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INFRASONIC DATA REDUCTION

by

George Ohring

GCA CORPORATION
GCA TECHNOLOGY DIVISION
Bedford, Massachusetts 01730

Contract No. F19628-68-C-0305
Project No. 7639
Task No. 763910
Work Unit No. 76391001

FINAL REPORT
Period Covered: March 1968 - December 1970

December 1970

Approved for public release; distribution unlimited.

Contract Monitor
Elisabeth F. Iliff
Terrestrial Sciences Laboratory

Prepared for:
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
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13 ABSTRACT

A multi-channel prediction-error filter technique is developed for suppressing noise on infrasonic signals. The technique uses samples of noise prior to a signal for deriving a Wiener prediction filter that is used to predict the noise during the first motion of the infrasonic signal. A computer program entitled MAXLKH is written to carry out the filtering technique. Application of the technique to actual infrasonic records indicates that noise has some degree of predictability and, hence, an enhancement of the infrasonic signal results. Further tests are suggested to quantify the amount of noise suppression and to optimize technique parameters such as filter length and prediction span. A discussion of the computer program is included.

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I. INTRODUCTION

The objective of the present contract was to develop digital techniques for the processing of infrasonic records. The records consist of infrasonic signals whose source is remote from the recording stations. The purpose of the processing is to obtain the best possible estimate of the infrasonic signal.

The pure infrasonic signal caused by an event is modified in two different ways before it is finally recorded at locations remote from the source: (1) as the signal propagates through the atmosphere, meteorological parameters such as wind and temperature affect the signal, and (2) the presence of noise at the recording sites further contaminates the signal. Thus it was decided to develop two different techniques for dealing with these two different effects.

To eliminate the meteorological, or propagation, effects on the signal, an empirical study was begun to relate the observed characteristics of the infrasonic signal to the meteorological conditions prevailing along the path of propagation. Unfortunately, due to the untimely termination of the contract, little progress was made in this area. Such a study should be continued, especially in view of the fact that theoretical work on infrasonic propagation has far outpaced sophisticated observational studies.

To eliminate or suppress the noise on infrasonic records, several digital filtering techniques were examined. A computer program that uses a prediction-error filter technique was developed for application to infrasonic records. This technique uses samples of noise prior to the infrasonic signal to develop a Wiener prediction filter, which when applied to the infrasonic record, predicts the noise during the start of the signal. Subtraction of this estimate of the noise from the original record provides an improved estimate of the infrasonic signal.

A short discussion of our planned activities on the empirical studies of atmospheric propagation effects on infrasonic signals is contained in Section II of this report. Section III contains a discussion of the several possible digital filtering techniques that were examined; an explanation of the prediction-error filter technique that was adopted; an analysis of the results obtained from application of the prediction-error filter technique to actual infrasonic seconds; and a detailed description of the computer program that was developed to accomplish the filtering. Section IV outlines our conclusions and contains suggestions for further evaluation and improvement of these techniques.

II. EMPIRICAL STUDIES OF CONCURRENT INFRASONIC AND METEOROLOGICAL DATA

A thorough review of the literature on the infrasonics problem was performed. Most of the work in the literature concerns the development of theoretical models to predict the propagation of acoustic-gravity waves in the atmosphere. The early theoretical models dealt solely with the propagation problem in a non-isothermal atmosphere and did not include the effect of winds (see, for example, Pfeffer, 1962). Later models included modeling of the explosive source (for example, Harkrider, 1964), but still did not include winds. The more recent work of MacKinnon (1968) and Pierce (1968) includes the effect of winds and indicates that winds are extremely important in the determination of the characteristics of infrasonic signals. The work of MacKinnon shows that the winds have a pronounced, but complicated effect upon the amplitudes of the infrasonic signals. Thus, recent theoretical work suggests that in order to arrive at estimates of source characteristics from infrasonic records, the effect of the atmosphere on the signal should be eliminated.

In our review of the literature, we found few observational analyses that attempted to relate observed characteristics of infrasonic waves to the prevailing meteorological situation. Furthermore, the few that were found (Wexler and Hass, 1952; MacKinnon, 1968) used rather gross analyses of the meteorological situation.

As a result of our review of the literature, we arrived at certain conclusions.

(1) The effect of the atmosphere on the characteristics of the observed infrasonic signal can be considerable.

(2) To estimate source strength from infrasonic signals one should eliminate the effect of the atmosphere.

(3) Previous empirical analyses of infrasonic data and concurrent meteorological data are either non-existent or were grossly performed.

Therefore, we planned to perform empirical analyses of infrasonic data and concurrent meteorological conditions. Guided by the results of the recent theoretical work, one should be able to develop empirical relationships between the meteorological conditions - in particular, integrated great circle winds and temperatures for key layers in the atmosphere - and characteristics of the signal, such as amplitude and period. The goal would be the development of an objective procedure for "normalizing" for prevailing atmospheric conditions. Given such a procedure, one would be in a much better position to estimate source characteristics from infrasonic signal characteristics measured remotely from the source.

For this purpose, we obtained, from the National Weather Records Center at Asheville, microfilm copies of analyzed daily surface and upper air charts for the Northern Hemisphere for times corresponding to infrasonic signals.

Unfortunately, due to the untimely termination of the contract, this research task was not carried out. The meteorological data are being transferred to the contract monitor under separate cover. It is hoped that such a study can be conducted in the near future.

III. DIGITAL FILTER STUDIES TO DEVELOP A NOISE AND BACKGROUND SUPPRESSION SCHEME

A. Basic Problem

The basic problem in the enhancement of infrasonic records can be summarized as follows. Infrasonic records are available from several instruments (channels) at slightly different locations. A schematic diagram of such records from a 3 channel network is shown as Figure 1. The record consists of a period of noise followed by a period of time in which the record consists of noise plus an infrasonic signal. Aside from possible time lags, the signal should be exactly the same at all three channels. The major characteristic of the signal is an initial high amplitude oscillation, which we shall call the first motion. This is generally followed by smaller amplitude oscillations. The problem is to take the records from the different channels and digitially manipulate them to obtain the best estimate of the infrasonic signal.

B. Digital Filters

To solve the problem of obtaining the best estimate of an infrasonic signal, we have reviewed several different types of digital filtering techniques:

(1) Wiener filter
(2) Maximum likelihood filter
(3) Prediction-error filter

The general Wiener filter is an enhancement and prediction filter. Enhancement is defined as separation of the signal from the signal and noise time series. Prediction is defined as the forecast of the signal for times greater than t, based upon information available up to time t. In general, one has a signal and noise time series, x_t, which consists of a signal s_t, and noise, n_t, so that

$$x_t = s_t + n_t \qquad (1)$$

The goal is to design a physically realizable (physically realizable means that the filter uses only the past history of the time series) digital filter so that when it is applied to x_t, the actual output y_t is the best approximation to the desired output $z_t = s_{t+\alpha}$ where α represents the prediction span. In most cases of Wiener filtering, it is assumed that the form of the signal is known, and that this is the desired output. The criterion employed in the derivation of the filter is the minimization of the squared difference between the filtered time series (output) y_t and the estimate

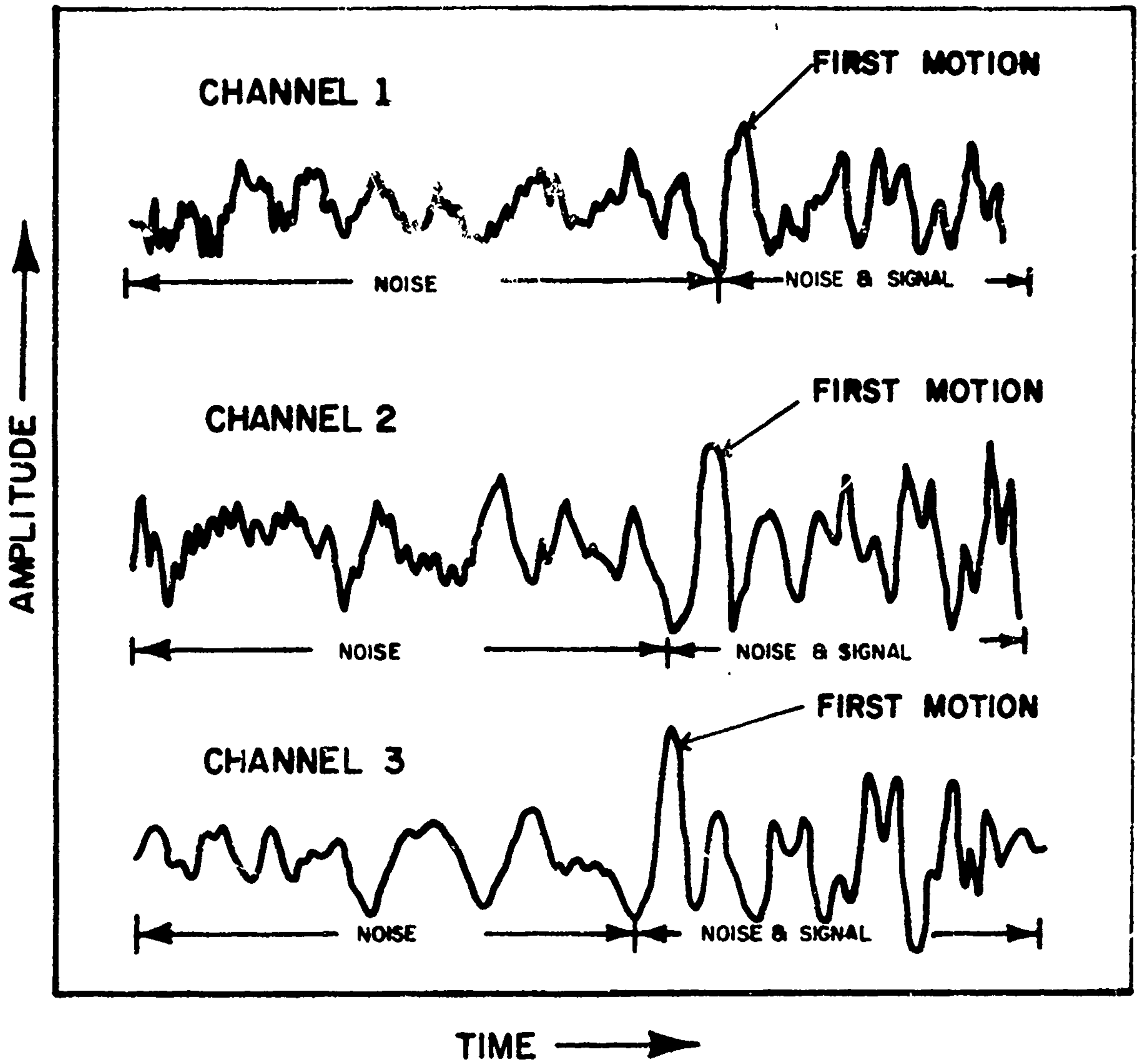


Figure '. Schematic diagram of infrasonic records.

of what the time series would be if noise were absent (desired output) z_t. Unfortunately, in the case of the infrasonic records we do not know precisely the form of the signal and, hence, we do not use Wiener filtering directly.

The maximum likelihood filter (see, for example, Green, et al., 1966) maximizes output signal-to-noise ratio under the restriction of zero frequency distortion of the signal. It has been utilized in the analysis of seismic data, where it is derived in the following manner. A sample of the noise record preceding an event is used to derive filter coefficients which, when applied to the noise record, will produce an output record of minimum variance (that is, will tend to drive the record to zeros). When this filter is passed over the entire length of record (that is, the noise portion plus the portion containing signal and noise), the record is driven to zero in the noise portion and to the signal in the signal and noise portion. However, this is not a predictive filter; it is implicitly assumed that the characteristics of the noise do not change in the signal and noise portion of the record. It is of possible application to the infrasonics problem since the only requirement for its development is the availability of a sample of noise preceding an event. As opposed to the Wiener technique, one need know nothing about the characteristics of the signal.

The prediction-error filter (see, for example, Claerbout, 1964) combines features of both the Wiener filter and the maximum likelihood filter. A prediction-error filter predicts the noise at a future time. It thus also differs from both the Wiener filter, which attempts to predict the signal at a future time, and the maximum likelihood filter, which attempts to estimate the noise at the present time. With a prediction of the noise, it is possible to subtract the predicted noise from the actual record, thus obtaining an improved estimate of the signal. The prediction-error filter will obviously work well if the noise has some degree of predictability. Like the maximum likelihood technique, it is applicable to the infrasonics problem, and, in principle, both should yield similar results. Because of the availability of a number of computer sub-routines (see Robinson, 1967) that are directly applicable, we decided to test this filtering technique on the infrasonic records. The technique is described in the next section (C); the computer program is presented in Section D; and the results are discussed in Section E. Further discussions of the various filtering techniques and our circuitous route to development of the final filtering technique are contained in the contract quarterly reports.

C. Prediction-Error Filter Technique for Analysis of Infrasonic Records

The prediction-error filter forecasts the noise at a future time. In general, the ability of such a filter to predict the noise will decrease with the length of the prediction span (time interval between time of last data input and time of predicted noise). Thus, if possible, it is desirable to have the prediction span as short as possible for a particular problem. In the infrasonics problem, as discussed above, a major feature of the signal is an initial relatively large amplitude oscillation. We may call this oscillation the first motion.

We shall assume that much of the information on the event that causes the infrasonic signal is concentrated in this first motion. Therefore, if we can obtain a good estimate of the first motion, we shall be in good shape. This is obviously easier than obtaining a good estimate of the entire length of signal, which requires a very long prediction span. Thus, for the analysis of infrasonic records we shall use a prediction span equal to the time period during which the first motion occurs.

In general, a prediction-error filter for a network of channels will use the history of the ith channel time series and the history of all the other time series in the network to predict the noise on the ith channel. When this noise is subtracted from the ith channel during the noise plus signal portion of the record, an estimate of the signal is obtained.

The filter is derived from the noise samples preceding the event, and can be derived as a Wiener filter that uses estimated future noise rather than estimated future signal as the desired output. In the development below, we follow Robinson (1967). Let

$$x_t \equiv x(t) = \begin{bmatrix} x_1(t) \\ x_2(t) \\ \cdot \\ \cdot \\ \cdot \\ x_N(t) \end{bmatrix} = \text{input time series (samples of noise preceding the event)} \qquad (2)$$

$$z_t \equiv z(t) = \begin{bmatrix} x_1(t) \\ x_2(t) \\ \cdot \\ \cdot \\ \cdot \\ x_M(t) \end{bmatrix} = \text{desired output time series } [x(t + \alpha)] \qquad (3)$$

$$y_t \equiv y(t) = \begin{bmatrix} y_1(t) \\ y_2(t) \\ \cdot \\ \cdot \\ \cdot \\ y_M(t) \end{bmatrix} = \text{output time series} \qquad (4)$$

where N is the number of input channels, M is the number of output channels, and α is the prediction span. The output time series is obtained from the convolution

$$y = (f)(x) \tag{5}$$

where f is the desired filter. f is derived by minimizing the expression $\Sigma(z_t - y_t)^2$. The desired output time series z_t is simply the noise preceding the event shifted in time by the prediction distance α. The output time series y_t represents predictions of the noise at absolute time $(t+\alpha)$ based upon application of the filter f to the input series x_t at time t.

The Wiener digital filter to predict the noise is based upon three assumptions which are implicit in its derivation and during its application:

(1) The noise statistics remain stationary for a time outside the noise sample interval.

(2) The approximation criterion is the minimization of the mean-square-error matrix between the desired output and the actual output.

(3) The filters are assumed to be linear and physically realizable.

The success of the filter depends essentially upon the existence of correlations between the desired output z_t and the input x_t. The assumption of linear filters implies use of linear correlation, namely, the autocorrelation function

$$\phi_{xx}(\tau) = E\left\{x_t \, x^T_{t-\tau}\right\}, \quad \tau = 0,1,2.... \tag{6}$$

of the input, and the cross-correlation function

$$\phi_{zx}(\tau) = E\left\{z_t \, x^T_{t-\tau}\right\}, \quad \tau = 0,1,2.... \tag{7}$$

between desired output and input.
The filter may be represented by the M x N matrix-valued cofficients

$$f_s \equiv f(s) = \begin{bmatrix} f_{11}(s) & f_{12}(s) \; ..... & f_{1N}(s) \\ f_{M1}(s) & f_{M2}(s) \; ..... & f_{MN}(s) \end{bmatrix} \tag{8}$$

It is assumed that mean values have been removed from the input and desired output, so $E\{x_t\}$ and $E\{z_t\} = 0$. The actual output, which is the convolution of the input with the filter, is given by the matrix equation

$$y_t = f_o \, x_t + f_1 \, x_{t-1} + ...+ f_m \, x_{t-m}, \tag{9}$$

where m is the length of the filter.

The error e_t between desired output and actual output is then

$$e_t = z_t - y_t = z_t - (f_o x_t + f_1 x_{t-1} + \dots f_m x_{t-m}) \tag{10}$$

The mean-square-error matrix is defined by $E\left\{e_t e_t^T\right\}$, which can be written as

$$E\left\{e_t e_t^T\right\} = \begin{bmatrix} E\left\{e_1^2(t)\right\} & E\left\{e_1(t)e_2(t)\right\} \dots & E\left\{e_1(t)\ e_M(t)\right\} \\ & \dots & \\ E\left\{e_M(t)\ e_1(t)\right\} & E\left\{e_M(t)e_2(t)\right\} \dots & E\left\{e_M^2\ (t)\right\} \end{bmatrix} \tag{11}$$

The values of the filter coefficients f_s are determined from the condition that the trace (abbreviated tr) I of the mean-square-error matrix be a minimum. This is accomplished by setting the partial derivative of

$$I = \text{tr}\ E\left\{e_t e_t^T\right\} = E\left\{e_1^2(t)\right\} + E\left\{e_2^2(t)\right\} + \dots\dots + E\left\{e_M^2(t)\right\} \tag{12}$$

with respect to each filter coefficient equal to zero. It can be shown that when this is done, the following normal equations are obtained

$$\left.\begin{aligned} f_o\ \phi_{xx}(0) + f_1\ \phi_{xx}(-1) + \dots + f_m\ \phi_{xx}\ (-m) &= \phi_{zx}\ (0) \\ f_o\ \phi_{xx}(1) + f_1\ \phi_{xx}(0)\ + \dots + f_m\ \phi_{xx}\ (1-m) &= \phi_{zx}(1) \\ &\dots \\ f_o\ \phi_{xx}(m) + f_1\ \phi_{xx}(m-1) + \dots + f_m \phi_{xx}\ (0) &= \phi_{zx}(m) \end{aligned}\right\} \tag{13}$$

The known quantities are the correlation coefficients ϕ, and the unknowns are the filters (f_o, f_1,....,f_m), which can be derived by solving these equations. Procedures for solution and further details in the derivation are given by Robinson (1967).

D. Computer Program MAXLKH

To accomplish the desired digital filtering, a computer program entitled MAXLKH was developed and tested. This program makes use of a number of sub-routines presented in Robinson (1967). Basically, what MAXLKH does is the following. It reads in infrasonic time series (x_t)

for a number of channels. The first portions of these time series represent noise, the second portions represent noise plus signal. The first portions are used as noise samples, are displaced to the left in time by the prediction span time, and become the desired output series z_t for Wiener filter derivations. Wiener filters are derived and are applied to the infrasonic records. This application results in an output time series for each channel that represents estimates of the noise for the time period that covers the noise portion and the first motion portion of the infrasonic record. These estimates of noise are subtracted from the original infrasonic record to obtain a predicted time series. The predicted time series should have minimal noise in the noise portion of the record and an enhanced first motion in the noise plus signal portion. For the time period after the first motion, the predicted time series is assumed to be the same as the original time series. Program MAXLKH includes a plotting sub-routine which permits the input, assumed output, output, and predicted time series to be presented on graphs.

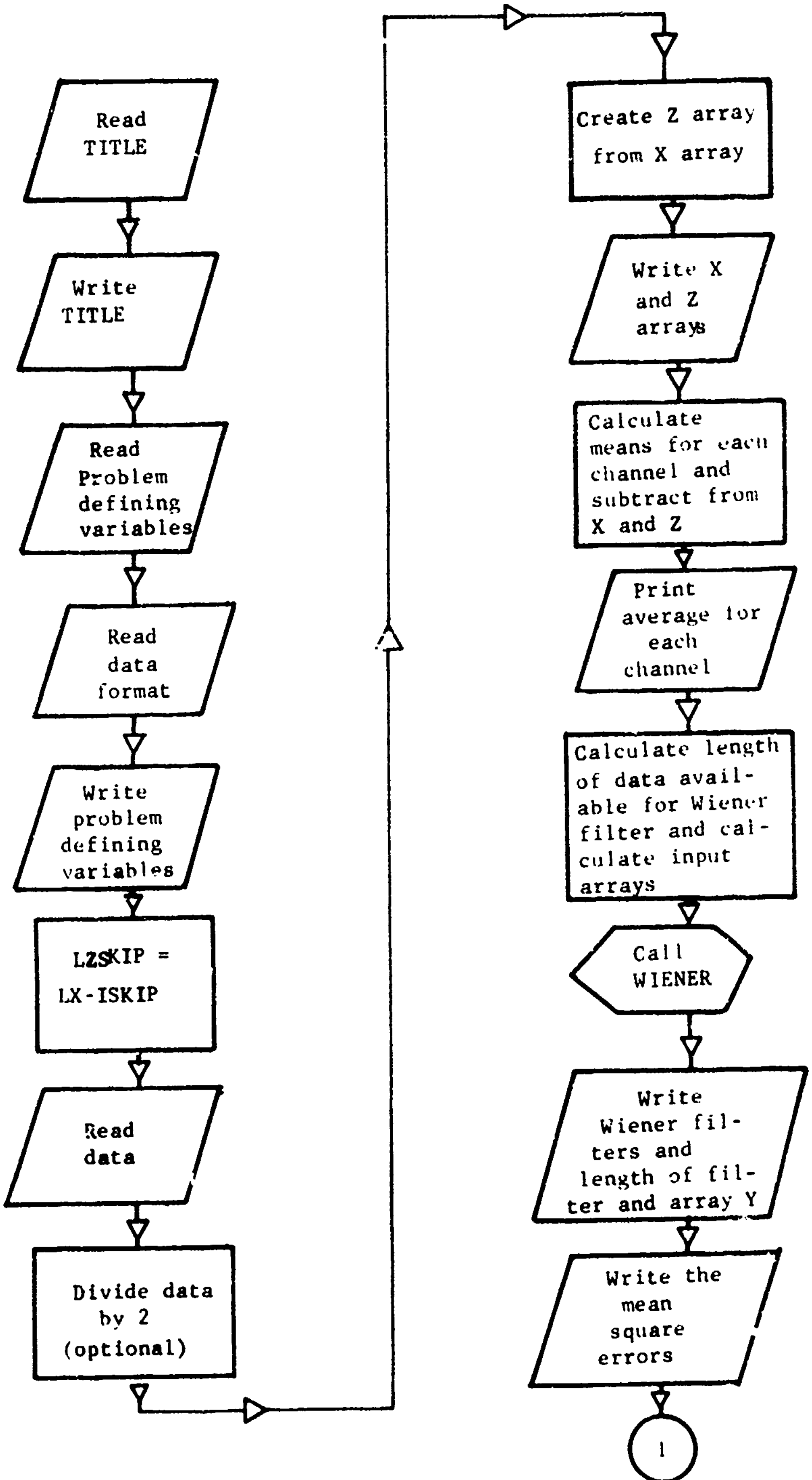
The remainder of this section contains information that is required to understand and operate this computer program. A flow chart of Program MAXLKH is shown in Figure 2. A list of variables appearing in MAXLKH is contained in Table 1, and dimensions of arrays contained in the program are shown in Table 2. The content of the data input cards is shown in Table 3.

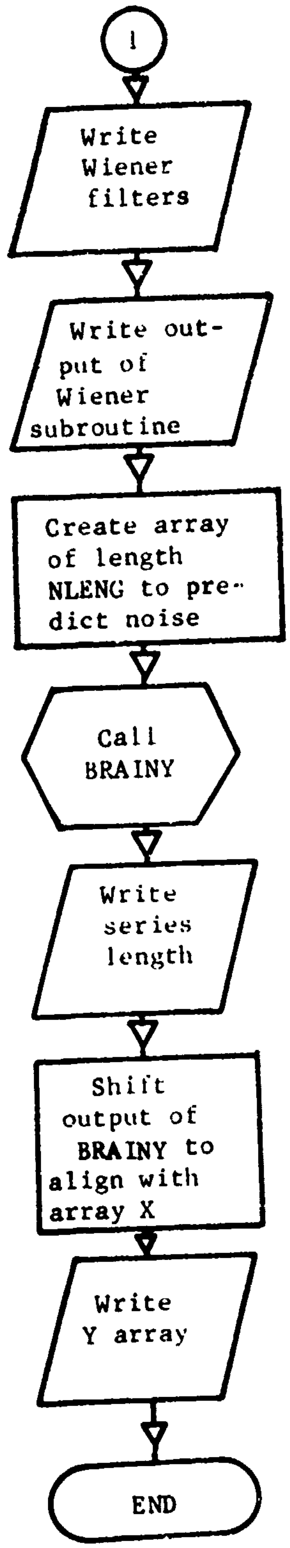
A program card deck is being supplied to the contract monitor under separate cover. To operate the program one must check those cards that have a blue top. These cards can vary from case to case, and can vary if the filter length is changed.

E. Results of Application of Program MAXLKH to Infrasonic Records

Traces of infrasonic records were provided by the contract monitor. These were digitized and punched on cards for use as input to program MAXLKH. Figure 3 indicates the results of application of MAXLKH to infrasonic data. Figure 3 is divided into 3 parts; 3a, 3b, and 3c, each part representing a different channel. On each part are four time series. From top to bottom, they are the input time series (x_t, the original infrasonic record), the assumed output time series (z_t, the original infrasonic record shifted to the left by an amount equal to the prediction span = ISKIP), the actual output time series (y_t, predicted noise time series plus zeros before the beginning and after the end of the noise series), and the time series representing the difference between the input time series and the output

Figure 2. Flow Chart of MAXLKH





Fi; re 2 (Continued)

TABLE 1

LIST OF VARIABLES APPEARING IN PROGRAM MAXLKH

AVG(I)	The average value of the I^{th} channel.
E(I)	The mean square error for a filter of length I.
F(I,J,K)	The filter for an I channel input by J channel output by K filter length.
FLOOR	Ignore
FORMAT	Array continuing data input format.
IC	Card reader device number.
ID	Array for plotter which titles first frame identification.
IP	Printer device code number.
ISKIP	Prediction span.
L	Length of predicted noise series (Filter length + input length NLENG).
LENGTH	Length of noise sample to be used in Wiener (= NLENG - ISKIP).
LF	Length of filter
LR	Max. length of filter
LW	Not used
LX	Length of initial input series
LX1	Length of noise sample used in finding filters = LENGTH
LY	Length of output (LX-ISKIP) + LF-1
LZ	Length of assumed output = LX-ISKIP
LZSKIP	LX - ISKIP
LZ1	Length of array used as z_t for Wiener program (length = LX1)
M	Number of output channels
N	Number of input channels
NLENG	Maximum length of data available to be used in finding the filters

TABLE 1 (Continued)

S (I)	Storage array for auto and cross correlations
TITLE (7)	Array which contains the title of the data set
X (I,J)	Input array
XY (I)	Temporary storage array
X' (I,J)	Array of data used to find the filters (length = LX1)
Y (I,J)	Output array
Yi (I,J)	Output array for data used to define the filters
Z (I,J)	Assumed output Z(I) = X(I + ISKIP)
Z1 (I,J)	Assumed output for data used to find Wiener filters (length = LZ1)

TABLE 2

DIMENSIONS OF ARRAYS APPEARING IN PROGRAM MAXLKH

AVG (I)	Where I = number of channels
XY (I)	Where I = maximum length of X or Z series
Title (7)	Fixed
Format (10)	Fixed
ID (10)	Fixed
X (I,J)	I is the number of input channels, J = channel length
Z (I,J)	I is the number of output channels, J = channel length
F (I,J,K)	I = number of output channels, J = number of input channels, K = maximum filter length
E (I)	I = maximum filter length
Y (I,J)	I = number of output channels, J = LX + LF-1
S (I)	I = (N·N·5·LR) + (M·N·LR) + (M·N)
X1 (I,J)	I = number of input channels, J = length of data used
Z1 (I,J)	I = number of output channels, J = LZ1 = LX1
Y1 (I,J)	I = number of output channels, J = (LX1 + LF-1)

TABLE 3

CONTENT OF DATA INPUT CARDS FOR PROGRAM MAXLKH

1st card	Title of data, 1st 40 columns
2nd card	N,LX,M,LZ,LR,LW,FLOOR, ISKIP, NLENG
	format (6I5,F5.3,3I5)
3rd card	Data format, columns 1 to 80
4th card	Input data
Nth card	Final input data

ISKIP = Prediction Span = 150
Filter Length = 25
NLENG = Noise Sample = 750

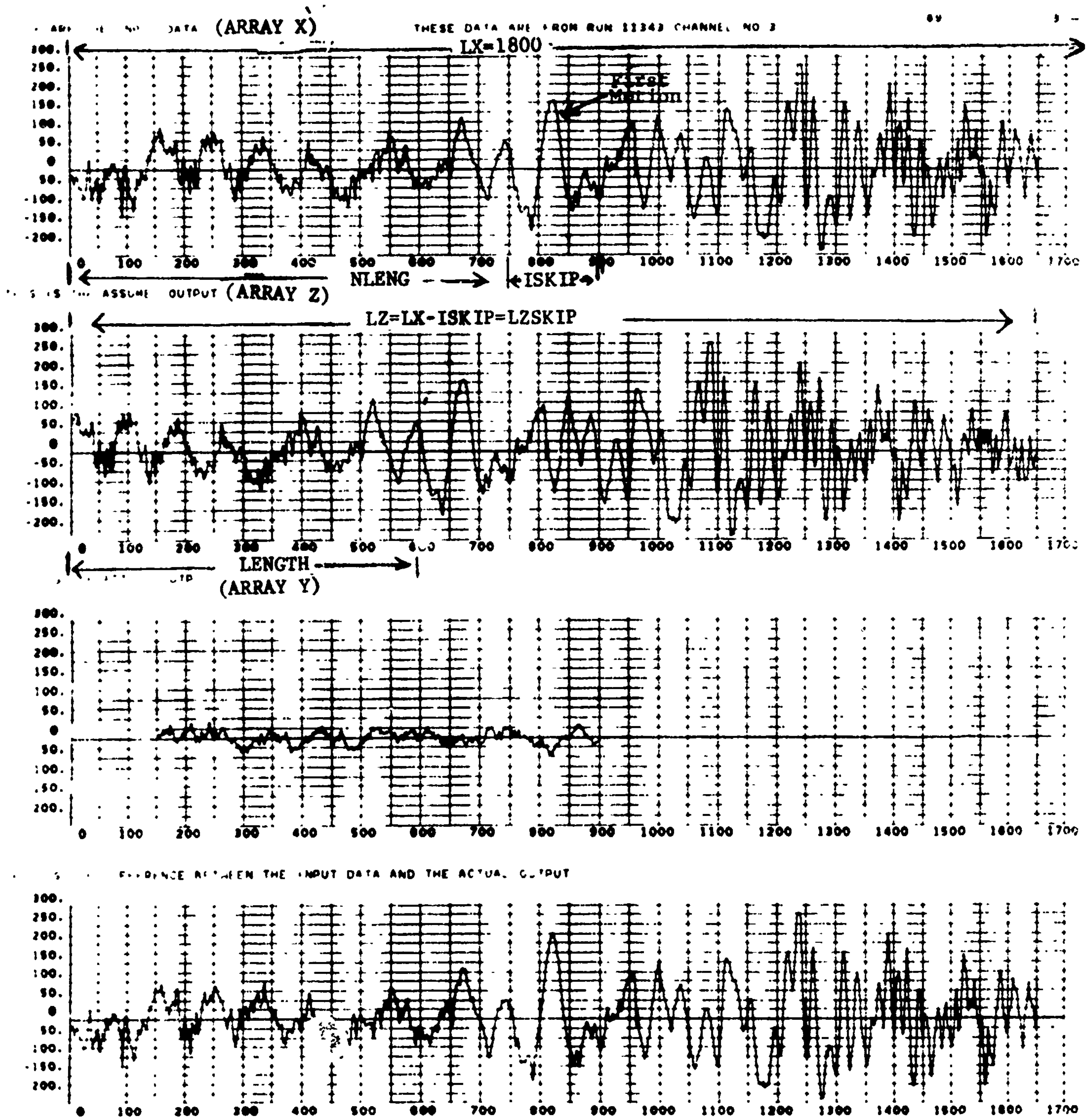


Figure 3a. Application of Program MAXLKH to Infrasonic Record 11343 Channel 3.

Prediction Span = 150
Filter Length = 25
Noise Sample = 750

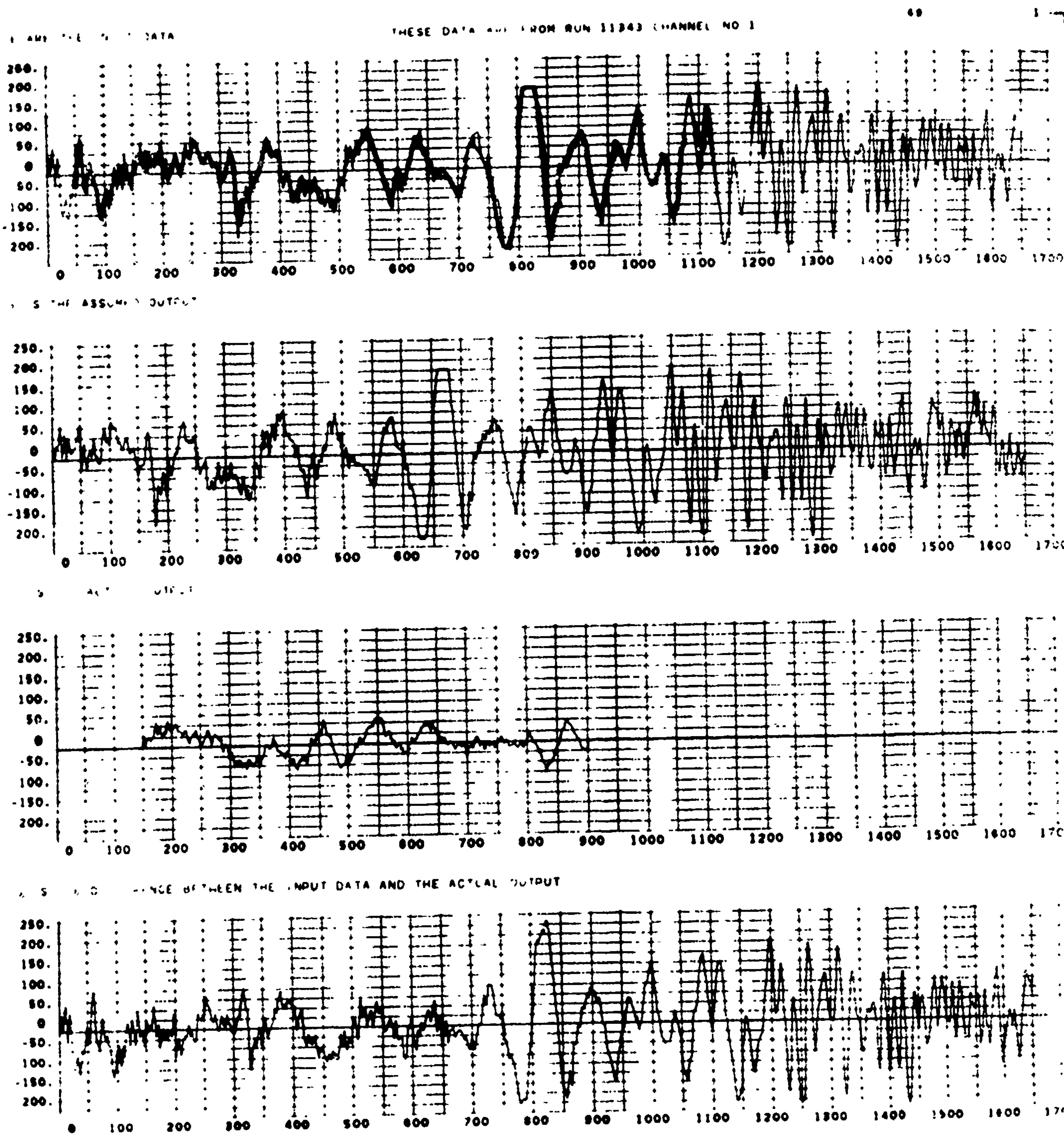


Figure 3b. Channel 1.

Seq. #5656AIL

Prediction Span = 150
Filter Length = 25
Noise Sample = 750

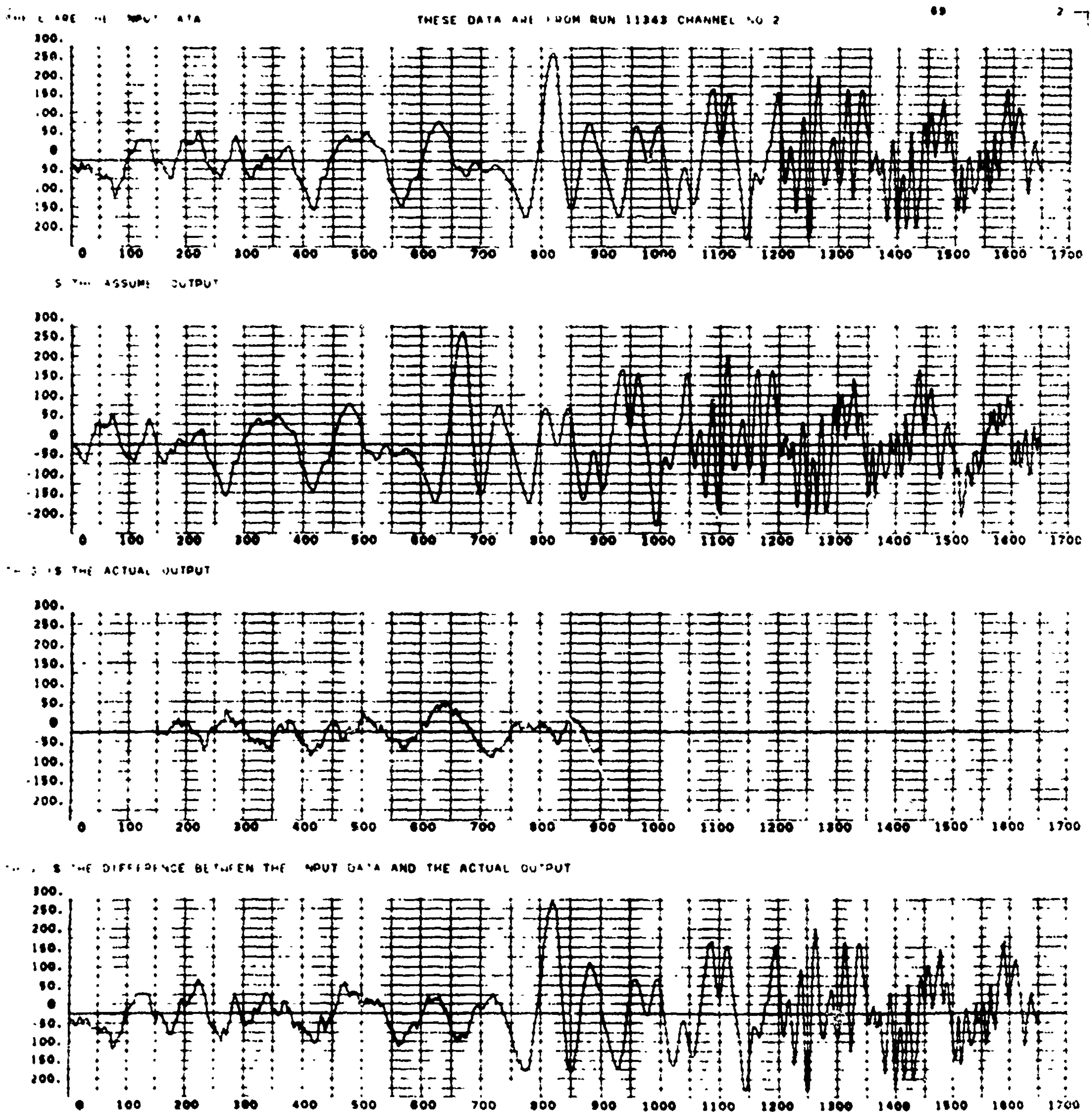


Figure 3c. Channel 2.

time series (x_t - y_t). This last time series represents the filtered time series and should have minimum noise prior to the event and enhanced first motion during the event.

Figure 3a also shows some of the variables used in the program. In this case, the prediction span (ISKIP) is 150 time units which covers the first motion and some additional oscillations. The total noise sample prior to the event has a length (NLENG) equal to 750 time units. However, since the prediction span is 150 units, not all of the total noise sample is available to derive the Wiener filter. After being shifted to the left 150 units, the length of noise sample actually used (LENGTH) in deriving the filter is 600 time units. These various lengths, plus several others, are illustrated in Figure 1a.

The success of the filter can be evaluated by comparing the input time series (top) with the filtered time series (bottom). For all three channels it can be seen that application of the filter has resulted in:

(1) A decrease in the noise prior to the event.

(2) An increase in the amplitude of the first motion.

The reduction of noise prior to the event makes the first motion easier to identify. The increase in amplitude of the first motion is presumably due to the fact that, in this case, noise had acted to reduce the amplitude of the first motion. The resulting first motion should thus represent an improved estimate of the signal prevailing at this time.

Application of the filtering technique to another set of infrasonic records is illustrated in Figure 4. In this case, the prediction span is somewhat shorter, 100 time units. Comparison of the filtered time series with the unfiltered series reveals a large reduction in noise prior to the event on all four channels. Presumably, there has been a comparable noise reduction during the time period covered by the first motion. Thus, the filtered time series should contain an improved estimate of the first motion.

If the filters worked perfectly, the first motions in the filtered time series would be identical on all channels. Since they are not perfect, the first motions differ somewhat. An improved estimate of the true value of the first motion can be obtained by averaging the individual filtered time series to obtain a mean value of the filtered time series during the first motion. This feature is not presently included in program MAXLKH, but can easily be added.

A last example of the application of program MAXLKH to infrasonic data is shown in Figure 5. In this case, no infrasonic signal is present

Seq. #5433ANI

Prediction Span = 100
Filter Length = 25
Noise Sample = 300

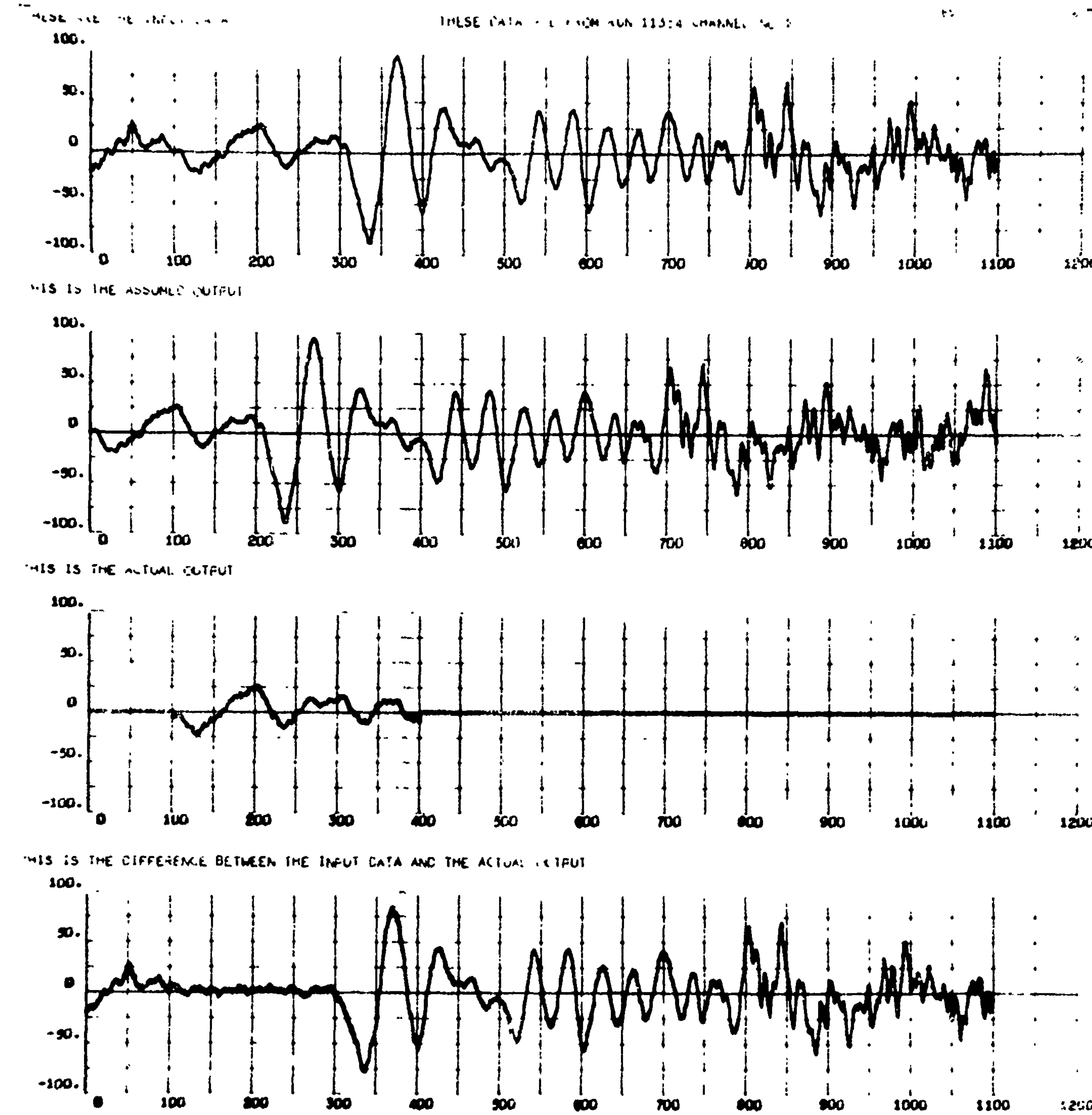


Figure 4a. Application of Program MAXLKH to Infrasonic Record 11354; Channel 1.

Prediction Span = 100
Filter Length = 25
Noise Sample = 300

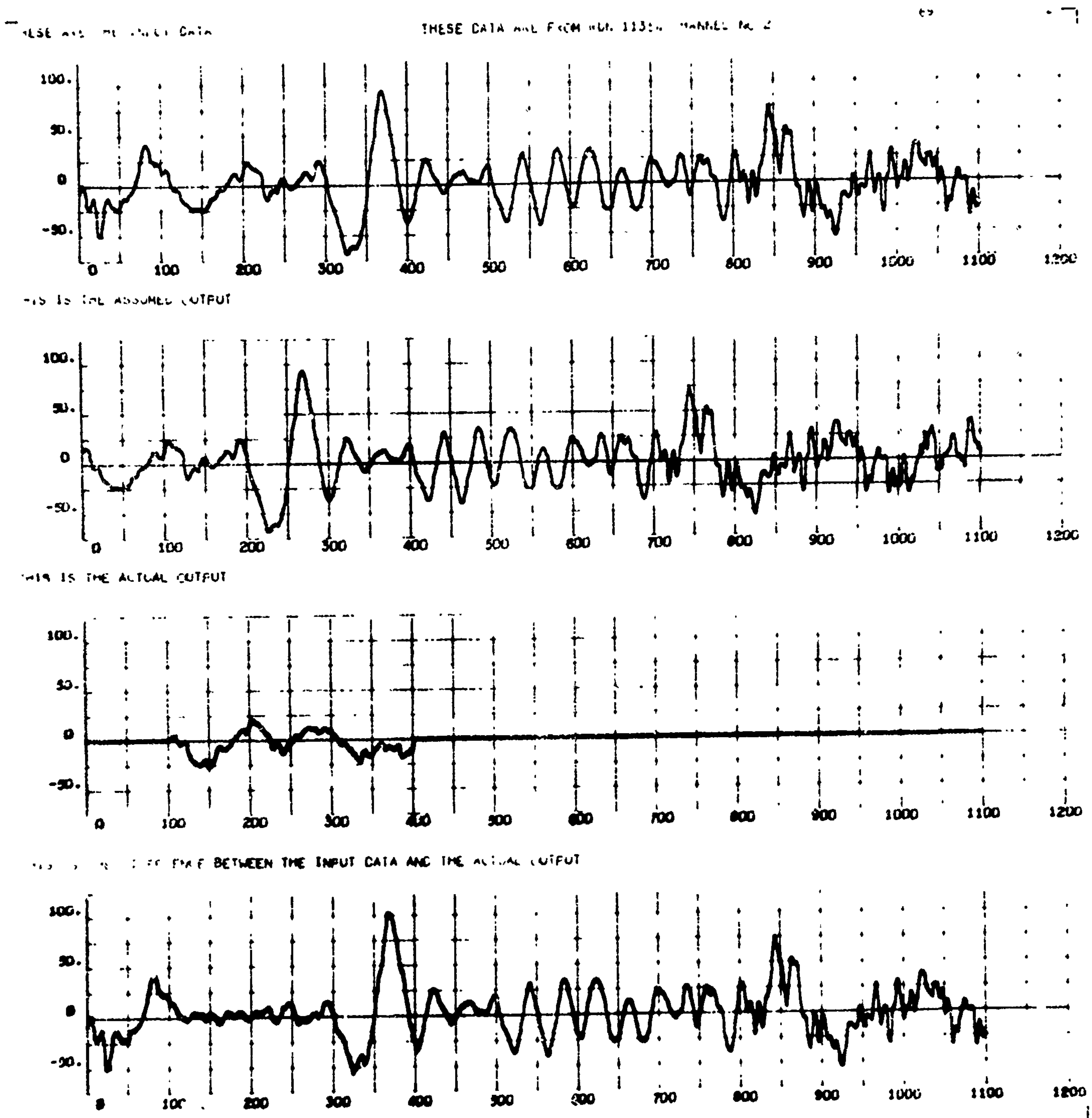


Figure 4b. Channel 2.

Seq. #5433ANI

Prediction Span = 100
Filter Length = 25
Noise Sample = 300

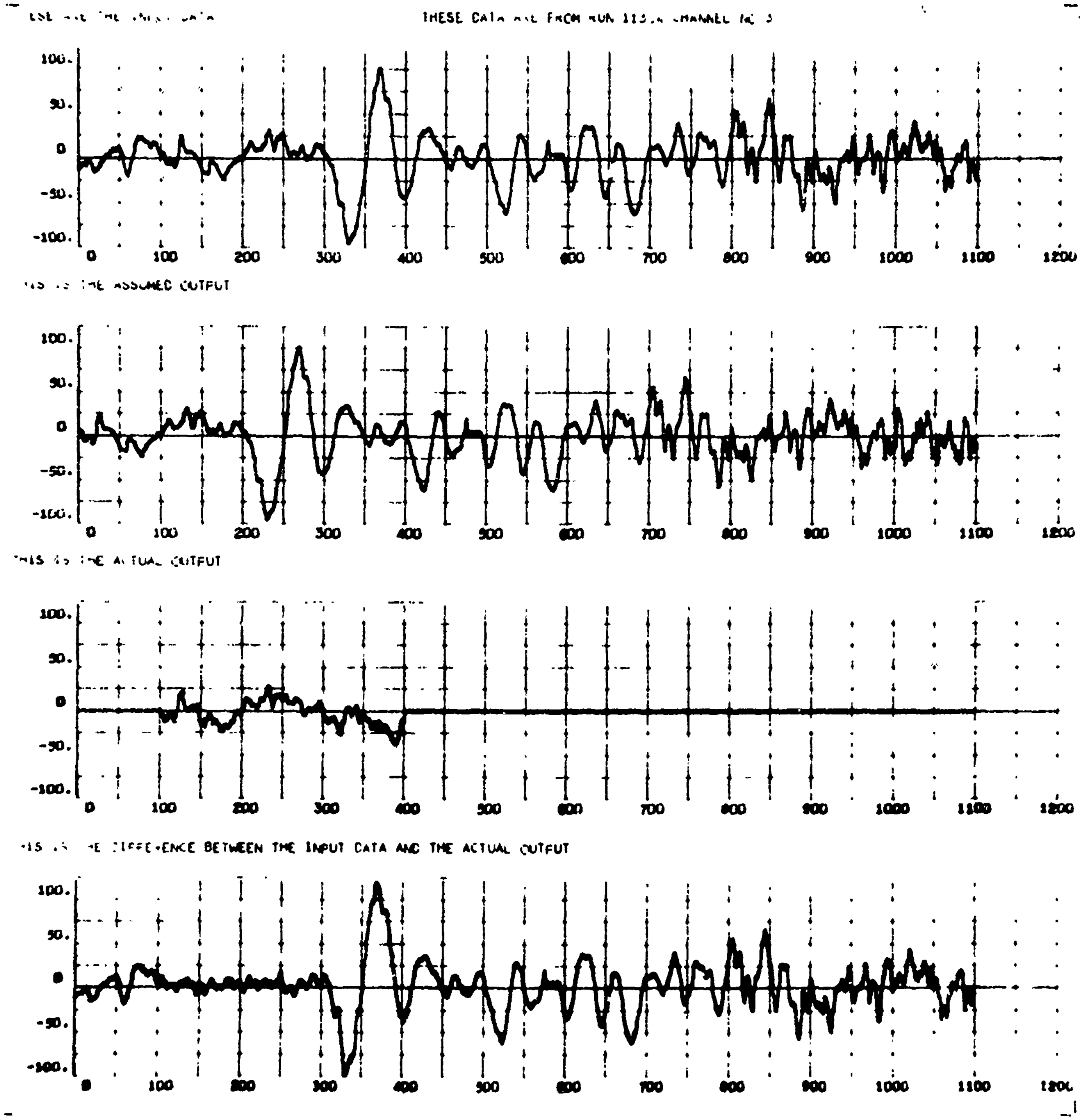


Figure 4c. Channel 3.

Prediction Span = 100
Filter Length = 25
Noise Sample = 300

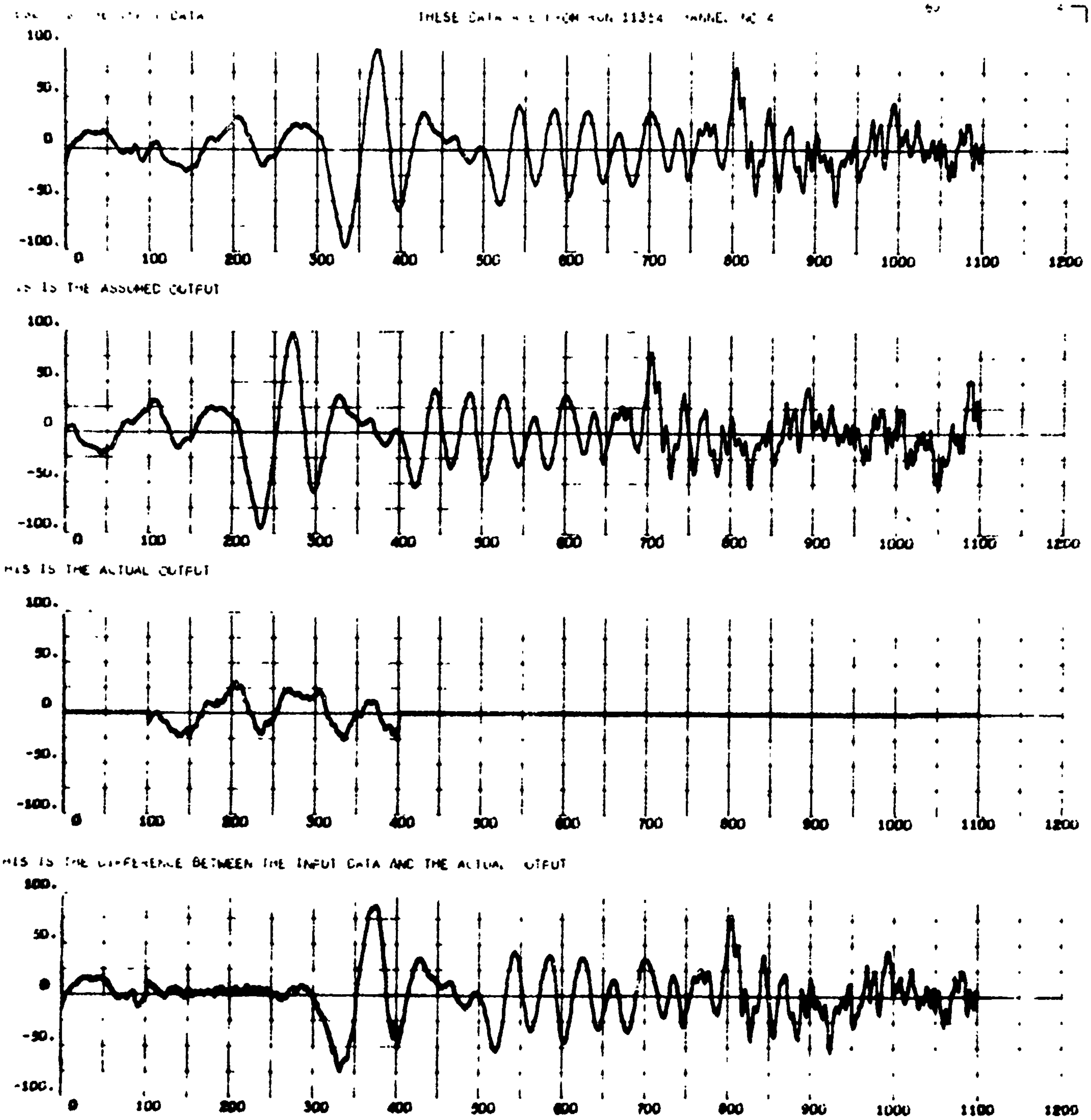


Figure 4d. Channel 4.

Prediction Span = 18
Filter Length = 18
Noise Sample = 160

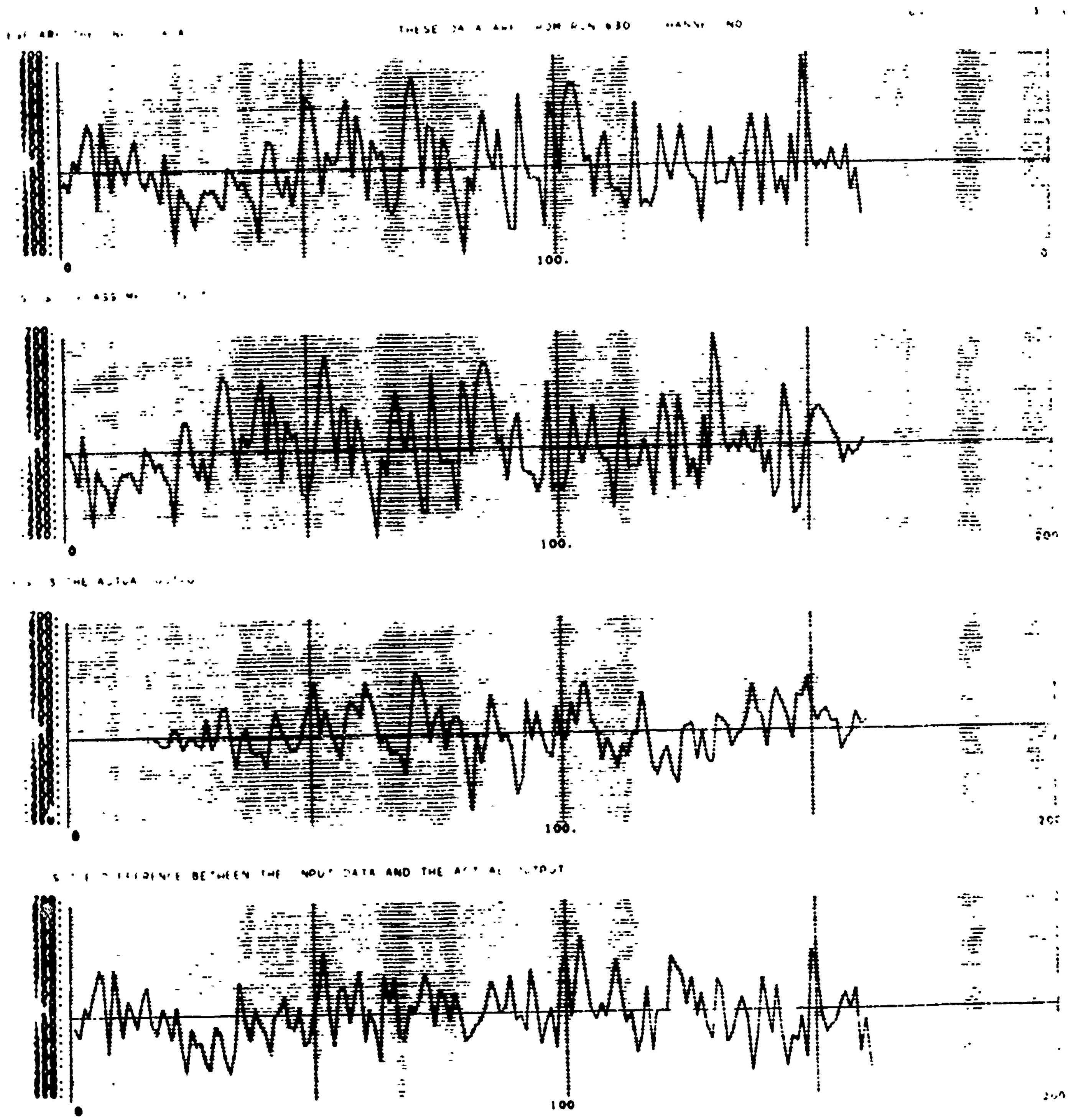


Figure 5a. Application of Program MAXLKH to Infrasonic Noise from Record 63010, Channel 1.

Prediction Span = 18
Filter Length = 18
Noise Sample = 160

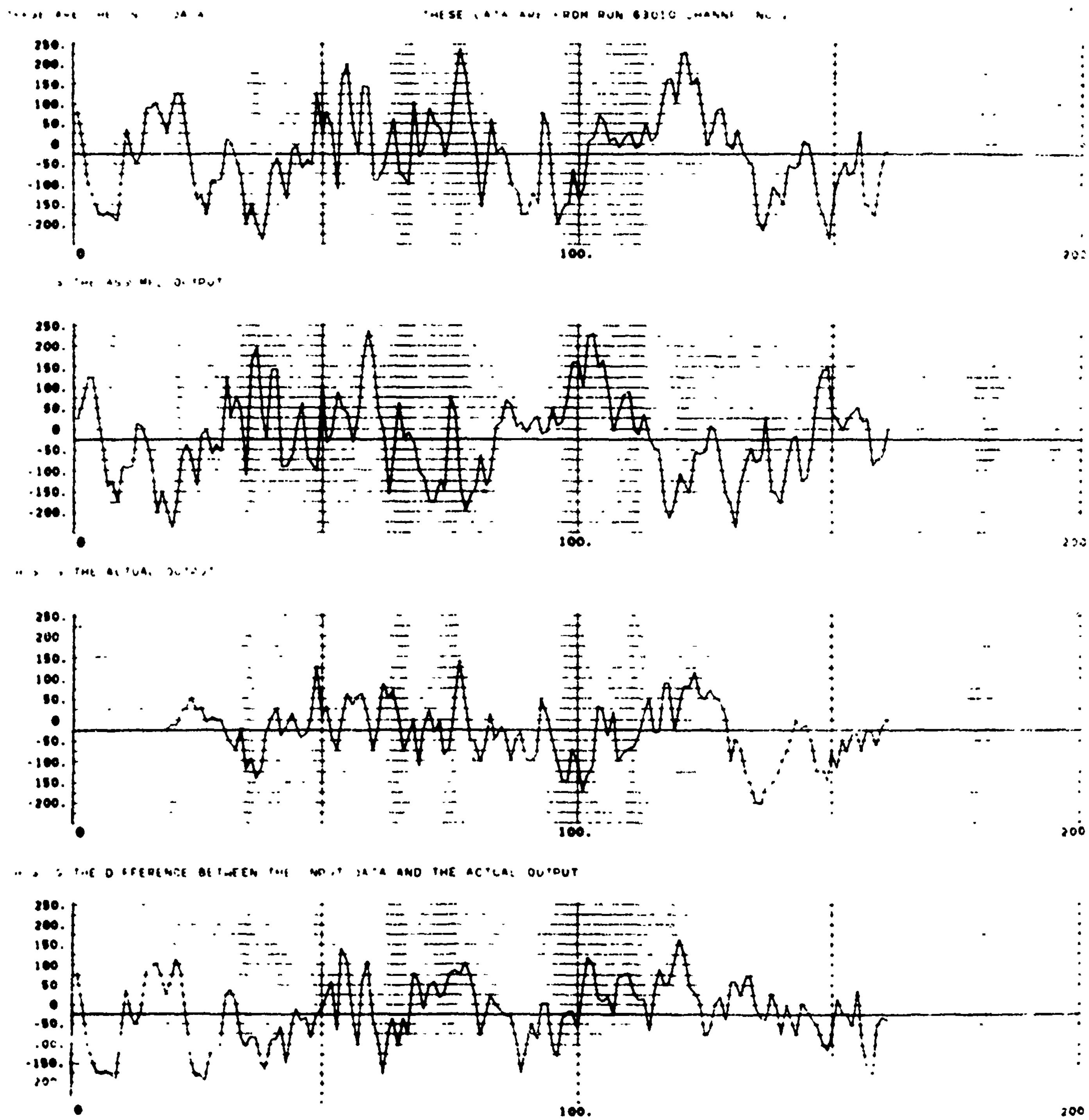


Figure 5b. Channel 2.

Prediction Span = 18
Filter Length = 18
Noise Sample = 160

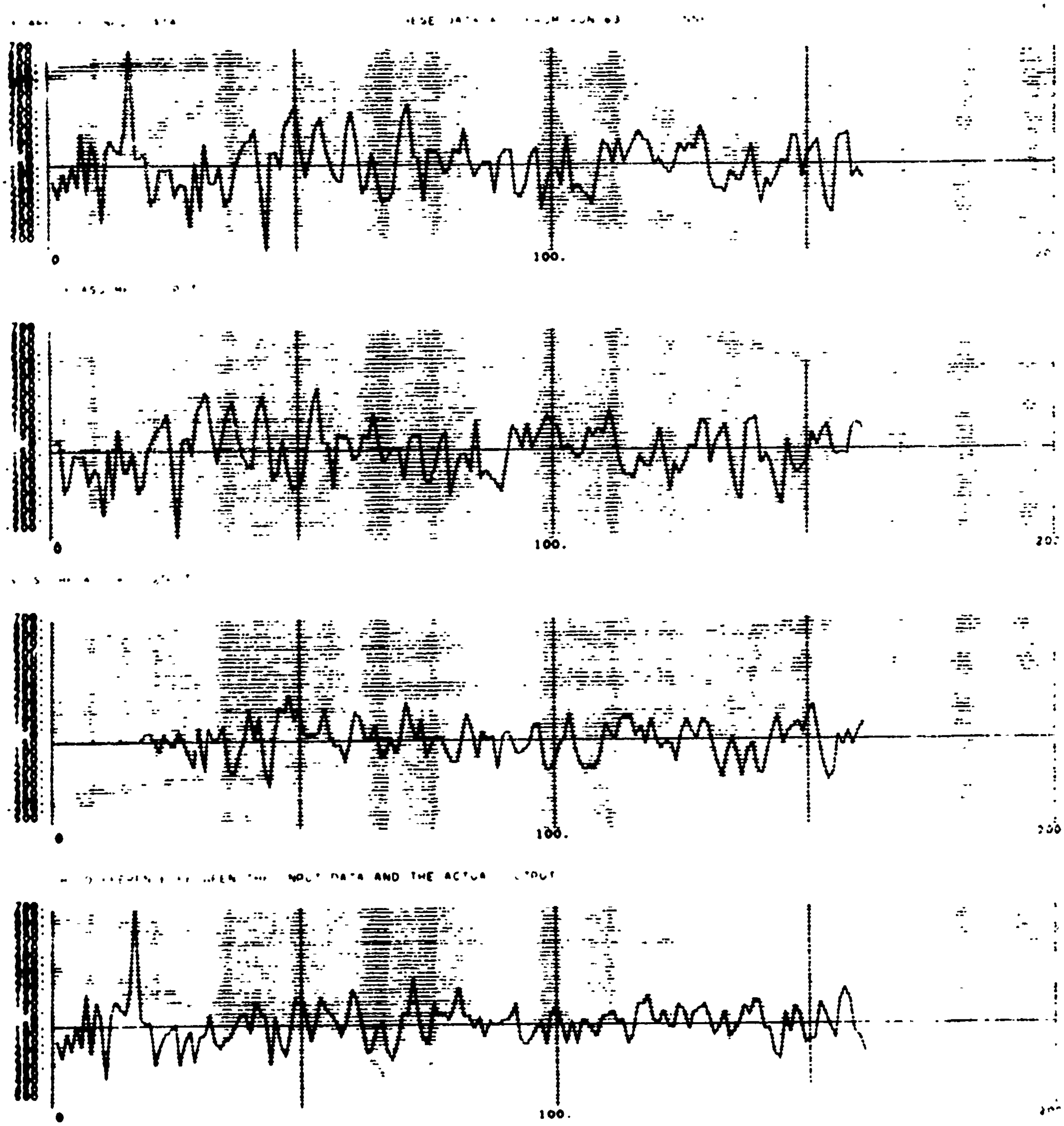


Figure 5c. Channel 3.

Prediction Span = 18
Filter Length = 18
Noise Sample = 160

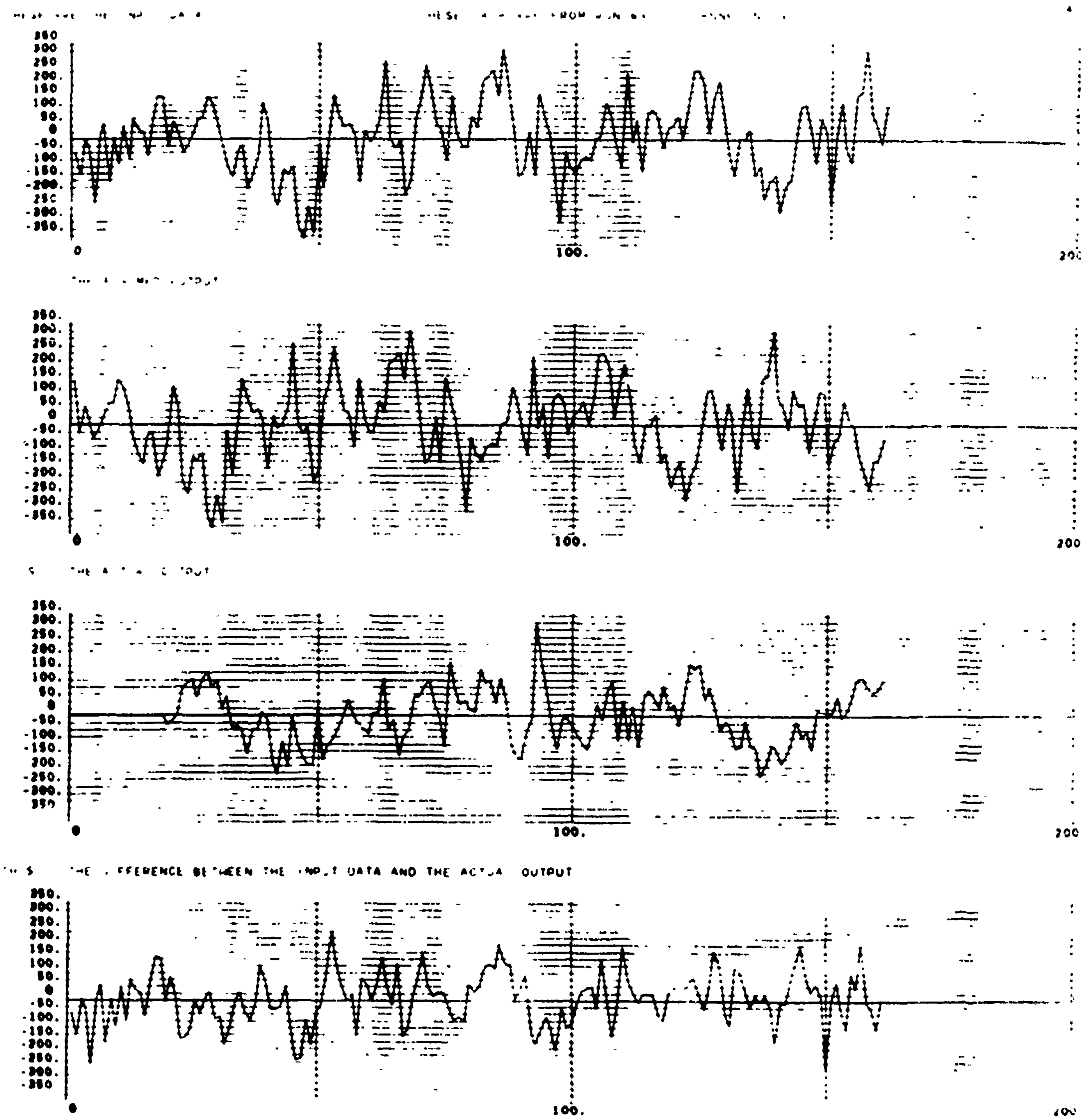


Figure 5d. Channel 4.

and the objective of the experiment is to determine how well a typical sample of noise can be predicted. The prediction span is short - 18 time units. A Wiener filter of length 18 is developed from this noise series, and is used to predict the noise. The predicted noise series are shown as the third graphs from the top in each part of Figure 4. When these predicted noise series are subtracted from the input noise series (top), one obtains the filtered times series (bottom). By comparing the bottom time series with the top time series, one can determine just how well the noise can be predicted. Perfect noise prediction would manifest itself by zeros in the bottom time series. Inspection of the graphs for all four channels reveals significant noise reduction for each channel. However, it is quite obvious that the noise prediction is far from perfect.

It would have been desirable to perform further experiments with the program. Unfortunately, because of the untimely termination of the contract this was not possible. Some suggestions for further work is contained in the conclusions and recommendations section.

IV. CONCLUSIONS AND RECOMMENDATIONS

The prediction-error filter technique appears to offer a promising means of digitally filtering infrasonic records to eliminate some of the unwanted noise and background. In this technique, a sample of the noise prior to an infrasonic signal is used to develop a Wiener prediction filter for predicting the noise during the first motion (first part of the event). Application of the filter to the original infrasonic record yields an estimate of the noise before and during the first motion. When this is subtracted from the original record, an improved estimate of the first motion is obtained. Results based upon application of such a filter to several sets of infrasonic records - including two samples containing infrasonic signals and one sample of pure noise - indicate that the noise does have some degree of predictability, and that a significant amount of noise reduction is accomplished by the filter. However, additional experiments are required to quantify how much of the noise is being suppressed and to determine optimum values for the parameters: filter length and prediction span. These experiments can best be performed on noise samples, since one can compare predicted and actual values of the noise. A sufficient number of experiments should be performed to cover the various types of noise and background that can occur in nature and to permit testing of various combinations of filter-length and prediction-span. It is also recommended that an averaging procedure be added to the technique. This would permit the averaging of the filtered time series from all the channels to obtain the best single estimate of the first motion.

The computer program MAXLKH that was developed under the contract to perform the filtering described above appears to be operating properly. Except for the modifications that would result from implementation of the recommended experiments, no changes are presently required in the program. It can be run on digitized sets of infrasonic data.

Unfortunately, because of the untimely termination of the contract, we were not able to pursue the other aspect of our research program - the empirical analysis of the relationship between the characteristics of a signal and the meteorological conditions prevailing along the path of propagation of the signal. It is recommended that such studies be undertaken in order to develop a technique for subtracting out the effect of the atmosphere on the propagation of an infrasonic signal. Once such a technique is developed, infrasonic records can be normalized to eliminate atmospheric propagation effects.

Once a technique for eliminating atmospheric propagation effects is developed, it can be combined with a noise suppression scheme to obtain an optimum estimate of the actual characteristics of the original infrasonic event. Implementation of the recommendations made above would help to achieve this goal.

ACKNOWLEDGEMENTS

Mr. Victor Corbin was responsible for writing the computer program and for providing the descriptive information on the computer program that is contained in this final report.

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