

Real-Time Update of Two H.F. Channel Evaluation Models by Oblique Sounding

D. R. UFFELMAN* AND P. A. HOOVER

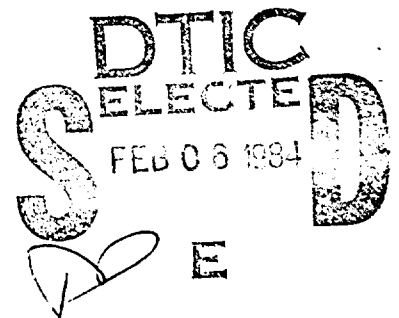
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) → The Naval Research Laboratory (NRL) has been examining techniques by which the HF propagation channel may be more accurately characterized by providing a real-time update capability to existing models of the channel. Several update sources are envisioned including data from vertical incidence sounders, topside sounders, and oblique sounders. This paper discusses new results obtained by updating two currently available models with oblique sounder data. The oblique sounders used (Continues)														

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20. ABSTRACT (Continued)

are associated with the BR Communications, Inc. AN/TRQ-35 tactical frequency management system (TFMS) currently in use by the Department of Defense. The approach is to obtain maximum observed frequency (MOF) information from an oblique sounder for a specific reference path. This information is used to obtain an update by forcing the model to fit the measurement over the reference path. As a measure of effectiveness, the updated model is then used to compute MOF's for experimental paths where MOF data are available coincident in time. In tactical scenarios, these would be unknown paths over which information is desired. Initial work indicates that providing a real-time update to a model from an oblique sounder may significantly improve the performance of the model over the reference as well as the experimental (unknown) paths.

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REAL-TIME UPDATE OF TWO H.F. CHANNEL EVALUATION MODELS BY OBLIQUE SOUNDING

1.0 INTRODUCTION

1.1 Objective

The objective of this report is to present new results obtained by the Ionospheric Effects Branch (Code 4180) of the Naval Research Laboratory (NRL) in a project whose objective is to provide a significantly improved capability for real-time propagation assessment and short-term forecasting of the HF channel in support of tactical missions. This is not a model development effort and it draws upon off the shelf models of the HF channel which may be modified to be updated by currently available ionospheric sensing instruments. The new results to be discussed concern our first attempt to update the model IONCAP using MOFs which were obtained from an oblique sounder net operating in the mid-latitude Atlantic region. These results will be compared with the application of the same technique to the much simpler model MINIMUF 3.5.

1.2 Summary of Results

The work done for this paper yielded mixed results. The NOSC model of maximum usable frequency (MUF), MINIMUF 3.5, was updated with oblique sounder information from one of the paths in a mid-latitude Atlantic sounder net. The results from this update indicate that MINIMUF was improved upon in its estimation of the MUFs over paths in that net. The same update process was applied to the MUF computation in the well known IONCAP model and the initial results indicate that IONCAP was only slightly improved upon. These results are encouraging enough, however, that this idea should be pursued with a larger data base in order to demonstrate its viability.

2.0 BACKGROUND

2.1 The NRL Program

For the past several years, NRL Code 4180 has evolved a program to provide accurate assessment and short-term forecasting of the HF propagation channel in support of tactical missions. The objective of this HF propagation assessment program is to establish the limitations of various schemes to update currently available channel models using presently available as well as envisioned future data sources. This program is composed of two major components which include existing models and data to update these models. The existing models being considered under this program are the MINIMUF 3.5 model of maximum usable frequency which is encompassed in the NOSC PROPNET system

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and IONCAP, a model which has been in a continuing state of evolution and originated at ITS. Other models will be considered as they become available and as time permits. Data sources considered in this program are oblique sounders (channel evaluators), vertical incidence sounders, topside sounders, total electron content (TEC) sensors (polarimeters), and insitu measurements of various types. The validity limits to be established for the various model/data source combinations are: temporal perishability, spatial perishability, geographical dependence, and the seasonal dependence.

The goal of this work is to provide the foundation of a system which will yield both real-time and anticipatory (short-term forecasting) selection of HF assets to perform various tactical C³I tasks in an optimum fashion. Applications of this effort are to HF asset management in general which includes the solution of problems dealing with frequency, antenna, and power determination. This effort would address problems in communications, networking, jamming, HFDF, and the general area of vulnerability analysis which encompasses signal security and anti-jamming. A number of benefits might be accrued from the successful conclusion of this work including reduced equipment assets and a reduction in the required manpower and training levels to operate HF radiating systems. In addition, one might expect increased HF circuit reliability and message throughput; a tactical HF propagation assessment capability and a capability to more effectively manage HF intercept resources. Although this program is not funded as an integral unit, NRL Code 4180 has been addressing various aspects of the problem as opportunities become available to accumulate the data and perform segments of the work.

2.2 An Automated HF Resource Management System

Verification of techniques which estimate characteristics of the HF propagation channel may be generally applied to systems that perform automated HF resource management. In fact, the ability to perform extremely accurate calculations of the HF channel upon which decisions can be based is the cornerstone of this type of system.

Figure 1 is a functional block diagram of such a system as envisioned by the author. Located near the center of the figure is the key to the successful operation of the system which is denoted as the propagation assessment in forecast module. This module should be driven by some type of real-time sensor data. For the purposes of this paper, an oblique sounder operating over a reference circuit is the sensor of choice. In addition, a set of supporting software which handles the decision making process regarding frequency selection is fed by the propagation assessment and forecast module. This supporting software would take into account the placement and condition of friendly assets, the condition and function of the adversaries assets, interference information, and some priority structure for these as related to particular jobs which must be accomplished. Factoring this information against the condition of the propagation medium, the system should be able to make an automatic determination of an optimum selection of resources. This will be required to be done on the computer since the problem is far too complicated and detailed for the human to perform. As a further refinement to these future systems, one could automate the actual selection of resources and message routing through these resources. A system of this sort could have direct application to currently planned automated systems such as that envisioned by NATO in the CROSS FOX Program.

AUTOMATED H.F. RESOURCE MANAGEMENT

APPLICATIONS

- CGMM
- JAM: A.J.
- SIG SEC
- HFDF

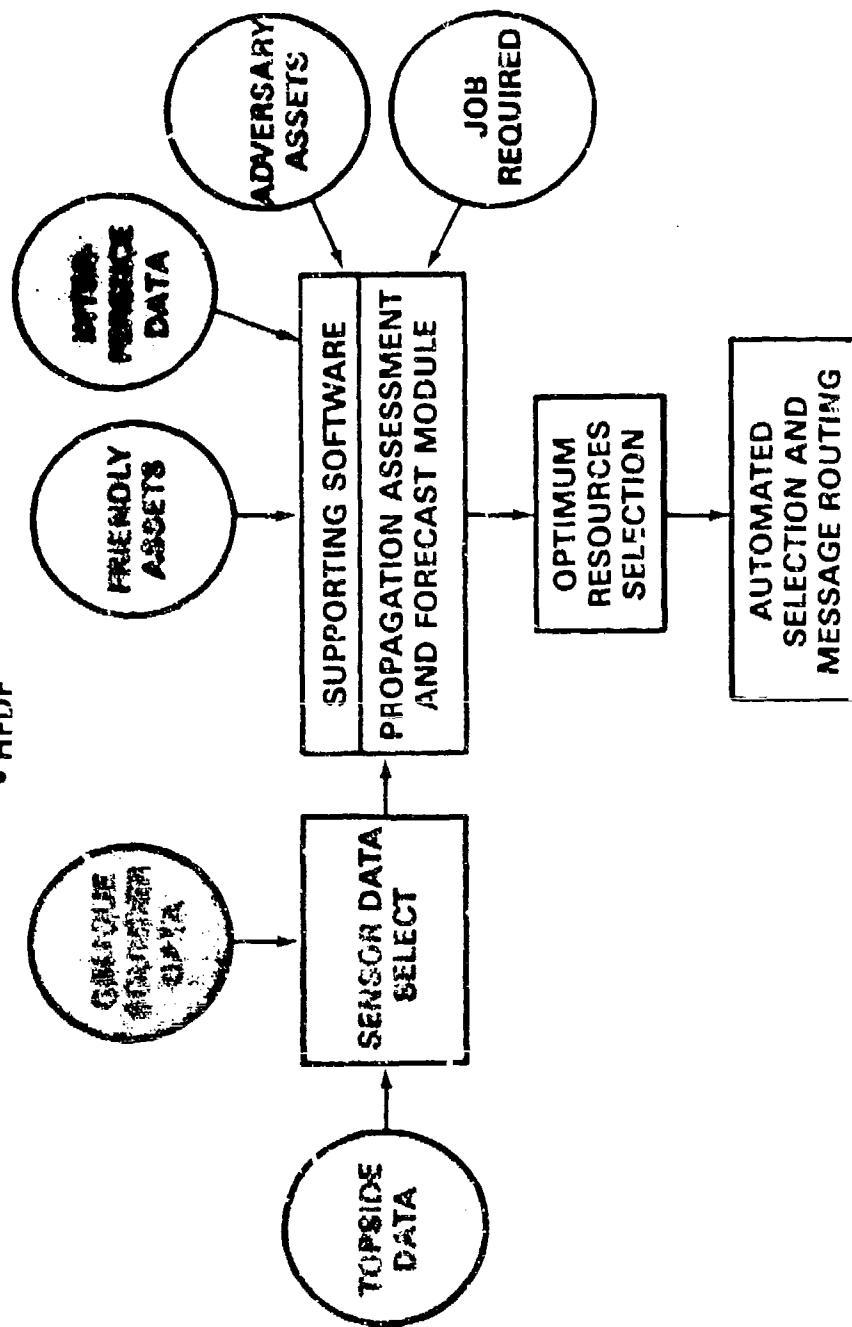


Figure 1. Conceptualization of an Automated HF Resource Management System.

3.0 DISCUSSION

3.1 Technique

The data source which feeds the propagation assessment module could be the AN/TRQ 35 tactical frequency management system (TFMS) which is currently used by the DoD. Figure 2 is a picture of this system which includes three separate pieces of equipment. The upper left hand corner shows the chirp sounder transmitter to which the chirp sounder receiver (located in the lower center) must be synchronized. The upper right hand corner shows an ancillary piece of equipment, the spectrum monitor, which allows one to determine some measure of the spectrum occupancy at the desired frequency. For the purposes of this paper, only output from the chirp sounder receiver is utilized. It is acknowledged, however, that interference data is extremely important to this problem and spectrum occupancy information in some form will be required in an integrated system.

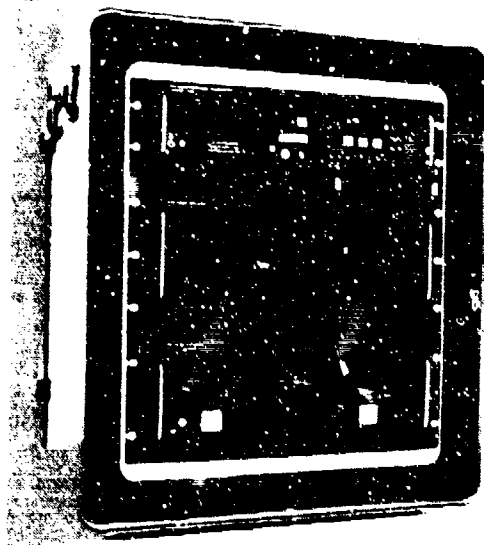
A form of the second major component of the propagation assessment program is represented in figure 3. This figure shows a picture of the Naval Ocean Systems Center (NOSC) Army PROPHET evaluation system (APES), with the particular characteristics of the system detailed. NRL's contribution to this effort is to provide a real-time update to PROPHET which is envisioned to make the system operate more accurately in a real-time and short-term forecasting mode. The portion of the system for which the update is provided is the model of the MUF, MINIMUF 3.5, which calculates the maximum usable frequency of the HF circuit in question.

The general approach to update is indicated in figure 4. Over a given circuit, the channel typically exhibits a diurnal variation of the maximum usable frequency somewhat like that displayed by the dotted line in the top part of the figure. A model tends to show the same type of diurnal variation, but quite often a bias is present. This is represented by a solid line in the figure. This calculated MUF is generally a function of some parameter such as sunspot number or 10.7 cm flux. The NRL approach is quite simply to force the model to fit at a specified time over a measured path, which is designated the reference path. The fit is accomplished by performing successive calculations of the maximum usable frequency while varying the driving parameter, in this case the sunspot number, until the model fits the measurement from the sounded circuit. The resulting sunspot number which yields this fit is then used to drive the model for the same path at future times as well as for other paths of interests. This new number is now designated the "pseudo" sunspot number. In experimental situations, the data from other sounder circuits in the network are compared to the model calculations driven by the pseudo sunspot number. These experimental paths are equivalent to unmeasured circuits in tactical situations.

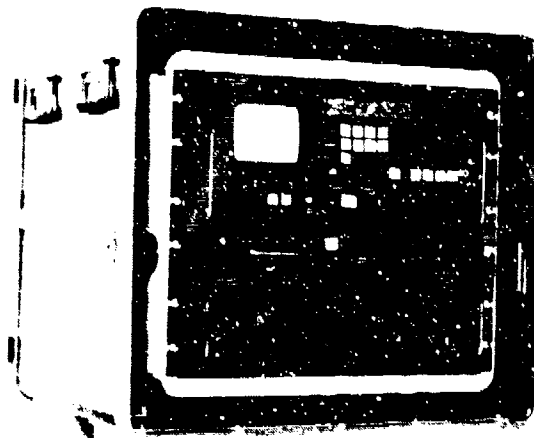
3.2 Results

3.2.1 IONCAP Update

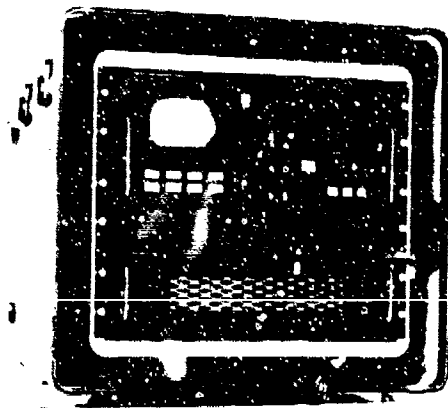
This report will document our first attempt at applying this technique to the MUF portion of the model IONCAP. In addition, we will compare the results of the IONCAP work to on-going work with the MINIMUF computer code which performs the MUF calculations in the PROPHET system. The data base used to do this work was obtained during an HF communications test in November 1981. The experimental configuration for this test is shown in figure 5. Oblique



CHIRP TRANSMITTER



SPECTRUM MONITOR

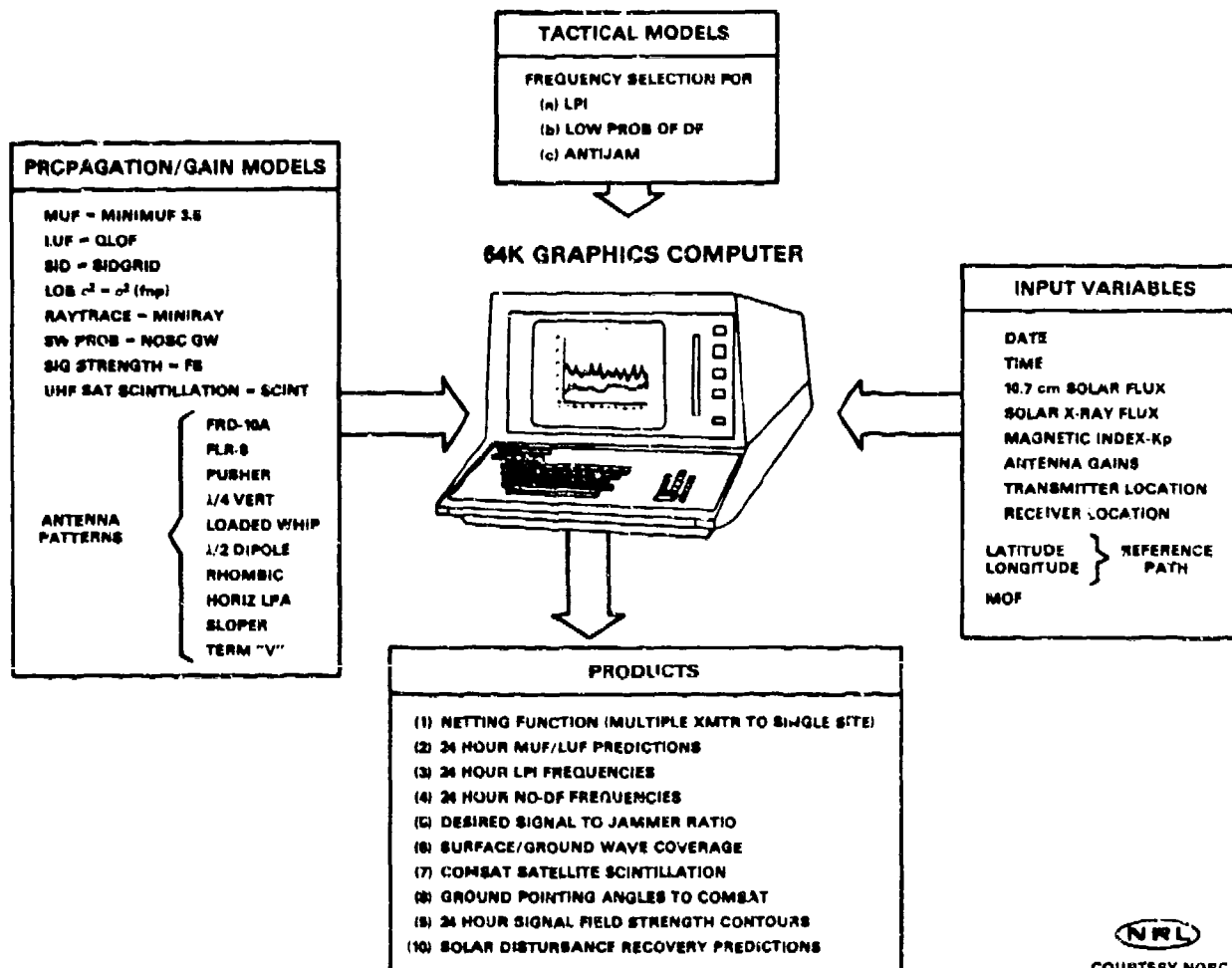


CHIRP RECEIVER

R-1017

Figure 2. The BR Communications, Inc. AN/TRQ-35 TFMS which is used as a data source for update work.

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



NRL

COURTESY NOSC

Figure 3. The APES System on which update can be performed.

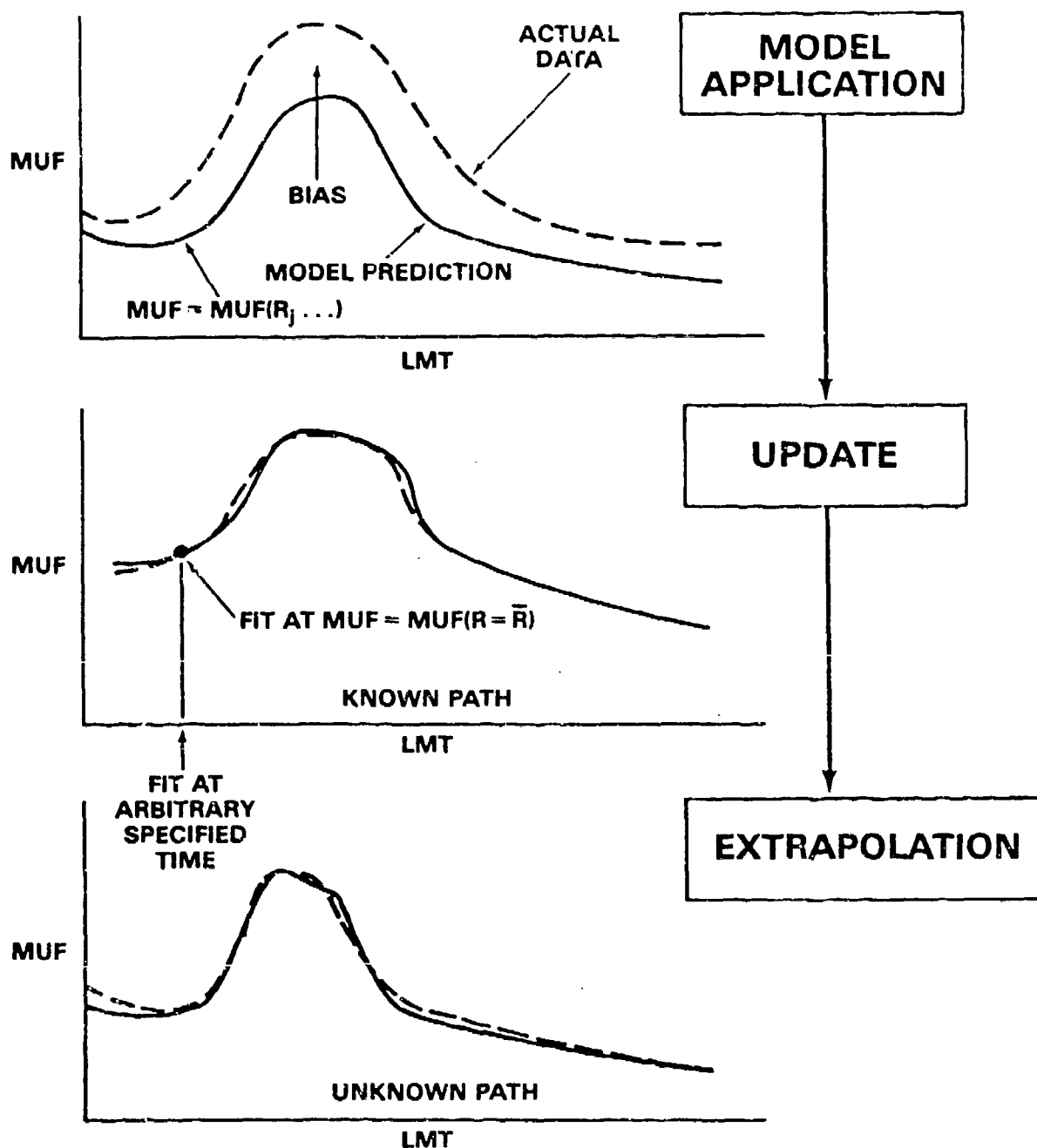


Figure 4. The NRL Approach to Model Update.

sounder transmitters were located at Robins AFB, SC; Isabela, Puerto Rico; and on-board a ship operating in the Atlantic. The ship was moving extremely slow and for the two days for which data is shown, the ship was approximately 1640 km and 112° from the receiver site located at the Naval Communications Area Master Station (NAVCAMSLANT) in Norfolk, Va. The Isabela transmitter is 2280 km and at 154° from Norfolk, and the Robins transmitter is 820 km and at bearing of 287° from the Norfolk receiver site.

The two days selected for this report are November 15 and 16, 1981. These were selected because the data set is generally complete for this period of time. Data obtained from the ship transmitter at other periods of this operation were somewhat sporadic since the ship's crew often shut the sounder transmitter down. NRL technicians located at NAVCAMSLANT obtained data from the oblique sounder receiver in the form of Polaroid photographs. These photographs were subsequently returned to NRL and scaled for maximum observed frequency (MOF)+, a band of optimum transmission frequencies (FOT band)*, and the lowest observed frequency (LOF)**.

Figure 6 is a plot of the scaled data for 15 through 16 November. Shown in this figure are the measured MOF, which is the highest solid line, the measured LOF, which is the lowest solid line, and the FOT bands, which are the vertical lines between the MOF and the LOF. The scalings for the three paths are shown in the figure where the longest path is displayed on top down to the shortest path on the bottom. Data from the two longest paths indicates MOFs above 30 MHz during some parts of the day. These data are scaled from the sounder and the instrument does not have the capability to operate above 30 MHz. Because of this situation, we have selected the Robins to Norfolk path as the source of the update (reference path). This path provides for MOFs within the sounder range throughout the full 24 hour day. Clearly it is not reasonable to derive an update at times and from circuits which show the 30 MHz thresholding effect, since the true value of the maximum observed frequency is not known. In addition, when comparing the model with the measured MOF, numerical comparisons are not made in areas where the sounder has thresholded at 30 MHz since the true values are not known.

In prior work done in this area, NRL has drawn upon the NOSC PROPHET system and its MINIMUF 3.5 algorithm to provide tactical frequency management information. This report contains the first attempt we have made to use the MUF calculation of the much larger and well known IONCAP program. To perform comparisons in the same way as has been done with the MINIMUF code, we have run the IONCAP program on the NRL Space Science Division VAX 11/780 computer. The MUF vs time data was then output in tabular form and hand keyed into the Tektronix 4052 terminal which is currently used to do our model update comparisons. The results of this initial effort are shown in the next few figures.

+MOF: The Maximum Observed Frequency (MOF) as scaled from NRL photographic data is the highest frequency observed on which transmission occurs over the circuit.

*FOT band: The FOT band is the highest band of frequencies which exhibits high signal strength and no multi-path.

**LOF: The lowest observed frequency (LOF) as scaled from NRL photographic data is the lowest frequency on which one observes energy transmitted over the circuit.



Figure 5. Experimental Configuration of a November 1981 HF Communications Test.

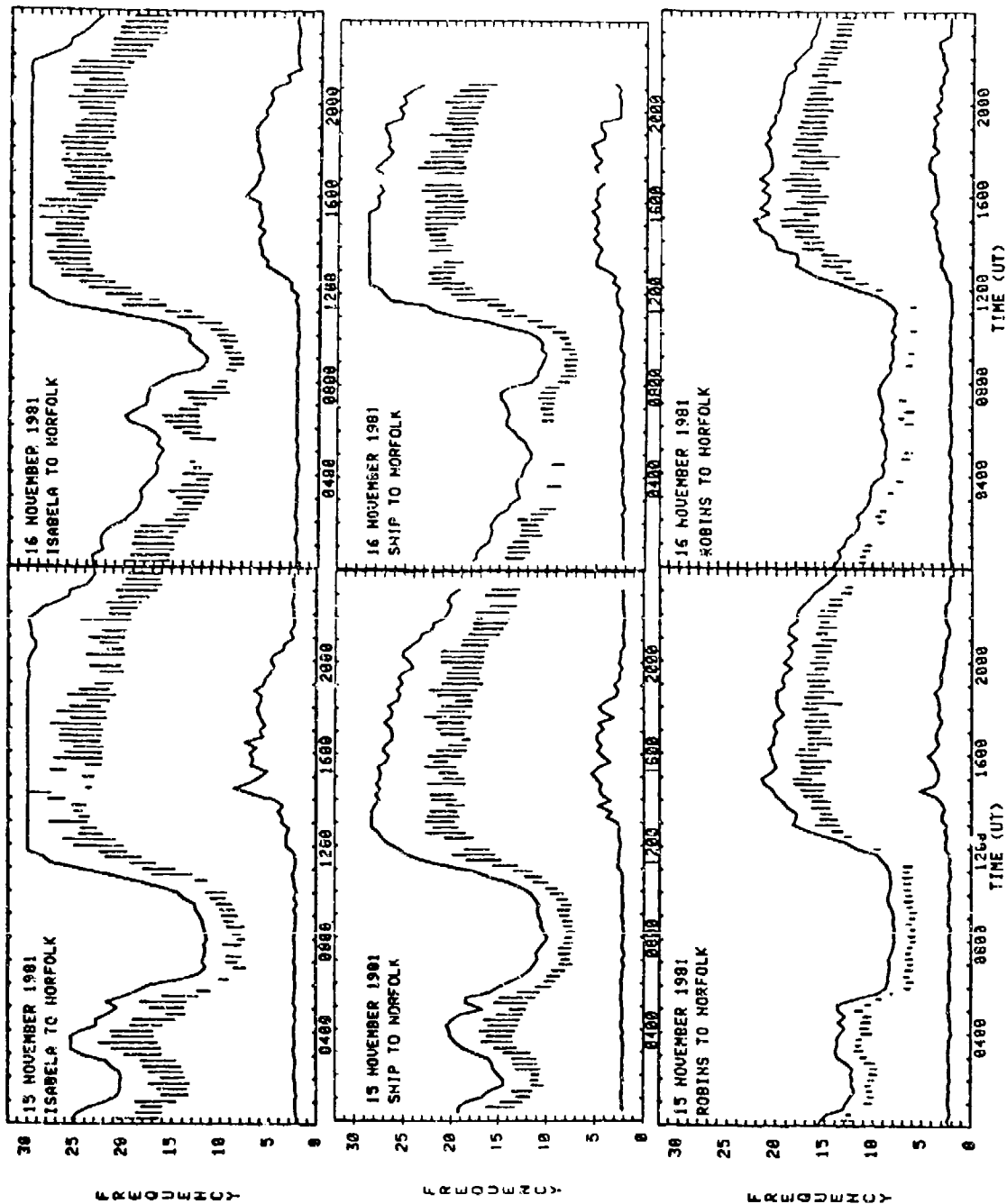


Figure 6. Measured MUF, LOF, and FOT for 15-16 November 1981 in the N.J.-Atlantic region.

Figures 7, 8, and 9 show the difference, indicated by vertical lines, between the actual (scaled) maximum observed frequency and the calculated IONCAP MUFs for the various paths indicated. For these illustrations, IONCAP was driven per instruction [4] by the twelve month running average sunspot number as well as by the five day average sunspot number, and by the daily sunspot number. It should be noted that the instructions [4] clearly caution the user not to use the short-term sunspot numbers for calculations. In the case of the MUF/MOF comparisons, if the results are improved upon we believe that the end result justifies the means. In the context of this report however, each of these three types of computations will be classed as unupdated modeling, since the real-time oblique sounder data was not used to drive the computation.

Figure 7 shows the result of "unupdated" IONCAP MUF computations for the Robins to Norfolk path on 15 and 16 November 1981. The rms error associated with each day and each path is shown in the upper left hand corner of the relevant plot. We note that on days when the midnight increase in MOF occurs, the rms error is somewhat worse for the IONCAP to observed MOF comparison due to this phenomenon. This occurs most notably on 15 November in figure 7. On November 16, the "improperly used" five day average sunspot number yielded particularly good results for the IONCAP to measured the MOF comparison where the rms error is only 1.5 MHz for the full 24 hour period.

Figure 8 shows the same comparisons as figure 7, but for the next longest circuit which is the ship to Norfolk link. Over this path, the rms errors are somewhat worse than in the previous case but still respectable considering that this is an unupdated model. Again, the five day average sunspot number is the driving parameter which appears to yield the best fit to the true measured maximum observed frequencies. The rms errors for the twelve month running average are 3.6 and 2.68 MHz for November 15 and 16 respectively, while the five day sunspot numbers yielded 3.1 and 2.14 MHz for November 15 and 16, a definite improvement in the model performance.

Figure 9 is the IONCAP to sounder data comparison for the longest path which is the Isabela to Norfolk circuit. In this situation, a large portion of daylight hours yielded sounder data which is thresholded at the 30 MHz upper limit of the sounder. At these data points, the rms error calculation is not made even though the large area of vertical lines misleads one to think that there is an error. The trend is such however, that if sounder measurements were available above 30 MHz, the error should be quite small over this region. The large rms error for this case comes about from the midnight increase of the maximum observed frequency. If one excepts this particular situation which lasts about four hours around midnight, the unupdated model appears to fit the actual measured MOF in a very respectable fashion.

Next we consider the applicability of the NRL update technique to enhancing the MUF calculation in IONCAP. The IONCAP computation was forced to fit the measured maximum observed frequency at a point in time somewhat after local sunrise on the reference path (Robins to Norfolk). Figure 10 illustrates the result of using the Robins to Norfolk reference path data to force IONCAP to fit at 1500Z. This fit yielded a pseudo-sunspot number which was then used to drive the the IONCAP calculation for the remainder of the day over the Robins to Norfolk path. The resulting rms error was improved upon over the 12 month running average for both 15 and 16 November. This same pseudo-sunspot number was then used on each day to drive the calculation for the other two paths. Again the update improved upon the accepted way for computing MUF with IONCAP.

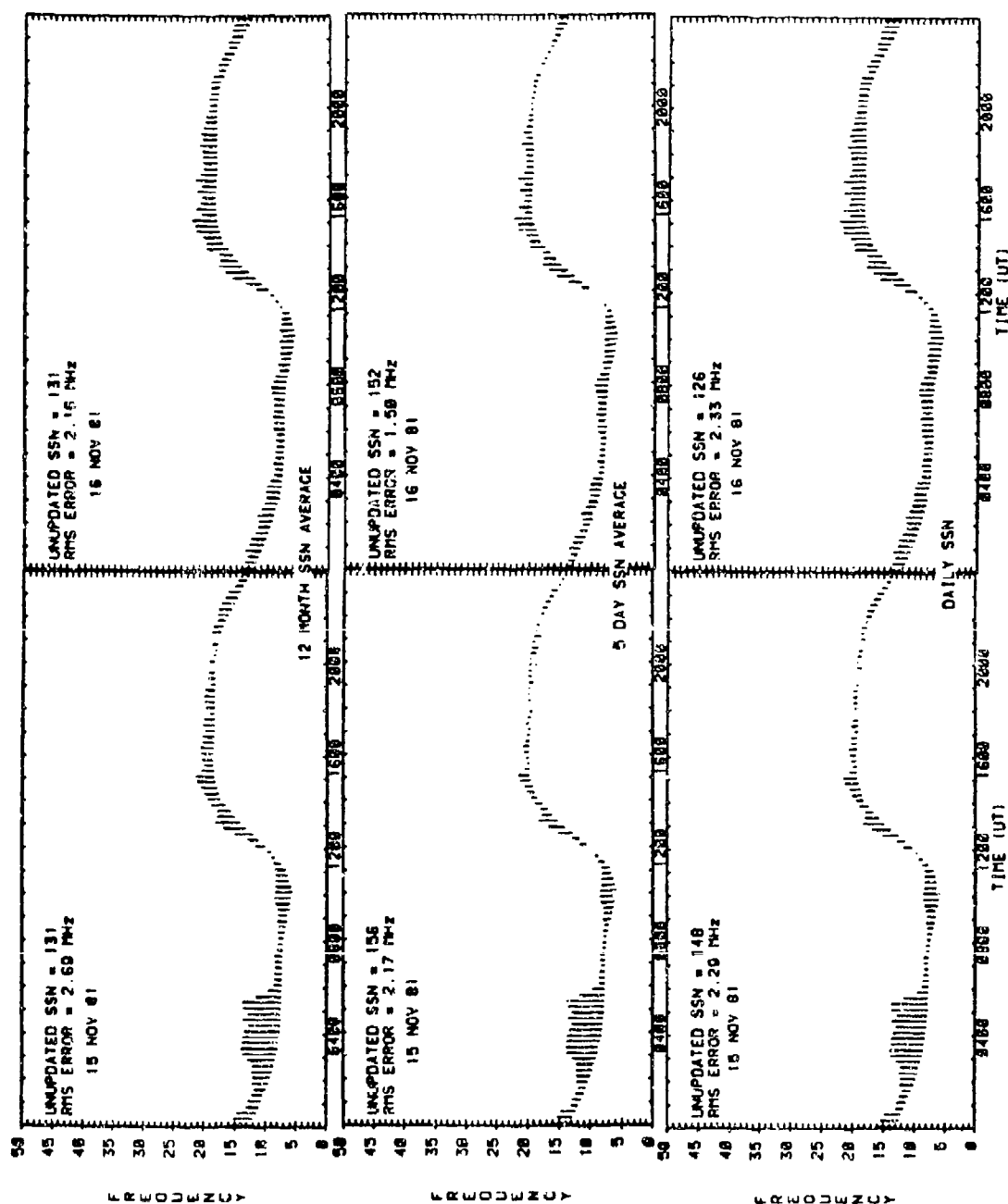


Figure 7. A comparison between the MUF and the IONCAP MUF for 15-16 November 1981 on the Robins to Norfolk circuit.

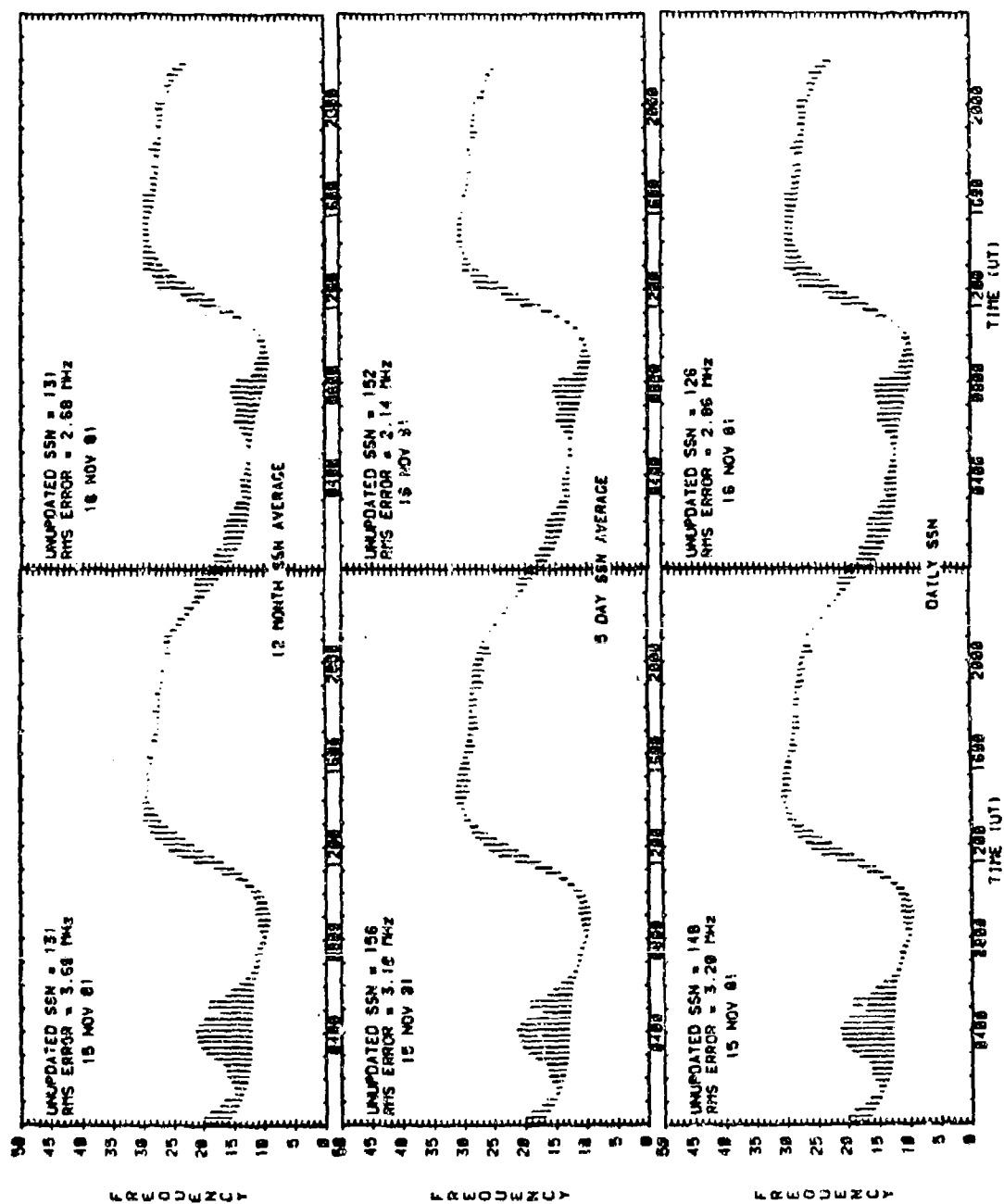


Figure 8. A Comparison between the MUF and the IONCAP MUF for 15-16 November 1981 on the Ship to Norfolk link.

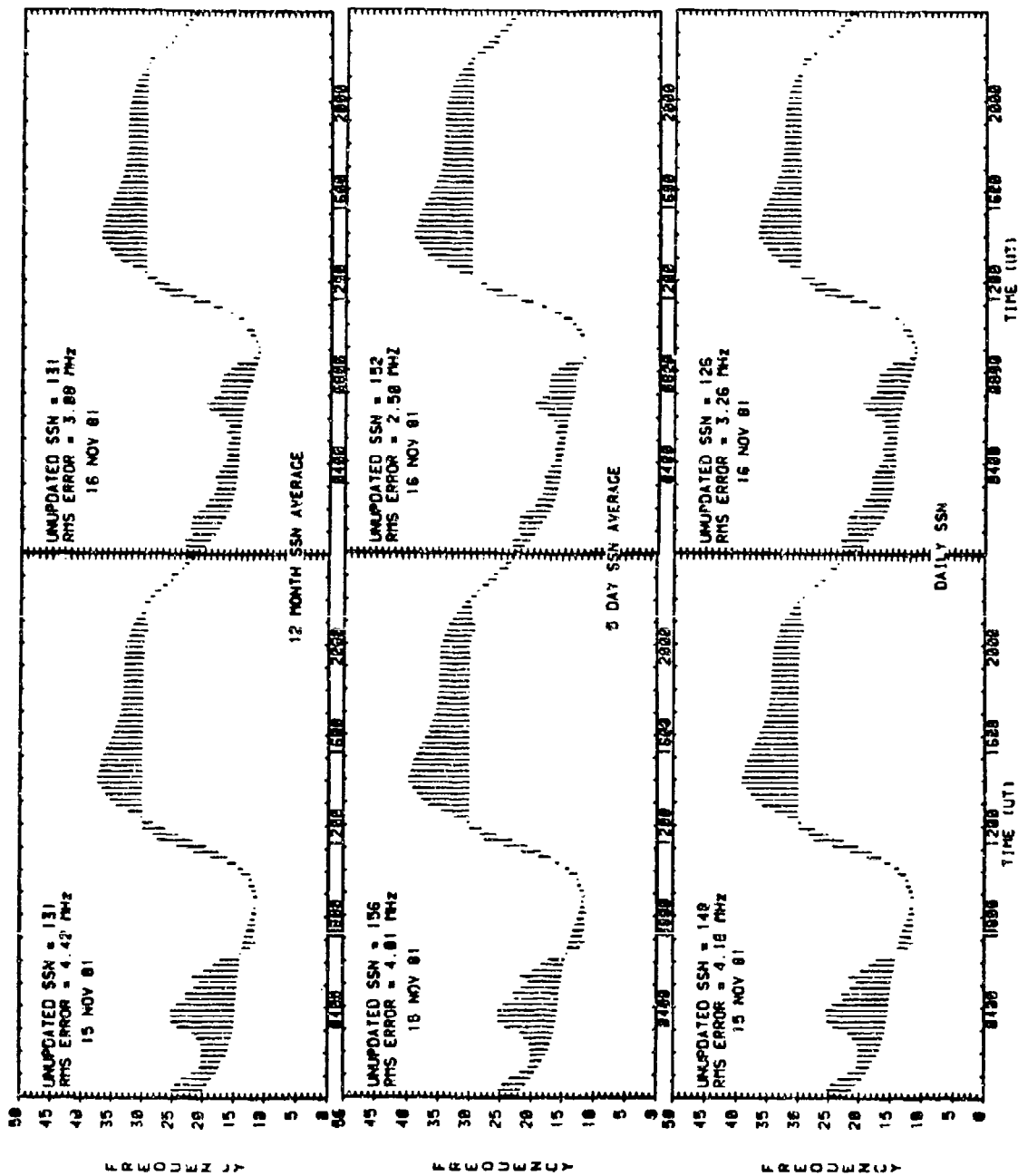


Figure 9. A Comparison between the NOF and the IONCAP MUF for 15-16 November 1981 on the Isabela to Norfolk link.

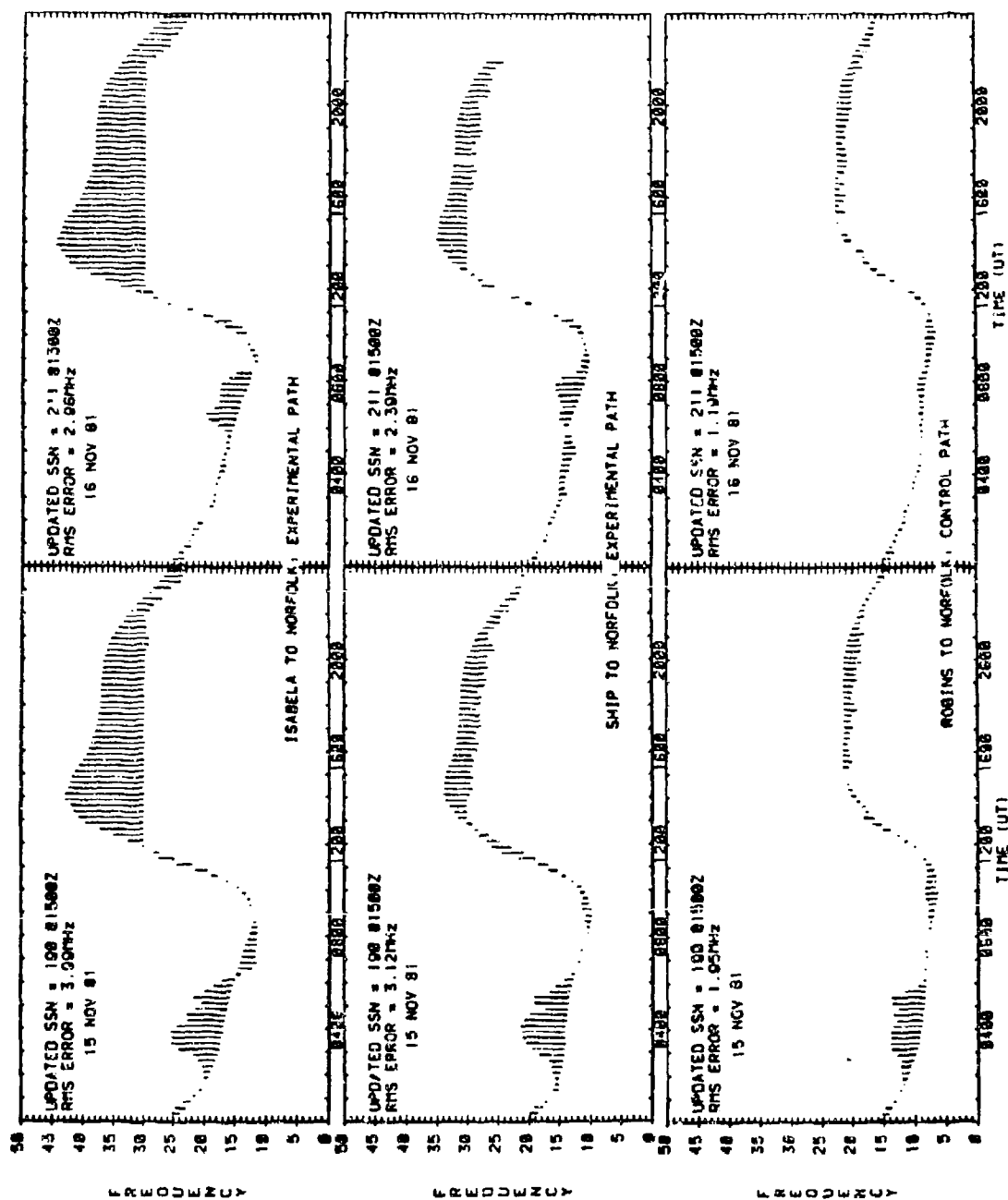


Figure 10. IONCAP MUF to MUF Comparison using 1500Z update from the Robins path.

Table 1 summarizes these results indicating that the update technique as drawn from the reference path at 1500Z improved upon the standard technique of computing MUF.

Table I. RMS (MHz) Errors of various configurations for MINIMUF

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	5.06
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

Also note that an update at 1300Z yielded worse results than utilizing some sort of daily sunspot number. The reader is reminded, however, that the The User's Manual for IONCAP^[4] states that one should never use daily sunspot numbers in driving the model. Although this initial data set is admittedly extremely limited, it is quite interesting to note how well the daily sunspot numbers drive the model to give an accurate calculation of the MUF of the channel. More work should be done here since the limited data set in this case may not be yielding truly representative results in terms of the viability of the model update technique. The same might be said for the results obtained by using the daily sunspot numbers.

3.2.2 Comparison to a MINIMUF Update

With this same data set, we also explored the effectiveness of updating the MINIMUF algorithm. Figure 11 shows the fit of MINIMUF to the data set for the Robins to Norfolk path using several different configurations of the 10.7 cm flux driving parameter⁺. This circuit was selected since it

⁺ The 10.7 cm flux and sunspot number are related by an empirically derived function [λ].

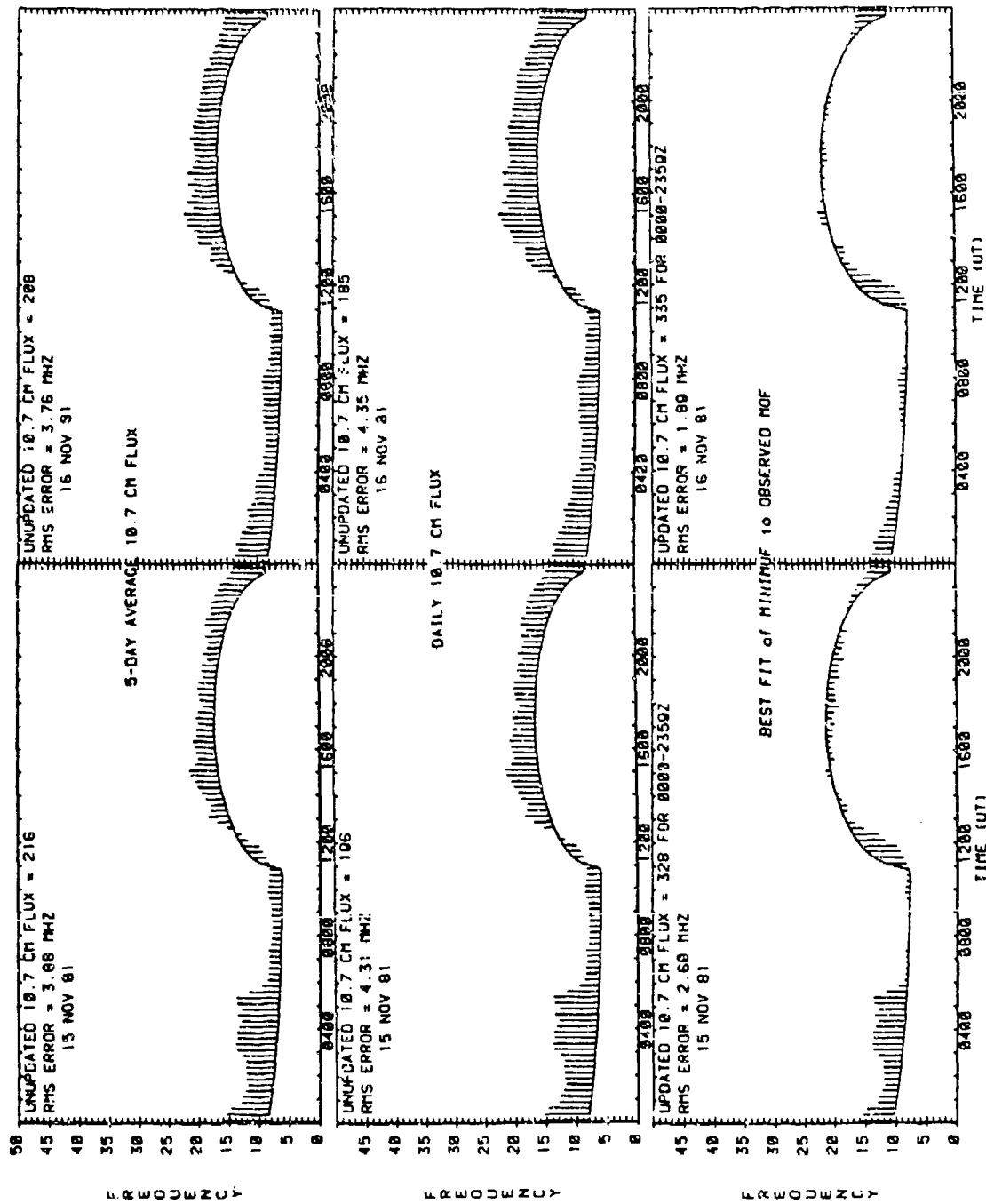


Figure 11. The unupdated MINIMUF as compared to the measured MOF's.

was the control path. Notice that the five day running average 10.7 cm flux allows MINIMUF to obtain rms errors relative to the measured MUF which are commensurate with the 3.71 MHz rms stated as its accuracy [13]. Using the daily 10.7 cm flux, the errors are again in the low 4 MHz range. The best possible fit achievable with MINIMUF is shown by the lower part of the figure. This best fit is derived by running the MINIMUF program until the minimum in the rms error between the model and the measurements is reached. Hence the best fit possible with MINIMUF on the 15 November is 2.6 MHz and 1.89 MHz on the 16 November. If an update were performed for this circuit, one would hope that the update would yield a rms error which closely approaches the minimum represented by the lower part of the figure.

Figure 12 shows the result of updating MINIMUF 3.5 at 1300Z using Robins to Norfolk as the control path. Also represented on this plot are the FOT bands as computed by MINIMUF by taking .85 of the MUF. This is represented by the solid line which is below but parallel to the MINIMUF computation. The vertical lines indicate the difference between the model MUF and the actual MUF. A comparison of these data with the previous figure indicate that one can obtain a significant increase in accuracy for the Robins circuit by updating MINIMUF with the technique. To illustrate this numerically, Table II is provided. Table II indicates the rms errors which result from updating MINIMUF at 1300Z. Note that on each day the 1300Z update approaches the absolute minimum possible with the model. This is quite different from the IONCAP situation where in almost every instance the update at 1300Z yielded worse results as compared to the five day and the daily sunspot number cases. Also the 1300Z update of IONCAP did only marginally better than using the twelve month average sunspot number.

Table II. RMS (MHz) Errors of various configurations for IONCAP

SITUATION \ PATH	ROBINS TO NORFOLK	SHIP TO NORFOLK	ISABELA TO NORFOLK
15 NOV 81			
12 MONTH AVERAGE SSN	2.69	3.60	4.42
6 DAY AVERAGE SSN	2.17	3.10	4.01
1 DAY SSN	2.29	3.20	4.10
UPDATE @1300Z	2.85	4.42	4.93
UPDATE @1500Z	1.95	3.12	3.99
16 NOV 81			
12 MONTH AVERAGE SSN	2.16	2.68	3.08
6 DAY AVERAGE SSN	1.50	2.14	2.50
1 DAY SSN	2.33	2.86	3.26
UPDATE @1300Z	1.91	3.13	3.71
UPDATE @1500Z	1.19	2.39	2.96

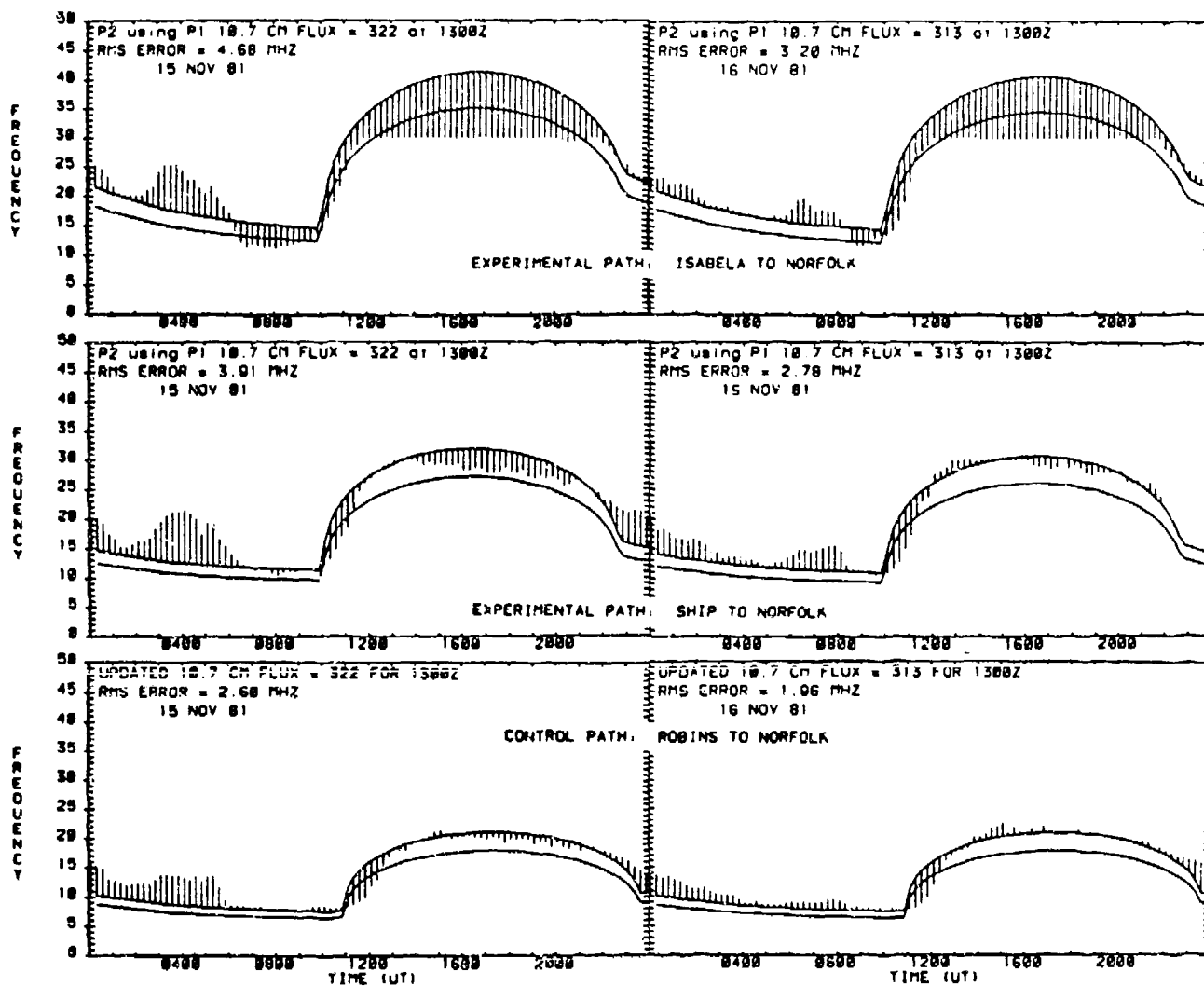


Figure 12. The result of updating MINIMUF 3.5 using control path data at 1300Z. Also plotted is a calculated FOT at .85 MUF.

4.0 SUMMARY AND CONCLUSIONS

This paper represents a first attempt at employing the update technique to the MUF computation of IONCAP. The idea is to find and use a model which provides the basic form of the diurnal variation of the HF channel. IONCAP provides a form which has more character than does MINIMUF and it was originally thought that IONCAP would yield better results. In this initial test however, the IONCAP results were quite discouraging compared to the much simpler MINIMUF model. Updated MINIMUF yielded somewhat better statistics as well as a generally consistent improvement over the unupdated computations of MUF. It is also remarked that the one day and the five day sunspot numbers gave very good results in the "unupdated" case for IONCAP. Since the IONCAP Manual cautions one to never use daily sunspot numbers to drive the model, these results should be tested on larger data base.

5.0 RECOMMENDATIONS

This is our first attempt at examining the MUF computation in IONCAP in the light of a simple update technique. The results are encouraging enough that this technique should be examined for a larger and geographically more diverse data base which is composed of two or more simultaneously operating oblique sounder sites. In addition, updating more frequently should also be examined as well as making a determination of the best possible fit obtainable by IONCAP in the same manner as was done with MINIMUF (bottom figure 11). The use of real-time update should be given serious consideration as far as the enhancement of tactical HF systems operation is concerned, particularly along the lines of using the physically small code MINIMUF 3.5.

ACKNOWLEDGMENTS

As with any effort, a number of individuals contribute to the product. Most notable are Mr. Larry O. Harnish who endeavored to obtain the data and generate some of the analysis software, and Dr. Mark Daehler who managed to get IONCAP to operate on a VAX 11/780.

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