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AN ATLAS OF REDUCED DATA
OBTAINED IN A COOPERATIVE HF DIRECTIONAL
PROPAGATION EXPERIMENT OVER A 1330 KILOMETER PATH
(MARCH 1967 — MARCH 1968)

by

ALBERT D. BAILEY
EDWARD W. ERNST
LEON J. MILLER
WALTER W. WOOD

RAL PUBLICATION NO. 344

September 1968

Technical Report No. 7
Contract N00014-67-A-0306-0002

Supported by:
Office of Naval Research
and the
Naval Electronics Systems Command

RADIOLOCATION RESEARCH LABORATORY
DEPARTMENT OF ELECTRICAL ENGINEERING
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

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Radiolocation Research Laboratory
Department of Electrical Engineering
Engineering Experiment Station
University of Illinois
Urbana, Illinois

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A radio direction finder is a device which is used to measure the direction of arrival of radio waves as received. Sometimes the measured angle of arrival coincides with the great circle line of travel between the signal source and the receiver and, for these times, there is no problem. There are many other times when the measured angle of arrival as received or the measured bearing is, hopefully, close to the bearing of the source and then there is a problem. The report that is contained here speaks to the latter problem as it exists in the high frequency band.

Radio direction finding has a long history. One could state that the radio science was born in 1887 at the time of Hertz's experiments. Direction finding devices were being patented at least as early as 1899. Various instruments and systems have been developed and improved upon during the ensuing 70 year period. The majority of the improvements have been made in the radio direction finding instrument itself and the instrumental errors are, or can be made, vanishingly small. However, a corresponding degree of improvement in overall accuracy of measurement in the high frequency band (3-30 mHz) has not been realized; the reason given is, "we are being limited by the propagation errors".

The cooperative directional propagation experiment to be described here had a degree of control that probably has not been possible in any prior experiment. It required the cooperation of several large agencies to provide the reduced data which are shown.

The set of data provides to the designers and users of radio direction finders good, lengthy, and representative examples of the directions of arrival of radio waves as received under realistic conditions of
ionospherically propagated signals over an intermediate range path.

The set of data permits one to make correlations with other recorded
time coincident ionospheric events which occurred during the times of
observation and which may, therefore, be significant.

The set of data has been found to be useful independently in its
own context. Selected cases have already demonstrated that present
theories on ionospheric propagation, currently available 3-D ray tracing
programs and measured ionograms obtained in the neighborhood of the
region of wave interaction all lead to consistent results. This is
evolved by the very close agreement between reconstructed angles of
arrival for a given time and those actually measured.

We have, for good and apparent reasons, resisted the strong desire
to infer what is happening at many instances of time. Some of these
"D.F. events" have been studied and reported by Dr. R. M. Jones of ESSA
and Dr. N. Rao of this laboratory. Our graduate students are already
involved in other aspects.

One may close by saying, "another torch has been lit and it is
hoped that its rays will illuminate the problem area in HF directional
propagations so that optimum solutions may be seen".
ACKNOWLEDGEMENT

The successful operation of a directional propagations experiment performed on the scale of this experiment depends upon the cooperative, untiring and persistent efforts of many people working together at their appointed tasks for a common goal. The experiment embraced the area of the USA east of the Great Divide. It is practically impossible to name all of the people within this area who contributed to the outcome of the experiment. We will attempt to name those who were immediately involved in the University of Illinois - University of Houston path.

The target transmitter and oblique incidence transmitters at the University of Houston transmitting station were supervised by Dr. Thomas Whitaker of the Department of Electrical Engineering. Mr. Samuel Anzelmo, research assistant, operated the equipment.

The path midpoint C-4 type ionosonde station near Jacksonville, Arkansas was operated by Lt. Col. (ret.) Frank Jenkins.

The receiving station (RDF station s.w. of Bondville, Illinois) required many services. System operators and station watch standers were: Eric Anderson, David Bates, Roy Beckwith, John Huff, Donald Jeanblanc, Frank Luksander, Jack Miller, Mike Rice, and Walter Wood.

Mr. Stanley Bengtson maintained and operated the vertical incidence ionosonde equipment and the oblique incidence receiving equipment.

Mr. William C. McClurg supervised the digital data recording system at the receiving site.

The reduction of the recorded data by the G-20 digital computer was directed by Dr. Edward Ernst. Mr. Roger Vossler supervised the computer operation and prepared the data files. Mr. Edward Cox prepared the CALCOMP plotter routines for making the final reduced data plots.
Preparation of the reduced data formats for publication was done by John Huff, George Morris, Walter Wood, and Jack Miller.

Mr. Jack Miller designed the special instrumentation for the measurement of the apparent elevation angle of arrival.

The very helpful and cooperative assistance of Lowell Tveten, Robert Hunsucker, Tom Georges, Dale Whittaker, and others at ESSA, Boulder, Colorado is appreciated.

Special recognition is due Dr. Edgar C. Hayden who supervised the design and construction of the radiolocation system at the University of Illinois. He also planned the installation of the Houston transmitting site. He built well! The system was used as an instrument for directional propagations research and the fruits of the experiment are given below.
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1. INTRODUCTION

The geometry for the cooperative HF Directional Propagation Experiment is shown in Figure 1. The propagation path for the reduced data given in this report is the Houston, Texas to Champaign-Urbana nominal path. Exact location data on the several facilities is given on each plate in chapter 6.

A variable frequency continuous wave transmitter was located at Alta Loma, Texas, south of Houston. The transmitting antenna was a 2-bay log periodic antenna pointed toward Urbana. An oblique incidence ionosonde transmitter was also operated with the same array on a time shared basis. The duty cycle was a one-minute duration, i.e., 43 seconds of cw transmission and then 17 seconds of oblique incidence ionosonde operation.

Five C-4 type vertical incidence ionosondes were operated in the neighborhood of the path midpoint. The ESSA/ITSA group operated the four ionosondes at Springfield, Mo., Greenwood, Miss., Texarkana, Ark., and Ponca City, Okla., respectively, on a five-minute cycle. The University of Illinois operated a fifth C-4 ionosonde at the path midpoint near Jacksonville, Ark., on a one-minute cycle. The University of Illinois also operated a Granger-type v.i. ionosonde and oblique incidence ionosonde receiver at the receiving endpoint on a one-minute cycle.

The radio direction finder receiver was of the CDAA type and experience with this system has demonstrated that the instrumental error of the system is less than 1/2 degree in the sector of study. Accordingly, the measured bearing is considered to be a valid measure angle of arrival of the signal as received. The wave interference effects, the lateral deviations in azimuth and the vertical angle deviations
Figure 1: Geometry for the Cooperative Directional Propagation Experiment
(longitudinal deviations) are all completely assignable to the propagation path(s) through the ionospheric region in the neighborhood of the region of the path midpoint.

The ESSA/ITSA group at Boulder was carrying out experiments on the path between their Table Mountain site and Cape Kennedy. The GCB propagation paths intersected at a point near Jacksonville, Arkansas and the angle of intersection is very close to 90 degrees.

The frequency of the cw transmission from the Houston target transmitter was 8.0 mHz during the daytime hours and 12.235 mHz during the nighttime hours.

Azimuthal data (bearing and deviation plots) were recorded at two-minute intervals during the months of March through September 1967 and at one-minute intervals thereafter.

A continuous five day experiment was carried out each month during the period March 1967 through June 1968. The first thirteen months of data have been reduced and are reported later below (chapter 6). The five day period was chosen to bracket the times of the international geophysical days for each month. This permits later correlation studies of our reduced data with that of other cooperating groups.

The data obtained by the group at Boulder are reported elsewhere. The plates in chapter 6 show the availability status of v.i. ionosonde data obtained by their four ionosondes. Some "Doppler ionosonde" data obtained by Dr. T. Georges of ITSA is shown in the earlier plates of chapter 6.
2. THE MEASURED DATA VECTOR

The experiment was controlled in the sense that characteristics of the transmitter and the propagation path were either known or determinable. The receiver was instrumented to measure most but not all of the physically observable quantities. For example, the relative amplitudes of the obliquely incident propagation modes should have been monitored from the outset. The subset of data that was measured during any short observation interval constitutes a column vector in the matrix sense and it is very convenient to represent the data in this sense. Several transformations are made upon the measured column vector to produce the reduced data vector.

The measured data (column) vector consists of the following entries:

<table>
<thead>
<tr>
<th>Entry</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>I</td>
<td>Interval (date, month, year)</td>
</tr>
<tr>
<td>t</td>
<td>Time, U.T., within the interval</td>
</tr>
<tr>
<td>f(t)</td>
<td>Frequency in mHz, 8.00 mHz during the daylight hours, 12.235 mHz during the dark hours</td>
</tr>
<tr>
<td>a(t)</td>
<td>Indicated bearing or azimuthal angle of arrival as received</td>
</tr>
<tr>
<td>Δϕ₁(t)</td>
<td>Differential phase between first phantom array</td>
</tr>
<tr>
<td>Δϕ₂(t)</td>
<td>Differential phase between second phantom array</td>
</tr>
<tr>
<td>Δϕ₃(t)</td>
<td>Differential phase between third phantom array</td>
</tr>
<tr>
<td>JA,h'(f,t)</td>
<td>Midpoint ionogram record obtained at path midpoint near Jacksonville, Arkansas</td>
</tr>
<tr>
<td>TK,h'(f,t)</td>
<td>Midpoint ionogram record obtained at path midpoint near Texarkana, Arkansas</td>
</tr>
<tr>
<td>SP,h'(f,t)</td>
<td>Midpoint ionogram record obtained at path midpoint near Springfield, Missouri</td>
</tr>
</tbody>
</table>
PC,h'(f,t)  Midpoint ionogram record obtained at path midpoint near Ponca City, Oklahoma

GW,h'(f,t)  Midpoint ionogram record obtained at path midpoint near Greenwood, Mississippi

UI,h'(f,t)  Midpoint ionogram record obtained at path midpoint near Bondville, Illinois (University of Illinois)

At(f,t)  Houston-Urbana oblique incidence ionogram

JA,Δf(f,t)  Doppler ionosonde data obtained at path midpoint

UI,Δf(f,t)  Doppler ionosonde data obtained near receiving endpoint

Coincidently, another data vector was obtained on the Boulder to Cape Kennedy path by the ESSA/ITSA group working under the principal direction of Mr. Lowell Tveten.

There were other observers who also accumulated data vectors on the Houston transmissions.

Most of the measured raw data are maintained in various files at the University of Illinois.
3. MEASUREMENT OF APPARENT ELEVATION ANGLE

Measurements of apparent elevation angle were made using a technique originally conceived by Bailey. This technique was the subject of further theoretical studies by Jones, Schlicht, and Ernst, where the concept of "Phantom Antennas" was introduced, i.e., the addition of voltages from a pair of symmetrically disposed antennas (with respect to the boresight). From measurements of the differential phase angle between two such Phantom Antennas, values of elevation angle can be obtained by use of the equation:

\[ \psi = \frac{2\pi d}{\lambda} \cos \theta \cos \alpha \]

where
\[ d \] = horizontal spacing along the boresight between the Phantom Antennas
\[ \lambda \] = wave length of signal
\[ \alpha \] = difference between azimuthal angle of arrival of signal and azimuthal alignment of Phantom Antennas. (For these data, this angle is assumed to be zero)
\[ \psi \] = differential phase angle between Phantom Antennas
\[ \theta \] = apparent elevation angle

It should be noted at this time that for the elevation angle data presented, the determination of the value to be used for "d" in the above equation was based upon the assumption that the phase center for the antennas of the array is located at the screen radius.


For the elevation angle data presented in this Atlas, two Phantom Antennas were used and they are identified as the Front Phantom and the Rear Phantom. The Front Phantom consisted of two adjacent antennas of the array, so selected such that the boresight of the incoming signal passed between these two antennas. The output of these two antennas was added by a RF combiner to create the Front Phantom. By the RF addition of voltages from two other symmetrically disposed antennas, the Rear Phantom was formed and it was located directly behind the Front Phantom on the boresight. To avoid ambiguity problems, the horizontal spacing along the boresight ("d" in the above equation) between the Front and Rear Phantom Antennas was restricted to a distance of one-half wave length or less for any given operating frequency.

Each Phantom Antenna was fed through RF diode switches to a matched twin-channel receiver, the Front Phantom being fed to one channel of the receiver and the Rear Phantom to the other channel. Test signals, used to measure phase drift in the receiver and phasemeter calibration, were also connected to the inputs of the receiver by means of the diode switches.

At the output of the 250 kHz IF amplifiers of each receiver, a phasemeter was connected to measure the differential phase angle between the receiver channels. The phasemeter output is an analog voltage which is proportional to the phase angle difference appearing at its input terminals. This voltage measurement was then recorded on magnetic tape for processing by the digital computer.

For every data sample, two differential phase voltage measurements proportional to elevation angle were made. These measurements were 600 milliseconds apart in time. In addition to this, phase voltage
measurements of phase drift between receiver channels and calibration of the phasemeter were performed by means of test signals connected to the receiver inputs by the diode switches.

To calculate the apparent elevation angle for each data sample, a computer program was written to perform a simple average of the two differential phase voltage measurements, after correction of these measurements for any phase drift in the receivers. Then a running-average window of 20-minutes duration was performed on the simple-average values. The 20-minute running average used here is similar to that used for the bearing calculations. When all the averaging has been completed, the differential phase angle for each data sample is then found by multiplying the averaged differential phase voltage by the phasemeter conversion constant. This gives the value for $\psi$ in degrees for use in the elevation angle equation. For any given frequency, all other parameters are known and the apparent elevation angle $\theta$ can be calculated.

It should be stressed that the apparent elevation angle is obtained from a calculation which assumes that the effective reference phase center for each antenna is located at the screen radius. Experimental results have indicated that the effective phase center lies close to but not on the screen radius. Accordingly, the results should be interpreted as being qualitatively indicative of elevation angle of arrival. The averaged results are close to the results of 3-D ray tracing studies for the path.
4. DATA REDUCTION PROCEDURES FOR THE ATLAS

The data from which the direction of arrival of the signals is determined are recorded at the Bondville Road Field Station on magnetic tape with the High Speed Data System. The bearing deviation is computed from recorded data which includes the amplitude of the sum voltage sampled at 1° increments of scanner rotation over the designated sector of the scan. Time, the sector width, and the sector center are other data used for computing the bearing. The data tapes are then decoded, edited, the format of the information changed, and the data then becomes part of the Master RRL Data File.

The data were recorded in groups of eight successive scans taken at one or two minute intervals. Bearings were computed from the data for each scan. A sector width of 30° and a sector center of 209° has been used for most of the data reported here.

Bearings were computed using a center of gravity technique first suggested by Smith and modified by Jones. In this procedure, the largest value of the sum voltage in the scan is determined. Using this value as a reference, successive values to the right of the maximum values are examined until one of the following conditions is found:

1. The voltage falls below 0.1 of the maximum voltage.
2. A null is found as indicated by a value smaller than two successive following values.

The process is then repeated to the left of the maximum voltage. The voltage sampled between the right and left limits as determined above describe the major lobe of the response to the signal. The azimuthal coordinate of the centroid of the major lobe is then computed. This value is the bearing for the scan.
The eight bearings computed from the group of eight scans are averaged and the mean (average bearing) and the standard deviation for the group determined. The average bearing for the group and the standard deviation for the group are then plotted as a function of time. This is the bearing and deviation plot. At those times for which no data are available, no data are plotted. It should be noted that the standard deviation is plotted as (maximum value of bearing - standard deviation) versus time. Thus, a zero value for the standard deviation would be plotted at the top and increasing values toward the bottom.

The average bearings were further averaged using a conventional running average technique. This is the mean value (running average) of all average bearing values within a specified window or interval of time. The plots shown here are for window widths of 20 minutes and 2 hours. Thus, for the 20 minute window, 20 successive values of average bearing were used as input for computation of the running average. (Note: If the data were recorded at two minute intervals, only ten successive values would be used.) The running average determined is then plotted versus time. The time chosen is the time at the center of the window. The running average is recomputed for each one minute (or two minute) increment of time. If no average bearing exists for one or more of the time values included in the interval, an average is computed for those that do exist. If the time value at the center of the interval is one for which no value of average bearing exists, the data are not plotted.

All computations were made using the CDC G-20 computer operated by the Radiolocation Research Laboratory and the plots were drawn using a CALCOMP plotter.
5. FORMAT FOR THE REDUCED DATA

The reduced data for each 24-hour day are plotted as functions of Universal Time and Central Standard Time. Six characteristic types of reduced data plots are presented and the order of presentation (from top to bottom) is shown in the format of Figure 2.

A very large amount of information has been compacted into a plate. In the compacting process the size of some of the printed labels became small. We apologize for this. The printing is crisp and can be discerned and recovered readily with a reading-glass type magnifier (optical data processing). We hope the end result justifies the means that were taken here.

The first characteristic type of reduced data is the oblique ionogram data. The oblique ionograms for the path were edited for the frequency of transmission at the time, either 8 mHz or 12.235 mHz, and the delay times for the modes in evidence at that time were plotted along the ordinate axis direction. It would have helped considerably if the relative amplitude of each mode had been measured and plotted. This was done near the end of the experiment.

The second characteristic type of reduced data is the bearing and deviation plot. The GCB for the target transmitter was 209.12 degrees. In the lower portion of this plot is shown the measured azimuthal angle of arrival of the signal as received, or the indicated bearing. It is obtained from a short-period sample average and is labelled average bearing in that sense. At the top of the plot and projecting downwards is the magnitude of the associated standard deviation. The standard deviation often appears to be vanishingly small at night but of the order of 1° to 2° during the day. Points having a standard deviation larger
Figure 2. Format for reduced data.
than approximately 3° should probably be ignored.

The third characteristic type of data consists of time averaged bearing plots. A 20-minute window and a 2-hour window, respectively, was used. The lower plot is the 20-minute running average. It is seen that the wave interference effects have been reduced very considerably but the "quasi-20-minute period variations" appear. The upper plot is the two hour running average and it is indicative of the diurnal effects or solar effects. We also call it the "diurnal curve".

The fourth characteristic type of data is the apparent elevation angle of arrival averaged over a 20 minute period. It was pointed out earlier above that these data are more apparent than real because the effective radius of the array to be used in making the calculation is not finally established; ray tracing results indicate that the plotted curve is probably too high. The curve is indicative of the trend and demonstrates an unused capability.

The fifth characteristic type of data is the Doppler data obtained near the path midpoint. The legend on the extreme right such as 4T, 4G, 4S, 3G, etc., should be interpreted as the 4.0 mHz cw signal from Texarkana, the 4.0 mHz cw signal from Greenwood, the 4.0 mHz signal from Springfield, the 3.0 mHz signal from Greenwood, respectively, etc. What is actually plotted is the differential frequency between a transmitted cw signal and its received version. Two very stable oscillators are used; one determines the transmitted cw signal, the other determines the local oscillator frequency at the receiving site, and the difference frequency is an indicator of variations in the propagation medium along the line of travel. These data were provided by Mr. Tom Georges of ESSA.

The sixth characteristic type of data is of the "yes-no" type. It
indicates by the presence (mark) or absence (space) of points along a line the availability of vertical incidence ionosonde data for each of the six vertical incidence ionosondes involved in the experiment.
6. THE ATLAS OF REDUCED DATA

In the following sixty-five plates are contained the several families of plots of reduced data as described in the previous section.

There were times when some (one or more) equipment was not functioning and for those times a gap will appear in the data.

One will note intervals where the oblique ionograms showed no evidence of propagation but an angle of arrival was recorded along with a very large standard deviation. These intervals should normally be excluded from any statistical treatment of the data.

These plates are given without further comment at this point. One must, therefore, draw his own inferences about events in time that may be of particular interest. We believe that the results truly represent directional propagation effects. The systematic error is very small by comparison, i.e., it is not significant in the statistical sense.
Plate 2.

15 March 1967
Plate 6.

11 April 1967
OBLIQUE IONOGRAM DATA
Camp Wallace Field Station (25° 22' 35" N, 95° 02' 22" W) to Bondville Road Field Station (40° 02' 56" N, 88° 22' 50" W)
Points indicate possible modes of transmission of transmitter frequencies as shown. Path length: 1332.78 km 12 APRIL 1967

BEARING DEVIATION PLOT
Transmitter 10 kW, located Camp Wallace, Texas, 25° 22' 35" N, 95° 02' 22" W Bearing Data Points at min. intervals
Antenna at Camp Wallace, Granger, 2-BAY LOG-PERIODIC Mid-path point near Jacksonville, Arkansas, 34.6° N, 92.0° W
Receiver Wullenweber, Located near Bondville, Illinois, 40° 02' 56" N, 88° 22' 50" W 12 APRIL 1967

BEARING DEVIATION PLOTS - TIME AVERAGED 12 Apr 1967
Plate 8.

13 April 1967
Plate 9.

14 April 1967
Plate 10.

15 April 1967
Plate 11.

9 May 1967
OBLIQUE IONOGRAM DATA
Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W) to
Bonaville Road Field Station (40° 02' 58" N, 88° 22' 50" W)
Points indicate Possible Modes of Transmission at Transmitter Frequencies as Shown Path Length = 1332.78 km 10 MAY 1967

BEARING DEVIATION PLOT
Transmitter 10 kw, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W Bearing Data Points at min. intervals Antenna at Camp Wallace, Granger, 2-BAY LOG-PERIODIC Mid-path Point Near Jacksonville, Arkansas, 34° 8' N, 92° 0' W Receiver Wullenweber, Located Near Bonaville, Illinois, 40° 02' 58" N, 88° 22' 50" W 10 MAY 1967

BEARING DEVIATION PLOTS - TIME AVERAGED 10 May 1967
Plate 12, 10 May 1967

VERTICAL SOUNDER DATA

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<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
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<td>91.0° W</td>
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<tr>
<td>SP</td>
<td>37.7° N</td>
<td>91.2° W</td>
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<td>PC</td>
<td>34.6° N</td>
<td>91.0° W</td>
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<td>GW</td>
<td>33.7° N</td>
<td>90.7° W</td>
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<tr>
<td>UI</td>
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</tr>
<tr>
<td>JA</td>
<td>34.8° N</td>
<td>91.7° W</td>
</tr>
</tbody>
</table>

DOPPLER DATA
(Courtesy of Mr. T. M. Geoghegan of ESSA Research Labs, Boulder, CO.)

APPARENT ELEVATION ANGLE of ARRIVAL
- 20 Minute Average

10 MAY 1967

Universal Time
OBLIQUE IONOGRAM DATA

Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W) to Bonneville Road Field Station (40° 02' 56" N, 89° 22' 50" W)

Points indicate possible modes of transmission of transmitter frequencies as shown. Path Length = 1323.78 km 13 JUNE 1967

BEARING DEVIATION PLOT

Transmitter: 100 kW, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W Bearing Data Points at min intervals
Antenna at Camp Wallace, Granger, 2-BAY LOG-PERIODIC Mid-path Point Near Jacksonville, Arkansas, 35° 06' N, 92° 00' W
Receiver: Wullner, Located Near Bonneville, Illinois, 40° 02' 56" N, 89° 22' 50" W 13 JUNE 1967

BEARING DEVIATION PLOTS - TIME AVERAGED 13 June 1967
OBLIQUE IONOGRAM DATA
Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W) to Bandville Road Field Station (40° 02' 56" N, 88° 22' 50" W)
Points indicate possible modes of transmission at transmitter frequencies as shown. Path Length - 1332.78 km 14 JUNE 1967

BEARING DEVIATION PLOT
Transmitter 10 kw, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W Bearing Data Points at min. intervals
Antenna of Camp Wallace, Granger, 2-BAY LOG PERIODIC Mid-path Point Near Jacksonville, Arkansas, 34° 06' N, 92° 07' W
Receiver Wullenweber, Located Near Bandville, Illinois, 40° 02' 56" N, 88° 22' 50" W 14 JUNE 1967

BEARING DEVIATION PLOTS - TIME AVERAGED 14 June 1967
OBLIQUE IONOGRAM DATA

Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W) to Bondville Road Field Station (40° 02' 58" N, 88° 22' 50" W)
Points indicate possible modes of transmission at transmitter frequencies as shown. Path Length: 1532.70 km 15 JUNE 1967

BEARING DEVIATION PLOT

Transmitter 10 kW, Located Camp Wallace, Texas. 29° 22' 35" N, 95° 02' 22" W Bearing Data Points at min intervals Antenna at Camp Wallace, Granger, 2-BAY LOG-PERIODIC Mid-path Point Near Jacksonville, Arkansas. 34° 8' N, 92° 0" W Receiver Wullenweber, Located Near Bondville, Illinois. 40° 02' 58" N, 88° 22' 50" W 15 JUNE 1967

BEARING DEVIATION PLOTS - TIME AVERAGED 15 June 1967
Plate 18.

15 June 1967
Plate 19.

16 June 1967
Plate 20.

17 June 1967
Plate 21.

18 July 1967
Plate 23.

20 July 1967
Plate 24.

21 July 1967
OBLIQUE IONOGRAM DATA

Transmitter: 10-kw, Located at Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W
Antenna at Camp Wallace; Granger, 2-BAY LOG-PERIODIC Mid-path Point Near Jacksonville, Arkansas, 34° 8' N, 92° 0' W
Receiver: Muller, Located at Bondville, Illinois, 40° 02' 58" N, 88° 22' 50" W

Points indicate possible modes of transmission at transmitter frequencies as shown. Path length = 1332 km 22 JULY 1967

BEARING DEVIATION PLOT 22 July 1967

Transmitter: 12-kw, Located at Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W
Antenna at Camp Wallace; Granger, 2-BAY LOG-PERIODIC Mid-path Point Near Jacksonville, Arkansas, 34° 8' N, 92° 0' W
Receiver: Muller, Located at Bondville, Illinois, 40° 02' 58" N, 88° 22' 50" W

BEARING DEVIATION PLOTS - TIME AVERAGED 22 July 1967

APPARENT ELEVATION ANGLE OF ARRIVAL - 20 Minute Average 22 JULY 1967
Plate 25.
22 July 1967
Plate 26.

15 August 1967
OBELIQUE IONGRAM DATA

Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W) to Bondville Road Field Station (40° 02' 56" N, 88° 22' 50" W)

Points indicate possible modes of transmission at transmitter frequencies as shown. Path Length = 1332.78 km 16 AUGUST 1967

BEARING DEVIATION PLOT 16 August 1967

Transmitter 10 kHz, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W Bearing Data Points at 5 min intervals
Antenna at Camp Wallace, Granger, 2-BAY LOG PERIODIC Mid-path Point Near Jacksonville, Arkansas, 34° 8' N, 90° 0' W
Receiver Wullenweber, Located Near Bondville, Illinois, 40° 02' 56" N, 88° 22' 50" W

BEARING DEVIATION PLOTS - TIME AVERAGED 16 August 1967

APPARENT ELEVATION ANGLE of ARRIVAL  - 20 Minute Average 16 AUGUST 1967
Plate 27.

16 August 1967

VERTICAL SOUNDER DATA

TK - TEXARKANA, Arkansas 33° N, 94° W
SP - SPRINGFIELD, Missouri 37° N, 93° W
PC - PONCA CITY, Oklahoma 35° N, 97° W
GW - GREENWOOD, Mississippi 33° N, 90° W
UI - URBANA, Illinois 40° N, 88° W
JA - JACKSONVILLE, Arkansas 34° N, 92° W

16 August 1967
OBLIQUE IONOGRAM DATA
Camp Wallace Field Station (29° 22' 35'' N, 95° 02' 22'' W) to Bandville Road Field Station (40° 02' 58'' N, 88° 22' 50'' W)
Points indicate possible modes of transmission at transmitter frequencies as shown. Path length = 1332.78 km. 17 AUGUST 1967

BEARING DEVIATION PLOT 17 August 1967
Transmitter 10 kW, located Camp Wallace, Texas, 29° 22' 35'' N, 95° 02' 22'' W. Bearing data points at 5 min. intervals
Antenna at Camp Wallace, Granger, 2-BAY LOG-PERIODIC. Mid-path point near Jacksonville, Arkansas, 34° 6' N, 95° 0 W
Receiver Wullenweber, located near Bandville, Illinois, 40° 02' 58'' N, 88° 22' 50'' W

BEARING DEVIATION PLOTS — TIME AVERAGED 17 August 1967

APPARENT ELEVATION ANGLE OF ARRIVAL 17 August 1967
- 20 Minute Average
Plate 28.

17 August 1967
OBLIQUE IONGRAM DATA
Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W) to Bondville Road Field Station (40° 02' 56" N, 88° 22' 50" W)
Points indicate possible modes of transmission at transmitter frequencies as shown. Path length - 1332.76 km. 19 September 1967

BEARING DEVIATION PLOT  19 September 1967
Transmitter: 10 kw, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W. Bearing data points at min intervals.
Antenna at Camp Wallace, Granger, 2-BAY LOG-PERIODIC Mid-path point near Jacksonville, Arkansas, 34° 6' N, 92° W
Receiver: Wullenweber, Located near Bondville, Illinois, 40° 02' 56" N, 88° 22' 50" W

BEARING DEVIATION PLOTS - TIME AVERAGED  19 September 1967

APPENDIX  B: TABLES AND EQUATIONS
Plate 31.

19 September 1967
OBLIQUE IONOGRAM DATA
Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W)
Bonnieville Road Field Station (40° 02' 56" N, 88° 22' 50" W)
Points indicate possible modes of transmission at transmitter frequencies as shown. Path length - 133.78 km 20 September 1967

NO DATA AVAILABLE

BEARING DEVIATION PLOT 20 September 1967
Transmitter 10 kW, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W. Bearing data points at min. intervals. Antenna at Camp Wallace, Grasper, 2-BAY LOG-PERIODIC Multipath Points Near Jacksonville, Arkansas, 34° 48' N, 92° 00' W. Receiver Wellpinston, Located Near Bonnieville, Illinois, 40° 02' 56" N, 88° 22' 50" W.

BEARING DEVIATION PLOTS - TIME AVERAGED 20 September 1967

APPARENT ELEVATION ANGLE OF ARRIVAL - 20 Wave Forms
Plate 32.

20 September 1967
OBlique IONOGRAM DATA
Camp Wallace Field Station (29° 22' 35" N, 96° 02' 22" W) to Bondville Road Field Station (40° 02' 58" N, 88° 22' 50" W)
Points indicate Possible Modes of Transmission at Transmitter Frequencies as Shown
Path Length - 1332.78 km 21 September 1967

NO DATA AVAILABLE

BEARING DEVIATION PLOT 21 September 1967
Transmitter 10 kw, Located Camp Wallace, Texas, 29° 22' 35" N, 96° 02' 22" W
Bearings Data Points at 5 min. intervals
Antenna at Camp Wallace, Granger, 2-8 BAY LOG-PERIODIC
Mid-path Point Near Jacksonville, Arkansas, 34° 08' N, 92° 06' W
Receiver Wullenweb, Located Near Bondville, Illinois, 40° 02' 58" N, 88° 22' 50" W

BEARING DEVIATION PLOTS - TIME AVERAGED 21 September 1967

-2.235 MHz
8,000 MHz
Transmitter Frequency
Plate 33.

21 September 1967
OBlique Ionogram Data
Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W) to Bondville Road Field Station (40° 02' 58" N, 88° 22' 50" W)
Points indicate possible modes of transmission at transmitter frequencies as shown. Path length - 1332.78 km 23 September 1967

No Data Available

Bearing Deviation Plot 23 September 1967
Transmitter: 10 kw, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W. Bearing Data Points at min. Intervals.
Antenna: at Camp Wallace, Granger, 2-BAY LOG-PERIODIC. Mid-path Point Near Jacksonville, Arkansas, 34° 6" N, 92° 0" W.
Receiver: Wallenweber, Located Near Bondville, Illinois, 40° 02' 58" N, 88° 22' 50" W.

Bearing Deviation Plots - Time Averaged 23 September 1967

8000 MHz
Transmitter Frequency
12.235 MHz
NO DATA AVAILABLE
OBlique Ionogram Data

Camp Wallace Field Station (28° 22' 35" N, 95° 02' 22" W) to Bondville Field Station (40° 02' 56" N, 86° 22' 50" W)

Points indicate possible modes of transmission at transmitter frequencies as shown. Path length = 1332.78 km 25 October 1967

BEARING DEVIATION PLOT

Transmitter: 10 kw, Located Camp Wallace, Texas, 29°22'35"N, 95°02'22"W. Bearing data points at min. intervals. Antenna at Camp Wallace, Granger, 2-BAY LOG-PERIODIC. Mid-path Point: Near Jacksonville, Arkansas, 34°6' N, 92°0' W. Receiver: Wullenweber, Located Near Bondville, Illinois, 40°02'56"N, 86°22'50"W 25 October 1967

NO DATA AVAILABLE

BEARING DEVIATION PLOTS - TIME AVERAGED 25 October 1967

NO DATA AVAILABLE

APPARENT ELEVATION ANGLE of ARRIVAL - 20 Minute Average 25 October 1967
Plate 37.

25 October 1967
NO DATA AVAILABLE

BEARING DEVIATION PLOTS - TIME AVERAGED 26 OCTOBER 1967

NO DATA AVAILABLE
NO DATA AVAILABLE

VERTICAL SOUNDER DATA

TK - TEXARKANA, Arkansas  33.5° N, 94.0° W
SP - SPRINGFIELD, Missouri  37.5° N, 93.5° W
PC - YONCA CITY, Oklahoma  34.0° N, 97.0° W
GW - GREENWOOD, Missouri  35.0° N, 90.0° W
UI - URBANA, Illinois  40.0° N, 88.0° W
JA - JACKSONVILLE, Arkansas  36.0° N, 93.0° W

Plate 38. 26 October 1967
OBLIQUE IONOGRAM DATA

Points indicate possible modes of transmission at transmitter frequencies as shown. Path length = 1332.75 km 28 October 1967

BEARING DEVIATION PLOT

Transmitter 10 kW, Located Camp Wallace, Texas, 29° 22' 35" N, 94° 02' 22" W. Bearing data points at 1 min. intervals.
Antenna at Camp Wallace, Granger, 2-BAY LOX-PERIODIC Mid-path point near Jacksonville, Arkansas, 32° 56' N, 91° 07' W.
Receiver Wullenweber, located near Bondville, Illinois, 40° 02' 55" N, 88° 22' 50" W 28 October 1967

NO DATA AVAILABLE

BEARING DEVIATION PLOTS - TIME AVERAGED 28 October 1967

NO DATA AVAILABLE

APPARENT ELEVATION ANGLE OF ARRIVAL 20 Minute Average 28 October 1967
Plate 40.

28 October 1967
OBlique ionogram data

Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W) to Bondville Road Field Station (40° 0' 58" N, 80° 22' 50" W)

Points indicate possible modes of transmission of transmitter frequencies as shown. Path length - 1332.78 km. 14 November 1967

Bearings Deviation Plot

Transmitter: 10 kw, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W
Antenna: 2-Bay LOG-PERIODIC

Receiver: Wullenweber, Located Near Bondville, Illinois, 40° 0' 58" N, 80° 22' 50" W

Path length - 1332.78 km. 14 November 1967

Bearings Deviation Plots - Time Averaged

4.625 MHz

-2.225 MHz

-2.225 MHz

14 November 1967
Plate 42.

15 November 1967
Plate 43.

16 November 1967
Plate 44.

17 November 1967
Plate 47.

13 December 1967
Plate 48.

14 December 1967
OBLIQUE IONOGRAM DATA
Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W) to Bondville Road Field Station (40° 02' 58" N, 88° 22' 50" W)
Points indicate possible Modes of Transmission of Transmitter Frequencies as Shown Path Length - 1332.79 km 15 DECEMBER 1967
NO DATA AVAILABLE

BEARING DEVIATION PLOT
Transmitter: IO km, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W Bearing Data Points at min. intervals Antenna at Camp Wallace, Granger, 2-BAY LOG-PERIODIC Mid-path Point Near Jacksonville, Arkansas, 34° 8' N, 92° 0" W Receiver: Wullenweber, Located Near Bondville, Illinois, 40° 02' 58" N, 88° 22' 50" W 15 DECEMBER 1967

BEARING DEVIATION PLOTS - TIME AVERAGED 15 DECEMBER 1967
OBLIQUE IONOGRAM DATA

Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W) to Bondville Field Station (40° 02' 55" N, 88° 22' 50" W)
Points indicate possible modes of transmission at transmitter frequencies as shown
Path Length = 1332.76 km 16 JANUARY 1968

BEARING DEVIATION PLOT

Transmitter 10 kW, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W
Bearing Data Points at min. Intervals
Antenna at Camp Wallace, Granger, 2-BAY LOG-PERIODIC Mid-path Point Near Jacksonville, Arkansas, 34° 08' N, 92° 00' W
Receiver Wullenweber, Located Near Bondville, Illinois, 40° 02' 55" N, 88° 22' 50" W 16 JANUARY 1968
Plate 52.

17 January 1968
OBLIQUE IONGRAM DATA

Comp Wallace Field Station (29°22'35"N, 95°02'22"W) to Bondville Road Field Station (40°02'58"N, 88°22'50"W)

Points indicate possible modes of transmission at transmitter frequencies as shown. Path length = 332.7 km 18 JANUARY 1968

BEARING DEVIATION PLOT

Transmitter 10 kW, Located Camp Wallace, Texas, 29°22'35"N, 95°02'22"W  Bearing Data Points at min. intervals

Antenna at Camp Wallace, Granger, 2-BAY LOG-PERIODIC  Mid-path Point Near Jacksonville, Arkansas, 34°6"N, 92°0"W

Receiver Wullenweber, Located Near Bondville, Illinois, 40°02'58"N, 88°22'50"W  18 JANUARY 1968

BEARING DEVIATION PLOTS - TIME AVERAGED 18 January 1968

APPARENT ELEVATION ANGLE of ARRIVAL  - 20 Minute Average 18 JANUARY 1968
NO DATA AVAILABLE

DOPPLER DATA

NO DATA AVAILABLE

VERTICAL SOUNDER DATA

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<thead>
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<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
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<td>SP - Springfield, Missouri</td>
<td>37.7° N, 93.3° W</td>
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<td>PC - Ponca City, Oklahoma</td>
<td>35.6° N, 97.0° W</td>
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<td>GW - Greenwood, Massapequa</td>
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<tr>
<td>UI - Urbana, Illinois</td>
<td>40.0° N, 88.3° W</td>
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<td>JA - Jacksonville, Arkansas</td>
<td>34.6° N, 93.7° W</td>
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OBlique Ionogram Data
Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W)
Bondville Road Field Station (40° 02' 56" N, 88° 22' 50" W)
Points indicate possible modes of transmission at transmitter frequencies as shown. Path length - 1332.70 km 19 January 1968

Bearing Deviation Plot
Transmitter 10 kW, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W
Bearing data points at min intervals
Antenna at Camp Wallace, Granger, 2-Bay Log-Periodic
Mid-path Point Near Jaxville, Arkansas, 34° 06' N, 92° 03' W
Receiver Wullenweber, Located Near Bondville, Illinois, 40° 02' 56" N, 88° 22' 50" W
19 January 1968

Bearing Deviation Plots - Time Averaged 19 January 1968
NO DATA AVAILABLE

19 JANUARY 1968

DOPPLER DATA

NO DATA AVAILABLE

19 JANUARY 1968

VERTICAL SOUNDER DATA

TK - TECUMSEH, Arkansas 33° 57' N, 91° 35' W
SP - SPRINGFIELD, Missouri 37° 17' N, 93° 22' W
PC - PONCA CITY, Oklahoma 37° 06' N, 97° 17' W
GW - GREENWOOD, Mississippi 33° 35' N, 90° 11' W
IU - URBANA, Illinois 40° 07' N, 88° 17' W
JA - JACKSONVILLE, Arkansas 34° 38' N, 92° 17' W

19 JANUARY 1968

Universal Time

Central Standard Time
Plate 55.
20 January 1968.

VERTICAL SOUNDER DATA

TK - TEXARKANA, Arkansas  33° 5' N, 94° 0' W
SP - SPRINGFIELD, Missouri  37° 7' N, 93° 7' W
PC - PONCA CITY, Oklahoma  36° 1' N, 97° 17' W
GW - GREENWOOD, Mississippi  33° 5' N, 90° 0' W
UI - URBANA, Illinois  40° 0' N, 88° 3' W
JA - JACKSONVILLE, Arkansas  34° 8' N, 91° 0' W

NO DATA AVAILABLE
Plate 57.
21 February 1968
OBLIQUE IONOGRAHM DATA

Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W) to

Borodino Road Field Station (40° 02' 58" N, 88° 22' 50" W)

Points indicate Possible Modes of Transmission at Transmitter Frequencies as Shown. Path Length - 1332.78 km 22 February 1968

BEARING DEVIATION PLOT

Transmitter 10kW, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W Bearing Data Points at min. intervals
Antenna at Camp Wallace, Granger, 2-BAY LOG-PERIODIC Mid-path Point Near Jacksonville, Arkansas, 34° 8' N, 92° 0' W
Receiver Wulfenweiler, Located Near Borodino, Illinois, 40° 02' 58" N, 88° 22' 50" W 22 February 1968

BEARING DEVIATION PLOTS - TIME AVERAGED 22 FEBRUARY 1968
NO DATA AVAILABLE
OBLIQUE IONGRAM DATA
Camp Wallace Field Station (29° 22' 35" N, 95° 02' 22" W) to Bondville Road Field Station (40° 02' 56" N, 86° 22' 50" W)
Points indicate possible modes of transmission at transmitter frequencies as shown. Path length = 1332.78 km. 23 FEBRUARY 1968

BEARING DEVIATION PLOT
Transmitter: 10 kw, Located Camp Wallace, Texas, 29° 22' 35" N, 95° 02' 22" W
Bearing Data Points at 1 min intervals
Antenna: Camp Wallace, Granger, 2-BAY LOG-PERIODIC Mid-path Point Near Jacksonville, Arkansas, 34.6° N, 92° 0 W
Receiver: Wullenweber, Located Near Bondville, Illinois, 40° 02' 56" N, 86° 22' 50" W
23 FEBRUARY 1968

BEARING DEVIATION PLOTS - TIME AVERAGED 23 FEBRUARY 1968

APPARENT ELEVATION ANGLE OF ARRIVAL - 30 Minute Average 23 FEBRUARY 1968
Plate 59.

23 February 1968
Plate 60.

24 February 1968
OBLIQUE IONOGRAM DATA

Points indicate possible modes of transmission of transmitter frequencies as shown. Path length: 1,332.7 km 02 March 1968

BEARING DEVIATION PLOT 02 March 1968

Transmitter 10 kW, located Camp Wallace, Texas, 29°22'35" N, 95°02'22" W. Bearing data points at min intervals.

Antenna at Camp Wallace, Granger, 2-BAY LOG-PERIODIC. Mid-path point near Jacksonville, Arkansas, 34°08' N, 92°0 W.

Receiver Wullenweber, located near Bondville, Illinois, 40°02'56" N, 88°22'50" W.

BEARING DEVIATION PLOTS - TIME AVERAGED 02 March 1968

APPARENT ELEVATION ANGLE OF ARRIVAL - 20 Minute Average 02 March 1968
Plate 62.

13 March 1968
Plate 65.

16 March 1968
7. AVAILABILITY STATEMENT

The data from which the bearing and deviation plots have been made is available in tabular and punched card format for a nominal charge. Each point of data includes the following information:

1) Date
2) Time
3) Average bearing (average of eight successive scans)
4) Standard deviation for the group of eight

Vertical incidence ionogram data for the Jacksonville station, vertical incidence ionogram data for the receiving endpoint and oblique ionosonde data for the path are available for a nominal charge.

All of the above data are available from the Radiolocation Research Laboratory.

Data for the other vertical incidence ionosondes may be obtained from the Data Center at ESSA, Boulder, Colorado.
### Document Title

**AN ATLAS OF REDUCED DATA OBTAINED IN A COOPERATIVE HF DIRECTIONAL PROPAGATION EXPERIMENT OVER A 1330 KILOMETER PATH**

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### Abstract

This is a collection of reduced data, arranged in chronological order. The data were obtained on a 1330 km propagation path between Alta Loma, Texas and Bondville, Illinois.

Data for 13 months, 5 days per month are included (65 days). Each daily chart contains:

1. Oblique ionograms (propagation modes)
2. Bearing deviation plots (azimuth)
3. Average deviation plots (20 minute and 2 hour)
4. Elevation angle of arrival
5. Doppler data
6. Vertical ionograms (availability information)
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