(4)

SINGLE ANTENNA PHASE ERRORS
for
NAVSPASUR RECEIVERS

M.D. Andrews

E.J. Wadiak

Interferometrics Inc.

30 November 1988

EXECUTIVE SUMMARY

Interferometrics Inc. has investigated the phase errors on single antenna NAVSPASUR data. We find that the single antenna phase errors are well modeled as a function of signal strength only. The phase errors associated with data from the Kickapoo transmitter are larger than the errors from the low-power transmitters (*i.e.*, Gila River and Jordan Lake). Further, the errors in the phase data associated with the Kickapoo transmitter show significant variability among data taken on different days.

We have applied a quadratic polynomial fit to the single antenna phases to derive the Doppler shift and chirp, and we have estimated the formal errors associated with these quantities. These formal errors have been parameterized as a function of peak signal strength and number of data frames. We find that for a typical satellite observation the derived Doppler shift has a formal error of $\lesssim$ 0.2 Hz and the derived chirp has a formal error of $\lesssim$ 1 Hz/sec. There is a clear systematic bias in the derived chirp for targets illuminated by the Kickapoo transmitter. Near-field effects probably account for the larger phase errors and the chirp bias of the Kickapoo transmitter.

CONTENTS

EXECUTIVE SUMMARY i

CONTENTS ii

TABLES iii

FIGURES iv

EXHIBITS v

INTRODUCTION 1

ANALYSIS METHOD 1

  Observation Processing 2

  Error Modeling 6

  Doppler and Chirp Processing 7

RESULTS and ANALYSIS 8

  Phase Error Model 8

  Doppler and Chirp Uncertainties 9

  Doppler and Chirp Accuracy 10

CONCLUSIONS 11

APPENDIX A 37

TABLES

1. Summary of Observations 13

2a (Part 1). Processed Observations - Kickapoo 14

2a (Part 2). Processed Observations - Kickapoo (cont'd) 15

2b (Part 1). Processed Observations - non-Kickapoo 16

2b (Part 2). Processed Observations - non-Kickapoo (cont'd) 17

3a (Part 1). Mean Doppler Uncertainty - Kickapoo 18

3a (Part 2). Mean Doppler Uncertainty - Kickapoo (cont'd) 19

3b (Part 1). Mean Chirp Uncertainty - Kickapoo 20

3b (Part 2). Mean Chirp Uncertainty - Kickapoo (cont'd) 21

3c (Part 1). Mean Doppler Uncertainty - non-Kickapoo 22

3c (Part 2). Mean Doppler Uncertainty - non-Kickapoo (cont'd) 23

3d (Part 1). Mean Chirp Uncertainty - non-Kickapoo 24

3d (Part 2). Mean Chirp Uncertainty - non-Kickapoo (cont'd) 25

FIGURES

1a. RMS Phase Errors - Kickapoo 26

1b. RMS Phase Errors - non-Kickapoo 27

2a. Distribution of Doppler Residuals - Kickapoo 28

2b. Distribution of Doppler Residuals - non-Kickapoo 29

2c. Distribution of Chirp Residuals - Kickapoo 30

2d. Distribution of Chirp Residuals - non-Kickapoo 31

3a. Chirp Residuals vs. Range - Kickapoo 32

3b. Chirp Residuals vs. Range - non-Kickapoo 33

EXHIBITS

1. Raw Data Format 34

2. De-rotated Data Format 35

3. De-rotated and Edited Data Format 36

I. INTRODUCTION

In an earlier study entitled *The Determination of NAVSPASUR Phase Difference Errors* (hereafter Paper I), Interferometrics Inc. modeled the errors present on the phase difference between antennas at a given receiver site. In a multi-element interferometer array such as that used at NAVSPASUR receiver sites, it is the phase *difference* data which allows the calculation of the direction cosines to the target. The phase difference error model which resulted from our previous analysis is a crucial factor in estimating how well the direction cosines and cosine rates are determined.

In addition to the phase difference information, there is also information content in the time variability of the phases on each of the individual antenna elements. From this data we can obtain the Doppler shift and the time rate of change of the Doppler shift (hereafter Doppler and chirp) for the target in question. In the present work Interferometrics Inc. has analyzed NAVSPASUR data to determine the single antenna phase errors and examine how well these data can be used to determine Doppler and chirp.

A second Interferometrics Inc. report entitled *NAVSPASUR System Performance Analysis* (hereafter Paper II) contained an examination of how well satellite position and velocity could be determined by NAVSPASUR as a single system. It is demonstrated in Paper II that the Doppler measurement plays an important role in the determination of position and velocity. Hence, the present analysis bears directly on the question of overall system accuracy.

The research reported in this paper was done to complement the previous work and to cover topics not considered in those papers. There were three major goals accomplished in this study. First, the single antenna phase errors were modeled. Second, the formal errors on the determination of Doppler and chirp were parameterized. Finally, the data were examined to determine whether systematic effects are present which bias the determination of Doppler and/or chirp.

There are two major sections to this report. The first section presents the method of analysis and the second section contains the results. There are three sets of results presented herein: the models of the single antenna phase errors, a parameterization of the uncertainties in Doppler and chirp, and an assessment of the accuracy or "correctness" of the values of Doppler and chirp.

II. ANALYSIS METHOD

In this section we present a discussion of the analysis method used in this study. We first discuss the processing method applied to each observation and then consider the global analysis performed on each of three data sets.

During the initial data processing it became evident that there were significant differences in the phase errors between data associated with the Kickapoo transmitter and that associated with the two low-power transmitters. In contrast, for data associated with any given transmitter, there were no significant differences between the phase errors at different receiver sites. We have therefore analyzed the Kickapoo and non-Kickapoo data separately, but have otherwise combined the data from the different receiver sites.

The analysis of the data sets had two major parts. First, the single antenna phase error model was determined. Second, the uncertainties in Doppler and chirp were calculated along with the Observed minus Calculated (O-C) values for Doppler and chirp.

Three sets of data, supplied by NAVSPASUR management, were processed in the course of this study. Table 1 provides a summary of these data sets. The total number of identified observations is listed in the Table, together with a breakdown by transmitter. Also shown is the number of observations which were eliminated at each stage of the processing. Each of these data sets contained data from all three transmitting stations and either four or five receiving stations.

Only observations for which the target satellite was identified were processed, since only those scans had the predictions which are required to calculate O-C. Further, only observations recorded in the 36 Hz wide "full Doppler" channel were analyzed since there were not enough data from the narrower channels to provide a statistically significant sample.

Observation Processing

An example of a typical satellite observation is presented in Exhibit 1, which contains data from the Hawkinsville receiver site (receiver station #5). The first four lines of Exhibit 1 contain header information which identifies the NAVSPASUR catalog number of the satellite, the Doppler channel in which the data were recorded, the time and date of the observation, the number of phase and amplitude data frames, the predicted time of fence crossing and the predicted satellite state vector based on the NAVSPASUR catalog, and other control information. Following the four header lines there are up to 55 data lines, each of which contains an average power level and the measured phases for each of the dipole arrays at the receiver site. The average power levels are expressed in deciBels below 1 mWatt, *i.e.*, 144 ⇒ -144 dBm. Therefore, smaller numbers correspond to stronger signals. This average power is commonly, if incorrectly, referred to as the amplitude and we will adopt this usage.

For receiving stations 1, 3, 4, and 6 there are twelve dipole arrays, hereafter antennas; stations 2 and 5 have only eleven antennas. The phase at each antenna is measured 54.98 times per second and recorded as a 6-bit integer. The 6-bit sampling explains why the phases in Exhibit 1 are integers between 0 and 63. The phase measurement is thus quantized in units of approximately 6 degrees. Each set of antenna phases and associated amplitude is referred to as a data frame.

The first step in processing each observation was to remove the phase wraps from the data. These phase wraps occur since the phase is measured modulo 2π radians. The observation in Exhibit 1 contains at least four such phase wraps on each antenna. In order to track the phase as a function of time, these phase wraps must be removed.

The phase wraps are removed in subroutine DEROT (see Appendix A). The data frame with the strongest signal is located and phase cycles are removed starting from that point. The slope of the phase curve is determined using the frames immediately preceding and following the peak. The slope is then used to predict the next phase value and rotation(s) of phase are added or subtracted so that the corrected phase is within $\pm\pi$ radians of the prediction.

If the slope at the amplitude peak is not well determined, the phases are not corrected. DEROT returns an error flag if any one of the antennas is not processed. When this happens, the entire observation is discarded and the next observation is read and processed. As can be seen from Table 1, typically 15-25% of the available observations are flagged during the derotation process and eliminated from further analysis. Almost all of the discarded scans had signal-to-noise ratios (as defined below) of 10 dB or less.

Data from 18 August, 1988 has been processed to examine how many of the antennas in a flagged observation are typically not successfully processed in DEROT. For Kickapoo observations, approximately 77% of the scans had 4 or fewer "bad" antennas and about 41% had only one antenna which was not successfully processed in DEROT. The corresponding statistics for the non-Kick data were 85% and 52%, respectively.

The failure of the derotation algorithm appears to be caused in large part by the relatively crude phase recovery scheme we have adopted. No attempt has been made to process these observations by using a more sophisticated phase recovery algorithm. Due to the large quantity of data processed here, a more elegant derotation algorithm would impose a prohibitive computational burden. We have analyzed the phase errors on those antennas which successfully derotated for a random sample of flagged scans and are convinced that we have not biased our results by dropping these scans from further consideration.

The decision to discard the whole scan rather than continue processing using only the recovered antennas was made to reduce bookkeeping complications. While this does eliminate a portion of the data, there are sufficient data that survived all of the processing. In particular, there remain sufficient low amplitude data in our sample.

Each antenna is processed separately in a single call to DEROT with the phase units changed to radians. The array of phases returned from DEROT for the observation of Exhibit 1 is shown in Exhibit 2, with the location of the strongest signal indicated. For the frames near this point, the line-to-line change in phase is well behaved and the several antennas show roughly similar phase curves.

A careful examination of Exhibit 2 shows an additional deficiency in the DEROT subroutine. For the first antenna, the change in phase between frames 18 and 19 is in the wrong direction (*i.e.*, the change on antenna #1 is positive with increasing distance from the peak data frame, while the other 10 have negative phase changes). The DEROT algorithm is not accurate at average power levels of $\lesssim$ -153 dBm.

Previous work (Paper I) has indicated that the effective noise level for "full Doppler" mode NAVSPASUR observations is -152 dBm. Therefore, it was decided that -152 dBm would be used as an amplitude cutoff. The observations were edited to eliminate those frames with lower average power. This editing was done by moving forward and backward from the peak amplitude to locate the first frame in each direction with power < -152 dBm. These frames and all data frames beyond these were deleted.

In some observations, the signal falls below -152 dBm as one moves away from the peak and then comes back to greater strength. Only the contiguous frames with amplitude $\geq$ -152 dBm surrounding the peak were used in further processing. Exhibit 3 contains the observation of Exhibit 2 after editing. The series of Exhibits 1-2-3 illustrates the above discussion. In Exhibit 1, there is a secondary peak at frame 10. However, the data editing removes the first twenty frames.

No further processing was done on an observation unless 10 or more frames remained after the data were edited. The minimum processing requirement of ten frames was arrived at by trial-and-error. It was determined that the results of our phase fitting were generally not reliable for those observations containing fewer than 10 frames. This criterion eliminated approximately 10% of the Kickapoo and about 6% of the non-Kick observations.

The actual parameter fitting for each antenna was done in subroutine WGHTPOLY, which is a generalized, weighted, least-squares polynomial fitting routine. There are two key assumptions in this procedure. First, the phase errors are assumed to be random with a Gaussian distribution. Second, in the absence of noise, the data and the model would agree exactly.

Previous results have indicated that, for most observations, the time dependence of the phase on each antenna is well modeled by

$$\phi(t) = c_0 + c_1(t - t_0) + c_2(t - t_0)^2 \tag{1}$$

where $\phi(t)$ is the phase at time t, and c_0, c_1, c_2 represent the fitting coefficients. The reference time t_0 is taken to be the predicted pass time.

The constant term coefficient c_0 is the phase at the reference time t_0. At $t = t_0$, $c_1 = d\phi/dt$ is the the true rate of change of the phase. In units of rotations/sec, this is the Doppler shift at time t_0 with respect to the center frequency of the digital filter. The Doppler shift with respect to the NAVSPASUR transmit frequency is obtained by summing this coefficient with the center frequency of the digital filter. The chirp is given by $\frac{1}{2}c_2$, in units of rotations/sec^2.

The call to WGHTPOLY requires three arrays: time, phase, and expected phase error. The time is calculated with respect to the predicted pass time for ease in comparing observations and predictions. The phase is the DEROTated data for each individual antenna. The expected phase error is predicted from the amplitude, and must be known prior to running the program. This error vector controls the weighting of the phase data and determines the uncertainties in the parameters.

The fitting routine returns the three polynomial coefficients, a value of the reduced chi-square, and the covariance matrix. The reduced chi-square returned from the fitting routine indicates the quality of the fit for the parameter determination. It is calculated by

$$\chi^2 = \frac{1}{(N-3)} \sum \frac{[\phi_n - (c_0 + c_1(t_n - t_0) + c_2(t_n - t_0)^2)]^2}{E_n^2} \tag{2}$$

where ϕ_n, t_n, and E_n are the values of the phase, time, and *a priori* error for the n^{th} data point; N is the total number of data points. The quantity in the brackets [] is termed the residual.

A value of reduced chi-square of ~ 1 tends to indicate reasonable agreement between the error model and the residuals and is a sign of good agreement between the data and the polynomial fit. If chi-square is small (*e.g.*, ≤ 0.2), it may indicate that the errors from the error model are significantly larger than the errors on the data. If chi-square is large it may indicate that the errors from the error model are too small and/or the data is not well fit by a second order polynomial. The various possibilities can only be distinguished by inspection of the residuals.

The covariance matrix elements (array COVAR) returned from the fitting routine allow the uncertainties (vector UNC) in the parameters and the correlation coefficients to be calculated. The parameter uncertainties are given by the square roots of the diagonal elements of COVAR, and the correlation coefficients are obtained from the off-diagonal elements scaled by the uncertainties, *i.e.*,

$$\mathrm{UNC}(n) = \sqrt{\mathrm{COVAR}(n,n)}, \tag{3a}$$

$$\mathrm{CORL}(n,m) = \mathrm{COVAR}(n,m)/[\mathrm{UNC}(n) * \mathrm{UNC}(m)]. \tag{3b}$$

The fitting routine occasionally returned non-physical values of the parameters. While it is not clear why this happened, the observations with "bad" fits were easily recognized.

These solutions had calculated Doppler shifts far outside the frequency range of the digital filters, very large values for the reduced chi-square, and large correlation coefficients. The observations were eliminated if the absolute value of the correlation between c_1 and c_3 exceeded 0.99. This criterion sucessfully eliminated all the bad fits without eliminating any useful data. Approximately 2% of the Kickapoo and 4% of non-Kick observations were eliminated in this manner.

The parameter uncertainties are formal errors, which means that these uncertainties represent how much the parameter determination will be affected by the errors in the data. The value of the uncertainty represents how consistent the parameter determinations will be from one antenna to another at a single site (*i.e.*, an indication of the *precision* of the measurement). The uncertainties do not tell whether or not the parameters agree with reality (*i.e.*, how *accurate* they are).

To assess the accuracy of the parameter determination, values of Doppler and chirp **O-C** were calculated. NAVSPASUR has supplied *a priori* positions and velocities for each satellite observation which have been used to Calculate the expected values of Doppler and chirp. These expected values are subtracted from the **O**bserved values derived from the parameter fits, to obtain **O-C**s. In the absence of systematic errors in the catalog predictions, any systematic effects which bias the Doppler and chirp determinations can be uncovered by analyzing these **O-C** values.

Error Modeling

The uncertainties in the parameters are calculated from the phase error model only. While the goal of this study was to examine how well the Doppler and chirp can be measured, a necessary first step was to determine the single antenna phase error model. A proper error model is essential to properly calculate the uncertainties.

The error model derived in Paper I for the errors on the phase differences was used as a first-guess error model in this analysis. It was not expected that the single antenna phase errors would be the same as the errors on differenced phases in Paper I. First, the errors in Paper I were for antenna *pairs* rather than for individual antennas. Second, there were systematic effects seen in Paper I which led to roughly constant phase difference error for signal-to-noise ratios $\gtrsim$ 10dB. Finally, there may be other systematic effects present which cancel when taking phase differences, but that will increase the errors on the single antenna phases.

A version of the fitting program called ACCUM was written to accumulate and analyze the phase residuals. The residuals are the phase data minus the value calculated from the fit parameters. In the absence of systematic effects, these residuals (the term inside the brackets [] in Equation 2) will be due to random measurement errors on the phases.

In ACCUM, the residuals are binned by amplitude and accumulated for all successfully processed data. The accumulated residuals are used to calculate the mean and RMS (Root-Mean-Square) phase error at each amplitude. Only those antennas for which the value of the reduced chi-square is lower than a preselected value are used in order to eliminate "bad" solutions. The program also totals the number of reduced chi-square values < 1.0 and > 1.0.

The first step in processing each data tape was to determine the phase error model. As was the case for the phase difference errors in Paper I, the phase error statistics here turn out to be well described by a single parameter model, *i.e.* they depend only on the received amplitude.

The correct error model was derived by analyzing the residuals and adjusting the error model to make the model agree with the RMS of the post-fit residuals. An initial guess was made for the error model and the fitting program run. The RMS of the post-fit residuals was used to revise the error model estimate, and the entire process iterated.

The iteration was continued until two criteria were met. First, the number of antenna solutions with reduced chi-square < 1.0 was approximately equal to the number with reduced chi-square > 1.0. Second, the calculated RMS error at each amplitude was consistent with the predictions of the error model. For the final error models the level of agreement was usually better than ±2°.

Doppler and Chirp Processing

After the proper phase error models were determined, each data set was run through the program FITS. This algorithm re-processed all of the observations and generated output files for further analysis.

One file contained the results of the parameter determination and the reduced chi-square for each antenna of an observation together with the uncertainties and correlation coefficients for that observation. There is only one set of uncertainties for each observation since the phase error model depends only on the amplitude, which is the same for all antennas.

The second major output file contained the 11 or 12 pairs of values of Doppler and chirp O-C for each fully processed observation. This file also contains the reduced chi-square value for each antenna and a header line that identifies the observation. The third major output file lists the parameter uncertainties, the peak amplitude, and the number of continuous data frames greater than -152 dBm.

There is also a file written which contains a line for each observation indicating whether the processing succeeded. The FITS algorithm also allows a file to be written which contains all of the post-fit residuals. This has not been done on any of the complete data sets because the files are too large.

III. RESULTS and ANALYSIS

This study has produced three sets of results: the phase error models, the parameterization of the formal Doppler and chirp uncertainties, and the analysis of the Doppler and chirp residuals (**O-C**).

Phase Error Model

The data tape of 4Feb88 was originally processed using the error model derived in Paper I. It was clear from the results of the initial processing that the actual phase errors on observations involving the Kickapoo transmitter were larger than both the input error model and the non-Kick errors. The error analysis method described above was developed to properly determine the error model for this data tape.

There were two clear indications that the initial input errors were too small. First, the reduced chi-square values were too large. Almost all of the chi-square values were > 1.0. Second, the formal uncertainties in the parameters were much less than the observed variation in the parameters. In particular, the chirp determination for all of the antennas should be the same to within the formal errors. The Kickapoo observations had antenna-to-antenna variations that were 10-20 times the formal errors.

The original error model gave more reasonable agreement for the non-Kick transmitters. The errors (and results) for Jordan Lake and Gila River have been compared with no obvious differences seen between the two low powered transmitters. While there has not been any detailed comparison of the several receiving sites, there is no obvious difference in either the errors or other results for the different receiving stations.

The derived error models for the three data sets are shown in Figures 1a and 1b. The phase error in degrees is plotted versus power above the -152 dBm noise level. The distribution of the residuals used to determine the error model has been examined and it is in reasonable agreement with the assumption of Gaussian random errors.

The Kickapoo errors of Figure 1a are substantially larger than the non-Kick errors of Figure 1b. Further, the Kickapoo errors for the three tapes are not in agreement; the three curves do not even have the same shape. The agreement between the 4Feb88 and 25Apr88 tapes at large signal-to-noise (SNR) may not be significant since there is only a small amount of data with signals this strong and as a consequence the RMS is not well determined. There were several iterations done for each Kickapoo data set to insure that the resulting error model accurately represented the errors in that data set. The error model derived from one tape does not yield an acceptable fit to the other data tapes.

All three sets of data yield essentially identical error models for the non-Kick transmitters (see Figure 1b). Furthermore, there is no significant difference in the errors between the Jordan Lake and Gila River transmitters.

The errors plotted in Figure 1 decrease with increasing power, eventually levelling off for very high SNR data ($\gtrsim$35 dB SNR for Kickapoo data, $\gtrsim$20 dB SNR for non-Kick data). The magnitude of the errors for the very high SNR data is consistent with the error expected due to the 6 bit phase sampling, which imposes a roughly 6 degree quantization on the reported antenna phase.

It was expected that near-field effects would lead to larger errors for Kickapoo observations. It was not anticipated that the difference between the Kickapoo and non-Kick errors would be so dramatic. Also, there was no reason to expect the marked variation we see among the Kickapoo error models for the three different data sets. The scope of this study has not allowed a quantitative assessment of the large Kickapoo phase errors. However, it is likely that the larger magnitude of the Kickapoo phase errors is due to near- field effects. Most, if not all satellites observed are at ranges shorter than the far-field distance of $\approx$ 15,000 km. In the near-field region, there is significant structure in the Kickapoo beam which may account for the larger errors.

Interferometrics Inc. has prepared a report titled *Theoretical Radiation Patterns of NAVSPASUR Transmitter Antennas*, which demonstrates the dramatic near-field effects in the Kickapoo beam. This report also demonstrates that changes in the bay-to-bay phasing will produce large changes in the beam pattern. It is plausible that the differences among the three data sets are caused by long-term temporal variations in the bay-to-bay phasing of the array.

Doppler and Chirp Uncertainties

All of the successfully processed observations have been combined so that the uncertainties in the Doppler and chirp determinations could be examined. The early analysis made it clear that the magnitude of the uncertainties was determined by two main factors: the peak amplitude and the number of data frames.

Tables 2a and 2b show the total number of observations for the Kickapoo and non-Kick transmitters as a function of number of data frames and the peak amplitude. It was necessary to combine the three data sets to improve the quality of the statistics.

The Kickapoo observations tend to have larger peak signal strength and more data frames than the non-Kick observations. The median observation from Kickapoo has 31 data frames and a peak signal strength of -134 dBm. The corresponding numbers for non-Kick are 28 data frames and -141 dBm, respectively. (Note that the maximum of 55 data frames per observation is set by software limitations at the receivers.)

Tables 3a-d contain the mean uncertainties for Doppler and chirp; Tables 3a and 3b present the Kickapoo results while Tables 3c and 3d present the results for the non-Kick transmitters. Uncertainties are only reported for those combinations of peak amplitude and number of data frames for which there are two or more observations. The uncertainties decrease rapidly as the number of data frames increases. There is also a significant decrease in the uncertainties as the peak amplitude increases, with some flattening out for very high SNR.

For any given amplitude and number of data frames, the uncertainties in Doppler and chirp are significantly smaller for non-Kick observations than for Kickapoo observations (due to the smaller RMS phase errors). However, since the Kickapoo transmitter typically produces more data frames and a larger peak amplitude than non-Kick, the typical observation will have roughly equal uncertainties for any of the three transmitters. The median non-Kick observation has uncertainties of 0.14 Hz in Doppler and 0.63 Hz/sec in chirp. The corresponding numbers for Kickapoo are 0.24 Hz and 0.89 Hz/sec.

Doppler and Chirp Accuracy

O-C values have been calculated to determine the degree to which the fitting algorithm determines the "correct" value of the parameters. Histograms of **O-C** for both Doppler and chirp are shown in Figures 2a-d. The histogram for the Kickapoo Doppler (Figure 2a) is more sharply peaked than the corresponding non-Kick plot (Figure 2b). Both Doppler histograms peak at 0 Hz, which indicates that there are no large systematic offsets in the Doppler determination. If the distributions are taken to be normal, the standard deviations are 4.3 Hz and 13.7 Hz for Kickapoo and non-Kick, respectively.

Mr. F. Lipp of NAVSPASUR has estimated that the position prediction will have an RMS error of ~ 8 km. In Appendix A of Paper II, the partial derivatives of Doppler and chirp with respect to position are evaluated. Typical values for the position partial derivatives are ~ 1 Hz/km. This implies that the width of the histogram for the Kickapoo Doppler may be due to the quality of the predictions. A more accurate assessment of the accuracy of the observed Doppler will require the analysis of NAVSPASUR observations of satellites with very well determined *a priori* positions and velocities, *e.g.* LAGEOS, Starlette, and the GPS satellites.

The Doppler **O-C**s for the non-Kick observations are larger than those for Kickapoo, while the formal uncertainties are smaller. Furthermore, the non-Kick histogram (Figure 2b) is nearly flat over about 20 Hz; the distribution is clearly not Gaussian and is much wider than predicted by the formal errors. These two factors may indicate the presence of one or more small, but significant, systematic offsets affecting the non-Kick transmitter. Data from the Jordan Lake and Gila River transmitters have been analyzed separately, and each individual station's data closely resembles Figure 2b. It is clear that further analysis is needed to verify and understand these possible systematic biases.

Figures 2c and 2d present the histograms of chirp **O-C** for the Kickapoo and non-Kick transmitters, respectively. The chirp **O-C**s for the non-Kick observations are quite small and are sharply peaked at 0 Hz/sec. The non-Kick **O-C** histogram is consistent with the uncertainties of Table 3d.

The situation is strikingly different for the Kickapoo chirp. The histogram is much wider, does not peak at zero, and is strikingly asymmetric. This is a clear indication that there are systematic effects present which bias the Kickapoo chirp determination.

This bias in the Kickapoo chirp has been previously observed. NRL Memo Report #4831, entitled *Experimental Observation of Naval Space Surveillance Satellite Signals with an Out-of-Plane Receiving Station*, by S. H. Knowles, W. B. Waltman, and R. H. Smith reported an average chirp bias of +10 Hz/sec for Kickapoo observations.

The large bias on the Kickapoo chirp appears to be due primarily to near-field effects. This conclusion has been tested by obtaining additional data and plotting the chirp **O-Cs** as a function of range. Figures 3a and 3b display the chirp **O-C** versus range for Kickapoo and non-Kick respectively for the 18 August, 1988 data set. The magnitude of the Kickapoo **O-C** (Figure 3a) is clearly a function of range, as would be expected for near-field effects. Figure 3b shows no significant range effect. It is clear that further work is necessary to quantitatively understand the effect of range on the chirp determination.

It is appropriate at this point to discuss how well we expect the Doppler shift to be determined by NAVSPASUR in normal operation. In this report, we have parameterized the formal uncertainty in the Doppler for a single antenna. The several antennas at a receiving station can be combined to reduce the formal uncertainty by a factor of about 3.

It is clear from an analysis of **O-Cs** that the non-Kick Doppler observations are not as accurate as the corresponding Kickapoo observations. Given the size of the errors in the satellite predicted positions we have been unable in this study to determine the absolute accuracy of either the Kickapoo or non-Kick Doppler measurements. Any quantitative assessment of the Doppler accuracy will require the analysis of NAVSPASUR observations of satellites with very well determined *a priori* position and velocity.

It is our opinion, based on this and other studies, that NAVSPASUR should be able to determine the Doppler for most satellite observations to an accuracy on the order of 0.1–1.0 Hz. Achieving this limit will require that the systematic effects be thoroughly understood. Further work is required to test this conclusion.

IV. CONCLUSIONS

Interferometrics Inc. has investigated the phase errors on single antenna NAVSPASUR data. We find that the single antenna phase errors are well modeled as a function of signal strength only. The phase errors on observations involving the Kickapoo transmitter are larger than the errors on observations from the low power transmitters. Further, the three data sets which were analyzed herein yielded signicantly different error models for the Kickapoo transmitter.

The formal errors in the determination of the Doppler shift and chirp have been parameterized as a function of peak signal strength and number of data frames. The typical satellite observation will determine the Doppler shift with a formal error of ~ 0.2 Hz and the chirp with a formal error of $\lesssim$ 1Hz/sec.

The Doppler and chirp residuals (**O-C** values) have been examined for indications of possible bias due to systematic errors. The distribution of both the Kickapoo Doppler and the non-Kickapoo chirp residuals are consistent with the formal errors in these parameters and the RMS errors in the NAVSPASUR position and velocity predictions. The Kickapoo chirp residuals show a clear range-dependent bias which is likely to be caused by near-field effects. The non-Kickapoo Doppler residuals exhibit a non-Gaussian distribution and a greater RMS deviation than expected, given the formal uncertainties in the Doppler calculations and the RMS errors in the NAVSPASUR position and velocity predictions. Further study is needed to identify the source of these larger errors.

TABLE 1

Summary of Observations

	Total Observations	DEROT Error	< 10 Frames	Bad Fit	Number Processed	Fraction Good
	4FEB88 13:30 to 4FEB88 17:00					
Kickapoo	5692	780	1133	200	3579	0.629
non-Kick	4074	853	786	148	2347	0.576
	25MAR88 22:30 to 26MAR88 3:30					
Kickapoo	7191	1152	1081	321	4637	0.645
non-Kick	5677	1219	700	208	3003	0.585
	21JUN88 15:30 to 21JUN88 22:00					
Kickapoo	8892	1214	1510	232	5856	0.659
non-Kick	5677	1306	885	138	3348	0.590

This Table lists the total number of full-Doppler observations for each of the three data tapes processed for this report. The observations are broken down between the Kickapoo and non-Kick transmitters and the number of observations eliminated at each stage of the processing is listed. Also shown are the total number of observations that survived the processing.

TABLE 2a
PART 1

THE TOTAL NUMBER of PROCESSED OBSSERVATIONS
for the KICKAPOO TRANSMITTER
as a *FUNCTION* of PEAK SIGNAL STRENGTH and the NUMBER OF DATA FRAME with AMPLITUDE > -152 dBm

# of FRAMES	PEAK SIGNAL STRENGTH (dB below a mWatt)																												
	152	151	150	149	148	147	146	145	144	143	142	141	140	139	138	137	136	135	134	133	132	131	130	129	128	127	126	125	124
10			18	13	17	20	14	14	15	14	18	11	8	5	9	5	7	3	4	3	3	1	6	2	1	1		1	0
11		1	8	19	23	18	14	22	12	17	10	9	7	13	5	10	10	4	3	6	4	1		1	1				0
12		1	4	10	23	14	27	23	12	15	11	14	13	6	13	7	9	6	4	3	2		2	1	1	2		1	0
13		1	4	14	19	34	32	25	30	19	17	9	11	11	10	13	9	13	13	2	3	3	2	3	3	2		1	0
14			2	10	12	19	16	16	17	12	18	17	14	10	7	9	2	6	2	4	4	2	2	1		2	2		0
15			2	4	16	16	20	22	18	12	14	12	15	11	10	8	5	9	4	2	4	8	5	3	3	2	2	1	1
16			3	4	9	24	24	26	22	12	19	20	18	6	5	10	9	6	9	4	4	4	2	2		3	1	1	0
17			1	8	13	26	26	36	31	33	27	20	25	20	10	16	9	9	6	7	10	4	1	4	5	2	2	1	1
18			1	6	9	9	18	17	23	25	13	20	18	18	6	11	6	8	3	3	6	4	7		3	1	3	2	1
19			1	8	10	13	15	19	28	22	22	26	17	15	9	19	13	7	11	10	7	7	10	5	3		2		0
20				3	3	13	21	21	26	33	26	14	24	25	8	13	21	12	7	7	3	5	6	6	3	3	3	4	2
21				6	6	19	22	33	30	37	46	24	31	23	35	19	16	30	13	12	12	13	7	7	6	6	4	1	0
22				2	8	15	11	15	21	18	13	19	24	21	25	22	11	13	11	3	7	7	11	4	6	3	1	1	5
23				1	6	10	12	14	21	25	29	25	18	22	19	24	25	19	11	11	8	9	8	6	2	7	5	4	0
24				2	9	13	11	23	25	30	21	27	20	29	16	21	24	20	20	10	14	10	8	13	8	7	5	4	5
25						13	19	12	33	33	29	24	37	42	26	33	23	21	22	18	23	19	18	10	13	11	5	5	7
26				1	2	8	21	10	20	14	25	19	21	20	28	22	17	16	17	13	17	10	16	12	7	9	7	3	1
27				4	3	7	9	12	14	16	19	17	20	19	27	26	21	16	16	23	19	15	9	10	7	13	6	3	3
28					2	4	7	7	14	16	19	16	28	19	24	17	30	29	36	16	19	13	14	15	10	9	10	10	3
29				1		3	13	13	22	21	27	24	29	29	31	34	19	33	29	35	18	17	21	14	15	13	15	9	9
30					1	1	5	12	11	11	17	18	21	23	23	16	18	24	21	22	13	15	18	6	12	10	8	3	5
31						5	4	7	14	9	21	13	18	23	19	25	26	23	21	16	14	19	12	12	13	10	12	7	5
32					1	1	4	4	9	9	7	16	29	25	15	26	24	31	17	28	19	16	18	23	11	9	13	13	13
33						2	2	7	16	13	20	24	26	20	45	22	29	34	22	26	26	27	27	17	20	13	16	13	15
34						1	1		2	7	12	14	14	13	10	21	17	12	26	26	22	16	20	11	8	11	14	7	4
35					1	2	1	1	6	9	13	13	14	18	19	17	25	21	33	26	21	19	26	17	17	13	15	8	12
36							3	2	5	10	16	8	21	10	27	20	29	22	28	25	35	32	18	13	19	16	16	10	17
37				1	3		2	2	7	7	12	12	14	26	18	16	18	21	19	25	23	19	24	25	27	21	15	11	20
38								2	2		5	10	14	11	18	13	18	16	15	15	16	15	16	17	16	20	9	10	5
39				1			1	1		3	6	8	14	8	11	13	7	10	21	20	22	14	19	14	14	9	17	12	11
40					1	1		2	2	1	5	5	7	16	9	17	22	14	15	25	15	13	24	16	18	19	11	11	11
41						2	1	1	2	1	1	5	9	5	14	16	18	18	21	23	23	20	20	13	15	19	12	9	10
42						1	1		1	1	1	2	4	9	10	10	8	10	13	14	13	11	17	19	11	12	16	9	8
43							1	1	1	2	1	4	6	8	11	8	9	12	13	11	16	21	18	11	17	14	15	7	9
44							1	3		1	4	3	1	9	8	19	2	15	15	11	17	12	16	22	9	9	11	14	7
45					2	1	2	3	2	1	2	6	7	5	6	12	10	8	15	8	15	17	17	17	16	15	14	13	13
46						2					3	1	3	3	12	9	9	9	10	9	18	13	13	11	9	9	4	7	3
47						1				1	2		1	4	6	5	8	11	8	4	12	9	16	13	14	12	9	8	12
48							1	1	1	2	3	1	1	4	6	7	9	6	10	6	9	13	13	15	5	5	12	11	9
49						1	3	1	2	1	1	1	4	3	8	5	5	11	12	15	12	15	15	15	14	8	12	8	10
50							1	1	1	1	4	2		2	2	3	4	7	7	6	12	6	10	8	8	10	11	3	9
51												1			3	2	4	4	9	7	4	6	7	14	10	12	4	9	6
52						1	1	1	1		1	1	1	3	1	1	6	3	3	2	5	8	9	4	8	8	3	5	4
53						1		4	3	1	1	1	1	2	1	5	2	4	7	9	3	5	7	12	14	12	5	4	10
54					1		1								1	1		3	3	2	2	3	5	5	4	5	8	7	4
55						1	1	3	8	19	11	17	11	9	13	16	11	15	25	22	30	24	30	33	39	46	50	41	40

Table 2a (Part 1)

TABLE 2a
PART 2

THE TOTAL NUMBER of PROCESSED OBSSERVATIONS
for the KICKAPOO TRANSMITTER
as a FUNCTION of PEAK SIGNAL STRENGTH and the NUMBER OF DATA FRAME with AMPLITUDE > -152 dBm

# of FRAMES	PEAK SIGNAL STRENGTH (dB below a mWatt)																							
	123	122	121	120	119	118	117	116	115	114	113	112	111	110	109	108	107	106	105	104	103	102	101	100
10																								
11		1						1																
12																								
13	1																							
14	1																							
15				2																				
16	2								1															
17	1			1																				
18	1		2																					
19		2					1			1														
20		1			2		1																	
21	1	2		1	2								1											
22	2	1					1										1							
23			1	1	1																			
24	3	2			1	1																		
25	3	6	1	1	1		1																	
26	4		3	1		1	1					1												
27	3	1	1			1				1														
28	5	7	2	5	2	2			1															
29	5	4	6	3	3		2	2																
30	2	5	2	3		1																		
31	5	7	5	3	2	1	1		1						1									
32	5	6	3	4	5	1	2	1																
33	11	9	10	2	8	3	2		1		1	1												
34	4	4	5	3	3	1	2	2					1											
35	11	7	4	6	2	3	1	1	2									1						
36	7	8	7	4	8	3	3	1	1	1	1													
37	12	7	6	7	3	6	5	3	1	1	1													
38	8	2	6	4	2	1		2			1													
39	11	6	5	6	4	2	4	4	1					2										
40	9	8	9	4	3	3	2						1		1									
41	5	[illegible]	2	1	5	1	3	4	2	2		2												
42	4	[illegible]	4	2	4	1	1	1	1	1	1													
43	5	6	1	4	5	4				1	2													
44	5	6	4	2	3	2	1	1	1		2							1						
45	3	4	9	5	3	2	3	1	4	1	2	1				1								
46	2	4	2	2	2	3		1	1	1	2			1										
47	5	6	5	3	3	1	2	1	1		1	1												
48	1	3	7	5	1	7	2				1			1										
49	9	4	6	3	1	4	2	1	3	1	1													
50	6	6	2		2		2	1				1												
51	5	2	3	1	1	1	1						1											
52	6	2	2		1	2				1														
53	8	7	5	6	5	1	2			1								1						1
54	2	1	4	1	1	2																		
55	39	36	30	28	30	12	9	10	8		1	3	3								1	2		2

Table 2a (Part 2)

TABLE 2b
PART 1

THE TOTAL NUMBER of PROCESSED OBSSERVATIONS
for the GILA RIVER and JORDAN LAKE TRANSMITTERS
as a FUNCTION of PEAK SIGNAL STRENGTH and the NUMBER OF DATA FRAME with AMPLITUDE > -152 dBm

PEAK SIGNAL STRENGTH (dB below a mWatt)

# of FRAMES	152	151	150	149	148	147	146	145	144	143	142	141	140	139	138	137	136	135	134	133	132	131	130	129	128	127	126	125	124
10		6	14	9	9	7	5	7		9	5	2	4	1	1	1	2	3	2		2	1		1				1	0
11		5	16	10	8	5	11	13	5	4	7	3	2	1	2		1	2	1	3	4		1	1			2		0
12		5	20	21	14	8	12	9	4	12	6	7	3	6	7	3	2	1		2	4	1	2	1	2			1	0
13		1	12	36	39	44	35	38	22	19	17	5	9	8	8	3	7	6	3		2		1		2	2	4	1	0
14	1	1	15	12	11	14	6	4	7	7	10	5	4	3	5	7	2	2	1	3	2	1	2	1	2	2			0
15		5	8	12	20	9	10	9	12	12	11	8	3	4	6	3	3	5	6	3	2	1	1	1	1	1		1	2
16			12	22	8	15	8	17	7	11	13	7	3	9	5	9	7	4	3	3	2	3	3	1	1	3	1	2	1
17			10	21	35	35	43	29	31	25	23	19	20	13	16	12	4	9	4	4	4	5	4	4	1	1	2	2	0
18			8	17	15	9	16	10	11	14	4	9	4	5	8	6	5	6	9	4	7	2	2	2	1	3	2	1	0
19			6	8	16	12	12	15	4	7	16	9	10	9	14	9	4	3	9	3	5	4	3		3	3	1	1	3
20		1	5	17	14	11	5	14	8	11	11	10	11	5	9	6	7	8	3	4	10	2	6	7	4	2	2	1	1
21			4	14	24	35	42	28	38	36	39	26	31	24	12	12	19	11	11	11	10	5	8	7	2	3	3	1	1
22			6	12	18	10	16	8	8	10	7	4	3	5	4	11	10	7	6	6	11	5	7	3	2	3	1		3
23			7	11	19	13	17	9	16	12	12	12	12	10	12	17	10	9	12	12	7	3	7	3	1		2	3	1
24			3	8	14	6	14	6	11	22	8	12	18	9	13	10	10	10	12	4	7	5	7	10	2	4	3	1	5
25				19	25	30	44	27	31	32	32	28	34	26	28	27	18	16	23	11	6	3	14	7	10	6	4	1	3
26			1	4	14	13	11	5	4	10	8	15	9	15	13	16	5	10	10	10	9	5	4		3	4	2	2	3
27			3	12	12	14	8	11	10	8	6	11	7	8	7	11	9	8	7	10	6	7	8	2	4	2	4	5	3
28			1	5	14	24	13	17	8	10	22	16	15	11	13	12	3	22	14	14	8	9	5	5	4	9	7	2	3
29			3	10	13	25	29	31	29	26	28	23	30	24	24	23	25	17	23	14	16	11	11	7	10	4	2	2	6
30				6	13	12	15	8	9	5	6	15	6	11	10	8	7	12	11	7	8	5	3	2	4	2	4	2	0
31			1	5	11	17	10	8	10	11	11	5	11	8	14	10	4	7	7	4	9	4	5	6	4	5	2	3	0
32		1	1	4	10	11	10	13	9	11	6	7	10	9	9	10	9	13	9	9	6	4	6	5	7	3	2	1	1
33				5	6	19	19	20	25	22	18	30	23	13	17	24	12	23	15	16	14	9	5	12	8	3	3	1	0
34				5	5	6	8	5	5	11	11	4	6	7	5	6	5	4	6	8	7	5	3		4	1	3	1	1
35				1	7	6	7	9	4	7	5	10	7	7	9	8	4	6	9	2	11	6	4	3	3	3		1	1
36				2	6	3	12	12	4	9	8	5	9	11	7	10	5	7	5	7	4	7	4	5	2		2		1
37				1	4	14	19	21	16	22	20	17	22	19	18	16	19	26	16	14	14	10	11	6	6	2	3	4	2
38					6	6	8	1	6	11	8	7	2	4	2	5	4	6	2	1	2	3	5		1	2	1		0
39				2	4	8	11	11	9	6	4	4	3	5	6	7	7	5	6	6	7	4	5	3	2		3		1
40					5	8	5	14	11	9	4	3	9	9	9	6	10	10	4	12	10	6	7	6	2	2	3	3	0
41				1	1	9	17	11	19	15	16	14	9	15	11	13	14	9	8	11	18	11	7	3	4	2		2	1
42						3	4	3	6	7	6	5	4	3	4	3	3	2	3		1	4	2	1	1	2	1	1	1
43				2	3	3	3	7	5	11	4	3	4	1	4	8	6	7	3	2	5	1	5	7	7	1	2	3	1
44			1	1	3	4	1	5	1	5	6	5	4	5	4	7	5	6	3	5	3	2	3	4	1	3	2		1
45					2	4	9	9	7	8	13	10	8	8	5	12	9	15	11	11	8	6	3	6	3	5	5	3	0
46						2	2	3	3	2	3	3	4	2	3	1	1	1	3		2	5	2	1	5		1	1	0
47					3	4	5	4	3	5	3	2	2	4	4	1	4			3		2	1	1	2	1		1	1
48				1	2		2	5	6	5	2	4	2	2	2	3	6	3	4	2	2		1	2	1	2			0
49					1	1	9	4	8	11	8	11	7	10	6	10	8	7	7	3	4	7	3	6	2	3	1	2	0
50				1		1	1	3	1	1	2	3	1	2		3	4	3	1	2		4	1	1		1			0
51				1	1	2	3	1	6	1	2	3	2	1	2	1	1	3	1	1	2	2	4	2					1
52						3	3		2	4	2	1	4	2	1	6	2	2			2		3	1	3	1			1
53						1	6	4	1	8	10	4	11	10	4	7	4	2	3	2	1	2	4	5	3	2	2	1	0
54					1		2	2	1	2	2	2	1	3		1		2	1	1	2	1	1	1		1			0
55			1		2	8	15	11	17	23	21	36	27	26	17	18	16	29	23	20	7	13	9	11	13	4	1	3	1

Table 2b (Part 1)

TABLE 2b
PART 2

THE TOTAL NUMBER of PROCESSED OBSSERVATIONS
for the GILA RIVER and JORDAN LAKE TRANSMITTERS
for the KICKAPOO TRANSMITTER
as a FUNCTION of PEAK SIGNAL STRENGTH and the NUMBER OF DATA FRAME with AMPLITUDE > -152 dBm

	PEAK SIGNAL STRENGTH (dB below a mWatt)																							
# of FRAMES	123	122	121	120	119	118	117	116	115	114	113	112	111	110	109	108	107	106	105	104	103	102	101	100
10																								
11							1																	
12																								
13		1		1	1																			
14																								
15								1									1							
16																								
17		1																						
18	1	1							1															
19	5	2	1																					
20	1	1			1	1																		
21		3			1			1	1						1									
22		1		1																				
23	2	1			1																			
24	1	4		1		1			1															1
25	1	2			2																			
26	1	1																						
27	2										1													
28		3	1	1					1															
29	1	1	1		1																			
30	3	1																						
31	1	1																						
32	1	1																						
33	1	3	1	1								1												
34																								
35		1			1				1															
36			1				1																	
37	3	1	2	1		1			1															
38		1	1																					
39																								
40	2			1																				
41																								
42				3																				
43											1													
44	1	1																						
45		3																						
46																								
47																								
48								1																
49	1	1		1																				
50																								
51				1																				
52	1																							
53		1	1																					
54																								
55			1	2	1	1																		

Table 2b (Part 2)

TABLE 3a
PART 1

MEAN UNCERTAINTY OF DOPPLER DETERMINATION (Hz)
FOR THE KICKAPOO TRANSMITTER
AS A FUNCTION OF PEAK AMPLITUDE AND THE NUMBER OF DATA FRAMES WITH AMPLITUDE > -152
THREE TAPE AVERAGE

	PEAK AMPLITUDE dBm																				
# OF FRAMES	-152	-151	-150	-149	-148	-147	-146	-145	-144	-143	-142	-141	-140	-139	-138	-137	-136	-135	-134	-133	-132
10			4.47	4.06	3.95	4.59	3.80	3 67	3.46	3.43	2.99	3.29	3.13	1.90	4.17	3.65	3.73	1.96	2.25	1.49	2.43
11			2.43	4.49	3.28	2.53	3.13	2.99	2.87	2.55	2.25	2.56	2.95	2.76	2.92	2.91	2.86	2.87	1.94	2.98	1.75
12			3.78	3.04	3.26	3.14	2.50	2.16	2.85	2.79	2.11	2.27	2.67	1.38	1.77	1.39	2.26	1.88	1.37	1.86	0.80
13			2.58	3.40	2.54	2.54	1.92	2.13	2.63	2.03	1.78	1.90	1.99	2.19	1.34	2.05	1.98	1.95	2.05	1.06	3.16
14			1.93	2.19	2.38	2.50	2.08	2.14	1.22	1.36	1.52	1.67	1.94	1.95	2.30	0.90	1.30	1.04	0.48	0.83	0.88
15			2.11	2.58	1.83	1.72	1.28	1.58	1.22	1.04	1.35	1.45	1.59	1.21	1.58	1.49	0.36	1.61	1.49	2.49	1.40
16			1.85	1.82	1.37	1.57	1.44	1.53	1.05	1.41	1.30	1.28	1.04	0.73	1.73	0.97	1.17	0.92	1.19	0.75	1.22
17				1.30	1.00	0.98	1.00	1.17	1.12	1.19	1.29	1.13	0.84	0.98	1.19	0.78	0.95	0.78	1.36	0.59	0.96
18				1.14	0.99	1.21	1.22	0.98	0.98	0.83	1.36	1.17	0.87	1.01	0.71	1.03	0.81	1.12	0.63	1.45	1.15
19				0.67	1.04	0.72	0.94	0.83	0.82	0.78	0.87	0.92	1.02	0.92	0.79	0.64	0.81	0.58	0.68	0.96	0.94
20				1.08	0.60	0.71	0.80	0.60	0.71	0.86	0.87	0.85	0.71	0.83	0.68	0.84	0.72	0.90	0.53	0.89	0.93
21				0.60	1.08	0.65	0.58	0.82	0.60	0.65	0.69	0.56	0.63	0.64	0.69	0.67	0.88	0.57	0.57	0.65	0.90
22				0.22	0.59	0.66	0.53	0.57	0.66	0.59	0.58	0.56	0.59	0.60	0.44	0.52	0.32	0.66	0.40	0.92	0.54
23					0.60	0.66	0.49	0.60	0.49	0.41	0.56	0.49	0.56	0.41	0.56	0.56	0.47	0.47	0.55	0.50	0.48
24				0.56	0.58	0.51	0.57	0.41	0.40	0.60	0.43	0.43	0.55	0.50	0.40	0.52	0.46	0.52	0.45	0.44	0.43
25						0.51	0.54	0.40	0.37	0.46	0.37	0.38	0.40	0.47	0.46	0.51	0.58	0.42	0.49	0.45	0.31
26					0.19	0.55	0.48	0.43	0.43	0.41	0.36	0.38	0.35	0.38	0.38	0.32	0.30	0.43	0.32	0.28	0.42
27				0.62	0.54	0.41	0.31	0.32	0.22	0.40	0.35	0.36	0.31	0.38	0.36	0.32	0.35	0.27	0.33	0.35	0.34
28					1.11	0.45	0.43	0.28	0.31	0.29	0.31	0.31	0.32	0.28	0.41	0.34	0.33	0.33	0.33	0.34	0.33
29						0.38	0.38	0.28	0.27	0.29	0.27	0.23	0.27	0.29	0.26	0.30	0.29	0.25	0.29	0.25	0.27
30							0.29	0.37	0.29	0.26	0.27	0.33	0.22	0.29	0.28	0.25	0.23	0.26	0.31	0.29	0.25
31						0.35	0.32	0.36	0.27	0.30	0.20	0.23	0.23	0.18	0.23	0.22	0.25	0.24	0.24	0.28	0.31
32							0.36	0.24	0.25	0.18	0.18	0.23	0.21	0.17	0.22	0.21	0.21	0.22	0.16	0.22	0.17
33						0.57	0.14	0.20	0.23	0.22	0.18	0.20	0.23	0.21	0.22	0.15	0.20	0.23	0.20	0.25	0.19
34									0.11	0.20	0.19	0.25	0.17	0.19	0.25	0.19	0.15	0.17	0.16	0.20	0.17
35						0.61			0.16	0.21	0.28	0.19	0.16	0.18	0.13	0.13	0.19	0.20	0.17	0.18	0.19
36							0.11	0.26	0.21	0.15	0.14	0.21	0.13	0.18	0.16	0.13	0.17	0.17	0.14	0.14	0.15
37					0.48		0.40	0.37	0.15	0.17	0.24	0.15	0.19	0.13	0.13	0.12	0.12	0.15	0.13	0.15	0.13
38								0.12	0.21		0.22	0.15	0.12	0.13	0.11	0.14	0.15	0.17	0.17	0.14	0.12
39										0.09	0.19	0.16	0.13	0.13	0.13	0.16	0.13	0.08	0.11	0.12	0.12
40								0.17	0.22		0.16	0.26	0.12	0.11	0.10	0.11	0.15	0.12	0.13	0.13	0.15
41						0.14			0.26			0.11	0.11	0.11	0.09	0.13	0.13	0.09	0.12	0.12	0.09
42												0.11	0.10	0.12	0.11	0.12	0.09	0.16	0.14	0.09	0.10
43										0.27		0.17	0.11	0.11	0.11	0.11	0.09	0.10	0.12	0.10	0.11
44								0.18			0.15	0.09		0.09	0.07	0.11	0.08	0.11	0.08	0.08	0.08
45					0.35		0.13	0.22	0.19		0.08	0.12	0.08	0.07	0.12	0.10	0.08	0.10	0.09	0.09	0.09
46						0.19					0.14		0.11	0.13	0.09	0.09	0.09	0.10	0.09	0.12	0.09
47											0.08			0.07	0.09	0.09	0.07	0.06	0.08	0.10	0.08
48										0.19	0.10			0.05	0.06	0.07	0.07	0.12	0.08	0.09	0.07
49							0.18		0.11				0.08	0.04	0.07	0.08	0.09	0.08	0.07	0.08	0.06
50											0.16	0.16		0.16	0.05	0.07	0.09	0.08	0.14	0.07	0.07
51															0.08	0.08	0.12	0.05	0.08	0.06	0.07
52														0.09			0.07	0.05	0.06	0.08	0.06
53								0.15	0.21					0.12		0.06	0.06	0.11	0.07	0.07	0.06
54																		0.05	0.07	0.13	0.05
55								0.20	0.14	0.13	0.13	0.14	0.14	0.18	0.09	0.11	0.10	0.12	0.10	0.09	0.10

Table 3a (Part 1)

TABLE 3a
PART 2

MEAN UNCERTAINTY OF DOPPLER DETERMINATION (Hz)
FOR THE KICKAPOO TRANSMITTER
AS A FUNCTION OF PEAK AMPLITUDE AND THE NUMBER OF DATA FRAMES WITH AMPLITUDE > -152
THREE TAPE AVERAGE

# OF FRAMES	PEAK AMPLITUDE dBm -131	-130	-129	-128	-127	-126	-125	-124	-123	-122	-121	-120	-119	-118	-117	-116	-115	-114	-113	-112	
10		4.36	2.80																		
11																					
12		2.34			1.60																
13	1.94	1.78	1.06	1.28	1.15																
14	0.95	1.64			1.60	1.47															
15	1.24	0.54	0.49	1.46	1.84	0.59						1.66									
16	1.33	1.43	0.65		1.48				0.73												
17	0.72		0.60	0.91	1.10	1.23															
18	0.93	0.80		1.39		1.01	0.31				0.91										
19	1.16	0.60	0.64	0.70		0.91				1.33											
20	0.57	0.73	0.83	0.44	0.81	0.70	0.75	0.98					0.14								
21	0.52	0.88	0.61	0.59	0.54	0.51				0.71			0.37								
22	0.68	0.51	0.37	0.56	0.39			0.43	0.26												
23	0.50	0.32	0.48	0.40	0.46	0.34	0.30														
24	0.43	0.73	0.64	0.31	0.41	0.41	0.54	0.45	0.36	0.37											
25	0.42	0.40	0.42	0.36	0.34	0.38	0.25	0.33	0.30	0.38											
26	0.36	0.41	0.35	0.35	0.29	0.35	0.36		0.19		0.42										
27	0.34	0.35	0.22	0.29	0.37	0.30	0.63	0.41	0.30												
28	0.29	0.26	0.25	0.30	0.33	0.28	0.35	0.32	0.36	0.18	0.28	0.35	0.31	0.16							
29	0.29	0.27	0.23	0.22	0.28	0.21	0.23	0.26	0.24	0.16	0.14	0.28	0.29		0.14	0.16					
30	0.27	0.24	0.24	0.25	0.20	0.21	0.33	0.27	0.16	0.19	0.29	0.18									
31	0.26	0.28	0.27	0.18	0.19	0.23	0.21	0.20	0.23	0.23	0.16	0.25	0.28								
32	0.16	0.22	0.19	0.17	0.27	0.17	0.18	0.20	0.20	0.13	0.26	0.20	0.15		0.11						
33	0.19	0.20	0.20	0.15	0.27	0.21	0.23	0.21	0.20	0.14	0.12	0.12	0.14	0.13	0.04						
34	0.20	0.17	0.22	0.13	0.21	0.17	0.08	0.16	0.11	0.19	0.19	0.15	0.18		0.14	0.07					
35	0.14	0.16	0.18	0.16	0.15	0.15	0.17	0.15	0.17	0.18	0.12	0.07	0.14	0.14			0.17				
36	0.14	0.15	0.17	0.13	0.17	0.12	0.14	0.12	0.11	0.17	0.16	0.16	0.20	0.07	0.08						
37	0.14	0.13	0.11	0.16	0.12	0.11	0.15	0.11	0.13	0.12	0.07	0.14	0.14	0.11	0.08	0.10					
38	0.13	0.11	0.16	0.14	0.12	0.12	0.13	0.12	0.10	0.08	0.12	0.11	0.13			0.22					
39	0.12	0.12	0.12	0.13	0.13	0.11	0.08	0.11	0.12	0.08	0.07	0.16	0.13	0.14	0.05	0.11					
40	0.13	0.14	0.11	0.11	0.15	0.12	0.10	0.11	0.10	0.08	0.09	0.15	0.07	0.09	0.07						
41	0.10	0.12	0.12	0.14	0.10	0.10	0.09	0.12	0.11	0.09	0.14	0.07	0.11		0.09	0.09	0.04	0.05		0.09	
42	0.14	0.13	[illegible]	0.11	0.10	0.13	0.11	0.12	0.08	0.09	0.07	0.12	0.10								
43	0.11	0.14	0.09	0.09	0.07	0.08	0.07	0.14	0.09	0.09		0.12	0.07	0.07					0.08		
44	0.10	0.10	0.08	0.10	0.10	0.10	0.07	0.07	0.10	0.09	0.05	0.05	0.10	0.10					0.04		
45	0.10	0.08	0.12	0.09	0.08	0.09	0.11	0.10	0.18	0.08	0.07	0.10	0.10	0.08	0.04		0.08		0.05		
46	0.10	0.12	0.09	0.10	0.07	0.05	0.07	0.05	0.05	0.06	0.11	0.06	0.09	0.09					0.08		
47	0.09	0.09	0.08	0.09	0.09	0.09	0.08	0.09	0.08	0.07	0.11	0.09	0.08		0.09						
48	0.08	0.07	0.11	0.10	0.08	0.08	0.09	0.08		0.03	0.11	0.08		0.06	0.07						
49	0.08	0.08	0.07	0.08	0.10	0.08	0.08	0.06	0.11	0.09	0.08	0.08		0.05	0.08		0.07				
50	0.07	0.05	0.07	0.08	0.07	0.08	0.06	0.10	0.09	0.08	0.06		0.07		0.05						
51	0.08	0.07	0.08	0.11	0.09	0.05	0.07	0.05	0.07	0.08	0.04										
52	0.05	0.05	0.08	0.07	0.07	0.06	0.09	0.05	0.06	0.05	0.05			0.05							
53	0.08	0.06	0.08	0.05	0.06	0.04	0.08	0.06	0.10	0.05	0.04	0.04	0.06		0.14						
54	0.07	0.09	0.05	0.04	0.06	0.06	0.07	0.08	0.03		0.07			0.07							
55	0.06	0.08	0.07	0.08	0.07	0.07	0.07	0.05	0.06	0.05	0.06	0.06	0.05	0.06	0.10	0.06	0.05			0.04	0.06

Table 3a (Part 2)

TABLE 3b
PART 1

MEAN UNCERTAINTY OF CHIRP DETERMINATION (HZ/SEC)
FOR THE KICKAPOO TRANSMITTER
AS A FUNCTION OF PEAK AMPLITUDE AND THE NUMBER OF DATA FRAMES WITH AMPLITUDE > -152
THREE TAPE AVERAGE

# OF FRAMES	PEAK AMPLITUDE dBm -152	-151	-150	-149	-148	-147	-146	-145	-144	-143	-142	-141	-140	-139	-138	-137	-136	-135	-134	-133	-132
10			24.80	23.66	23.02	22.41	22.74	22.05	20.23	20.58	19.93	19.20	17.91	17.82	20.81	17.20	18.81	17.60	17.32	16.71	15.27
11			19.40	19.15	18.16	17.21	17.75	16.77	16.46	14.85	14.08	14.43	14.01	14.35	13.49	14.99	13.74	13.55	13.91	15.00	13.74
12			15.58	15.63	14.97	13.81	13.65	12.43	12.74	12.89	11.94	11.92	12.01	10.84	10.92	12.03	9.99	11.46	9.89	10.33	12.15
13			13.03	12.23	11.68	10.68	10.67	10.41	10.48	9.15	9.37	9.60	9.78	8.68	9.34	9.20	8.23	8.78	9.33	8.13	7.99
14			10.15	9.63	9.68	9.56	9.49	8.90	9.01	7.47	7.90	7.94	8.11	9.02	7.23	7.60	7.50	6.98	7.08	6.18	7.56
15			9.59	8.12	7.89	8.18	7.32	7.64	7.34	6.63	6.54	6.17	6.40	6.04	6.94	6.11	6.50	6.52	6.43	7.19	5.20
16			7.55	7.05	7.23	6.67	6.39	6.40	6.05	6.20	5.76	5.66	5.40	5.86	6.29	5.49	5.33	5.24	4.75	4.93	4.91
17				6.00	5.90	5.37	5.51	5.17	5.14	4.97	4.64	4.68	4.67	4.69	4.71	4.51	4.48	4.35	4.75	4.04	4.23
18				5.41	4.98	4.53	4.57	4.64	4.77	4.32	3.96	4.12	4.12	3.69	3.86	4.00	3.70	4.14	3.65	3.97	3.75
19				4.52	4.26	4.23	3.81	4.05	3.91	3.86	3.62	3.53	3.68	3.73	3.44	3.21	3.40	3.46	3.09	3.40	3.72
20				4.06	3.81	3.55	3.50	3.38	3.29	3.21	3.15	3.35	3.16	3.00	3.08	3.16	2.79	2.85	2.82	3.03	2.85
21				3.60	3.38	3.11	2.97	3.04	2.95	2.90	2.89	2.80	2.75	2.68	2.77	2.65	2.75	2.66	2.72	2.71	2.55
22				3.16	3.00	2.80	2.79	2.70	2.58	2.59	2.53	2.58	2.36	2.44	2.44	2.41	2.55	2.35	2.24	1.96	2.09
23					2.56	2.47	2.33	2.35	2.32	2.24	2.34	2.28	2.15	2.00	2.11	2.06	2.08	2.04	2.06	2.11	2.05
24				2.37	2.37	2.28	2.15	2.13	2.02	2.02	1.91	2.12	2.07	1.98	2.01	1.91	1.91	1.84	1.85	1.73	1.70
25						2.07	1.89	1.91	1.74	1.81	1.84	1.78	1.69	1.75	1.67	1.66	1.71	1.76	1.64	1.54	1.62
26					1.93	1.93	1.81	1.62	1.60	1.54	1.64	1.62	1.59	1.59	1.64	1.58	1.42	1.48	1.35	1.43	1.38
27				2.02	1.94	1.74	1.63	1.53	1.42	1.51	1.45	1.41	1.48	1.46	1.42	1.40	1.39	1.35	1.26	1.31	1.30
28					1.83	1.57	1.50	1.35	1.36	1.35	1.37	1.34	1.29	1.34	1.33	1.34	1.27	1.29	1.22	1.14	1.18
29						1.54	1.34	1.27	1.28	1.19	1.19	1.17	1.12	1.18	1.15	1.13	1.18	1.04	1.12	1.06	1.00
30							1.30	1.20	1.14	1.07	1.08	1.04	1.02	1.12	1.06	1.16	1.02	1.04	1.02	1.02	1.02
31						1.34	1.14	1.08	1.04	1.01	1.00	0.98	0.96	0.96	0.91	0.94	0.93	0.90	0.89	0.87	0.96
32							1.05	1.00	0.98	0.98	0.88	0.88	0.90	0.90	0.93	0.93	0.84	0.90	0.84	0.89	0.82
33						1.17	0.97	0.96	0.86	0.84	0.85	0.86	0.82	0.83	0.82	0.80	0.83	0.81	0.79	0.79	0.80
34									0.85	0.83	0.76	0.83	0.75	0.75	0.73	0.80	0.73	0.74	0.73	0.73	0.73
35						0.97			0.77	0.78	0.78	0.72	0.70	0.71	0.71	0.69	0.74	0.70	0.68	0.68	0.65
36							0.76	0.75	0.73	0.68	0.70	0.69	0.66	0.62	0.63	0.67	0.62	0.68	0.65	0.62	0.63
37					0.82		0.84	0.76	0.69	0.67	0.64	0.60	0.65	0.59	0.59	0.59	0.58	0.61	0.59	0.57	0.60
38								0.69	0.72		0.64	0.58	0.57	0.59	0.58	0.57	0.57	0.59	0.57	0.56	0.53
39										0.56	0.58	0.55	0.53	0.54	0.56	0.52	0.51	0.53	0.52	0.52	0.52
40								0.52	0.53		0.52	0.56	0.52	0.48	0.47	0.49	0.48	0.49	0.50	0.50	0.48
41						0.62			0.50			0.51	0.46	0.47	0.44	0.48	0.49	0.45	0.44	0.45	0.46
42												0.43	0.43	0.43	0.43	0.43	0.44	0.47	0.45	0.42	0.40
43										0.60		0.43	0.42	0.40	0.38	0.39	0.40	0.41	0.40	0.41	0.40
44								0.44			0.41	0.40		0.40	0.37	0.39	0.40	0.37	0.38	0.37	0.38
45					0.58		0.50	0.48	0.41		0.52	0.38	0.36	0.37	0.36	0.37	0.35	0.37	0.36	0.35	0.36
46						0.49					0.36		0.36	0.34	0.37	0.32	0.35	0.34	0.35	0.38	0.34
47											0.34			0.34	0.33	0.33	0.36	0.33	0.33	0.30	0.31
48										0.34	0.38			0.31	0.33	0.30	0.32	0.30	0.30	0.29	0.29
49							0.42		0.32				0.34	0.30	0.28	0.30	0.29	0.30	0.30	0.29	0.29
50											0.29	0.31		0.31	0.27	0.26	0.27	0.26	0.30	0.28	0.29
51															0.27	0.31	0.26	0.25	0.27	0.25	0.25
52														0.25			0.25	0.23	0.23	0.23	0.25
53								0.30	0.26					0.23		0.24	0.23	0.25	0.24	0.23	0.24
54																		0.22	0.22	0.20	0.22
55								0.25	0.22	0.24	0.22	0.21	0.22	0.20	0.22	0.21	0.22	0.20	0.20	0.20	0.19

Table 3b (Part 1)

TABLE 3b
PART 2

MEAN UNCERTAINTY OF CHIRP DETERMINATION (HZ/SEC)
FOR THE KICKAPOO TRANSMITTER
AS A FUNCTION OF PEAK AMPLITUDE AND THE NUMBER OF DATA FRAMES WITH AMPLITUDE › -152
THREE TAPE AVERAGE

PEAK AMPLITUDE dBm

# OF FRAMES	-131	-130	-129	-128	-127	-126	-125	-124	-123	-122	-121	-120	-119	-118	-117	-116	-115	-114	-113	-112	-111
10		17.07	15.59																		
11																					
12		8.59			8.85																
13	8.27	7.52	8.51	8.47	8.69																
14	7.32	7.88			5.75	6.43															
15	5.80	5.76	6.17	6.03	5.91	5.05						3.78									
16	4.87	4.89	5.40		5.55				4.14												
17	4.50		4.06	3.69	3.50	3.48															
18	3.67	3.44		3.14		3.42	2.88				2.37										
19	3.15	3.30	3.05	3.79		3.16				2.86											
20	2.50	2.55	2.52	2.37	2.62	2.48	2.74	2.62					1.99								
21	2.47	2.31	2.49	2.60	2.24	2.35				1.91			1.75								
22	2.23	2.11	2.01	2.07	1.98			1.84	1.82												
23	2.04	2.18	1.81	1.71	1.94	1.67	1.93														
24	1.80	1.68	1.84	1.69	1.80	1.66	1.52	1.44	1.58	1.50											
25	1.62	1.49	1.48	1.46	1.55	1.60	1.44	1.53	1.64	1.28											
26	1.36	1.37	1.36	1.46	1.63	1.37	1.29		1.30		1.30										
27	1.29	1.44	1.30	1.30	1.28	1.34	1.38	1.28	1.20												
28	1.25	1.14	1.25	1.13	1.24	1.19	1.16	1.02	1.13	1.08	1.18	1.06	0.85	0.78							
29	1.16	1.03	1.07	1.04	1.15	1.06	0.99	0.98	0.95	0.91	0.93	0.92	0.99		0.92	0.63					
30	1.03	0.93	0.96	0.99	0.97	0.95	0.90	0.96	0.80	0.88	0.80	0.82									
31	1.00	0.83	0.93	0.90	0.90	0.86	0.95	0.82	0.78	0.82	0.80	0.75	0.78								
32	0.82	0.82	0.83	0.78	0.81	0.83	0.72	0.74	0.73	0.72	0.79	0.70	0.67		0.56						
33	0.81	0.80	0.80	0.77	0.71	0.76	0.73	0.72	0.64	0.70	0.71	0.67	0.63	0.65	0.50						
34	0.73	0.71	0.74	0.64	0.66	0.67	0.68	0.70	0.66	0.60	0.61	0.58	0.74		0.59	0.47					
35	0.63	0.63	0.65	0.64	0.64	0.63	0.64	0.65	0.64	0.60	0.63	0.52	0.53	0.60			0.51				
36	0.62	0.60	0.64	0.58	0.60	0.54	0.56	0.57	0.49	0.57	0.55	0.53	0.53	0.52	0.43						
37	0.57	0.60	0.57	0.55	0.54	0.53	0.54	0.54	0.54	0.56	0.50	0.50	0.41	0.44	0.53	0.36					
38	0.54	0.53	0.50	0.54	0.52	0.50	0.50	0.52	0.46	0.50	0.45	0.46	0.50			0.47					
39	0.52	0.49	0.51	0.50	0.47	0.49	0.49	0.48	0.47	0.41	0.40	0.46	0.40	0.40	0.39	0.39					
40	0.47	0.48	0.45	0.47	0.43	0.46	0.44	0.45	0.41	0.44	0.43	0.39	0.40	0.42	0.43						
41	0.45	0.42	0.43	0.43	0.41	0.41	0.43	0.42	0.41	0.41	0.38	0.37	0.39		0.37	0.31	0.31	0.37		0.33	
42	0.40	0.42	0.45	0.41	0.39	0.37	0.37	0.39	0.38	0.38	0.38	0.36	0.31								
43	0.39	0.40	0.39	0.37	0.37	0.37	0.37	0.36	0.35	0.39		0.34	0.34	0.32					0.28		
44	0.38	0.38	0.37	0.37	0.36	0.35	0.35	0.33	0.34	0.37	0.31	0.34	0.33	0.36					0.25		
45	0.34	0.36	0.34	0.33	0.34	0.33	0.33	0.31	0.31	0.28	0.31	0.32	0.30	0.30	0.28		0.26		0.26		
46	0.34	0.34	0.33	0.32	0.32	0.30	0.31	0.31	0.30	0.29	0.27	0.31	0.28	0.31					0.28		
47	0.31	0.32	0.32	0.29	0.33	0.31	0.30	0.28	0.30	0.29	0.26	0.31	0.25		0.23						
48	0.31	0.29	0.29	0.32	0.26	0.28	0.29	0.27		0.28	0.27	0.26		0.23	0.23						
49	0.30	0.29	0.29	0.29	0.30	0.27	0.28	0.27	0.27	0.26	0.25	0.24		0.24	0.25		0.21				
50	0.27	0.27	0.26	0.28	0.26	0.25	0.25	0.25	0.26	0.24	0.21		0.21		0.22						
51	0.24	0.28	0.25	0.26	0.26	0.26	0.24	0.23	0.24	0.23	0.22										
52	0.25	0.23	0.29	0.25	0.24	0.22	0.21	0.21	0.21	0.24	0.23			0.21							
53	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.21	0.21	0.21	0.21	0.22	0.18		0.17						
54	0.26	0.26	0.21	0.19	0.21	0.23	0.21	0.22	0.22		0.20			0.17							
55	0.20	0.19	0.20	0.19	0.20	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.17	0.16	0.16	0.15	0.15			0.13	0.11

Table 3b (Part 2)

TABLE 3c
PART 1

MEAN UNCERTAINTY OF DOPPLER DETERMINATION (Hz)
FOR THE GILA RIVER AND JORDAN LAKE TRANSMITTERS
AS A FUNCTION OF PEAK AMPLITUDE AND THE NUMBER OF DATA FRAMES WITH AMPLITUDE > -152
THREE TAPE AVERAGE

	PEAK AMPLITUDE dBm																				
# OF FRAMES	-152	-151	-150	-149	-148	-147	-146	-145	-144	-143	-142	-141	-140	-139	-138	-137	-136	-135	-134	-133	-132
10		2.08	2.35	2.29	1.75	2.49	2.32	1.31		1.41	1.97	1.81	1.71				1.02	0.74	0.57		1.00
11		1.27	1.79	2.12	1.99	1.67	1.48	1.39	1.94	1.61	0.95	0.81	0.44		1.16			0.60		0.43	0.33
12		2.09	1.70	1.50	1.31	1.77	1.18	1.43	0.58	1.22	0.92	0.94	0.58	0.54	0.72	1.03	0.72			0.25	0.47
13			1.31	1.19	1.39	1.24	1.07	0.96	0.93	0.96	0.90	0.65	0.55	0.66	0.83	0.98	0.72	0.63	0.64		0.65
14			1.34	1.51	1.13	1.00	0.99	0.93	0.83	0.97	1.15	0.62	0.76	0.40	0.51	0.63	0.58	0.48		0.49	0.80
15		1.47	0.85	0.90	1.15	1.21	0.89	0.96	0.77	0.73	0.44	0.66	0.97	0.81	0.82	0.58	0.62	0.42	0.64	0.59	0.32
16			0.94	0.83	1.13	0.82	0.49	0.78	0.82	0.55	0.59	0.62	0.63	0.44	0.52	0.51	0.32	0.28	0.32	0.48	0.62
17			0.71	0.89	0.80	0.62	0.62	0.73	0.49	0.57	0.46	0.56	0.39	0.43	0.31	0.47	0.27	0.40	0.29	0.22	0.24
18			0.84	1.00	0.78	0.63	0.63	0.46	0.68	0.56	0.58	0.52	0.40	0.31	0.39	0.42	0.21	0.28	0.45	0.28	0.44
19			0.52	0.67	0.50	0.63	0.60	0.54	0.51	0.45	0.40	0.54	0.44	0.44	0.19	0.33	0.27	0.27	0.34	0.33	0.41
20			0.80	0.55	0.50	0.62	0.65	0.51	0.35	0.32	0.39	0.33	0.24	0.23	0.27	0.35	0.31	0.33	0.25	0.17	0.21
21			0.67	0.42	0.41	0.44	0.39	0.42	0.41	0.38	0.32	0.34	0.37	0.28	0.25	0.29	0.21	0.22	0.20	0.16	0.22
22			0.35	0.61	0.53	0.42	0.35	0.39	0.25	0.26	0.32	0.36	0.23	0.21	0.21	0.25	0.24	0.36	0.20	0.24	0.18
23			0.35	0.44	0.44	0.38	0.28	0.38	0.37	0.23	0.35	0.24	0.30	0.22	0.18	0.24	0.23	0.18	0.22	0.19	0.21
24			0.28	0.23	0.28	0.37	0.27	0.35	0.32	0.22	0.14	0.18	0.19	0.25	0.21	0.21	0.16	0.14	0.15	0.27	0.16
25				0.36	0.31	0.26	0.27	0.23	0.25	0.23	0.25	0.21	0.13	0.18	0.18	0.17	0.21	0.17	0.15	0.21	0.17
26				0.18	0.32	0.30	0.25	0.39	0.14	0.19	0.17	0.20	0.20	0.17	0.14	0.11	0.14	0.11	0.13	0.12	0.13
27			0.24	0.24	0.20	0.27	0.24	0.19	0.25	0.12	0.17	0.21	0.23	0.16	0.14	0.15	0.15	0.13	0.17	0.15	0.09
28				0.31	0.37	0.19	0.19	0.11	0.18	0.16	0.17	0.14	0.15	0.13	0.14	0.15	0.17	0.13	0.10	0.11	0.11
29			0.72	0.28	0.29	0.21	0.19	0.15	0.18	0.15	0.16	0.14	0.14	0.11	0.12	0.10	0.11	0.13	0.11	0.08	0.11
30				0.19	0.24	0.15	0.24	0.23	0.16	0.17	0.21	0.13	0.11	0.13	0.09	0.14	0.08	0.09	0.09	0.07	0.13
31				0.23	0.13	0.18	0.14	0.20	0.11	0.16	0.13	0.09	0.10	0.09	0.09	0.12	0.09	0.11	0.12	0.14	0.07
32				0.20	0.21	0.15	0.17	0.16	0.15	0.13	0.13	0.12	0.10	0.08	0.11	0.09	0.09	0.09	0.08	0.10	0.09
33				0.27	0.13	0.18	0.14	0.15	0.13	0.11	0.11	0.09	0.11	0.10	0.11	0.09	0.07	0.08	0.07	0.07	0.06
34				0.12	0.21	0.15	0.12	0.10	0.13	0.15	0.11	0.11	0.12	0.09	0.08	0.08	0.09	0.06	0.10	0.06	0.07
35					0.21	0.15	0.13	0.13	0.08	0.15	0.11	0.10	0.07	0.09	0.08	0.07	0.13	0.06	0.09	0.04	0.08
36				0.14	0.07	0.16	0.10	0.12	0.15	0.07	0.09	0.08	0.10	0.09	0.08	0.06	0.06	0.05	0.08	0.05	0.06
37					0.13	0.11	0.12	0.11	0.12	0.08	0.10	0.09	0.07	0.10	0.07	0.07	0.06	0.06	0.07	0.06	0.05
38					0.09	0.10	0.12		0.08	0.09	0.08	0.08	0.12	0.05	0.05	0.09	0.04	0.06	0.05		0.03
39				0.12	0.13	0.10	0.08	0.10	0.10	0.07	0.06	0.05	0.02	0.07	0.06	0.05	0.08	0.04	0.05	0.04	0.04
40					0.12	0.07	0.10	0.11	0.11	0.10	0.07	0.05	0.05	0.05	0.06	0.07	0.03	0.05	0.08	0.06	0.05
41						0.10	0.08	0.09	0.09	0.06	0.07	0.06	0.06	0.05	0.06	0.06	0.07	0.04	0.04	0.05	0.05
42						0.11	0.11	0.09	0.07	0.08	0.10	0.06	0.05	0.09	0.03	0.07	0.04	0.04	0.04		
43				0.09	0.21	0.13	0.06	0.06	0.06	0.09	0.05	0.05	0.09		0.08	0.04	0.04	0.05	0.03	0.05	0.06
44					0.06	0.10		0.12		0.07	0.05	0.03	0.05	0.04	0.05	0.07	0.06	0.03	0.04	0.03	0.02
45					0.05	0.06	0.10	0.10	0.12	0.07	0.06	0.05	0.04	0.05	0.04	0.04	0.05	0.04	0.03	0.04	0.04
46						0.05	0.04	0.11	0.04	0.08	0.05	0.05	0.03	0.03	0.05				0.04		0.05
47					0.08	0.15	0.08	0.08	0.08	0.05	0.11	0.06	0.06	0.05	0.04		0.03			0.05	
48					0.22		0.08	0.06	0.06	0.07	0.08	0.04	0.04	0.05	0.04	0.04	0.05	0.02	0.04	0.04	0.02
49							0.05	0.05	0.12	0.07	0.05	0.07	0.05	0.04	0.02	0.02	0.03	0.04	0.03	0.04	0.03
50								0.04			0.04	0.08		0.04		0.04	0.03	0.03		0.07	
51						0.04	0.08		0.07		0.06	0.08	0.04		0.06			0.08			0.07
52						0.13	0.05		0.05	0.03	0.07		0.04	0.03		0.04	0.04	0.04			0.01
53							0.08	0.03		0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.05	0.01	0.02	0.02	
54							0.04	0.03		0.04	0.04	0.04		0.03				0.04			0.05
55					0.04	0.09	0.08	0.09	0.05	0.05	0.03	0.04	0.06	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03

Table 3c (Part 1)

TABLE 3c
PART 2

MEAN UNCERTAINTY OF DOPPLER DETERMINATION (Hz)
FOR THE GILA RIVER AND JORDAN LAKE TRANSMITTERS
AS A FUNCTION OF PEAK AMPLITUDE AND THE NUMBER OF DATA FRAMES WITH AMPLITUDE > -152
THREE TAPE AVERAGE

# OF FRAMES	PEAK AMPLITUDE dBm -131	-130	-129	-128	-127	-126	-125	-124	-123	-122	-121	-120	-119	-118	-117	-116	-115	-114	-113	-112	-111
10																					
11						0.66															
12		0.53		0.45																	
13				0.67	0.17	0.69															
14		0.31		0.28	0.59																
15								0.44													
16	0.50	0.48			0.33		0.33														
17	0.46	0.42	0.38			0.25	0.24														
18	0.38	0.31	0.27		0.34	0.25															
19	0.25	0.28		0.30	0.47			0.38	0.23	0.25											
20	0.12	0.27	0.20	0.25	0.33	0.42															
21	0.22	0.22	0.16	0.16	0.20	0.19				0.19											
22	0.19	0.18	0.20	0.20	0.17			0.14													
23	0.15	0.13	0.29			0.22	0.17		0.20												
24	0.15	0.12	0.18	0.14	0.15	0.15		0.14		0.10											
25	0.16	0.15	0.10	0.11	0.10	0.13		0.08		0.03			0.03								
26	0.12	0.13		0.17	0.15	0.17	0.13	0.09													
27	0.10	0.16	0.09	0.04	0.14	0.09	0.07	0.17	0.20												
28	0.06	0.11	0.09	0.10	0.10	0.08	0.10	0.17		0.11											
29	0.11	0.06	0.12	0.06	0.08	0.07	0.15	0.09													
30	0.06	0.09	0.07	0.10	0.09	0.05	0.05		0.11												
31	0.12	0.07	0.07	0.10	0.07	0.19	0.14														
32	0.07	0.05	0.08	0.05	0.09	0.08															
33	0.07	0.06	0.08	0.07	0.06	0.04				0.04											
34	0.05	0.04		0.05		0.04															
35	0.05	0.04	0.04	0.05	0.07																
36	0.07	0.04	0.04	0.02		0.05															
37	0.05	0.05	0.05	0.07	0.01	0.04	0.04	0.03	0.04		0.04										
38	0.06	0.05			0.04																
39	0.07	0.07	0.03	0.01		0.03															
40	0.05	0.05	0.04	0.06	0.03	0.05	0.03		0.04												
41	0.04	0.04	0.02	0.04	0.01		0.02														
42	0.0[illegible]	0.06			0.03							0.05									
43		0.03	0.03	0.05		0.03	0.06														
44	0.05	0.03	0.02		0.03	0.05															
45	0.02	0.03	0.04	0.03	0.02	0.03	0.03			0.03											
46	0.02	0.03		0.03																	
47	0.04			0.03																	
48			0.03		0.01																
49	0.02	0.05	0.03	0.04	0.02		0.01														
50	0.05																				
51	0.03	0.04	0.01																		
52		0.04		0.02																	
53	0.01	0.02	0.03	0.04	0.02	0.04															
54																					
55	0.03	0.02	0.02	0.04	0.03		0.02					0.01									

Table 3c (Part 2)

TABLE 3d
PART 1

MEAN UNCERTAINTY OF CHIRP DETERMINATION (Hz/sec)
FOR THE GILA RIVER AND JORDAN LAKE TRANSMITTERS
AS A FUNCTION OF PEAK AMPLITUDE AND THE NUMBER OF DATA FRAMES WITH AMPLITUDE > -152
THREE TAPE AVERAGE

PEAK AMPLITUDE dBm

# OF FRAMES	-152	-151	-150	-149	-148	-147	-146	-145	-144	-143	-142	-141	-140	-139	-138	-137	-136	-135	-134	-133	-132
10		14.63	14.19	13.39	12.09	11.71	11.05	10.40		9.23	8.32	8.77	8.07				6.26	6.04	5.60		5.72
11		10.93	11.26	10.93	10.22	9.31	9.28	8.37	8.01	7.11	6.92	6.33	5.68		5.84			4.45		4.48	4.84
12		9.36	9.17	8.52	7.94	7.38	6.89	6.79	5.88	5.94	5.45	5.00	5.59	4.60	4.60	3.96	4.07			3.54	3.63
13			7.22	7.02	6.42	5.99	5.66	5.32	4.91	4.70	4.35	4.21	4.13	3.87	3.31	3.65	3.42	3.08	3.33		2.96
14			5.91	5.83	5.55	5.00	4.76	4.43	4.11	3.77	3.84	3.69	3.05	2.99	3.10	2.99	3.06	2.65		2.40	2.42
15		4.87	5.37	4.77	4.59	4.36	4.07	3.79	3.39	3.45	3.00	2.91	2.67	2.63	2.73	2.37	2.20	2.27	2.33	2.36	2.34
16			4.15	3.91	3.86	3.63	3.45	3.26	2.94	2.82	2.67	2.62	2.30	2.30	2.12	2.21	2.15	1.93	1.95	1.61	1.97
17			3.68	3.48	3.34	3.10	2.90	2.68	2.52	2.42	2.25	2.07	1.98	1.92	1.77	1.68	1.70	1.63	1.53	1.40	1.49
18			3.06	3.08	2.93	2.72	2.56	2.38	2.18	2.10	2.14	1.91	1.82	1.87	1.56	1.69	1.44	1.51	1.54	1.36	1.20
19			2.81	2.56	2.51	2.36	2.24	2.07	1.97	1.83	1.77	1.74	1.64	1.52	1.50	1.32	1.27	1.20	1.28	1.10	1.15
20			2.23	2.39	2.39	2.00	1.97	1.89	1.69	1.63	1.55	1.43	1.41	1.33	1.31	1.25	1.14	1.08	1.05	1.11	0.98
21			2.06	2.00	1.93	1.82	1.71	1.60	1.52	1.42	1.34	1.24	1.22	1.17	1.06	1.08	1.02	0.99	0.87	0.87	0.87
22			1.98	1.81	1.75	1.59	1.55	1.39	1.42	1.32	1.18	1.23	1.09	1.02	0.98	0.94	0.98	0.92	0.79	0.81	0.80
23			1.60	1.65	1.60	1.48	1.43	1.36	1.22	1.13	1.14	1.04	1.00	0.90	0.91	0.86	0.80	0.77	0.75	0.70	0.73
24			1.55	1.49	1.41	1.28	1.22	1.16	1.12	1.01	1.02	0.95	0.87	0.80	0.80	0.73	0.73	0.78	0.71	0.67	0.65
25				1.32	1.27	1.15	1.10	1.04	0.97	0.92	0.88	0.78	0.76	0.73	0.70	0.66	0.65	0.61	0.58	0.56	0.55
26				1.18	1.18	1.06	1.02	0.92	0.90	0.82	0.79	0.75	0.74	0.70	0.64	0.65	0.59	0.59	0.54	0.53	0.53
27			1.08	1.13	1.07	0.98	0.92	0.89	0.83	0.77	0.72	0.72	0.65	0.64	0.60	0.56	0.54	0.52	0.49	0.48	0.53
28				0.94	0.96	0.92	0.82	0.80	0.76	0.71	0.67	0.63	0.63	0.57	0.53	0.53	0.52	0.48	0.47	0.48	0.44
29			1.02	0.90	0.86	0.82	0.78	0.73	0.66	0.63	0.58	0.56	0.52	0.51	0.49	0.47	0.45	0.43	0.42	0.42	0.39
30				0.84	0.81	0.75	0.72	0.72	0.63	0.63	0.53	0.54	0.55	0.48	0.45	0.43	0.42	0.42	0.41	0.38	0.37
31				0.77	0.72	0.70	0.67	0.62	0.59	0.55	0.52	0.48	0.47	0.44	0.44	0.42	0.42	0.39	0.36	0.36	0.34
32				0.74	0.68	0.67	0.62	0.60	0.53	0.50	0.49	0.44	0.44	0.40	0.39	0.36	0.37	0.35	0.35	0.32	0.30
33				0.64	0.60	0.59	0.56	0.51	0.48	0.46	0.44	0.41	0.39	0.37	0.36	0.34	0.32	0.33	0.29	0.30	0.29
34				0.59	0.58	0.58	0.52	0.52	0.47	0.44	0.42	0.44	0.38	0.36	0.34	0.33	0.30	0.30	0.29	0.28	0.25
35					0.59	0.54	0.50	0.45	0.46	0.40	0.38	0.37	0.35	0.32	0.31	0.30	0.28	0.26	0.27	0.25	0.25
36				0.58	0.50	0.47	0.46	0.44	0.43	0.38	0.37	0.33	0.33	0.29	0.31	0.29	0.29	0.25	0.23	0.24	0.23
37					0.48	0.44	0.42	0.39	0.37	0.35	0.34	0.31	0.29	0.28	0.26	0.25	0.24	0.23	0.22	0.24	0.21
38					0.44	0.44	0.41		0.37	0.33	0.32	0.31	0.28	0.26	0.25	0.25	0.23	0.24	0.22		0.19
39				0.44	0.40	0.38	0.39	0.35	0.35	0.33	0.28	0.26	0.26	0.25	0.24	0.22	0.23	0.21	0.20	0.20	0.18
40					0.40	0.37	0.38	0.34	0.32	0.30	0.29	0.28	0.24	0.23	0.21	0.20	0.20	0.21	0.20	0.19	0.17
41						0.35	0.33	0.30	0.28	0.26	0.26	0.25	0.23	0.22	0.21	0.20	0.18	0.18	0.19	0.17	0.16
42						0.34	0.31	0.29	0.28	0.27	0.25	0.26	0.21	0.22	0.18	0.21	0.19	0.19	0.18		
43				0.36	0.33	0.29	0.30	0.27	0.26	0.26	0.23	0.22	0.21		0.19	0.17	0.16	0.17	0.17	0.18	0.14
44					0.30	0.29		0.27		0.24	0.22	0.21	0.20	0.18	0.17	0.17	0.17	0.14	0.14	0.14	0.15
45					0.27	0.28	0.27	0.25	0.23	0.21	0.20	0.18	0.18	0.19	0.16	0.15	0.16	0.15	0.14	0.14	0.12
46						0.27	0.25	0.22	0.22	0.22	0.19	0.20	0.18	0.17	0.16				0.15		0.13
47					0.28	0.25	0.26	0.22	0.22	0.19	0.19	0.19	0.18	0.15	0.15		0.16			0.13	
48					0.25		0.25	0.20	0.21	0.19	0.18	0.17	0.15	0.14	0.16	0.14	0.13	0.14	0.13	0.11	0.10
49							0.22	0.20	0.18	0.18	0.16	0.15	0.15	0.14	0.13	0.14	0.12	0.11	0.11	0.15	0.11
50								0.20			0.16	0.16		0.13		0.12	0.12	0.11		0.11	
51						0.19	0.18		0.16		0.15	0.14	0.14		0.12			0.10			0.10
52						0.19	0.19		0.17	0.16	0.15		0.13	0.13		0.11	0.11	0.12			0.11
53							0.17	0.18		0.14	0.14	0.12	0.12	0.11	0.11	0.10	0.11	0.10	0.09	0.11	
54							0.16	0.17		0.14	0.13	0.13		0.11				0.11			0.10
55					0.17	0.17	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.09	0.09	0.08	0.08	0.07	0.07	0.07	0.07

Table 3d (Part 1)

TABLE 3d
PART 2

MEAN UNCERTAINTY OF CHIRP DETERMINATION (Hz/sec)
FOR THE GILA RIVER AND JORDAN LAKE TRANSMITTERS
AS A FUNCTION OF PEAK AMPLITUDE AND THE NUMBER OF DATA FRAMES WITH AMPLITUDE > -152
THREE TAPE AVERAGE

# OF FRAMES	PEAK AMPLITUDE dBm -131	-130	-129	-128	-127	-126	-125	-124	-123	-122	-121	-120	-119	-118	-117	-116	-115	-114	-113	-112	-111
10																					
11						4.43															
12		3.22		3.25																	
13				2.99	2.37	2.63															
14		3.06		2.38	2.61																
15								1.54													
16	1.55	1.78			1.48		1.47														
17	1.51	1.35	1.38			1.27	1.20														
18	1.19	1.35	1.17		1.09	1.19															
19	1.08	1.11		1.04	1.15			0.98	1.15	0.86											
20	0.94	0.95	0.90	0.92	0.92	1.00															
21	0.95	0.81	0.81	0.79	0.83	0.91				0.80											
22	0.79	0.80	0.80	0.79	0.75			0.74													
23	0.61	0.67	0.76			0.66	0.57		0.58												
24	0.59	0.60	0.61	0.56	0.60	0.62		0.56		0.62											
25	0.51	0.54	0.53	0.54	0.53	0.50		0.54		0.44			0.47								
26	0.54	0.53		0.47	0.50	0.43	0.55	0.45													
27	0.44	0.47	0.43	0.45	0.39	0.40	0.42	0.42	0.43												
28	0.44	0.46	0.41	0.42	0.44	0.40	0.38	0.46		0.39											
29	0.39	0.37	0.39	0.37	0.37	0.45	0.38	0.36													
30	0.34	0.31	0.30	0.34	0.30	0.33	0.29		0.30												
31	0.36	0.31	0.31	0.30	0.33	0.30	0.33														
32	0.27	0.29	0.32	0.29	0.29	0.25															
33	0.26	0.28	0.27	0.25	0.33	0.23				0.24											
34	0.26	0.24		0.29		0.27															
35	0.25	0.23	0.22	0.24	0.22																
36	0.23	0.22	0.22	0.20		0.21															
37	0.21	0.21	0.19	0.21	0.19	0.19	0.20	0.17	0.18		0.17										
38	0.20	0.20			0.16																
39	0.20	0.19	0.16	0.17		0.14															
40	0.17	0.17	0.18	0.18	0.15	0.15	0.14		0.16												
41	0.15	0.16	0.13	0.16	0.15		0.13														
42	0.15	0.16			0.14							0.13									
43		0.14	0.14	0.15		0.13	0.13														
44	0.14	0.14	0.12		0.14	0.13															
45	0.13	0.12	0.12	0.14	0.11	0.11	0.10			0.12											
46	0.12	0.11		0.12																	
47	0.13			0.11																	
48			0.11		0.10																
49	0.10	0.11	0.10	0.11	0.10		0.08														
50	0.10																				
51	0.10	0.10	0.09																		
52		0.09		0.08																	
53	0.09	0.08	0.08	0.08	0.08	0.08															
54																					
55	0.07	0.06	0.07	0.06	0.07		0.06					0.05									

Table 3d (Part 2)

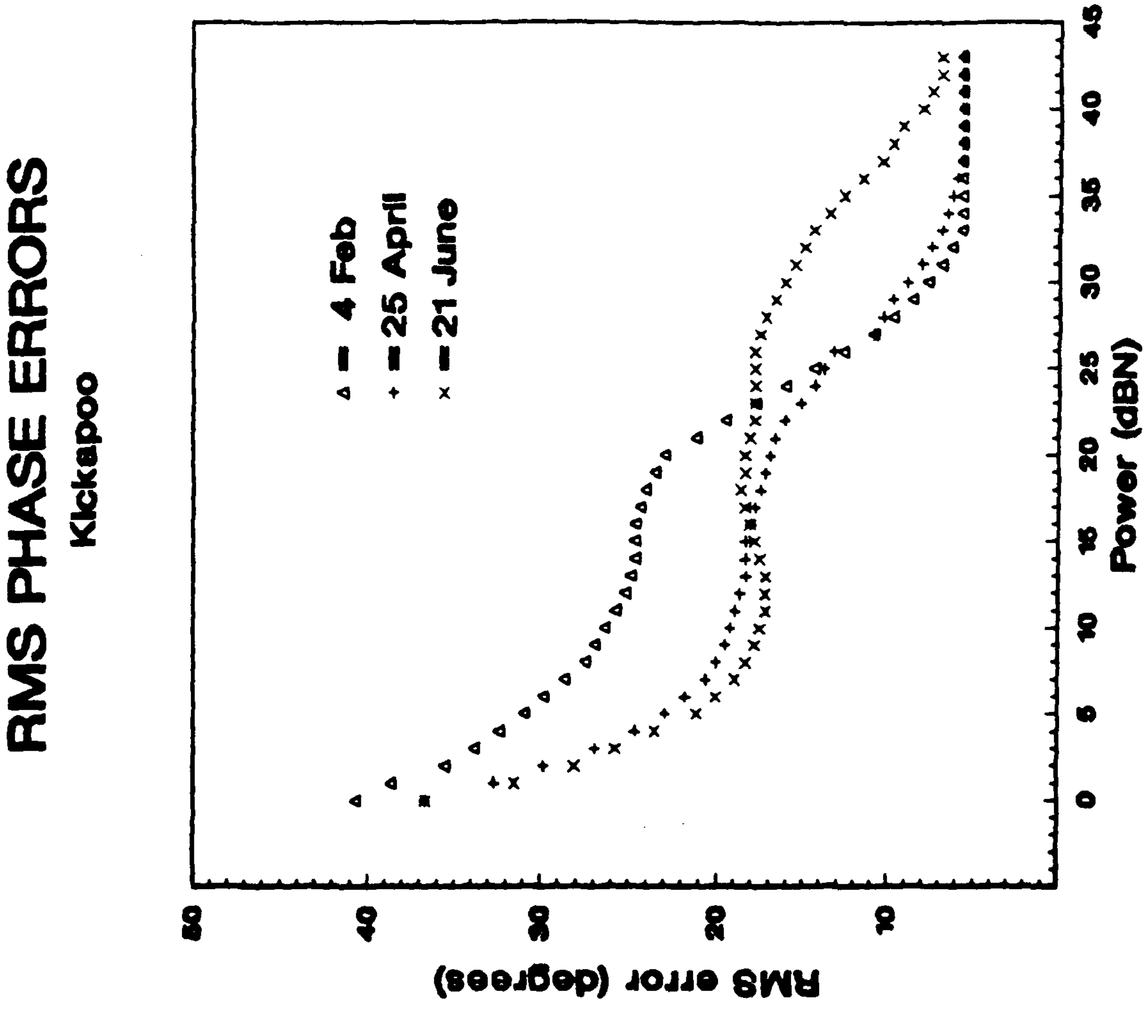

RMS PHASE ERRORS
Kickapoo
△ = 4 Feb
+ = 25 April
× = 21 June
RMS error (degrees)
10
20
30
40
50
Power (dBN)
0
5
10
15
20
25
30
35
40
45

Figure 1a

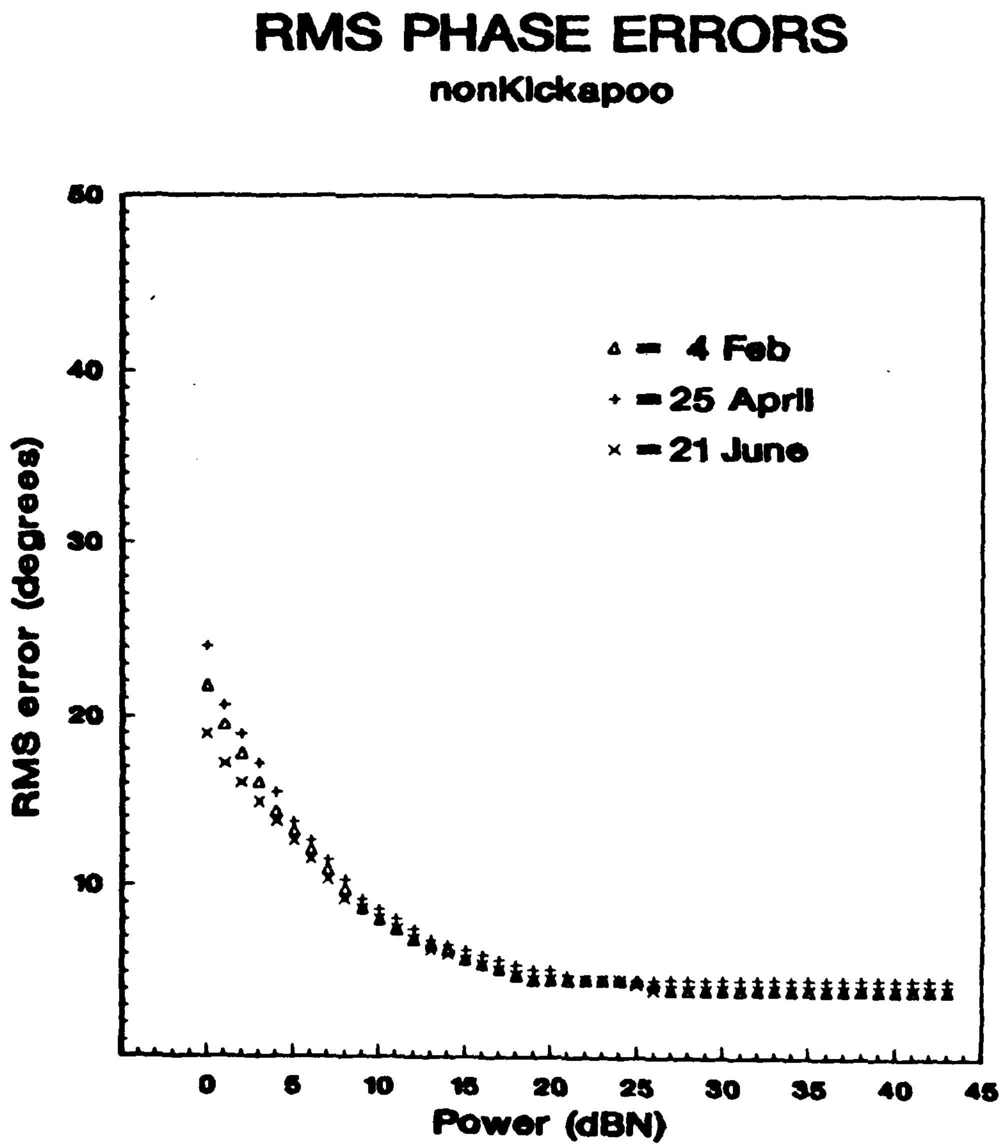

RMS PHASE ERRORS
nonKickapoo
△ = 4 Feb
+ = 25 April
× = 21 June
RMS error (degrees)
50
40
30
20
10
0
5
10
15
20
25
30
35
40
45
Power (dBN)

Figure 1b

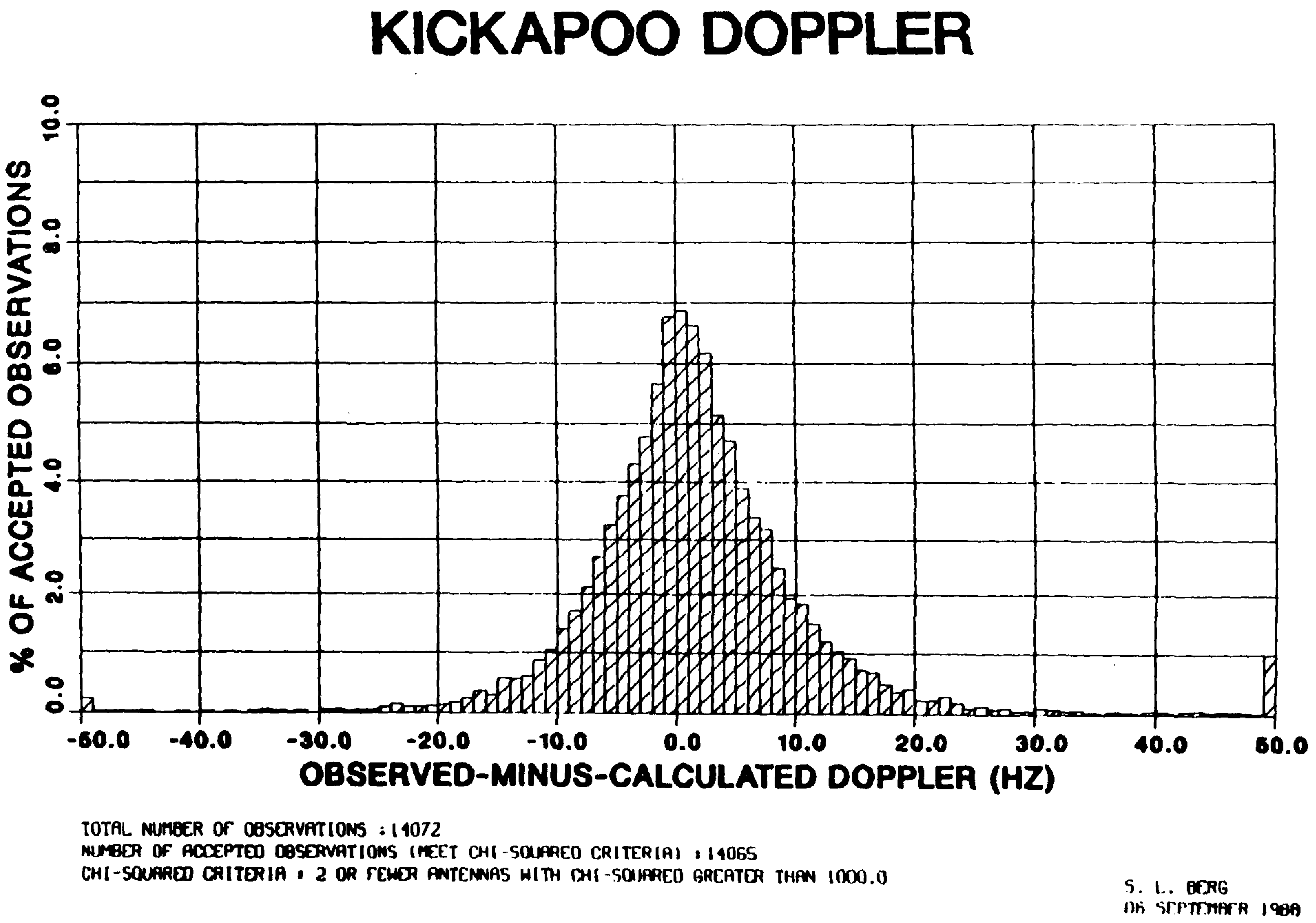
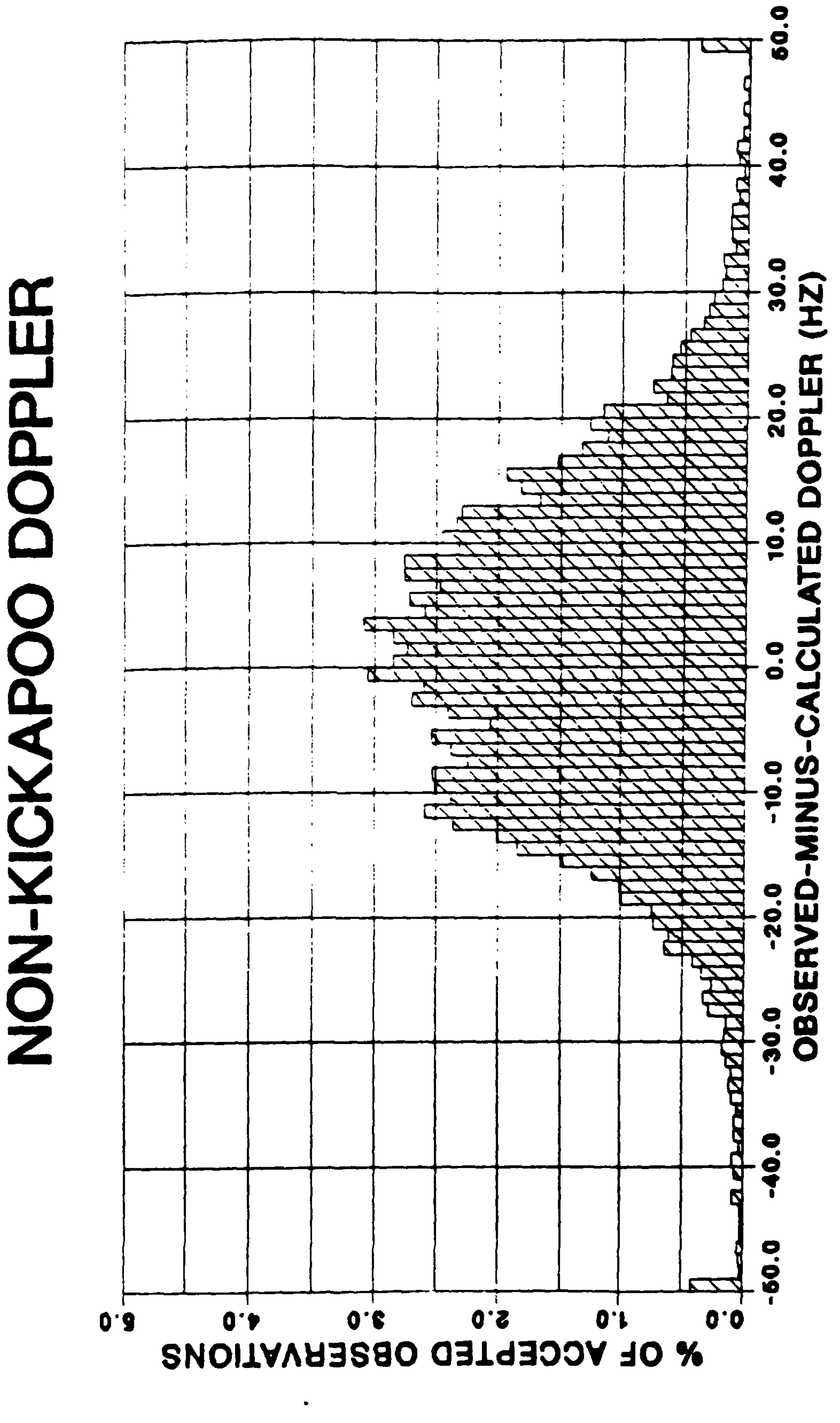

KICKAPOO DOPPLER
% OF ACCEPTED OBSERVATIONS
0.0
2.0
4.0
6.0
8.0
10.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0
OBSERVED-MINUS-CALCULATED DOPPLER (HZ)
TOTAL NUMBER OF OBSERVATIONS : 14072
NUMBER OF ACCEPTED OBSERVATIONS (MEET CHI-SQUARED CRITERIA) : 14065
CHI-SQUARED CRITERIA : 2 OR FEWER ANTENNAS WITH CHI-SQUARED GREATER THAN 1000.0
S. L. BERG
06 SEPTEMBER 1988

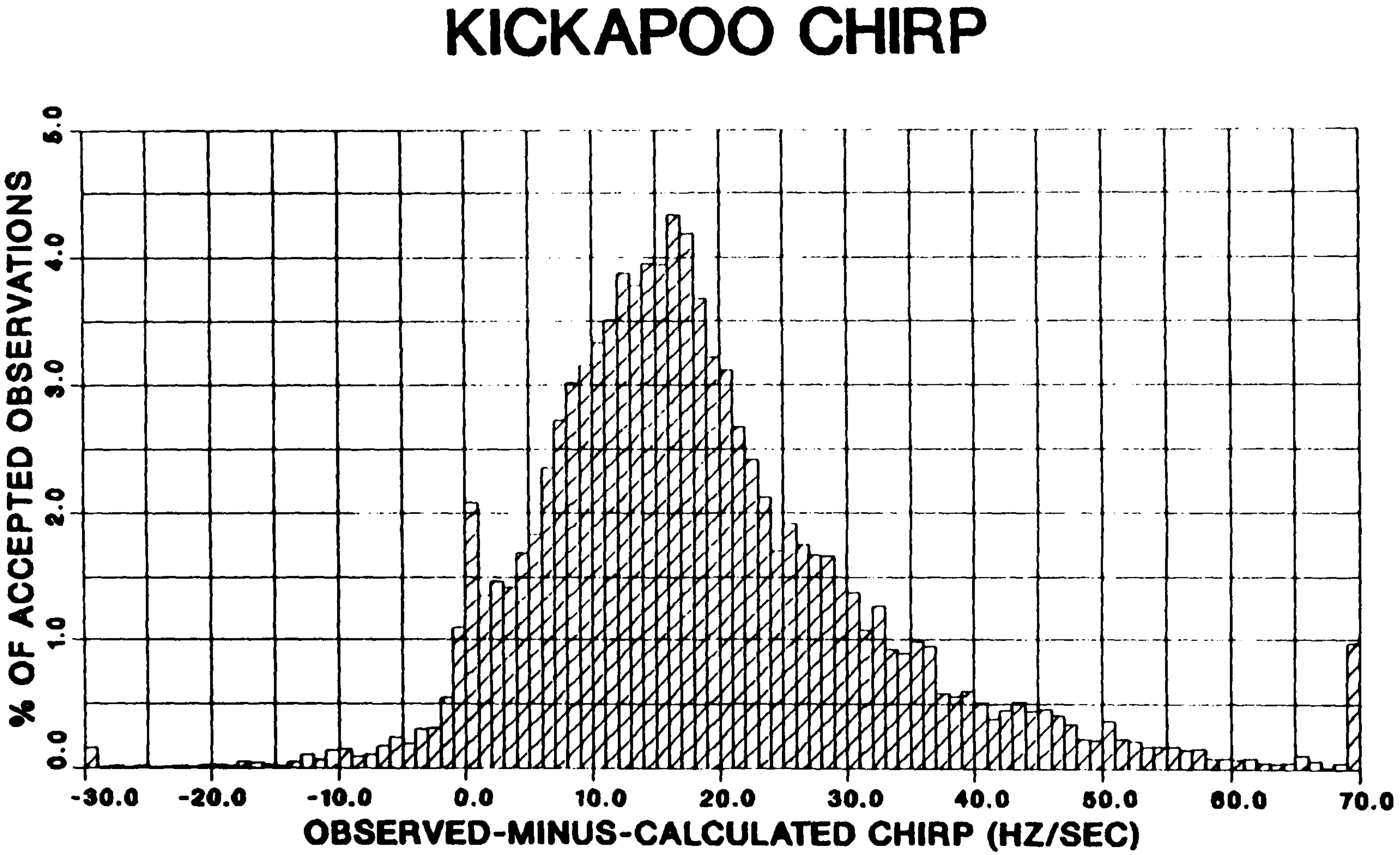
Figure 2a



TOTAL NUMBER OF OBSERVATIONS : 8698
NUMBER OF ACCEPTED OBSERVATIONS (MEET CHI-SQUARED CRITERIA) : 7623
CHI-SQUARED CRITERIA : 2 OR FEWER ANTENNAS WITH CHI-SQUARED GREATER THAN 3.0

S. L. BERG
25 AUGUST 1988

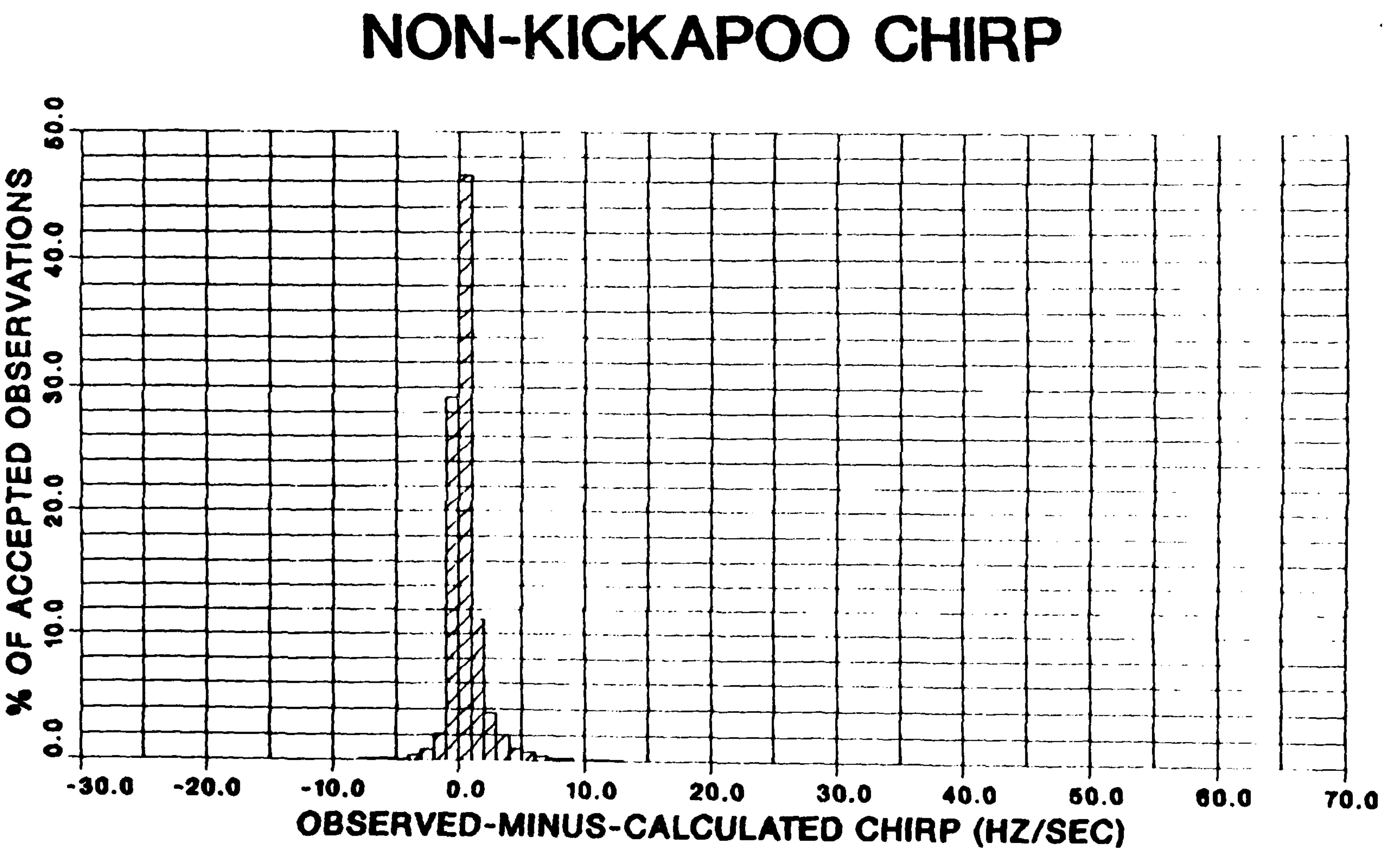
Figure 2b



TOTAL NUMBER OF OBSERVATIONS : 14072
NUMBER OF ACCEPTED OBSERVATIONS (MEET CHI-SQUARED CRITERIA) : 10927
CHI-SQUARED CRITERIA : 2 OR FEWER ANTENNAS WITH CHI-SQUARED GREATER THAN 3.0

S. L. BERG
25 AUGUST 1988

Figure 2c



TOTAL NUMBER OF OBSERVATIONS : 8698
NUMBER OF ACCEPTED OBSERVATIONS (MEET CHI SQUARED CRITERIA) : 7623
CHI-SQUARED CRITERIA : 2 OR FEWER ANTENNAS WITH CHI SQUARED GREATER THAN 3.0

S. L. BERG
25 AUGUST 1988

Figure 2d

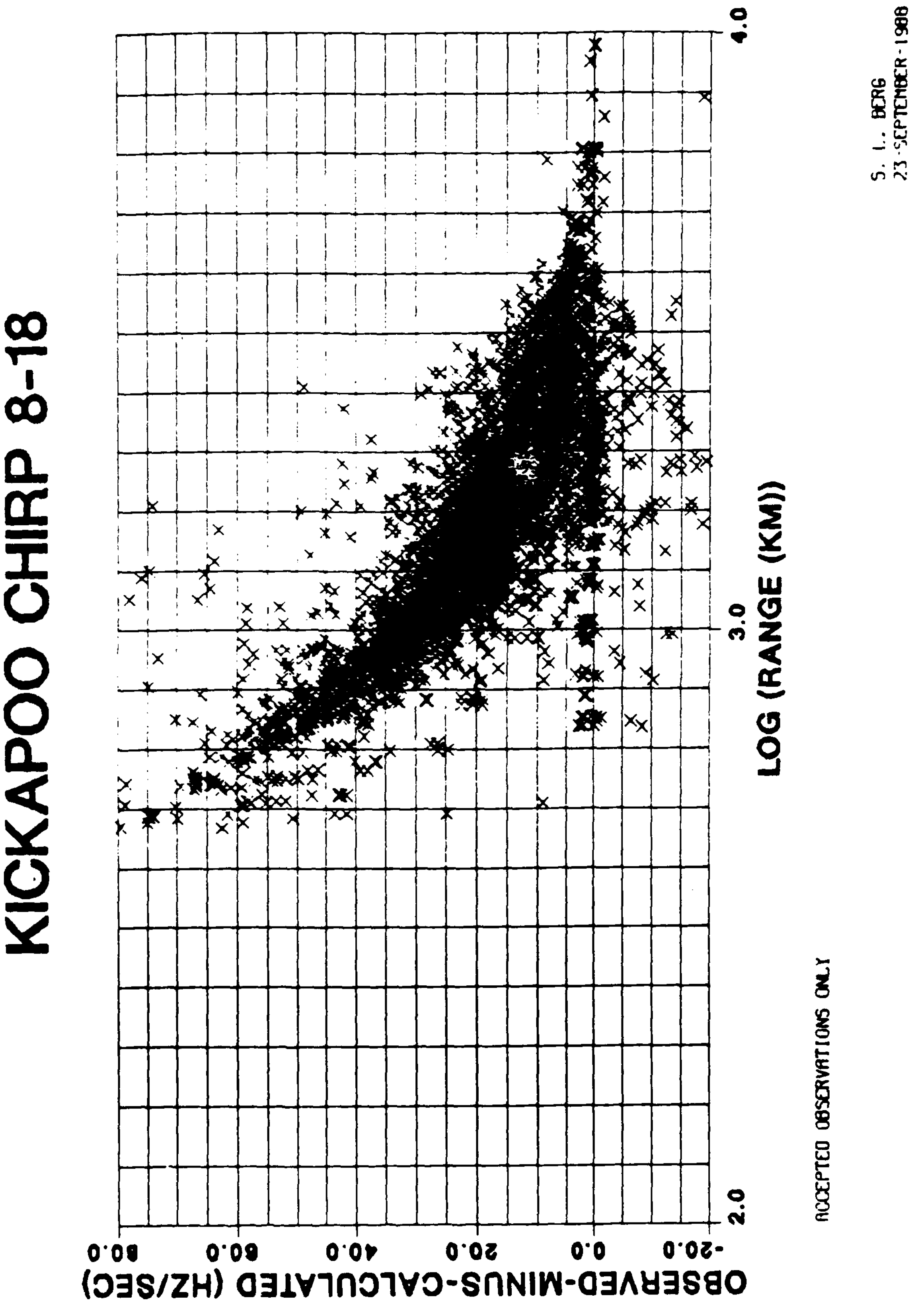

KICKAPOO CHIRP 8-18
LOG (RANGE (KM))
2.0
3.0
4.0
OBSERVED-MINUS-CALCULATED (HZ/SEC)
-20.0
0.0
20.0
40.0
60.0
80.0
ACCEPTED OBSERVATIONS ONLY
S. L. BERG
23 SEPTEMBER 1988

Figure 3a

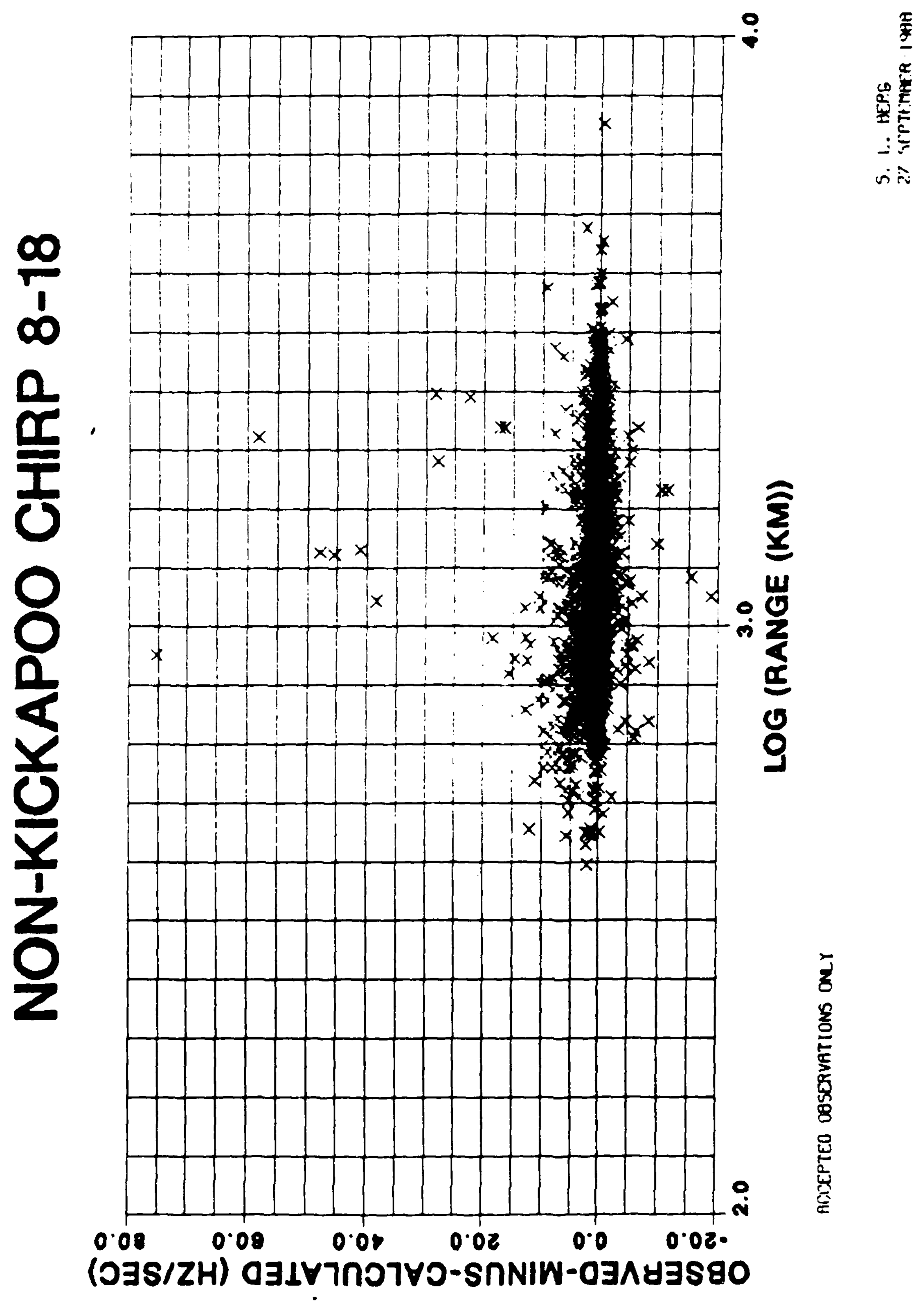

NON-KICKAPOO CHIRP 8-18
OBSERVED-MINUS-CALCULATED (HZ/SEC)
80.0
60.0
40.0
20.0
0.0
-20.0
LOG (RANGE (KM))
2.0
3.0
4.0
ACCEPTED OBSERVATIONS ONLY
S. L. BERG
27 SEPTEMBER 1988

Figure 3b

```
  -5052  5  9  -3937        88  8 18 57447.457          55
  33  32  32  29  33  30  32  34  35  26  28   0        1 0 1 0
57448.348    1489218.00   -6147552.50    3784791.75   3744.69 -2512.10 -5542.46
57448.129   0.69701165  0.00003023  0.00299731 -0.00381652 -3927.000    -36.758
160      49 48 23 36 59 46  2 19 56 53 32
159      22 11 41 26 24 29 14 53 40 37 16
158      46 40  9 37  2 47 49 27 18 63 46
156      10 17 34  3 18 33 11 54 50 19 48
156      50 35  1 43 58  5 40 17 12 63 50
154       8  1 32  3 21 14 13 45 54 21  3
154      32 20 59 30 41 48 34 15  0 42 30
156       3 50 15 56 17  2  2 34 31 10 38
154      18 18 48 18 36 35 30  1 55 33 31
151      50 36  4 36  0 53 52 21 20 53 46
154       3 51 32  4 22 17  4 50 43 17 52
153      30 25 52 23 51 44 46 13 62 42 36
152      51 51 13 49  5 13 57 29 29  1 58
152      13  4 32  2 36 23 13 62 40 18  8
154      38 19 51 20 39 41 29 11 63 38 32
154      55 46  4 48  0 62 28 33 17  0 24
155      17  0 25 61 20 13 46 58 33 15 58
155      33 15 47 17 32 29 60 19 48 34 63
154       8 33 60 31 27 35 16 33  2 49  7
153      11 45  5 42 46 54 36 43 21  1  1
152      29 18 15 61  0  9 53 22 33 16 50
150      35 28 30 13 13 17  3 34 47 32  1
148      61  0 43 20 29 32 19 45 62 46 23
147       7  8 53 32 41 43 33 61 13 56 41
146      20 24  3 45 51 58 45  8 24  2 46
145      33 34 12 55  0  5 56 23 35 15  1
144      43 46 22  5 10 16  1 35 47 29 13
142      52 58 31 15 20 26 13 45 57 37 31
142      63 63 41 23 31 33 21 54  1 45 34
142       8  7 48 30 38 44 31  0 10 52 45
140      14 14 55 35 46 50 36  8 16 57 57
140      20 22 62 45 53 57 45 15 24  3 63
140      28 28  2 50 60  0 49 21 30  7  7
139      32 32  8 54  1  4 56 27 36 11 13
139      35 35 13 59  4  8 62 32 41 15 21
139      38 38 16 63 10 13  0 34 45 19 24
138      42 42 17  2 12 14  2 37 47 22 29
138      44 44 19  2 14 15  4 38 49 22 32
138      44 44 21  2 15 17  5 38 49 20 33
138      44 44 20  3 15 16  7 40 50 20 34
138      43 44 19  1 14 17  5 38 49 18 35
138      40 41 18  0 13 15  3 37 48 16 35
139      37 37 17  0 12 13  2 35 47 15 36
139      34 34 14 60  7 12  0 32 44 12 34
139      30 31 10 55  3  5 61 29 41  4 32
139      25 27  4 50 63  1 54 26 35 63 28
141      18 20  0 46 56 61 49 18 29 59 25
141      13 14 56 40 50 52 43 12 22 51 19
142       2  6 49 33 44 47 35  3 17 47 15
142      61 63 39 25 34 35 31 62 10 35  6
144      50 50 30 17 28 30 19 52  0 28 63
143      41 41 21  9 17 20 10 45 57 17 56
146      30 30 13 61  6  6  0 30 43  5 47
147      18 17  0 41 60 62 51 20 34 53 36
147      12  5 52 36 46 47 46 11 26 46 25
```

EXHIBIT 1: Raw data. The first three lines contain header information which identifies the target satellite, receiver and transmitter, observation time, Doppler channel, predicted pass time and state vector, and some control information.

```
   160  55.13 -58.07 -54.24 -52.97 -56.99 -58.27 -56.30 -73.48 -57.28 -57.58 -78.49
   159  52.47 -55.42 -52.47 -53.95 -54.14 -53.65 -55.13 -70.15 -52.57 -52.87 -73.78
   158  48.55 -52.57 -49.33 -52.87 -50.02 -51.89 -51.69 -66.42 -48.45 -50.31 -70.83
   156  45.01 -48.55 -46.88 -49.92 -48.45 -46.98 -49.14 -63.76 -45.31 -48.35 -70.64
   156  42.66 -46.78 -43.84 -45.99 -44.52 -43.44 -46.29 -61.11 -42.76 -44.03 -70.44
   154  38.53 -43.84 -40.79 -43.64 -41.87 -42.56 -42.66 -58.36 -38.63 -41.87 -68.77
   154  34.61 -41.97 -38.14 -40.99 -39.91 -39.22 -40.60 -55.03 -37.65 -39.81 -59.84
   156  31.76 -39.02 -36.18 -38.44 -35.98 -37.45 -37.45 -53.16 -34.61 -36.67 -52.77
   154  26.95 -35.88 -32.94 -35.88 -34.12 -34.21 -34.70 -50.12 -32.25 -34.41 -47.17
 * 151  23.81 -34.12 -30.97 -34.12 -31.37 -32.45 -32.54 -48.15 -29.40 -32.45 -39.42
   154  19.19 -32.64 -28.23 -30.97 -29.21 -29.70 -30.97 -45.31 -27.15 -29.70 -32.54
   153  15.56 -28.91 -26.26 -29.11 -26.36 -27.05 -26.85 -42.66 -25.28 -27.24 -27.83
   152  11.34 -26.36 -23.81 -26.56 -24.59 -23.81 -25.77 -41.09 -22.24 -24.99 -25.67
   152   7.61 -24.69 -21.94 -24.89 -21.55 -22.83 -23.81 -37.85 -21.16 -23.32 -24.30
   154   3.78 -23.22 -20.08 -23.12 -21.25 -21.06 -22.24 -36.57 -18.90 -21.35 -21.94
   154  -0.83 -20.57 -18.41 -20.37 -18.80 -19.00 -22.33 -34.41 -17.13 -18.80 -16.44
   155  -4.57 -18.80 -16.35 -19.09 -16.84 -17.52 -20.57 -31.96 -15.56 -17.33 -13.11
   155  -9.28 -17.33 -14.19 -17.13 -15.66 -15.95 -19.19 -29.50 -14.09 -15.46 -12.62
** 154 -11.73 -15.56 -12.91 -15.76 -16.15 -15.36 -17.23 -21.84 -12.32 -13.99 -11.83
 ! 153 -11.44 -14.38 -12.03 -14.68 -14.28 -13.50 -15.27 -14.58 -10.46 -12.42 -12.42
   152  -9.67 -10.75 -11.04 -12.81 -12.52 -11.63 -13.60 -10.36  -9.28 -10.95 -13.89
   150  -9.08  -9.77  -9.57 -11.24 -11.24 -10.85 -12.22  -9.18  -7.90  -9.38 -12.42
   148  -6.53  -6.23  -8.30 -10.55  -9.67  -9.38 -10.65  -8.10  -6.43  -8.00 -10.26
   147  -5.55  -5.45  -7.31  -9.38  -8.49  -8.30  -9.28  -6.53  -4.96  -7.02  -8.49
   146  -4.27  -3.88  -5.94  -8.10  -7.51  -6.82  -8.10  -5.45  -3.88  -6.04  -8.00
   145  -2.99  -2.90  -5.06  -7.12  -6.23  -5.74  -7.02  -3.98  -2.80  -4.76  -6.14
   144  -2.01  -1.72  -4.07  -5.74  -5.25  -4.66  -6.14  -2.80  -1.62  -3.39  -4.96
   142  -1.13  -0.54  -3.19  -4.76  -4.27  -3.68  -4.96  -1.82  -0.64  -2.60  -3.19
   142  -0.05  -0.05  -2.21  -3.98  -3.19  -2.99  -4.17  -0.93   0.15  -1.82  -2.90
   142   0.83   0.74  -1.52  -3.29  -2.50  -1.91  -3.19   0.05   1.03  -1.13  -1.82
   140   1.42   1.42  -0.83  -2.80  -1.72  -1.33  -2.70   0.83   1.62  -0.64  -0.64
   140   2.01   2.21  -0.15  -1.82  -1.03  -0.64  -1.82   1.52   2.41   0.34  -0.05
   140   2.80   2.80   0.25  -1.33  -0.34   0.05  -1.42   2.11   2.99   0.74   0.74
   139   3.19   3.19   0.83  -0.93   0.15   0.44  -0.74   2.70   3.58   1.13   1.33
   139   3.49   3.49   1.33  -0.44   0.44   0.83  -0.15   3.19   4.07   1.52   2.11
   139   3.78   3.78   1.62  -0.05   1.03   1.33   0.05   3.39   4.47   1.91   2.41
   138   4.12   4.12   1.67   0.20   1.18   1.37   0.20   3.63   4.61   2.16   2.85
   138   4.37   4.37   1.91   0.25   1.42   1.52   0.44   3.78   4.86   2.21   3.19
!! 138   4.37   4.37   2.11   0.25   1.52   1.72   0.54   3.78   4.86   2.01   3.29
   138   4.37   4.37   2.01   0.34   1.52   1.62   0.74   3.98   4.96   2.01   3.39
   138   4.27   4.37   1.91   0.15   1.42   1.72   0.54   3.78   4.86   1.82   3.49
   138   3.98   4.07   1.82   0.05   1.33   1.52   0.34   3.68   4.76   1.62   3.49
   139   3.68   3.68   1.72   0.05   1.23   1.33   0.25   3.49   4.66   1.52   3.58
   139   3.39   3.39   1.42  -0.34   0.74   1.23   0.05   3.19   4.37   1.23   3.39
   139   2.99   3.09   1.03  -0.83   0.34   0.54  -0.25   2.90   4.07   0.44   3.19
   139   2.50   2.70   0.44  -1.33  -0.05   0.15  -0.93   2.60   3.49  -0.05   2.80
   141   1.82   2.01   0.05  -1.72  -0.74  -0.25  -1.42   1.82   2.90  -0.44   2.50
   141   1.33   1.42  -0.74  -2.31  -1.33  -1.13  -2.01   1.23   2.21  -1.23   1.91
   142   0.25   0.64  -1.42  -2.99  -1.91  -1.62  -2.80   0.34   1.72  -1.62   1.52
   142  -0.25  -0.05  -2.41  -3.78  -2.90  -2.80  -3.19  -0.15   1.03  -2.80   0.64
   144  -1.33  -1.33  -3.29  -4.57  -3.49  -3.29  -4.37  -1.13   0.05  -3.49  -0.05
   143  -2.21  -2.21  -4.17  -5.35  -4.57  -4.27  -5.25  -1.82  -0.64  -4.57  -0.74
   146  -3.29  -3.29  -4.96  -6.53  -5.65  -5.65  -6.23  -3.29  -2.01  -5.74  -1.62
   147  -4.47  -4.57  -6.23  -8.49  -6.63  -6.43  -7.51  -4.27  -2.90  -7.31  -2.70
   147  -5.06  -5.74  -7.41  -8.98  -8.00  -7.90  -8.00  -5.15  -3.68  -8.00  -3.78
```

EXHIBIT 2: The phases in radians as output by DEROT. The locations of the -153 dBm amplitude cut-off at frame number 20 (!) and the amplitude peak at frame number 39 (!!) are shown. Also indicated are the secondary peak at frame number 10 (*) and the phase reversal on antenna 1 at frame number 19 (**).

152	-9.67	-10.75	-11.04	-12.81	-12.52	-11.63	-13.60	-10.36	-9.28	-10.95	-13.89
150	-9.08	-9.77	-9.57	-11.24	-11.24	-10.85	-12.22	-9.18	-7.90	-9.38	-12.42
148	-6.53	-6.23	-8.30	-10.55	-9.67	-9.38	-10.65	-8.10	-6.43	-8.00	-10.26
147	-5.55	-5.45	-7.31	-9.38	--8.49	-8.30	-9.28	-6.53	-4.96	-7.02	-8.49
146	-4.27	-3.88	-5.94	-8.10	-7.51	-6.82	-8.10	-5.45	-3.88	-6.04	-8.00
145	-2.99	-2.90	-5.06	-7.12	-6.23	-5.74	-7.02	-3.98	-2.80	-4.76	-6.14
144	-2.01	-1.72	-4.07	-5.74	-5.25	-4.66	-6.14	-2.80	-1.62	-3.39	-4.96
142	-1.13	-0.54	-3.19	-4.76	-4.27	-3.68	-4.96	-1.82	-0.64	-2.60	-3.19
142	-0.05	-0.05	-2.21	-3.98	-3.19	-2.99	-4.17	-0.93	0.15	-1.82	-2.90
142	0.83	0.74	-1.52	-3.29	-2.50	-1.91	-3.19	0.05	1.03	-1.13	-1.82
140	1.42	1.42	-0.83	-2.80	-1.72	-1.33	-2.70	0.83	1.62	-0.64	-0.64
140	2.01	2.21	-0.15	-1.82	-1.03	-0.64	-1.82	1.52	2.41	0.34	-0.05
140	2.80	2.80	0.25	-1.33	-0.34	0.05	-1.42	2.11	2.99	0.74	0.74
139	3.19	3.19	0.83	-0.93	0.15	0.44	-0.74	2.70	3.58	1.13	1.33
139	3.49	3.49	1.33	-0.44	0.44	0.83	-0.15	3.19	4.07	1.52	2.11
139	3.78	3.78	1.62	-0.05	1.03	1.33	0.05	3.39	4.47	1.91	2.41
138	4.12	4.12	1.67	0.20	1.18	1.37	0.20	3.63	4.61	2.16	2.85
138	4.37	4.37	1.91	0.25	1.42	1.52	0.44	3.78	4.86	2.21	3.19
138	4.37	4.37	2.11	0.25	1.52	1.72	0.54	3.78	4.86	2.01	3.29
138	4.37	4.37	2.01	0.34	1.52	1.62	0.74	3.98	4.96	2.01	3.39
138	4.27	4.37	1.91	0.15	1.42	1.72	0.54	3.78	4.86	1.82	3.49
138	3.98	4.07	1.82	0.05	1.33	1.52	0.34	3.68	4.76	1.62	3.49
139	3.68	3.68	1.72	0.05	1.23	1.33	0.25	3.49	4.66	1.52	3.58
139	3.39	3.39	1.42	-0.34	0.74	1.23	0.05	3.19	4.37	1.23	3.39
139	2.99	3.09	1.03	-0.83	0.34	0.54	-0.25	2.90	4.07	0.44	3.19
139	2.50	2.70	0.44	-1.33	-0.05	0.15	-0.93	2.60	3.49	-0.05	2.80
141	1.82	2.01	0.05	-1.72	-0.74	-0.25	-1.42	1.82	2.90	-0.44	2.50
141	1.33	1.42	-0.74	-2.31	-1.33	-1.13	-2.01	1.23	2.21	-1.23	1.91
142	0.25	0.64	-1.42	-2.99	-1.91	-1.62	-2.80	0.34	1.72	-1.62	1.52
142	-0.25	-0.05	-2.41	-3.78	-2.90	-2.80	-3.19	-0.15	1.03	-2.80	0.64
144	-1.33	-1.33	-3.29	-4.57	-3.49	-3.29	-4.37	-1.13	0.05	-3.49	-0.05
143	-2.21	-2.21	-4.17	-5.35	-4.57	-4.27	-5.25	-1.82	-0.64	-4.57	-0.74
146	-3.29	-3.29	-4.96	-6.53	-5.65	-5.65	-6.23	-3.29	-2.01	-5.74	-1.62
147	-4.47	-4.57	-6.23	-8.49	-6.63	-6.43	-7.51	-4.27	-2.90	-7.31	-2.70
147	-5.06	-5.74	-7.41	-8.98	-8.00	-7.90	-8.00	-5.15	-3.68	-8.00	-3.78

EXHIBIT 3: Edited data. Only the data frames above -153 dBm surrounding the peak are retained for futher processing. A careful examination of the phases in the first 20 frames in Exhibit 2 shows that this is a reasonable approach.

APPENDIX A

This appendix contains annotated listings of the algorithms used in this study. There are two versions of the main algorithm, called ACCUM and FITS. Each of these programs call DEROT, WGHTPOLY, and DPLCHR. The subroutine GAUSSJ is called by WGHTPOLY.

```
      PROGRAM ACCUM
C
C******************************************************************************
C
C     PROGRAM ACCUM
C
C******************************************************************************
C
C     AUTHOR: DR. M. ANDREWS
C     DATE: 24 JUNE, 1988
C     LANGUAGE: FORTRAN ANSI-77  (VAX/VMS operating system)
C     FILE:    VX7770::SPACE:[ANDREWS.CODE]ACCUM.FOR
C
C
C     SUBROUTINES CALLED: DEROT,WGHTPOLY
C
C     LINK/LOAD INSTRUCTIONS: LINK ACCUM,DEROT,WGHTPOLY,GAUSSJ
C
C     PROGRAM DESCRIPTION: This routine takes out the phase wraps and then
C                          does a weighted third order polynomial fit to the
C                          phase as a function of time.  The output files are
C                          set-up to test the error model.  This program is
C                          almost identical to FITS except for error analysis.
C
C     PROGRAM ALGORITHM (PSEUDOCODE): SEE SUBROUTINES
C
C     INPUTS    EXPLICIT: There are three input files required.
C                      1) Error model table which is transmit station specific.
C                         - Read from FOR007.
C                      2) Antenna positions in Earth centered X,Y,Z coordinate
C                          system.  Free format read from file ANTPOS.DAT.
C                         - Read from FOR008.  SPACE:[ANDREWS.FILES]ANTPOS.DAT
C                      3) NAVSPASUR Phase4 data files.
C                         - Read from FOR009.
C
C               IMPLICIT: A few constants.
C
C     OUTPUTS   EXPLICIT: There is just one major output file.  FOR016 which
C                            contains a summary of the errors that come out
C                            of the fitting.
C
C     MAJOR VARIABLES: In order of appearance.
C
C             ERR(45) an array that contains the model of phase error as a
C                 function of amplitude.  The argument is dB above -153 dBm.
C                 For more than 45 dB use the value at 45.
C
C             CHICUT the CHI SQUARED cutoff.  Residuals will be used for
C                 accumulation in the error analysis only if the value of CHI
C                 SQUARED returned by WGHTPOLY is less than CHICUT.
C
C             ISAT NAVSPASUR catalogue number of the satellite.
C
C             NRC NTR the identifies for the reciever station 1-6 and the
C                 transmit station 7-9.
C
C             IDOP is the center frequency ( MINUS 10Hz ) of the digital filter
C                 w.r.t. 216.98 MHz and is roughly equal to the Doppler shift.
C
C             IYR IMON IDAY RSEC are the year, month, day, and time in seconds
C                 on that day of the start of data record.
C
C             NLINES number of data frames in that observation.
C
C             TPRED is the predicted pass time in seconds which is always
C                     close to RSEC.
C
C             IAMP(55) IPHS(55,12) these arrays contain the Phase4 data.  There
C                     will be NLINES values for amplitude and NLINES times 11 or
C                     12 phases (11 phases if NRC = 2 or 5, 12 otherwise).  The
```

```
C                     units on IAMP are dBm with the minus sign OMITTED.  Smaller
C                     numbers are stronger signals.  IPHS is phase sample with
C                     6 bits; hence there are integers from 0-63.
C
C              RPHS(55,12) the phases returned from DEROT.  The rotations of
C               phase
C                     have been put back into the data.  The units are radians.
C                     After fitting, this array is changed to fold the residuals.
C
C              IERR the error flag from DEROT, = 0 or 1.  If IERR=1, stop processing
C                     of this observation and write "IERR=1" to unit 13.
C
C              MIAMP the maximum amplitude in the observation, e.i., the minimum
C                     value of IAMP.
C
C              IFRST ILAST NUM these variables show where the good data is in the
C                     observation.  IFRST and ILAST identify the first and last frames
C                     in which IAMP < 153.  This span of data will contain the peak
C                     amplitude.  NUM is the number of good frames.  If NUM < 10, stop
C                     processing this observation and write the value of NUM to unit 13.
C
C              A1(55) A2(55) SIG(55) are the three arrays passed to WGHTPOLY.  They
C                     contain the times, the phase data, and the errors on the phase.
C                     The time is taken w.r.t. TPRED.
C
C              A3(3) contains the three parameters that come out of the fit.  1 is
C                     a phase offset.  2 is the Doppler.  3 is the coefficient of T*T
C                     which is 1/2 of the chirp.
C
C              COVAR(3,3) is the symmetric covariance matrix.
C
C              CHISQ(12) is the reduced Chi squared returned by WGHTPOLY.
C
C              NOBS INOFIT NFEW these are respectively the number of observations
C                     in the data set, the number for which DEROT returned IERR=1,
C                     and the number in which NUM < 10.
C
C              RMEAN(66) RMS(66) are the mean and RMS of the residuals for all of
C              the accumulated data at a given amplitude.
C
C              IACCUM(66,202) this array is used to accumulate the residuals.
C
C  MODIFIED: 19 July, 1988.  A blank read added due to change in the content
C                        of the data file.
C
C  MODIFIED: 8 September, 1988. Read statements changed to account for change in
C                        data format.
C
C************************************************************************
C
            IMPLICIT REAL*8(A-H,O-Z)
            INTEGER*4 IACCUM(66,202),NLES,NGRTR
            DIMENSION X(99),Y(99),A(20),RES(99),CHISQ(12),
        1                IAMP(55),IPHS(55,12),RPHS(55,12),ERR(45),
        2                SIG(99),COVAR(3,3),RMEAN(66),RMS(66)
C
            TINCR = 1./54.98
            KMAX = 0
            KMIN = 67
            INOFIT = 0
            NOBS = 0
            NFEW = 0
            NLES = 0
            NGTTR = 0
C
C   Read the error model table.
C
            DO J=1,45
               READ(7,*) INTG, ERR(J)
             ENDDO
```

```
C
C   Read the cutoff value of Chi Square that will determine which
C   residuals are passed to IACCUM Array.
C
          WRITE(6,*) 'ENTER CHI SQUARE CUTOFF'
          READ(5,*)  CHICUT
C
C   For each satellite observation read the data.  The start times
C   is TSTRT.  The phases get loaded into the X array.  The Y array
C   is then loaded with the time zero at first occurance of maximum AMPL.
C   Call DEROT and when the phases successfully derotate call WGHTPOLY
C   NANT times.
C
 301      READ(9,*,END=321) ISAT,NRC,NTR,IDOP,IYR,IMON,IDAY,RSEC,
     1                  NLINES
          ISAT = ABS(ISAT)
          NOBS = NOBS + 1
C
C     Two blank reads to skip lines with stuff we don't need and TPRED.
C
          READ(9,*,END=321)
          READ(9,*,END=321)TPRED
          READ(9,*,END=321)
          NANT=12
          IF(NRC.EQ.2 .OR. NRC.EQ.5) NANT=11
             DO II=1,NLINES
                READ(9,*,END=321) IAMP(II), ( IPHS(II,J), J=1,NANT)
             ENDDO
C
C     Find line number of first occurance of maximum in amplitude.
C         NOTE: largest amplitude is smallest number.
C
          MIAMP = 190
            DO 101 J=1,NLINES
               IF( IAMP(J).GE.MIAMP) GOTO 101
               MIAMP = IAMP(J)
               NMAX = J
 101        CONTINUE
C
C     Call DEROT which will derotate the phases of all antennas in one call.
C
C     If IERR = 1 did not get a good derotation so go to next observation.
C
          CALL DEROT(NLINES,NANT,IAMP,IPHS,RPHS,IERR)
          IF( IERR.EQ.1) INOFIT=INOFIT + 1
          IF( IERR.EQ.1) GOTO 302
C
C     Pass only the "good" data to the fitting routine.
C     Go forward and backward from line NMAX and stop if IAMP greater
C     than 152.
C
          IFRST = 0
             DO J=1,NMAX-1
                IF( IAMP( NMAX-J) .GT. 152) GOTO 311
             ENDDO
          IFRST = 1
 311      IF( IFRST .EQ. 0) IFRST = NMAX - J + 1
             DO J=NMAX+1,NLINES
                IF( IAMP(J) .GT. 152) GOTO 312
             ENDDO
 312      ILAST = J-1
C
C     Don't continue unless there are 10 or more good lines.
C
          NUM = ILAST - IFRST + 1
          IF(NUM .LT. 10) NFEW = NFEW + 1
          IF(NUM .LT. 10) GOTO 302
C
C     Load up the SIG array by using the ANDREWS error model.
C     Load up X with times. T=0 at first occurance of max amplitude.
```

```
C
          DO 102 II=1,NUM
             J = II + IFRST -1
             INDX= 153 - IAMP(J)
             IF(INDX.GT.45) INDX=45
             SIG(II) = ERR(INDX)
             X(II) = (J - NMAX)*TINCR
 102       CONTINUE
C
C    Call WGHTPOLY for each antenna.
C
          DO 103 II=1,NANT
             DO J=1,NUM
               JJ = J + IFRST - 1
               Y(J) = RPHS(JJ,II)
              ENDDO
C
             CALL WGHTPOLY(X,Y,SIG,NUM,A,3,COVAR,CHISQ(II) )
C
             IF(CHISQ(II) .LE.1.0) NLES = NLES + 1
             IF(CHISQ(II) .GT.1.0) NGRTR = NGRTR + 1
C
C    Calculate the residuals and replace the elements of RPHS so that
C    it will contain residuals rather than data.
C
              DO J=1,NLINES
                T = (J - NMAX)*TINCR
                CALC = A(1) + A(2)*T + A(3)*T*T
                RPHS(J,II) = RPHS(J,II) - CALC
               ENDDO
 103       CONTINUE
C
C   Increment the IACCUM array using only the data points used in the fitting.
C   For each amplitude bin the residuals into cells .03 radians wide.
C   The first and last bins contain respectively those residuals less than
C   -3.0 and greater than +3.0 radians.
C
C   K is determined by the magnitude of the amplitude and INDEX by the
C   magnitude of the residual.  Amplitude of -152 dBm is the smallest and
C   goes into the K=1 bin.  Use KMAX to keep track of the largest amplitude
C   and KMIN for smallest.
C
          DO 104 L=IFRST,ILAST
             K = IAMP(L) - 152
             IF(K.GT.0) K=0
             K= ABS(K) + 1
             IF(K.GT.KMAX) KMAX = K
             IF(K.LT.KMIN) KMIN = K
               DO 105 J=1,NANT
                 IF( CHISQ(J) .GT. CHICUT ) GOTO 105
                 IF( RPHS(L,J) .LT. 0.0 ) INDEX = INT((RPHS(L,J)-.015)/.03)
                 IF( RPHS(L,J) .GE. 0.0 ) INDEX = INT((RPHS(L,J)+.015)/.03)
                 INDEX = 101 + INDEX
                 IF( INDEX .LT.    1) INDEX = 1
                 IF( INDEX .GT. 202) INDEX = 202
                 IACCUM(K,INDEX) = IACCUM(K,INDEX) + 1
 105           CONTINUE
 104        CONTINUE
C
C   Return to reading.
C
 302     READ(9,*,END=321)
          GOTO 301
C
 321     CONTINUE
          WRITE(16,*) 'NOBS=',NOBS,' INOFIT=',INOFIT,' NFEW=',NFEW
          WRITE(16,*) 'N Chisquare LE 1=',NLES,'N Chisquare GT 1.0=',NGRTR
C
C   When the end of the file is reached analyse the residuals and print
C   out the results.
```

```
C
C   Use the contents of IACCUM to calculate the MEAN and RMS for each
C   amplitude.
C
C   Print the results.
C
             DO 106 II= KMIN,KMAX
                IAMPL = II - 153
                SUM = 0.0
                SUM2 = 0.0
                NIN = 0
                  DO 107 J=2,201
                      IF(J .LT. 101) RESID = .03*(J-101) - .015
                      IF(J .GT. 101) RESID = .03*(J-101) + .015
                      IF(J .EQ. 101) RESID = 0.0
                      N = IACCUM(II,J)
                      NIN = NIN + N
                      SUM = SUM + N*RESID
                      SUM2 = SUM2 + N*RESID*RESID
 107               CONTINUE
                 IF(NIN.LT.10) GOTO 106
                 RMEAN(II) = SUM/NIN
                 RMS(II) = ( NIN/(NIN-1) )*( SUM2/NIN - RMEAN(II)*RMEAN(II))
                 RMS(II) = SQRT( RMS(II) )
C
                 WRITE(16,201) IAMPL,IACCUM(II,1),IACCUM(II,202),NIN,
     1                       RMEAN(II),RMS(II), ( IACCUM(II,K), K=2,201)
 201            FORMAT(1X,I4,'  NLOW=',I6,'  NHIGH=',I6,'  NIN=',I6,10X,
     1                           '  MEAN=',F7.2,'  RMS=',F7.2, 20(/,10I8),/ )
 106        CONTINUE
            END
```

```
            PROGRAM FITS
C
C ************************************************************************
C *
C *        PROGRAM FITS
C *
C ************************************************************************
C
C   AUTHOR: DR. M. ANDREWS
C   DATE: 24 JUNE, 1988
C   LANGUAGE:  FORTRAN ANSI-77  (VAX/VMS operating system)
C   FILE:        VX7770::SPACE:[ANDREWS.CODE]FITS.FOR
C
C   SUBROUTINES CALLED: DEROT,WGHTPOLY,DPLCHR
C
C   LINK/LOAD INSTRUCTIONS: LINK FITS,DEROT,WGHTPOLY,DPLCHR,GAUSSJ
C
C   PROGRAM DESCRIPTION: This routine takes out the phase wraps and then does
C                                     a weighted third order polynomial fit to the phase as
C                                     function of time.  The observed Doppler and chirp come
C                                     out of this fitting.  The output files are set-up to aid
C                                     further analysis.
C
C  PROGRAM ALGORITHM (PSEUDOCODE): SEE SUBROUTINES
C
C  INPUTS    EXPLICIT: There are three input files required.
C                                  1) Error model table which is transmit station specific.
C                                     - Read from FOR007.
C                                  2) Antenna positions in Earth centered X,Y,Z coordinate
C                                      system.  Free format read from file ANTPOS.DAT.
C                                     - Read from FOR008.  SPACE:[ANDREWS.FILES]ANTPOS.DAT
C                                  3) NAVSPASUR Phase4 data files.
C                                     - Read from FOR009.
C
C                  IMPLICIT: A few constants.
C
C  OUTPUTS  EXPLICIT: There are five output files.
C   !! NOTE !!  For large data sets it is necessary to restrict the output
C                 by inserting C, comment, at the appropriate points.
C                                  1) FOR012 will contain a header line to identify the
C                                      observation.  The derived Doppler and chirp along with
C                                      the Chi Squared value on the fit for each antenna is
C                                      printed.  The uncertainties in the quantities and the
C                                      elements of the covariance matrix are printed.
C                                  2) FOR013 contains a header line which identifies the
C                                      satellite and lists the pass time.  For each
C                                      observation, list the transmitter and receiver numbers
C                                      and "GOOD FIT" if everthing worked.  Otherwise, list
C                                      reason for no fit.
C                                  3) FOR014 lists the maximum amplitude and the number of
C                                      data lines with amplitude > -153 dBm and the
C                                      uncertentles in Doppler and chirp.
C                                  4) FOR015 lists the O-C, Observed minus Calculated values
C                                      for Doppler and chirp.  Observed values from the
C                                      fitting, calculated values from DPLCHR.
C                                  5) FOR016 lists the residuals from the polymonial fit.
C                                      *NOTE* This output file will be comparable in size to
C                                               data file.
C
C  MAJOR VARIABLES: In order of appearance.
C
C        ERR(45) an array that contains the model of phase error as a function of
C              amplitude.  The argument is dB above -153 dBm.  For more than 45 dB
C              use the value at 45.
C
C        RECPOS(6,12,3) TRPOS(9,3) these two arrays contain respectively the
C              antenna positions for the receivers and transmitters. The file
C              SPACE:[ANDREWS.FILES]ANTPOS.DAT has been set-up so that the free
C              format read in the code will work.  The arguements of RECPOS are
C              station # (1-6), antenna # (1-12), coordinate index (1-3: 1-X,
```

```
C        2-Y,3-Z.  The transmit stations are numbered 7-9 as identified
C        by NAVSPASUR.  The second index is coordinate as above.
C
C     ISAT NAVSPASUR catalogue number of the satellite.
C
C     NRC NTR the identifies for the reciever station 1-6 and the transmit
C        station 7-9.
C
C     IDOP is the frequency of the digital filter w.r.t. 216.98 MHz
C        and is roughly equal to the Doppler shift.
C
C     IYR IMON IDAY RSEC are the year, month, day, and time in seconds on
C        that day of the start of data record.
C
C      NLINES number of data frames in that observation.
C
C      TPRED SX SY SZ VX VY VZ the predicted pass time and the position and
C        velocity of the satellite at time TPRED.
C
C      TOBS AEW ANS REW RNS FDOP FRATE the solution time and the values of
C        the of the EW angle and the NS angle in radians, the rate of change
C        of sine of the EW and NS angles in radians/sec., the fitted Doppler
C        and chirp as determined by NAVSPASUR at time TOBS.
C
C      IAMP(55) IPHS(55,12) these arrays contain the Phase4 data.  There
C        will be NLINES values for amplitude and NLINES times 11 or 12
C        phases (11 phases if NRC = 2 or 5, 12 otherwise).  The units on
C        IAMP are dBm with the minus sign OMITTED.  Smaller numbers are
C        stronger signals.  IPHS is phase sample with 6 bits; hence there
C        are integers from 0-63.
C
C      RPHS(55,12) the phases returned from DEROT.  The rotations of phase
C        have been put back into the data.  The units are radians.
C        After fitting, this array is changed to fold the residuals.
C
C      IERR the error flag from DEROT, = 0 or 1.  If IERR=1, stop processing
C        of this observation and write "IERR=1" to unit 13.
C
C      MIAMP the maximum amplitude in the observation, e.i., the minimum
C        value of IAMP.
C
C      IFRST ILAST NUM these variables show where the good data is in the
C        observation.  IFRST and ILAST identify the first and last frames
C        in which IAMP < 153.  This span of data will contain the peak
C        amplitude.  NUM is the number of good frames.  If NUM < 10, stop
C        processing this observation and write the value of NUM to unit 13.
C
C      A1(55) A2(55) SIG(55) are the three arrays passed to WGHTPOLY.  They
C        contain the times, the phase data, and the errors on the phase.
C        The time is taken w.r.t. TPRED.
C
C      A3(3) contains the three parameters that come out of the fit.  1 is
C        a phase offset.  2 is the Doppler.  3 is the coefficient of T*T
C        which is 1/2 of the chirp.
C
C      COVAR(3,3) is the symmetric covariance matrix.
C
C      CHISQ is the reduced Chi squared for this particular fit.
C
C      DOP(12) CHRP(12) contain the Doppler and chirp for the given antenna
C        number as calculated in DPLCHR.
C
C      COEFF(5,12) holds the answers.  (1,J) is the phase offset in rotations
C        at T=0 for antenna number J; (2,J) is the Doppler; (3,J) is the chirp
C        (4,J) is the value of reduced Chi squared; (5,1-3) contain the formal
C        errors on offset Doppler and chirp; (5,4-6) contain the correlation
C        for offset-Doppler, offset-chirp, and Doppler-chirp.
C
C      OMC(12,2) contains the Observed Minus Calculated, O-C, values for each
C        antenna of Doppler (J,1) and chirp (J,2).
```

```
C             For chirp, O-C is simply 0.5*A3(3) - CHRP with units of Hz/sec.
C             For Doppler, O-C = ( IDOP + 10.0 + A2(2) ) - DOP with units of Hz.
C                  Note: IDOP + 10.0 is the center frequency of the digital filter.
C
C         NOBS INOFIT NFEW these are respectively the number of observations
C             in the data set, the number for which DEROT returned IERR=1,
C             and the number in which NUM < 10.
C
C  MODIFIED: 29 August to conform to a new data format.
C
C
C
C***********************************************************************
C
           IMPLICIT REAL*8 (A-H,O-Z)
C
           DIMENSION A1(55),A2(55),A3(3),COEFF(5,12),
     1                IAMP(55),IPHS(55,12),RPHS(55,12),ERR(45),
     2                SIG(55),COVAR(3,3),DOP(12),CHRP(12),
     3                RECPOS(6,12,3),TRPOS(9,3),OMC(12,2)
C
C    Initialize constants.
C
           TINCR = 1./54.98
           TWOPI = 6.2831853
           INOFIT = 0
           IOLD = 0
           NOBS = 0
           NFEW = 0
           NFAIL = 0
C
C  Read the phase error model table.
C       NOTE: The error model may be specific to a single transmitter
C               and/or receiving channel.  The data must be presorted to
C               be compatible with the error model.
C
           DO J=1,45
              READ(7,*) INTG, ERR(J)
           ENDDO
C
C  Read the X,Y,Z positions for each receive and transmit antenna.
C      NOTE: File SPACE:[ANDREWS.FILES]ANTPOS.DAT  has been generated so
C              the following read will work.
C
           READ(8,*) RECPOS,TRPOS
C
C    Read the data and print a header line for each new satellite.
C
 301  READ(9,*,END=999) ISAT,NRC,NTR,IDOP,IYR,IMON,IDAY,RSEC,
     1           NLINES
           IF(ISAT.EQ.0) GOTO 302
           NOBS = NOBS + 1
           IF(ISAT.EQ.IOLD) GOTO 302
           WRITE(13,201) ISAT,IYR,IMON,IDAY,RSEC
 201       FORMAT(1X,/,1X,'SATELLITE #',I6,'   OBSERVED ON ',3I3,F10.3)
           IOLD = ISAT
 302  CONTINUE
C
C    Do one blank read and then read position and velocity and the
C    NAVSPASUR solutions.
C
C    NOTE: This is the correct code for data tape of 18August.
C
           READ(9,*,END=999)
           READ(9,*,END=999)TPRED,SX,SY,SZ,VX,VY,VZ
           READ(9,*,END=999)TOBS,AEW,ANS,REW,RNS,FDOP,FCHRP
C
C    Read NLINES data frames.  There are twelve antennas unless the
C    receiving station is 2 or 5.
C
```

```
        NANT=12
        IF(NRC.EQ.2 .OR. NRC.EQ.5) NANT=11
C
          DO II=1,NLINES
            READ(9,*,END=999) IAMP(II), ( IPHS(II,J), J=1,NANT)
          ENDDO
C
C     If ISAT=0 the observation is not identified and should not be processed.
C
        IF(ISAT .EQ. 0) GOTO 303
C
C     Find line number of first occurance of maximum in amplitude.
C        NOTE: largest amplitude is smallest number.
C
        MIAMP = 190
        DO 101 J=1,NLINES
          IF( IAMP(J).GE.MIAMP) GOTO 101
          MIAMP = IAMP(J)
          NMAX = J
 101    CONTINUE
C
C     Call DEROT which will derotate the phases of all antennas in one call.
C
C     If IERR = 1 did not get a good derotation so go to next observation and
C     print a line out.
C
        CALL DEROT(NLINES,NANT,IAMP,IPHS,RPHS,IERR)
          IF( IERR.EQ.1) THEN
            INOFIT=INOFIT + 1
            WRITE(13,202) NRC,NTR,NLINES,MIAMP,RSEC
 202       FORMAT(1X,4I5,F12.3,'    IERR=1')
            GOTO 303
          ENDIF
C
C     Pass only the "good" data to the fitting routine.
C     Go forward and backward from line NMAX and stop if IAMP greater
C     than 152.
C     Previous results indicate -152 dBm is the effective noise floor.
C
        IFRST = 0
          DO J=1,NMAX-1
            IF( IAMP( NMAX-J) .GT. 152) GOTO 304
          ENDDO
        IFRST = 1
 304    IF( IFRST .EQ. 0) IFRST = NMAX - J + 1
C
        DO J=NMAX+1,NLINES
          IF( IAMP(J) .GT. 152) GOTO 305
        ENDDO
 305    ILAST = J-1
C
C     Don't continue unless there are 10 or more good lines.
C     Previous results indicate that at least 10 frames are needed
C     for reasonable fits.
C
        NUM = ILAST - IFRST + 1
          IF(NUM .LT. 10) THEN
            WRITE(13,203) NRC,NTR,NLINES,MIAMP,RSEC,NUM
 203       FORMAT(1X,4I5,F12.3,'   NUM=',I1)
            NFEW = NFEW + 1
            GOTO 303
          ENDIF
C
C     Load up the SIG array by using the ANDREWS error model.
C
C     Load up A1 with times. T=0 at TPRED.
C
        TSTRT = RSEC - TPRED
          DO 102 II=1,NUM
            J = II + IFRST -1
```

```
                   INDX= 153 - IAMP(J)
                   IF(INDX.GT.45) INDX=45
                   SIG(II) = ERR(INDX)

                   A1(II) = (J - 0.5)*TINCR + TSTRT
 102           CONTINUE
C
C     Call WGHTPOLY for each antenna.
C     Call DPLCHR for each antenna.
C     Results with proper units go into COEFF.
C
                DO 103 II=1,NANT
                 DO J=1,NUM
                    JJ = J + IFRST - 1
C
C     A2 will contain the data.
C
                    A2(J) = RPHS(JJ,II)
                 ENDDO
C
                          CALL WGHTPOLY(A1,A2,SIG,NUM,A3,3,COVAR,CHISQ)
C
C     The matrix inversion will fail for some scans.  Test the value of
C     COVAR(1,3) to see if the result is reasonable.
C
                 TEST = ABS( COVAR(1,3)/ SQRT( COVAR(1,1)*COVAR(3,3) ) )
                 IF(TEST.GT.0.99) THEN
                      WRITE(13,204) NRC,NTR,NLINES,MIAMP,RSEC
 204                 FORMAT(1X, 4I5,F12.3,'  INVERSION FAILED')
                      NFAIL=NFAIL + 1
                      GOTO 303
                 ENDIF
C
                             CALL DPLCHR(SX,SY,SZ,VX,VY,VZ,DOP(II),CHRP(II),
        1                 RECPOS(NRC,II,1),RECPOS(NRC,II,2),RECPOS(NRC,II,3),
        2                 TRPOS(NTR,1),TRPOS(NTR,2),TRPOS(NTR,3))
C
C     Change the units to rotations so that Dopler will be Hertz and chirp
C     Hertz/sec.  This puts TWOPI in a number of places. The center frequency
C     of the digital filter is IDOP + 10.0.
C
C     **NOTE:**  The chirp is twice A3(3)
C                   This is obvious and follows from
C                   Phi(t) = Phi(T=0) + Doppler*T + 0.5*chirp*T*T
C
                   COEFF(1,II) = A3(1)/TWOPI
                   COEFF(2,II) = A3(2)/TWOPI
                   OMC(II,1) = ( IDOP + 10.0 + COEFF(2,II) ) - DOP(II)
                   COEFF(3,II) = 2.0*A3(3)/TWOPI
                   OMC(II,2) = COEFF(3,II) - CHRP(II)
C
                   COEFF(4,II) = CHISQ
C
C     Calculate the residuals and replace the elements of RPHS so that it
C     will contain the residuals.  Residuals will be in units of radians.
C
                DO J=IFRST,ILAST
                   T= (J - 0.5 )*TINCR + TSTRT
                   CALC = A3(1) + A3(2)*T + A3(3)*T*T
                   RPHS(J,II) = RPHS(J,II) - CALC
                ENDDO
 103    CONTINUE
C
C     Load the uncertainties and the correllation coefficients into
C     COEFF(5,1-6).
C
                   COEFF(5,1) = SQRT( COVAR(1,1) )/TWOPI
                   COEFF(5,2) = SQRT( COVAR(2,2) )/TWOPI
                   COEFF(5,3) = 2.0*SQRT( COVAR(3,3) )/TWOPI
C
```

```
                  COEFF(5,4) = COVAR(1,2)/ SQRT( COVAR(1,1)*COVAR(2,2) )
                  COEFF(5,5) = COVAR(1,3)/ SQRT( COVAR(1,1)*COVAR(3,3) )
                  COEFF(5,6) = COVAR(2,3)/ SQRT( COVAR(2,2)*COVAR(3,3) )
C
C     Print out the results.
C     Header line and coefficients go into 12.
C     File 13 will contain a header line and indicate a good fit.
C     File 14 has uncertainties in Doppler and Chirp.
C     File 15 O-C for Doppler and Chirp.
C     File 16 the residuals from the fitting.
C
       WRITE(12,205)ISAT,NRC,NTR,IYR,IMON,IDAY,TPRED,NUM,MIAMP,IDOP,RSEC
 205  FORMAT(1X,/,1X,I7,5I3,F10.3,2I4,I7,F10.3)
C
C     For reduced output add comments here.
C
            DO JJ=1,NANT
               WRITE(12,206)JJ,COEFF(1,JJ),COEFF(2,JJ),COEFF(3,JJ),COEFF(4,JJ)
            ENDDO
 206  FORMAT(1X,I6,F8.2, 3F12.2)
C
            WRITE(12,207) (COEFF(5,K), K=1,6)
 207  FORMAT(1X,6F10.4)
C
            WRITE(13,208) NRC,NTR,MIAMP,NUM,RSEC
 208  FORMAT(1X,4I5,F12.3,'   GOOD FIT')
C
            WRITE(14,209) NRC,NTR,MIAMP,NUM,COEFF(5,2),COEFF(5,3)
 209  FORMAT(1X,4I4,2F10.2)
C
C   For reduced output add comments here.
C
            WRITE(15,210)ISAT,NRC,NTR,IYR,IMON,IDAY,TPRED,RSEC,MIAMP,NUM,
     1                 IDOP,DOP(NANT),CHRP(NANT)
               DO L=1,NANT
                  WRITE(15,211)L,OMC(L,1),OMC(L,2),COEFF(4,L)
               ENDDO
 210  FORMAT(1X,/,1X,I7,2I3,3X,3I3,/,2F12.3,4X,2I4,3X,I6,2X,2F8.2)
 211  FORMAT(1X,I2,3F10.2)
C
C   Print out header line and the residuals.
C
C   This will be a large output file - add comments to reduce output!
C
               WRITE(16,212) ISAT,NRC,NTR,TPRED,RSEC
               DO JJ=IFRST,ILAST
                  WRITE(16,213) IAMP(JJ), ( RPHS(JJ,K),K=1,NANT )
               ENDDO
 212  FORMAT(1X,/,1X,3I5,2F10.3)
 213  FORMAT(1X,I6,12F7.2)
C
C   Return to reading.
C
 303  READ(9,*,END=999)
            GOTO 301
C
C   Branch to this point when EOF encountered during read.
C
 999  CONTINUE
       WRITE(13,*) 'NOBS=',NOBS,' INOFIT=',INOFIT,' NFEW=',NFEW,
     1                  ' NFAIL=',NFAIL
C
            END
```

```
             SUBROUTINE DEROT(NAMPL,NANT,IAMPL,IPHS,RPHS,IERR)
C *******************************************************************
C*
C*  SUBROUTINE DEROT
C*
C *******************************************************************
C
C    AUTHOR: DR. M. ANDREWS
C    DATE: 24 JUNE, 1988
C    LANGUAGE:      FORTRAN ANSI-77  (VAX/VMS operating system)
C    FILE:            VX7770::SPACE:[ANDREWS.CODE]DEROT.FOR
C
C    CALLING ROUTINE: FITS
C
C    PROGRAM DESCRIPTION: This a somewhat simple minded program whcih removes
C                               the phase wraps from NAVSPASUR Phase4 data.  The
C                               first occurance of the maximum amplitude is located,
C                               the slope of the phase curve is determined, and the
C                               slope used to predict and correct the phase.
C
C    INPUTS    EXPLICIT: All contained in the calling list.
C
C    OUTPUTS   EXPLICIT: All contained in the calling list.
C
C    MAJOR VARIABLES:
C
C            NAMPL, NANT the number of data frames and the number of antennas.
C
C            IAMPL(55), IPHS(55,12) arrays that contain the raw integer amplitudes
C                        and phases.
C
C            RPHS(55,12) the real number values of the phases returned by this
C                        program.  Units are radians.
C
C            IERR the error flag which indicates whether or not all the phases
C                        have been successfully processed.  = 1 indicates error.
C
C
C    MODIFIED:
C
C ***************************************************************************
C
             IMPLICIT REAL*8 (A-H,O-Z)
             DIMENSION IAMPL(55),IPHS(55,12),RPHS(55,12)
C
C     Set constant values.  FACTR converts from six bit integers to radians.
C
             TWOPI=6.2831853
             FACTR= TWOPI/64.
             IERR=0
C
C     Reset the RPHS array to 0.
C
             DO II=1,55
                DO JJ=1,12
                   RPHS(II,JJ)=0.
                ENDDO
             ENDDO
C
C     Find the index of the minimum of the amplitude i.e., STONGEST
C     signal.  Will derotate phases by starting there and working
C     out.
C
             IMIN = 200
                DO 111 LL=1,NAMPL
                   IF(IAMPL(LL) .GE. IMIN) GOTO 111
                   IMIN = IAMPL(LL)
                   IREF = LL
 111           CONTINUE
C
```

```
C     If the first or last amplitude has been selected move in one place.
C
            IF(IREF.EQ.1) IREF=IREF + 1
            IF(IREF.EQ.NAMPL) IREF=IREF - 1
C
C     Select antenna  number III.
C
C     Unwind the phase by starting at IREF index and going to top and
C     bottom.
C
C     At the start use the points before and after IREF to calculate a
C     slope.  Use the slope to predict the next value.   Adjust the
C     rotations as needed to get close to the predictor.
C
C     Convert phases to radians.
C
            DO 101 III=1,NANT
C
            IDIF1 = IPHS(IREF,III) - IPHS(IREF-1,III)
            IF(IDIF1.LT.-32) IDIF1 = IDIF1 + 64
            IF(IDIF1.GT. 32) IDIF1 = IDIF1 - 64
C
            IDIF2 = IPHS(IREF+1,III) - IPHS(IREF,III)
            IF(IDIF2.LT.-32) IDIF2 = IDIF2 + 64
            IF(IDIF2.GT. 32) IDIF2 = IDIF2 - 64
C
C     Check to see that these differences are either small or of the same
C     sign.
C
C     If the slope is not well determined at the amplitude peak, set IERR=1
C     and do not attempt to process the phases.
C
            IF( ABS(IDIF1 + IDIF1) .LT. 10)  GOTO 301
C
            IF( ABS(IDIF1)+ABS(IDIF2) .NE. IABS( IDIF1+IDIF2 ) ) GOTO 981
C
 301 CONTINUE
C
C     Set ISLOPE to the slope at peak and convert phase at peak to radians.
C
            ISLOP = ( IDIF1 + IDIF2 )/2
            RPHS(IREF,III) = IPHS(IREF,III)*FACTR
            NROT = 0
            ISLOPE=ISLOP
C
C     Work from peak to the beginning of the scan.
C
               DO JJ=1,IREF-1
                    II=IREF-JJ
C
C     Predict the phase based on the previous phase value and the slope.
C
                    IPRDCT = IPHS(II+1,III) - ISLOPE
C
C     Calculate difference between observed and predicted integer phase value.
C     Add or subtract a rotation to make the data closer to the prediction.
C
                    IDIFF = IPHS(II,III) - IPRDCT IF(IDIFF.LT.-32)
                    NROT = NROT+1
                    IF(IDIFF.GT. 32) NROT = NROT-1
C
C     Calculate phase in radians.
C
                    RPHS(II,III) = ( IPHS(II,III) + 0.5)*FACTR  + NROT*TWOPI

C
C     Recalculate the slope.
C
                    ISLOPE =NINT( ( RPHS(II+1,III) - RPHS(II,III) )/FACTR)
               ENDDO
```

```
C
C     Do the same thing from the peak to the end of the scan.
C     Reinitialize NROT and ISLOPE.
C
            ISLOPE=ISLOP
            NROT = 0
C
            DO II=IREF+1,NAMPL
C
               IPRDCT = IPHS(II-1,III) + ISLOPE
               IDIFF = IPHS(II,III) - IPRDCT
C
               IF(IDIFF.LT.-32) NROT = NROT+1
               IF(IDIFF.GT. 32) NROT = NROT-1
C
               RPHS(II,III) = ( IPHS(II,III) + 0.5)*FACTR   + NROT*TWOPI
               ISLOPE = NINT( ( RPHS(II,III) - RPHS(II-1,III) )/FACTR)
            ENDDO
 101       CONTINUE
            RETURN
C
 981       IERR=1
C
C    If this point is reached the slope is not properly determined and
C    no predictor is calculated.
C
            RETURN
            END
```

```
      SUBROUTINE WGHTPOLY(X,Y,SIG,NDATA,A,NA,COVAR,CHISQ)
C
C ****************************************************************************
C *
C *   SUBROUTINE WGHTPOLY
C *
C ****************************************************************************
C
C   AUTHOR: DR. M. ANDREWS
C   DATE: 24 JUNE, 1988
C   LANGUAGE:      FORTRAN ANSI-77  (VAX/VMS operating system)
C   FILE:            VX7770::SPACE:[ANDREWS.CODE]WGHTPOLY.FOR
C
C   CALLING ROUTINES: ACCUM,FITS
C
C   SUBROUTINES CALLED: GAUSSJ
C
C   PROGRAM DESCRIPTION: This is a general weighted polynomial fitting
C                                 routine.  The functional form is
C                                 Y = A(0) + A(1) + A(2)*X**2 + etc.
C                                 The routine uses Chi Squared minimization to determine
C                                 the polynomial coefficients.  The covariance matrix
C                                 and the reduced Chi Squared are returned.
C                                 This routine is adapted from an algorithm in Numerical
C                                 Recipes which should be consulted for details.
C
C   INPUTS      EXPLICIT: All in calling list
C
C   OUTPUTS   EXPLICIT: All in calling list
C
C   MAJOR VARIABLES:
C
C         X,Y,S are three arrays of length NDATA which contain the variable
C              and the error values.
C
C         NDATA is the number of data points.
C
C         A is an array of length NA that contains the fit parameters.
C
C         NA is the number of parameters solved for.  The polynomial order
C              is NA-1.
C
C         COVAR is two dimensional array of dimension NA*NA.  The diagonal
C              elements are the square of the uncertainties in the parameters
C              The off-diagonal elements are the correlation coefficients
C              scaled multiplied by the diagonal elements.
C
C         CHISQ is the value of the reduced Chi Squared.
C
C  MODIFIED:
C
C
C*****************************************************************************
      IMPLICIT REAL*8 (A-H,O-Z)
C
C   The dimension of the arrays is the calling list is controlled by the values
C   of NA and NDATA.  Dimension on FX and S limit order to 20 i.e. X**19.
C
      DIMENSION X(NDATA),Y(NDATA),SIG(NDATA),FX(20),S(20),
     1            A(NA),COVAR(NA,NA)
C
C   Initialize the necessary matrices.
C
        DO J=1,NA
           DO K=1,NA
              COVAR(J,K) = 0.0
           ENDDO
           A(J) = 0.0
        ENDDO
C
```

```
C    Loop over the data and increment the normal equations.
C        NOTE: Replace a zero value of X by 1*10-5 to prevent errors.
C
             DO 101 II=1,NDATA
                DATA = X(II)
                IF( ABS( X(II) ) .LT. 0.00001) DATA = 0.00001
C
C    Load the array FX(I) by FX(I) = DATA**(I-1).
C
                DO J=1,NA
                   FX(J) = DATA**(J-1)
                ENDDO
                YM = Y(II)
                SIG2I = 1./SIG(II)**2
                DO 101 J=1,NA
                  WT = FX(J)*SIG2I
                  DO K=1,J
                     COVAR(J,K) = COVAR(J,K) + WT*FX(K)
                  ENDDO
                  A(J) = A(J) + YM*WT
 101           CONTINUE
C
C  Fill in across the diagonal from symmetry.
C
             IF(NA.EQ.1) GOTO 102
                DO 102 J=2,NA
                   DO 102 K=1,J-1
                      COVAR(K,J) = COVAR(J,K)
 102           CONTINUE

C
C     Rescale the matrix to insure numerical stability.
C
                DO J=1,NA
                   S(J) = SQRT( COVAR(J,J) )
                   IF( S(J) .EQ. 0.0)  S(J) = 1.0
                ENDDO
                DO J=1,NA
                   A(J) = A(J)/S(J)
                   DO K=1,NA
                      COVAR(J,K) = COVAR(J,K)/( S(J)*S(K) )
                   ENDDO
                ENDDO
C
C     Call GAUSSJ to invert the matrix.
C
             CALL GAUSSJ(COVAR,NA,NA,A,1,1)
C
C     Scale back to correct units.
C
                DO J=1,NA
                   A(J) = A(J)/S(J)
                      DO K=1,NA
                         COVAR(J,K) = COVAR(J,K)/( S(J)*S(K) )
                      ENDDO
                ENDDO
C
C     Calculate chi-square by summing the differences of data, Y's,
C     and the values calculated using the fit parameters.
C     Convert to reduced Chi Squared by dividing by NDATA - NA which
C     is the number of degrees of freedom.
C
             CHISQ=0.0
             DO 103 II=1,NDATA
                DATA = X(II)
                IF( ABS( X(II) ) .LT. 0.00001) DATA = 0.00001
                SUM=0.0
                   DO J=1,NA
                      SUM = SUM + A(J)*DATA**(J-1)
                   ENDDO
```

```
                  RESID = Y(II) - SUM
                  CHISQ = CHISQ + ( RESID/SIG(II) )**2
 103  CONTINUE
            CHISQ = CHISQ/( NDATA - NA )
            RETURN
            END
```

```
      SUBROUTINE DPLCHR(X,Y,Z,VX,VY,VZ,DOPLR,CHIRP,XR,YR,ZR,XT,YT,ZT)
C
C **********************************************************************
C *
C *         SUBROUTINE DPLCHR
C *
C **********************************************************************
C
C  AUTHOR: DR. M. ANDREWS
C  DATE: 24 JUNE, 1988
C  LANGUAGE:      FORTRAN ANSI-77  (VAX/VMS operating system)
C  FILE:              VX7770::SPACE:[ANDREWS.CODE]DPLCHR.FOR
C
C  CALLING ROUTINE: FITS
C
C  PROGRAM DESCRIPTION: This subroutine uses the position and velocity of
C                               a satellite along with the tranmitter and receiver
C                               positions to calculated the expected Doppler and
C                               chirp.  This code was specifically written for the
C                               bi-static geometry of NAVSPASUR at 216.98 MHz.  It
C                               can be easily generalized by adding FEMIT to the
C                               call.
C
C  PROGRAM ALGORITHM (PSEUDOCODE): The actual calculation is the classic,
C                    non-relativistic Doppler shift.  The calculation is repeated
C                    at T=1 sec to obtain the chirp.  Acceleration from a point
C                    source Earth and corrections for rotating coordinate system
C                    are included.
C
C  INPUTS    EXPLICIT:  All containing in call list.
C
C  OUTPUTS  EXPLICIT: All contained in call list.
C
C  MAJOR VARIABLES:
C
C          X,Y,Z,VX,VY,VZ are the position and velocity of the satellite in an
C                    Earth centered coordinate system; units m and m/sec.
C
C          DOPLR,CHIRP are the calculated Doppler and chirp
C
C          XR,YR,ZR,XT,YT,ZT are the positions of the reciver(R) and transmitter(T)
C                    in Earth centered, rotating coordinate system.
C
C          FEMIT is the frequency emitted by the transmitter.  For NAVSPASUR,
C                    FEMIT = 216.98 MHz.
C
C          GM is gravitational constant for the Earth.
C
C          OMEGA is angular velocity of the Earth.
C
C  MODIFIED:
C
C ***************************************************************************
C
          IMPLICIT REAL*8 (A-Z)
C
C         Enter values for constants.
C
          FEMIT = 216980000.
          VLGHT = 299792458.
          GM = 3.986124E14
          OMEGA = 6.2831853/( 23.*3600. + 56.*60. )
C
C     GM is the gravitational constant and OMEGA is the angular velocity of
C     the earth.
C
C     Calculate the acceleration of the satellite based on position and
C     point source gravity with centrifigal and coriolis force added.
C
C     Gravity terms.
```

```
C
             GCNST = -1.0*GM/( ( X*X + Y*Y + Z*Z ) **1.5)
             AGX = GCNST * X
             AGY = GCNST * Y
             AGZ = GCNST * Z
C
C      Coriolis terms.
C
             ACORX = 2*OMEGA*VY
             ACORY = -2*OMEGA*VX
C
C      Centrifigal terms.
C
             ACENX = OMEGA*OMEGA*X
             ACENY = OMEGA*OMEGA*Y
C
C      Total acceleration.
C
             AX = AGX + ACORX + ACENX
             AY = AGY + ACORY + ACENY
             AZ = AGZ
C
C      Velocity at time T=1 sec.
C
             VX1 = VX + AX
             VY1 = VY + AY
             VZ1 = VZ + AZ
C
C      Position at T=1sec.
C
             X1 = X + VX + .5*AX
             Y1 = Y + VY + .5*AY
             Z1 = Z + VZ + .5*AZ
C
C      Calculate the position vector and distance from the transmitter to the
C      satellite at T=0 and T=1sec.
C
             XSAT= X - XT
             YSAT= Y - YT
             ZSAT= Z - ZT
C
             XSAT1 = X1 - XT
             YSAT1 = Y1 - YT
             ZSAT1 = Z1 - ZT
C
             D1 = SQRT( XSAT*XSAT + YSAT*YSAT + ZSAT*ZSAT )
             D5 = SQRT( XSAT1*XSAT1 + YSAT1*YSAT1 + ZSAT1*ZSAT1 )
C
C      Take the dot product of the velocity and the unit radius vector to
C      get velocity along line of sight.
C
             DOT1 = ( XSAT*VX + YSAT*VY + ZSAT*VZ )/D1
             DOT5 = (XSAT1*VX1 + YSAT1*VY1 + ZSAT1*VZ1 )/D5
C
C      Calculate the Doppler shifted frequency.
C
             FREQ1 = FEMIT*(1.0 - DOT1/VLGHT)
             FREQ5 = FEMIT*(1.0 - DOT5/VLGHT)
C
C      Repeat the above calculation for the receiver.
C
             XSTA = X - XR
             YSTA = Y - YR
             ZSTA = Z - ZR
C
             XSTA1 = X1 - XR
             YSTA1 = Y1 - YR
             ZSTA1 = Z1 - ZR
C
             D2 = SQRT( XSTA**2  +  YSTA**2  +  ZSTA**2 )
```

```
         D6 = SQRT( XSTA1*XSTA1 + YSTA1*YSTA1 + ZSTA1*ZSTA1)
C
         DOT2 = ( XSTA*VX + YSTA*VY + ZSTA*VZ )/D2
C
         DOT6 = (XSTA1*VX1 + YSTA1*VY1 + ZSTA1*VZ1 )/D6
C
         FREQ2 = FREQ1*(1D0 - DOT2/VLGHT)
         FREQ6 = FREQ5*(1D0 - DOT6/VLGHT)
C
C  Doppler is final frequency minus transmit frequency.
C      **NOTE** This agrees with NAVSPASUR sign convention.
C  Chirp is rate of change of Doppler.
C
         DOPLR = FREQ2 - FEMIT
         CHIRP = FREQ6 - FREQ2
C
         RETURN
         END
```

```
          SUBROUTINE GAUSSJ(A, N, NP, B, M, MP)
C
C    This routine has been lifted intact from Numerical Recipes.
C    Consult the book for information on this algorithm.
C
C        LINEAR EQUATION SOLUTION BY GAUSS-JORDAN ELIMINATION.  A IS AN
C        INPUT MATRIX OF N BY N ELEMENTS, STORED IN AN ARRAY OF PHYSICAL
C        DIMENSIONS NP BY NP.  B IS AN INPUT MATRIX OF N BY M CONTAINING
C        THE M RIGHT-HAND SIDE VECTORS, STORED IN AN ARRAY OF PHYSICAL
C        DIMENSIONS NP BY MP.  ON OUTPUT, A IS REPLACED BY ITS MATRIX
C        INVERSE, AND B IS REPLACED BY THE CORRESPONDING SET OF SOLUTION
C        VECTORS.
C
             IMPLICIT REAL*8 (A-H,O-Z)
             PARAMETER(NMAX=50)
             DIMENSION A(NP,NP),B(NP,MP),IPIV(NMAX),INDXR(NMAX),INDXC(NMAX)
C
C        THE INTEGER ARRAYS IPIV, INDXR, AND INDXC ARE USED FOR BOOKKEEPING
C        ON THE PIVOTING.  NMAX SHOULD BE AS LARGE AS THE LARGEST ANTICI-
C        PATED VALUE OF N.
C
          DO 11 J=1, N
             IPIV(J)=0
 11      CONTINUE
          DO 22 I=1,N
             BIG = 0.
             DO 13 J=1,N
                IF(IPIV(J).NE.1) THEN
                   DO 12 K=1,N
                      IF(IPIV(K).EQ.0) THEN
                           IF(ABS(A(J,K)).GE.BIG) THEN
                                 BIG=ABS(A(J,K))
                                 IROW=J
                                 ICOL=K
                           ENDIF
                        ELSE
                           IF(IPIV(K).GT.1) STOP 'SINGULAR MATRIX.'
                      ENDIF
 12               CONTINUE
                ENDIF
 13         CONTINUE
                      IPIV(ICOL)=IPIV(ICOL) + 1
C
C        WE NOW HAVE THE PIVOT ELEMENT, SO WE INTERCHANGE ROWS, IF NEEDED,
C        TO PUT THE PIVOT ELEMENT ON THE DIAGONAL.  THE COLUMNS ARE NOT
C        PHYSICALLY INTERCHANGED, ONLY RELABELED:  INDX(I), THE COLUMN OF
C        THE ITH PIVOT ELEMENT, IS THE ITH ELEMENT THAT IS REDUCED, WHILE
C        INDXR(I) IS THE ROW IN WHICH THAT PIVOT ELEMENT WAS ORIGINALLY
C        LOCATED.  IF INDXR(I) .NE. INDXC(I) THERE IS AN IMPLIED COLUMN
C        INTERCHANGE.  WITH THIS FORM OF BOOKKEEPING, THE SOLUTION B'S
C        WILL END UP IN THE CORRECT ORDER, AND THE INVERSE MATRIX WILL BE
C        SCRAMBLED BY COLUMNS.
C
                      IF (IROW.NE.ICOL) THEN
                        DO 14 L=1,N
                                 DUM=A(IROW,L)
                                 A(IROW,L)=A(ICOL,L)
                                 A(ICOL,L)=DUM
 14                    CONTINUE
                        DO 15 L=1,M
                                 DUM=B(IROW,L)
                                 B(IROW,L)=B(ICOL,L)
                                 B(ICOL,L)=DUM
 15                    CONTINUE
                      ENDIF
                      INDXR(I)=IROW
                      INDXC(I)=ICOL
                      IF(A(ICOL,ICOL).EQ.0.) STOP 'SINGULAR MATRIX'
                      PIVINV = 1./A(ICOL,ICOL)
                      A(ICOL,ICOL)=1.
```

```
                 DO 16 L=1,N
                   A(ICOL,L)=A(ICOL,L)*PIVINV
16              CONTINUE
                 DO 17 L=1,M
                   B(ICOL,L)=B(ICOL,L)*PIVINV
17        CONTINUE
                 DO 21 LL=1,N
                   IF(LL.NE.ICOL) THEN
                           DUM=A(LL,ICOL)
                           A(LL,ICOL)=0.
                           DO 18 L=1,N
                              A(LL,L)=A(LL,L)-A(ICOL,L)*DUM
18                        CONTINUE
                           DO 19 L=1,M
                              B(LL,L)=B(LL,L)-B(ICOL,L)*DUM
19                        CONTINUE
                   ENDIF
21              CONTINUE
22   CONTINUE
                 DO 24 L=N,1,-1
                   IF(INDXR(L).NE.INDXC(L)) THEN
                      DO 23 K=1,N
                         DUM=A(K,INDXR(L))
                         A(K,INDXR(L))=A(K,INDXC(L))
                         A(K,INDXC(L))=DUM
23                     CONTINUE
                   ENDIF
24              CONTINUE
      RETURN
      END
```