appears on the Philippine signal in autumn when the *F*-layer at the path midpoint displays an anomaly denoted by the symbol "R" or "S" having a top frequency of higher than 14 megacycles per second. A pulse test exhibited a pattern of multipath signals extending over more than 1 millisecond. Bearing of the *F*-layer scatter, an evening phenomenon, gradually deviates westwards from the great-circle path with the lapse of time.

1. Introduction

Great progress has been made in the study of transmission by way of inhomogenities in the ionosphere, commonly termed scattering in the *E*-layer. In addition, *F*-layer scatter in the Far East has been pointed out by R. Bateman and others [1][2] and a peculiar signal enhancement has been reported recently by the authors [2] as a kind of scatter associated closely with sporadic *E*. Continuous measurements of signal strength, bearing, and angle of elevation at about 50 Mc/s have been carried out in Tokyo on Okinawa and Philippine signals transmitted until the end of October 1959 as the continuation of a part of the United States program for the IGY.

Aside from characteristics of *E*s propagation which will be reported as an interest in the field of communications engineering, the following will mainly describe the types of scatter mentioned above.

2. Scope of Observation

2.1. Signals Measured and Experimental Circuits

An outline of the experimental circuits is shown in figure 1. Continuous waves of 2-kw output were emitted towards the middle part of Japan at 49.68 Mc/s from Okuma, Okinawa, and at 49.84 Mc/s from Poro, the Philippines. Each of the transmitting antennas was a horizontal 5-element Yagi, having a gain of 7 db relative to a dipole, a height of 12 m above the ground, and a half-power beamwidth of 54°. The measurements were conducted at Fukuoka receiving station, near Tokyo, from October 1958 through October 1959. Pulse signals, from Poro, were observed in autumn 1959.

The orientations of both paths were almost from southwest to northeast. The transmitting antenna used at Okuma was beamed to 35°13′ E of N deviating northwards by 8.5° off the great-circle path to Tokyo. Surface path length between Okuma and Tokyo is 1480 km, and Poro and Tokyo is 2850 km. So one-hop *E*s propagation may exist over the former circuit and two-hop *E*s or one-hop *F*2 propagation over the latter.

The Yamagawa and Okinawa ionosphere stations are located 330 km and 160 km from the path midpoints, respectively, as seen in figure 1.

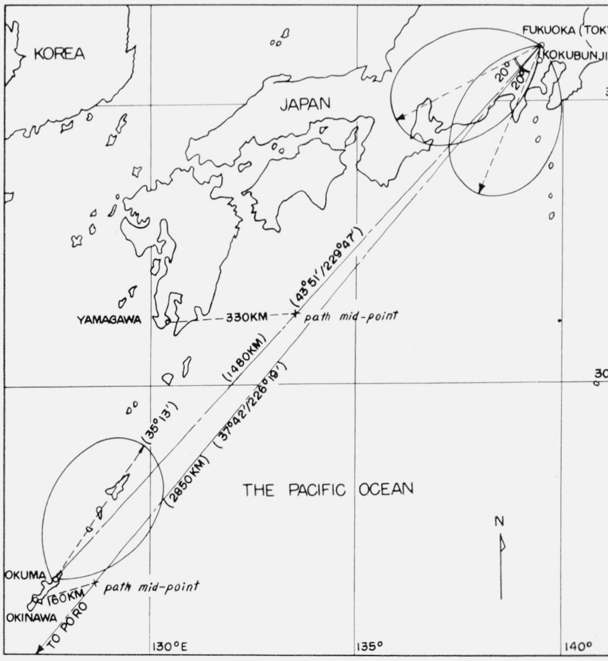


FIGURE 1. *Map of the Far East, showing the forward scatter paths and the ionosphere stations.*

[1] Contribution from Kokusai Denshin Denwa Co., Tokyo, Japan.
[2] Figures in brackets indicate the literature references at the end of this paper.

2.2. Method of Observation

Three 5-element Yagis A, B, and C of same construction as the transmitting antenna were used for the measurements. Yagis A and B were mounted 30.6 m high on two iron poles separated by 105 m, directivities being shifted by 20° westwards and southwards from the true bearing of Okuma respectively. Yagi C was mounted at a height of 12.6 m, being beamed to the same direction as Yagi A. Bearing and angle of elevation were obtained from the ratios of voltages induced on Yagis A and B and on Yagis A and C, respectively.

The ratio of voltages was continuously recorded using two sets of voltage ratio meters [2] which are capable of measuring angles of arrival accurately even on a low level of the signal strength. The output voltage of the meter was logarithmically compressed and indicated by a pen recorded as open-circuit voltage measured at 75 Ω impedance in decibels above 1 μv.

3. Observational Results

3.1. Okuma-to-Tokyo Transmission

Figures 2 and 3 show typical results observed on the Okuma signal in winter and summer months, respectively. Figure 4 exhibits an example of appearance of the pen records during a period including all types of scatter.

In winter, the signal received is mainly the normal *E*-layer scatter including meteoric bursts throughout the day. Attenuation of the scatter in the ionosphere is estimated to be between 72 and 82 db in the median value, showing the maximum at about 1800 J.s.t. and the minimum around midday.

As seen in figure 4, the signal strength sometimes rises to a maximum of 30 db above the level of the normal value, late in the evening. This phenomenon will be referred to as *E*s scatter and its characteristics will be discussed later.

Hourly median angles of arrival are indicated by dots, and ranges between upper and lower quartiles are shown by lengthwise lines in figures 2 and 3. Bearing data explicitly show a diurnal variation which deviates westwards off the true bearing during the period of 1800 to 1000 J.s.t. and slightly southwards early in the afternoon. Seasonal and diurnal distributions of hourly median bearings are exhibited in figure 5 representing contours of equal bearings. The figure shows a feature of regular diurnal variation with a tendency of deviating westwards a few degrees off the true bearing on the average throughout a year. The fact that the main lobe of the transmitting antenna is beamed northwards off the great-circle path may be one of the causes of the average deviation of bearing. However, attention must be drawn to the fact that the diurnal variation including the average deviation is quite similar to W. R. Vincent and others' results of best antenna angle for meteoric bursts [3]. The seasonal variation of bearing showed a complicated but periodic behavior.

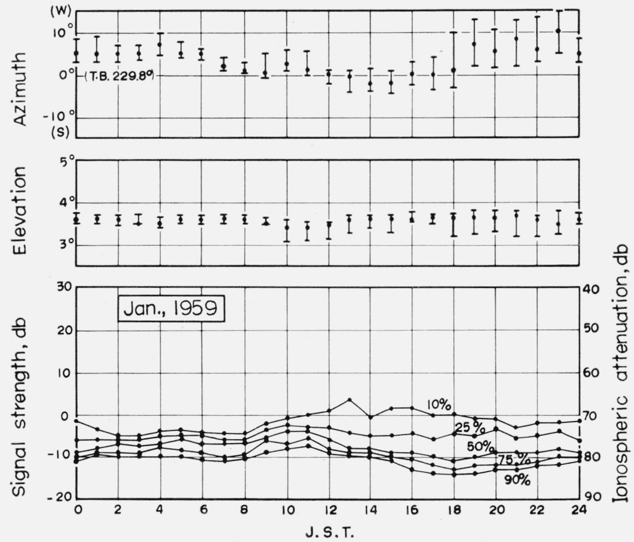


FIGURE 2. *Diurnal curves of signal strength, angles of arrival.* Okuma-Tokyo, 49.68 Mc/s, January 1959.

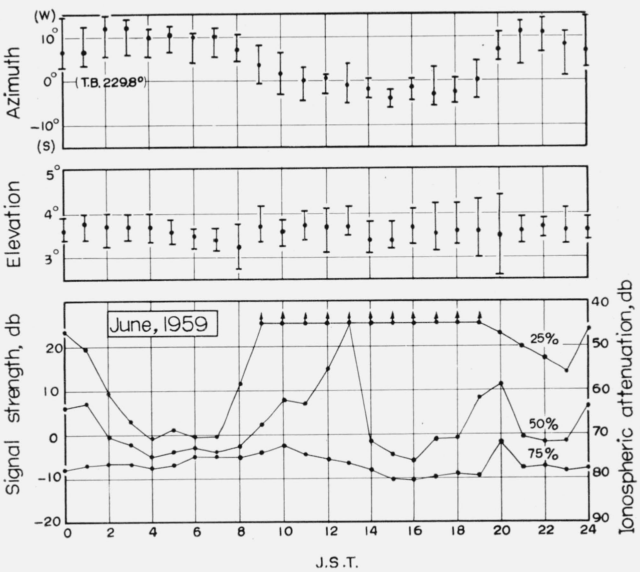


FIGURE 3. *Diurnal curves of signal strength, angles of arrival.* Okuma-Tokyo, 49.68 Mc/s, June 1959.

No noticeable variation of angle of incidence was observed in the median value. The minimum, however, was clearly observed during a period of 1100 to 1200 J.s.t. during all the months except summer, when the normal *E*-layer scatter was mainly received.

In summer when *E*s reflections are most common, and produce an increase of many times the normal signal level, hourly values of angles of arrival are distributed in a wider range than those observed in winter as seen in figures 2 and 3.

The range of quartiles of signal strength, bearing, and angle of elevation shows the minimum excursion at about 0600 J.s.t. early in the morning.

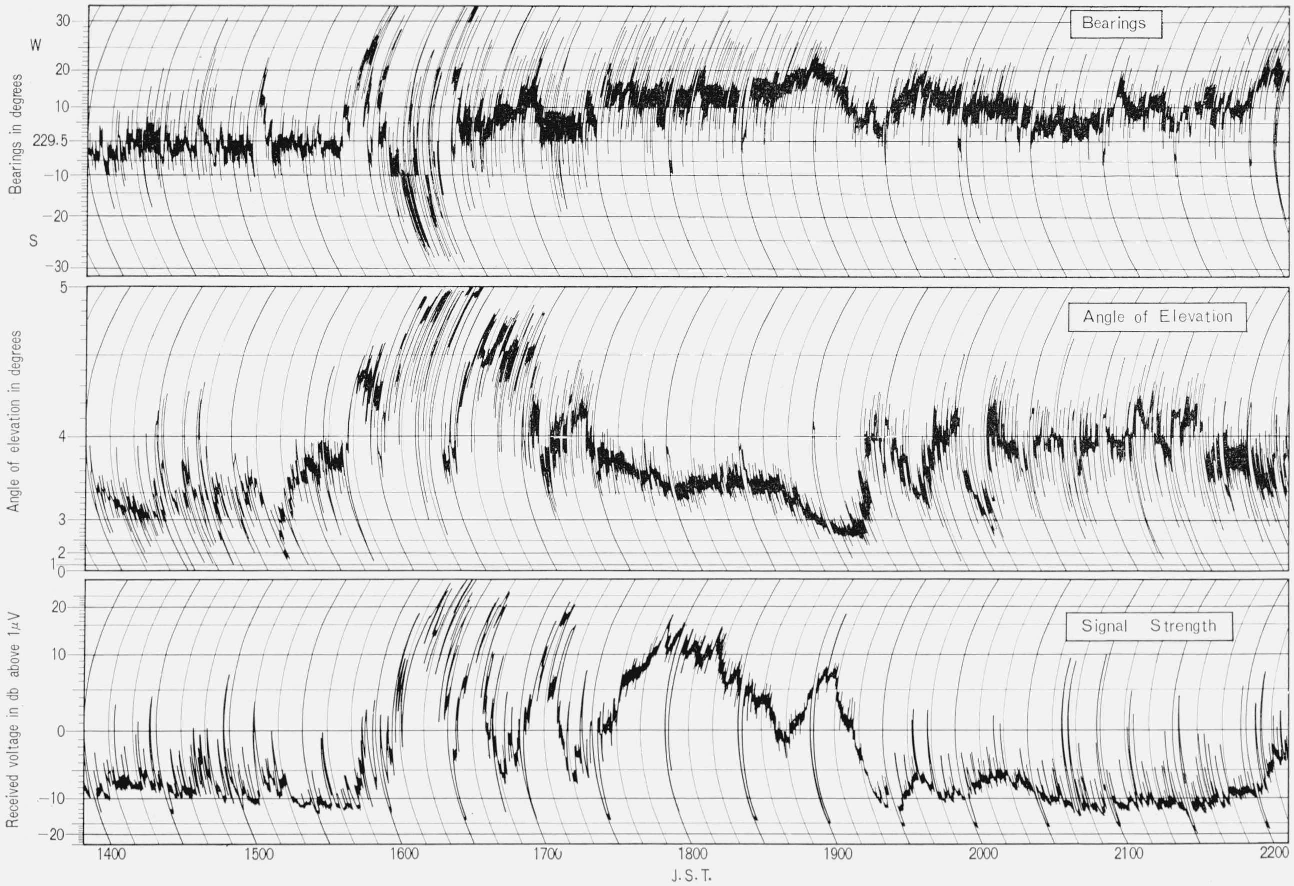


FIGURE 4. *A typical record of angles of arrival and signal strength observed on January 12, 1959.*

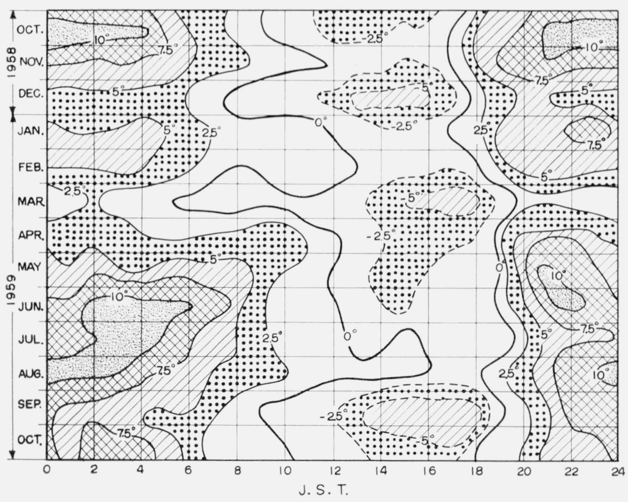


FIGURE 5. *Contours of equal bearing.*
Okuma-Tokyo, 49.68 Mc/s, October 1958–October 1959.

3.2. Poro-to-Tokyo Transmission

The signal from Poro was received only a small part of the time, except in summer and autumn. Judging from the characteristic appearance of sporadic E, most of the signals received in summer are inferred to be two-hop propagation by way of the Es specular reflection. Most hourly median bearings observed in summer were nearly the true bearing. Hourly median angles of elevation were between 3.5° and 3.9° and they showed lower values in the daytime. These angles observed are slightly lower than the calculated by estimating height of sporadic E to be 90 km.

On the other hand, it is obvious that the signal received in autumn was propagated via the F-region. Behavior of this signal will be described in the later chapter.

4. Sporadic-E Scatter

4.1. General

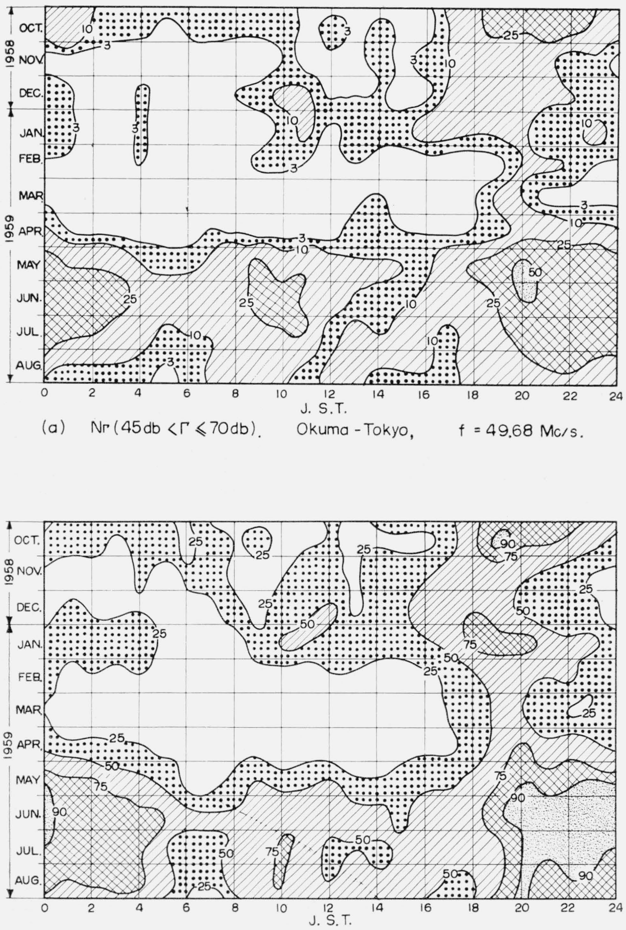
As mentioned above, a remarkable signal enhancement is nightly observed on Okuma signal, sometimes attaining a level 30 db higher than that of the normal E-layer scatter. The authors called the event "Es evening enhancement" [2], because it is closely associated with sporadic E and it is likely to occur late in the evening. The enhancement appears to represent sporadic E scatter because of the following features. The Es scatter does not undergo as rapid a change in signal strength as sporadic E propagation and shows a gradual variation over an hour to several hours.

When this takes place, variations of bearing and angle of elevation are always observed. These variations are quite different from that of Es propagation as shown in figure 4. The Es scatter closely correlates with some type of sporadic E at the path midpoint rather than the magnitude of the foEs itself. The relationship is now explored.

4.2. Rate of Occurrence

Judging from a statistical study of foEs and attenuation in the ionosphere, Γ, the signal of $\Gamma \leqq 45$ db is assumed to be reflected by sporadic E and the signal of $\Gamma > 70$ db as the normal E-layer scatter. An analysis was made of the signal of 45 db $< \Gamma \leqq 70$ db, the range in which most of the Es scatter is included.

Seasonal and diurnal distributions of signals of 45 db $< \Gamma \leqq 70$ db are shown in figure 6(a) indicating contours, of equal occurrence rates of reception in percentage, N_Γ. One of the most distinctive features in the figure is that the maximum rate appears late in the evening. The authors tried to find some ionospheric factor which had a close correlation with the distribution in figure 7(a). This was found to be the occurrence of the descriptive symbol "M" [3] associated with the "critical frequency" of sporadic E (foEs). Figure 6(b) indicates contours of equal occurrence of such sporadic E, N_M, observed at the Yamagawa ionosphere station. Comparing the temporal distributions of figure 6(a) and figure 6(b), it is seen that there is a reasonably good correlation between the two sets of data.



(a) Nr (45db < Γ ≤ 70db). Okuma - Tokyo, f = 49.68 Mc/s.

(b) Nм. Yamagawa.

FIGURE 6. *Contours of equal rates in percentage of* N_Γ *and* N_M.

N_Γ: rate of occurrence of Es scatter, and N_M: rate of occurrence of Es affixed by symbol "M" at the path midpoint.

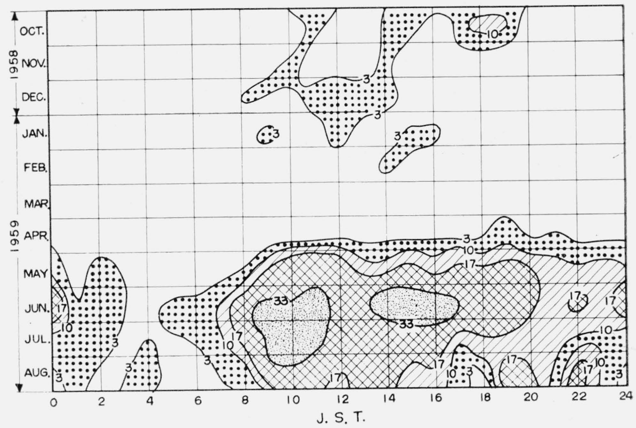


FIGURE 7. *Contours of equal rate in percentage of foEs above 7.5 Mc/s at Yamagawa.*

N_F (foEs $\geq$ 7.5 Mc/s).

For reference, the occurrence of sporadic E with foEs above 7 Mc/s, N_F, is shown in figure 7. This figure is pertinent enough for the purpose of investigating correlation because N_F for any value of foEs gives a similar distribution to that of figure 7. Figures 6(a) and 7 have a resemblance to each other in seasonal variation, but not always in diurnal variation.

In order to obtain quantative relationship between N_Γ and N_M, hourly mean values of N_Γ and N_M for 3 months every season are plotted as a correlation diagram shown in figure 8. From the figure, the following relation is calculated:

$$N_\Gamma = 0.42\, N_M^2,$$

where correlation coefficient between them is 0.9 and correlation ratio is 0.94.

An analysis using data observed at the Kokubunji ionosphere station, which is located 750 km from the path-midpoint, did not result in as good an association as the above. This may be because the station is too far away to give a good correlation.

4.3. Angles of Arrival

Needless to say, the measured angles of arrival are influenced by the signals from all the modes of propagation present. The data were, therefore,

[3] M, Measurement questionable because the ordinary and extraordinary components are not distinguishable.

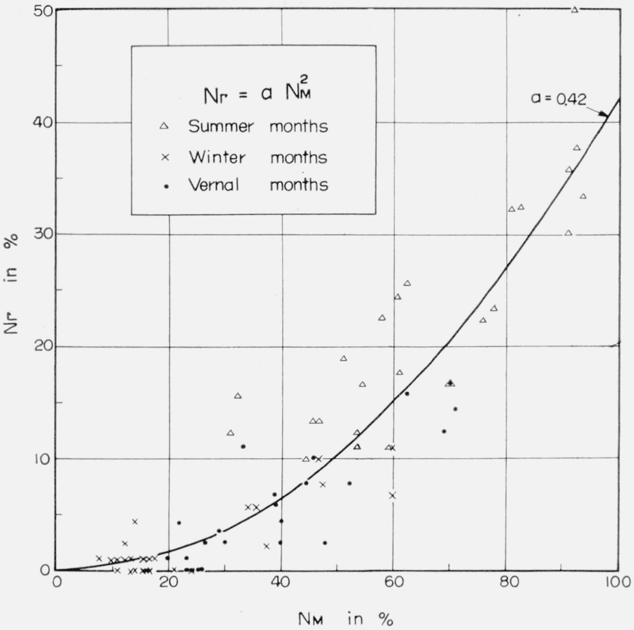


FIGURE 8. *Correlation between* N_Γ *and* N_M.

N_Γ: rate of occurrence of *E*s scatter, and N_M: rate of occurrence of *E*s affixed by symbol "M".

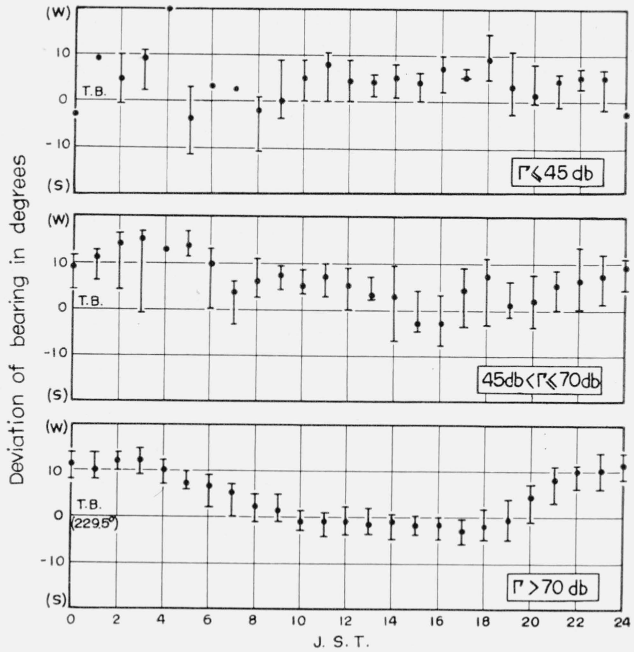


FIGURE 9. *Bearing in each range of* $\Gamma \leq 45$ *db,* 45 *db* $< \Gamma \leq 70$ *db and* $\Gamma > 70$ *db.*

Okuma-Tokyo, 49.68 Mc/s, July 22–August 21, 1959.

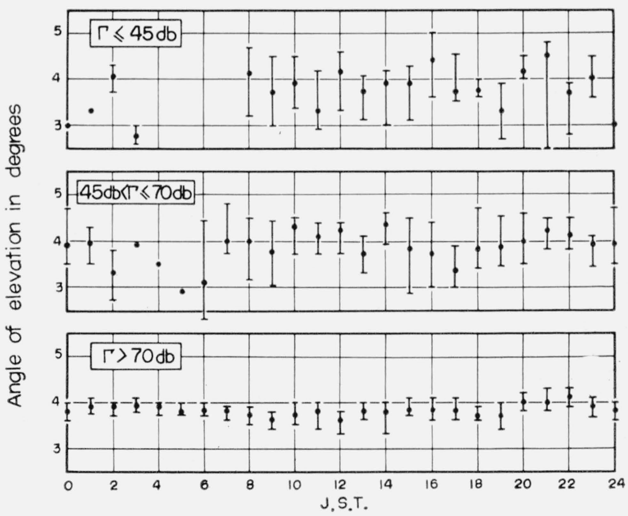


FIGURE 10. *Angle of elevation in each range of* $\Gamma \leq 45$ *db,* 45 *db* $< \Gamma \leq 70$ *db and* $\Gamma > 70$ *db.*

Okuma-Tokyo, 49.68 Mc/s, July 22–August 21, 1959.

arranged into three groups according to the previous classification of ionospheric attenuation, namely: $\Gamma > 70$ db, 45 db $< \Gamma \leqq 70$ db, and $\Gamma \leqq 45$ db. Arrangement was made, in this manner, of the data obtained during a period in July and August 1959, for which wide dynamic range recordings were available. Figures 9 and 10 are the results of measurements.

From these figures the following features are noted: The normal *E*-layer scatter of $\Gamma > 70$ db showed a regular diurnal variation of angle of arrival with a narrow range of quartile distributions; on the contrary, the *E*s-reflected signal of $\Gamma \leqq 45$ db displayed a wide distribution of angles of arrival with no clear diurnal variation and a westerly deviation of bearing of several degrees on the average. On the other hand, the bearings of the *E*s scatter of 45 db $< \Gamma \leqq 70$ db exhibited a diurnal variation similar to that of the normal scatter, being accompanied with a wider distribution than that of the normal scatter.

From the results mentioned above, it is inferred that the *E*s evening enhancement or *E*s scatter is not caused by the normal reflection from sporadic-*E* clouds but by an irregularity of sporadic *E*, and that the diurnal variation of bearing of the *E*s scatter may be related to the same mechanism as that of the normal *E*-layer scatter.

5. *F*-Layer Scatter

F-layer scatter was pointed out by R. Bateman and others [1] as an evening enhancement observed in the Far East in autumn. The event frequently occurred over the Poro-to-Tokyo path in the evening hours in September and October. When this took place, *F*-layer measurements at the Okinawa ionosphere station quite near the path midpoint always indicated either of the following conditions:

(a) *F*2 critical frequency higher than the 18 Mc/s required for the normal reflection in oblique incidence propagation at the used frequency, or

(b) *F*2-layer critical frequency qualified by the symbol "R" or "S",[4] where the top frequency was higher than about 14 Mc/s.

Figure 11 is a typical example illustrating such a correspondence of the signal strength with the "*f*-plot" of ionospheric data. There is no doubt that the signal received in autumn is closely associated with the *F*2-layer. It is also obvious that ionosperic layers other than the *F*2-layer did not take part in the propagation during the period of autumnal observation where especially sporadic *E* was inactive. Figure 12 shows diurnal curves of reception of signal, N_r, and N_I, the occurrence of the two ionospheric conditions, "R" and "S", observed in October 1959. Fair agreement can be seen between N_r and N_I. The spread-*F* condition was rarely observed at Okinawa which is quite near the path midpoint, during the observational period.

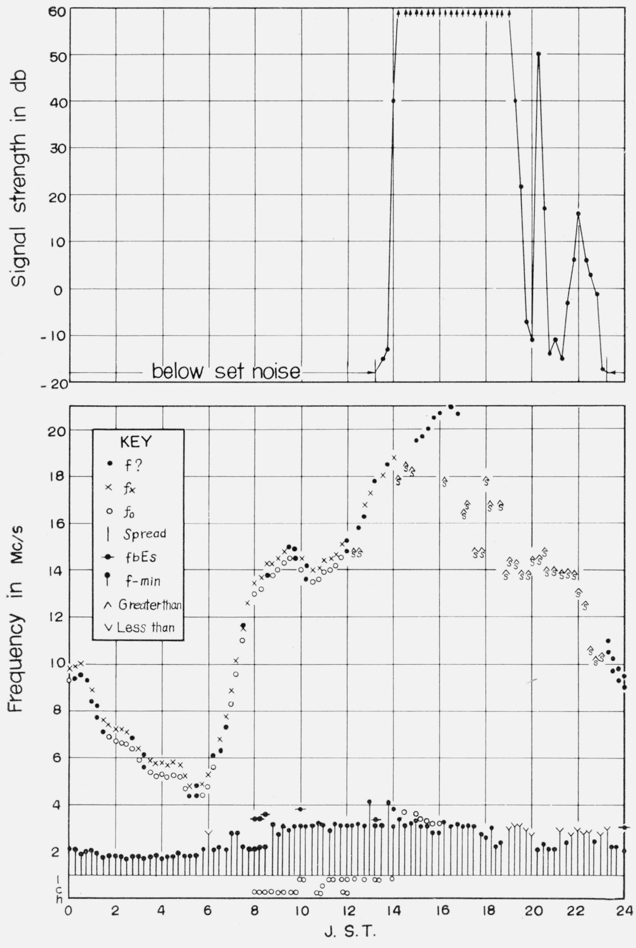


FIGURE 11. *Diurnal curves of signal strength and* f-*plot of ionospheric data observed at the Okinawa ionosphere station.*

Poro, the Philippines—Tokyo, 49.84 Mc/s, October 7, 1959.

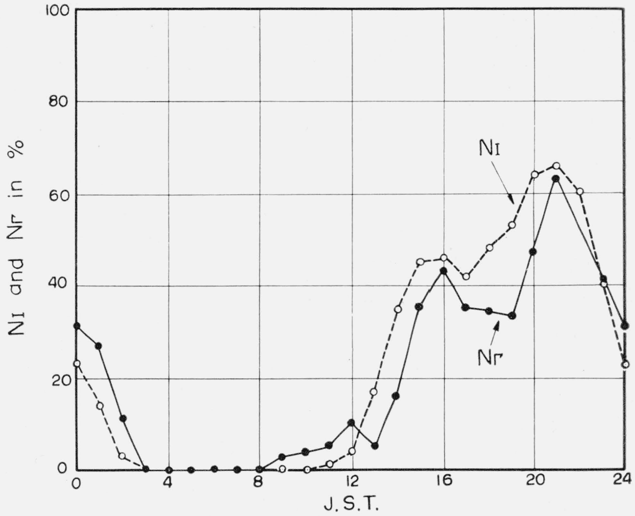


FIGURE 12. *Comparison of* N_r *and* N_I.

N_r: rate of reception of *F*-layer scatter.
Poro, the Philippines-Tokyo, 49.84 Mc/s, October 1959.
N_I: rate of occurrence of the ionospheric anomalies at Okinawa.

Pulse signal of 50 microseconds duration was observed at Tokyo on September 23, 1959. Figure 13 exhibits the typical A-display of the received pulse. It is composed of a number of components corresponding to various propagation paths spreading over a range of more than 1 msec. The maxi-

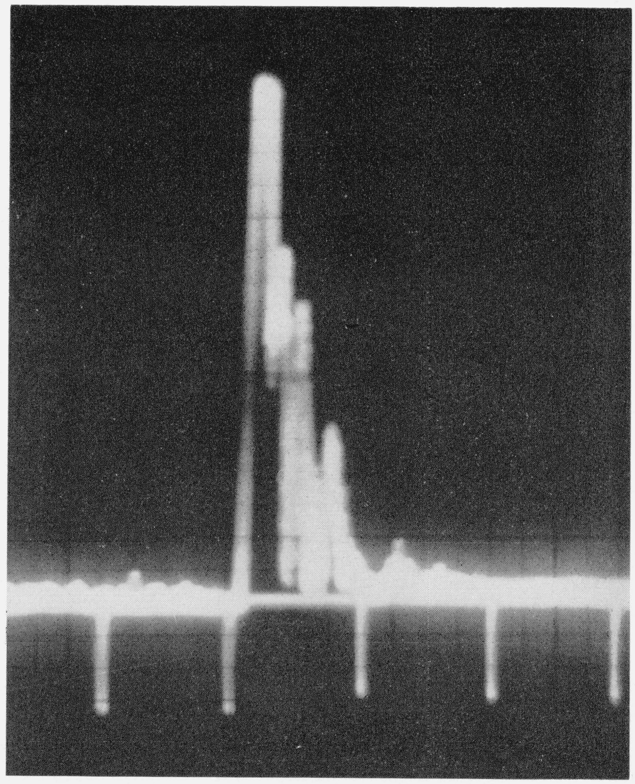


FIGURE 13. *A typical* A-*display of the received pulse.*

Poro, the Philippines-Tokyo, 49.84 Mc/s, 2203 J.s.t., September 23, 1959, time mark of 1 msec.

[4] R, Measurement influenced by, or impossible because of, absorption in the vicinity of a critical frequency.
S, Measurement influenced by, or impossible because of, interference or atmospherics.

mum delay time is of the same order as that observed by R. Bateman and others [1] for the Poro-to-Onna, Okinawa, path (1347 km). The ionospheric condition when the picture was taken corresponded to the case (b) above. From these observations, it is inferred that the received signal is propagated by way of scattering from an anomaly in the $F2$-layer peculiar to a region in the low latitude in addition to the normal $F2$-propagation.

Figure 14 shows the results observed in October 1959. The signals generally arrive from the true bearing early in the evening, but their bearings gradually deviate westwards with the lapse of time. It is one of the future problems to clarify whether the westerly deviation is caused by movement of the anomaly or by such mechanism as scattering from field-alined blobs of ionization in the F region as suggested already [1].

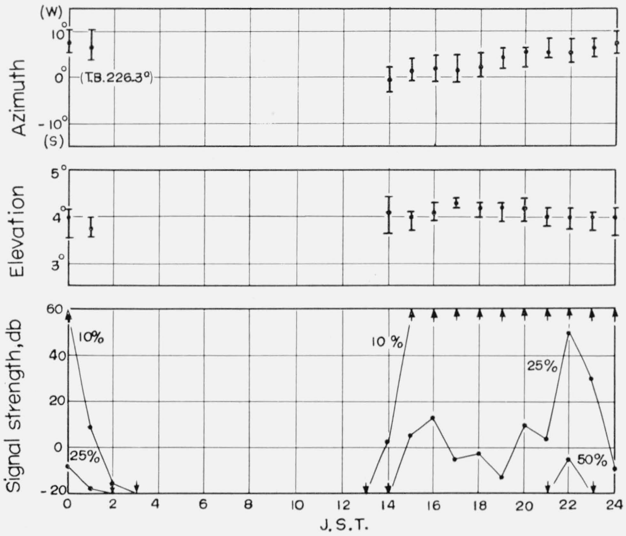


FIGURE 14. *Diurnal curves of signal strength, angles of arrival.*

Poro, the Philippines-Tokyo, 49.84 Mc/s, October 1959.

The authors express their thanks to Dr. S. Namba, Chief of Research Laboratory, K.D.D., for his encouragement in the study, to CRPL and The Voice of America in the United States Government, and the Radio Research Laboratories, Japan, for their cooperation and assistance in the continuation of transmissions and in the data arrangement.

6. References

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[2] K. Miya, T. Sasaki, and M. Ishikawa, Angles of arrival of a VHF signal in ionospheric forward propagation, Rep. Ionosphere and Space Research, Japan **8,** 187 (1959).

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(Paper 65D1–107)