Development of Techniques to Assess Interference to the MF Broadcasting Services

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DEVELOPMENT OF TECHNIQUES TO ASSESS INTERFERENCE TO THE MF BROADCASTING SERVICES

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The Institute for Telecommunication Sciences has embarked upon a program to improve the techniques that are used to determine medium frequency broadcasting parameters. This work is motivated by the fact that increased transmitter power which is planned by a number of Administrations in the Western Hemisphere could seriously impact MF broadcast service areas in the United States by giving rise to unacceptable interference levels. In order to provide a technically accurate tool for use in assessing the performance of MF broadcast operations, efforts have been undertaken to develop a capability to determine the broadcast service area, taking into account both groundwave and skywave modes of propagation. In addition, a program of monitoring long distance skywave signals has been initiated as part of a joint NTIA/FCC endeavor. These long-distance signals will be used to form the basis for changes in existing MF skywave prediction programs.

Key Words: AM analysis model; MF broadcasting; MF interference; MF prediction methods; MF sky-wave signal observations

1. INTRODUCTION

Medium-frequency (MF) AM broadcasting is a principal means of commercial broadcasting in the United States. The MF spectrum is heavily used, particularly in urban regions, and this heavy use often precludes comparable service in rural areas because of regulatory requirements imposed upon AM broadcasters. With population shifts and demographic changes in the past forty years, it is perhaps worthwhile to re-examine the broadcast regulations in light of current national priorities. Any changes to broadcasting regulations can come about only after detailed technical, economic, and regulatory studies have been completed and all questions of major concern have been answered in a manner that is satisfactory to all interested parties. Changes in broadcasting operations in one region of the country can result in a reduction of service areas of currently operating stations in adjacent regions.

Modifications to AM broadcasting operations can not be undertaken unilaterally in the United States because of agreements, especially agreements between the United States and its neighbors in the Western Hemisphere. In recent years, it has become apparent that certain Western Hemisphere nations intend to modify their MF

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broadcasting operations primarily by using higher powered transmitters and transmitting signals on more frequencies. In order to address this problem and limit potential interference to current and future operations in the Western Hemisphere, the International Telecommunications Union (ITU) has scheduled a Regional Administrative MF Broadcasting Conference of the Western Hemisphere (Region 2). The first session of the Conference was held in Buenos Aires in March, 1980, and established the basis for preparing a frequency assignment plan for the MF broadcasting band in Region 2. This first session considered propagation data, modulation standards, channel spacing, protection ratios (including noise levels), required field strengths, transmitting antenna characteristics, transmitter power, and planning. The second session, convened in November 1981, drew up an agreement and an associated frequency plan of assignments in the MF broadcasting band for Region 2. It is necessary that the plan that is finally adopted be consistent with the projected United States use of the medium-frequency band. In order to assure that this is the case, the Institute for Telecommunication Sciences (ITS) has undertaken studies aimed at more efficiently utilizing the MF spectrum. The present report provides a description of the studies that were directed at the propagation aspects of medium-frequency broadcasting.

Propagation of MF radio waves involves both the groundwave and skywave modes. Normal, local broadcasting service is provided by the groundwave mode. Skywave propagation is important during nighttime hours when the ionospheric absorption is much reduced and can provide service to distant locations. Propagation of distant signals via the skywave mode at night can also lead to interference to local services. This report is devoted to describing the models that have been used to estimate AM broadcasting service characteristics based upon groundwave mode considerations that are modified in a simplified manner to incorporate the effects of skywave modes of propagation at night. The model that has been used is one developed by the Federal Communications Commission (FCC). In Section 3, studies directed toward more advanced skywave propagation prediction methods are discussed. Included in the section is a review of existing skywave propagation models as well as a description of an experiment that has been initiated as a joint NTIA/FCC endeavor to monitor long-distance skywave signals on the island of Puerto Rico. In Section 4, the results described in the preceding two sections will be used to demonstrate their applicability to an AM broadcasting scenario, and a discussion of where future efforts should lie will be given.

2. FCC AM ANALYSIS OF GROUND-WAVE STUDIES*

2.1 Description of the AM analysis model

For about three decades, the prediction of MF broadcast coverage in the U.S. has been accomplished by using a map of soil conductivities in conjunction with a set of graphs giving signal strength versus distance constructed for the AM broadcast frequencies (540-1600 kHz) (see FCC, 1976, Rules and Regulations, Vol. 3, Section 73.190, Figure 2, and Section 73.184, graphs 1-19). The equivalent distance method was used to compute the field strengths and contour plots for each station could be deduced by taking into account factors such as antenna gain and peak radiated power. This procedure was time consuming for the large number of stations that the FCC had to deal with so, in order to speed up the process, the FCC created computer data bases and developed a computer analysis program. This program has been called the AM analysis model and has been adopted for use in this study.

The model was designed as an evaluation tool to examine the interference potential of proposed stations to existing stations. The model has a great deal of flexibility and permits the user to change or vary critical parameters. For example, all interference tolerance limitations can be provided as input to the model and can be changed at the user's discretion. The data bases contained within the model are digitized groundwave propagation curves, soil conductivity data, the AM station data base, and the demographic data files by state and county. The end result is a model that allows the user to examine the details of the calculation, to accept those interference levels which exceed specified limits but are judged to be tolerable, and to interact with the model.

2.2 Modules of the AM Analysis Model

The AM Analysis Model is an interactive model which permits analysis of proposed station parameters in order to calculate interference to and from existing stations and summarizes the analyses. The inputs to the model are grouped into five areas: frequency, location, proposed station data, interference tolerances, and responses for output formats. All the input requests have at least two selectable options, either pre-selected or user-supplied. The pre-selected options minimize the time required by the user to specify standard data such as the use of existing domestic interference criteria.

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*The remarks in this section have been derived from Anderson (1980) and Phillip Tremper (private communication, 1981).

From these inputs, the model permits evaluation of the acceptability of the proposed stations at each of the locations specified on each of the frequencies specified. The processing order is established by the user's assignment of a priority to each location and frequency entered. The night-time and day-time theoretical interference limits are then computed to and from all relevant existing stations in the AM data base. If the computed interference values exceed the pre-established interference criteria, the model rejects the proposed frequency and processes the next frequency. If the model rejects all the input frequencies, the site location is tagged as unassignable and the next site is processed. Those frequencies at a given location that pass all the interference criteria are assignable at that location. These assignments are recorded in a temporary data file for consideration as existing stations in the next analysis. The model continues with the next location in the list. After all the locations have been processed, the results are tabulated with either one or no assignment per site and the model can then be used to analyze the assigned locations again at the user's request. The subsequent passes will attempt to identify other frequencies that can be assigned at the sites.

The output provides an indication of which frequency and site is being analyzed, if interference criteria have been violated, and which frequencies can be assigned at the specified sites. Intermediate and detailed reports can be obtained at the option of the user. The detailed reports that are obtained from the model include an information line from each module entered by the model. (Intermediate reports that are obtained are more concise, but can be redundant.) A table summarizing the results is printed at the end of the processing which lists the number of assignments made at each site on the defined frequencies.

The main feature of the model is its use in assigning frequencies to tentative locations subject to chosen interference criteria. The model allows for analysis of up to 300 locations and 125 different frequencies. Once the model has provided an assignment, the information is treated as if the assignment were part of the regular AM station inventory. The user may override a frequency rejection, however. Other features of the model are the ability to investigate site feasibility based on U. S. county by county population information (using each county's median geographic coordinates) and to alter the channeling plan from the standard 10 kHz spacing to any other specified spacing.

2.3 Analysis Modules

After the model accepts the user-designated inputs, the program attempts to assign a proposed station at the specified location. The analysis consists of two main parts, one for night-time and one for day-time. In both areas, theoretical interference checks are made based upon the class of the proposed station. For a proposed unlimited station operation, the night-time interference check is made before the day-time interference check.

There are three parts to the night-time analysis. First, there is the computation of the existing station's RSS (the square root of the sum of the squares) limit of potential interferers; second, there is the computation of the proposed station's contribution to this limit; and third, the computation of the existing station's contribution to the proposed station's limit.

The model computes the RSS limit of all the existing interferences to an existing station. The model accomplishes this by retrieving existing night-time stations on a specific frequency and then computes station by station field strengths from all other stations of the set to the particular station of interest. The field strength from a contributing station is the maximum field in the direction of the station of interest modified by its skywave field factor taken at a desired percentage of the time and its protection ratio (see ITU, 1980, pp. 41-46).

The RSS limit is calculated using the 50 percent exclusion rule. For example, let e_1, e_2, . . ., e_n be a list of the field strengths of potential interferers, ordered from greatest to least. If 50 percent of e_1 is greater than e_2, then e_2, e_3, . . ., e_n are excluded as potential interferers and the RSS limit used is e_1. Otherwise, the RSS is calculated for e_1 and e_2. If 50 percent of this new value is greater than e_3 then e_3, e_4, . . ., e_n are no longer considered and the RSS limit used is $\sqrt{e_1^2 + e_2^2}$. If not, continue and terminate when the 50 percent exclusion rule is applicable. If the proposed station's signal at the existing station is less than one half of the joint RSS limit, then the proposed station's signals are considered to be tolerable; otherwise, the proposed station is rejected. These interference checks are continued until it is established that the proposed station will not interfere with any existing station, or until the proposed station is rejected.

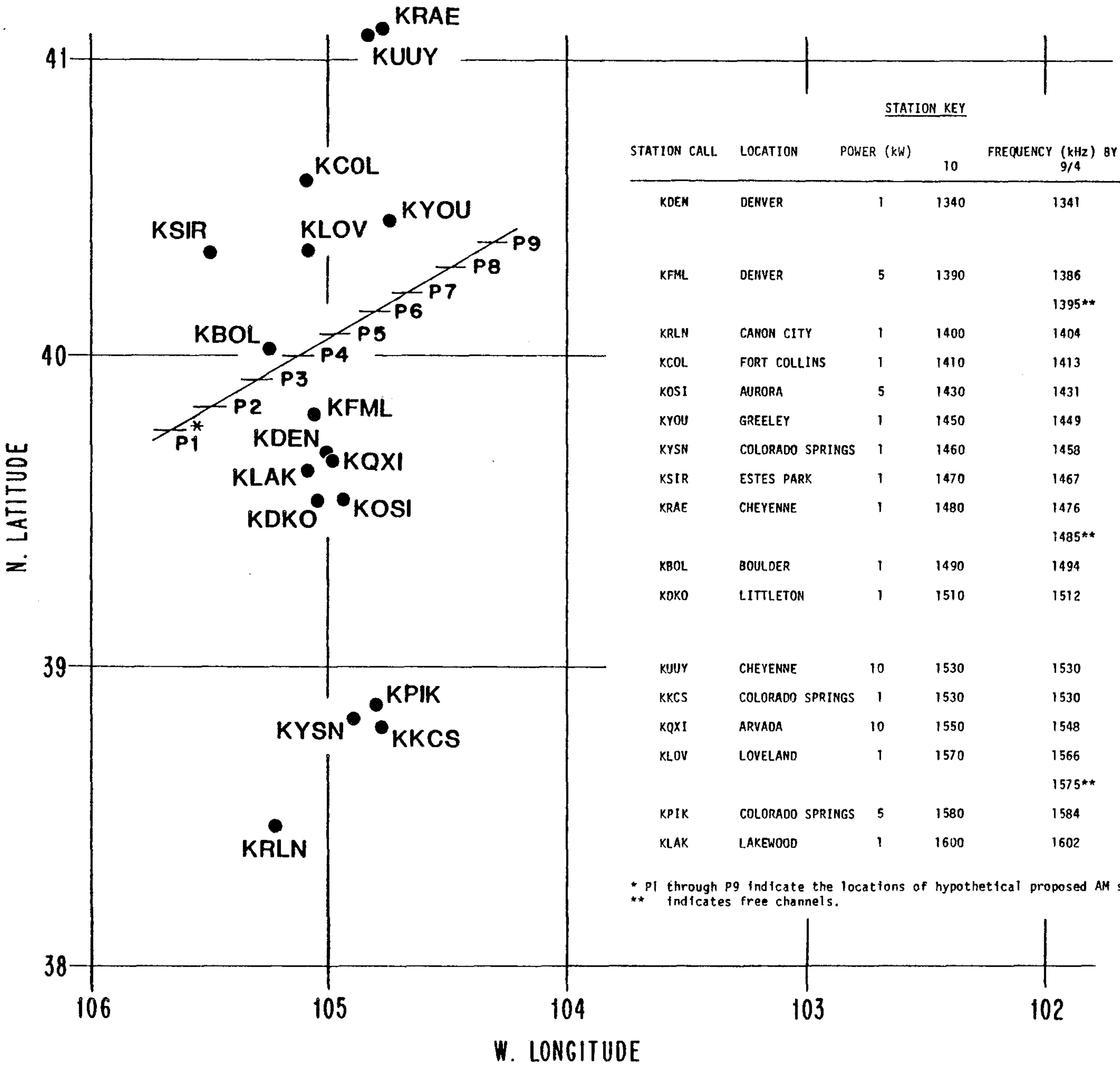
The maximum field computations are determined from the radiated field strengths at one mile along the great circle path between the two stations. The process is one of determining the azimuth and the vertical angle that yields the maximum far-field radiation values. The azimuth is assumed to be the great circle azimuth from the station causing the interference to the receiving station. The vertical angle is selected from a range of angles established from the distances between stations.

The model makes the day-time analyses based upon the equivalent distance method. This requires input from three sources. The first contains key data including station frequency, power, azimuthal information, and antenna parameters for computing radiation patterns. The second source contains soil conductivity data for each azimuth of interest (user specified). The third source contains the digitized data from the appropriate groundwave field strength graph. The equivalent-distance calculations are carried out by the successive calculation of net distance correction factors for each conductivity zone crossed on a given azimuth.

In order for a proposed station to pass the day-time interference checks, protected contours on existing co-channel stations and existing stations on the first three adjacent channels must not be violated. Similarly, the protected contours for the proposed station must not be violated unless the user accepts the interference limit calculated. The distance and bearing between stations is computed by algorithms using spherical trigonometric relationships. The far field radiation computations at one mile are based upon the work given by Howard, W. Sams and Co., (1975).

It is worthwhile to illustrate how the AM analysis model can be used to aid in assigning frequencies in the AM broadcasting spectrum. Assume that a local station is to be located in the Boulder, Colorado, area and it will operate only during the daytime. The frequencies to be tested range from 1340 kHz to 1600 kHz and nine proposed sites were chosen more or less uniformly spaced along an arbitrary diagonal path. The distribution of proposed sites, p1 through p9, along with other AM stations of interest can be seen in Figure 1. The example simply addresses whether such a proposed station would be accepted in terms of interference to and from existing stations. No consideration is given to the topography of the sites or the economics involved.

Three channeling plans were chosen to test the daytime interference criteria as required by the FCC. These criteria are shown in Table 1. The contours specified there are in terms of mV/m and at the protected contour there is a permissible amount of interference allowed. There are two types of interference shown. The first, denoted by RX, is caused by a proposed station, co-channel with or adjacent channel to the existing one, exceeding a specified signal intensity at some point on a specified protected contour about the existing station. The second, denoted



STATION KEY

STATION CALL	LOCATION	POWER (kW)	FREQUENCY (kHz) BY PLAN 10	9/4	9/9
KDEN	DENVER	1	1340	1341	1332
					1350** 1359**
KFML	DENVER	5	1390	1386	1395
				1395**	
KRLN	CANON CITY	1	1400	1404	1404
KCOL	FORT COLLINS	1	1410	1413	1413
KOSI	AURORA	5	1430	1431	1431
KYOU	GREELEY	1	1450	1449	1449
KYSN	COLORADO SPRINGS	1	1460	1458	1458
KSIR	ESTES PARK	1	1470	1467	1467
KRAE	CHEYENNE	1	1480	1476	1476
				1485**	
KBOL	BOULDER	1	1490	1494	1485
KDKO	LITTLETON	1	1510	1512	1503
					1521** 1530**
KUUY	CHEYENNE	10	1530	1530	1539
KKCS	COLORADO SPRINGS	1	1530	1530	1539
KQXI	ARVADA	10	1550	1548	1557
KLOV	LOVELAND	1	1570	1566	1575
				1575**	
KPIK	COLORADO SPRINGS	5	1580	1584	1584
KLAK	LAKEWOOD	1	1600	1602	1602

* PI through P9 indicate the locations of hypothetical proposed AM stations
** indicates free channels.

Figure 1. Boulder, Colorado area and proposed station sites to demonstrate the AM analysis model.

Table 1. U. S. Daytime Interference Criteria

CLASS	CHANNELING PLAN	INTERFERENCE TYPE	CHANNELS OFF	CONTOURS (mV/m) PROTECTION	CONTOURS (mV/m) INTERFERENCE
I-A	9 & 10	RX	0	0.100	0.005
I-B	9 & 10	RX	0	0.100	.005
NON-I	9 & 10	RX	0	.500	.025
ALL	9 & 10	RX	1	.500	.500
ALL	9 & 10	TX	2	2.000	25.000
ALL	9 & 10	TX	3	25.000	25.000

RX	proposed transmitter site to receiver
TX	proposed transmitter site to existing transmitter site

by TX, is caused by a proposed station, on a second or third adjacent channel to the existing one, exceeding a signal of 25 mV/m at the existing protected contour. Violations of these criteria are grounds for rejecting the proposed station.

The first channeling plan chosen was the existing 10 kHz channel-separation. The second was a 9 kHz plan where all stations which were affected by a frequency change would shift by no more than ±4 kHz (9/4 plan). The third plan was also a 9 kHz channel-separation plan, but the frequency shift could be as much as ±9 kHz

(9/9 plan). The 9/4 and 9/9 plans allow for 12 new channels in the entire AM band. For the 9/4 plan, the new channels start at 585 kHz and every 90 kHz thereafter and end at 1575 kHz. For the 9/9 channel-separation, the new channels are paired and start with 630, 639 kHz and every 180 kHz thereafter and end with 1521,1530 kHz. The 9/4 plan would allow stations on 540 kHz to 1530 kHz in increments of 90 kHz to remain on those frequencies, while for the 9/9 plan only those stations from 540 kHz to 1440 kHz in increments of 180 kHz would be unchanged.

The results using the 10 kHz channel-separation plan to locate a new station in the Boulder area showed that no new assignments could be made. Each potential site was listed for the frequencies 1340 to 1600 in increments of 10 kHz. It was found that either a station existed on a co-channel or on a first or second adjacent channels for which unacceptable interference was generated. The 9/4 channel-separation plan offered no new assignments as well. Frequencies considered started at 1341 and ended at 1602 with free channels on 1395, 1485, and 1575 kHz. On each of these free channels, adjacent channel interferences to the existing stations precluded a new assignment. The remaining frequencies violated co- or adjacent channel criteria.

The 9/9 test channel-separation plan yielded results that showed new assignments could be made. Because of the paired nature of the free channels, the adjacent channel interference was reduced significantly allowing new station allocations. At two of the sites, three frequencies were found to be acceptable; at six of the sites, two frequencies were found to be acceptable, and at one site, one frequency was acceptable. All of the acceptable frequencies were ones that could become available for assignment because of the 9/9 plan.

3. MF SKYWAVE PREDICTION STUDIES

3.1 MF Skywave Prediction Methods

In the previous section, the FCC AM analysis program was described. It was mentioned that this program takes account of both groundwave and skywave MF modes. The skywave calculations are based upon simplified assumptions, however. In order to correct this situation, a detailed study of MF skywave prediction methods and propagation processes has been undertaken by the Institute for Telecommunication Sciences. In this section, various methods for estimating the field strength of MF skywaves are discussed. The discussion is somewhat brief with appropriate references being given to more detailed descriptions of each of the methods described. Much of the discussion provided in the subsequent subsections follows from the work of PoKempner (1980). For purpose of providing predictions of MF skywave field strength for this study, six different methods have been investigated. These methods are referred to as the Cairo Curves, the FCC Curves, the CCIR (International Radio Consultative Committee) recommended method, an approximation to that method given by Wang (1979), a method developed by CCIR Interim Working Party 6/4 for use in Region 2, and the method for Region 2 which was adopted by the 1980 Regional Administrative Broadcasting Conference (ITU, 1980).

3.1.1 Cairo Curves

The Cairo Curves (Figure 2) are based on measurements taken in the northern hemisphere during the winters of 1934/35, 1935/36, and 1936/37. Measurements were made at frequencies between 695 and 1185 kHz on 23 paths between North America and Europe, North America and South America, and South America and Europe. The North-South curve shown in Figure 2 was derived from data obtained from transequatorial propagation paths, and the East-West curve was derived from data observed primarily at high latitudes. The original curves were in terms of the quasi-maximum value for 1 kW radiated versus distance. This was defined as the value exceeded not more than five percent of the time, with the median being about .35 of this quasi-maximum value. Subsequently, the CCIR reduced these curves by 9 dB to approximate a median value (CCIR, 1978a). New measurements made by the European Broadcast Union showed good agreement with the Cairo Curves out to 2000 km (PoKempner, 1980). It was noted that the slope of the Cairo Curves beyond that distance was independent of frequency, geographic location, and solar activity.

3.1.2 The FCC Curves

There are two sets of FCC curves for skywave propagation. The first set, shown in Figure 3, is based on recordings on 500 transmission paths at frequencies ranging from 640 to 1190 kHz and distances of 160 to 4000 km during February, March, and April, 1935, a period of relatively low solar activity. The data have been normalized to an equivalent transmitting antenna radiating 160.9 μV/m at the vertical angle corresponding to one ionospheric reflection (Barghausen, 1966).

The second set of FCC Curves [shown in FCC (1976), Section 73.190, Figures 1 and 2] is based on an extensive measurement campaign in the U. S. and Canada extending from 1939 to 1944. Recordings were made on 23 paths ranging from 400 to 3500 km and transmitting on frequencies ranging from 540 to 1500 kHz. All measurements were made two hours after sunset at the western end of the path. Only data observed during the year of 1944 were used in the second set of FCC Curves, however, since that was the year that minimum solar activity occurred. The highest skywave field

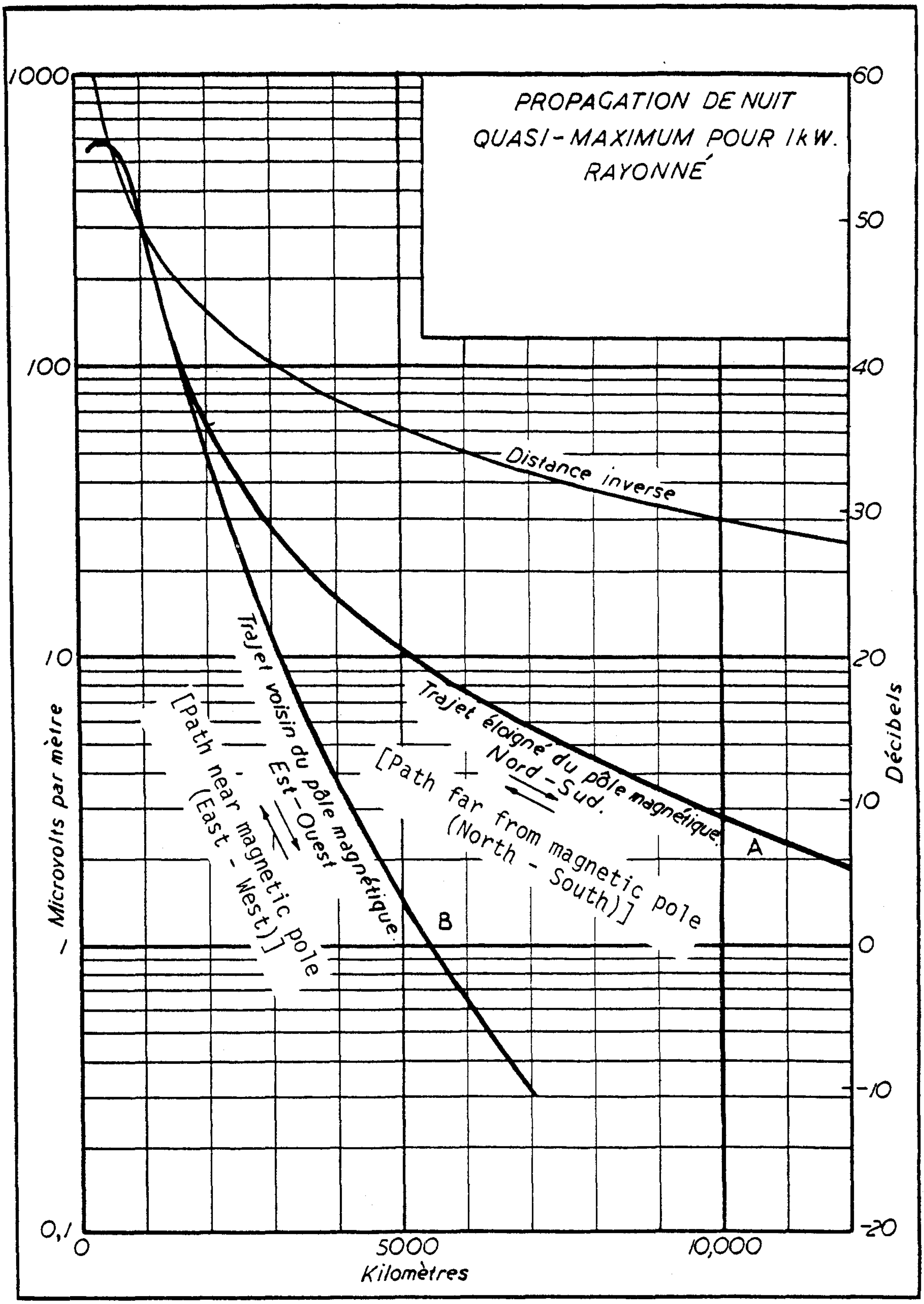
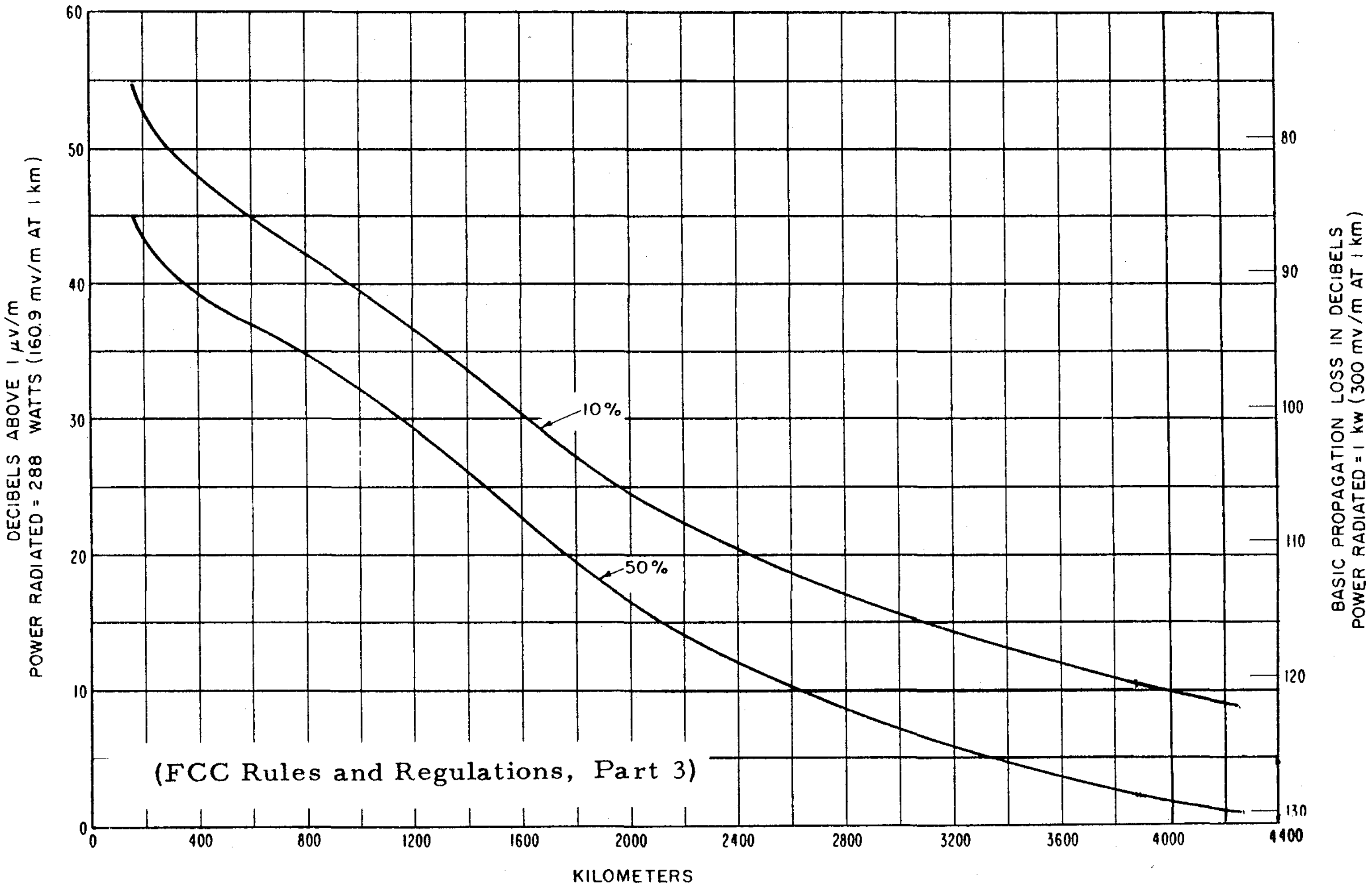


Figure 2. Quasi-maximum field intensity at great distances for propagation at night for a radiated power of 1 kW.



(FCC Rules and Regulations, Part 3)

Figure 3. U.S. sky-wave field strength exceeded 10 percent and 50 percent of the time at 1000 kHz. Based on 1935 measurements, vertical polarization, and second hour after sunset at west end of path (Barghausen, 1966).

strengths are expected to occur during years of solar minimum, therefore, the 1944 data represent the worst case for determining service areas and interference. These measurements were made at somewhat higher latitudes than the first set of measurements. Both sets of curves include curves of the field strengths exceeding 10 and 50 percent of the year or the period of observation, up to distances of 4300 km for the 1935 curves and about 4000 km for the 1944 curves. The 1944 curves are presented as a function of geographic latitude and are used by the FCC for determining frequency assignments for domestic non-clear-channel broadcasting stations. The 1935 curves are used for determining frequency assignments for inter-regional clear-channel broadcasting stations and were adopted by treaty in 1960 by Canada, Cuba, the Dominican Republic, and the Bahama Islands and, at the same time, by Mexico in a separate treaty (PoKempner, 1980).

3.1.3 The CCIR Method

The current recommended CCIR (Recommendation 435-3) skywave field-strength prediction method is (CCIR, 1978b):

$$F_o = 106.6 - 2 \sin \phi - 20 \log p - 10^{-3} k_R p - L_p + G_s \quad \text{dB}(\mu\text{V/m})$$

where

F_o is the annual median field strength (dB above µV/m) at the reference time;

ϕ is a geomagnetic latitude parameter (degrees);

p is slant propagation distance in km;

k is a basic loss factor;

k_R is a loss factor dependent on R, the 12-month smoothed Zurich sunspot number;

L_p is the excess polarization-coupling loss (dB); and

G_s is the sea gain correction (dB).

The loss factor is given by

$$k_R = k + 10^{-2} bR,$$

where

$$k = 3.2 + 0.19 f^{0.4} \tan^2(\phi + 3),$$

f is frequency in kHz, and b, a solar activity dependence factor, is 4 for North American paths, 1 for Europe and Australia, and 0 elsewhere.

The complete prediction method and description of the pertinent parameters are discussed in PoKempner (1980) and can also be found in CCIR (1978b).

3.1.4 The Wang 1979 Method

This is a proposed modification to that recommended in CCIR (1978b) and discussed in Section 3.1.3. Wang (1979) suggested that the basic loss factor, k, be changed to:

$$k = (0.0667\ |\phi| + 0.2) + 3\tan^2(\phi + 3) \quad \text{for} \quad (0 \leq |\phi| \leq 60°).$$

This improves the accuracy in high- and low-latitude areas without affecting the prediction in middle-latitude areas. In addition, it is assumed that the basic loss factor is independent of frequency. Another change proposed by Wang (1979) relates to the solar activity dependence factor, b. The CCIR recommends setting b = 4 for North America and b = 0 for South America. Wang proposed the following formula:

$$\begin{aligned} b &= 0.4\ |\phi| - 16 && \text{for} \quad |\phi| \geq 45° \\ b &= 0.0 && \text{for} \quad |\phi| < 45°. \end{aligned}$$

3.1.5 The IWP 6/4 Method

The CCIR Interim Working Party 6/4 met in special session in Geneva in October 1979 to determine a method for MF skywave prediction for use in Region 2. This method is described in detail in CCIR (1979). The method follows that of Wang (1979) rather closely except it is confined to periods of low solar activity (i.e., b = 0).

3.1.6 Region 2 Conference Method

The first session of the Region 2 Administrative MF Broadcasting Conference (ITU, 1980) adopted a method for MF skywave prediction which is a composite of the Cairo North-South and FCC curves. However, both curves are normalized to a characteristic field strength of 100 mV/m at 1 km corresponding to an equivalent monopole radiated power of -9.5 dB (kW). The normalized FCC median curve is used to a distance of 4,250 km and the normalized Cairo North-South curve, transformed to the median curve discussed in Section 3.1.1, is used for the interval of 4,250 km to 10,000 km.

3.1.7 Summary

It should be pointed out that numerous studies have been undertaken to evaluate the relative accuracy of the methods described above using as a basis actual observations of field strength. Such studies, however, suffer from the fact that, in some instances, the observations may be questionable or that the observations themselves were used as the basis for developing the method described. The latter statement particularly applies to the Cairo Curves and the FCC Curves. These limitations notwithstanding, it is useful to quote the results of detailed studies undertaken by PoKempner (1980) as applied to MF circuits in Region 2. She finds that the IWP 6/4 method appears to give the best overall estimate of field strength, followed by the CCIR recommended method. However, for very long paths (i.e., greater than 8000 km), there is an indication from PoKempner's results that the Cairo north-south curve yields the best results for Region 2 broadcasting circuits. Much of Region 2 interference potential lies on skywave paths of less than 8,000 km and even the IWP 6/4 method tends to underpredict field strengths for skywaves reflecting from lower geomagnetic latitudes. The need for adequate data to improve existing models becomes essential.

3.2 MF Signals Observed at Puerto Rico

In an effort to obtain data that provide reliable estimates of MF skywave signal strength and that can be used to improve the MF skywave models, the ITS, along with the FCC, has implemented a monitoring program at Cabo Rojo, Puerto Rico. Highly directional Beverage antennas are being used to monitor signals between 2300 and 0600 hours, local time, from discrete locations in South America. In addition, signals from a station in Spain and a station in Senegal are being monitored to provide data from Europe and Africa to locations in Region 2. The data are being recorded continuously using a controling computer, a programmable receiver, and a programmable digital voltmeter. The system is capable of automatically measuring the received signal level on ten (10) different signals. The signal level on each frequency is averaged over a one-minute period. The average signal level and the variance for each of these one-minute periods is then recorded on to magnetic tape along with date/time information.

Table 2 provides a listing of the stations being monitored along with the frequency, call signs, and power of transmission. In Table 3, the field strength (in dB relative to 1 μV/m) predicted are given for the signals using the skywave prediction methods given by the Cairo Curves, the FCC Curves, the CCIR-recommended method, the approximation to that method given by Wang (1979), the IWP 6/4 method, and the Region 2 Conference method. Values for the FCC method are given only for paths that are confined to North America. Generally for each path, the predicted values of field strength for each method can differ by as much as 8 to 9 dBu.

Figures 4 through 10 show the relative voltage for signals observed between August 8 and August 15 from Buenos Aires (870 kHz), Rio de Janeiro (1220 kHz), Brasilia (980 kHz), Guayaquil (870 kHz), Bogota (1130 kHz), Zambrano (680 kHz), and Barcelona (738 kHz). The horizontal axis shows the local time at the receiver and

Table 2. Monitoring Summary of MF Skywaves at Cabo Rojo, Puerto Rico

f(kHz)	Time (Local)	Antenna*	Audible AM Signals	Recorded AGC/AM Audio	Most Likely Station	Power (kW)
870		3	YES	YES	LRA, BUENOS AIRES, ARGENTINA	100
1220		3	YES	YES	ZYJ458, RIO de JANEIRO, BRAZIL	150
980		3	YES	YES	ZYH707, BRASILIA, BRAZIL	600
870		4	YES	YES	RADIO CRISTAL GUAYAQUIL, ECUADOR	20
1130		4	YES	YES	BOGOTA, COLOMBIA	20
680		2	YES	YES	HJBO ZAMBRANO, COLOMBIA	100
738		1	(CARRIER)	YES	BARCELONA, SPAIN	250

*ALL BEVERAGE ANTENNAS: 1 ≈ 95°T; 2 ≈ 140°: 3 ≈ 165°; 4 ≈ 180°

Table 3. Predicted Field Strength (dB above 1 μV/m) for Stations Being Monitored at Cabo Rojo, P. R.

TRANSMITTER	POWER (kW)	DISTANCE (km)	CAIRO	FCC	CCIR	WANG 79	IWP 6/4	REGION 2 CONF.
BUENOS AIRES (f = 870 kHz)	100	5901	28.0	-	30.9	37.2	32.1	28.0
Rio de Janeiro (f = 1220 kHz)	150	5239	31.8	-	34.8	40.0	36.2	31.8
BRASILIA (f = 980 kHz)	600	4309	41.8	-	45.4	49.4	46.7	41.8
GUAYAQUIL (f = 870 kHz)	20	2640	36.0	22.6	38.8	40.6	39.9	22.6
BOGOTA (f = 1130 kHz)	20	1666	44.5	33.0	46.1	47.6	47.1	33.0
ZAMBRANO (f = 680 kHz)	100	1340	55.2	47.0	54.2	55.5	55.0	47.0
BARCELONA (f = 738 kHz)	250	3593	41.0	-	42.0	45.1	43.7	41.0

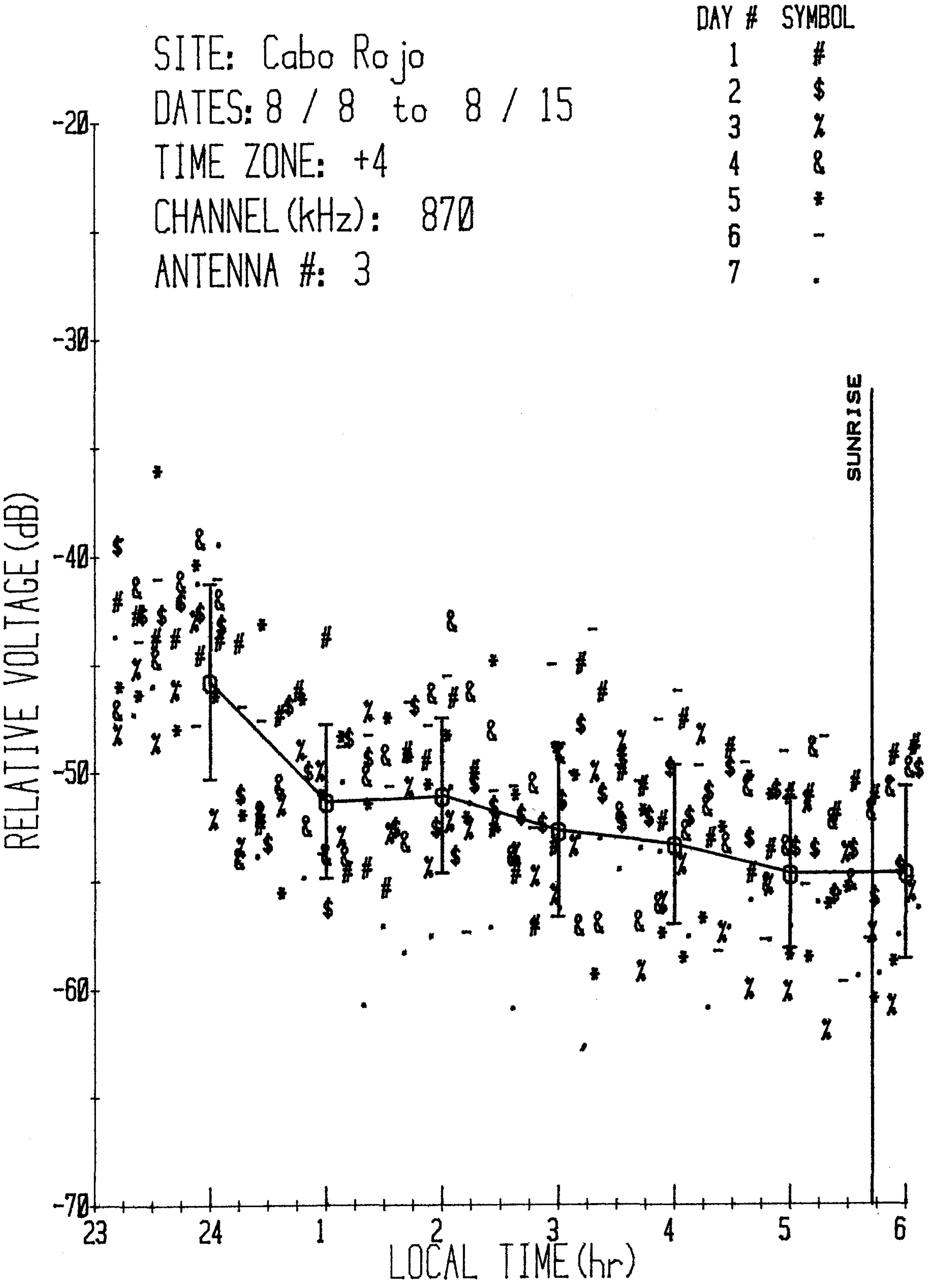


Figure 4. Daily measurements, hourly averages and standard deviations: LRA 100 kW Buenos Aires, Argentina; Beverage antenna #3, 165°T.

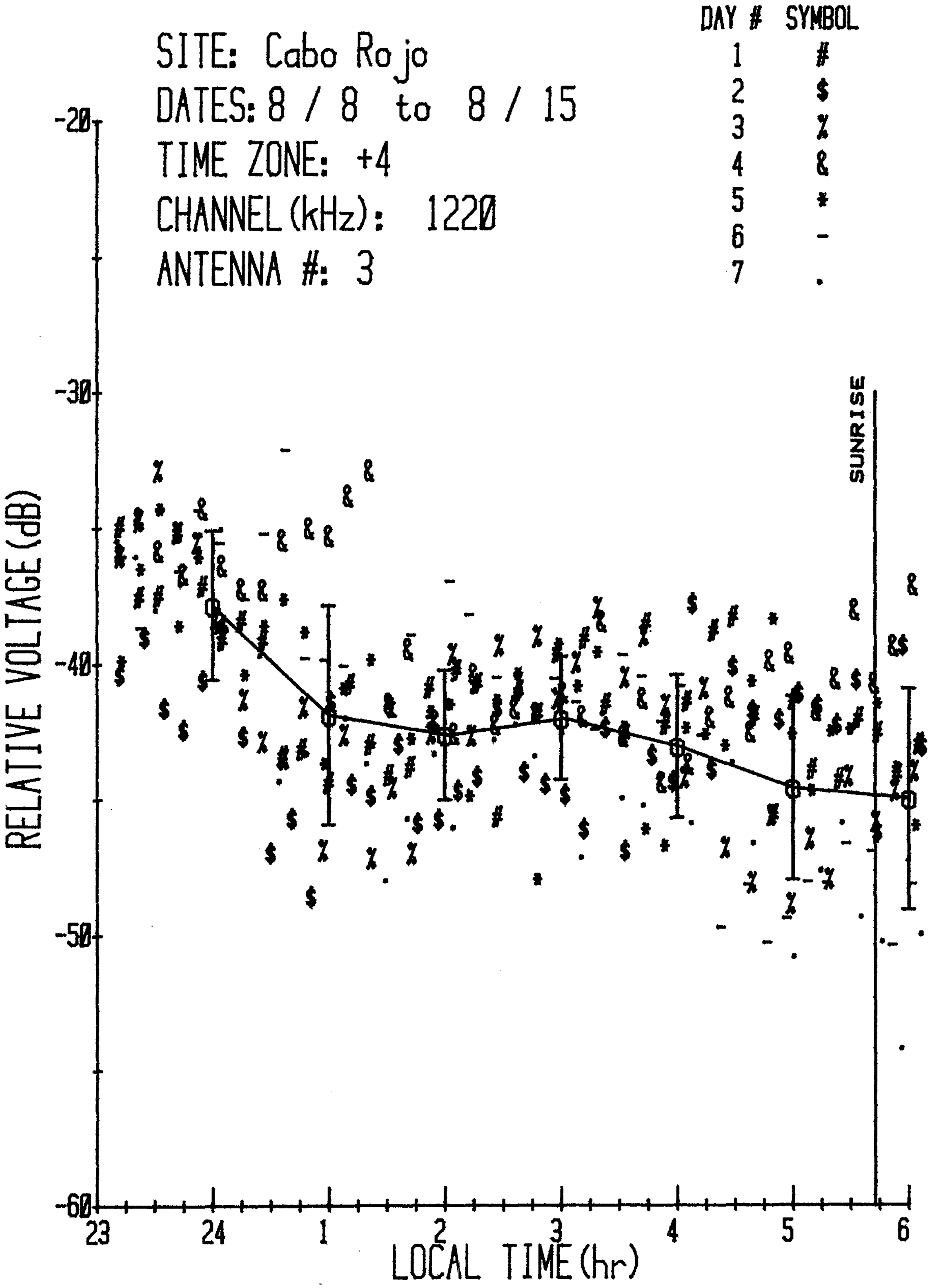


Figure 5. Daily measurements, hourly averages and standard deviations: ZYJ458 150 kW Rio de Janeiro, Brazil; Beverage antenna #3, 165°T.

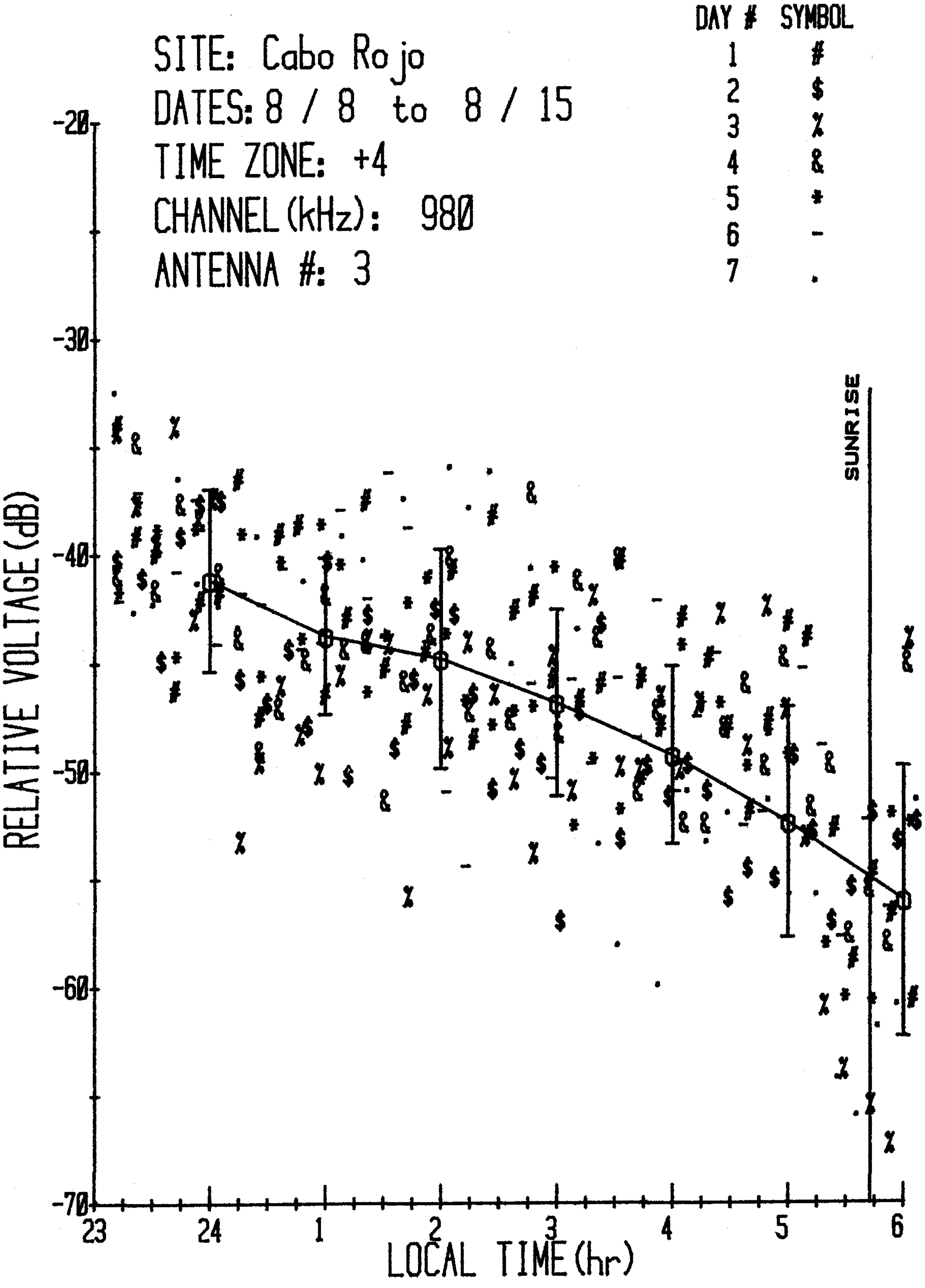


Figure 6. Daily measurements, hourly averages and standard deviations: ZYH707 600 kW Brasilia, Brazil; Beverage antenna #3, 165°T.

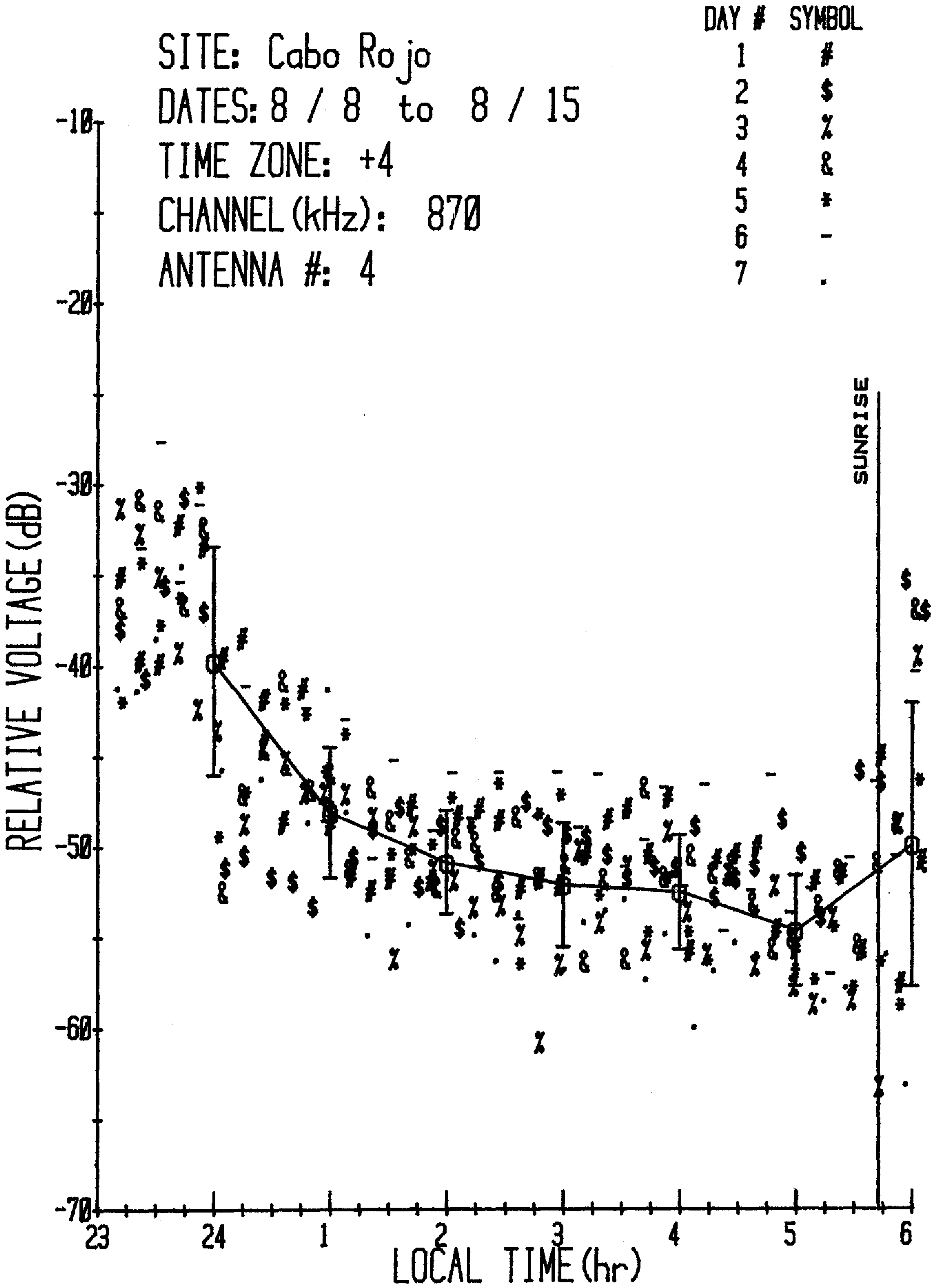


Figure 7. Daily measurements, hourly averages and standard deviations: Radio Cristal 20 kW Guayaquil, Ecuador; Beverage antenna #4, 180°T.

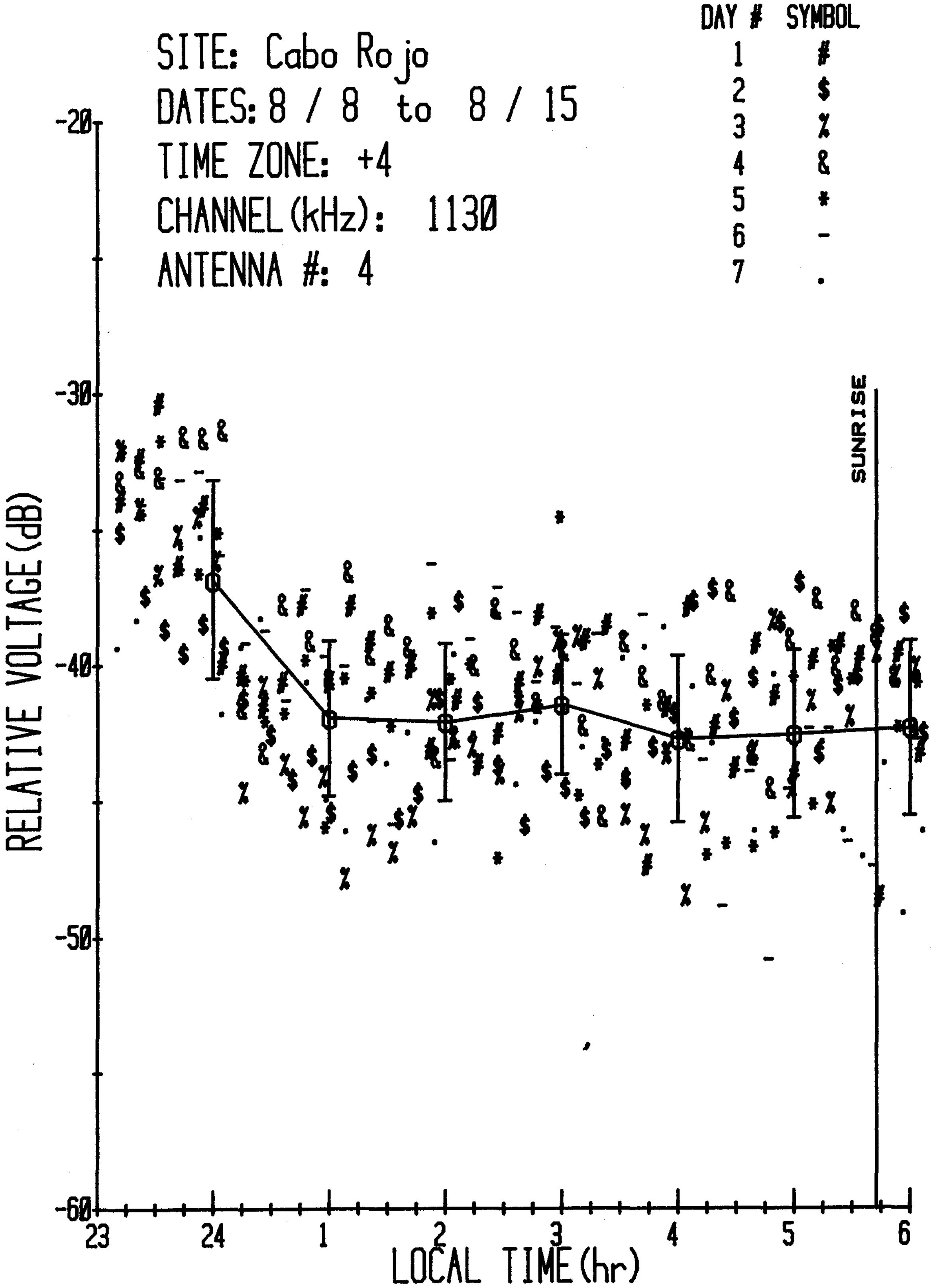


Figure 8. Daily measurements, hourly averages and standard deviations: 20 kW Bogota, Colombia; Beverage antenna #4, 180°T.

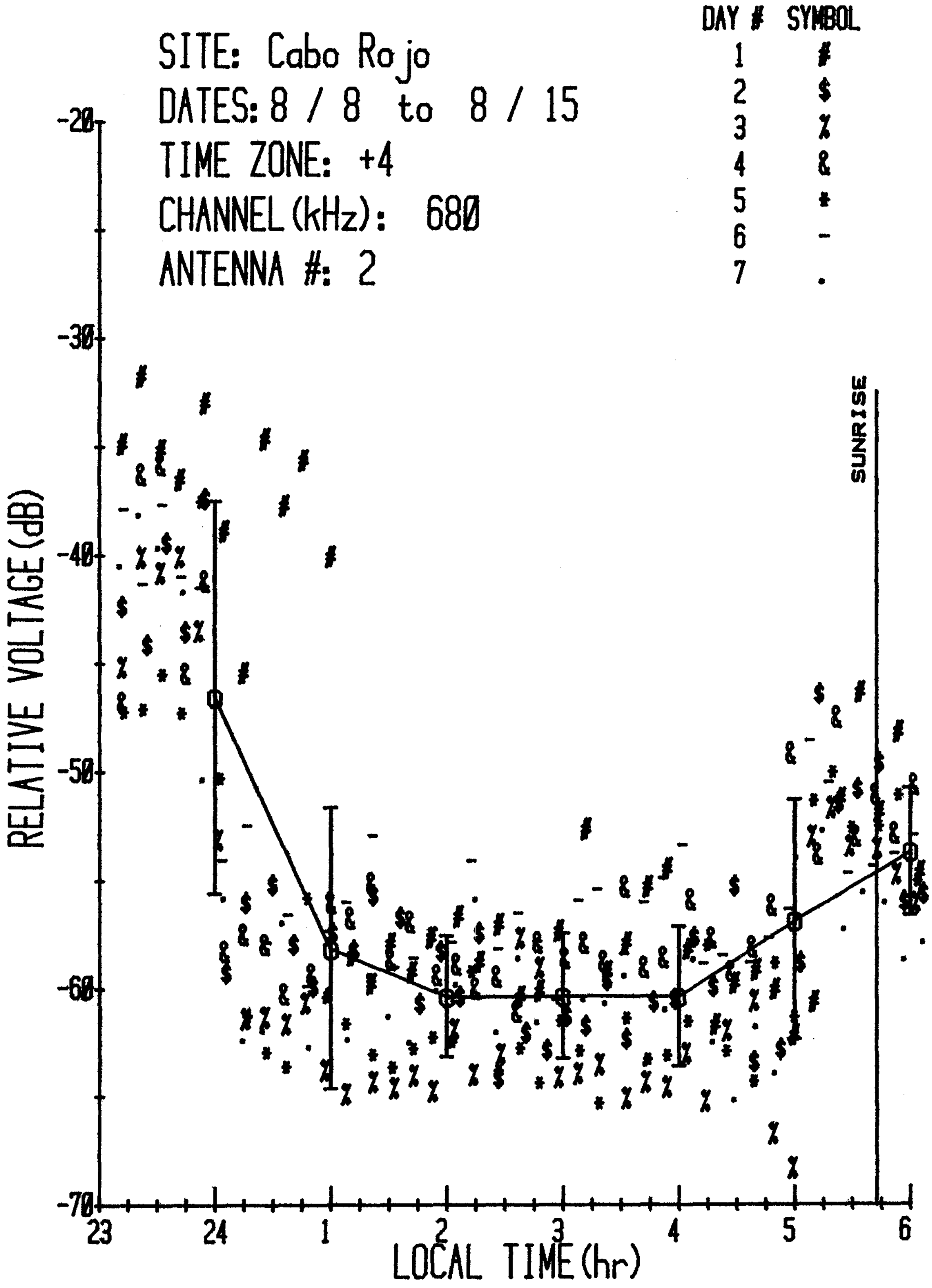


Figure 9. Daily measurements, hourly averages and standard deviations: 100 kW Zambrano, Colombia; Beverage antenna #2, 140°T.

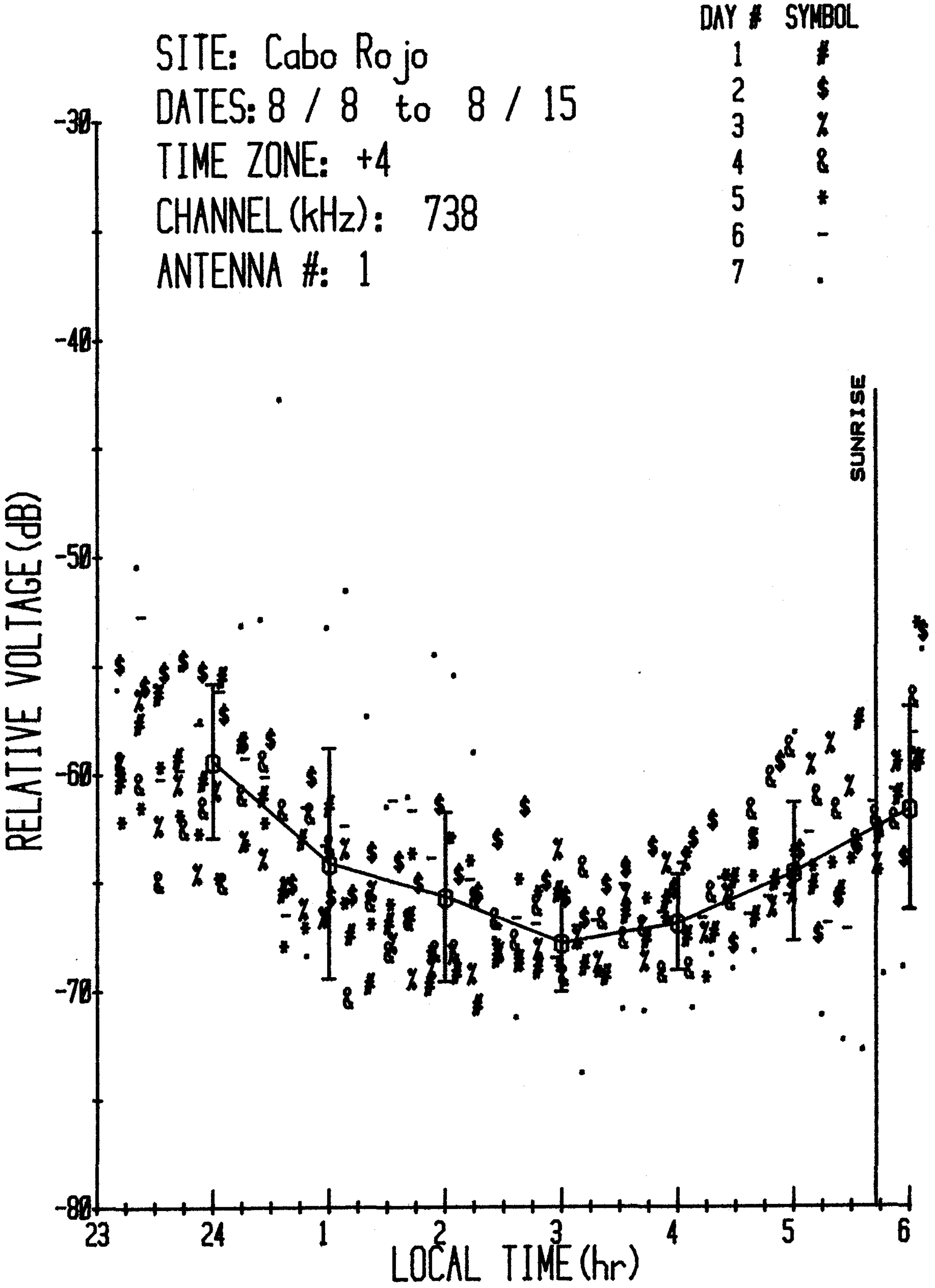


Figure 10. Daily measurements, hourly averages and standard deviations: 250 kW Barcelona, Spain; Beverage antenna #1, 95°T.

the vertical axis displays the relative voltage in decibels. The solid lines on the figures show the hourly average value along with the standard deviation. It can be seen that there is a lot of day-to-day variation in the value of the field strength--sometimes exceeding ±10 dB. This degree of variation exceeds the differences between the various prediction methods listed in Table 3. Even though the observations represent one-minute average values of field strength and the predicted values are yearly medians, the results indicate that it may be just as important to account for the day-to-day variation in field strength as it is to develop an accurate (in absolute terms) field strength prediction scheme. In assessing interference potential, the day-to-day variations in MF skywave field strength will have to be taken into account if the future observations at Cabo Rojo display the same characteristics.

The values of field strength shown in Figures 4 through 10 appear to approach a constant average value sometime between 0100 and 0300 hours local time at the receiver for all the observations except from Brasilia. The exact cause of the high values before midnight is not known; it is assumed that the high values of the signal strength before local midnight are due to interfering signals from local stations being received by the antenna. Clearly, further work is required in this area.

In order that the data displayed in Figure 4 through 10 be converted to decibels above 1 μV/m, it is necessary to incorporate the gain of the Beverage antenna into the observations. This has not been accomplished to date and must await further study. In the Appendix, data observed for selected time intervals and on selected frequencies from August 16 to September 5 are shown. The day-to-day variability in the observations are quite obvious as is the trend for lower minimum field strengths to occur in the early morning local time. For a typical local time, 0130 to 0230, Appendix Figures A1 to A24 show the median statistics for the monitored channels from August 8 to September 5. These statistics (that is, the computed median and upper and lower deciles) are for data from the specified hour for each monitoring-day.

4. DISCUSSION AND CONCLUSIONS

The work described in the previous sections is part of a continuing effort at ITS to develop methods and techniques for use in improving the management of the MF spectrum for broadcasting purposes. The decisions made at the 1979 General World Administrative Radio Conference (G-WARC) call for the existing MF broadcast spectrum to be expanded from the current upper limit of 1605 kHz to 1705 kHz by

1990 (ITU, 1979). This expansion will present an opportunity to improve AM broadcast services throughout the United States, particularly in the rural parts of the country.

At the same time that plans are being developed to expand the MF broadcast spectrum, certain Administrations are planning to increase their MF broadcasting capabilities with enhanced transmitter power. It is possible that the enhanced transmitter power that is planned by certain Administrations in the Western Hemisphere will lead to nighttime interference to existing AM broadcasting services in the United States. In order to assess this possibility in a more realistic manner and then develop appropriate corrective action (if necessary), the MF skywave signal monitoring in Puerto Rico is being undertaken. These data will be used to develop an accurate method for predicting the strength of MF skywave signals that are propagated over long distances in the Western Hemisphere. The improved skywave model will be incorporated into the AM analysis program so that a technically acceptable tool can be obtained to assess interference potential to current U. S. operations.

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During the course of this study, the authors have benefitted from the support provided by numerous individuals. Mr. Douglass Crombie has been a constant source of expertise and has provided keen insight into numerous aspects of this project. Ms. Margo PoKempner has been most helpful in assisting in the automation of the various MF skywave prediction programs used in this study. The skywave observational program being conducted at Cabo Rojo, Puerto Rico, would not have been possible without the untiring efforts of Messrs. John Carroll, Richard Espeland, and Gene Wasson. The authors are grateful to Mr. Phillip Tremper of the Federal Communications Commission for his assistance with the AM analysis program. The support and interest in this project provided by Messrs. John Wang, William Daniel, and William Luther, all of the Federal Communications Commission, is most appreciated.

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APPENDIX. OBSERVATIONS OF MF SKYWAVE SIGNALS OBSERVED AT CABO ROJO, PUERTO RICO

In the following figures, the relative voltage related to skywave field strength of MF signals emanating from South America is shown. The figures provide an indication of the day-to-day and hour-to-hour changes in signal strength observed at Cabo Rojo, Puerto Rico. The time periods for which the data were observed are indicated on the figures as is the frequency that was monitored. Further work is being undertaken to relate changes seen in the figures to propagation-related geophysical phenomena such as solar and geomagnetic activity. Table 2 provides a listing of the stations corresponding to the indicated frequency.

The median statistics for 0130 to 0230 local time for each monitoring-day is displayed by channel for data collected from August 8 to September 5 in Figures A19 to A24.

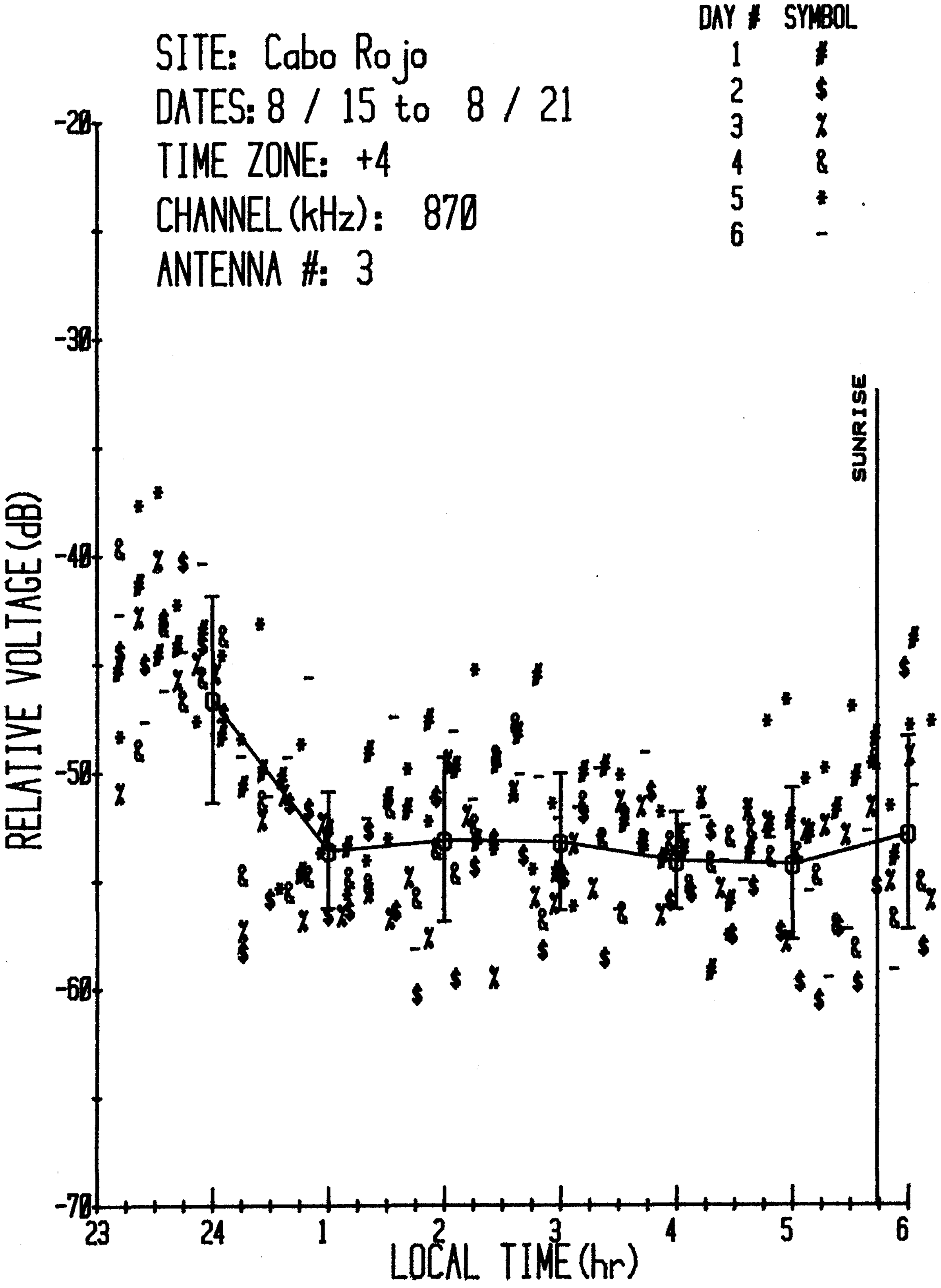

Figure A1. Daily measurements, hourly averages and standard deviations: LRA 100 kW Buenos Aires, Argentina; Beverage antenna #3, 165°T.

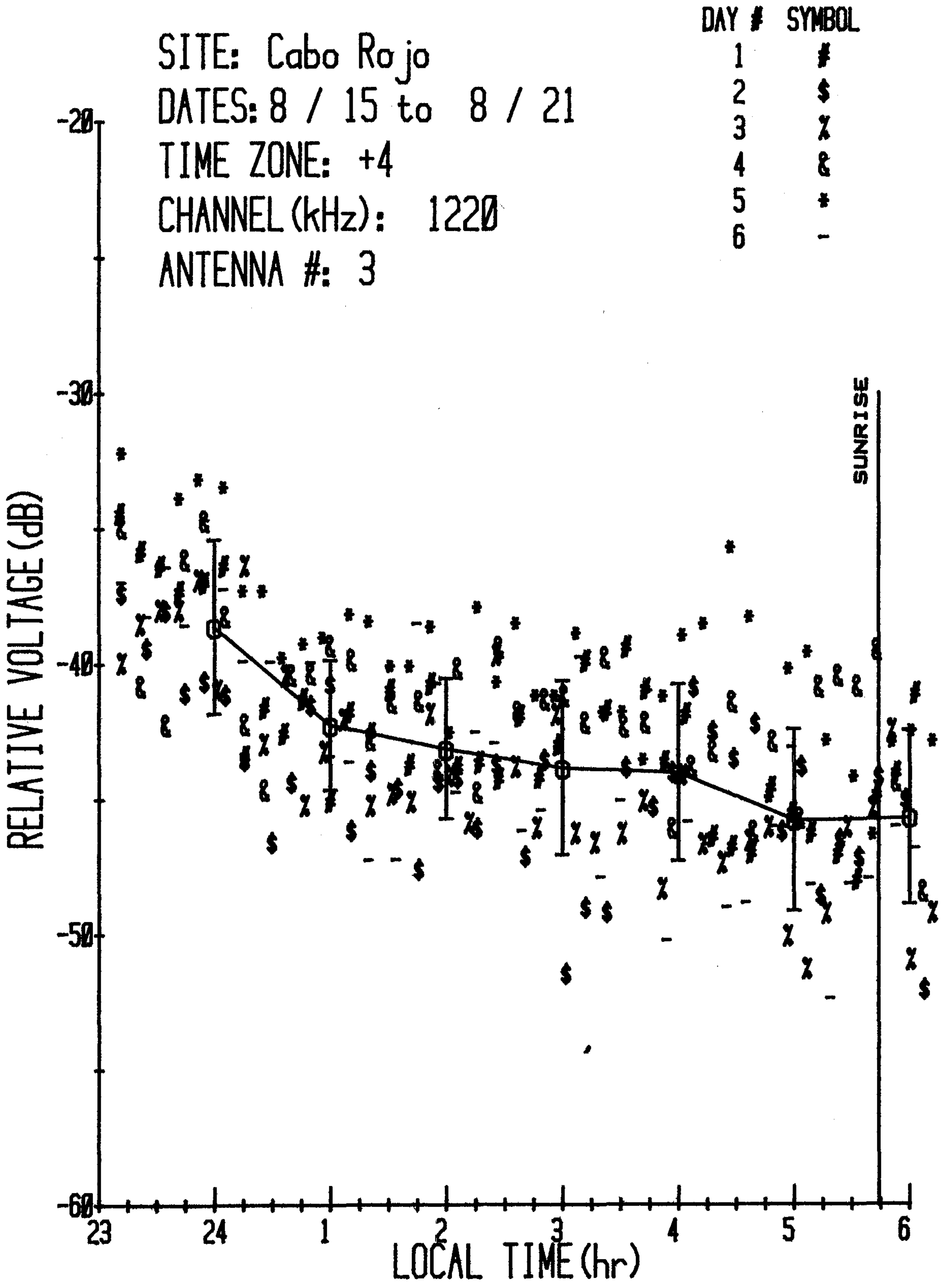

Figure A2. Daily measurements, hourly averages and standard deviations: ZYJ458 150 kW Rio de Janeiro, Brazil; Beverage antenna #3, 165°T.

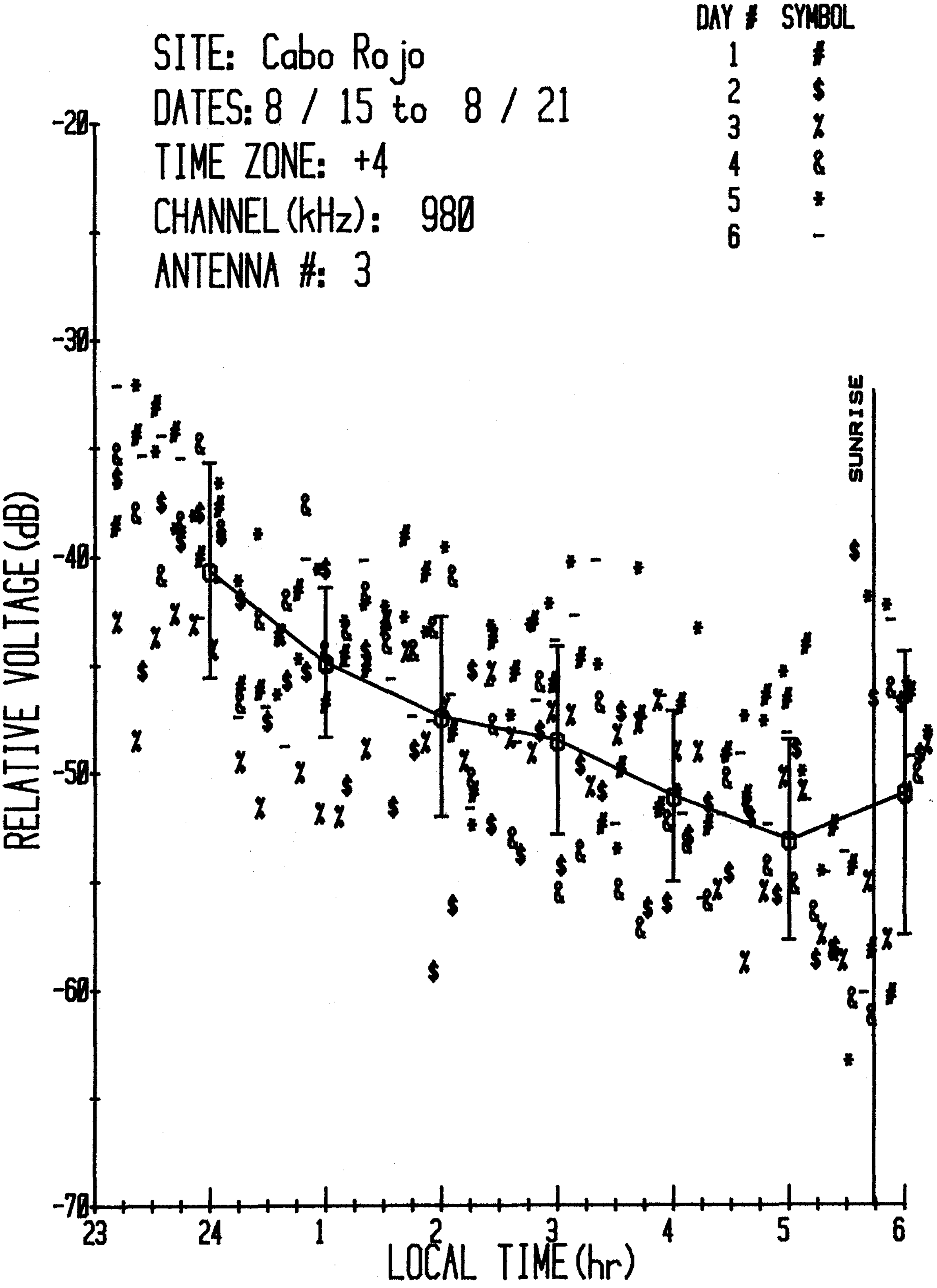

Figure A3. Daily measurements, hourly averages and standard deviations: ZYH707 600 kW Brasilia, Brazil; Beverage antenna #3, 165°T.

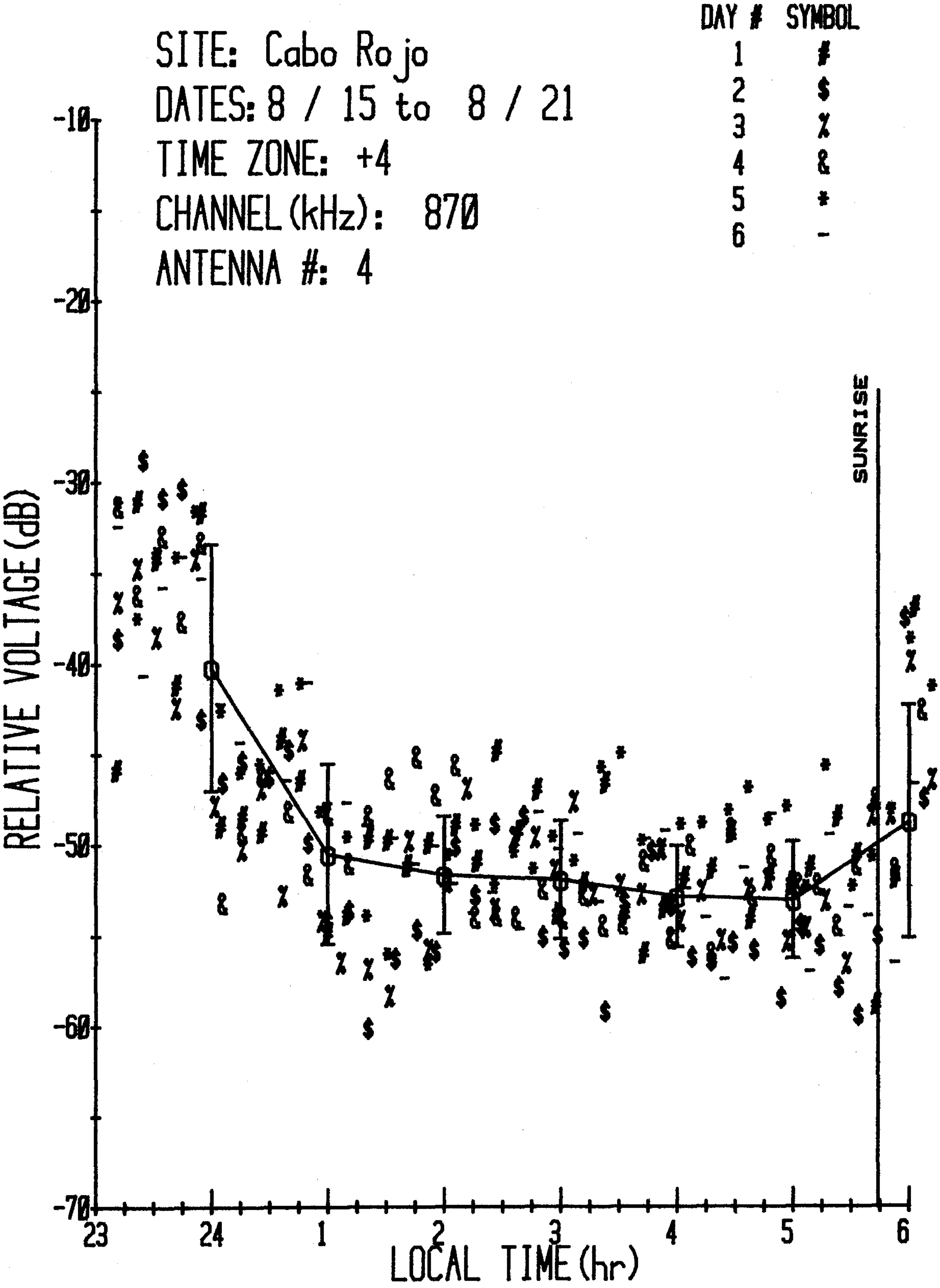

Figure A4. Daily measurements, hourly averages and standard deviations: Radio Cristal, Guayaquil, Ecuador; Beverage antenna #4, 180°T.

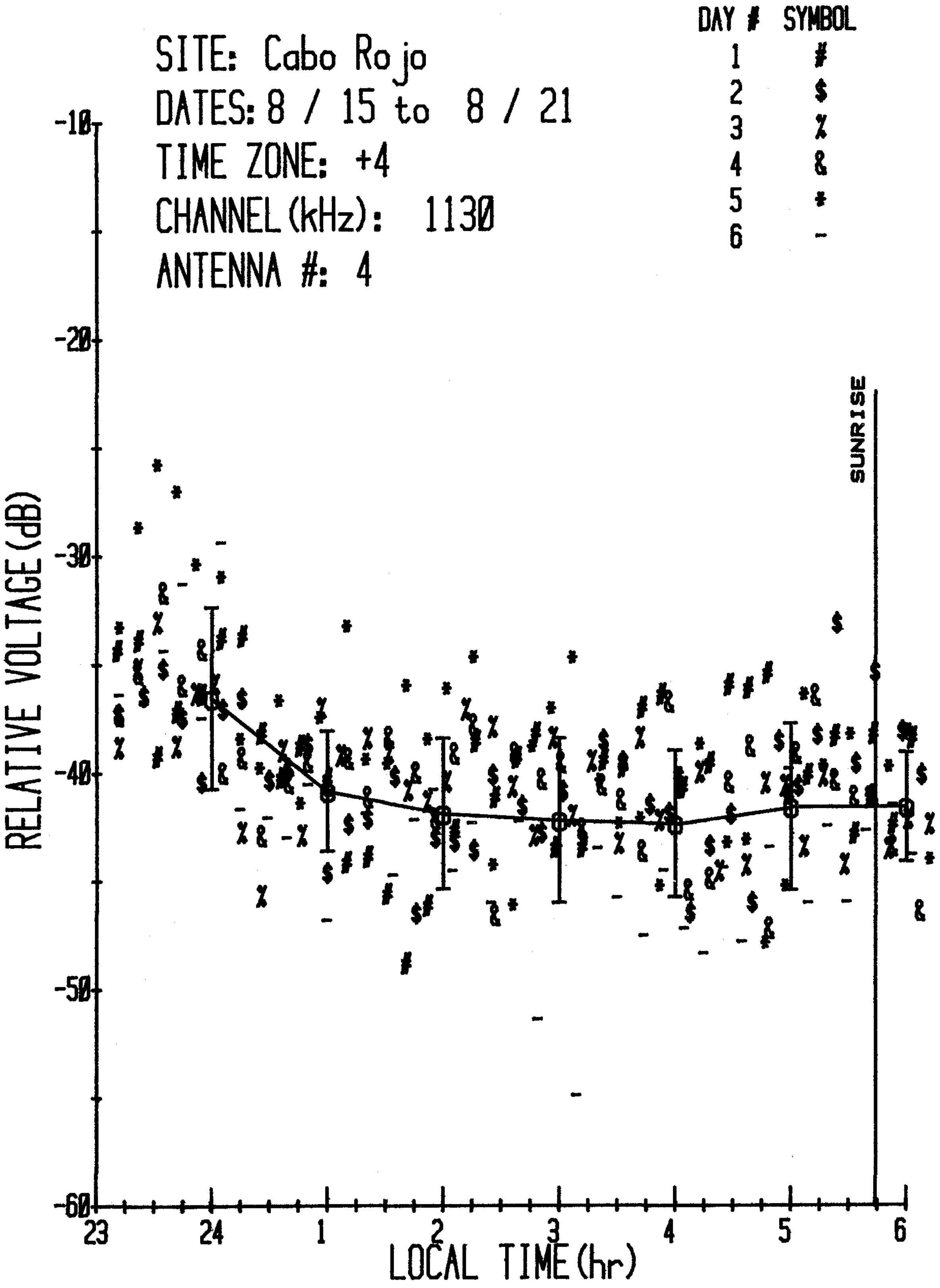

Figure A5. Daily measurements, hourly averages and standard deviations: 20 kW Bogota, Colombia; Beverage antenna #4, 180°T.

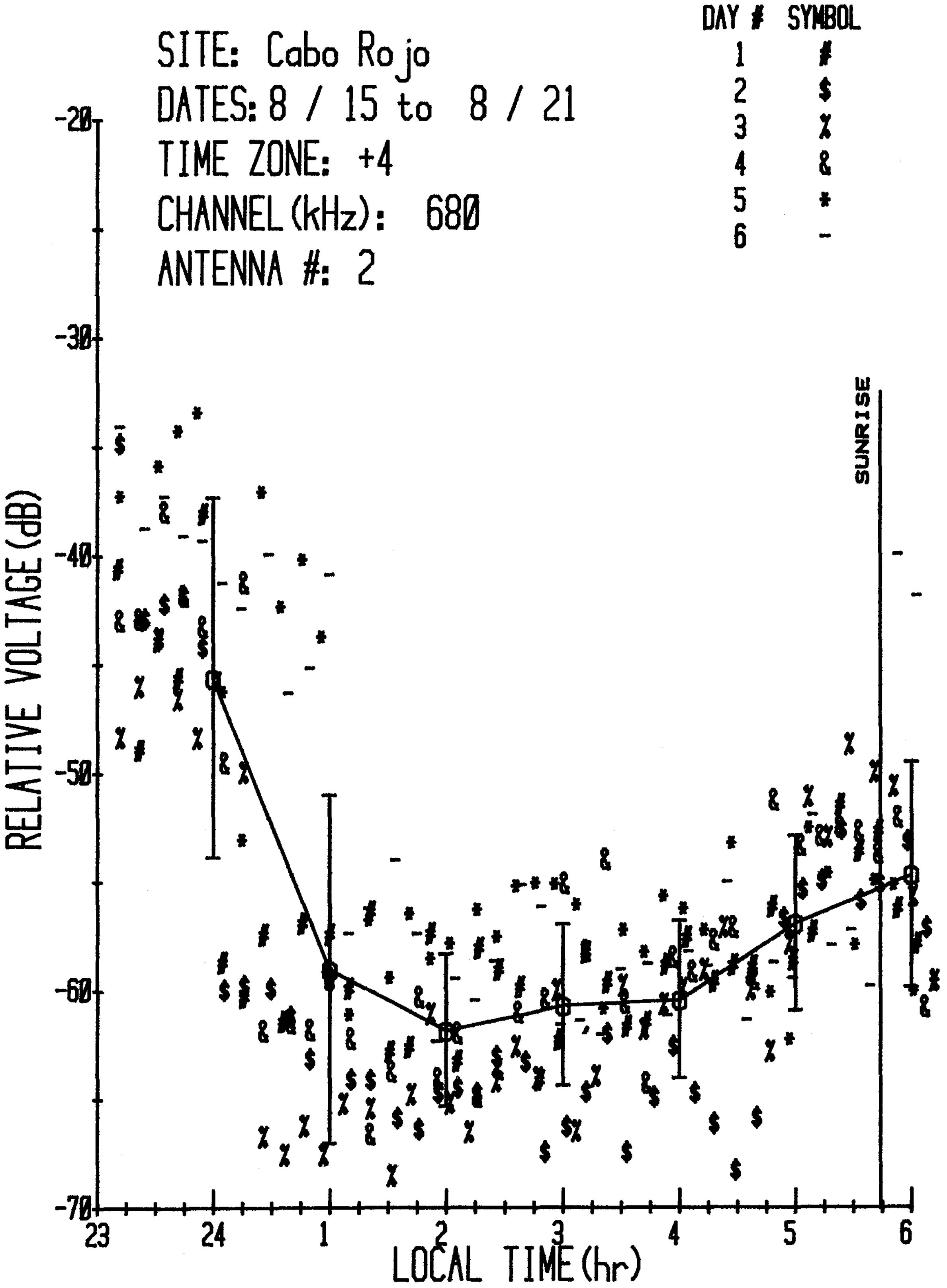

Figure A6. Daily measurements, hourly averages and standard deviations: HJBO 100 kW Zambrano, Colombia; Beverage antenna #2, 140°T.

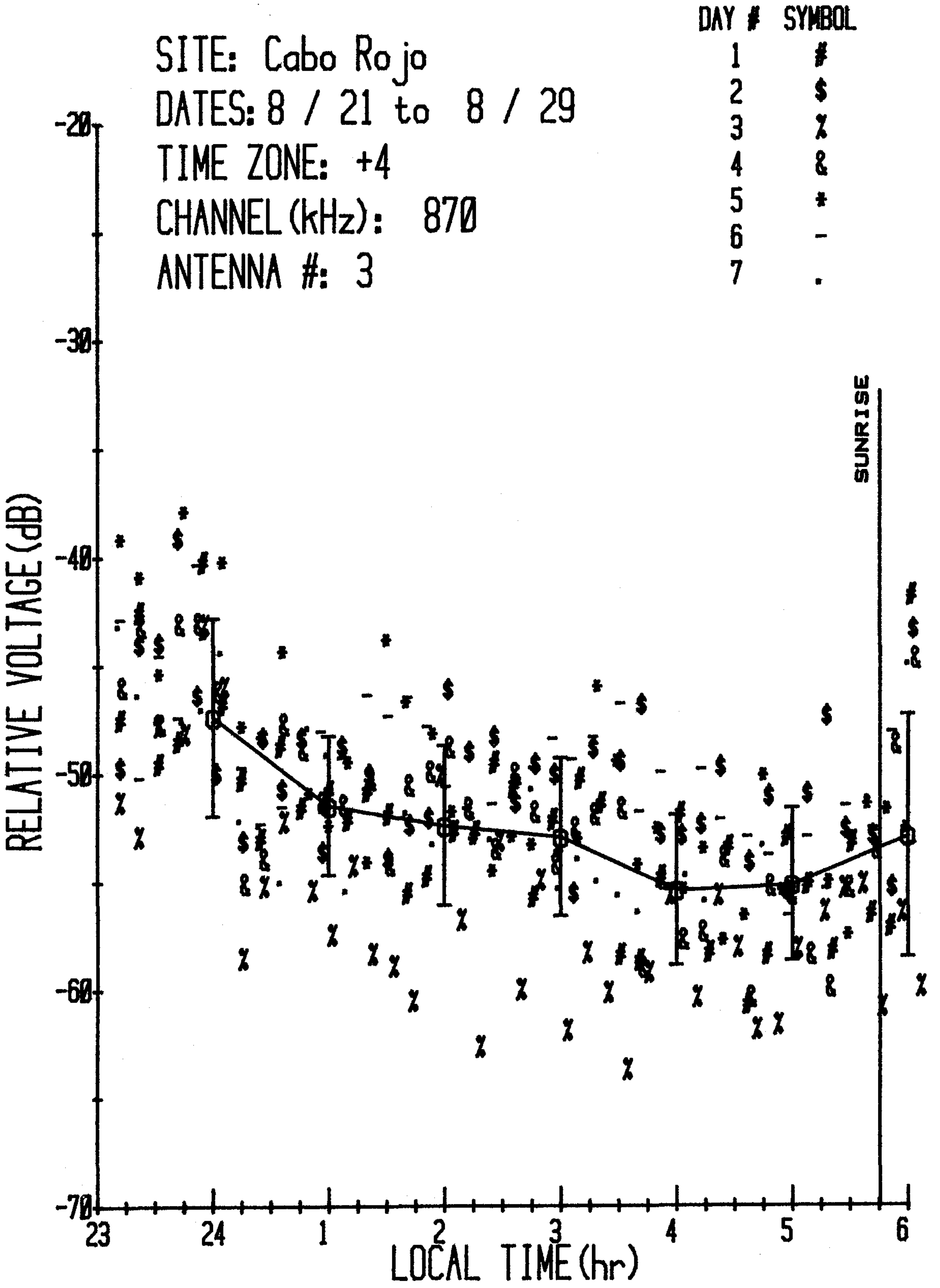

Figure A7. Daily measurements, hourly averages and standard deviations: LRA 100 kW Buenos Aires, Argentina; Beverage antenna #3, 165°T.

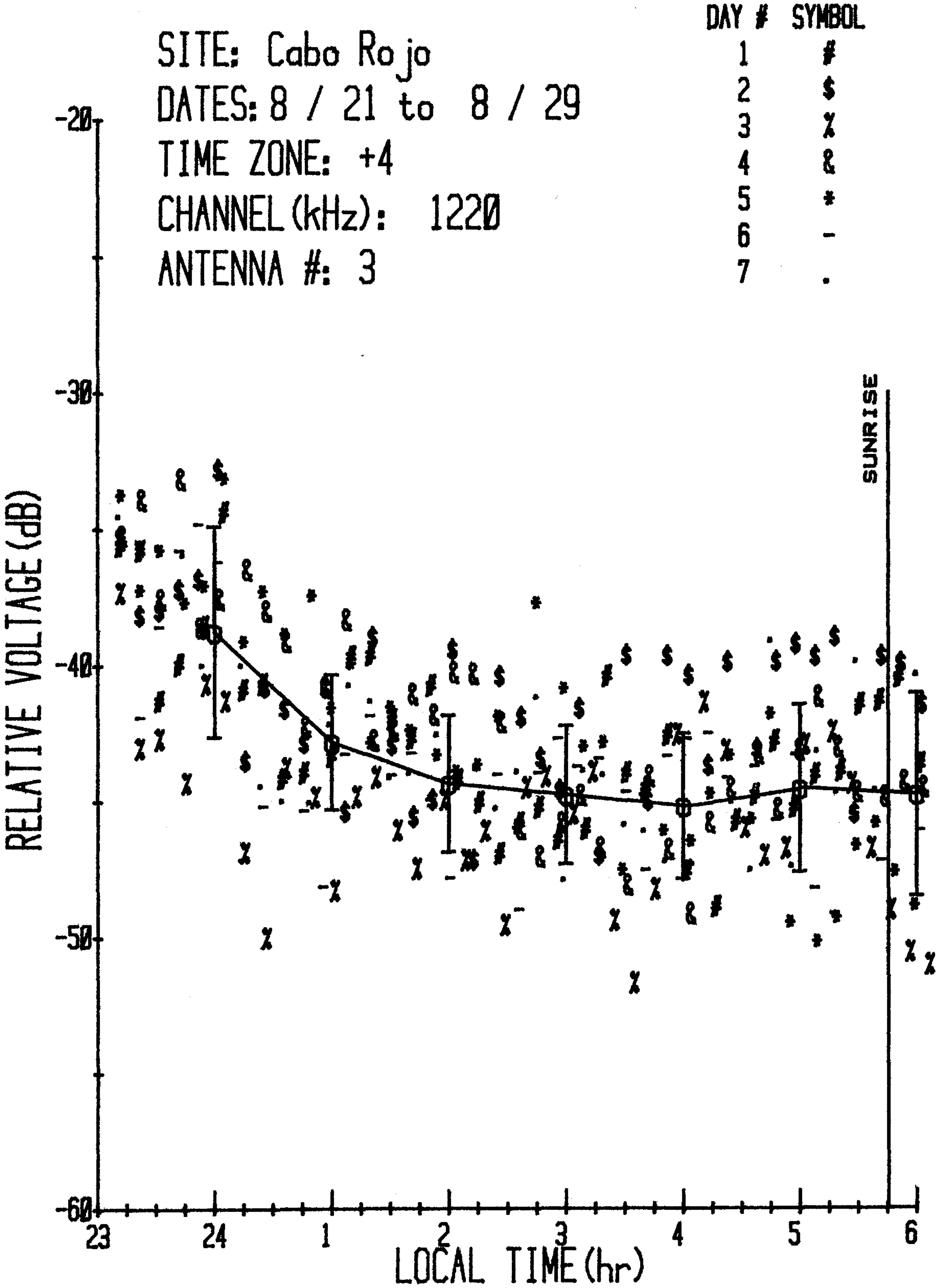

Figure A8. Daily measurements, hourly averages and standard deviations: ZYJ458 150 kW Rio de Janeiro, Brazil; Beverage antenna #3, 165°T.

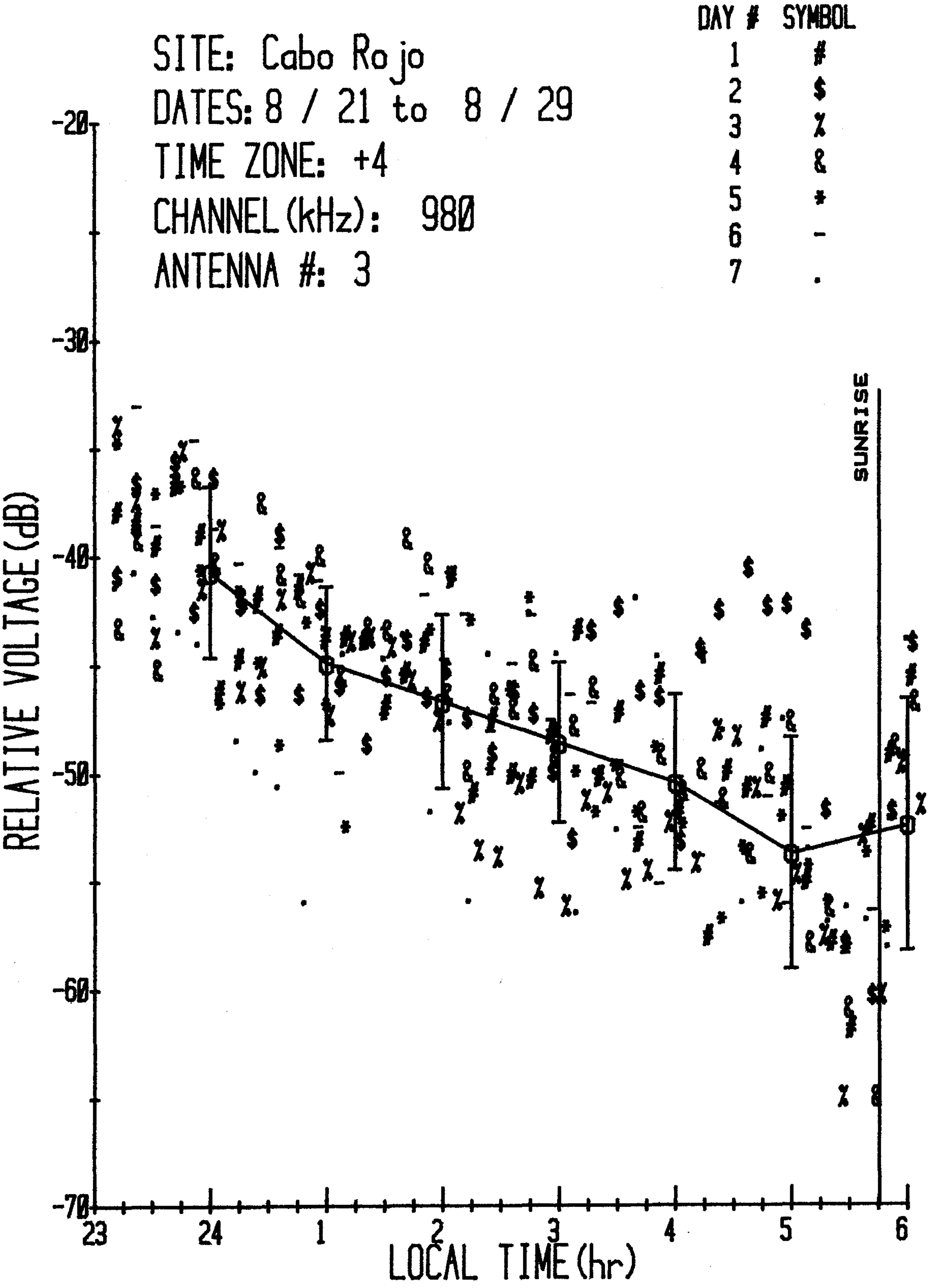

Figure A9. Daily measurements, hourly averages and standard deviations: ZYH707 600 kW Brasilia, Brazil; Beverage antenna #3, 165°T.

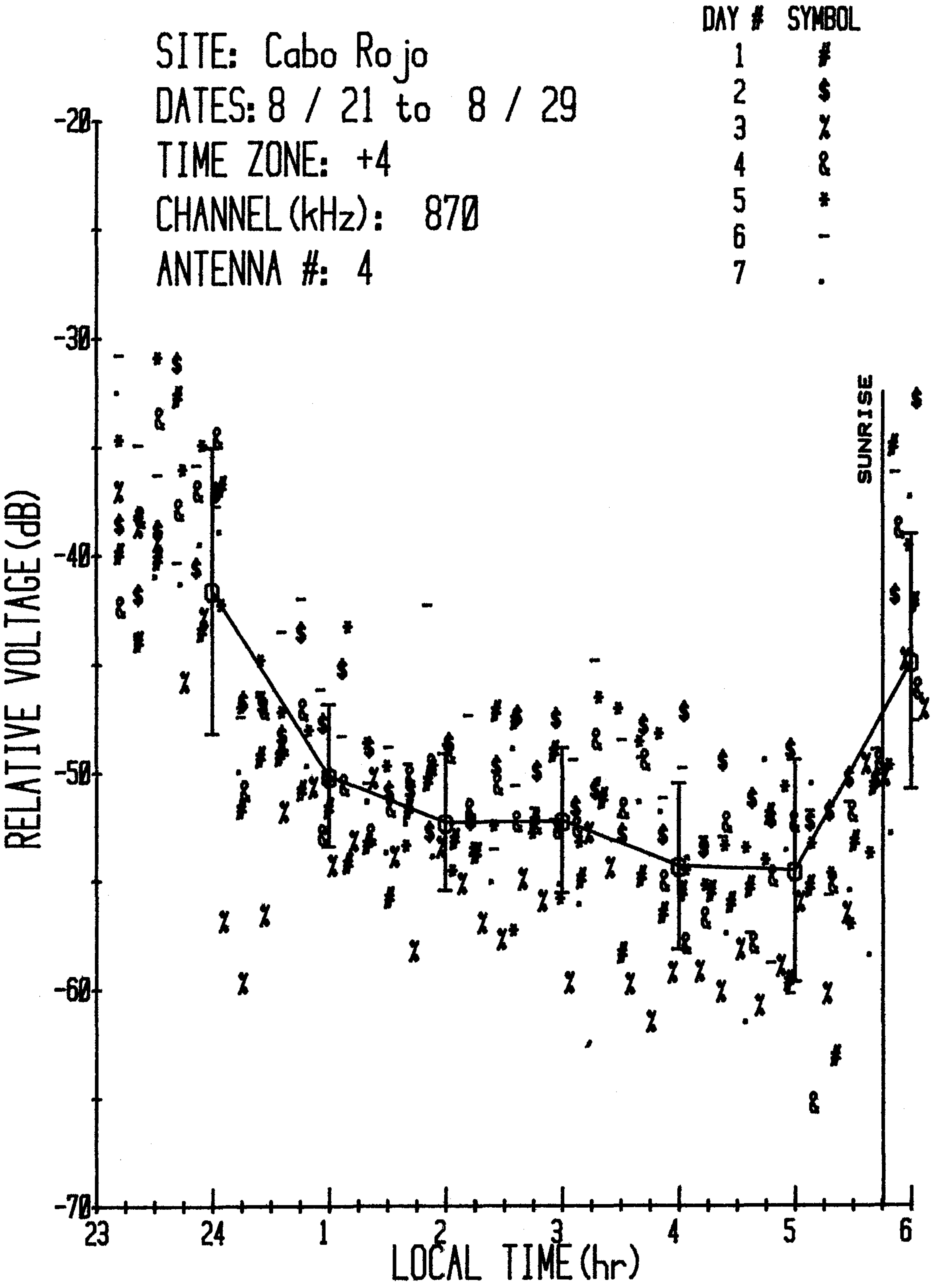

Figure A10. Daily measurements, hourly averages and standard deviations: Radio Cristal 20 kW Guayaquil, Ecuador; Beverage antenna #4, 180°T.

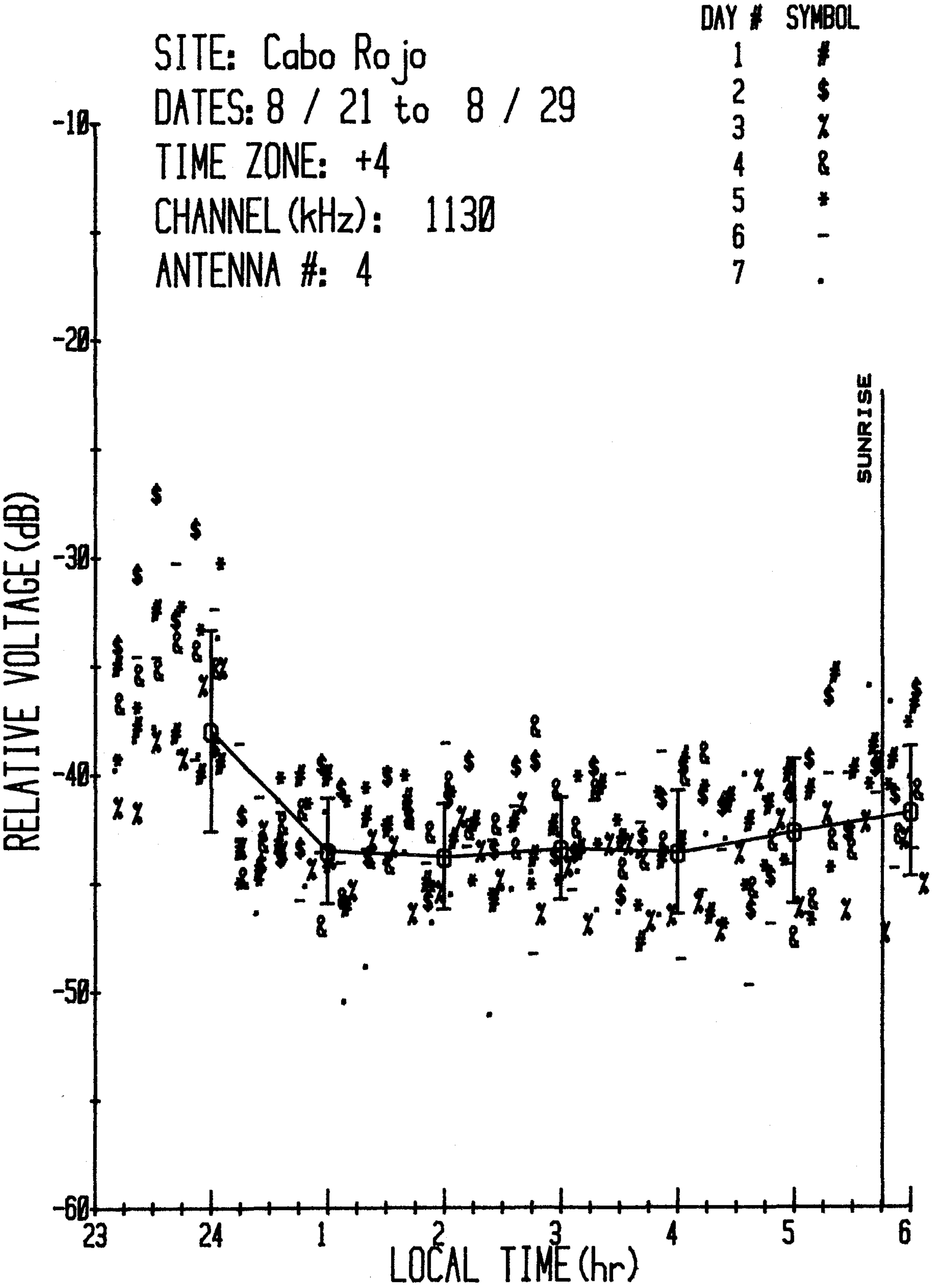

Figure A11. Daily measurements, hourly averages and standard deviations: 20 kW Bogota, Colombia; Beverage antenna #4, 180°T.

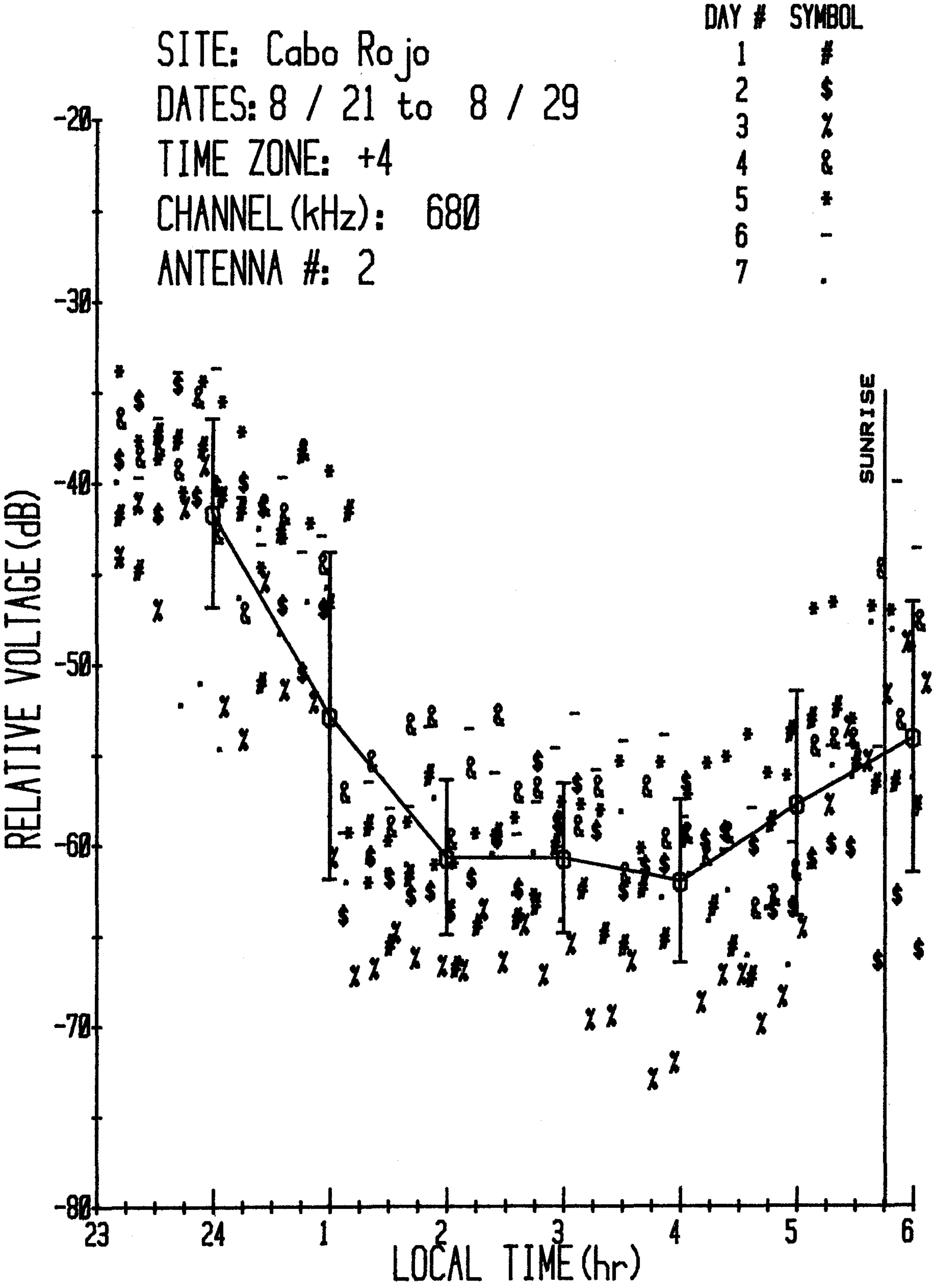

Figure A12. Daily measurements, hourly averages and standard deviations: HJBO 100 kW Zambrano, Colombia; Beverage antenna #2, 140°T.

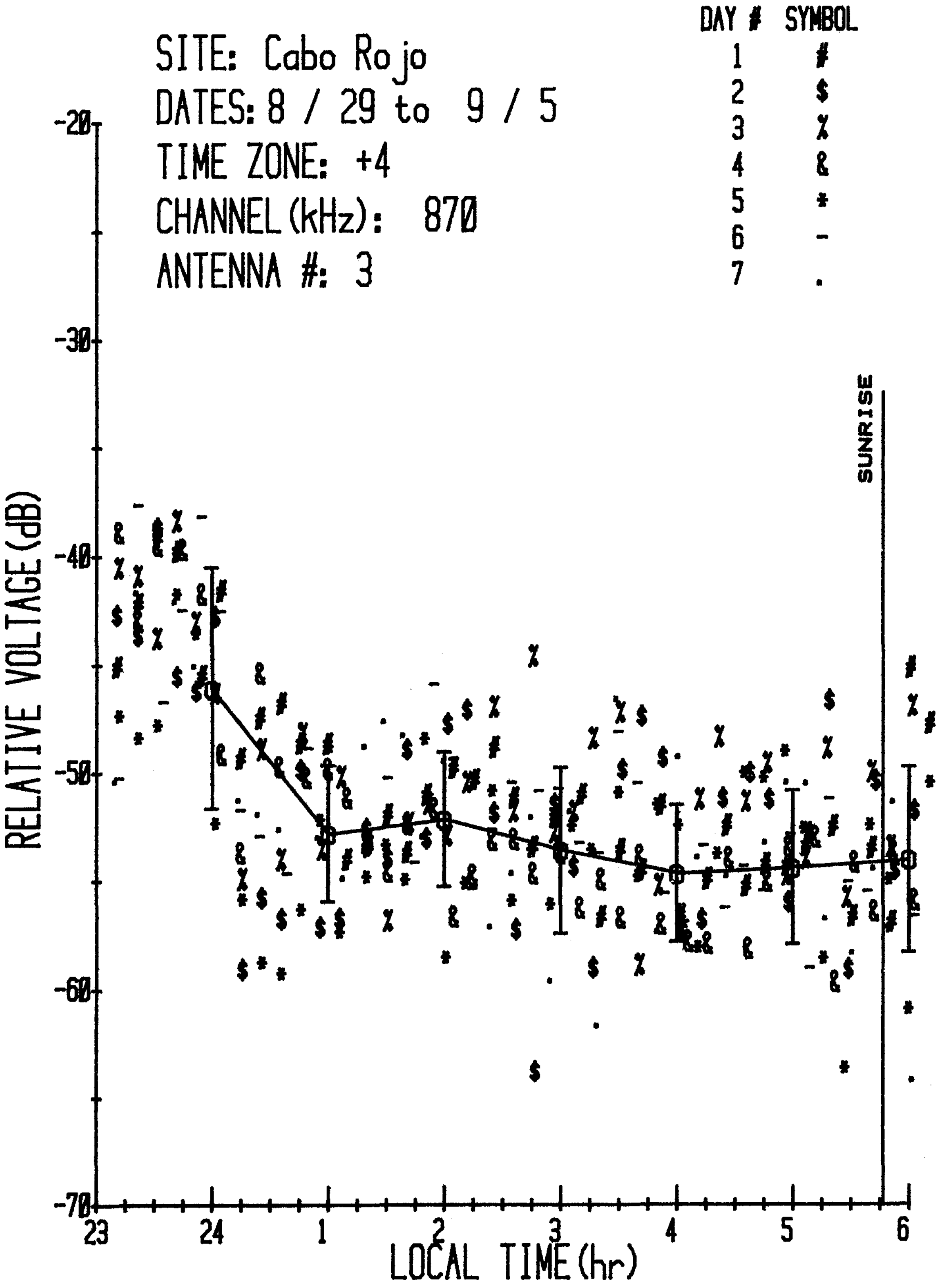

Figure A13. Daily measurements, hourly averages and standard deviations: LRA 100 kW Buenos Aires, Argentina; Beverage antenna #3, 165°T.

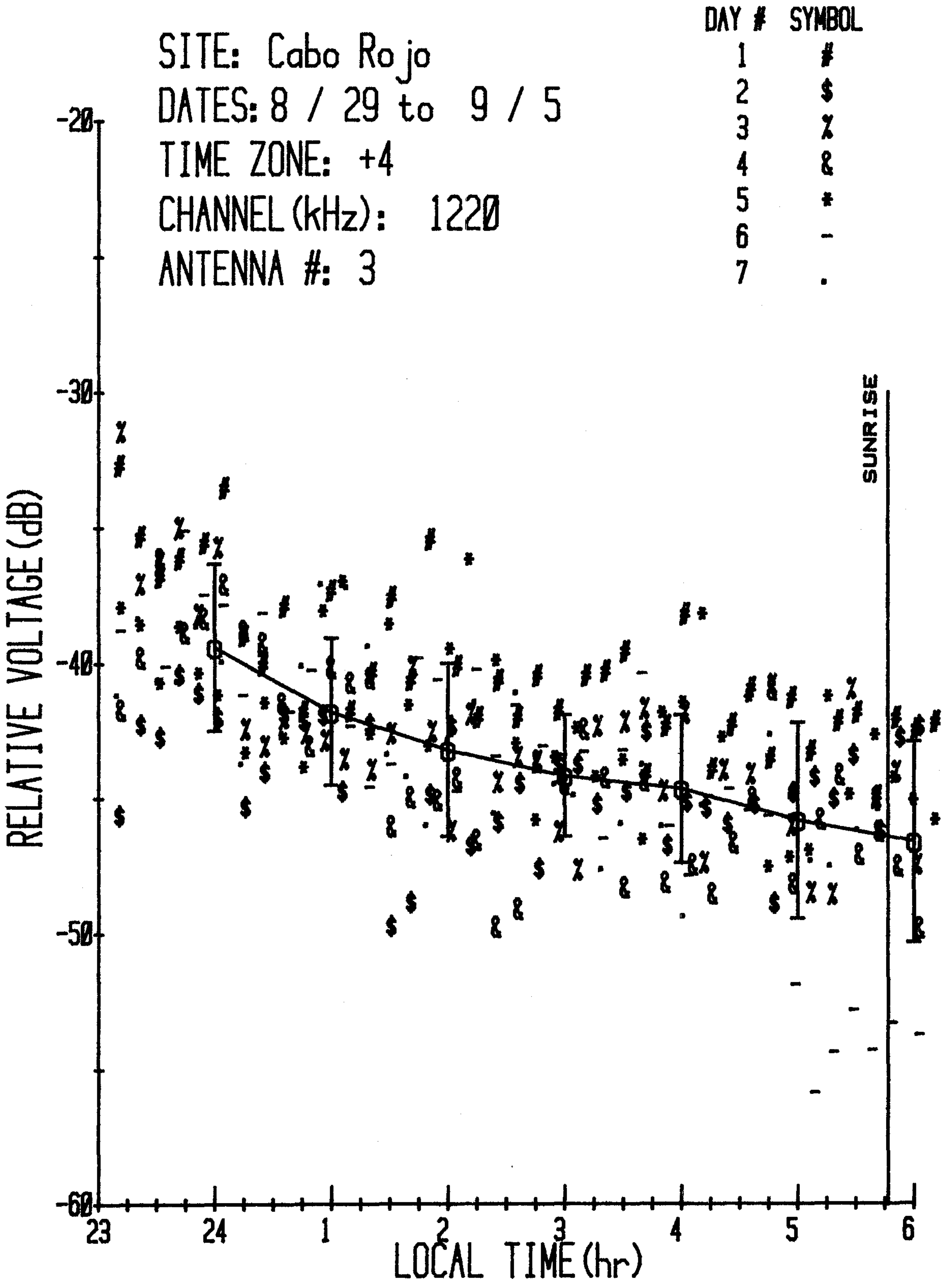

Figure A14. Daily measurements, hourly averages and standard deviations: ZHJ458 150 kW Rio de Janeiro, Brazil; Beverage antenna #3, 165°T.

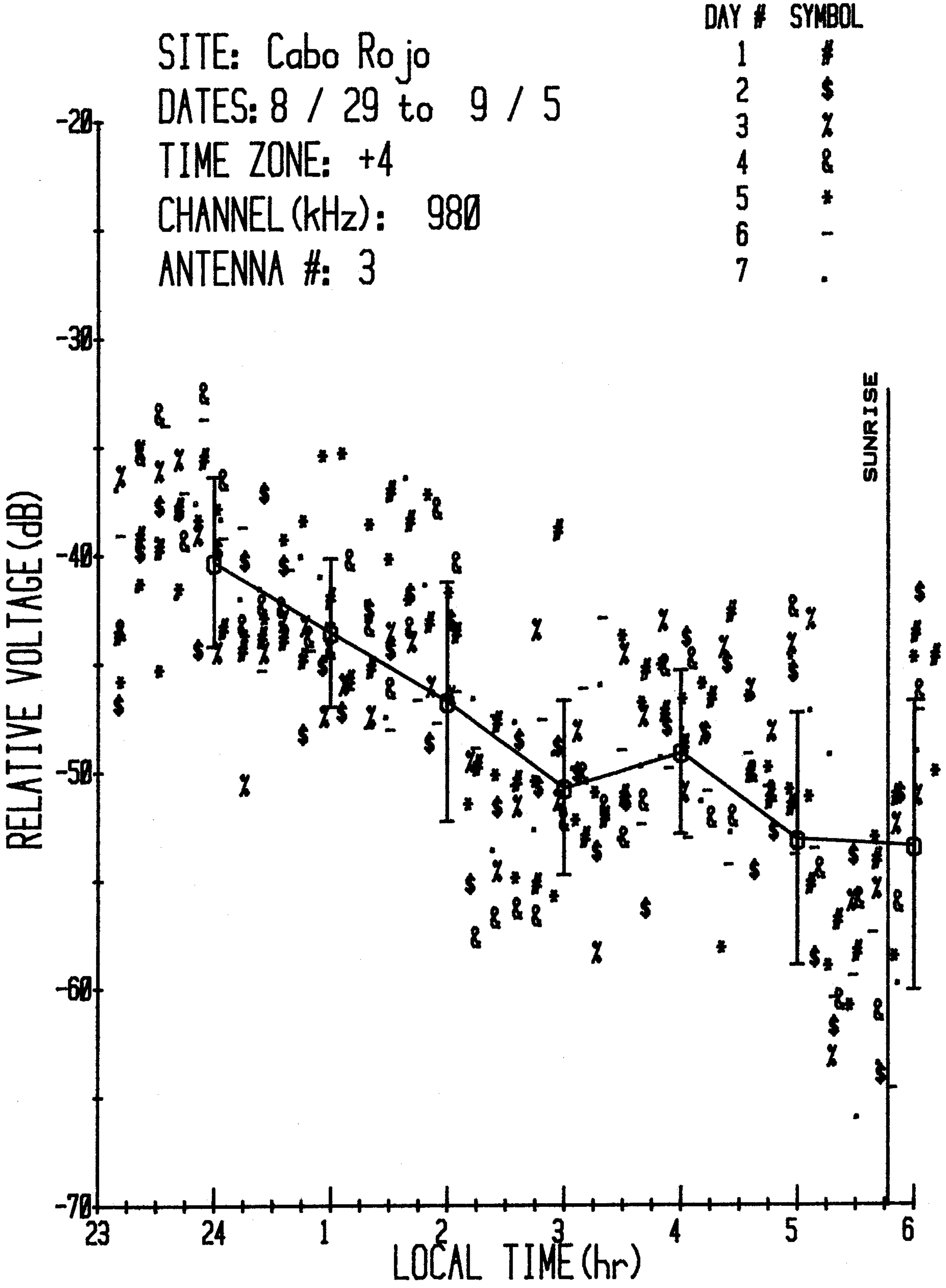

Figure A15. Daily measurements, hourly averages and standard deviations: ZYH707 600 kW Brasilia, Brazil; Beverage antenna #3, 165°T.

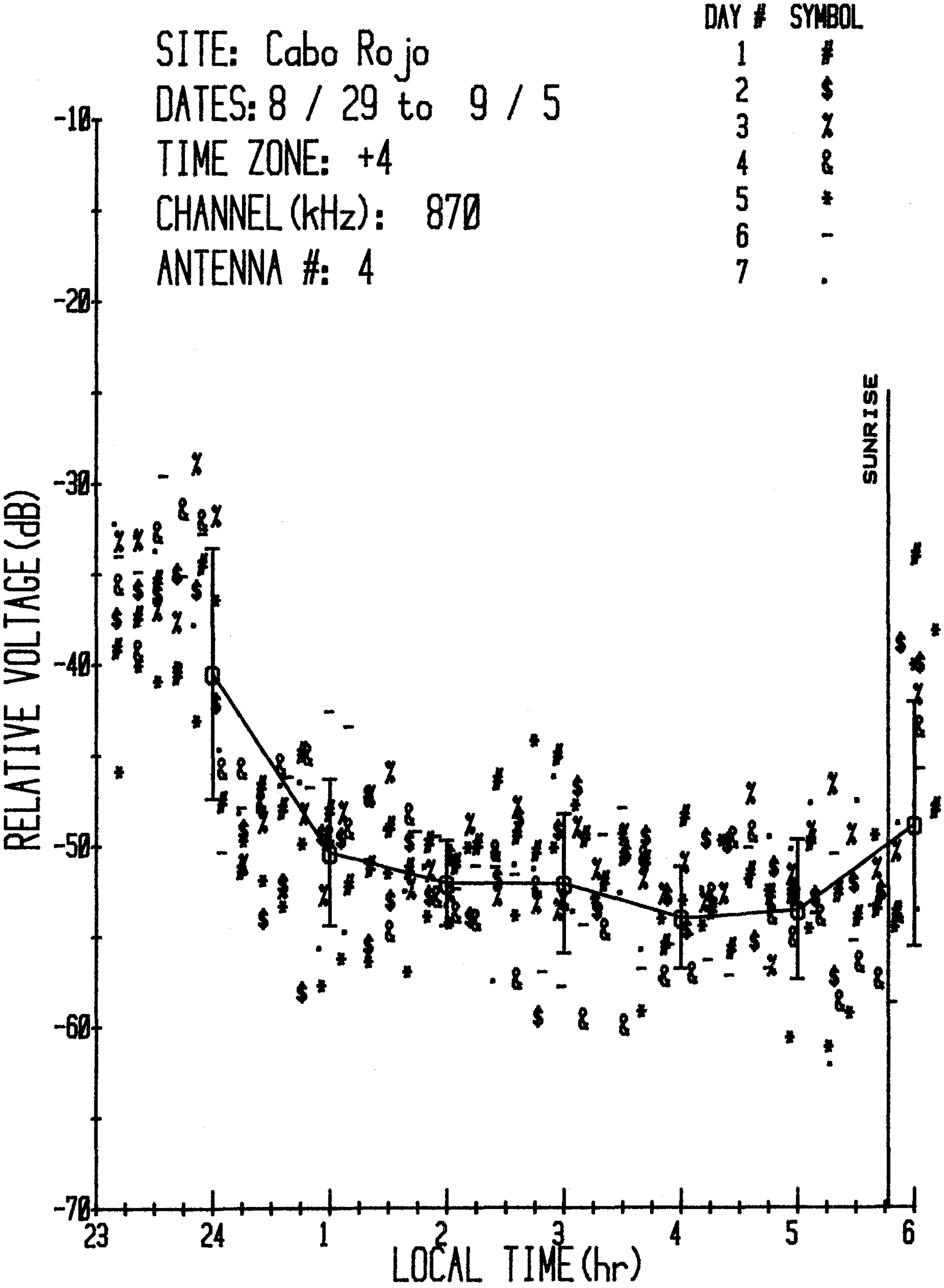

Figure A16. Daily measurements, hourly averages and standard deviations: Radio Cristal 20 kW Guayaquil, Ecuador; Beverage antenna #4, 180°T.

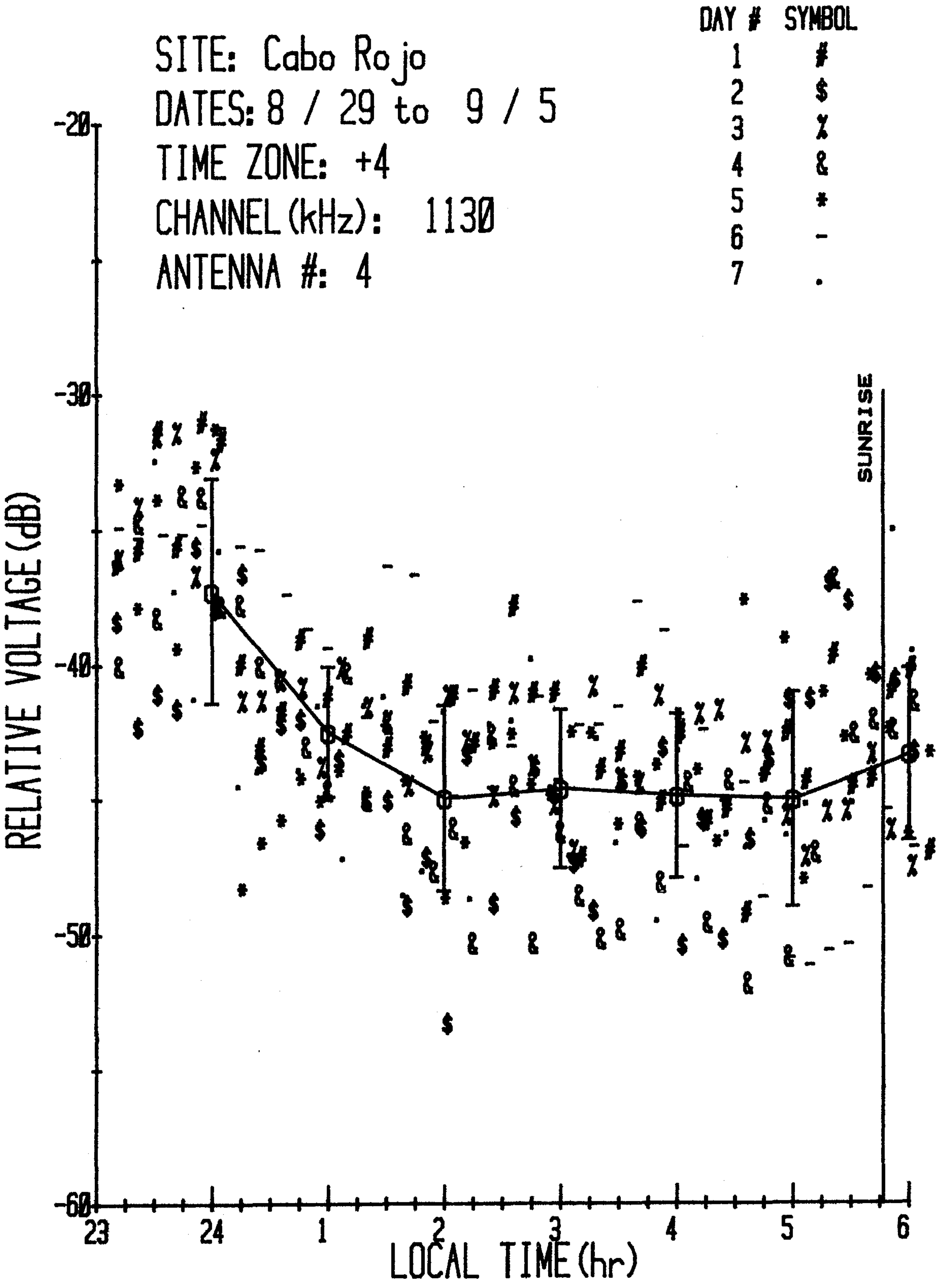

Figure A17. Daily measurements, hourly averages and standard deviations: 20 kW Bogota, Colombia; Beverage antenna #4, 180°T.

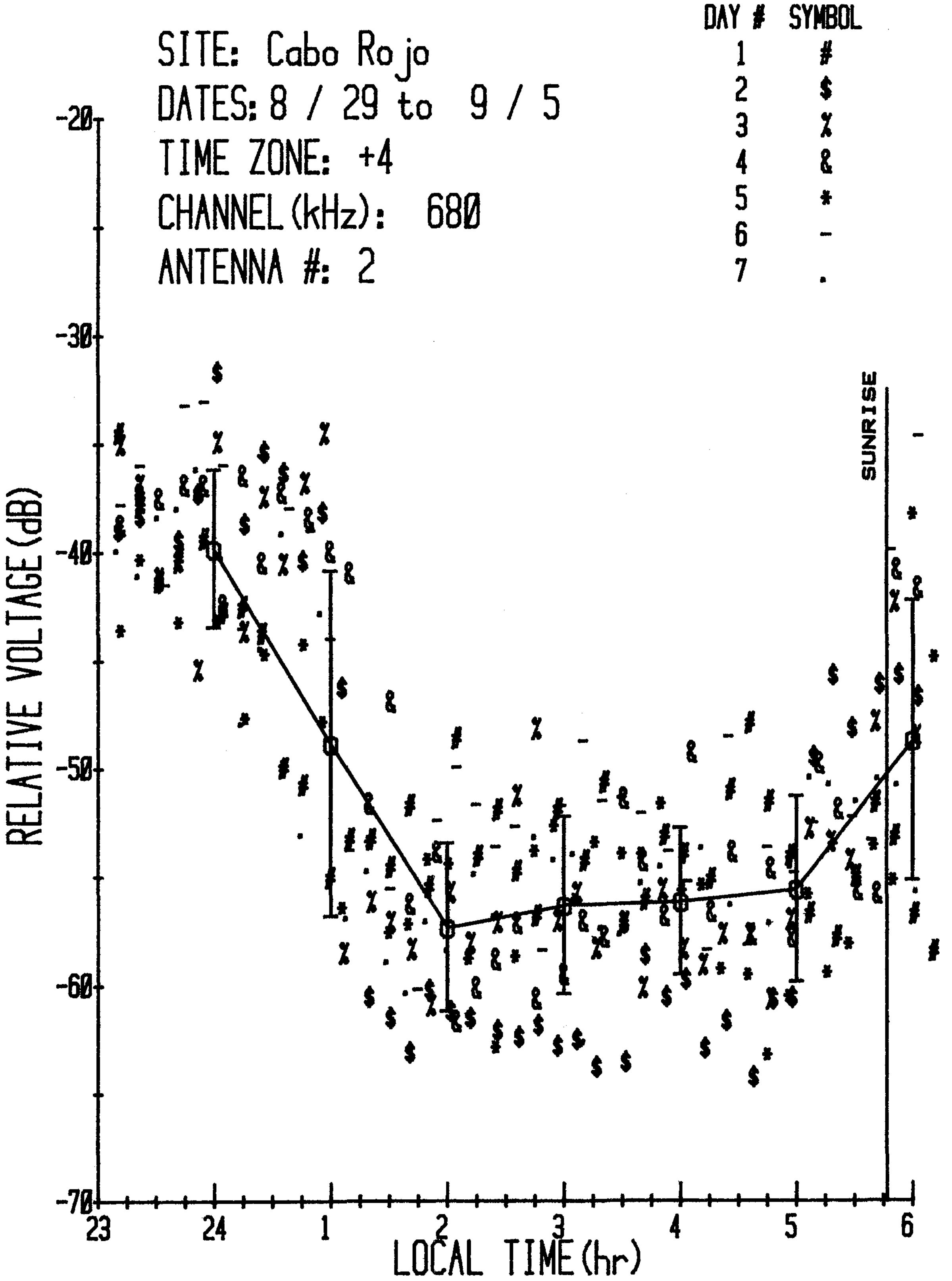

Figure A18. Daily measurements, hourly averages and standard deviations: HJBO 100 kW Zambrano, Colombia; Beverage antenna #2, 140°T.

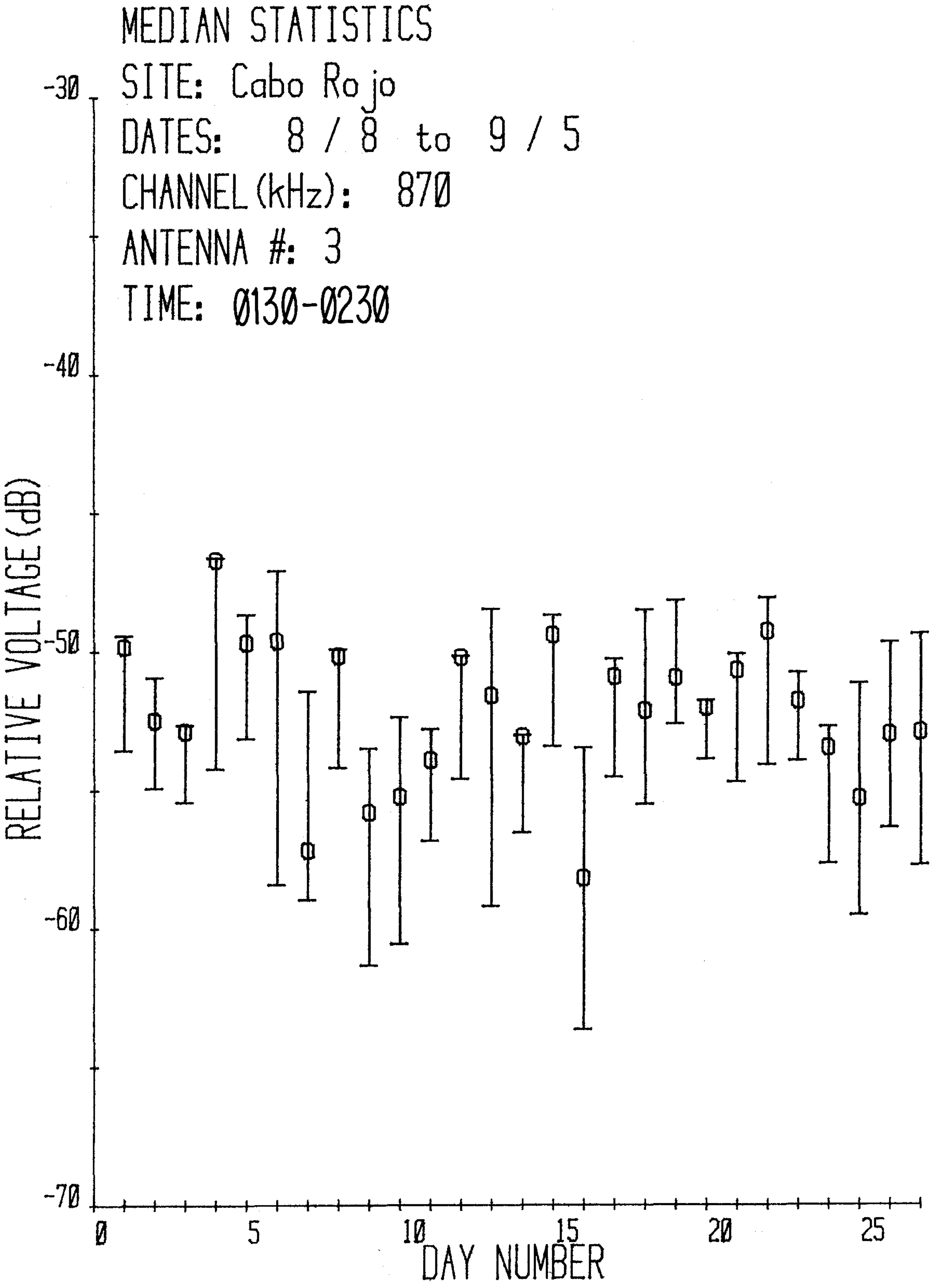

Figure A19. Hourly medians, upper and lower deciles: LRA 100 kW Buenos Aires, Argentina; Beverage antenna #3, 165°T.

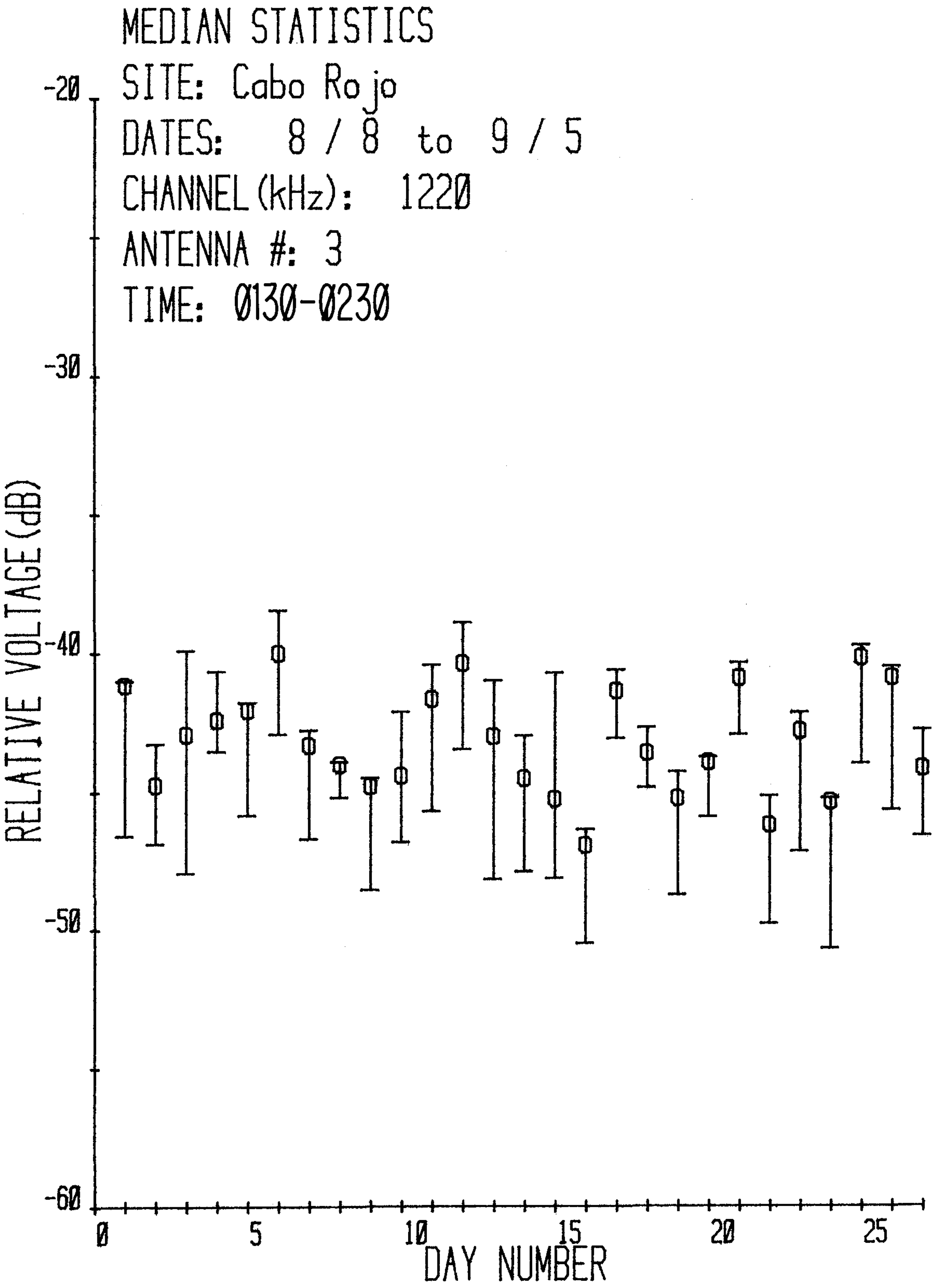

Figure A20. Hourly medians, upper and lower deciles: ZYJ458 150 kW Rio de Janeiro, Brazil; Beverage antenna #3, 165°T.

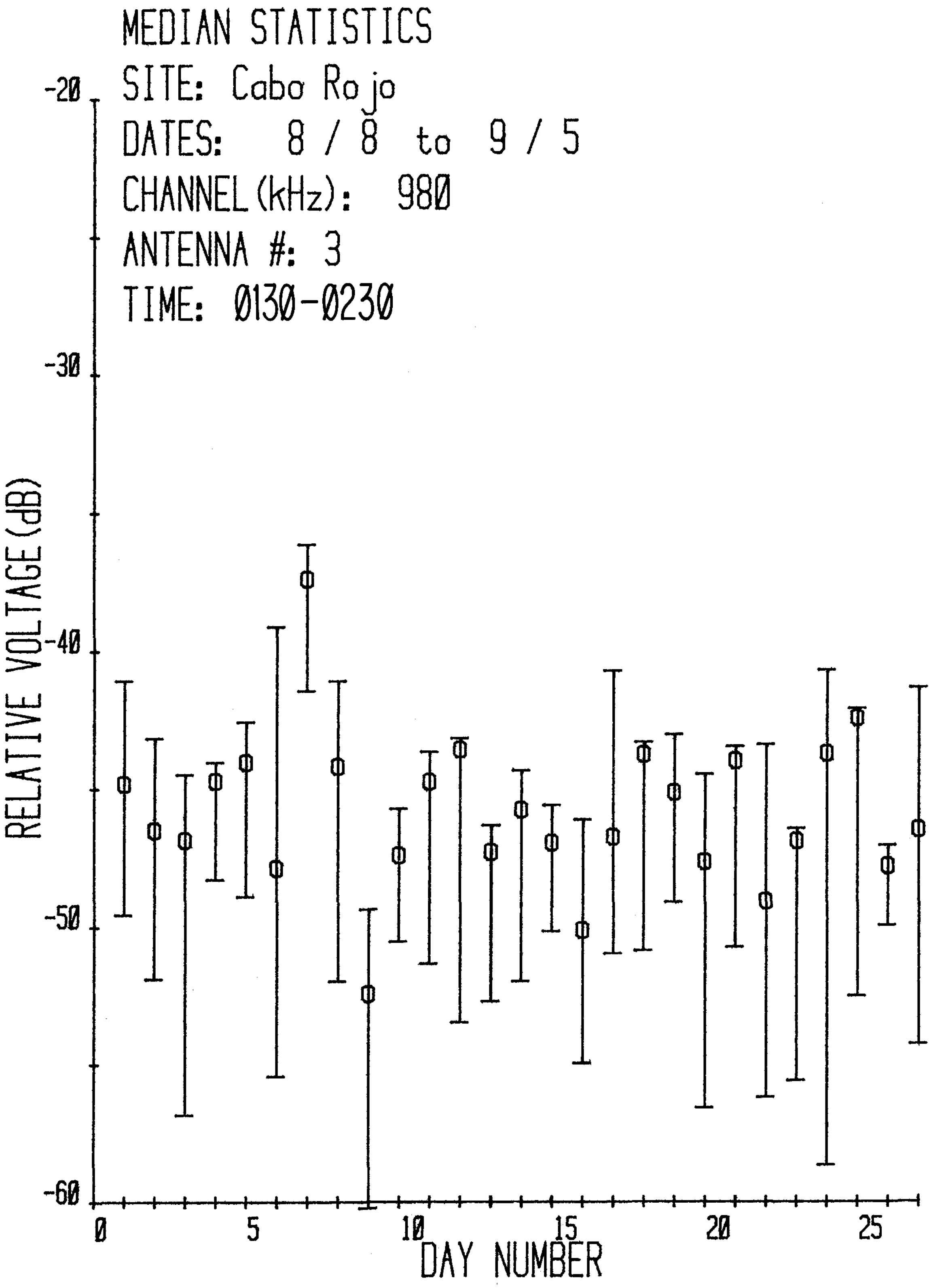

Figure A21. Hourly medians, upper and lower deciles: ZYH707 600 kW Brasilia, Brazil; Beverage antenna #3, 165°T.

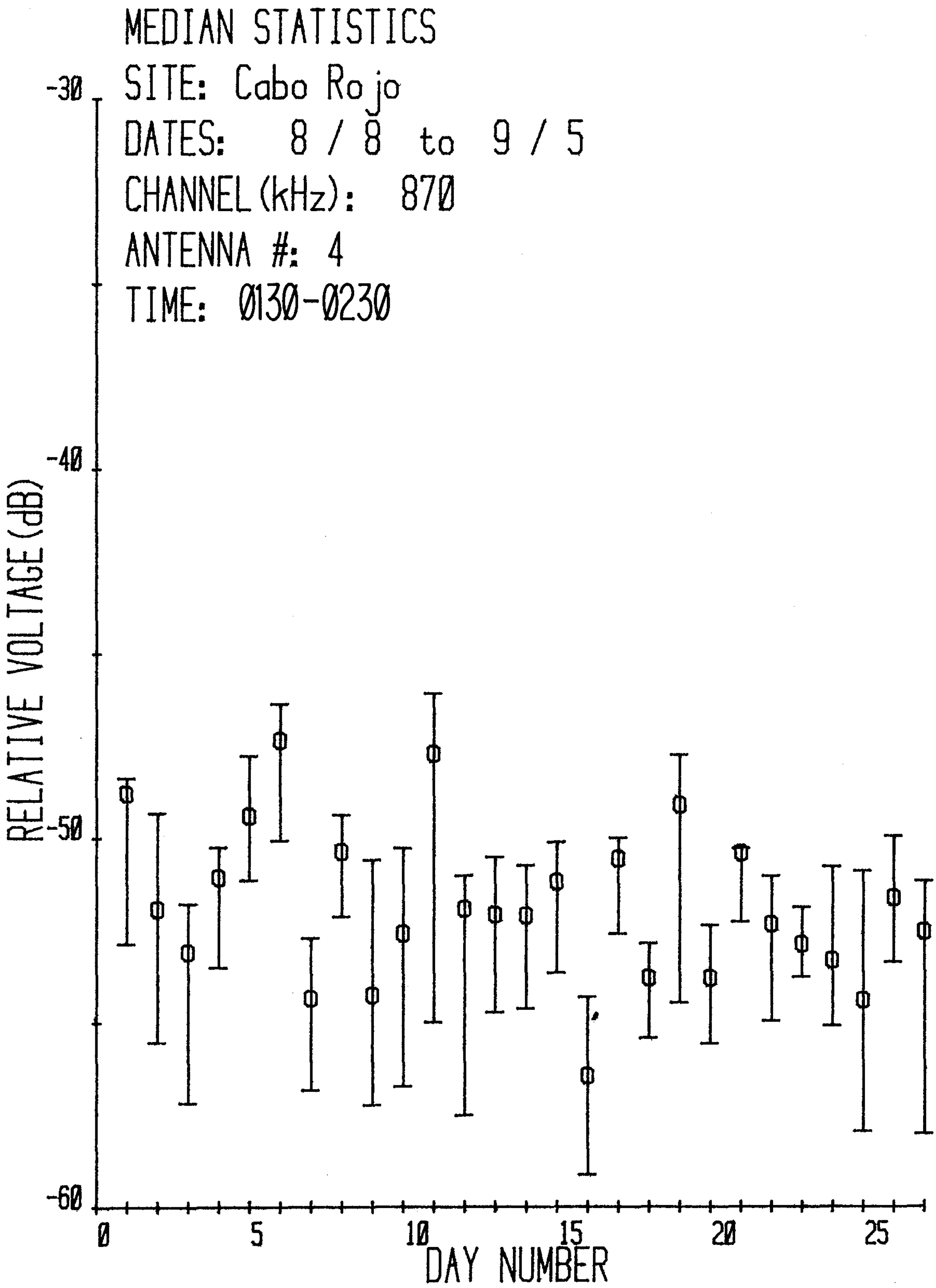

Figure A22. Hourly medians, upper and lower deciles: Radio Cristal 20 kW Guayaquil, Ecuador; Beverage antenna #4, 180°T.

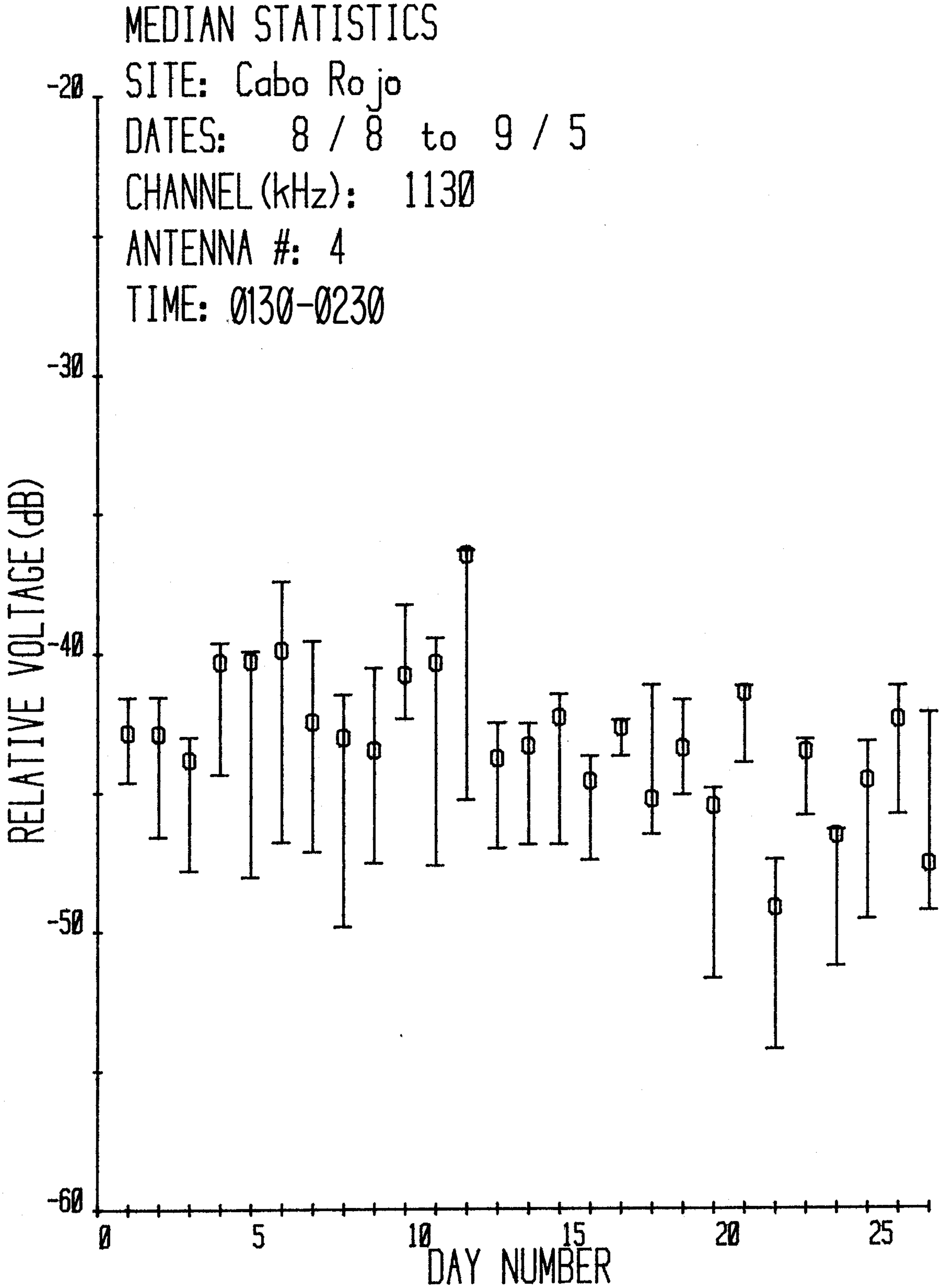

Figure A23. Hourly medians, upper and lower deciles: 20 kW Bogota, Colombia; Beverage antenna #4, 180°T.

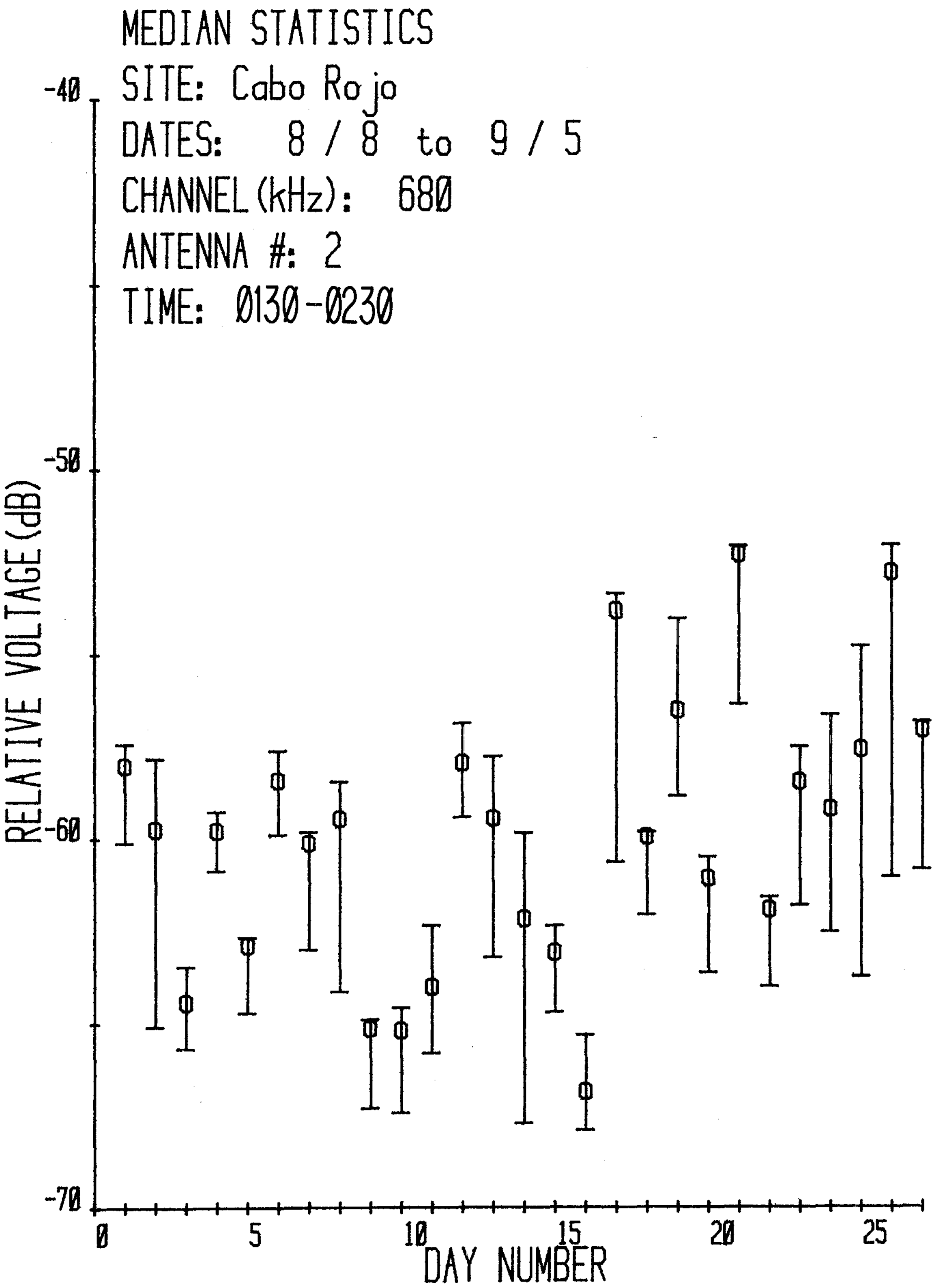

Figure A24. Hourly medians, upper and lower deciles: HJBO 100 kW Zambrano, Colombia; Beverage antenna #2, 140°T.

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The Institute for Telecommunication Sciences has embarked upon a program to improve the techniques that are used to determine medium frequency broadcasting parameters. This work is motivated by the fact that increased transmitter power which is planned by a number of Administrations in the Western Hemisphere could seriously impact MF broadcast service areas in the United States by giving rise to unacceptable interference levels. In order to provide a technically accurate tool for use in asssessing the performance of MF broadcast operations, efforts have been undertaken to develop a capability to determine the broadcast service area, taking into account both groundwave and skywave modes of propagation. In addition, a program of monitoring long distance skywave signals has been initiated as part of a joint NTIA/FCC endeavor. These long-distance signals will be used to form the basis for changes in existing MF skywave prediction programs.

16. Key Words *(Alphabetical order, separated by semicolons)*

AM analysis model; MF broadcasting; MF interference; MF prediction methods; MF skywave signal observations

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