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ANALYSIS OF AIR-GROUND RADIO WAVE PROPAGATION MEASUREMENTS AT 800 MHz

U.S.
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NOVEMBER 1971

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ANALYSIS OF AIR-GROUND RADIO WAVE PROPAGATION MEASUREMENTS AT 800 MHz

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ANALYSIS OF AIR-GROUND RADIO WAVE PROPAGATION MEASUREMENTS AT 800 MHz

by

G. D. Gierhart, A. P. Barsis, M. E. Johnson, E. M. Gray, and F. M. Capps

ABSTRACT

An analysis is presented of air-ground radio wave propagation measurements, which were performed using an airborne transmission source at approximately 6,400 m above msl. Receiving antennas were slightly within and beyond line-of-sight of the airborne transmitters. Received signal level data were obtained on 823.75 MHz and 847.75 MHz. Data were analyzed for short-term and long-term statistics of basic transmission loss. Long-term fading range statistics were compared with values calculated using a modified Longley-Rice model and good (∿ 1%) agreement was obtained. This model appears to underestimate the long-term median transmission loss by about 3 dB.

Key Words: air-ground communications, transmission loss, tropospheric propagation.

1. INTRODUCTION

An analysis is presented of air-ground propagation measurements that were performed between 1961 and 1964 using airborne transmission facilities of the Midwest Program on Airborne Television Instruction (MPATI). The measurements consisted of radio wave propagation data taken between an airborne transmitting source and several ground receiving stations. Transmitters operating on two UHF TV channels were in an aircraft flying at a nominal altitude of 6,400 m (21,000 ft.) above mean sea level (msl) over Montpelier, Indiana. Six receiving antennas were located slightly within and beyond the radio horizon of the transmitting aircraft. Measurements were made during an approximate 2-year period. This report includes descriptive analyses of UHF air-ground propagation data and a comparison of long-term statistics with estimates made using the modified "Longley-Rice" model described in appendix A.

The report is organized so that discussions of experimental arrangements (sec. 2), short-term variability (sec. 3), and long-term variability (sec. 4) are followed by the conclusions (sec. 5) of the study. The model used to estimate transmission loss is discussed in appendix A.

Detailed descriptions of the experimental arrangements and some preliminary analyses are contained in unpublished reports on "Measurement procedures for air-to-ground propagation studies at 850 Mc/s," by R. S. Kirby and A. P. Barsis, NBS Memo. Rept. PM-83-47, Nov. 1961; "National Bureau of Standards measurement program on UHF airborne television," by R. S. Kirby, A. P. Barsis, and P. L. McQuate, NBS Rept. 7274, June 1962; "UHF field intensity measurements" (Smith Electronics project reports for contract CST-7355, 1962-1963); and "Preliminary results of UHF in air-to-ground propagation measurements," by A. P. Barsis, NBS Rept. 7917, June 1963. Because of the limited availability of these documents, much of the information in them has been incorporated into the present report. Specific details concerning the documents cited have been given here for completeness, since the references (sec. 7) do not include documents with limited availability. Additional information concerning them may be obtained from the authors of this report.

2. EXPERIMENTAL ARRANGEMENTS

Transmissions originated from a modified DC-6 aircraft, flying at a nominal altitude of 6,400 m above msl in a "figure-eight" pattern within a circle of 16 km radius centered on the coordinates 40°32'N 85°17'W (near Montpelier, Indiana). The axis of the flight pattern depended on prevailing winds. Transmissions were provided by MPATI between 9 a.m. and 2 p.m., CST, Monday through Thursday, each week during the school year (summer sessions included). The transmissions provided numerous schools in the Midwest region with educational television programs. For data extraction and analysis, the laboratory now known as the Institute for Telecommunication Sciences (ITS) was supplied daily logs giving the transmitter power on the two channels

(UHF television channels 72 and 76) and orientation of the figure-eight flight pattern. Nominal characteristics of the airborne transmitting equipment are summarized in table 1.

One of the unique features of the aircraft installation was the transmitting antenna, which was lowered during flight using a stabilized boom approximately 7 m below the aircraft. Thus time variations in transmission loss due to changes in

Table 1. Airborne Transmitter Facilities

Main Transmitting Equipment	
Aircraft: Douglas DC-6AB, serial N6815C	
Channel 72, KS2XGA, 818-824 MHz	
Power rated visual plus aural	12 kW peak
Actual	6 kW peak
Aural	10 dB below actual peak
Antenna gain relative to isotropic	8.7 dB
Polarization	Horizontal
Channel 76 KS2XGD, 842-848 MHz	
Power rated visual plus aural	12 kW peak
Actual	5 kW peak
Aural	10 dB below actual peak
Antenna gain relative to isotropic	8.2 dB
	Horizontal
Alternate Transmitting Equipment	
Aircraft: Douglas DC-6AB, serial N6813C	
All parameters are the same except the actual power output is somewhat less--on the order of 3-4 kW peak.	

attitude of the aircraft were all but eliminated. A photograph of one of the aircraft in flight with the antenna extended is shown in figure 1. A special computer using inputs from a Tactical Air Navigation (TACAN) station kept the aircraft position constantly on display so that the figure-eight pattern could be flown with accuracy. Occasionally stabilization of the antenna became defective and it was necessary to fly a circle with a constant roll angle. In this situation the antenna was maneuvered manually to a position counteracting the roll, but remaining essentially in one position during the flight.

The high gain of the transmitting antenna was obtained through the use of vertical directivity, which in turn necessitated the use of antenna stabilization as described above. Model measurements were made to determine the patterns. Figure 2 shows a typical vertical pattern obtained by the Westinghouse Electric Corporation from one of several model antennas used. The transmitting antennas employed a small amount of electrical tilting downward. The horizontal patterns were quite uniform, and serious antenna-gain variations because of changes in aircraft heading were not expected to occur.

Receiving stations were at Cleveland, Ohio (operated by Smith Electronics, Inc.), Allegan, Michigan (operated by the Federal Communications Commission), Milwaukee, Wisconsin

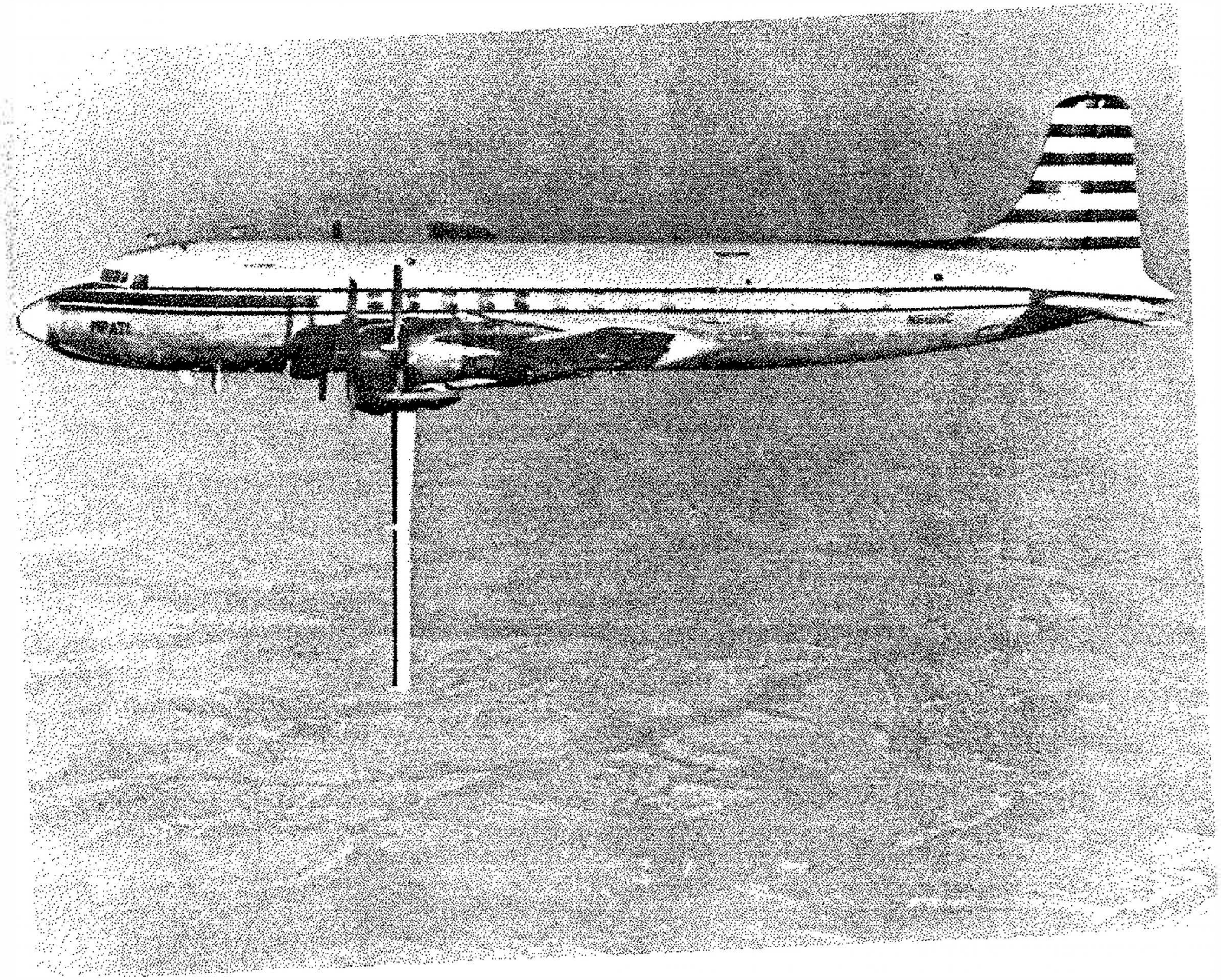

Figure 1. Airborne transmitting facility over Montpelier, Indiana.

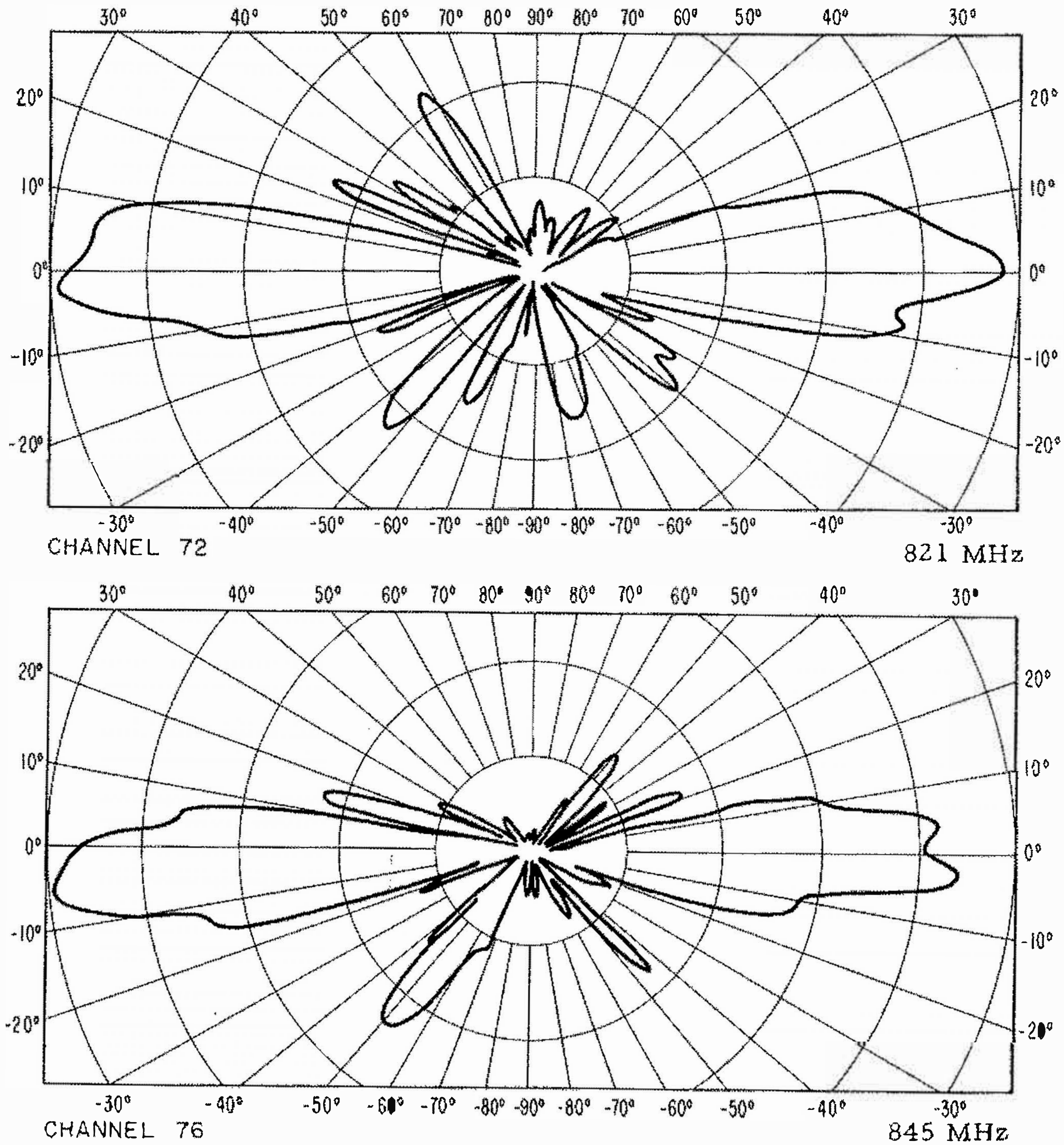

Figure 2. Vertical patterns of airborne antennas. Based on modeling data from Westinghouse Electric Corporation. Units for the radial scales are not given since they are unknown to the authors.

(operated by the Journal Co.), and Louisville, Kentucky (operated by WHAS-TV). At each of these locations, sound carriers of the TV signals at 823.75 and/or 847.75 MHz were recorded, using relatively narrow-band receivers and strip charts. Calibrations were made daily with standard signal generators. Except for the Allegan installation, all receivers, recorders, calibration equipment, and antennas were furnished by ITS, and standard operating routines were supplied to the operators after initial equipment installation and check-out by ITS personnel.

Received power levels were determined by signal generators calibrated against laboratory standards, and appropriate signal generator correction terms were included in the conversion factors. All measured data were converted to basic transmission loss (Rice et al., 1967, sec. 2.4) by using measured or estimated values of antenna gains and line losses, and by information contained in the transmitter logs (for transmitter power). Free-space antenna gains were assumed. "Measured" or "observed" basic transmission loss data referred to in this report are terms used for "data derived from measurements" via the procedures just described.

The outline map in figure 3 shows the relative location of the transmitter "orbit center" and the receiving sites. The 322 km radius circle denotes an approximate location of a smooth-earth radio horizon, d_{Ls1}, for the aircraft and does not include an allowance for the horizon distance, d_{Ls2}, associated with the receiving antennas (table A.2).

Table 2 provides pertinent parameters for the propagation paths. These parameters are used in the data analysis and transmission loss calculations. Distances shown are from the nominal orbit center.

Partial terrain profiles from the receiving sites toward the transmitter are shown in figures 4 through 7. Values for the direct ray arrival angle, θ_h, are given on the profiles for each appropriate site. The significance of this angle will be discussed in section 5.

Table 2. Propagation Path Parameters

			Receiving Antenna	
Location	Total Path Distance, km	Frequency MHz	Height Above Ground, m	Gain in dB Above Isotropic
Allegan	237	823.75	9	13.6
Cleveland	319	847.75	142	14.6
Cleveland	319	847.75	9	14.9
Cleveland	319	823.75	9	14.0
Louisville	258	823.75	99	13.9
Milwaukee	358	847.75	61	12.5

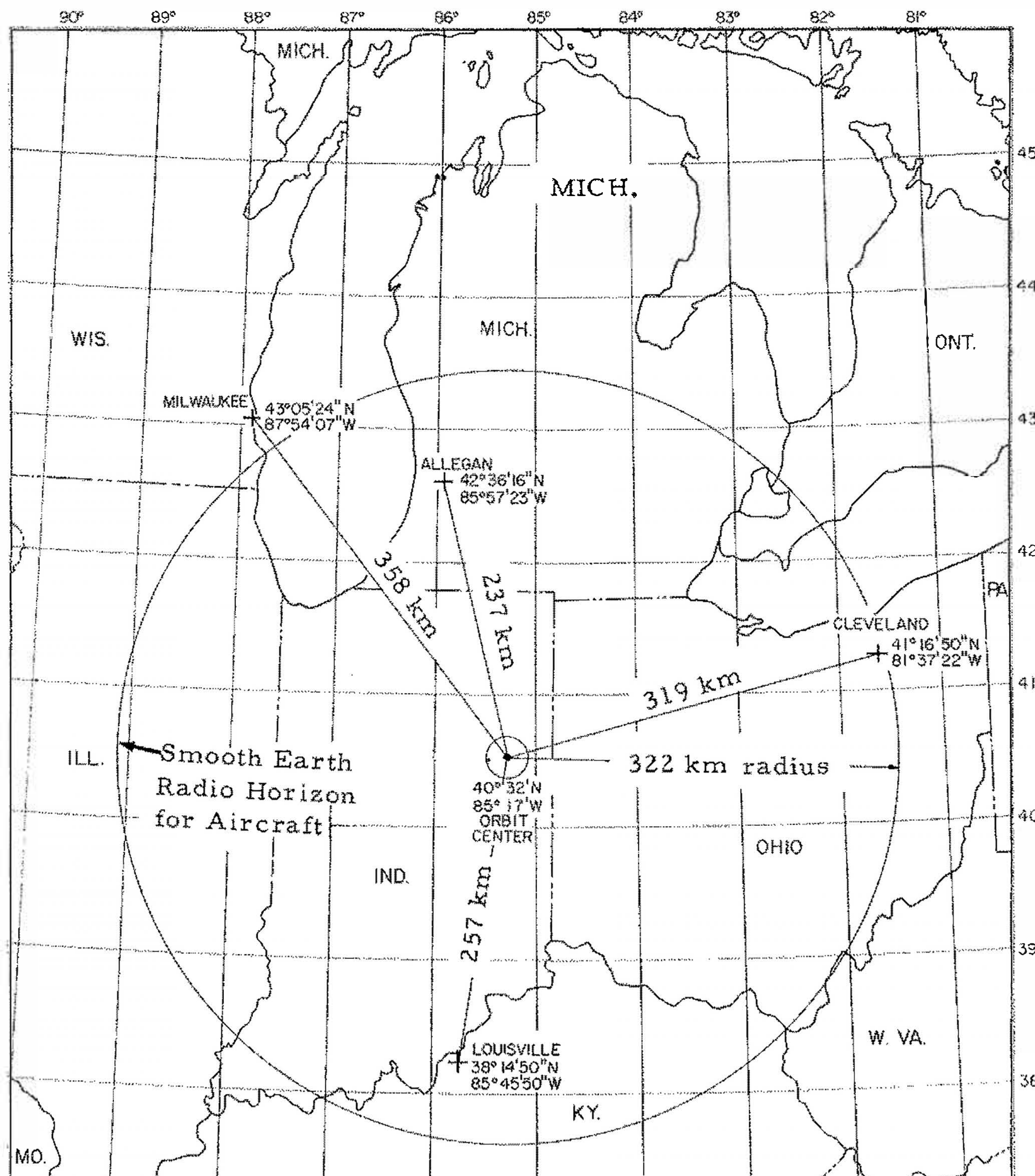

Figure 3. Map showing propagation paths.

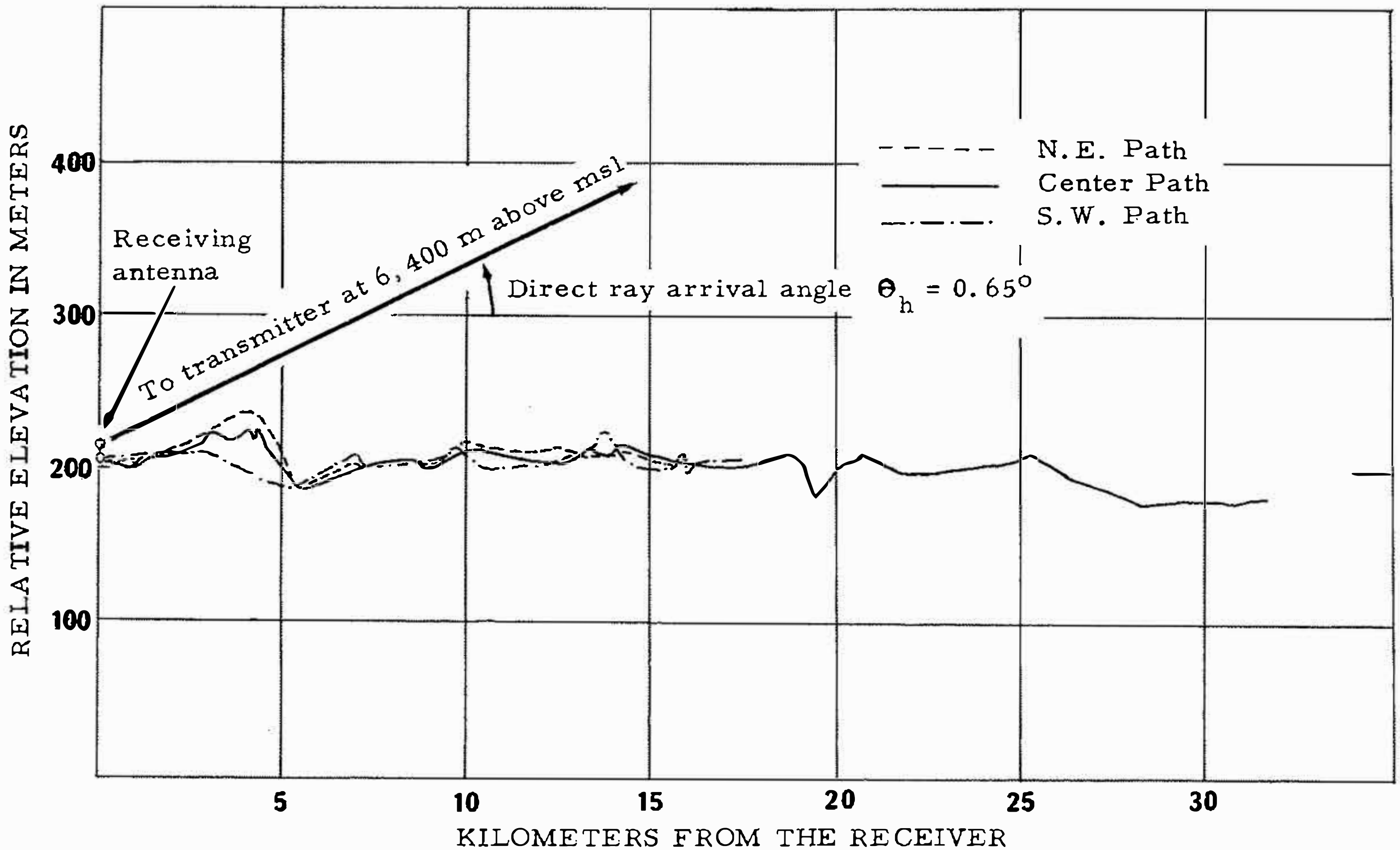

Figure 4. Terrain profiles for Allegan path.

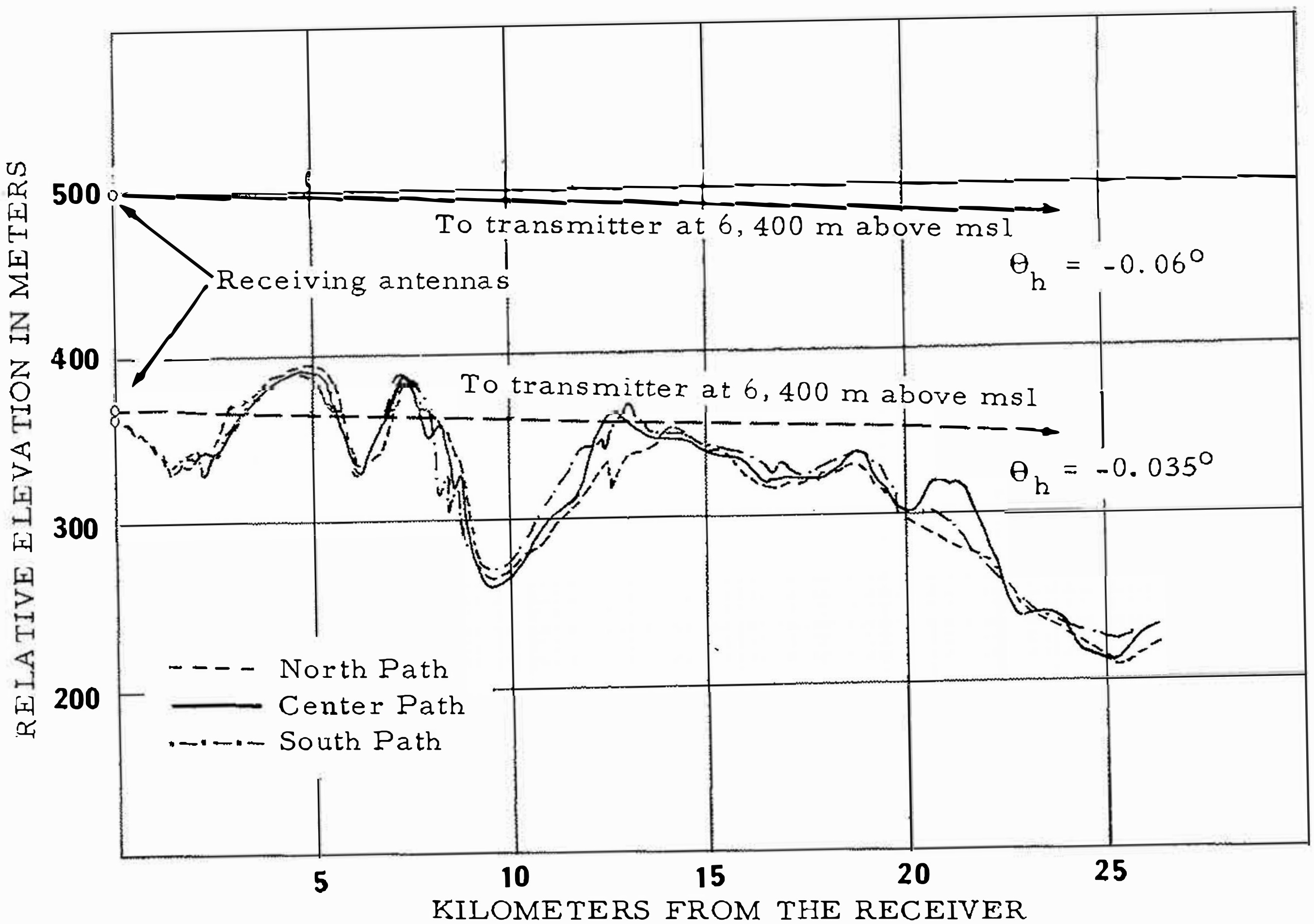

Figure 5. Terrain profiles for Cleveland paths.

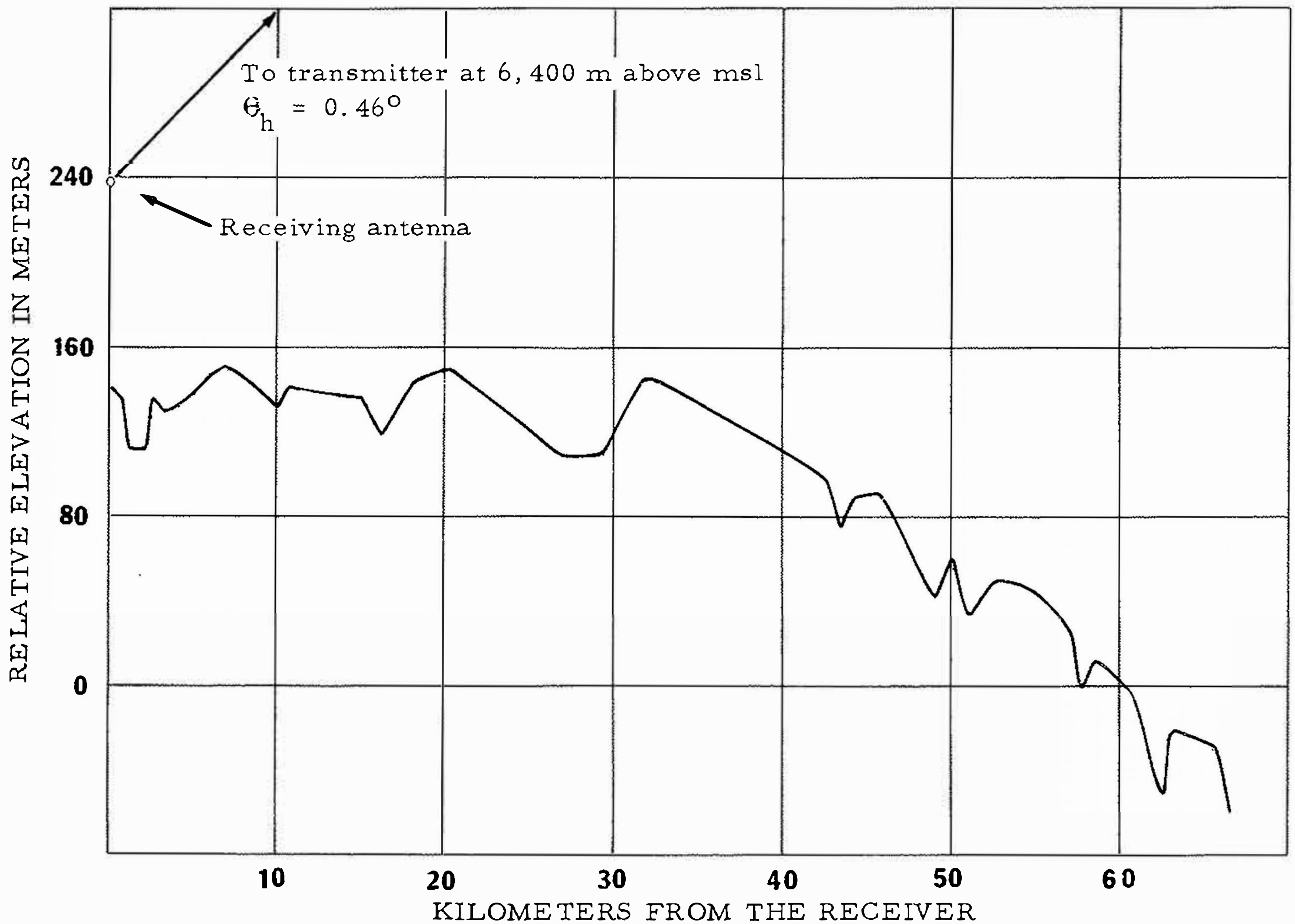

Figure 6. Terrain profile for Louisville path.

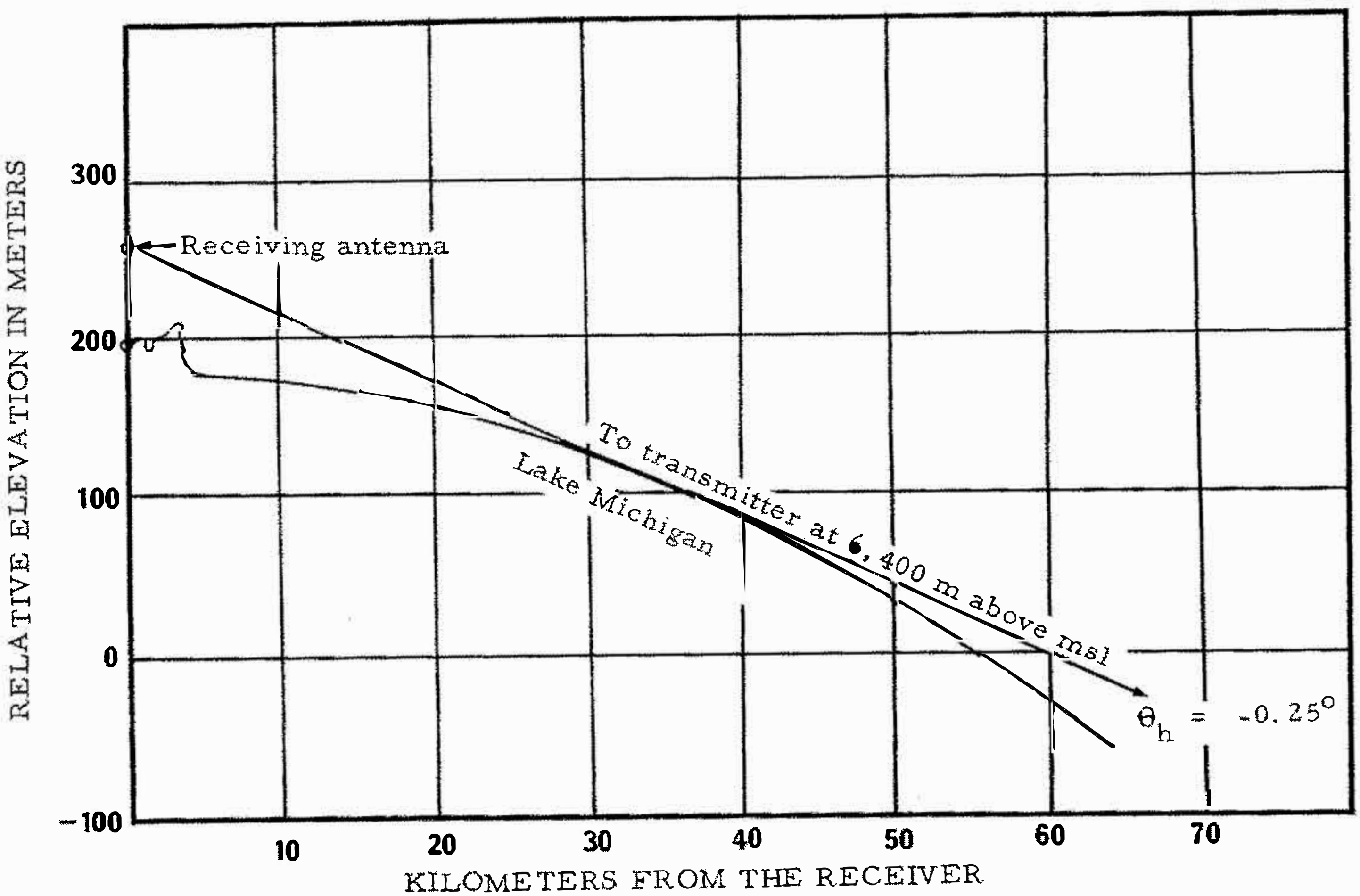

Figure 7. Terrain profile for Milwaukee path.

For Allegan and Cleveland, three profiles are shown for each path: one to the orbit center and two tangent to a circle of 16 km radius about the orbit center, which represents the limits of the flight pattern. For the Milwaukee path the three profiles are not shown separately since their significant portions are over Lake Michigan and essentially identical. Only a single profile is shown for the Louisville path since the clearance between the direct ray path and terrain is large, and the other profiles would also have large clearances. All profiles have been drawn on the customary basis of an effective earth radius to permit representation of radio rays by straight lines (Rice et al., 1967, sec. 6.2; Bean and Dutton, 1966, sec. 3.6). Consequently, the vertical elevation scale shown on the left margin of each graph represents height above msl only at the zero distance point and denotes relative values at other distances. Direct ray paths to the aircraft are shown. They provide an indication of the extent to which terrain near the receiving antennas is likely to influence the received fields. The great height of the airborne transmitting antenna eliminates the need for detailed information near the aircraft orbit.

Photographs of the receiving sites are shown in figures 8 through 11. The antennas at all receiving sites were corner reflectors similar to the one shown in figure 8.

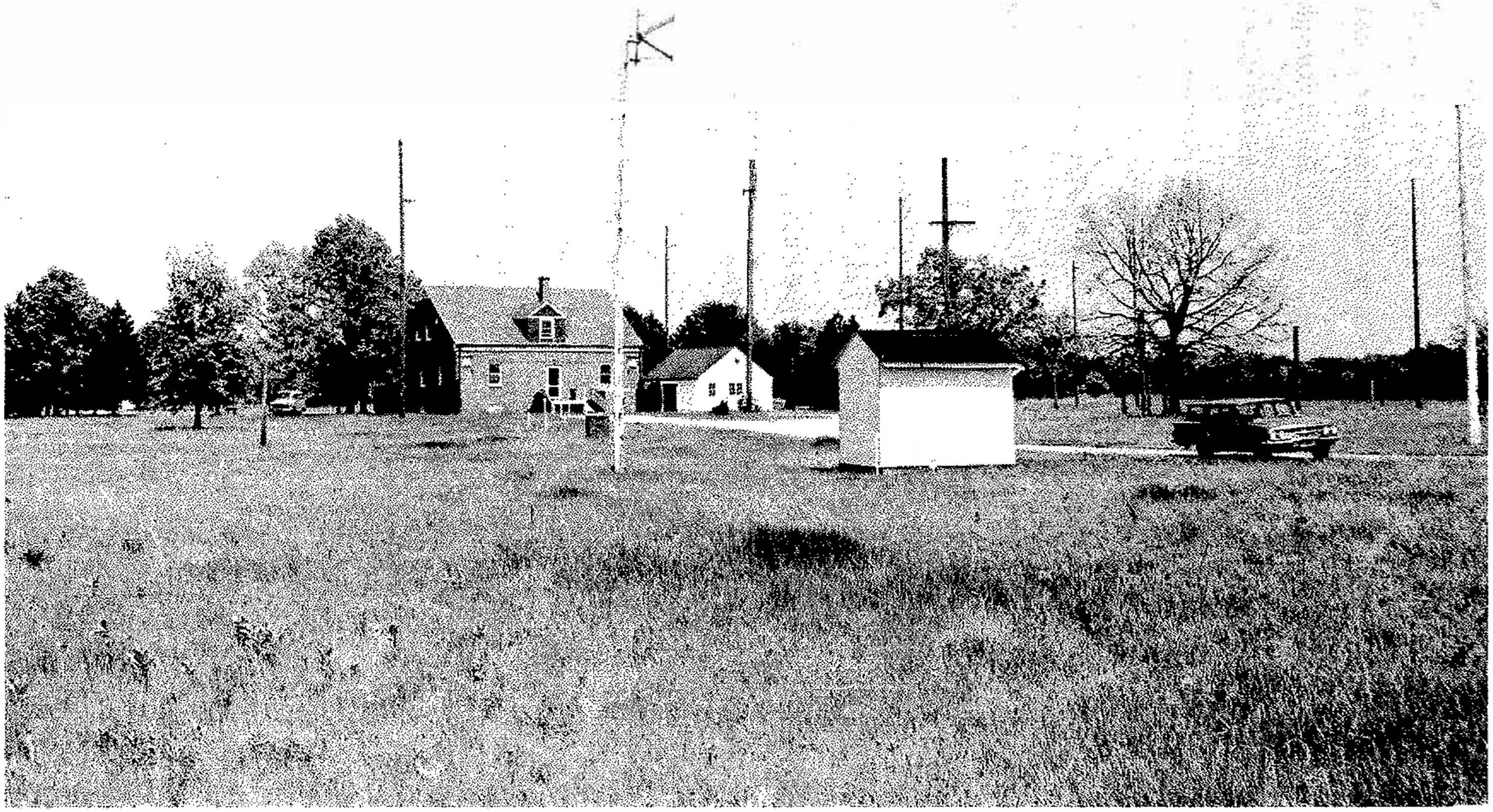

Figure 8. Photograph of Allegan site. The antenna (corner reflector) is 9 m above ground.

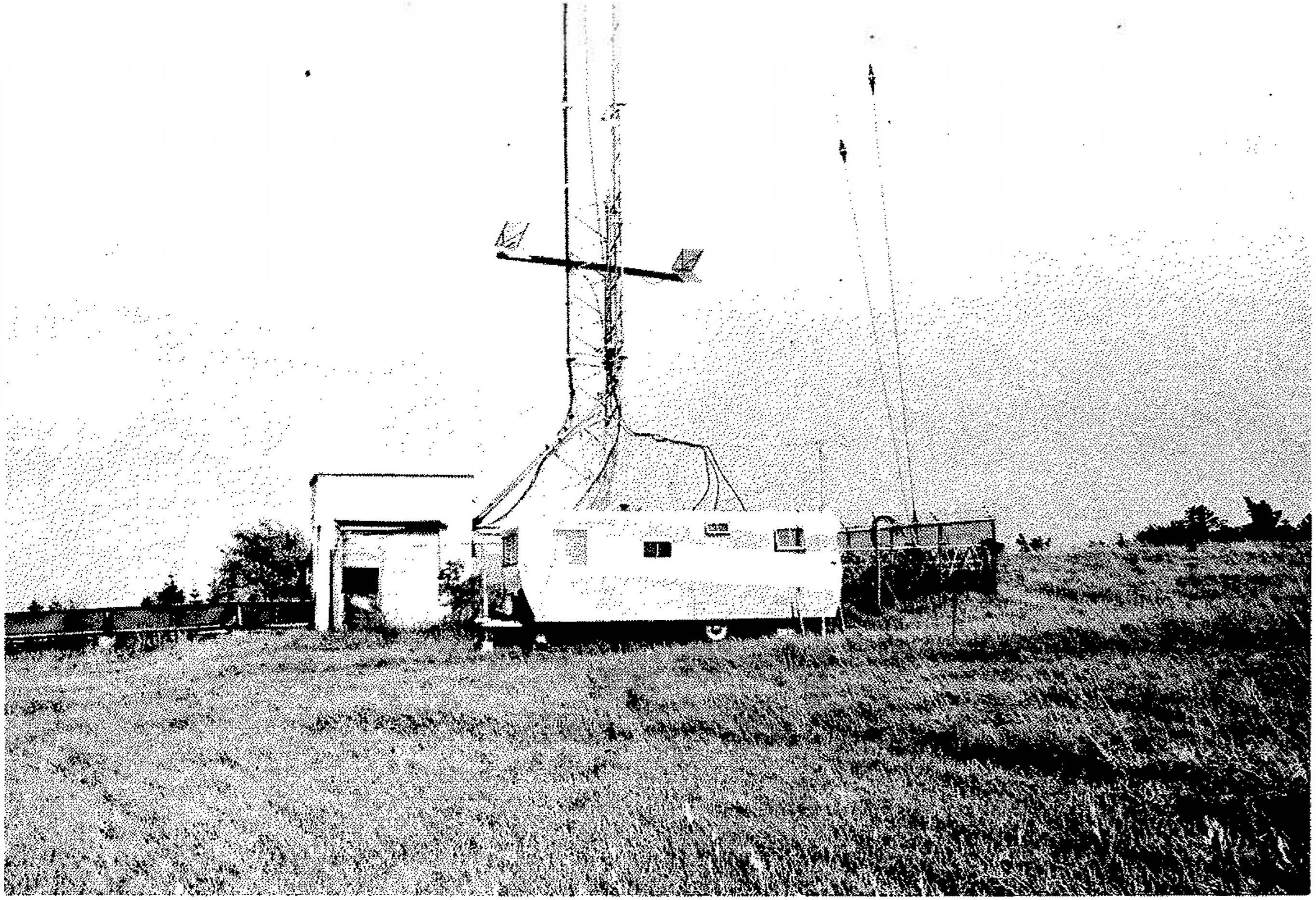

Figure 9. Photograph of Cleveland site. Antennas shown are 9 m above ground. The high antenna (not shown) is 142 m above ground.

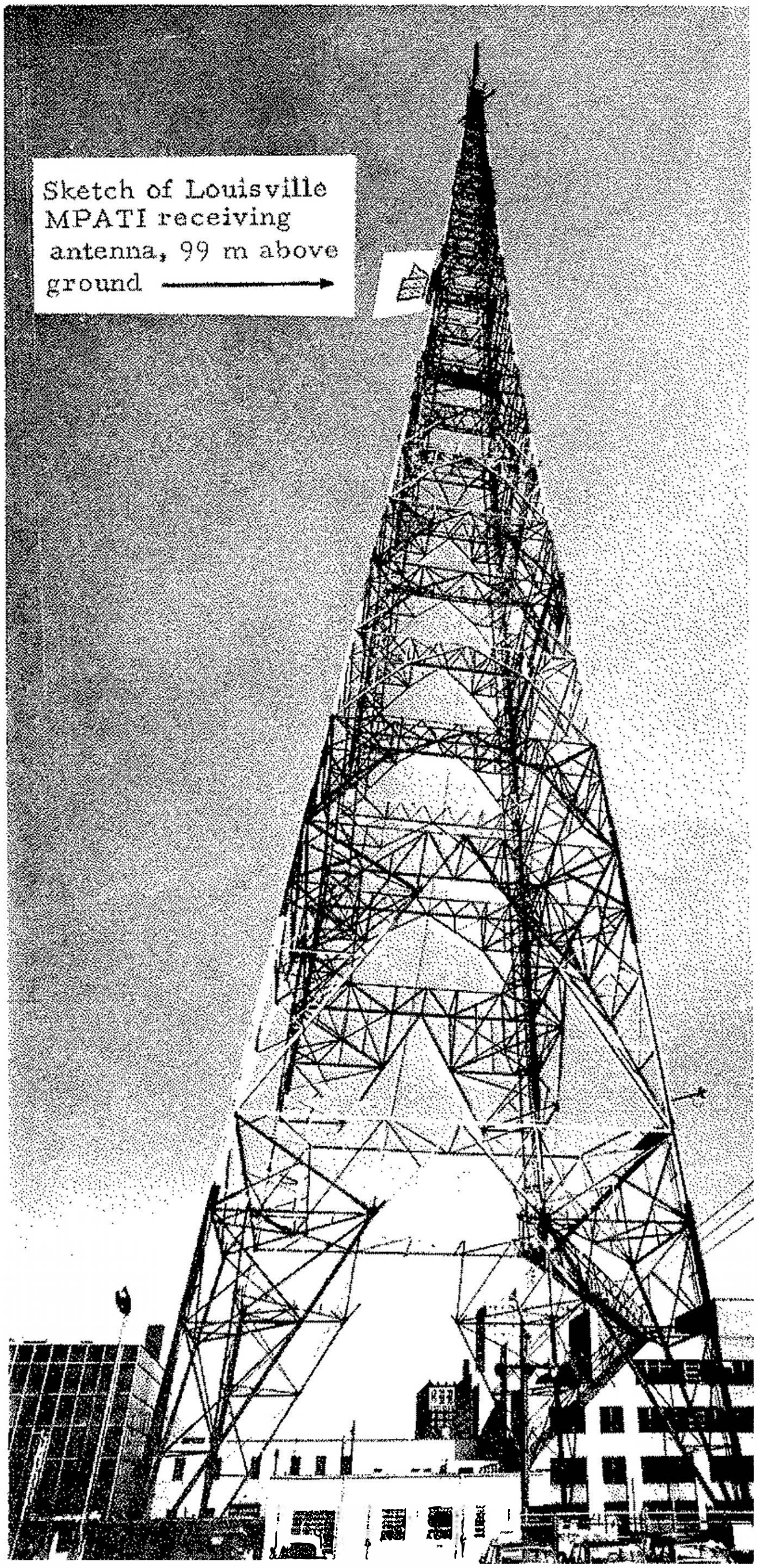

Photo courtesy of the Louisville Courier Journal.

Figure 10. Photograph/ sketch of Louisville site.

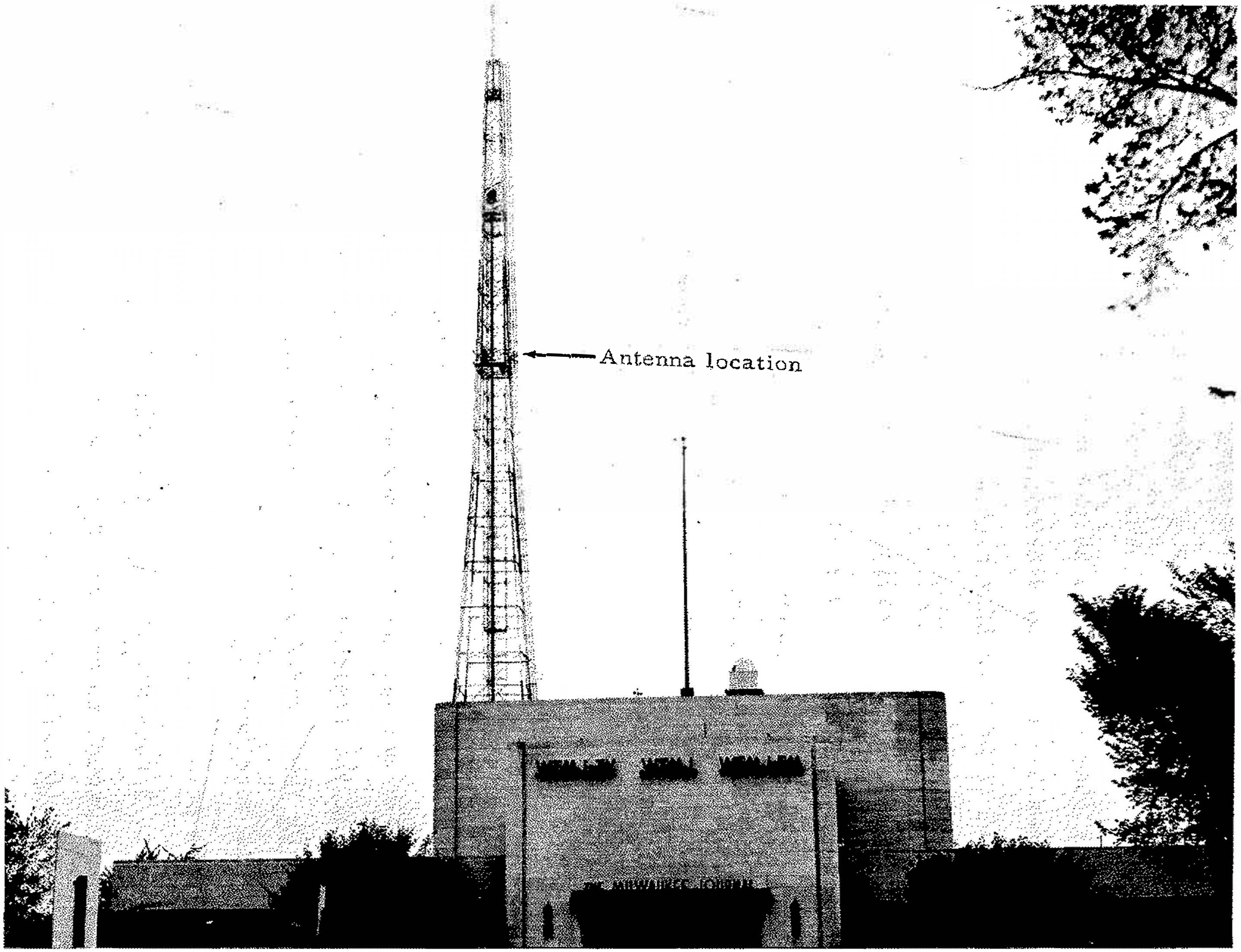

Figure 11. Photograph of Milwaukee site. The receiving antenna is 61 m above ground.

Terrain profiles for the Allegan paths (fig. 4) suggest that the transmitting orbit is within line-of-sight of the Allegan receiving antenna, but trees (fig. 8) prevent line-of-sight conditions. The height and location of these hardwood trees has not been determined exactly, but they were estimated to be 6 to 12 m high and 60 to 120 m from the Allegan antenna.

The Cleveland receiving station recorded signal levels received on three antennas at two different frequencies: 847.75 MHz on the antenna 142 m above ground, and 823.75 MHz and 847.75 MHz on the two antennas 9 m above ground. Terrain profiles for the Cleveland paths (fig. 5) show that a line-of-sight path exists for the high antenna. However, the terrain is covered by a hardwood forest and is probably too rough to support specular reflection for this path, so that the median value of basic transmission loss observed would be expected to be close to or somewhat below the free-space value. The two low antennas, however, are not within the horizon of the transmitting orbit. A common horizon is formed by the rounded obstacle between 4.5 and 4.8 km from the receiver.

The path profile to the Louisville receiving site shown in figure 6 does not show the buildings (fig. 10) which are high enough to reduce the clearance implied by the profile, but probably not high enough to have a significant effect on propagation conditions. Beyond Louisville the path is characterized by rolling, wooded terrain. The Louisville installation used an existing transmission line system with cable attached to the tower, inaccessible to ITS personnel, and an old transmission line system of unknown configuration located within the structure of the building. The limited resources available for the Louisville tests were insufficient to allow either an accurate measurement of line loss or the installation of a new cable with known characteristics. An input VSWR of 4.7 to 1 at the receiver end of the line and uncertainty concerning the cable configuration within the building made it impossible to estimate the line loss accurately. Consequently, the analysis of the Louisville data was based on line loss estimates discussed in section 4.3; the resulting values of basic transmission loss should not be considered accurate in an absolute sense. However, they may be considered accurate in a relative way for evaluating transmission loss variations because the error in line loss can be assumed to be constant.

As demonstrated by the terrain profile in figure 7, the Milwaukee path extends for more than 70 km across Lake Michigan, which provides a smooth, diffracting surface near the receiving antenna. This path may change from a within-the-horizon path to a slightly beyond-the-horizon path as the aircraft follows its flight pattern.

3. SHORT-TERM VARIABILITY

Short-term variability of tropospheric propagation data is usually defined as the variability of transmission loss within an hour or less (Rice et al., 1967, sec. V). Such variability is caused by a combination of effects of the flight pattern of the transmitting aircraft, and short-term variations in atmospheric parameters. For the MPATI data it was more convenient to use the signal level variations within each 5 hour broadcast day as a basis for short-term variability studies; thus, the short-term variability statistics presented here are influenced by variability that is normally considered long-term. The character of received carrier levels is discussed (sec. 3.1), a method of presenting fade duration statistics illustrated (sec. 3.2), and transmission loss distributions observed for the various propagation paths during days of greatest variability are shown (fig. 17).

3.1. Flight Pattern Effects

The flight pattern of the DC-6 was usually a "figure eight" within a circle having a 16-km radius, shown in figure 12. The pilot flew in a direction enabling him to turn into the wind at the ends of the figure eight. Consequently the same flight pattern was normally maintained during each measurement period (5 hours). Data were classified in accordance with flight pattern orientation so that its effects

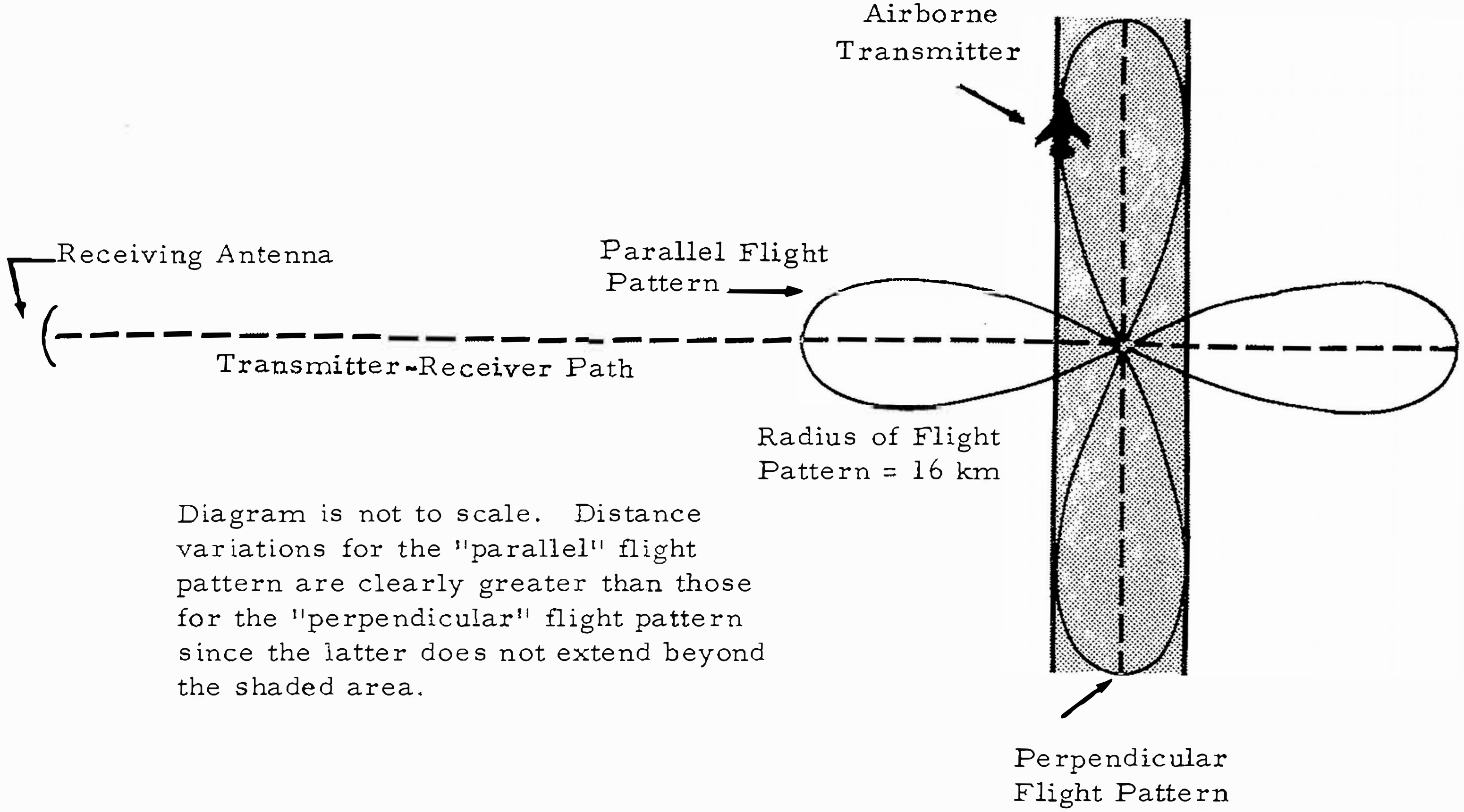

Figure 12. Airborne transmitter flight patterns.

upon the received signal could be investigated. Since a complete flight pattern takes about 15 min, the variability introduced by it is approximately averaged over an hour and averaged quite well over the daily recording period (sec. 4.1).

As an illustration, data samples for 1 hour each of 2 selected days are presented in figures 13 and 14. The flight pattern on May 8 had its axis oriented NE-SW, essentially perpendicular to the Milwaukee path, whereas the orientation on May 24 was NW-SE, essentially parallel to the Milwaukee path. This difference is reflected most strikingly in the May 24 Milwaukee data in figure 14, which show a very regular fading pattern of approximately 15 min with a range of at least 20 dB. A similar period can also be detected in the Allegan data, although partially masked by the superimposed, more rapid fading. No comparable period is discernible for the Cleveland high-tower data, which show a great deal of rapid fading with a range less than 10 dB. The basic 15-min period is discernible for both frequencies received by the Cleveland low antennas, and the instantaneous signal levels received (823.75 and 847.75 MHz) seem to be well correlated. Notice that those signals were also correlated on May 8 (fig. 13) and that the flight-pattern period is again visible in those records.

With the exception of the Milwaukee path the propagation characteristics do not appear to be sensitive to small changes in path distance in a systematic fashion. Actually, Milwaukee is the only path where a change of ± 16 km can radically change transmission loss levels; this results in the much larger variability shown for Milwaukee in figure 14. Signal levels are usually influenced by reflections from terrain and by atmospheric phenomena which tend to mask systematic distance dependences. Propagation conditions such as the relative phase of reflected rays may be so sensitive to aircraft location in addition to atmospheric conditions that signal levels fail to repeat on successive orbits and variations that appear random tend to obscure periodic variations. Even the Milwaukee signal level records were influenced by this masking effect; e.g., the periodic nature of the Milwaukee signal shown in figure 14 (flight pattern parallel to path) is not present in figure 13 (pattern perpendicular). Nevertheless, the variability associated with the perpendicular pattern (fig. 13) is not significantly less than that associated with the parallel pattern (fig. 14), as would be expected from a simple monotonic dependence of transmission loss on distance. Simple monotonic transmission loss versus distance curves that could characterize propagation for paths such as Milwaukee are sketched in figure 15 along with the signal level patterns that would result from them as the aircraft completes one orbit (fig. 12).

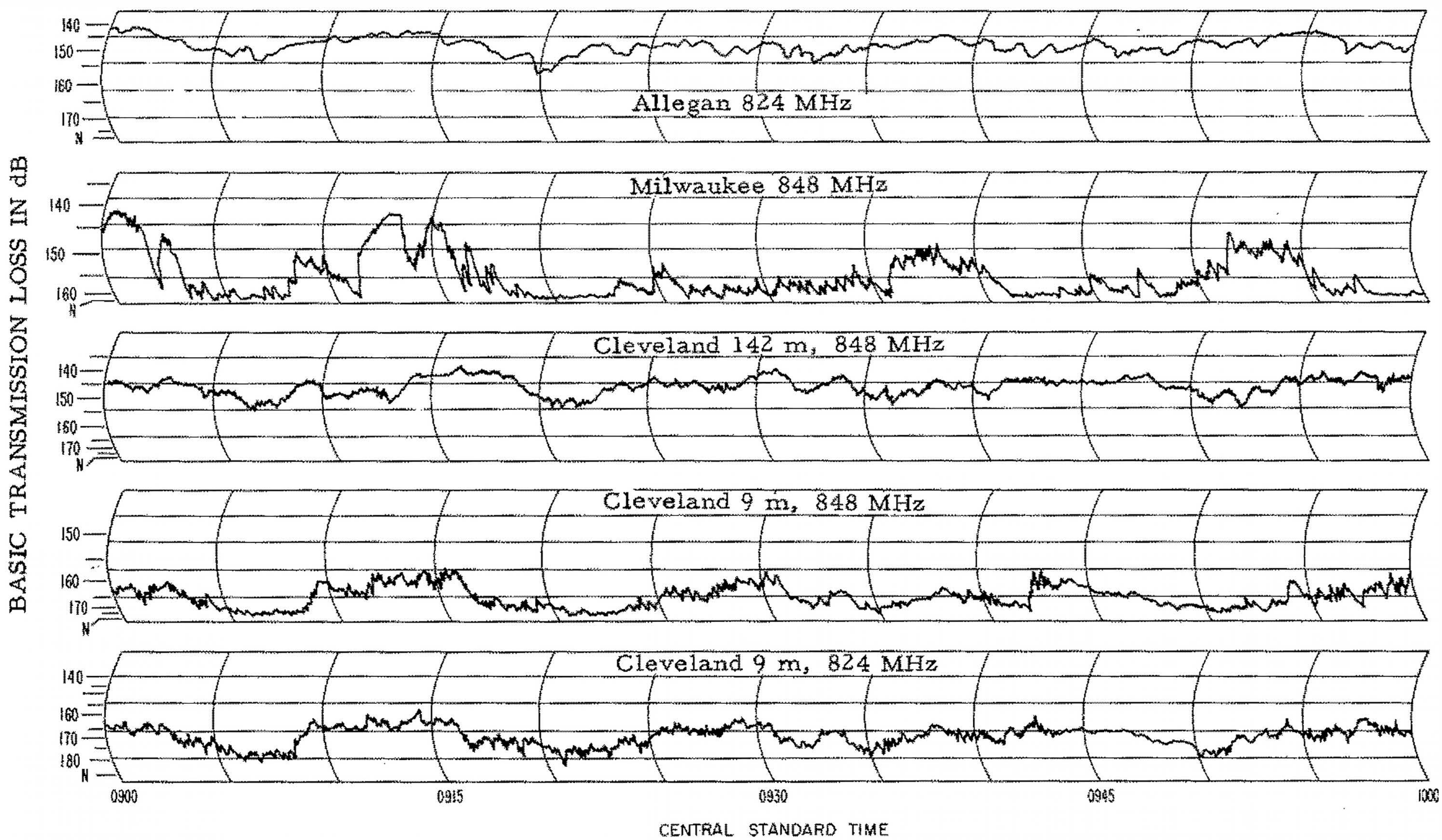

Figure 13. Data samples for May 8, 1962.

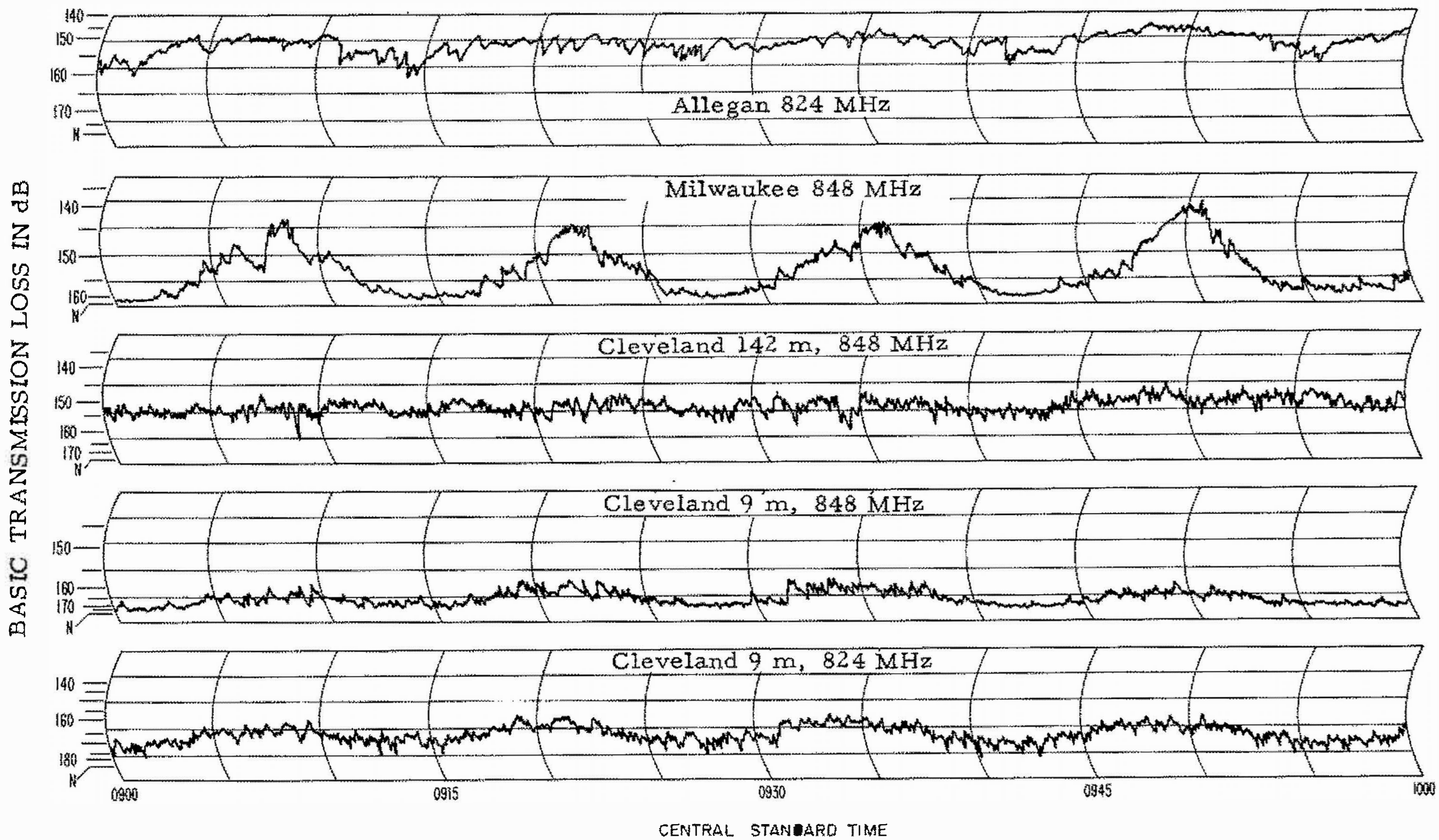

Figure 14. Data samples for May 24, 1962.

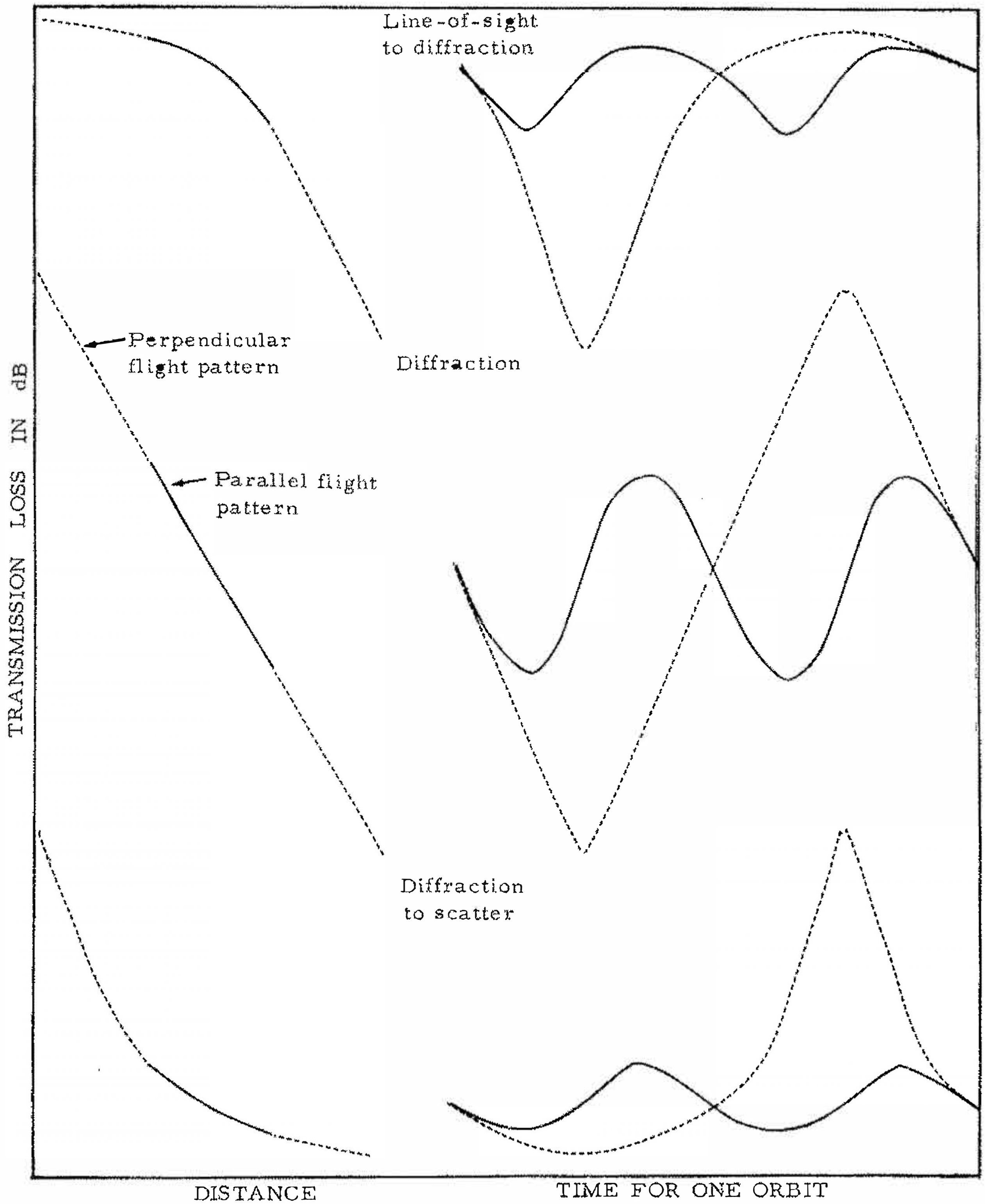

Figure 15. Qualitative transmission loss variations due to aircraft motion.

Figure 15 indicates that a parallel flight pattern would be expected to have a greater signal level variation and longer period (one cycle per orbit) than a perpendicular pattern (two cycles per orbit). The center curve set (diffraction region) would be expected to characterize best the variation of long-term median transmission loss with distance for the Milwaukee path. However, the bottom set (diffraction to scatter region) is more typical of the periodic signal level recordings made at Milwaukee (fig. 14). A more extensive analysis would be required to determine if this observation is significant in terms of the long-term transmission loss characteristics (see sec. 4) or if it implies that an aircraft altitude less than the 6,400 m above msl should be used for predicting transmission loss.

3.2. Fading Statistics

Analyses of the duration of fades and of signal enhancements are useful in evaluating telecommunication systems performance. A data reduction method has been developed to determine the percentage of time during which measured signal levels remain either above or below specified levels. This method is demonstrated here using the Milwaukee data for the 2 days discussed earlier (May 8 and May 24, 1962); the flight pattern was perpendicular to the propagation path from the orbit center to Milwaukee on May 8 and parallel on May 24.

The graphs in figure 16 show signal level and fadeout distributions for the Milwaukee data on May 8 and May 24, 1962. The top graph shows the cumulative distributions of instantaneous basic transmission loss values for the total recording time on the 2 days (4 hours each). The two lower graphs depict the distributions of fadeout and enhancement duration and are interpreted as follows.

Consider the curve labeled "159.3" on the middle graph (for May 8). It shows, in relation to the abscissa (percentage of fades) and ordinate (fadeout durations) scales, that about 6% of all fades below this 159.3 dB basic transmission loss level were longer than 70 sec, and about 11% of such fades were longer than 20 sec. This level can be related to the median for this particular day (154.5 dB), or any other arbitrary level. Similarly, the duration statistics of signal enhancements above arbitrary levels may be determined from the right half of the graph; as an example, 5% of the signal enhancements above the 144.1 dB level of basic transmission loss were longer than 70 sec. The two curves shown for the 154.5 dB illustrate that both fades and enhancements could be determined for any arbitrary level. With this type of presentation, curves for fades bend to the left while those for enhancements bend right. Asymptotic continuations of the curves (denoted by broken lines downwards) for short fadeout, or enhancement, durations would result in the

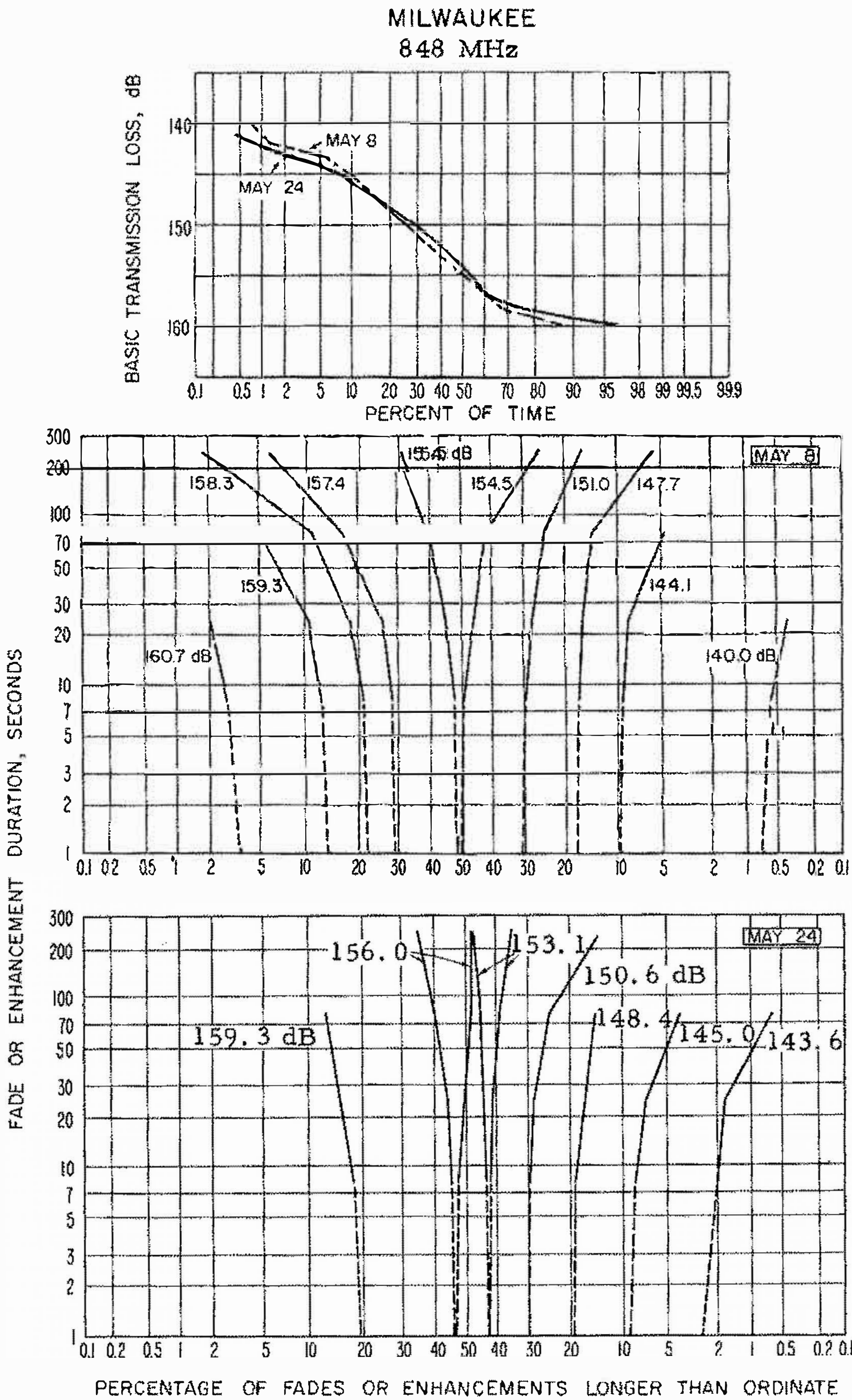

Figure 16. Signal level and fadeout distributions.

cumulative distribution of instantaneous signal levels similar to those shown in the top graph. The right half of the abscissa scale of the transmission loss distribution corresponds to the left or fadeout portion of the fadeout distributions, and "percentage of time" for the right half of the distribution graph abscissa is 100% minus "percentage of fades" of the lower graphs.

The difference in the fading characteristics for the two days shown by the chart samples in figures 13 and 14 is reflected in the fadeout duration statistics but is not apparent from the cumulative distributions of the instantaneous signal levels. Comparison of the middle with the bottom graph in figure 16 shows that the fadeout duration curves for May 24 are much steeper than those for May 8. This is due to the more periodic fading observed on May 24 when the flight pattern was parallel with the propagation path; thus fades below a particular level tend to have a fixed duration. The more irregular signal characteristics observed on May 8, however, resulted in less steep duration curves with a greater variation in fade durations.

Such systematic analyses of all available data would provide more complete statistics of fade and enhancement durations. However, its usefulness would be limited because: (a) the most appropriate time interval and reference level depend upon the particular system characteristics (data rate, modulation, etc.) so that a single analysis would not have universal applicability; (b) the data were not recorded directly on magnetic tape, so that fades with durations less than 1 sec could not be included; and (c) the analysis would only be applicable to situations with parameters similar to those tested, and these parameters are not necessarily typical of air-ground communication links.

Within the limitations of the recording methods, the daily fading range is considered a short-term fading parameter. Daily fading range is defined here as the decibel difference of received power levels exceeded during 10 and 90% of the total recording time during each day. Table 3 lists the largest, median, and smallest fading ranges observed for the various paths with a summary of the number of recording days by season. Distributions showing transmission loss variability for the day having the largest fading range are shown in figure 17 for the various paths. In these distributions the ordinate scale is in decibels greater than the median power received for the day or decibels less than the median transmission loss for the day (labeled as L_b on each distribution). In these graphs a straight line indicates a normal distribution of the data. The statistical characteristics of daily fading ranges are further discussed in section 4.2.

Table 3. Daily 10- to 90-% Fading Ranges

Station	Number of Days			Daily Fading Range, dB		
	Winter	Summer	Total	Largest	Median	Smallest
Allegan	205	93	298	16	7.5	3
Cleveland						
upper, 847 MHz	64	42	106	13	6.0	2
lower, 847 MHz	97	42	139	26	11.5	4
lower, 823 MHz	43	32	75	20	11.0	2
Louisville	12	15	27	7	4.5	2
Milwaukee	96	85	181	29	12.5	1

Figure 17 shows a very large fading range for Milwaukee (28.9 dB) on April 5, 1962. Examination of the flight logs reveals that on that day the antenna was "fixed" and the aircraft was forced to fly in a circle at a constant roll (sec. 2). This arrangement could cause the aircraft antenna gain variations associated with aircraft orientation to be greater than normal. However, this is probably not the primary reason for the large fading range at Milwaukee since (a) other receiving stations operating that day had fading ranges less than their median values, (b) the Milwaukee path also had a 28.9 dB fading range and a larger loss (L_b = 164.6 dB) on March 19, 1962, when a parallel figure-eight flight pattern was flown, and (c) fading ranges larger than 25 dB were observed for 5% of the Milwaukee data taken during winter (fig. 23).

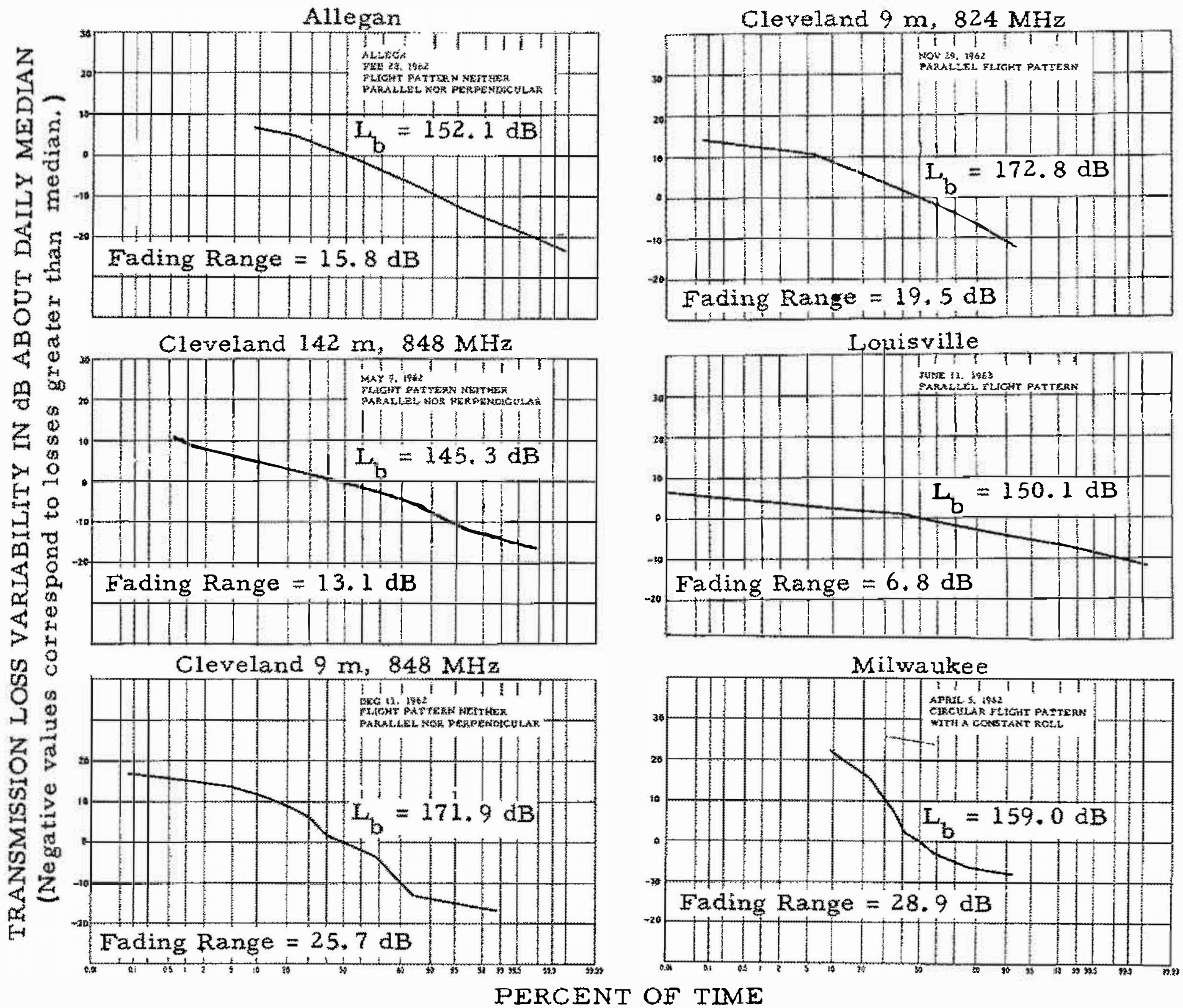

Figure 17. Transmission loss distributions for largest daily fading ranges.

The largest fading range (25.7 dB) observed for a Cleveland path (9 m, 848 MHz) occurred on December 11, 1962. On this date the other Cleveland paths had fading ranges of 4.2 dB (142 m, 848 MHz) and 8.5 dB (9 m, 824 MHz) which are not even half as large as the extremes shown for these paths on figure 17 (12.9 and 19.5 dB, respectively). Thus, a high fading range on one path does not necessarily indicate high fading ranges on other paths.

4. LONG-TERM VARIABILITY

Since one objective of this analysis is to test a modified Longley-Rice (appendix A) propagation model against air-ground radio wave propagation data, format and presentation of the data should conform as closely as possible to this model, which is largely based, however, on data obtained from ground communication links. Also, the present air-ground data differ from previous data with respect to both short-term and long-term variability. Short-term variability, caused primarily by phase interference fading, includes here variability due to the motion of the transmitting aircraft, as discussed in section 3.1. Long-term variability has usually been defined as variability of hourly median transmission loss values and can be predicted for point-to-point ground communication links with some confidence (Rice et al., 1967, sec. 10).

For simplicity, data reduction was performed in terms of daily transmission loss medians, where daily medians are for the 5 hour broadcast day. Both daily and hourly medians were determined for the Cleveland path with the high antenna for February through May, 1962. Cumulative distributions of these daily and hourly medians shown in figure 18 do not differ significantly, so that the use of daily medians appears to be justified.

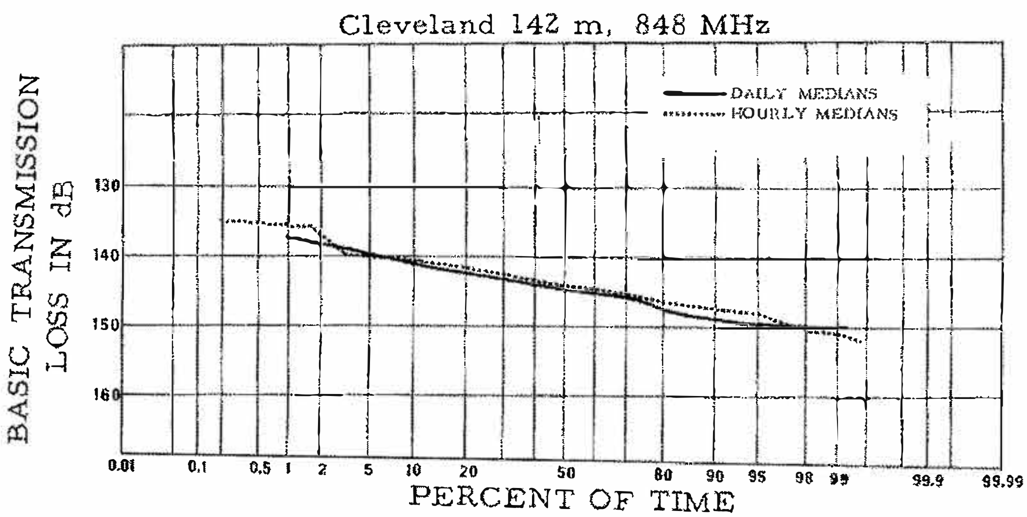

Figure 18. Comparison of daily and hourly medians. Based on data for the Cleveland path with the high antenna for February through May, 1962. These data include 54 daily medians and 266 hourly medians (daily recording periods did not always include 5 full hours).

Figure 19 is a graphical comparison of the overall medians of all daily median values for all propagation paths, including the 10- to 90-% ranges of daily medians; i.e., for each path the limits of the vertical bars read on the ordinate scale indicate the basic transmission loss values exceeded by 10 and 90% of all daily medians determined for the path from the measurements. The heavy dot denotes the overall median or the value exceeded by 50% of all daily medians, and the free space levels are indicated by dotted lines.

The number of available data samples is probably reflected to some extent in the 10- to 90-% ranges; e.g., the range for the Louisville data would probably be greater if more than 27 daily medians were available for the analysis. The large range for the Milwaukee data reflects the expected large variability of transmission loss because of path geometry (sec. 4.3). The lowest overall transmission loss median was obtained for Cleveland (high antenna), and free-space propagation conditions were approached for this line-of-sight path.

The common location of the receiving site for the three Cleveland paths and similarity in the chart recordings for the two lower antennas (figs. 13 and 14) suggest that transmission loss values for the three Cleveland paths may be correlated to some extent. Table 4 shows correlation

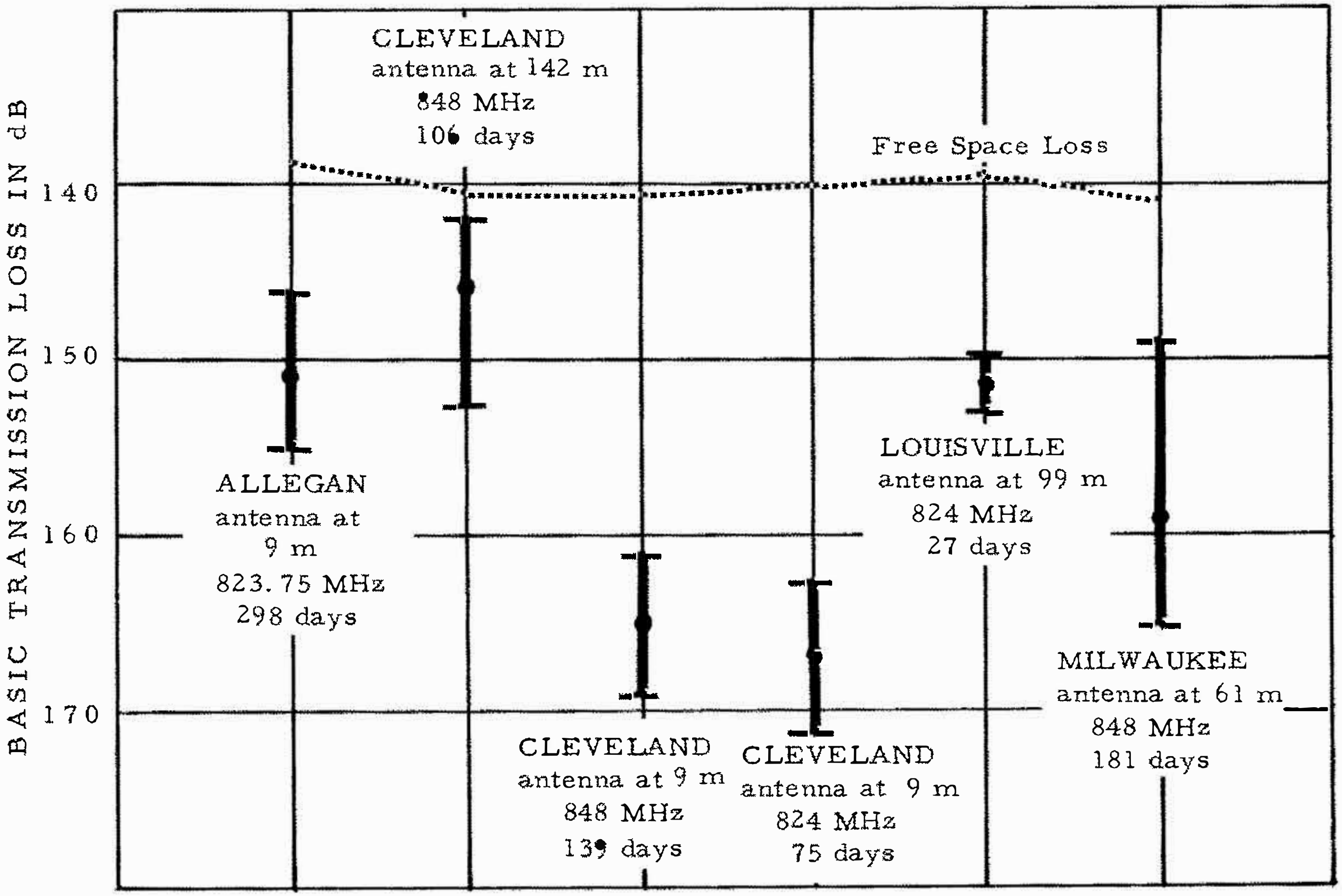

Figure 19. Medians and 10-to-90 % ranges of daily medians for all data.

Table 4. Correlation of Hourly Median Transmission Loss Values, Cleveland Paths

Combination	Number of Hours[(a)]	Sample Correlation Coefficient	90% Confidence Limits Upper	Lower
9-m antennas, 823.75 MHz and 847.75 MHz	54	+0.52	0.67	0.34
142-m antenna at 847.75 MHz and 9-m antenna at 847.75 MHz	311	+0.24	0.33	0.15
142-m antenna at 847.75 MHz and 9-m antenna at 823.75 MHz	54	+0.11	0.33	-0.12

(a) Available data for May 1, 1962, through May 21, 1962, were used.

coefficients for hourly median values of basic transmission loss, with their 90% confidence limits, which were obtained from the z-distribution formulation for a normal bivariate population (Bennett and Franklin, 1954, sec. 6.41).

The correlation coefficient between hourly median transmission loss values for the two frequencies at the lower antenna height appears to be statistically significant. It reflects the similar terrain and the average atmospheric conditions for the two paths, but does not provide information on coherence over the 24-MHz band between the two carriers. Coherence would be implied by high short-term correlation coefficients between "instantaneous" received signal levels, but the recording procedures used do not permit such a study.

An analysis of correlation coefficients between daily 10- to 90-% fading ranges (sec. 3.2) for the various paths, and between daily medians and daily fading ranges for each path did not show any values with a magnitude greater than 0.5. Daily fading ranges for the Milwaukee and Allegan paths are correlated with a sample correlation coefficient value of 0.45 for 127 daily samples. Correlation coefficients between daily medians and daily fading ranges for each path are shown in table 5. The values do not appear to be particularly significant, but the tendency toward negative correlation coefficients for the Cleveland high antenna and for Milwaukee should be noted. For both paths, the daily fading range appears to decrease with increasing transmission loss or decreasing signal level.

Table 5. Correlations of Daily Fading Ranges and Daily Medians

	Frequency MHz	Antenna Height m	Sample Correlation Coefficient r	Number of Samples n
Allegan	823.75	9	+0.24[a]	297
Cleveland	847.75	142	-0.39[a]	106
Cleveland	847.75	9	+0.11[a]	139
Cleveland	823.75	9	+0.24[a]	74
Louisville	823.75	99	+0.26	27
Milwaukee	847.75	61	-0.23[a]	181

(a) 90% confidence limits are within r ± 0.2.

4.1. Flight Pattern Effects

Flight pattern effects on long-term variability would be expected to be slight since the daily recording period (5 hours) is much longer than the flight pattern (15 min). Cumulative distributions of daily median basic transmission values observed for three flight-pattern orientations (fig. 12) shown in figure 20 are, for the most part, in accord with this expectation. Differences shown in figure 20 as being associated with an orientation change probably result from the limited nature of the available data; i.e., daily medians for particular days are available only for the flight-pattern orientation used on that day (sec. 3.1). However, it is interesting to note that the largest variabilities shown are not consistently associated with a particular orientation.

4.2. Seasonal Trends

The Rice et al. (1967, sec. III.7.1) long-term variability model for a continental temperate climate shows less transmission loss for summer (May-to-Oct.) than for winter (Nov.-to-April). Figure 21 illustrates the trend of the monthly mean of daily basic transmission loss medians for each propagation path by showing the available monthly means connected by straight lines. Strong seasonal effects can be identified only for the Milwaukee path (smooth-earth diffraction), where more than 15 dB difference appears between the June 1962 and

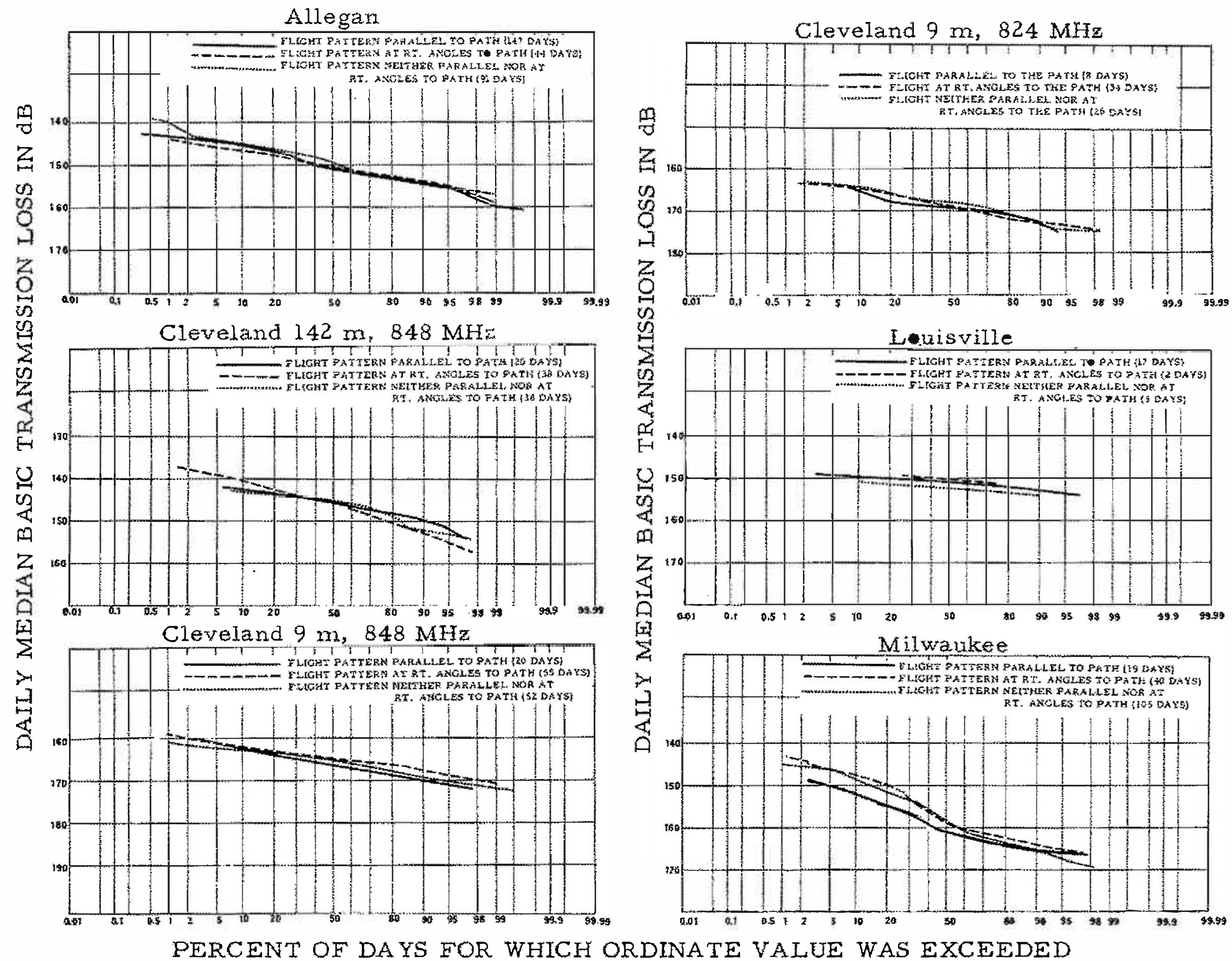

Figure 20. Transmission loss for various flight pattern orientations.

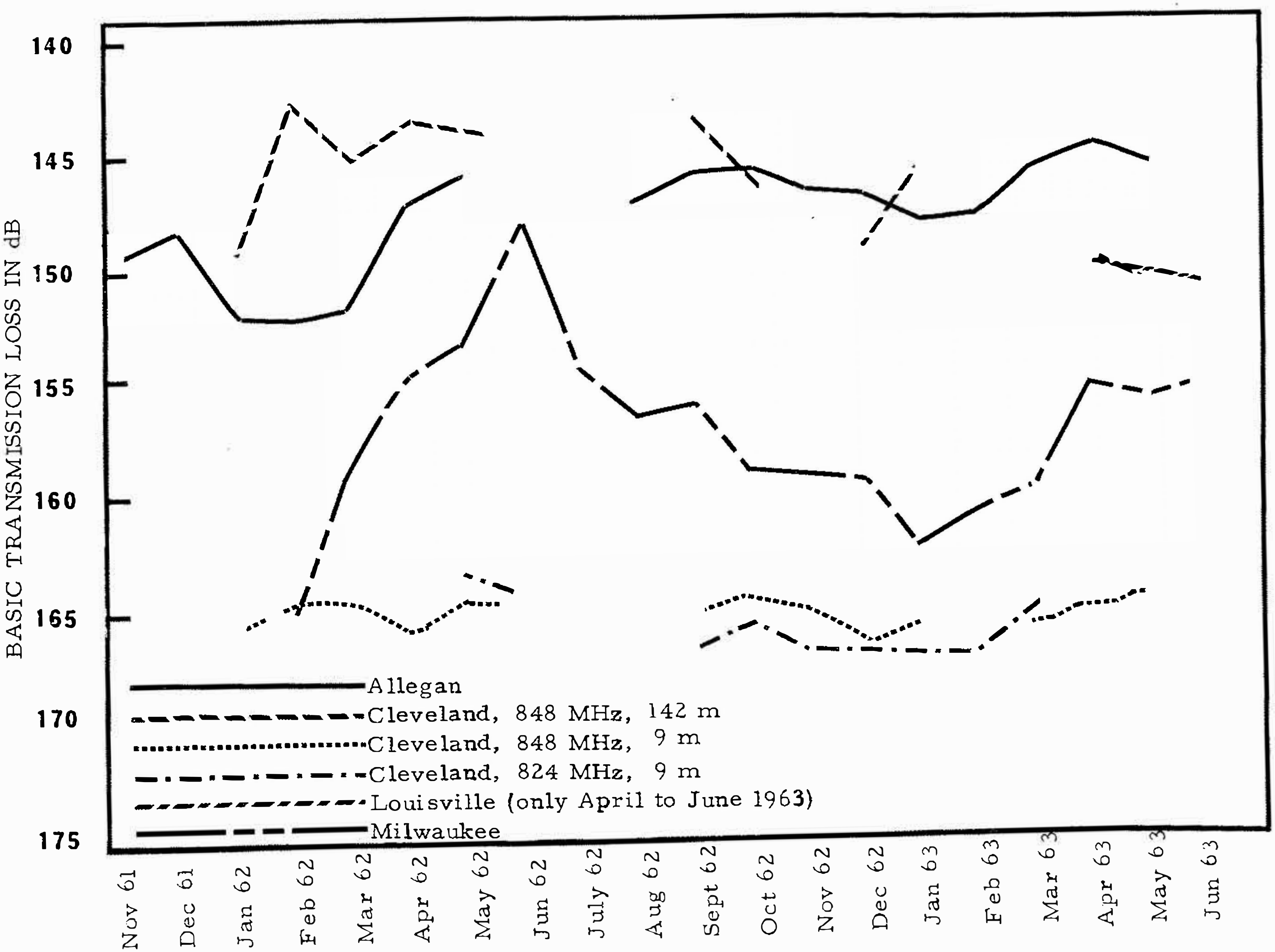

Figure 21. Monthly means of daily basic transmission loss medians.

Feb. 1962 observed monthly means. Month-to-month variations for the other paths were much smaller. Initial MPATI operational plans did not include regular flights during summer school sessions, and difficulties associated with providing the timely fiscal support necessary to operate the receiving sites prevented data collection at most sites during June, July, and August.

A more detailed breakdown of the Allegan data is shown in figure 22, where the number of days with high, average, and low median signal levels are compared on a month-by-month basis. High signal levels (corresponding to less than 145.5 dB basic transmission loss) occurred most often in April and October (summer time block), whereas low signal levels (corresponding to greater than 153 dB basic transmission loss) occurred most often in February and March (winter time block). Daily medians near the value corresponding to the calculated median transmission loss (152 dB) appear to be more uniformly distributed throughout the months for which data are available.

Cumulative distributions of daily median basic transmission loss and daily 10- to 90-% fading range are shown for summer and winter in figure 23. For all cases except Milwaukee, the difference between summer and winter long-term transmission loss medians is quite small, and the largest seasonal dependence indicated is about 5 dB. Similarly,

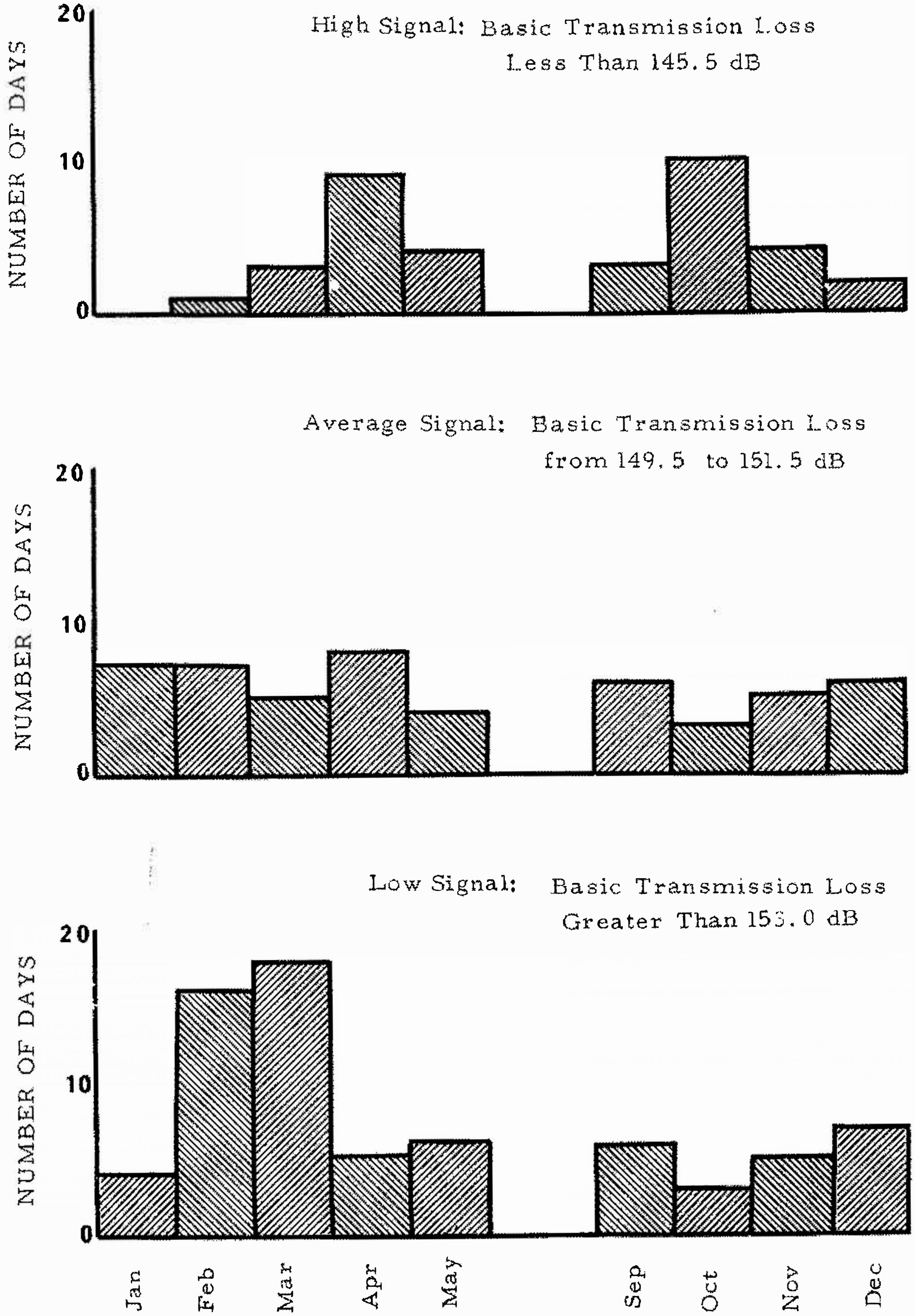

Figure 22. Seasonal trends, Allegan.

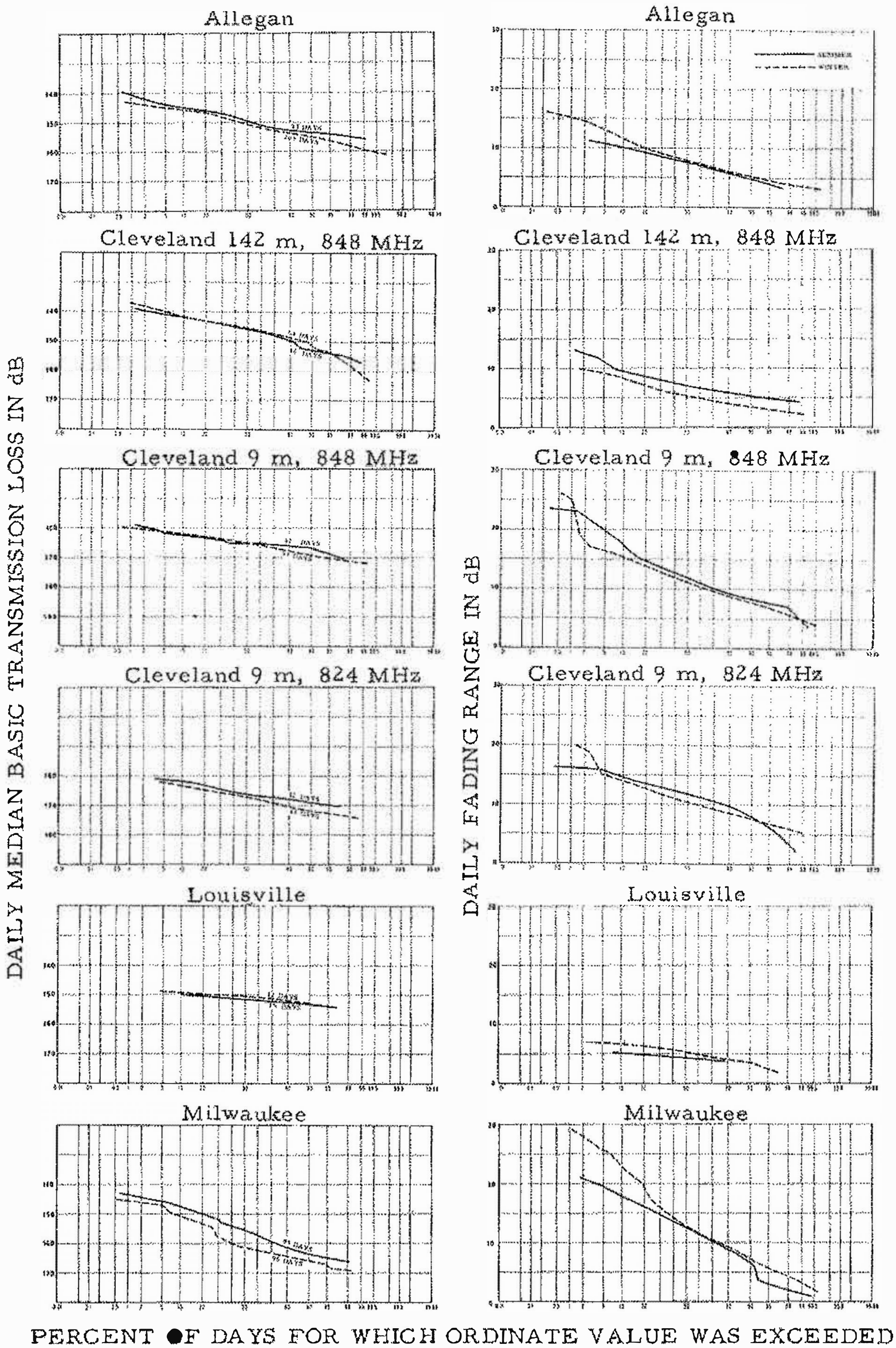

Figure 23. Distributions of daily medians and daily fading ranges for summer and winter.

the seasonal variation of daily fading range is small, and does not exceed 5 dB, except for Milwaukee. The long-term seasonal dependence of both parameters probably cannot be accurately gauged by the available MPATI data. Data for paths which have more than 80 days of data for each season (Allegan and Milwaukee) do tend to confirm the lower summer transmission loss levels implied by the Rice et al. (1967, sec. III.7.1) model, and indicate that higher daily fading ranges probably occur during winter. However, the recording period involved only about 5 hours (sec. 2), and the statistics for "daily" parameters presented here might be significantly different if data were available for a full 24-hour day.

4.3. Comparison of Observations with Predictions

Long-term characteristics of basic transmission loss observed (daily) are compared in this section with those predicted (hourly) using a modified Longley-Rice propagation model. This model and the specific parameters used in the predictions for the various paths are discussed in appendix A. It is based on a propagation model described by Longley and Rice (1968) and extended by Longley and Reasoner (1970) along with the long-term variability model given by Rice et al. (1967, sec. III.7.1) for specific time blocks (periods) in a continental temperate climate.

Cumulative distributions of observed daily and predicted hourly median basic transmission loss are shown in figure 24. Except for Louisville, the observed data may also be considered as estimates of the long-term (many years) cumulative distributions of hourly median basic transmission loss that would characterize each path. Confidence in these estimates could be improved by extending the length of the recording period, so that more data are obtained, and by performing data reduction in terms of hourly rather than daily medians. However, the uncertainty introduced by limited recording periods for these data can be considered to be dominant, and the uncertainty introduced by the use of daily rather than hourly medians neglected (see fig. 18).

Confidence intervals shown in figure 24 about predicted and measured distributions are based on methods given by Rice et al. (1967, sec. V.8) and Barsis et al. (1961, 1962). The predicted distributions thus constitute statistically expected values, and the limits are 0.05 and 0.95 confidence limits (see sec. A.5). The width of the confidence bands for the measured distributions is a function of the length of the measurement period (Barsis et al., 1962, sec. VIII). Since both predicted and measured distributions for a particular path are plotted on the same graph with the appropriate confidence bands, an indication of whether observed data or the prediction method provides a better estimate of the

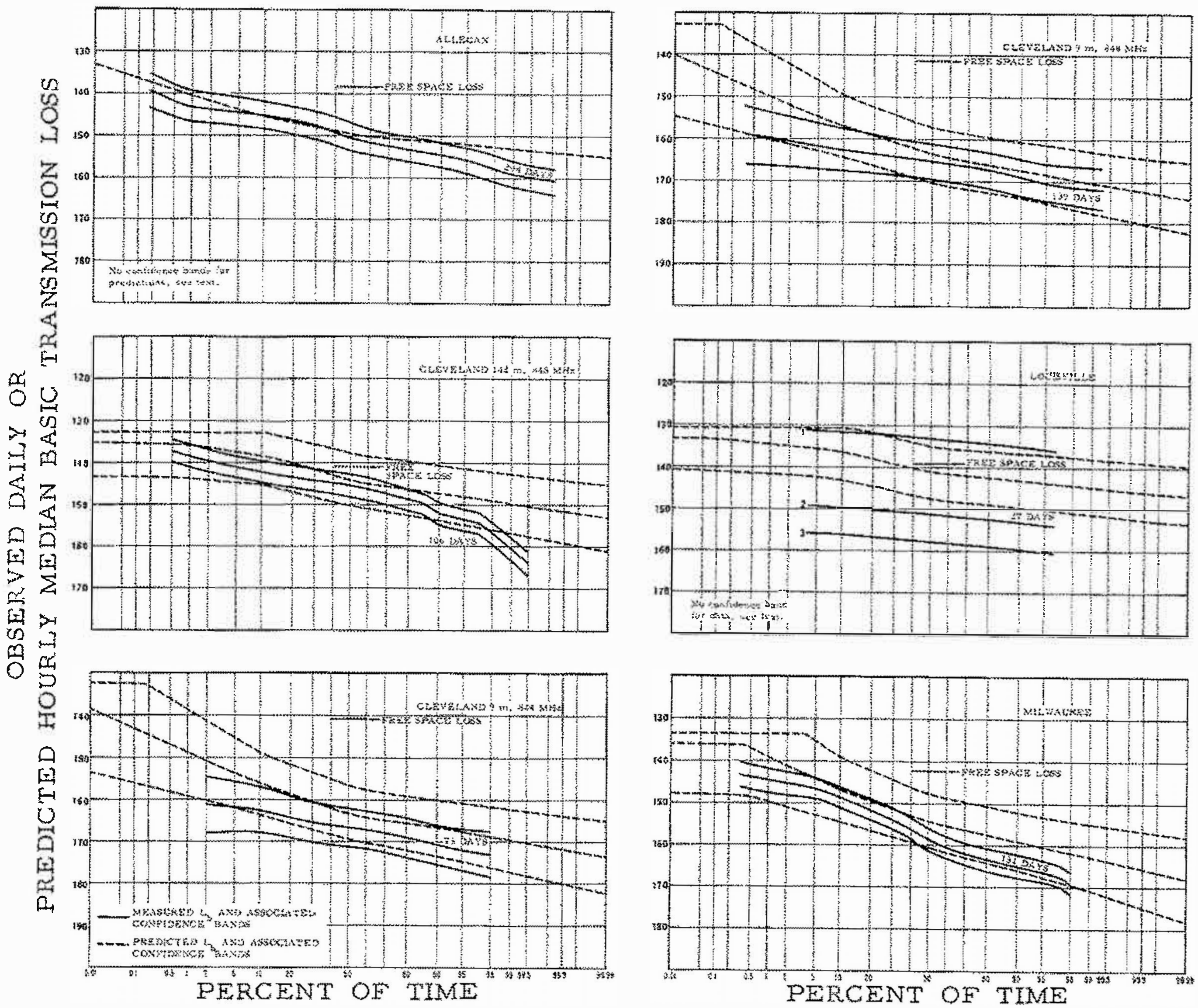

Figure 24. Observed and predicted distributions of basic transmission loss. The confidence bands shown correspond to a confidence level of 0.9 or 90%.

long-term distributions can be obtained by comparing confidence band widths. Except for the Louisville path, estimates based on data are more reliable. The bands corresponding to confidence levels of 0.05 and 0.95, given for the long-term data, indicate the extent of the uncertainty associated with limited recording periods when such data are used to estimate long-term characteristics. The probability is 0.90 that the transmission loss value given for a particular level by a cumulative distribution of hourly median basic transmission loss, based on a very long recording period (many years), would fall within the confidence bands that bracket the estimate based on the data presented here.

Confidence bands are not shown about predictions for the Allegan path since the prediction assumed a radio horizon formed by trees 12 m high, 60 m from the Allegan antenna. While these assumptions are within the 6- to 12-m height and 60- to 120-m range estimated to be reasonable (sec. 2), they are still assumptions. As an example, if a 6-m tree height at 120 m had been assumed, the median transmission loss predicted would be 5.9 dB less than shown. However, the variability about the median level would not be changed.

Also, because of the lack of absolute values for basic transmission loss, confidence limits are not shown for the long-term data obtained at Louisville (fig. 24). Cumulative distributions are shown assuming three different values of line loss: (1) 36.8 dB corresponding to a possible maximum value (based on a minimum basic transmission loss median 6 dB less than the free-space value); (2) 18.8 dB corresponding to an estimate based on visual inspection of the installation; and (3) 12.3 dB corresponding to the minimum possible value for a perfect line, except for a mismatch located at the receiver end.

It must be recognized, however, that a difference exists between the confidence band established about the calculated distributions and the confidence band established about the distributions derived from the measurements. The data-based estimates should be regarded as pertaining only to the specific paths over which the data were taken; there is a 0.9 probability that the transmission loss value given for a particular fraction of the time, q, by a cumulative distribution based on a very long (many years) recording period would fall within the confidence band shown. Estimates calculated by the prediction method should be considered applicable to a wide variety of paths that are similar enough to have identical prediction parameters. For a specific fraction of the time, q, 90 of each 100 such paths would be expected to have transmission loss values within the confidence band shown for the predicted distribution curves.

Estimates of long-term median (median of hourly medians) basic transmission loss, L_{bc}, from the prediction model can be compared with estimates, L_{bo}, based on data using statistics of the decibel difference, i.e.,

$$\Delta L = L_{bc} - L_{bo} \text{ dB}$$

where L_{bc} and L_{bo} are given in table 6. Values for ΔL were determined for four of the six air-ground paths, since the Louisville data and the Allegan predictions involve unknown parameters. These values, with the sample mean, variance, and standard deviation obtained from them, are given in table 7.

The sample mean obtained for ΔL is not unusually large for this type of comparison, where a small number (four) of sample values are used (Longley and Reasoner, 1970, figs. 30-57). However, some of the specific ΔL magnitudes are large enough to show that improvement in the prediction method is still desirable for application to air-ground communication links.

If it is assumed that the population (different paths) mean for ΔL is known to be zero, then the mean-square of ΔL given in table 7 is the best estimate of the population variance when the population is normally distributed (Bennett and Franklin, 1954, sec. 5.4.1.). The 9.39 dB^2 (3.1 dB root-mean-square) obtained here is not unusually large compared to the 19.35 dB^2 value (4.4 dB root-mean-square)

Table 6. Summary of Predicted and Observed Long-Term Values

Path	Median Basic Transmission Loss [a]			10- to 90-% Fading Range [a]	
	Predicted	Observed	Free Space	Predicted	Observed
Allegan	150.0 [b]	150.8	138.3	6.0	9.6
Cleveland					
847.75 MHz					
142 m	143.9	145.3	141.1	8.9	10.0
9 m	163.6	165.3	141.1	10.3	6.5
823.75 MHz					
9 m	163.1	166.5	140.8	10.4	8.3
Louisville	141.2	151.0 [c]	139.0	7.1	3.2
Milwaukee	154.2	158.8	142.1	12.0	16.0

(a) Measured in dB. The predicted values are hourly medians, and the observations are daily (5-hour) medians.

(b) Calculated for an assumed radio horizon.

(c) Obtained using an assumed 18.8 dB line loss.

Table 7. Comparisons of Long-Term Estimates

Path	ΔL [a]	R_F [b]
Allegan	(c)	1.60
Cleveland		
847.75 MHz		
142 m	-1.4	1.12
9 m	-1.7	0.63
823.75 MHz		
9 m	-3.4	0.80
Louisville	(c)	0.45
Milwaukee	-4.6	1.33

Statistics of ΔL Values

Sample mean = -2.8 dB

Sample variance = $1/3\ \Sigma\ (\Delta L + 2.8)^2 = 2.26\ dB^2$

Sample standard deviation = $\sqrt{2.26} = 1.5$ dB

Sample mean-square = $1/4\ \Sigma\ (\Delta L)^2 = 9.39\ dB^2$

Sample root-mean-square = $\sqrt{9.39} = 3.1$ dB

Statistics of R_F Values

Sample mean = 0.988

Sample variance = $1/5\ \Sigma\ (R_F - 0.988)^2 = 0.192$

Sample standard deviation = $\sqrt{0.192} = 0.44$

(a) Difference of predicted and observed long-term median basic transmission loss values in dB.

(b) Ratio of observed to predicted long-term fading range values. Discussion in text follows this table.

(c) Valid ΔL not available, see text.

reported by Barsis et al. (1961, sec. I.1) for the "mean-square deviation of observed from predicted time block medians" of ground-to-ground data from 53 propagation paths in the continental U.S.A., and from a location-to-location standard deviation of 10 dB (100 dB^2 variance) given for propagation over irregular terrain using low antennas (Longley and Rice, 1968, sec. 1-2).

This analysis of ΔL suggests that long-term median basic transmission loss values for air-ground paths can be more accurately estimated from the modified Longley-Rice propagation model (appendix A) if the mean of ΔL is used as a correction term. However, this procedure is justified only for paths with parameters similar to those tested, since it is based on a very limited amount of data.

Variability Y(q) of hourly transmission loss medians about their long-term median can be determined from the effective path distance d_e by using the power fading models developed by Rice et al. (1967, sec. 10.5). It provides a convenient means for comparing predictions of transmission loss variability with available data. Figure 25 illustrates such comparisons. Curves for Y(0.1) and Y(0.9) are shown for continental temperate climate variability models developed from empirical data for propagation between ground based terminals using (a) period of record data for all hours of the year, (b) time block data for all hours of the year, and

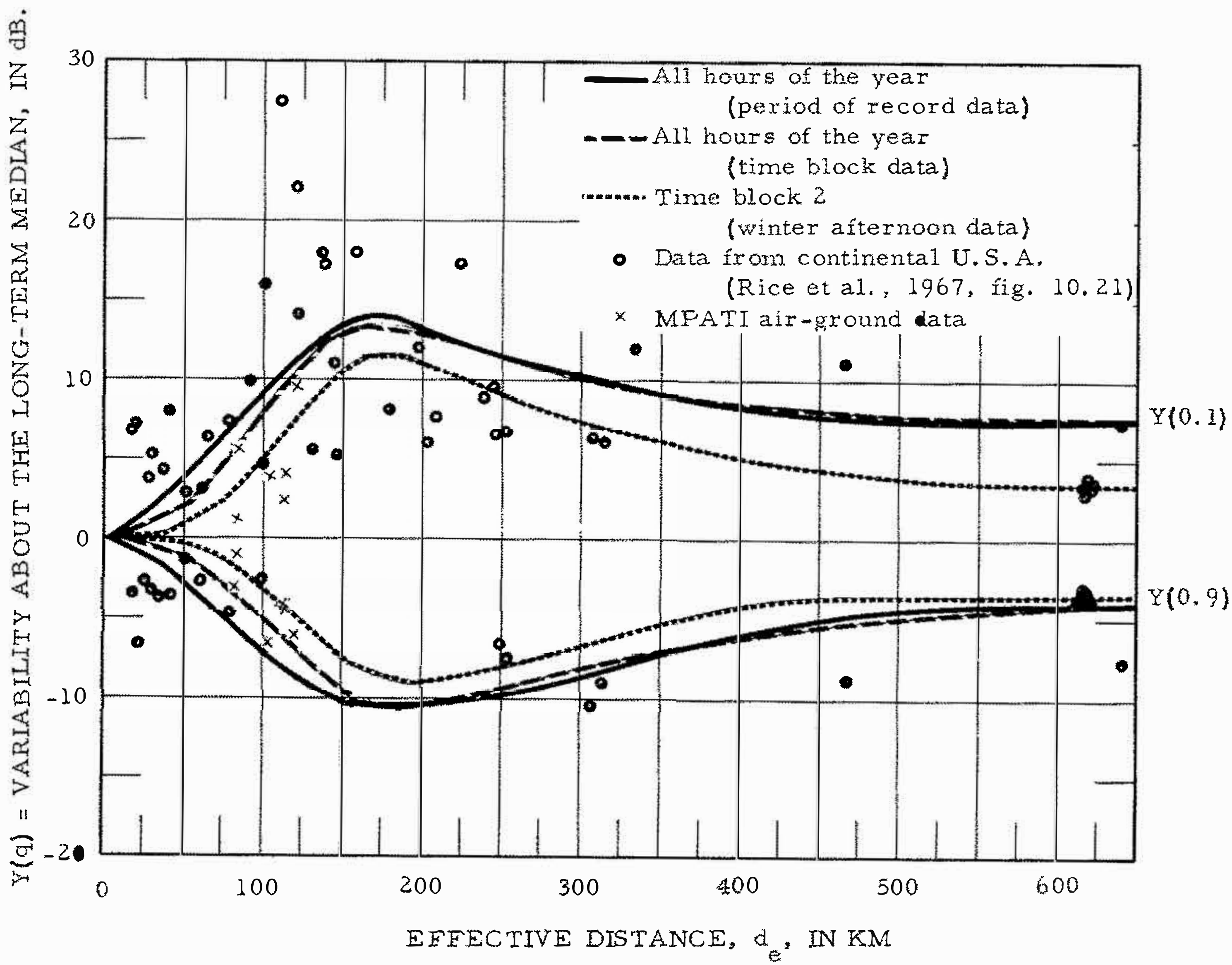

Figure 25. Long-term power fading continental temperate climate, 450-1000 MHz.

(c) time block 2 (winter afternoon) data. Similarly, small circles represent the period of record data just mentioned and the crosses are the MPATI air-ground data (d_e's for the MPATI paths are given in table A.2). Variability for the time block 2 model seems to fit the air-ground data best, and this is reasonable since these data were collected, for the most part, during a period for which winter afternoon propagation conditions would be expected to prevail.

The model based on period-of-record data is more recent and has a larger data base than the time block models, but these data have not been analyzed by time block. Earlier models were developed using a smaller data base for specific time blocks. Figure 25 shows that the all-hours model based on period-of-record data has a variability that is greater than that of the all-hours model based on time block data for $d_e < 200$ km. The extent by which the former exceeds the latter is an indication of the increase in variability that would be expected if the earlier time block analysis were repeated using the larger data base. At $d_e = 100$ km, the factor by which the fading range would increase is 1.25. However, the air-ground data presented here indicate that such an increase in variability is not required for air-ground applications even though it would be appropriate for ground-ground applications. Therefore, the variability models based on the early time block analysis (Rice et al., 1967, sec. III.7.1) are recommended for estimating variability about the long-term median in air-ground applications involving a continental temperate climate. Predictions presented here for the MPATI paths were made using the time block variability models with variabilities weighted in accordance with the amount of data recorded in the various time blocks (see appendix A).

Predicted fading range F_c is compared with observed fading range F_o by means of the ratio

$$R_F = \frac{F_o}{F_c}$$

where R_F is calculated for each of the six paths (Louisville included) from the fading ranges of table 6. Table 7 shows the resulting R_F's along with their sample means and standard deviations. However, the analysis of R_F does not imply that the long-term fading range for air-to-ground paths can be more accurately estimated from the modified Longley-Rice propagation model (appendix A) because the mean of R_F (0.988) is not significantly different from 1.000. As mentioned above, the fading range obtained from the model based on period-of-record data can be larger than that obtained from the model based on time-block data by a factor of 1.25 at d_e = 100 km. This factor is about 22% greater than the median R_F value from table 7.

5. CONCLUSIONS

Results of the air-ground propagation data analysis in the 820- to 850-MHz band have generally shown that basic transmission loss calculations made with the modified Longley-Rice model (appendix A) are adequate for air-ground links operating somewhat within, or just beyond their radio horizon, in a continental temperate climate (fig. 24). An empirical correction to the distribution mean was derived by comparing observed data with predicted values (tables 6 and 7). It could be applied to paths with parameters similar to those tested but probably should not be used otherwise.

The effects of the flight pattern of the transmitting aircraft are most pronounced for the link to Milwaukee, where path length is about equal to the radio horizon distance. Periodic signal level variations associated with the flight pattern were clearly distinguishable on May 8, 1962, when the pattern axis was parallel to the path (fig. 13), but not on May 24, 1962, when it was perpendicular to the path (fig. 14). Short term fading can be more serious for a perpendicular orientation (fig. 16). The effects of flight pattern orientation on long-term (daily medians) signal level variation is probably minor (sec. 4.1). Largest variabilities are not consistently associated with a particular flight pattern orientation (figs. 17, 20).

The long-term seasonal dependence of daily median transmission loss and daily fading range probably cannot be gauged accurately by available MPATI data (sec. 4.2). Data for paths which have more than 80 days of data for each season (Allegan and Milwaukee) do tend to confirm the lower summer transmission loss levels predicted by Rice et al. (1967, sec. III.7.1) and indicate that higher daily fading ranges occur during winter. However, the day-by-day correlation of daily fading ranges and daily median transmission loss values yielded correlation coefficients with magnitudes less than 0.4 (table 5).

Knowledge gained from the analysis of the MPATI data is certainly applicable to similar air-to-ground communication links. The successful modification of the Longley-Rice model to produce reasonable predictions for the MPATI paths suggests that simple modifications can extend the parameter ranges for which the model is valid. For example, the model could be adapted to within-the-horizon predictions for air-to-ground or earth-to-satellite links by making such simple modifications as (a) replacing the great-circle path distance by direct ray length in the calculation of free space loss, (b) incorporating the conditional adjustment factor A_Y (sec. A.3) into the calculation of the long-term median transmission loss, (c) using a simple formulation for atmospheric absorption (Gierhart et al., 1970, sec. A.3),

(d) using ray tracing data to estimate effective distance d_e for very high antennas, and (e) incorporating the $f(\theta_h)$ factor, recommended by Rice et al. (1967, fig. III-24) in the variability calculations. Ionospheric effects may be important for some earth-to-satellite links and should be accounted for in the system design even though their effect on the long-term variability (hourly medians) may be small (0 to 3 dB) since the short term fading (within-the-hour) associated with them can be large (20 dB or greater). These ionospheric effects (absorption, Faraday rotation, scintillation, etc.) are strongest at frequencies below 200 MHz, but cannot always be neglected at frequencies above 1 GHz (Millman, 1967; Aarons et al., 1971).

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Mrs. A. G. Longley
Mrs. R. K. Reasoner
Mr. P. L. McQuate

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[2] Copies of these reports are available by accession number from the National Technical Information Service, Operations Division, Springfield, Va. 22151.

APPENDIX A. PROPAGATION MODEL

The propagation model used to calculate the predictions of hourly median basic transmission loss given in figure 24 is described in this appendix. It is referred to as a modified Longley-Rice model since it is based on a propagation model described by Longley and Rice (1968) and revised by Longley and Reasoner (1970).

Key parameters associated with the models are described in table A.1. Most of these parameters are identical with those used by Rice et al. (1967), Longley and Rice (1968), Longley and Reasoner (1969), Longley (1971), and/or Gierhart et al. (1970). Values of these parameters for the MPATI paths are given in table A.2. Note that although the parameters given in these two tables are the same, the order in which they are given is different; i.e., the parameters in table A.1 are ordered in an alphabetic fashion while those of table A.2 are ordered by their approximate chronological use or calculation in the prediction process.

The prediction process consists of calculating (a) L_{bcr}, (b) the variability V(q) where the time availability q corresponds to the fraction of hours for which a corresponding value of L_b is not exceeded (or a corresponding value of available power at the receiving antenna is exceeded), (c) $L_b(0.5)$, (d) $L_b(q)$ for additional q's, and (e) confidence bands for $L_b(q)$. Methods used to perform these calculations

Table A.1. Key Prediction Parameters

Symbol	Comment
A_a	The long-term median attenuation of radio waves due to atmospheric absorption by oxygen and water vapor in decibels.
A_Y	The amount (in decibels) by which L_{bcr} is increased to prevent available powers from exceeding levels expected from free-space propagation by an unrealistic amount (3 dB for q = 0.1).
d	Great circle propagation path distance in kilometers.
d_e	Effective propagation path distance in kilometers as a function of d, f, h_{1e}, and h_{2e}.
$d_{L1,2}$	Great circle distances from the transmitting or receiving antennas to their corresponding radio horizons in kilometers.
$d_{Ls1,2}$	Distances from the transmitting or receiving antennas to their corresponding smooth earth radio horizons in kilometers.
f	Radio wave frequency in megahertz.
$h_{1e,2e}$	Effective antenna heights of the transmitting or receiving antennas in meters.
h_{grs}	Ground height above msl at receiving antenna in meters.
$h_{Lt,r}$	Height of the transmitter or receiver horizon obstacle above msl in meters.
h_t	Height of transmitting antenna in meters above msl.
$h_{tg,rg}$	Height of transmitting or receiving antenna above h_{grs} in meters.
$L_h(0.5)$	Long-term median value of basic transmission loss in decibels.
L_{bcr}	Calculated long-term reference value of basic transmission loss in decibels.

Table A.1. Continued

Symbol	Comment
L_{bf}	Basic transmission loss in free space in decibels.
N_s	Minimum monthly mean value of atmospheric refractivity at the earth's surface near a receiving site in N-units.
V(0.5)	Variability V(q) for q = 0.5.
Δh	An asymptotic value for the interdecile range of terrain heights in meters above and below a straight-line fit to relevant terrain.
$\theta_{e1,2}$	Radio horizon elevation angles at the transmitter or receiver in milliradians.
θ	The angular distance or the angle between radio horizon rays in milliradians.

are summarized in sections A.1 through A.5, respectively. Emphasis is placed on the modifications made to the Longley-Rice model to adapt it for the air-ground propagation predictions presented here, and the reader is referred to Rice et al. (1967), Longley and Rice (1968), and Longley and Reasoner (1970) for detailed descriptions of their methods.

Table A.2. Parameter Values Used in Predictions

Parameter		Allegan		Cleveland		Louisville	Milwaukee
f	MHz	823.75	847.75	847.75	823.75	823.75	847.75
h_{rg}	m	9.14	142.34	9.14	9.14	99.06	60.96
h_{2e}	m	9.14	142.34	9.14	9.14	99.06	82.3 [a]
h_{Lr}	m	217.9	(b)	390.0	390.0	(b)	176.8
d_{L2}	km	0.06 [c]	(b)	4.9	4.9	(b)	37.5
d_{Ls2}	km	12.5	49.0	12.4	12.4	41.2	32.3
h_{grs}	m	205.7	356.3	356.3	356.3	138.7	198.1
h_t	m	6400.0	6400.0	6400.0	6400.0	6400.0	6400.0
h_{tg}	m	6194.3	6043.7	6043.7	6043.7	6261.3	6201.9
h_{1e}	m	5980.0	5829.0	5829.0	5829.0	6047.0	5989.0 [a]
h_{Lt}	m	217.9	(b)	390.0	390.0	(b)	176.8
d_{L1}	km	236.8	(b)	313.7	313.7	(b)	319.8
d_{Ls1}	km	319.3	313.8	313.8	313.8	321.7	319.8
d	km	236.9	318.6	318.6	318.6	257.5	357.5
d_e	km	82.5	101.9	112.4	112.3	82.8	118.2
N_s	N-units	303.0	298.0	298.0	298.0	305.0	304.0

(a) Based on height above Lake Michigan

(b) Set to zero in Longley-Rice model for line-of-sight paths.

(c) Trees 12 m high, 60 m from antenna assumed (sec. 4.3).

Table A.2. Continued

Parameter		Allegan	Cleveland			Louisville	Milwaukee
Δh	m	20.0	30.0	30.0	30.0	10.0	0.0
θ_{e1}	mr	-39.1	-37.2	-37.0	-37.0	-37.6	-37.5
θ_{e2}	mr	51.0	-5.8	4.7	4.7	-4.8	-4.4
θ	mr	39.7	-5.6	5.4	5.4	-12.3	0.0
L_{bcr}	dB	150.2	141.1	163.9	163.6	139.0	154.7
L_{bf}	dB	138.3	141.1	141.1	140.8	139.0	142.1
A_a	dB	0.6	0.9	0.9	0.9	0.7	1.1
V(0.5)	dB	0.8	1.2	1.2	1.4	1.3	1.6
A_Y	dB	0.0	3.1	0.0	0.0	2.8	0.0
$L_b(0.5)$	dB	150.0	143.9	163.6	163.1	141.2	154.2

A.1. Calculation of L_{bcr}

The Longley-Rice model referred to in this report is the model introduced by Longley and Rice (1968) and revised by Longley and Reasoner (1970, sec. 3.5) to improve prediction accuracy for paths that are known to be line-of-sight or single-horizon paths. This model was developed using data taken over paths in irregular terrain with low antennas (< 20 m above ground). Its use is not recommended for antenna heights greater than 3000 m because (a) it does not allow for the decrease in effective antenna height associated with antenna heights greater than 1000 m, (b) Δh values are based on terrain irregularities along the entire great-circle path, whereas for air-ground paths terrain irregularity is only important between the radio horizon for the airborne terminal and the ground terminal, (c) empirical functions involving distance may yield unreasonable values since the line-of-sight range associated with air-ground paths can be much larger than that associated with point-to-point paths, and (d) approximations used to calculate the attenuation associated with propagation via forward scatter may not be valid for air-ground paths. To compensate, at least partially, for these factors, the model was modified so that (a) an appropriate reduction in the effective height of the aircraft was made (Rice et al., 1967, fig. 6.7), (b) estimates of Δh were based only on the terrain near the ground terminal, and (c) the revised formulation recommended by Longley and Reasoner (1970, sec. 3.5) for line-of-sight point-to-point is not applicable to air-ground paths and was not used. None of the MPATI paths are forward-scatter paths so that modifications to the scatter portion of the Longley-Rice model were not needed, but when estimates of propagation via forward scatter are required for air-ground links the more complete formulation by Rice et al. (1967) with computer program by Johnson (1967, sec. 7) should be used.

A.2. Calculation of V(q)

The long-term power fading model given by Rice et al. (1967, secs. 10.3, III.7.1) for various periods of time (time blocks) in the U.S.A. (continental temperate climate) was used to determine the variability V(q) for each path where the time availability q corresponds to the fraction of hours for which a corresponding value of L_b is not exceeded (or a corresponding value of available power at the receiving antenna is exceeded). Calculations for each path involved (a) the determination of variabilities applicable to time blocks 1 (Nov.-Apr., 0600-1300 hrs), 2 (Nov.-Apr., 1300-1800 hrs), 4 (May-Oct., 0600-1300 hrs), and 5 (May-Oct., 1300-1800 hrs), and (b) mixing these variabilities by the method recommended by Rice et al. (1967, sec. III.7.2) to adjust the predictions to the recording periods involved in the data, i.e., weighting time block variabilities in accordance with the number of hours of data recorded within the time blocks.

A.3. Calculation of $L_b(0.5)$

The median value of hourly median basic transmission loss $L_b(0.5)$ was calculated from L_{bcr}, median variability $V(0.5)$, median atmospheric absorption A_a, and a conditional adjustment factor A_Y, i.e.,

$$L_b(0.5) = L_{bcr} - V(0.5) + A_a + A_Y \text{ dB}. \qquad \text{(A.1)}$$

Sections A.1 and A.2 discuss the calculation of L_{bcr} and $V(0.5)$ which is $V(q)$ with $q = 0.5$. Atmospheric absorption was estimated using the method recommended by Rice et al. (1967, sec. 3.1).

The adjustment factor A_Y is identical with the factor introduced by Gierhart et al. (1970, sec. 3), and is added to L_{bcr} to prevent available signal power from exceeding levels expected for free-space propagation by an unrealistic amount (3 dB for $q = 0.1$) when L_{bcr} is close to its free-space value L_{bf} and $V(q)$ is large, i.e.,

$$A_Y = L_{bf} + V(0.1) - L_{bcr} - A_a - 3 \text{ dB}, \qquad \text{(A.2a)}$$

but if

$$A_Y < 0 \quad \text{set} \quad A_Y = 0. \qquad \text{(A.2b)}$$

A.4. Calculation of $L_b(q)$

The calculation of $L_b(0.5)$ was described in section A.3. Additional values of $L_b(q)$ were obtained using

$$L_b(q) = L_b(0.5) - Y(q) \text{ dB} \tag{A.3}$$

where $Y(q)$ is variability about $L_b(0.5)$. Values for $Y(q)$ were obtained using

$$Y(q) = V(q) - V(0.5) \text{ dB} \tag{A.4}$$

for $q \geq 0.1$, and by using interpolation between

$$Y(0.01) = \text{lesser of} \begin{cases} V(0.01) - V(0.5) \\ \quad\quad \text{or} \\ L_b(0.5) - L_{bf} + 5 \end{cases} \text{dB,} \tag{A.5a}$$

$$Y(0.001) = \text{lesser of} \begin{cases} V(0.001) - V(0.5) \\ L_b(0.5) - L_{bf} + 5.8 \end{cases} \text{dB,} \tag{A.5b}$$

and

$$Y(0.0001) = \text{lesser of} \begin{cases} V(0.0001) - V(0.5) \\ L_b(0.5) - L_{bf} + 6 \end{cases} \text{dB} \tag{A.5c}$$

for $q < 0.1$. The limiting expressions involving L_{bf} in (A.5) have been included to prevent available powers from exceeding levels expected from free-space propagation by an unrealistic amount; i.e., hourly median available power is not allowed to exceed the free-space level by 6 dB more than 0.01% of the time. Power received via a direct and reflected ray can produce hourly-median power levels 6 dB above the free-space level when the reflection coefficient is unity and the relative phase of the two signals is such that they are "in phase" for the whole hour.

A.5. Calculation of Confidence Bands

The method used to calculate confidence bands for the predictions is similar to that given by Rice et al. (1967, V.8) and Barsis et al. (1962). Mean-square-error of prediction $\sigma_{cr}^2(q)$ was estimated from

$$\sigma_{rc}^2(q) = 12.73 + \sigma_r^2 + 0.12\ Y^2(q)\ \text{dB}^2 \qquad \text{(A.6)}$$

where Y(q) was determined as in section A.4 and the mean-square-error associated with estimating system parameters σ_r^2 is taken as 2 dB^2.

Then values $L_b(q,Q)$ corresponding to the L_b value for a particular q and a particular confidence level Q were calculated for Q's of 0.05 and 0.95 using

$$L_b(q,0.05) = \text{greater of} \begin{cases} L_b(q) - 1.645\ \sigma_{rc}\ \text{dB} \\ L_{bf} - (6+1.645\ \sigma_r)\ \text{dB} \end{cases} \qquad \text{(A.7)}$$

and

$$L_b(q,0.95) = L_b(q) + 1.645\ \sigma_{rc}\ \text{dB} \qquad \text{(A.8)}$$

where the 1.645 value is appropriate for the Q values considered (Barsis et al., 1961 or 1962, table III; Rice et al., 1967, fig. V.7).

The limiting expression involving L_{bf} in (A.7) has been included to prevent available power from exceeding levels expected from free-space propagation by an unrealistic amount; the 6 dB term has about the same significance in (A.7) as it has in (A.5), and the 1.645 σ_r term allows the 6 dB above free-space limit on hourly-median available power to be exceeded when an error associated with estimating system parameters is considered.

APPENDIX B. TABULATION OF DAILY DATA

Daily median basic transmission loss values and the daily 10 to 90% fading ranges as described in section 4 with flight pattern orientation are given in table B.1. for those readers who wish to extend our analysis. All data upon which our analysis is based are included in this table.

The left hand column on each page shows month, day, and year, e.g., 11-27-61 is November 27, 1961. Other column headings give receiver site locations along with nominal frequency and antenna height above ground (fig. 3, table 2).

A code, FPO, shows flight pattern orientation. A plus sign (+) signifies that the axis of the flight pattern (fig. 12) was approximately perpendicular to the transmitter-receiver path (fig. 3). An equal sign (=) indicates that the axis of the flight pattern was approximately parallel to the path, and a small circle (o) indicates that the axis of the flight pattern was neither perpendicular nor parallel to the path. A small (u) signifies that the flight pattern is unknown.

Columns labeled L_{do} give daily observed basic transmission loss values in decibels. Most of the time these are median values for about five hours of recording from nine in the morning until two in the afternoon (sec. 2). In some cases they may be the median for four hours where one hour was lost due to technical difficulties. Blank areas indicate the absence of reliable data.

The daily 10- to 90-% fading ranges in decibels are listed under the columns headed F_{do} (observed daily fading range). On the rare occasions where the recording was split by an equipment failure, both L_{do} and F_{do} were computed by averaging values obtained for each valid part of the recording.

Table B.1. is arranged so that all available data for a particular time period may be viewed on the same or facing pages. The first page contains data for three sites, and the last two pages contain only Allegan data.

Table B.1. Tabulation of Daily Data

Date	Allegan 824 MHz 9 m			Cleveland 848 MHz 142 m			Cleveland 848 MHz 9 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
11-27-61	=	148.1	7.4						
11-28-61	o	150.5	3.6						
11-29-61	o	154.5	6.1						
11-30-61	=	146.7	6.9						
12-04-61	o	146.7	8.8						
12-05-61	o	149.0	10.3						
12-06-61	=	151.8	10.8						
12-07-61	=	149.9	8.1						
12-11-61	o	151.9	10.5						
12-12-61	=	150.6	10.4						
12-13-61	=	150.6	10.6						
12-14-61	o	148.0	10.0						
12-18-61	=	144.5	8.9						
12-19-61	o	146.3	6.9						
12-20-61	o	147.4	10.2						
12-21-61	=	147.7	7.6						
01-16-62				+	146.6	3.0			
01-17-62				o	163.8	1.6	o	165.8	10.8
01-18-62				+	157.2	3.6	+	165.2	10.4
01-29-62	o	152.1	10.0	o	144.2	5.5			
01-30-62	+	152.7	12.0	=	142.5	4.4			
01-31-62	o	152.7	13.0	o	143.7	4.7	o	167.3	14.1
02-01-62	+	152.2	11.3	=	143.5	7.1	=	166.9	12.2
02-05-62	=	153.2	11.8	+	138.5	9.4	+	161.3	12.7

Table (Continued)

Date	Allegan 824 MHz 9 m			Cleveland 848 MHz 142 m			Cleveland 848 MHz 9 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
02-06-62	o	154.6	14.3	o	141.8	4.1	o	166.7	9.4
02-07-62	=	153.7	12.7				+	166.2	11.1
02-08-62	o	151.1	10.7	o	143.8	4.4	o	165.0	7.6
02-12-62	=	151.3	9.4	+	137.2	3.8	+	161.8	8.6
02-13-62	o	151.3	13.2				o	168.9	10.9
02-14-62	o	153.1	13.0	o	142.3	3.7	o	163.4	12.1
02-15-62				+	148.6	5.5	+	167.8	9.2
02-19-62	=	154.4	14.3	+	143.8	4.0	+	165.9	10.5
02-20-62	o	152.8	12.0	o	144.7	4.8	o	167.8	15.9
02-21-62	o	154.9	10.7	o	142.6	4.7	o	162.8	9.6
02-22-62	o	152.1	5.9	o	145.2	6.3	o	164.4	11.8
02-26-62	o	152.8	13.1	o	143.6	9.4	o	162.0	11.8
02-27-62	=	150.2	9.8	+	143.9	6.2	+	165.0	15.0
02-28-62	o	152.1	15.8	o	144.6	4.9	o	163.9	8.3
03-01-62	=	155.1	15.0	+	143.7	3.4	+	165.9	11.0
03-05-62	=	157.2	15.2	+	143.4	5.5	+	164.1	9.4
03-06-62	+	152.9	13.0	=	144.1	5.4	=	168.8	10.4
03-07-62	+	150.0	9.2	=	144.5	7.7	=	166.3	11.4
03-08-62	+	155.0	9.2	=	145.5	9.4	=	164.9	13.4
03-12-62	+	150.3	9.4	=	146.0	4.8	=	168.9	9.7
03-13-62	o	156.8	12.0	o	142.5	3.9	o	164.3	10.1
03-14-62	=	150.8	9.8	+	142.4	4.1	+	164.5	10.5
03-15-62	o	154.4	11.6	o	146.4	4.6	o	164.0	8.2
03-19-62				+	147.5	5.2	+	162.5	10.5

Table B.1. (Continued)

Date	Cleveland 824 MHz 9 m			Milwaukee 848 MHz 61 m			Louisville 824 MHz 99 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
02-06-62									
02-07-62									
02-08-62									
02-12-62									
02-13-62									
02-14-62									
02-15-62									
02-19-62									
02-20-62									
02-21-62									
02-22-62									
02-26-62									
02-27-62				o	163.1	25.3			
02-28-62				=	168.4	16.3			
03-01-62				o	169.3	20.8			
03-05-62				o	167.9	21.2			
03-06-62				o	163.3	25.8			
03-07-62				o	159.7	25.0			
03-08-62				o	164.7	21.1			
03-12-62				o	168.8	20.4			
03-13-62				=	160.6	25.9			
03-14-62				o	169.0	16.0			
03-15-62				=	166.3	26.1			
03-19-62				o	164.6	28.9			

Table B.1. (Continued)

Date	Allegan 824 MHz 9 m			Cleveland 848 MHz 142 m			Cleveland 848 MHz 9 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
03-20-62				+	147.8	4.7	+	163.7	11.2
03-21-62	=	153.1	14.0	+	147.8	4.4	+	163.1	11.7
03-22-62	=	149.1	7.8	+	147.6	5.9	+	160.9	10.3
03-26-62	o	146.3	6.7	o	148.6	5.7	o	164.5	11.7
03-27-62	+	149.5	8.5	=	147.9	4.7	=	169.7	16.5
03-28-62	=	147.7	8.5	+	148.8	6.4	+	162.7	14.7
03-29-62	o	148.9	4.9	o	146.3	5.8	o	163.3	4.0
04-02-62	o	148.6	4.2	o	149.2	3.6	o	167.2	15.4
04-03-62	+	151.1	9.0				=	168.8	14.4
04-04-62	o	146.2	12.2	o	146.6	6.9	o	169.7	14.8
04-05-62	o	144.1	6.7	o	145.1	4.7	o	163.8	10.2
04-09-62	o	150.1	10.2				o	160.9	6.2
04-10-62				+	141.0	4.5	+	162.9	10.5
04-11-62	+	148.2	8.3	=	147.2	5.0	=	166.9	11.3
04-12-62	=	146.7	11.3	+	144.0	6.3	+	167.0	10.1
04-16-62	+	151.5	7.6	=	142.4	5.6	=	162.2	11.6
04-17-62				o	144.3	5.4	o	167.7	9.0
04-18-62	=	145.5	3.5	+	143.2	7.9	+	164.6	11.6
04-19-62							+	165.4	14.0
04-30-62	=	145.4	7.2	+	139.8	9.8	+	164.0	9.1
05-01-62	=	146.9	9.2	+	145.0	6.3	+	158.7	11.7
05-02-62	+	148.1	5.4	=	146.1	6.2	=	170.9	9.2
05-03-62	+	146.7	4.2						
05-07-62	o	145.7	5.2	o	141.5	7.7	o	163.5	13.2

Table B.1. (Continued)

Date	Cleveland 824 MHz 9 m			Milwaukee 848 MHz 61 m			Louisville 824 MHz 99 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
03-20-62				o	146.1	16.2			
03-21-62				o	160.3	25.2			
03-22-62				o	153.7	22.6			
03-26-62				+	146.8	14.2			
03-27-62				o	146.3	11.7			
03-28-62				o	144.9	6.7			
03-29-62				+	150.2	12.7			
04-02-62				+	162.8	11.9			
04-03-62				o	146.5	9.6			
04-04-62									
04-05-62				o	159.0	28.9			
04-09-62				+	157.0	22.2			
04-10-62				o	158.4	23.1			
04-11-62				o	150.0	15.4			
04-12-62				o	147.1	16.8			
04-16-62				o	155.1	22.5			
04-17-62				+	165.0	20.9			
04-18-62				o	152.1	12.9			
04-19-62				o	149.5	7.6			
04-30-62				o	158.9	20.9			
05-01-62				o	165.4	21.0			
05-02-62				o	148.9	9.9			
05-03-62				o	148.0	9.9			
05-07-62				+	147.7	9.2			

Table B.1. (Continued)

Date	Allegan 824 MHz 9 m			Cleveland 848 MHz 142 m			Cleveland 848 MHz 9 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
05-08-62	o	147.6	6.6	o	144.2	7.0	o	164.6	9.0
05-09-62				o	142.0	6.3	o	163.4	8.7
05-10-62	+	148.1	11.4	=	145.3	13.1	=	165.2	12.5
05-14-62				=	142.8	7.4	=	168.3	8.5
05-15-62	o	145.9	8.0	o	142.3	7.0	o	164.3	7.5
05-16-62	=	145.3	8.1	+	138.9	7.5	+	165.1	10.1
05-17-62	o	149.9	9.8	o	145.1	10.1	o	162.0	9.4
05-21-62	=	144.1	11.1	+	144.3	8.5	+	168.3	11.5
05-22-62	=	143.5	8.8	+	143.8	7.2	+	163.7	10.7
05-23-62				+	144.7	10.2	+	165.5	11.1
05-24-62	o	145.0	9.0	o	150.0	5.5	o	165.3	12.9

Table B.1. (Continued)

Date	Cleveland 824 MHz 9 m			Milwaukee 848 MHz 61 m			Louisville 824 MHz 99 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
05-08-62	o	166.3	10.6	+	154.4	15.7			
05-09-62	o	166.3	13.0	+	145.7	11.6			
05-10-62	=	167.1	12.2	o	157.4	17.6			
05-14-62				o	153.9	17.5			
05-15-62	o	161.2	10.7	=	148.6	10.4			
05-16-62	+	161.6	9.9	o	146.1	11.6			
05-17-62	o	164.5	13.5	o	149.1	16.6			
05-21-62	+	164.2	11.2	o	160.3	7.6			
05-22-62	+	162.2	11.9	o	163.4	21.4			
05-23-62	+	161.3	9.4	o	150.2	16.8			
05-24-62	o	163.1	11.3	=	154.6	12.7			
05-29-62				o	155.9	12.4			
06-07-62				+	150.5	11.7			
06-12-62				+	150.9	13.1			
06-14-62				+	145.8	12.5			
06-19-62				o	150.4	16.1			
06-21-62				+	148.4	10.3			
06-25-62				+	149.5	9.7			
06-26-62				o	145.2	12.9			
06-27-62				o	146.2	11.5			
06-28-62				o	151.0	12.8			
06-29-62				o	144.7	16.2			
07-03-62				+	159.1	3.1			
07-12-62				o	152.5	16.3			

Table B.1. (Continued)

Date	Allegan 824 MHz 9 m			Cleveland 848 MHz 142 m			Cleveland 848 MHz 9 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
08-09-62									
08-21-62									
08-27-62									
08-28-62	o	148.1	7.4						
08-29-62									
08-30-62	=	147.2	6.4						
08-31-62									
09-04-62	+	147.1	9.7				=	164.6	8.8
09-05-62	+	147.3	5.2						
09-06-62							o	166.1	19.0
09-07-62							o	164.7	17.7
09-08-62									
09-10-62	+	151.0	10.1	=	148.1	8.4	=	166.5	11.5
09-11-62	o	147.7	8.4	o	144.2	9.0	o	166.0	15.3
09-12-62	o	145.4	8.8	o	143.5	6.4	o	164.9	15.0
09-13-62	+	148.1	9.5	=	143.7	12.0	=	162.6	17.2
09-17-62	=	147.2	7.2	+	142.1	9.3	+	164.2	12.6
09-18-62	=	147.4	8.2	+	140.1	6.1	+	166.3	12.8

Table B.1. (Continued)

Date	Cleveland 824 MHz 9 m			Milwaukee 848 MHz 61 m			Louisville 824 MHz 99 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
07-17-62				+	155.8	7.4			
07-19-62				+	160.5	7.4			
07-26-62				o	150.6	16.5			
07-31-62				o	151.2	9.1			
08-02-62				o	154.5	12.1			
08-07-62				+	163.1	1.4			
08-09-62				o	162.1	14.7			
08-21-62				o	158.2	2.6			
08-27-62				+	153.7	10.3			
08-28-62									
08-29-62				o	152.6	11.7			
08-30-62									
08-31-62				o	155.9	16.7			
09-04-62				o	158.0	9.3			
09-05-62	=	167.7	11.2	o	159.6	9.3			
09-06-62				+	159.2	7.1			
09-07-62	o	168.4	14.5	+	142.7	17.5			
09-08-62				o	148.0	16.8			
09-10-62				o	156.0	17.9			
09-11-62	o	168.7	15.5	+	149.0	17.3			
09-12-62	o	167.5	13.0	+	156.6	18.7			
09-13-62	=	166.8	12.3	o	157.9	15.3			
09-17-62	+	169.5	14.0	o	154.3	12.1			
09-18-62	+	167.5	12.5	o	153.5	10.3			

Table B. (Continued)

Date	Allegan 824 MHz 9 m			Cleveland 848 MHz 142 m			Cleveland 848 MHz 9 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
09-19-62	o	149.0	6.7	o	143.5	6.4	o	165.6	15.8
09-20-62	o	145.7	7.9	o	145.9	4.6	o	171.3	20.9
09-24-62	o	146.2	6.8				o	166.2	13.7
09-25-62	=	144.9	6.7	+	143.5	9.4	+	163.2	14.5
09-26-62	o	139.0	10.7	o	144.5	7.2	o	165.1	13.3
09-27-62	=	148.3	6.9	+	144.0	6.4	+	166.5	14.8
10-01-62	=	144.9	11.1	+	145.1	9.2	+	163.9	9.7
10-02-62	o	144.9	4.8	o	148.1	9.2	o	165.7	22.8
10-03-62	+	145.6	7.1	=	147.7	7.2	=	163.6	7.5
10-04-62	=	146.8	8.4	+	145.1	8.3	+	166.4	11.3
10-08-62	u	144.3	6.9	u	147.1	6.3	u	166.4	12.8
10-09-62				u	145.0	6.9	u	163.9	12.3
10-10-62	u	145.4	6.5	u	148.8	6.4	u	165.5	14.5
10-11-62	u	146.6	8.1	u	146.5	8.7	u	163.8	13.2
10-15-62	o	144.2	7.2						
10-16-62									
10-17-62	=	144.2	7.1						
10-18-62	o	144.5	4.7						
10-22-62	o	144.0	9.0						
10-23-62	=	149.3	6.9						
10-24-62	+	150.0	4.4						
10-25-62	=	151.7	9.5						
10-29-62	o	145.8	9.2						
10-30-62	=	145.9	8.6						

Table [illegible] (Continued)

Date	Cleveland 824 MHz 9 m			Milwaukee 848 MHz 61 m			Louisville 824 MHz 99 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
09-19-62	o	166.3	12.8	+	159.9	7.0			
09-20-62	o	165.9	14.1	+	161.7	4.5			
09-24-62	o	164.3	15.8						
09-25-62	+	167.0	12.6	o	161.3	13.6			
09-26-62	o	164.8	12.7	+	163.5	17.3			
09-27-62	+	167.7	14.3	o	162.8	12.9			
10-01-62	+	166.3	11.0						
10-02-62				=	154.0	13.3			
10-03-62	=	165.9	8.2	o	154.3	14.1			
10-04-62	+	166.1	9.9	o	158.7	19.5			
10-08-62				u	159.8	16.8			
10-09-62				u	154.8	14.9			
10-10-62				u	155.8	12.5			
10-11-62				u	163.1	11.4			
10-15-62	o	162.3	7.3	=	155.9	12.9			
10-16-62				+	152.3	13.5			
10-17-62	+	161.8	10.4	o	155.9	12.6			
10-18-62				+	153.5	14.0			
10-22-62				+	163.7	8.6			
10-23-62	+	169.4	10.8	o	166.3	3.2			
10-24-62	=	167.3	9.8	o	165.9	2.5			
10-25-62	+	169.5	1.5	o	165.5	2.2			
10-29-62	o	166.1	6.1	=	164.1	13.6			
10-30-62				o	162.2	12.8			

Table B.1. (Continued)

Date	Allegan 824 MHz 9 m			Cleveland 848 MHz 142 m			Cleveland 848 MHz 9 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
10-31-62	=	151.0	10.2						
11-01-62	u	147.5	7.3						
11-05-62	+	149.8	4.8						
11-06-62	=	145.5	5.8						
11-07-62									
11-08-62	o	148.6	9.2						
11-12-62									
11-13-62	o	152.0	10.6						
11-14-62	o	145.2	7.0						
11-15-62	o	144.8	5.7						
11-26-62	=	148.9	9.0				+	166.9	14.5
11-27-62	+	146.0	5.2						
11-28-62	=	149.2	8.6				+	164.6	10.5
11-29-62	+	144.1	6.6				=	165.4	14.3
12-03-62	o	142.7	6.5	o	152.0	7.6			
12-04-62	o	147.1	7.4	o	153.1	9.2	o	165.1	9.6
12-05-62	o	146.6	5.5	o	152.4	3.6	o	166.8	10.6
12-06-62	o	148.7	8.9	o	146.2	3.8	o	168.3	16.3
12-10-62				o	146.7	5.2	o	168.9	12.3
12-11-62	o	150.2	7.8	o	147.1	4.2	o	171.9	25.7
12-12-62	+	150.7	8.5	=	149.6	6.3	=	172.2	7.3
12-13-62	o	148.0	6.0				o	164.5	13.3
12-17-62	+	147.4	4.7	=	153.8	7.5	=	166.6	11.0
12-18-62	=	146.6	6.3	+	149.4	6.6	+	162.6	11.1

Table (Continued)

Date	Cleveland 824 MHz 9 m			Milwaukee 848 MHz 61 m			Louisville 824 MHz 99 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
10-31-62				o	164.5	7.7			
11-01-62	u	166.5	12.8	u	164.7	8.4			
11-05-62	=	165.8	8.3	o	165.0	5.7			
11-06-62				o	162.3	11.0			
11-07-62				o	162.2	11.6			
11-08-62									
11-12-62	+	166.9	12.8	o	164.1	13.2			
11-13-62	o	170.3	9.9	+	166.0	10.5			
11-14-62	o	164.6	10.4	=	151.7	14.6			
11-15-62	o	165.3	10.1	+	160.6	13.4			
11-26-62				o	153.2	13.7			
11-27-62				o	158.4	14.0			
11-28-62	+	168.1	12.1	o	153.2	13.7			
11-29-62	=	172.8	19.5	o	154.5	11.0			
12-03-62				+	154.5	14.3			
12-04-62	o	165.3	10.1	+	161.3	11.4			
12-05-62	o	171.7	10.9	=	166.0	8.9			
12-06-62				+	165.5	5.3			
12-10-62	o	171.8	12.7						
12-11-62	o	166.0	8.5						
12-12-62	=	168.9	8.5						
12-13-62									
12-17-62				o	157.2	9.7			
12-18-62				o	152.5	17.2			

Table B.1. (Continued)

Date	Allegan 824 MHz 9 m			Cleveland 848 MHz 142 m			Cleveland 848 MHz 9 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
12-19-62				o	152.5	5.8	o	166.7	15.0
12-20-62	o	146.8	7.1	o	146.3	4.6	o	166.9	12.2
01-07-63	=	147.7	7.0	+	146.2	7.0	+	165.8	15.8
01-08-63	=	146.6	5.6	+	147.0	4.2	+	166.8	17.0
01-09-63	=	149.5	9.1	+	148.1	6.4	+	166.5	11.6
01-10-63				+	147.6	3.3	+	164.5	8.5
01-14-63	=	149.0	8.4	+	145.3	3.2	+	167.2	8.9
01-15-63	=	147.2	5.5	+	145.0	3.1	+	166.3	9.7
01-16-63							+	169.0	13.6
01-17-63	=	150.2	8.3				+		9.5
01-28-63	=	147.2	6.2						
01-29-63	=	150.3	7.2						
01-30-63	=	150.2	7.5						
01-31-63	=	149.9	6.5						
02-04-63	=	147.3	8.6						
02-05-63									
02-06-63	=	152.2	7.5						
02-07-63	=	144.4	5.3						
02-11-63	o	147.7	8.7						
02-12-63	=	150.8	8.6						
02-13-63	=	149.9	6.7						
02-14-63	=	151.8	9.8						
02-18-63	=	147.6	9.0						
02-19-63	o	147.0	8.0						

Table B.1. (Continued)

Date	Cleveland 824 MHz 9 m			Milwaukee 848 MHz 61 m			Louisville 824 MHz 99 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
12-19-62	o	165.8	14.2	+	160.4	14.8			
12-20-62	o	161.9	8.4	+	160.6	11.6			
01-07-63	+	166.5	15.8	o	163.6	6.8			
01-08-63	+	170.7	10.0	o	157.9	9.4			
01-09-63	+	162.9	8.7	o	162.2	12.7			
01-10-63	+	165.8	9.5	o	163.2	11.6			
01-14-63	+	167.8	8.6	o	164.2	6.4			
01-15-63	+	166.8	11.9						
01-16-63				o	165.4	5.2			
01-17-63	+	170.7	9.2	o	163.6	11.3			
01-28-63									
01-29-63	+	166.9	9.5	o	164.5	9.8			
01-30-63	+	165.9	8.7	o	161.5	13.7			
01-31-63	+	170.9	11.1	o	161.9	18.8			
02-04-63				o	164.3	9.7			
02-05-63	+	169.7	13.5	o	161.7	6.5			
02-06-63	+	161.6	4.8	o	158.9	15.0			
02-07-63				o	150.5	11.4			
02-11-63	o	172.8	6.7	+	160.9	6.1			
02-12-63	+	164.6	8.3	o	161.9	7.2			
02-13-63	+	169.6	10.9						
02-14-63	+	163.1	10.4						
02-18-63				o	161.5	11.0			
02-19-63	o	166.3	11.3	=	165.1	10.1			

Table B.1. (Continued)

Date	Allegan 824 MHz 9 m			Cleveland 848 MHz 142 m			Cleveland 848 MHz 9 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
02-20-63									
02-21-63	=	151.7	8.9						
02-25-63									
02-26-63	=	148.4	10.7						
02-27-63	=	147.0	5.5						
02-28-63	=	146.5	8.8						
03-04-63	=	144.9	8.8				+	160.5	13.4
03-05-63	o	148.4	9.4				o	167.3	11.6
03-06-63	o	147.3	7.6				o	165.4	11.6
03-07-63	=	148.5	7.0				+	170.6	15.7
03-11-63	=	145.0	7.4				+	167.5	7.7
03-12-63	o	146.7	6.2				o	163.7	18.8
03-13-63	o	146.1	4.4				o	168.8	14.6
03-14-63	=	148.4	7.8				+	166.4	9.6
03-18-63	o	145.7	3.6				o	164.3	9.2
03-19-63	o	147.0	10.7				o	170.3	9.3
03-20-63	o	146.1	4.8				o	163.5	12.1
03-21-63	=	146.9	5.3				+	165.0	15.4
03-25-63	o	145.0	7.3				o	170.7	11.1
03-26-63	o	147.9	5.9				o	163.1	9.2
03-27-63							+	160.8	10.0
03-28-63	+	145.3	7.1				=	170.7	15.6
04-01-63	=	142.6	5.7				+	164.7	9.7
04-02-63	o	146.7	8.4				o	164.3	7.8

Table B.1. (Continued)

Date	Cleveland 824 MHz 9 m			Milwaukee 848 MHz 61 m			Louisville 824 MHz 99 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
02-20-63	+	165.0	8.8	●	163.9	2.5			
02-21-63	+	170.8	10.1						
02-25-63	+	173.2	12.4						
02-26-63	+	166.7	11.3						
02-27-63	+	164.0	9.3	o	163.8	10.2			
02-28-63	+	166.4	13.5	o	162.5	9.3			
03-04-63	+	161.9	6.7	o	159.6	15.0			
03-05-63	o	165.8	13.0	+	163.1	11.8			
03-06-63	o	168.7	13.2	=	160.7	8.7			
03-07-63				o	162.9	10.4			
03-11-63				o	161.6	8.8			
03-12-63				+	160.0	12.9			
03-13-63				+	161.6	11.9			
03-14-63				o	162.6	12.0			
03-18-63				+	161.2	8.3			
03-19-63				=	160.0	17.5			
03-20-63				=	162.4	4.0			
03-21-63									
03-25-63				=	164.0	16.0			
03-26-63				=	162.1	11.0			
03-27-63				o	151.4	14.4			
03-28-63				o	152.2	9.3			
04-01-63									
04-02-63				=	159.5	16.7			

Table B.1. (Continued)

Date	Allegan 824 MHz 9 m			Cleveland 848 MHz 142 m			Cleveland 848 MHz 9 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
04-03-63	o	145.1	5.4				o	168.3	11.7
04-04-63	=	147.4	7.7				+	164.7	10.4
04-08-63	=	144.2	6.6				+	165.6	6.3
04-09-63	o	146.3	7.1				o	164.5	12.5
04-10-63	=	145.9	3.9				+	170.3	15.1
04-11-63	=	146.4	6.7				+	164.5	6.0
04-22-63	o	143.4	7.7						
04-23-63							+	163.9	13.9
04-24-63	=	146.3	6.6				+	166.1	7.3
04-25-63	=	147.8	8.5				+	164.9	8.3
04-29-63	=	144.6	6.7						
04-30-63	=	145.4	8.8						
05-01-63	+	147.3	4.2						
05-02-63	o	146.5	7.7						
05-06-63	u	145.2	7.0						
05-07-63	u	146.7	3.4						
05-08-63	u	146.3	8.3	u	152.7	7.7			
05-09-63				u	147.4	5.0			
05-13-63				u	152.7	6.0			
05-14-63				+	152.9	5.9			
05-15-63				o	152.0	5.0			
05-16-63				+	148.4	5.1			
05-20-63				+	156.6	5.8	+	165.6	8.2
05-21-63							+	166.1	9.0

Table B.1. (Continued)

Date	Cleveland 824 MHz 9 m			Milwaukee 848 MHz 61 m			Louisville 824 MHz 99 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
04-03-63				=	154.3	11.0	o	152.0	4.7
04-04-63				o	152.9	17.5	=	149.9	3.8
04-08-63				o	157.6	16.0	=	149.8	4.5
04-09-63				+	161.9	7.8	o	150.7	5.2
04-10-63				o	154.2	9.5	=	150.4	4.1
04-11-63				o	151.7	11.8	=	149.1	4.1
04-22-63				=	150.7	16.2	o	154.0	4.4
04-23-63							=	150.6	3.8
04-24-63							=	149.9	3.9
04-25-63							=	151.3	4.6
04-29-63				o	152.9	20.9	=	152.0	4.3
04-30-63							=	149.7	4.2
05-01-63							+	148.9	2.1
05-02-63				=	156.7	14.0	o	151.6	3.5
05-06-63				u	156.9	10.5	u	151.9	5.0
05-07-63				u	150.4	8.6			
05-08-63				u	160.6	16.6			
05-09-63				u	161.8	14.6			
05-13-63							u	151.7	5.9
05-14-63				o	154.0	12.7	=	151.6	5.3
05-15-63							o	151.1	6.5
05-16-63							=	150.2	6.2
05-20-63				o	156.1	10.4	=	151.7	5.6
05-21-63				o	159.5	11.6	=	151.8	5.9

Table B.1. (Continued)

Date	Allegan 824 MHz 9 m			Cleveland 848 MHz 142 m			Cleveland 848 MHz 9 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
05-22-63				+	153.3	3.6	+	164.5	4.8
05-23-63				+	149.2	6.1	+	166.1	10.3
05-28-63							+	162.1	10.0
06-04-63									
06-11-63									
06-18-63									
06-20-63									
09-03-63	+	150.8	5.5						
09-05-63	o	154.1	6.9						
09-09-63	=	152.3	6.5						
09-10-63	o	151.6	8.0						
09-11-63	=	153.8	5.5						
09-12-63	o	153.9	7.0						
09-16-63	=	151.5	7.2						
09-17-63	+	151.0	5.7						
09-18-63	=	154.6	6.9						
09-19-63	o	155.6	10.4						
09-23-63	=	151.3	5.0						
09-24-63	=	153.0	7.7						
09-25-63	+	151.7	6.3						
09-30-63	o	151.5	5.5						
10-01-63	=	152.9	4.0						
10-02-63	=	152.3	6.9						
10-07-63	=	152.4	7.3						

Table B.1. (Continued)

Date	Cleveland 824 MHz 9 m			Milwaukee 848 MHz 61 m			Louisville 824 MHz 99 m		
	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}	FPO	L_{do}	F_{do}
05-22-63				o	160.4	9.0	=	151.1	4.3
05-23-63				o	152.8	9.5	=	151.1	4.3
05-28-63									
06-04-63				o	150.6	13.8	=	153.5	4.4
06-11-63				o	161.4	16.4	=	150.1	6.8
06-18-63							+	151.3	3.0
06-20-63							o	152.6	6.3

Table B.1. (Continued)

Date	Allegan 824 MHz 9 m			Date	Allegan 824 MHz 9 m		
	FPO	L_{do}	F_{do}		FPO	L_{do}	F_{do}
10-08-63	=	152.0	5.6	11-21-63	+	150.0	6.1
10-09-63	=	152.6	8.1	12-02-63	=	151.4	7.1
10-10-63	=	152.7	6.6	12-03-63	+	154.5	4.3
10-14-63	=	152.6	8.6	12-04-63	=	152.6	5.0
10-15-63	+	152.6	4.5	12-05-63	o	153.1	4.7
10-16-63	=	152.2	8.7	12-09-63	=	151.8	3.9
10-17-63	=	152.6	7.9	12-10-63	=	154.7	8.3
10-21-63	+	152.1	6.2	12-11-63	=	153.4	7.0
10-22-63	o	152.5	7.3	12-12-63	=	160.5	8.3
10-23-63	=	151.1	7.8	12-16-63	=	152.9	7.2
10-24-63	o	151.7	5.8	12-17-63	+	151.3	3.3
10-28-63	=	153.8	9.2	12-18-63	o	155.3	7.9
10-29-63	+	152.4	3.9	01-08-64	o	151.2	7.6
10-30-63	o	153.8	7.5	01-09-64	+	149.9	5.6
10-31-63	o	145.5	6.0	01-14-64	o	157.0	14.8
11-04-63	=	152.0	7.5	01-15-64	=	152.7	5.7
11-05-63	=	151.2	5.3	01-16-64	=	153.4	8.0
11-06-63	=	150.7	6.7	01-27-64	=	151.9	6.6
11-07-63	o	153.5	4.8	01-28-64	o	153.0	4.8
11-12-63	=	153.4	7.3	01-29-64	=	154.5	8.5
11-13-63	+	159.1	7.2	01-30-64	+	150.0	6.0
11-14-63	+	153.5	4.8	02-03-64	o	152.6	4.4
11-18-63	o	151.9	9.1	02-04-64	o	155.7	7.4
11-19-63	=	152.8	7.3	02-05-64	+	153.0	5.7
11-20-63	o	152.1	9.8	02-06-64	+	153.2	10.3

Table B.1. (Continued)

Date	Allegan 824 MHz 9 m			Date	Allegan 824 MHz 9 m		
	FPO	L_{do}	F_{do}		FPO	L_{do}	F_{do}
02-10-64	=	155.0	8.4	03-25-64	=	153.3	8.9
02-11-64	+	154.9	3.3	03-26-64	=	154.6	8.8
02-12-64	o	152.7	9.4	04-06-64	=	151.2	6.4
02-13-64	=	155.9	9.2	04-07-64	=	152.0	9.0
02-17-64	+	153.2	5.4	04-08-64	=	154.7	7.6
02-18-64	o	152.6	7.7	04-13-64	=	150.9	8.0
02-19-64	+	152.0	5.4	04-14-64	=	154.5	8.9
02-20-64	o	154.5	4.9	04-15-64	=	159.0	9.4
02-24-64	=	154.1	6.3	04-16-64	=	156.7	9.4
02-25-64	=	153.5	8.7	04-27-64	+	149.5	6.8
02-26-64	=	155.2	7.8	04-28-64	=	151.5	8.2
03-02-64	=	154.2	8.7	04-29-64	o	152.7	3.9
03-03-64	=	153.7	7.5	04-30-64	=	150.9	7.6
03-04-64	=	149.1	5.5	05-04-64	=	153.0	8.6
03-05-64	=	152.7	9.2	05-05-64	=	150.6	7.6
03-09-64	=	153.5	7.3	05-06-64	o	152.4	7.6
03-10-64	=	150.6	7.4	05-07-64	=	152.5	9.7
03-11-64	=	154.3	7.8	05-11-64	=	152.3	8.3
03-12-64	=	158.3	11.0	05-12-64	=	154.1	9.1
03-16-64	=	159.5	9.5	05-13-64	=	151.2	4.1
03-17-64	=	153.9	7.7	05-14-64	+	156.0	8.7
03-18-64	o	157.3	6.7	05-18-64	=	153.6	6.6
03-19-64	=	154.5	9.1	05-19-64	=	151.3	11.1
03-23-64	=	152.7	6.8	05-20-64	=	153.1	10.3
03-24-64	=	152.9	9.0	05-21-64	+	153.5	8.4

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