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H. F. Frequency Management by Frequency Sharing as Assisted by Models Updated in Real-Time

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Frequency management systems for the high frequencies (HF) currently in use by the U.S. Department of Defense (DoD) rely heavily on manual selection of frequencies which have been allocated on a circuit by circuit basis. There is no capability to anticipate frequency changes (QSY's) in advance in a manner such that a frequency being released by one user can be utilized effectively and immediately by a second user. NRL has been examining a scheme by which a small computer model of the HF channel can be made to perform very accurately to anticipate channel characteristics in a short term prediction mode. It is proposed that this model be utilized to provide automated frequency management which would allow one to anticipate frequency availability and thereby allow sharing of frequencies between several users (frequency pooling). Utilizing data obtained from an oblique sounder net on the East Coast of the United States, this report suggests a method by which this may be accomplished.

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H. F. FREQUENCY MANAGEMENT BY FREQUENCY SHARING AS ASSISTED BY MODELS
UPDATED IN REAL-TIME

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MINIMUF   Spectrum utilization
PROPHET

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H. F. FREQUENCY MANAGEMENT BY FREQUENCY SHARING
AS ASSISTED BY MODELS UPDATED IN REAL-TIME

1.0 INTRODUCTION

1.1 Objective

The objective of this paper is to demonstrate the applicability of a system of oblique ionospheric sounders as coupled to a computer model of the maximum usable frequency of the HF channel to the general problem of the management of frequencies in the high frequency (HF) band.

1.2 Rationale

The technique discussed herein draws upon the strengths of information derived from both the direct measurement of a specific skywave transmission link by an oblique ionospheric sounder and the estimation of skywave propagation conditions as provided by a predictive model. The strength of the oblique ionospheric sounder is that over the particular link measured, this instrument can provide the user with specific and precise information about channel properties including the mode structure, the relative strength of the modes; and the characteristic frequencies of the link, such as the maximum observed frequency (MOF), the band of optimum transmission frequencies (FOT band), and the lowest observed frequency (LOF). These data, when coupled with channel occupancy information obtained at the receiver site, can provide the type of information which will allow one to initiate communications in the HF band which is extremely reliable. The weakness of the oblique sounder, however, is that it provides no information about circuits which are far from the circuit measured, nor does it provide information about the probable future state of the particular circuit measured. These two weaknesses of the oblique sounder are strong points of predictive algorithms. Predictive algorithms provide some insight as to the general circuit characteristics over a large area as well as information as to the future tendencies of the channel. The predictive algorithm's weak point, however, is that it provides imprecise information over the specific links which may be measured precisely by oblique sounders. This fact is quite understandable since predictive algorithms are based on mean values of large sets of measurements corresponding to the HF channel. Hence, one should always expect the oblique sounder to provide more precise information over a measured link in real time than the predictive algorithm.

Realizing that the oblique sounder's strength is the predictive algorithm's weakness and the predictive algorithm's strength is the oblique sounder's weakness, NRL (Code 4180) embarked on a program to couple these systems in a manner which would emphasize the strengths of each and minimize the weaknesses. Initial results from this work (7-9) indicate that this idea

is reasonable and, in fact, a very worthwhile prospect to pursue which may dramatically impact existing high frequency resource management systems. In fact, a highly accurate computer based propagation assessment and forecast module is believed to be the cornerstone of a new generation of automated HF resource management systems. This concept has applications to HF asset management in general including the selection of frequencies, antennas, and power levels; and includes HF problems in the areas of communications, networking, jamming, HF-DF, signal security, and anti-jamming. Benefits accruing from employing this technique include reduced required equipment assets, manpower, and training levels; and increased HF circuit reliability, message throughput, threat assessment capability, and the capability to manage HF intercept resources.

A generalized system employing a highly accurate HF propagation assessment and forecast module is visualized in figure 1. This generalized automated system would use information from various sensors as an input to a channel model. For this report, the oblique sounder is the input, however. Taking into account the various assets of both friends and adversaries operating in the area and the particular job required, supporting software based on a priority scheme would interact with the propagation assessment and forecast module to provide an optimum selection of resources for the particular job to be done. This system could be further improved by employing automatic selection of resources and message routing. As a side note, the NATO Cross Fox program draws heavily upon the idea of automatic resource selection and we believe it could be greatly aided by an accurate channel model. This report, however, will only discuss the application of this concept to the problem optimizing the use of frequency assets which are employed by various users.

1.3 Diurnal Variation of the Channel

Figure 2 is a representative diurnal frequency variation of the MUF and FOT over a typical day. The Naval Ocean Systems Center (NOSC) algorithm called MINIMUF 3.5 was used to derive the MOF over this representative link and the FOT was obtained by calculating .85 of the computed maximum usable frequency. Against this, a set of sample frequencies are plotted by attempting to stay close to the FOT. Note that with 5 different frequencies the diurnal variation of the channel is reasonably well matched to the FOT. If the number of frequencies available are at a premium however, one can communicate most of the day (assuming no co-channel interference) using the two frequencies which are denoted as the post-midnight frequency and the daytime frequency. With this latter scenario, HF communications would be expected to deteriorate for two periods during the day of several hours each at the post-sunrise and the pre-sunset times. If one has at his disposal accurate channel evaluation information as well as targets at a number of different ranges, the five frequency scenario could be used very effectively by several targets sharing the frequencies. However, if all the assets are at approximately the same range and the same sun-time, the ability to share these frequencies will be greatly degraded.2.0

2.0 BACKGROUND

Several years ago NRL Code 4180 embarked on a program to establish validity limits of schemes to update currently available HF channel models using presently available as well as future envisioned data sources. This program is currently couched in the Branch's HF Propagation Assessment
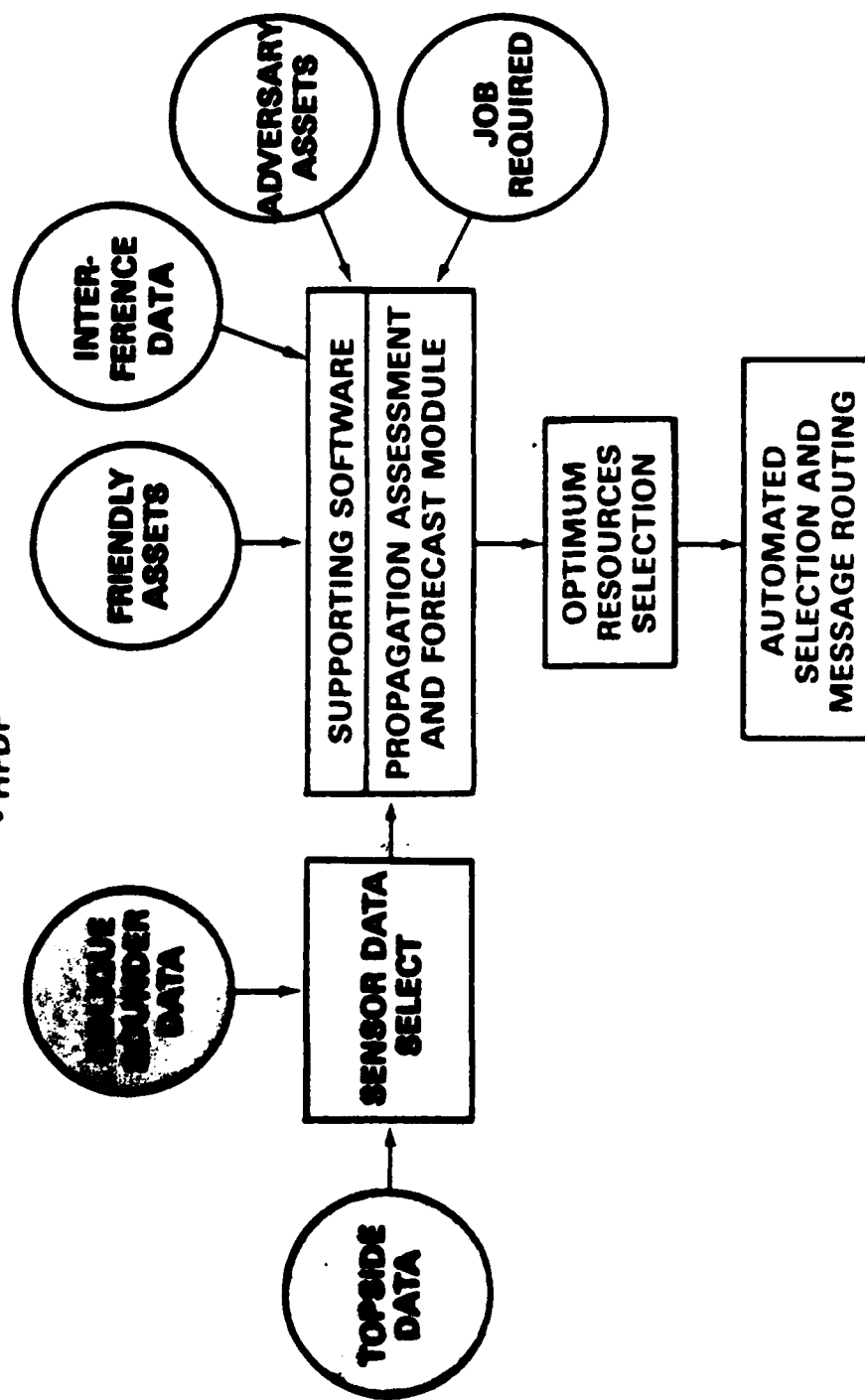
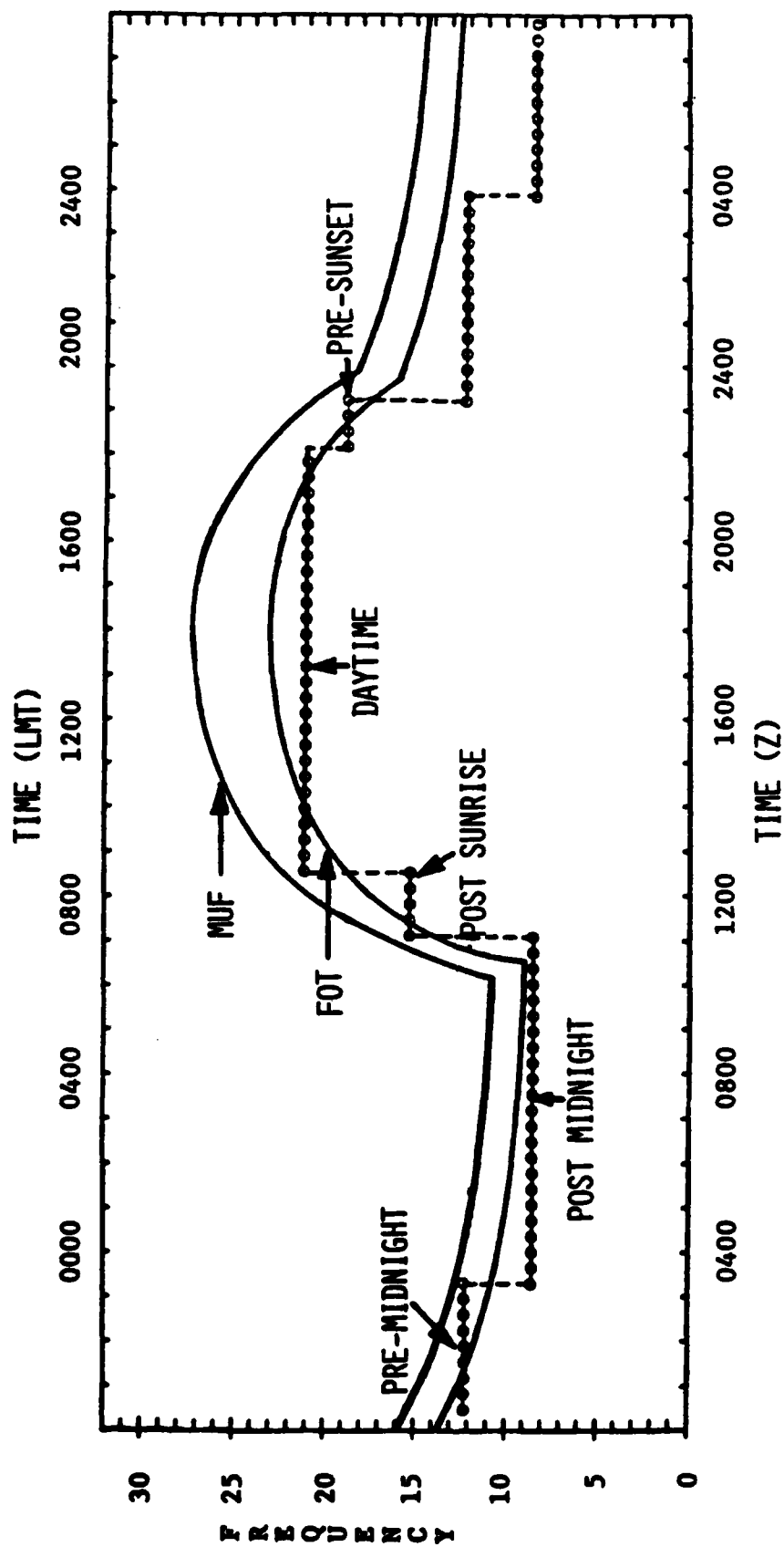Figure 1: A generalized automated H.F. resource management system

Figure 2: Example diurnal variability of the MUF and FOT for a typical day showing a frequency assignment strategy

Program. Components of the program encompass existing models and various
sources of data for the HF skywave channel. The existing models being
examined include but will not be limited to MINIMUF 3.5 (incorporated in the
NOSC PROPHET system) and IONCAP. The instrumentation being examined as
sources of update are oblique incidence sounders (channel evaluators), topside
ionospheric sounders, and vertical incidence sounders. The validity limits to
be established for this concept are temporal perishability, spatial
perishability, geographical dependence, and seasonal dependence.

The oblique sounder data for the model update discussed in this paper are
obtained from the BR Communications Inc. AN/TRQ-35 tactical frequency
management system (TFMS). These data are typically obtained during military
exercises and are in the form of polaroid photographs which are subsequently
scaled for maximum observed frequency (MOF)*, band of optimum transmission
frequencies (FOT band)+, and lowest observed frequency (LOF)**. The
AN/TRQ-35 TFMS equipment utilized to obtain these data are shown in figure 3.

The upper left hand corner shows the chirp sounder transmitter and its
companion receiver is in the lower center portion of the figure. The upper
right hand corner of the figure shows the spectrum monitor which is an
auxiliary piece of equipment used to measure channel occupancy in order to
minimize the selection of frequencies where interferring signals would degrade
the received signal-to-noise ratio. Each unit weighs several hundred pounds
and is rack mountable when removed from its shipping case.

The computer model (MINIMUF 3.5) utilized in this report is encompassed in
the Naval Ocean Systems Center PROPHET System. Figure 4 shows the
programmable calculator (Tektronix 4052) based system on which the model
update and frequency selection is envisioned to be implemented. The
particular configuration of the PROPHET system shown in figure 4 is the Army
PROPHET. Evaluation System (APES) for which a version exists allowing the
model to be updated every three hours. At this time however, frequency
management drawing upon frequency sharing capabilities is not included in APES.

Figure 5 is a drawing which illustrates the approach NRL employs to
perform model update in support of frequency management. The top illustration
in the figure indicates that the actual diurnal variation of the HF channel
over a given link has a characteristic pattern. The model prediction has a
pattern somewhat similar, but quite often a bias is present. The update
process is embodied in the middle portion of the figure. A measurement of the
maximum observed frequency is obtained from an oblique sounding over a known
circuit. The model is forced to fit over that circuit for the specific time
of the measurement. This is accomplished by varying the driving parameter for
the model which in this case is the 10.7 cm flux. After fitting the model at
this one point, it is then computed for the full 24 hour period and under
testing conditions compared to the measured MOF's for the rest of the day. The
comparison is done by calculating the rms error which is the indicator of the
goodness of fit. In tactical scenarios, the parameter which was derived from
the model update procedure is then used to compute other unknown paths. For
testing purposes, the "unknown" paths are typically other sounder circuits in

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* The MOF is defined as the highest F-region frequency over which
  transmission is observed on an oblique incidence ionogram.
+ The FOT Band is the highest band of frequencies exhibiting high signal
  strength and no multipath.
** The LOF is the lowest frequency over which transmission is observed on the
  ionogram.
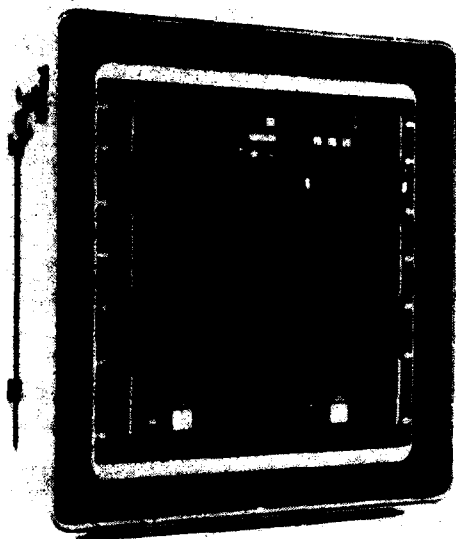
CHIRP TRANSMITTER
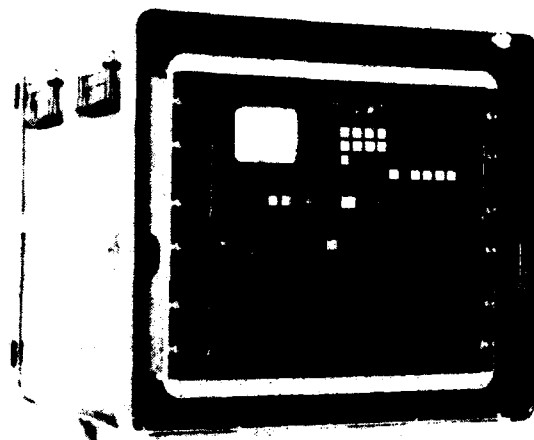
SPECTRUM MONITOR

CHIRP RECEIVER

R-1017

Figure 3: The B.R. Communications AN/TRQ-35 tactical frequency
management system

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INFORMATION FLOW DIAGRAM
ARMY PROPHET EVALUATION SYSTEM
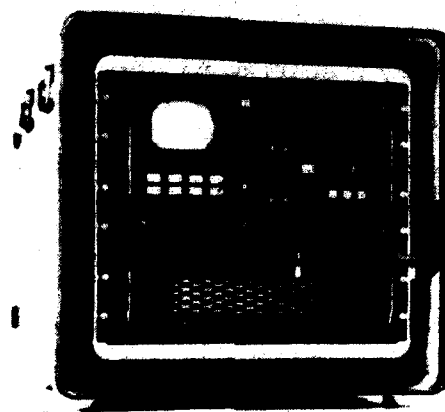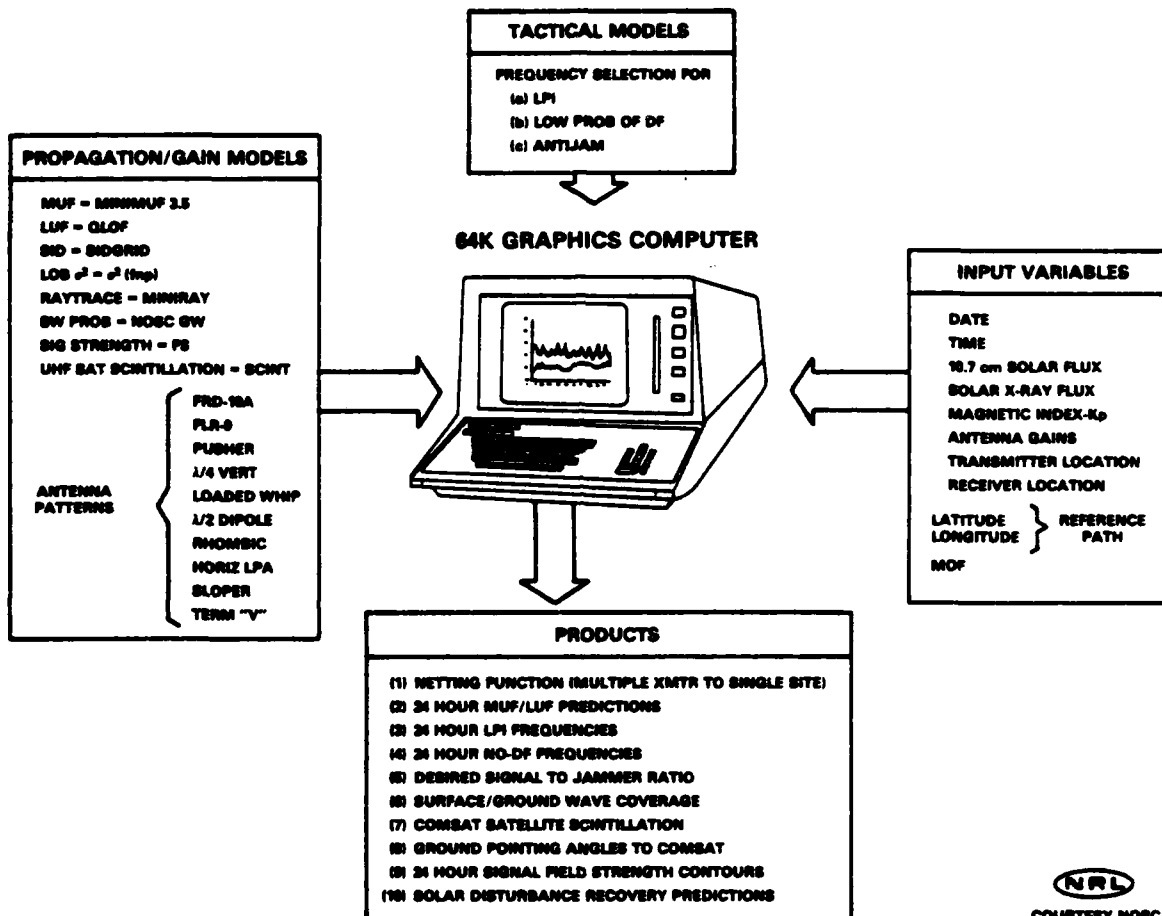### (Version 3 of NOSC HF Tactical Prediction Module-Dec 1980)

TACTICAL MODELS

FREQUENCY SELECTION FOR
- (a) LPI
- (b) LOW PROB OF DF
- (c) ANTIJAM

64K GRAPHICS COMPUTER

PROPAGATION/GAIN MODELS

- MUF = MINIMUF 3.5
- LUF = QLOF
- SID = SIDGRID
- LOS d² = d² (imp)
- RAYTRACE = MINIRAY
- GW PROB = NOSC GW
- SIG STRENGTH = FS
- UHF SAT SCINTILLATION = SCINT

ANTENNA PATTERNS
- FRD-10A
- FLR-9
- PUSHER
- 1/4 VERT
- LOADED WHIP
- 1/2 DIPOLE
- RHOMBIC
- HORIZ LPA
- SLOPER
- TERM "V"

INPUT VARIABLES

- DATE
- TIME
- 10.7 cm SOLAR FLUX
- SOLAR X-RAY FLUX
- MAGNETIC INDEX-Kp
- ANTENNA GAINS
- TRANSMITTER LOCATION
- RECEIVER LOCATION
- LATITUDE } REFERENCE
- LONGITUDE } PATH
- MOF

PRODUCTS

(1) NETTING FUNCTION (MULTIPLE XMTR TO SINGLE SITE)
(2) 24 HOUR MUF/LUF PREDICTIONS
(3) 24 HOUR LPI FREQUENCIES
(4) 24 HOUR NO-DF FREQUENCIES
(5) DESIRED SIGNAL TO JAMMER RATIO
(6) SURFACE/GROUND WAVE COVERAGE
(7) COMBAT SATELLITE SCINTILLATION
(8) GROUND POINTING ANGLES TO COMBAT
(9) 24 HOUR SIGNAL FIELD STRENGTH CONTOURS
(10) SOLAR DISTURBANCE RECOVERY PREDICTIONS

NRL

COURTESY NOSC

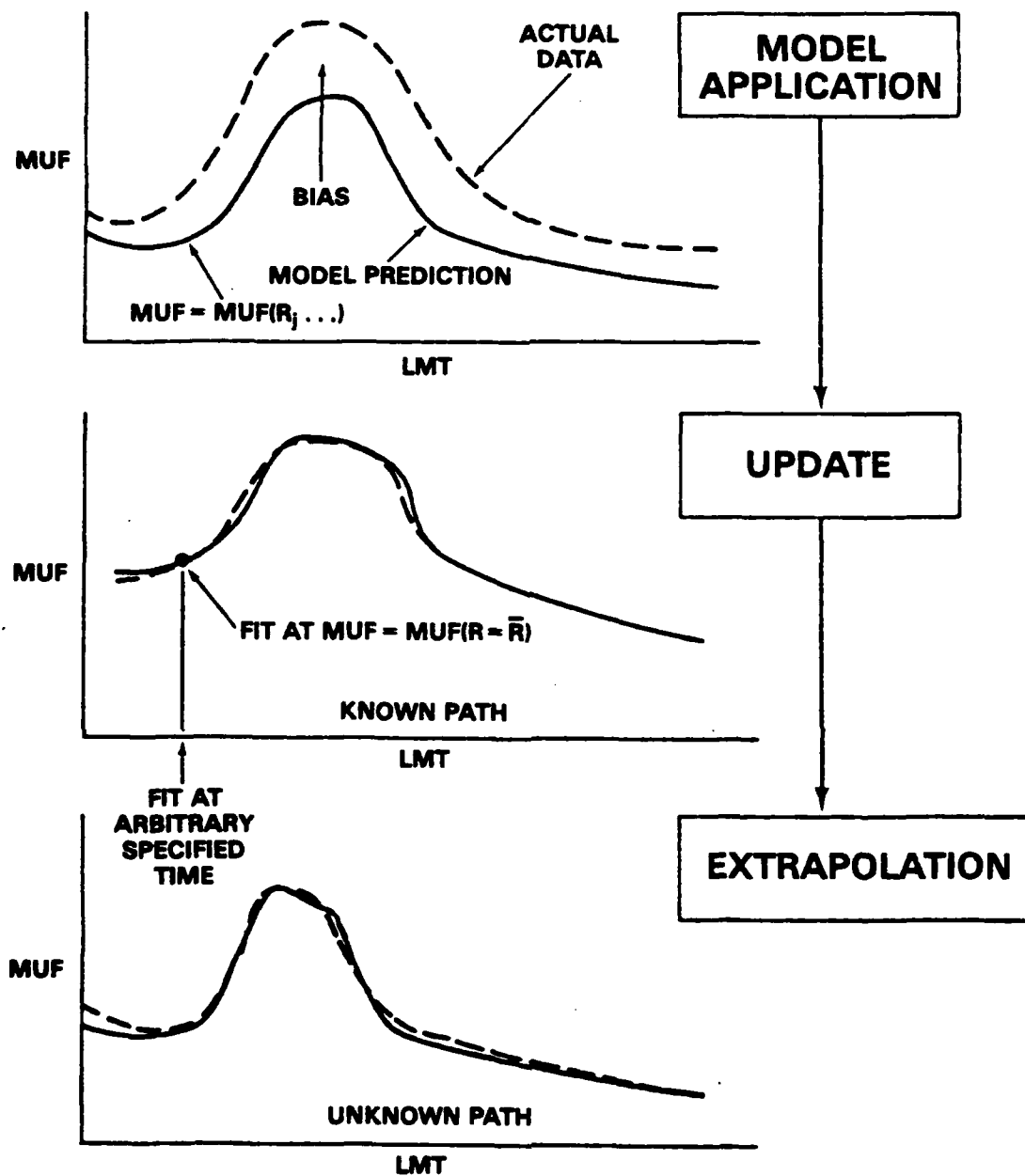Figure 4:   The NOSC PROPHET system as configured for the US Army

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Figure 5: The NRL approach to model update

the network. The diurnal variation of the maximum observed frequency is scaled from those sounder networks, the updated algorithm is run for those circuits, and an rms error comparison is made. The model update is deemed successful if the rms error of the experimental paths (unknown paths in tactical situations) are significantly lower than that yielded by employing the unupdated model.

With this basis, therefore, an attempt is made to show that the model update technique might be successfully employed to manage frequencies such that one frequency may be shared by a number of different assets at different times of the day. Further, by using this concept one obtains a capability to anticipate frequency changes yielding a significant increase in circuit reliability and message throughput. Finally, it is emphasized that this anticipation feature allows one to manage frequencies in a shared mode.

3.0 DISCUSSION

The data drawn upon for the purpose of this report was obtained during an HF communications test which occurred between 10 and 22 November, 1981. For the purposes of this test, oblique sounder transmitters were located at Robins AFB, South Carolina; Isabela, Puerto Rico and on-board a ship operating in the Atlantic. The receiver was located at the Naval Communications Station in Norfolk, Va. Figure 6 is a gnomonic projection (great circle) of the siting configuration. For the duration of this period NRL technicians photographed output from the oblique sounder receiver when transmitters were on the air. Isabela and Robins operated continuously and the ship sounder transmitter was operated intermittently. Data was returned to NRL and scaled for the MOF, LOF and the band of optimum frequency (FOT band) as previously defined.

November 15 and 16 were selected for this report since the data set from the three transmitters is almost complete. The measured and subsequently scaled MOF, LOF, and FOT bands for these dates are plotted in figure 7. Also shown in the figure by the horizontal dark lines are a number of simulated frequency assignments which were selected from the maritime and mobile bands. The values of these frequencies are indicated along the right margin and will be used to demonstrate a capability to share frequencies among the three different sites. In no way however, are these meant to be actual frequencies used. Since the FOT bands are areas of high signal strength and no multipath, frequencies assigned in these bands are the most desirable. Hence, the FOT bands were used to graphically select the frequency assignments along with a priority structure where the ship was given the highest priority, Isabela the next, and Robins the lowest priority. Several items should be noted. First, it is quite simple to select frequencies which are in the FOT band a large percentage of the time for the highest and second priority circuits. For the lowest priority circuit, frequencies are available near the FOT band for a smaller but still significant portion of the day. In addition, a stepped frequency assignment scheme is required in order to stay close to the FOT bands, particularly during transition times. One can imagine that if anticipatory information were available to determine the magnitude and direction of the channel variation, a new frequency could be selected in real-time in advance of the actual frequency change (QSY) and contact could be maintained during these transition times. Because of the anticipating property of the model update concept therefore, one would be able to use the existing frequency in order to communicate the selection of a new frequency such that during times of fairly rapid change, contact is continuous. The

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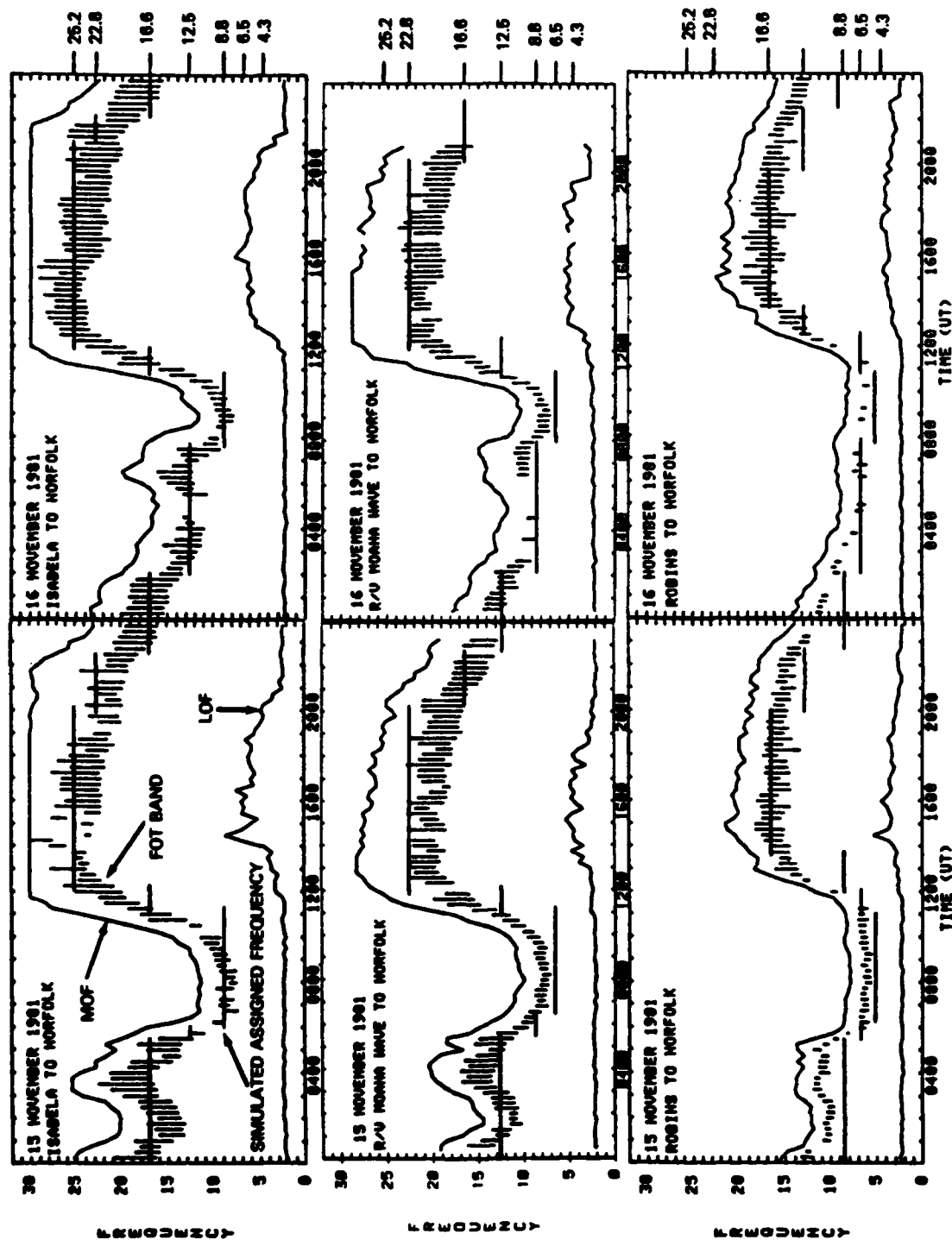Figure 6: Great circle map of H.F. test site configuration

Figure 7: Measured MOF, LOF, and FOT bands for 15 and 16 November 1981

third point to note is that for two of the paths, the ship and Isabela, the distance is great enough that frequencies approach and even exceed the 30 MHz limit of the sounder during a large part of the day-time hours. In this case the FOT band which was selected may not be the true band of optimum transmission frequencies, since that true band most likely lies above 30 MHz and closer to the MOF. Hence, if frequency assets and sounding information were available above 30 MHz, it may be possible to select lower loss and less cluttered frequencies during the day for these long paths. Therefore the 25.2 MHz frequency for Isabela and the ship which matches the scaled FOT bands may not be truly representative of the best frequency available to the user. Finally note that seven (7) frequencies service the three links and have the capability to provide high quality communications for a large percentage of the day. With current frequency assignment systems these three circuits may have used up as many as 30 frequencies. Hence one might envision a large saving in frequency assets due to frequency sharing based on the ability to monitor and anticipate variations in the channel. We will use this constructed frequency assignment strategy against an updated model of the MOF and calculated FOT to demonstrate that a shared frequency assignment scheme based on the model update procedure would closely approach the idealized simulated frequency assignment pattern shown in figure 7.

3.1 The Updated Versus Unupdated Model

The updated model is the basis of the proposed frequency sharing scheme. Therefore prior to embarking on a demonstraton of the viability of updated models as applied to frequency sharing schemes, we will demonstrate the improvement obtained by applying an update derived from an oblique sounder circuit to a model of the maximum observed frequency. To illustrate this, figure 8 is provided. This figure shows the difference between the unupdated model calculation of the maximum observed frequency and the measured maximum observed frequency. The top section in figure 8 indicates the difference between the two numbers when the five day average 10.7 cm flux is used to drive the model. Note that on 15 November the rms error is 5.42 MHz and on 16 November the rms error is 4.62 MHz. The middle portion of the figure illustrates the difference between the measured and modelled numbers when the daily 10.7 cm flux is used to drive the model calculation. In this instance, the daily 10.7 cm flux provided a larger rms error on both days than did the five day average 10.7 cm flux. The daily 10.7 error flux yielded rms errors approaching 6 MHz. The bottom portion of the figure indicates the best possible fit of the MINIMUF model to the observed MUF for a once per day update. This is obtained by running the model against the measured MOF until a minimum rms error is reached for the total day. The resulting 10.7 cm "pseudo-flux" is then used to drive the computation of the MOF. The bottom portion of the figure demonstrates therefore, that with this particular model, the very best one can expect from an update for the circuit between the ship and Norfolk for 15 November is 3.88 MHz rms and 2.58 MHz rms on 16 November. Hence, any model update scheme employed is considered to be doing very well with MINIMUF when the model to observed MOF error computation approaches the minimum possible for that model. It should be noted that the rms errors can be significantly reduced if one allows the fit to occur in segments which are less than 24 hours in length. During disturbed periods of time or for other applications this in fact is done. However, this technique is not shown in this report and will be reported later.
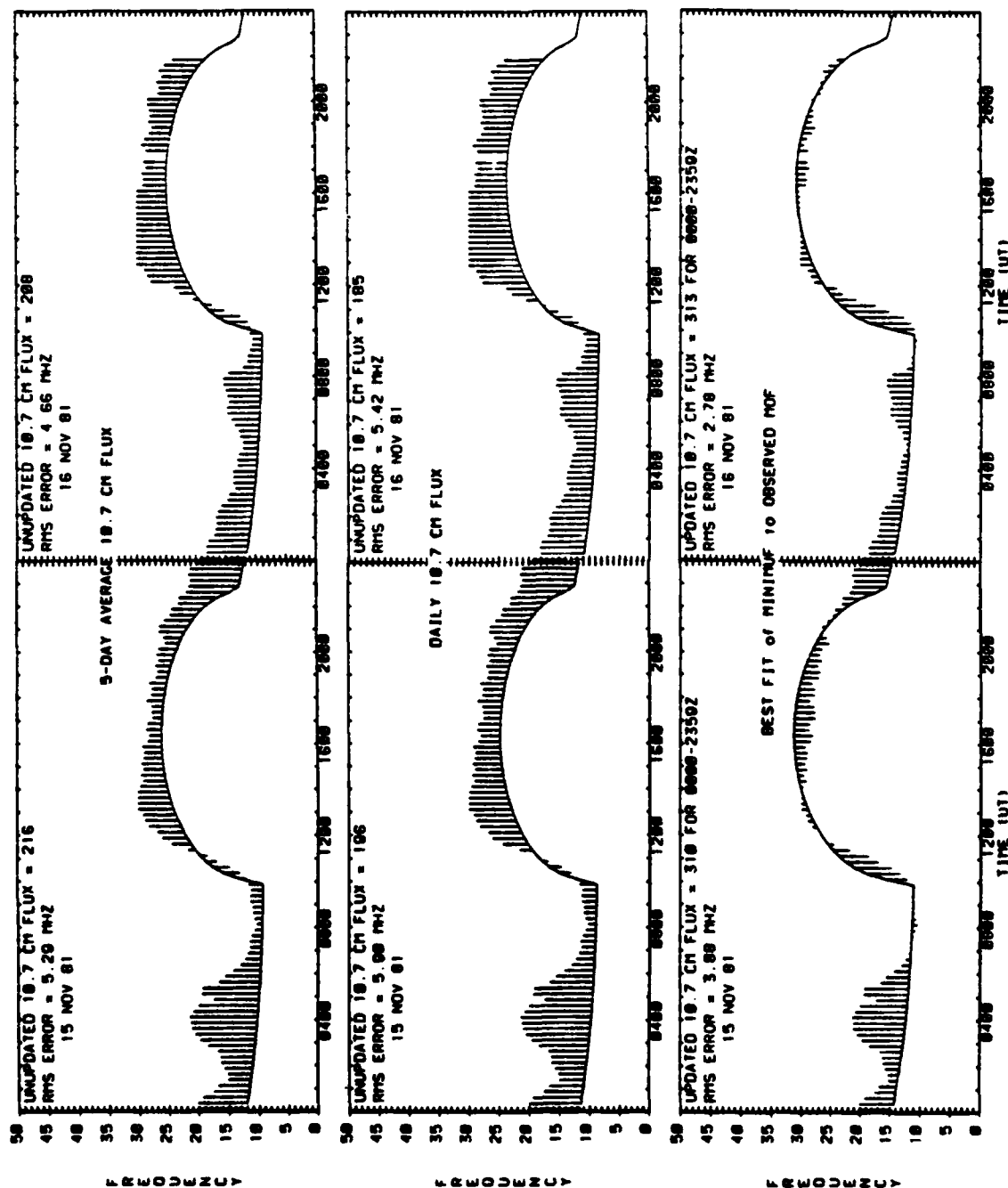
Figure 8: A comparison of the unupdated model with the MOF for data obtained on 15 and 16 November 1981

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For this report an update was performed by using a measurement of maximum observed frequency at 1300Z (0800 LMT) on each day over the Robins to Norfolk circuit. This is shortly after sunrise and this update time is selected based on prior experience with this technique. The resulting 10.7 cm flux, now designated the pseudo-flux, is then used to drive the model for the remainder to the day as well as for other circuits. In the instances shown herein, the 1300Z update drives the model in a hindcasting mode as well as forecasting for that day. This was done since our data are in 24 hour blocks internal to which the update is most usually performed. However, there is no reason why the technique cannot be extended so the update can be performed entirely in a forecasting mode for the following 24 hours of data.

The control path update is shown as the bottom part of figure 9. The pseudo-flux as derived from the control path for each day is next used to drive the model calculation for the other paths which are designated as experimental paths. Figure 9 shows graphically the comparison between the MOF as derived from the model and the measured MOF as obtained from the sounder for these experimental paths. Vertical lines indicate the difference between the two numbers. Also indicated in the figure are the rms errors due to each calculated MOF. It should be noted that when the oblique sounder MOF yields a frequency at 30 MHz the rms error calculation is not performed for that segment since, as is obvious in the top portion of figure 9, there is no information as to the actual MOF over the path. Naturally, the rms error calculation in this case would be erroneous. This is done for both updated and unupdated cases. For example, the data obtained between 1200Z and approximately 2200Z on 15 November over the Isabela to Norfolk circuit is not factored into the rms error calculation even though the graph indicates a large difference between the two numbers. Note however, that the true error is probably quite small since the trend of the data during transition is to agree with the MINIMUF computation. Figure 9 demonstrates that the simple MINIMUF model yields a very good fit in the update mode over the various circuits. Hence we have reached a point where our confidence has been fortified in the possibility that the model update approach may yield accurate frequency selection. In addition, note that if one could obtain more variability in the model itself, such as that produced by IONCAP, the possibility for fitting various features is greatly increased. We currently address this problem with MINIMUF by segmenting the model into shorter periods of time and performing an update on each segment.

The goodness of this fit is indicated more dramatically in Table I. In this Table we have listed the rms error derived for the various model to observed MOF calculations for each path and each day. We note that the update closely approaches the absolute minimum obtainable with the model and the update yields a significant improvement in the rms error between the unupdated model and the measured MOF. Note also that in two instances in the Table, the 1300Z update and the absolute minimum possible are one and the same. These errors may be greatly improved upon by segmenting the update to shorter periods of time and using the shorter segments in time to provide information as to frequency selection.

Hence, we have reached a point where our confidence has been fortified in the possibility that the model update approach may yield accurate frequency selection. In addition, note that if one could obtain more variability in the model itself, such as that produced by IONCAP, the possibility for fitting various features is greatly increased. We currently address this problem with MINIMUF by segmenting the model into shorter periods of time and performing an update on each segment.
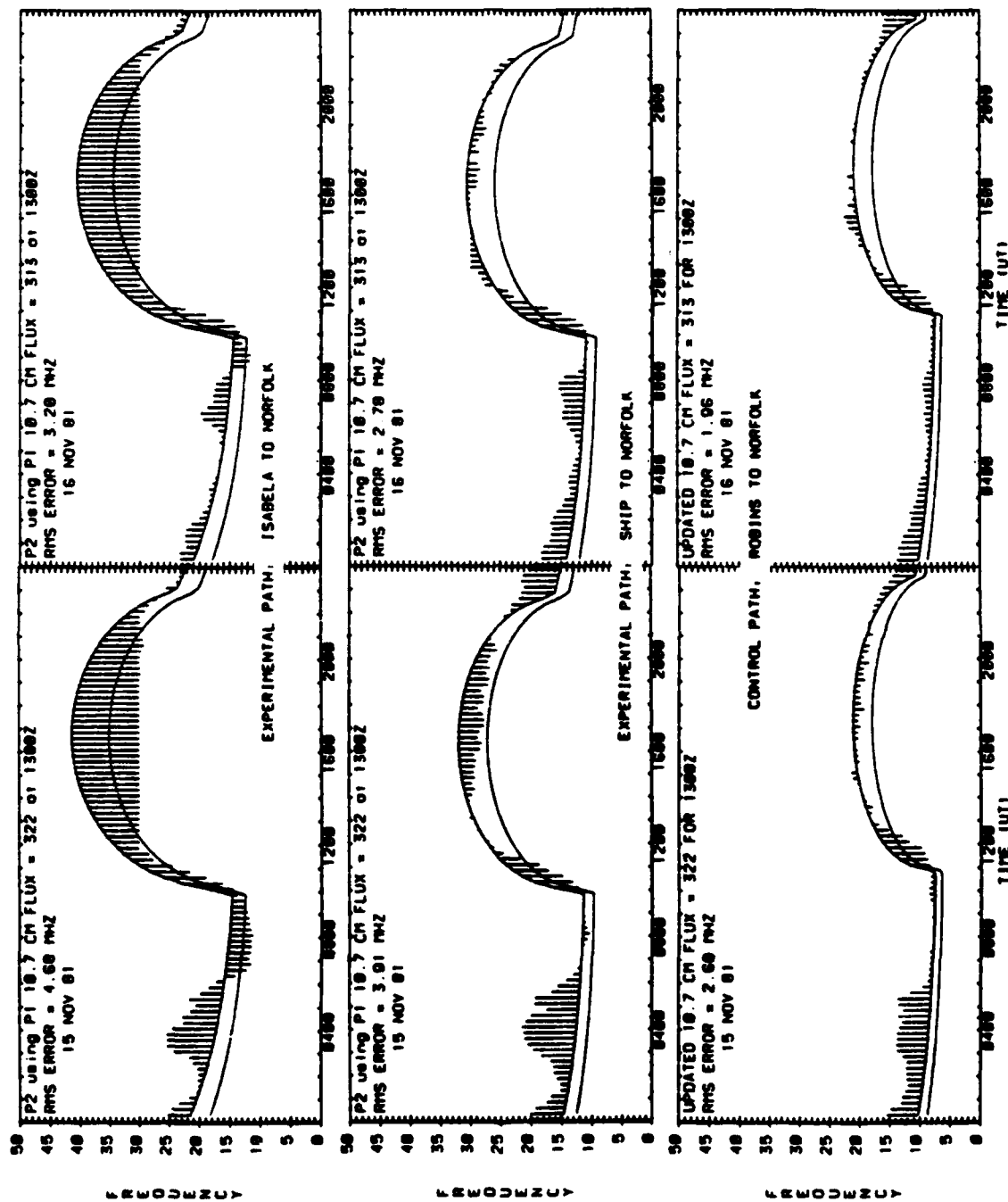
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Figure 9: A comparison of the measured MOF with the updated model using a pseudo-flux derived from the "control path" which is designated to be Robins to Norfolk

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Table I. RMS (MHz) Errors of various situations

PATH / SITUATION	ROBINS TO NORFOLK	SHIP TO NORFOLK	ISABELA TO NORFOLK
15 NOV 81			
5-DAY AVERAGE 10.7 cm FLUX	3.88	5.29	5.05
DAILY 10.7 cm FLUX	4.31	5.90	5.56
ABSOLUTE MINIMUM	2.60	3.88	4.34
1300Z UPDATE	2.60	3.91	4.68
16 NOV 81			
5-DAY AVERAGE 10.7 cm FLUX	3.76	4.66	4.34
DAILY 10.7 cm FLUX	4.35	5.42	5.07
ABSOLUTE MINIMUM	1.89	2.78	3.07
1300Z UPDATE	1.96	2.78	3.20

3.2 The Application of the Model Update Technique to Frequency Sharing

We have established the idea that it may be possible to obtain a very accurate model computation of the expected MOF for circuits in an operational area without having to actively measure each circuit. In order to demonstrate the applicability of a model which is accurately predicting the MOF of the HF channel, we have constructed a case based on the MOF and FOT data first shown in figure 7. In figure 7 we examined the scaled MOF, LOF, and FOT; selected a number of frequencies one might have available from the maritime and mobile bands; and constructed a frequency assignment scenario to simulate communications to the three assets which were represented by the oblique sounder circuits indicated in the figure 7. In doing the construction for figure 7, we roughly prioritized the paths in order of importance where the ship was priority one; the Isabela circuit was priority two; and the control path, Robins, was priority three. Now an attempt is made to show that if one utilizes a model which has been updated by an oblique sounder, the possiblity exists that a frequency selection scenario similar to that constructed by knowing all the conditions might be possible. This demonstration is the essence of figure 10. In figure 10 an overlay of the measured MOF, LOF, and FOT is provided along with the updated MOF and computed FOT (.85 MOF) to further emphasize the success of the technique.

The general rules that were applied in this construction would be quite simple to implement on the computer. The highest priority channels were given frequencies first. Frequencies were selected that were closest to the computed FOT, but not exceeding the computed MOF. Lowest priority paths were given unoccupied frequencies as close as possible to the computed FOT. When higher priority frequencies were projected to drop below about 66% of the FOT, a frequency change was determined to be in order and lower priority circuits were appropriately shifted in frequency. During transition times, frequencies were maintained for at least an hour and the "66% of the FOT" rule was relaxed.

Using the overlay of the actual channel data, one may deduce potential problems or improvements that have been obtained. Upon first comparison of figure 7 and figure 10, the frequency scenarios are almost identical. Since the priority scheme has been strictly enforced in figure 10 due to the fact that one is constructing the frequency scenario based on a computer algorithm, there are some slight differences between the two. The most striking differences occur in the top portion of figure 10. In two instances, the computed frequency exceeded the measured MOF by a small amount for periods of time not exceeding three hours. In most other instances, however, the computed frequency remained quite close to the measured FOT indicating that communications would be highly reliable at those times.

The actual implementation of the priority structure and the rules for frequency sharing have not been implemented on the computer. This report is an exercise in determining the applicability of the model update technique to sharing frequencies as well as an exercise to determine the rules that should be followed in constructing a computer algorithm to do this. This indicates that the application of a highly accurate updated model to frequency management problems could provide a new scheme of frequency management based on the pooling of frequencies and the sharing of frequencies in the pool among a number of terminals.

Finally, figure 11 has been included to indicate the possibility that the reliability of the frequency selection by the computer might be increased by selecting a different criterion for the FOT as related to the MOF. In this
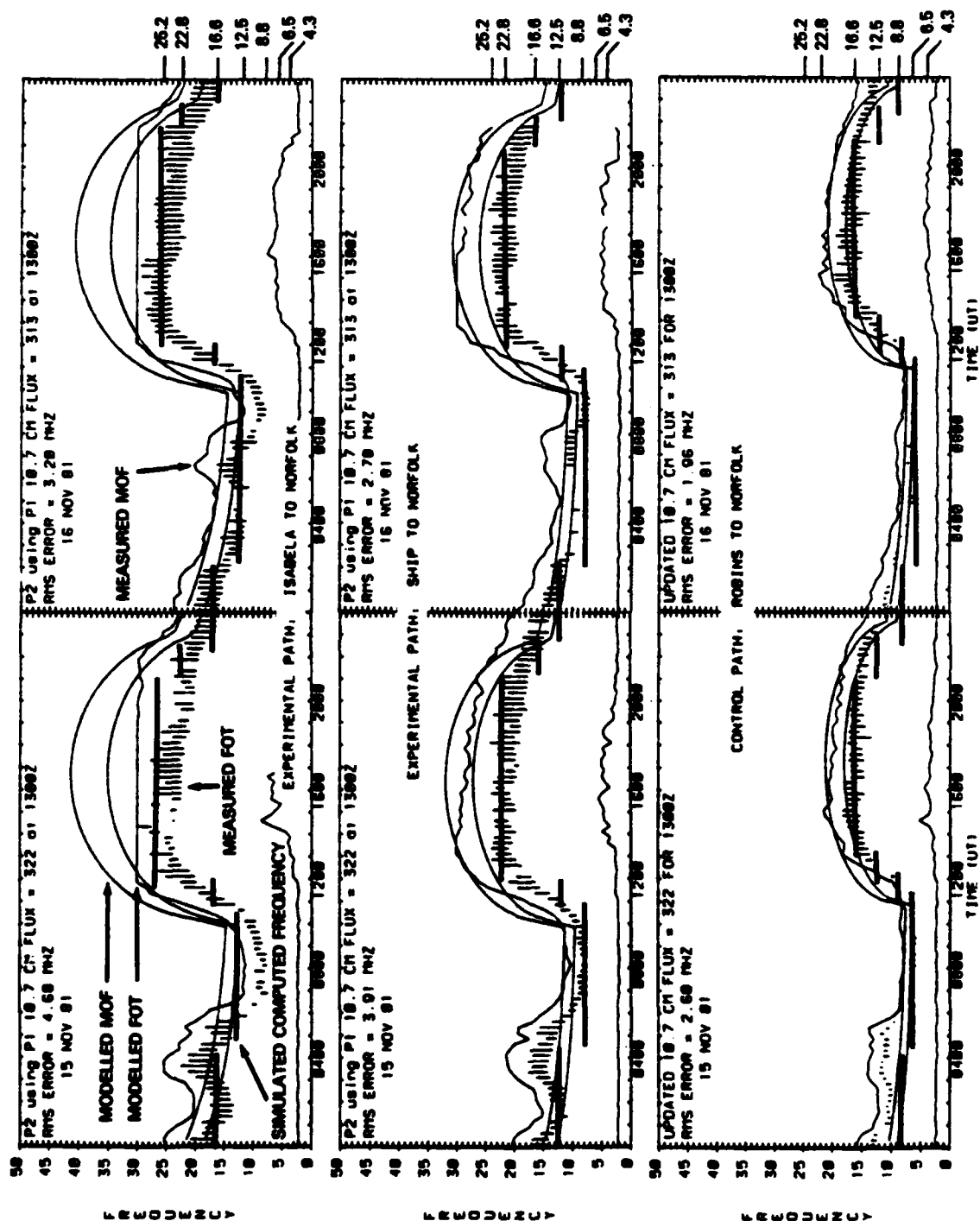
Figure 10: A simulated frequency selection scenario using updated model data
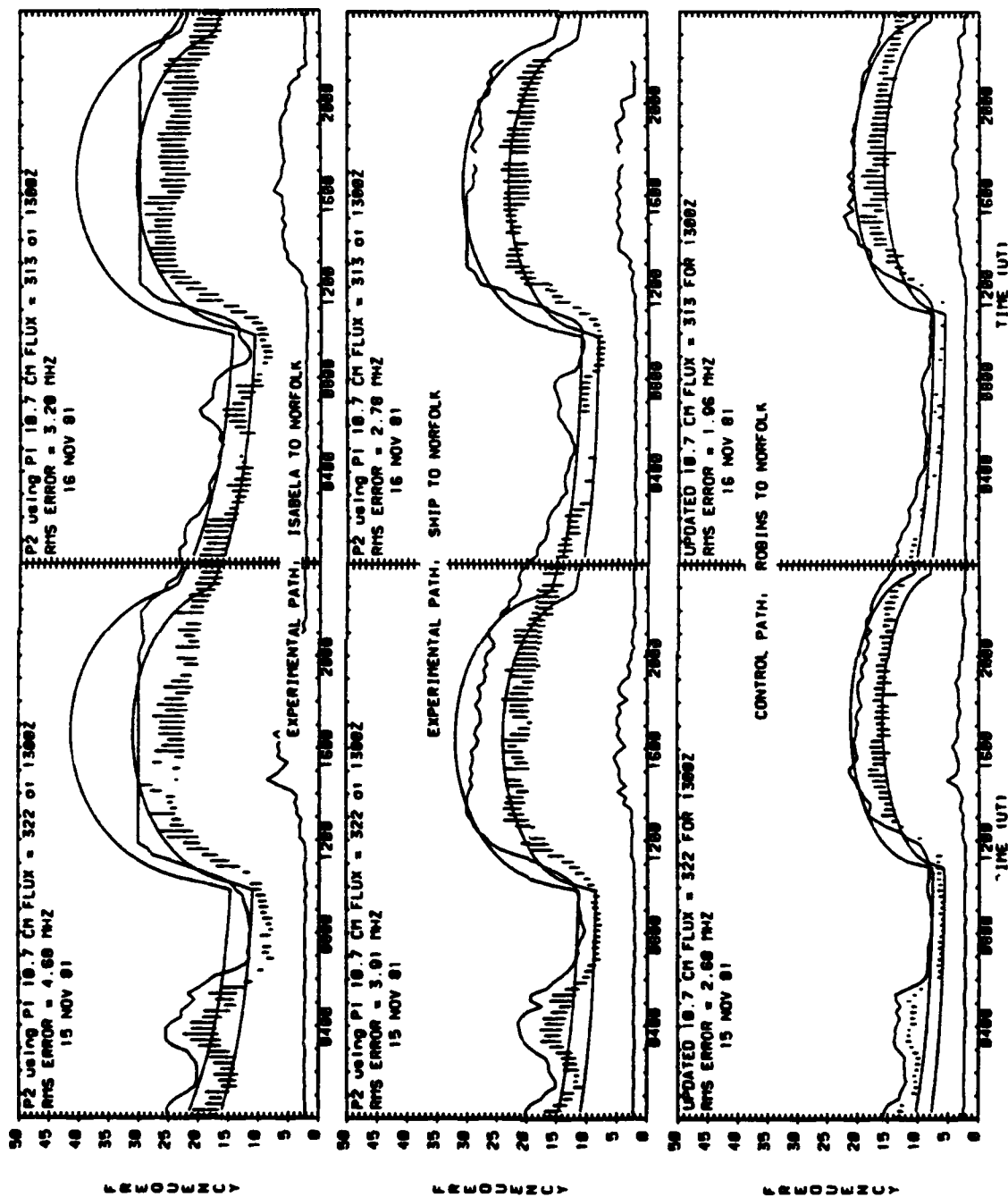
Figure 11: Updated model using a FOT = .75 MOF calculation

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figure, .75 x MOF was used to compute the FOT. We note that the computed FOT and the actual measured FOT are much more closely aligned here than in the previous figure where .85 of the MOF was used to compute the FOT. This .75 factor has been used in other systems (e.g., NOSC PROPHET system) to do different types of calculations. It is possible that further work in examining the FOT factor will lead to an improved algorithm for selecting shared frequencies.

4.0 CONCLUSIONS

This report has presented work whereby a simple model of the maximum observed frequency, MINIMUF 3.5, has been updated by oblique sounder information in a very simple manner. If this technique can be substantiated over a wide range of geographies and situations, the applications to tactical situations appear to be quite broad indeed. The specific application of this technique to the method of sharing frequencies as obtained from a pool of frequencies has been discussed in this report. Simulations provided herein indicate that it is probably worthwhile a exercise to implement a computer based scheme to do frequency management from a frequency pool employing a simple model of a maximum observed frequency as driven by an oblique sounder circuit. The benefits to be accrued from this if successful, are wide ranging and can lead to a great increase in the efficient use of a very limited number of HF frequencies. NRL Code 4180 will be pursuing this effort in order to impact automated HF resource management systems of the future .

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