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# STUDY TO DETERMINE CLOUD MOTION FROM METEOROLOGICAL SATELLITE DATA

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The overall objective of this study was to test processing techniques for deducing cloud motion vectors from overlapped portions of pairs of pictures made from meteorological satellites.

This was accomplished by programming and testing techniques for estimating pattern motion by means of cross correlation analysis with emphasis placed upon identifying and reducing errors resulting from various factors. Techniques were then selected and incorporated into a cloud motion determination program which included a routine which would select and prepare sample array pairs from the preprocessed test data. The program was then subjected to limited testing with data samples selected from the Nimbus IV THIR data provided by the 11.5 micron channel.

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# PREFACE

The overall objective of this study was to test processing techniques for deducing cloud motion vectors from overlapped portions of pairs of pictures made from meteorological satellites.

The approach was to examine some previously developed computer programs, test them with artificial image pairs, evaluate their methods and prepare a procedure for deducing pattern motion. Experimental data would be selected from polar orbiting satellite experiments and routines developed to prepare that data in format for input to the motion computation procedure. Actual data samples would then be used to evaluate the procedure and it would be modified accordingly.

Highlights incorporated into the program were:

a. Suppression of spurious cross covariance products by bounding the window area with neutral values.

b. Replacement of missing data with noise.

c. Normalization of cross correlations according to scale.

d. Exclusion of data which while valid to the sensor constitute noise to the cloud motion computation.

The completed program was applied to the selected data samples with different parametric values to measure its derivation of motion estimates, timing requirements, and its limitations. Vector computations were compared to ground truth data obtained independently as well as to manually estimated motions from pseudo color photographic images.

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FIGURES

FIGURES - contd.

# Section 1

## PROJECT HISTORY

The investigation of means of deriving quantitative measures of atmospheric motion by IBM scientists began in 1964-1965 with ESSA Contract CWb 1098, entitled "Wind Shear Measurement by Satellite Cloud Tracking." This study, performed by N. Woodrick, L. Bodin, and J. Leese, analyzed the problem of obtaining vertical wind shear information from satellite observations of the motions of clouds relative to each other.

Subsequently, during 1967 and early 1968, two studies were internally funded by the IBM Federal Systems Division.

The first study featured analysis of real satellite arrays, performing spectrum analysis only, using the Fast Fourier Transform method. It was conducted by J. Leese, R. DePew, and B. Clark. The second study featured cross-correlation analysis of synthesized arrays using the lagged product method. This work was accomplished by B. Clark, J. Leese, and N. Woodrick.

During the remainder of 1968, work performed by B. Clark, C. Bevans, and J. Leese, resulted in the preparation of experimental computer programs to extract data in 64 x 64 arrays from ATS data tapes provided by the National Environmental Satellite Center and perform motion computations through cross-correlation analysis using the Fast Fourier Transform. Work performed by R. Stallard and P. Wrotenbery investigated the technique of applying Fourier Analysis and Covariance (or correlation) to cloud data.

Since 1969, when he joined the organization, the application of the techniques to ATS data has been continued by Dr. J. A. Leese and his associates at the National Environmental Satellite Service.

The current study, which is the subject of this report, is a NASA-funded effort which investigates the feasibility of using these techniques to obtain cloud motion using data from a polar orbiting satellite. The investigation has been performed by B. Clark of IBM with guidance and support from J. Greaves and W. Shenk of the NASA Goddard Space Flight Center.

The major portion of the study was the development of computer programs to determine the amount of cloud motion during the interval between two overlapping satellite images. Debugging and initial testing of programs was done with array pairs previously generated from other source data.

Early in the second quarter of 1971, upon instructions from the Technical Monitor, consideration was undertaken of the design of a comparative experiment in which the digital technique being investigated under this contract would be compared to another method of estimating cloud motion by means of optical cross-correlation analysis, both using ATS data. Further detail of this consideration appears in Appendix D.

The investigation deferred agreement upon the type of data to be used (see Appendix D) for technique evaluation as well as the design and development of the array composition routines and acquisition of ground truth data. In the third quarter (September 1971) the Technical Monitor decided that the remainder of the study should be conducted as originally planned insofar as the remaining resources permitted. It was agreed that NASA would select data samples and provide data tapes to IBM within the succeeding two weeks. The number of tape pairs to be provided and the expected density of data points would have given from 15 to 50 cases with about 9 array pairs for each case, a total of 135 to 450 array pairs, available by mid-October.

Twenty cases were selected and requested by the Technical Monitor in the form of Grid Print maps, pseudo color photographs, black and white prints and digital tapes. Tape was the form needed for the testing of the programs in the study; the other standard output forms assisted in verifying and interpreting the tapes.

The first five sample cases proved unsatisfactory. From them it was apparent, however, that the source data did not include sufficient raw observations to yield useful data for a scale of 1 to 1 million. Hence further requests were for 1 to 2 million which would provide only about 65 columns in the overlapped area. It developed that with this scale the maximum number of rows could be about 135 without excessive degradation except at two corners.

When it became apparent that the remaining 15 cases could not be ready by the end of the eleventh month (January 1972) of the performance period a three-month contract extension was requested and granted. In the extended period four sample cases had been furnished by the start of the last month, two of which would form only one array pair each and two which would form five array pairs (not all independent but each pair displaced sixteen rows from its predecessor). These were used to test the array forming routines and the array processing programs; some program modifications were made as a result of that testing. In the last month of this extended period four more sample cases were furnished and the remainder of the twenty cases originally selected were found unsatisfactory. These last four cases were tried on several computer runs each but proved unreadable. A subsequent investigation revealed that the tapes were essentially blank due to the failure of the NASA programs used for the tape writing.

A short extension of the performance period at slight added cost was then requested and granted. New versions of the last four sample cases, with extended latitudinal range, were received when work was resumed. The tapes were found readable and their data agreed with the data appearing on their corresponding grid print maps.

In the limited time remaining available for computer processing some testing was conducted using the eight sample sets. Details describing these eight samples appear in Appendix E. A summary of tests performed appears in Appendix G while sample output results are included in Appendix H.

It became apparent as is further described in Sections 5 and 6 that for THIR (and probably HRIR) data the applications of this technique to polar orbiting satellite data is impractical due to the difficulty of obtaining sample image pairs containing useful data.

## Section 2

## SOME BASIC THEORY

Two basic theoretical considerations in this study are the concept of cross correlation and the relation of cloud top temperature (or equivalent black body temperature) to cloud top height.

### 2.1 The Cross Correlation Concept

Two dimensional cross correlation provides the basis for the algorithm used to estimate motion which has occurred between two image arrays observed at different times over the same geographic area.

Let $x_t$ denote the individual elements of a set X of measurements of some physical parameter and let the symbol $E[\overline{Y}]$ mean the "expected value of $\overline{Y}$". If the probability distribution $f_X(x)$ associated with the measurements is normal (Gaussian) it can be completely characterized by its mean

$$\mu = E[X] = \int_{-\infty}^{\infty} x f_X(x)\, dx$$

and its variance

$$\sigma^2 = E[(X-\mu)^2] = \int_{-\infty}^{\infty} (x-\mu)^2 f_X(x)\, dx.$$

Then only for a purely random series will neighboring values be independent. In general, neighboring values of a time series will be correlated. Hence, in addition to specifying the mean and variance it is necessary in the case of a stationary normal series to specify its autocovariance function. For a specified lag $\lambda$ this may be expressed as:

$$C(\lambda) = E[(X(t) - \mu) \cdot (X(t+\lambda) - \mu)]$$

$$= \int_{-\infty}^{\infty} (x_t - \mu)(x_{t+\lambda} - \mu) \; f_X(x) \, dx$$

In practice $C(\lambda)$ can be estimated by

$$C(\lambda) = \frac{1}{N} \sum_{t=1}^{N-\lambda} (x_t - \bar{x})(x_{t+\lambda} - \bar{x})$$

where

$$\bar{x} = \frac{1}{N} \sum_{t=1}^{N} x_t .$$

When two processes, say $W_1$ and $W_2$ are being studied it is possible that they have different scales or different variances. In this case we define the cross-correlation function for equal sized (say M-element) sets of elements from $W_1$ and $W_2$ as

$$R_{12}(\lambda) = \frac{C(\lambda)}{\sigma_1 \sigma_2}$$

where $C(\lambda) = \frac{1}{M} \sum_{t=1}^{m-\lambda} \left(w_{1_t} - \bar{w}_1\right)\left(w_{2_{t+\lambda}} - \bar{w}_2\right)$

and $\sigma_1$ and $\sigma_2$ denote the standard deviations of the two processes.

The essential features of two-dimensional cross-correlation are shown graphically in Figure 2-1. The input array consists of data values over an area for two different time periods as depicted by $X_0$ and $X_t$ in (a) of Figure 2.1. Cross-correlation coefficients are computed for different lag values of $X_t$ upon $X_0$. The value at lag (p, q) is given by

$$R(p, q) = \frac{\mathrm{Cov}(p, q)}{\sigma_{X_0} \sigma_{X_t}}$$

where R (p, q) is the cross-correlation coefficient at lag values p and q in the P and Q directions, respectively,

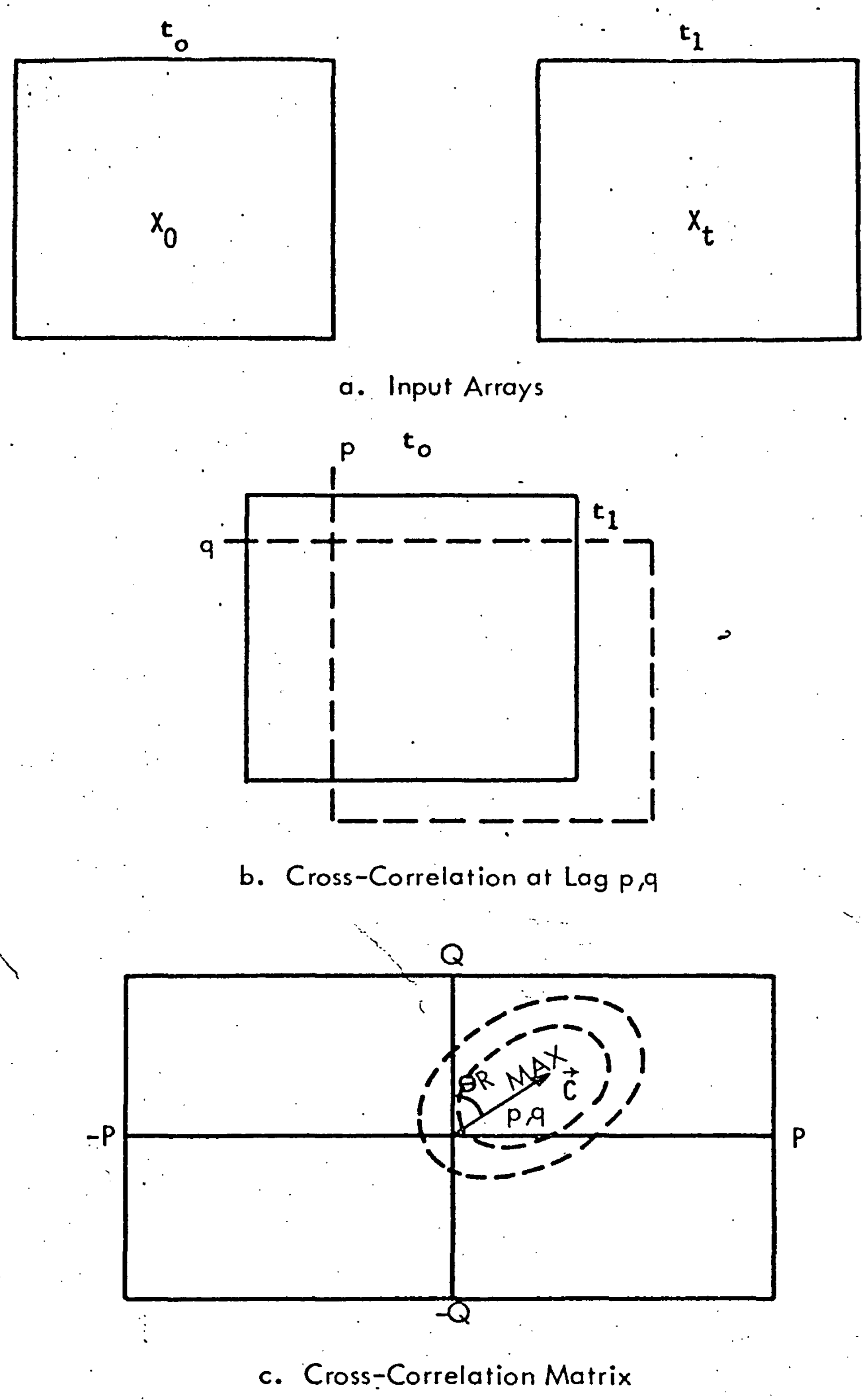


Figure 2.1 Graphical Representation of Two-Dimensional Cross-Correlation

Cov (p, q) is the covariance at lags p and q, and

$\sigma_{X_0}$ and $\sigma_{X_t}$ are the standard deviations of the input arrays $X_0$ and $X_t$ respectively.

The coefficients are determined over the limits

$$-P \leq p \leq P$$

$$-Q \leq q \leq Q$$

as shown in (c) of Figure 2-1. The limits of P and Q are a function of the particular problem and need not be symmetric in any direction.

The locations of the maximum values in the cross-correlation matrix are related to the cloud motion in the following manner:

$$|\vec{C}| = \frac{[(p'\Delta x)^2 + (q'\Delta y)^2]}{\Delta t}$$

$$= \tan^{-1} \frac{p'\Delta x}{q'\Delta y}$$

where

$|\vec{C}|$ is the speed of motion,

$\theta$ is the direction of motion,

p' and q' are the locations of the maximum in the correlation matrix

$\Delta x$ and $\Delta y$ are the finite sampling intervals for the input arrays in the x and y directions respectively.

$\Delta t$ is the time interval between the two pictures.

Some supporting derivations may be found in Appendix I.

## 2.2 The Relation of Cloud Top Temperature to Height

The image data used in this study consists of radiometric observations derived from the 10.5 - 12.5 micron window channel of the two channel high resolution scanning radiometer used in the Nimbus IV Temperature-Humidity Infrared Radiometer Experiment. Based upon the sensor calibration the radiance measurements have been converted to measures of equivalent black body temperature expressed in degrees K. The digital information is provided in this format, representing day or night cloud top or surface temperatures. These values of equivalent black body temperature have also been converted separately to units of grey scale which in turn have been displayed as black and white photographic images. In some cases the temperatures have been expressed in a more detailed color coded form as colored photographic images.

In using equivalent black body temperature data to represent images in which clouds may be embedded, it must be recognized that:

1. the temperature-height relationship is not biunique,

2. there can be considerable overlap in temperatures which might be observed at cloud tops, snow, ice, land or water surfaces.

## Section 3

## DATA FLOW

The capability used in deriving cloud motion estimates is made up of several elements which were not all active concurrently during the course of this study. The description of the capability is therefore presented by the identification of the various elements followed by an indication, through the flow of data and of manual and machine aided functions, of how these elements contribute to the study procedure.

### 3.1 Elements of the Cloud Motion Study Capability

1. The Nimbus IV Satellite

The Satellite was designed to be placed in an orbit which would be circular at 600 nautical miles, sun-synchronous having a local high noon equator crossing and an 81 degree retrograde inclination. Successive orbits would cross the equator at 26 degrees of longitude separation and the period would be about 107 minutes. It was launched successfully into a near circular orbit (at 587 x 593 nautical miles) on April 8, 1970. There were 10 meteorological experiments included in the spacecraft configuration. Details of the objectives and design characteristics of the Nimbus IV Spacecraft System appear in the Nimbus IV User's Guide.

2. Temperature Humidity Infrared Radiometer (THIR) Subsystem

The THIR Subsystem may be subdivided into three parts:

(1) The on-board portion which in turn is made up of the two channel high resolution scanning radiometer, the High Data Rate Storage Subsystem (HDRSS), and the Real Time Transmission Subsystem (RTTS). The HDRSS and the RTTS are shared with other experiments.

(2) The ground based data collection portion where the THIR information is demultiplexed and recorded on magnetic tape. This is part of the Data Acquisition Facility (DAF).

(3) The ground based data processing portion where the signal is demodulated, synchronized and recorded both as film strip and in digitized form on magnetic tape. This is part of the Nimbus Data Handling Facility (NDHF) located at Goddard Space Flight Center.

Details concerning the THIR Subsystem are included in the Nimbus IV User's Guide and the volumes of the Nimbus IV Data Catalog. Some extracted information is also included in Appendix A.

3. The NASA-Goddard Space Flight Center capability to prepare selected Nimbus IV sample data in the form of standard output products suitable for subsequent processing in the study. This involved both manual interpretation and selection procedures, the GSFC computing facility and certain computer programs. The sample selection was performed manually by the contract Technical Monitor based upon film strips and related data. The standard form reduced radiation data tape called the Nimbus Meteorological Radiation Tape - THIR, abbreviated NMRT-THIR, was or had been generated on the IBM System/360 computer using routine procedures. The NMRT-THIR for each data sample was processed by NASA and contractor personnel using three programs.

(1) The Nimbus HRIR Mapping program (NHM) which converts the digital data for a Mercator grid map. The Nimbus HRIR and THIR formats for the grid map are identical. The grid map is produced on a printer and the line images and related information are also output as unformatted FORTRAN records on a magnetic tape.

(2) The Pseudo Color Input Tape Generation Program (PCITG) which generates a magnetic tape copy of the mercator data set placed on disk by the grid print mapping program NHM.

(3) The Pseudo Color Mercator Mapping Program (PCMM) which produces a magnetic tape in a format compatible with color photograph facsimile equipment to generate a pseudo-color mercator projection map of the THIR data.

4. The cloud motion programs are also operated at the Goddard Space Flight Center computing facility under the sponsorship of the Technical Monitor. The first of these is an array formation program which reads data from two grid print output tapes, selects the desired records, organizes their data into subarrays and collates these for the two data times into array pair records on a single tape. The second is an array processing program which performs cross correlation analysis and determines estimated vectors represented pattern motion.

5. The investigation function is performed by the Principal Investigator with guidance from the Technical Monitor. Results are compared to weather data obtained through the National Oceanographic and Atmospheric Administration (NOAA), estimated vectors are interpreted, and overall study results are evaluated by the investigator.

## 3.2 Flow Through the Elements of the Study

The elements of the Cloud Motion Study procedure have been combined into a single diagram in Figure 3-1. The organization of the diagram presents the distribution of functions between these elements and suggests the routing of data through the major processing steps. Two diagrams from the Nimbus IV User's Guide provide more detail of the THIR Subsystem. Figure 3-2 shows the interrelation between the three portions of the subsystem in a simplified block diagram. Figure 3-3 further delineates the conversion from analog to digital data which is presented as a function of the Nimbus Data Handling Facility as well as the preparation of the NMRT-THIR tape which is the source of data for the Nimbus HRIR Mapping program.

In Figures 3-4 , 3-5 and 3-6 are shown the broad functional flow through the Array Formation and Array Processing programs developed during the study. These two programs are combined with a control program in the study to fit the polar orbiting type THIR data which was selected for the study. While the Array Processing program is generally adaptable to processing of pairs of rectangular arrays, the Array Formation Program and the Control Program which combine the two are dimensioned to fit the particular data used.

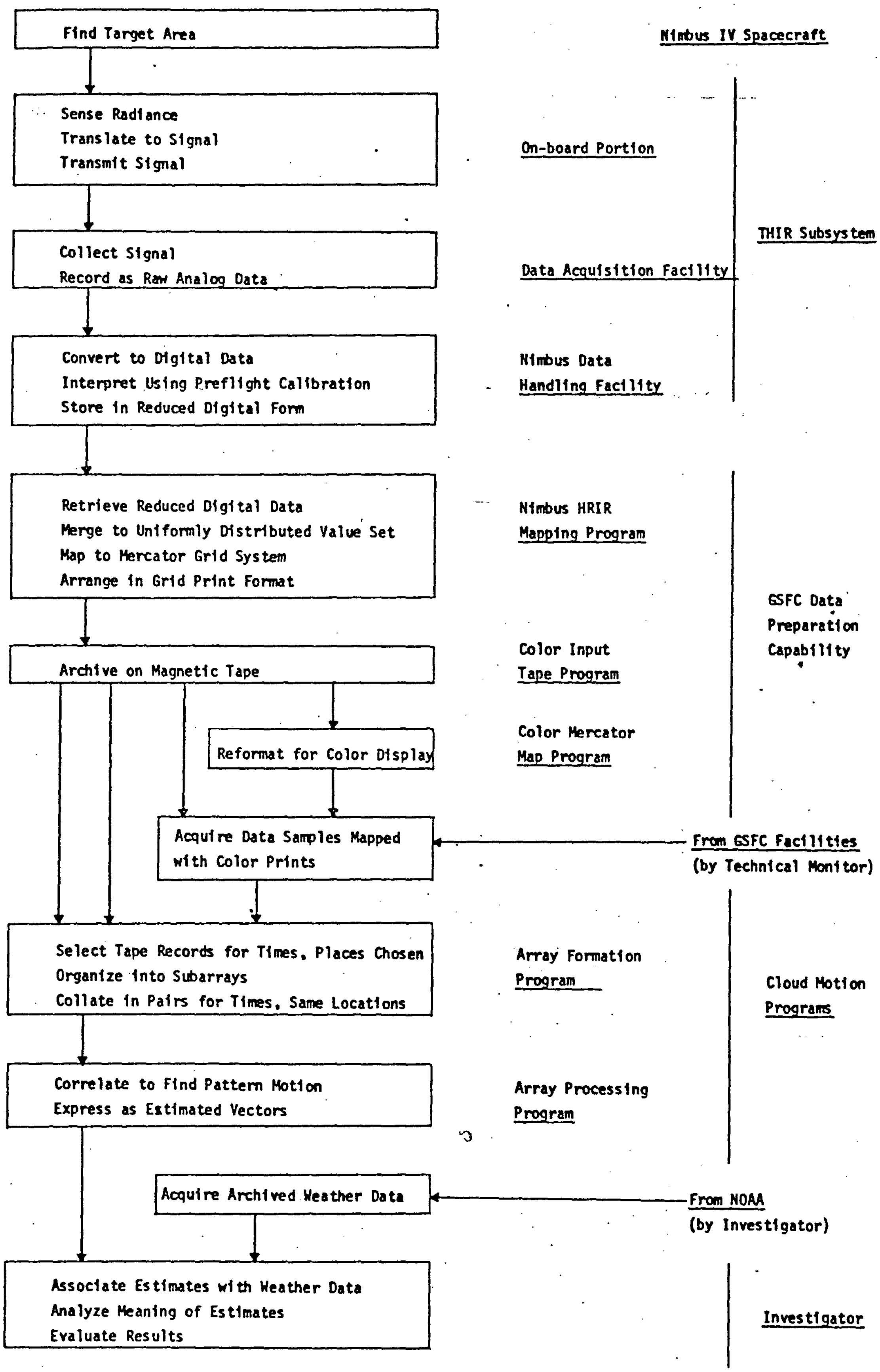


Figure 3-1. BROAD DATA AND FUNCTIONAL FLOW FOR STUDY

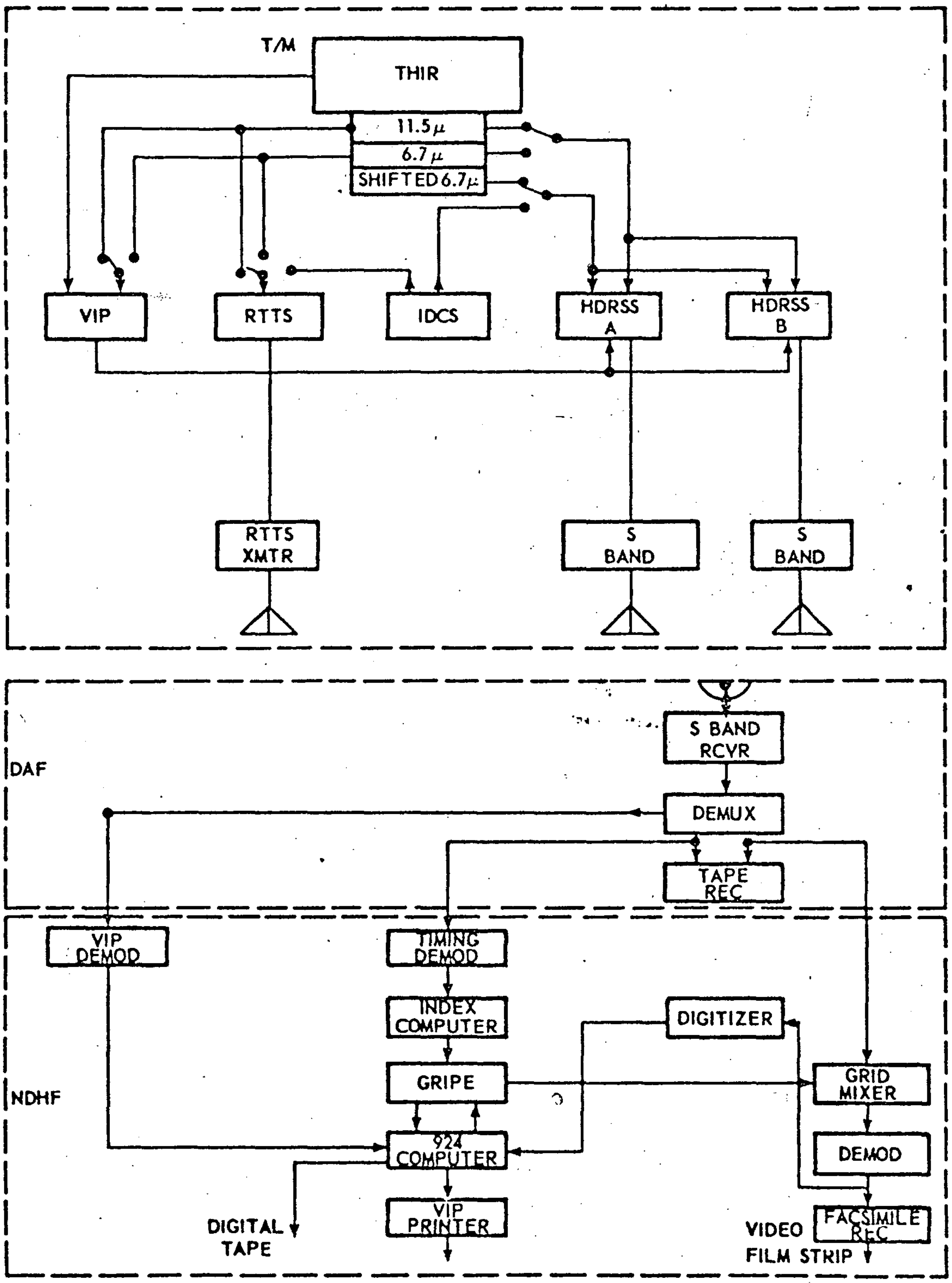


Figure 3-2. Simplified Block Diagram of the THIR Subsystem
(From Nimbus IV User's Guide)

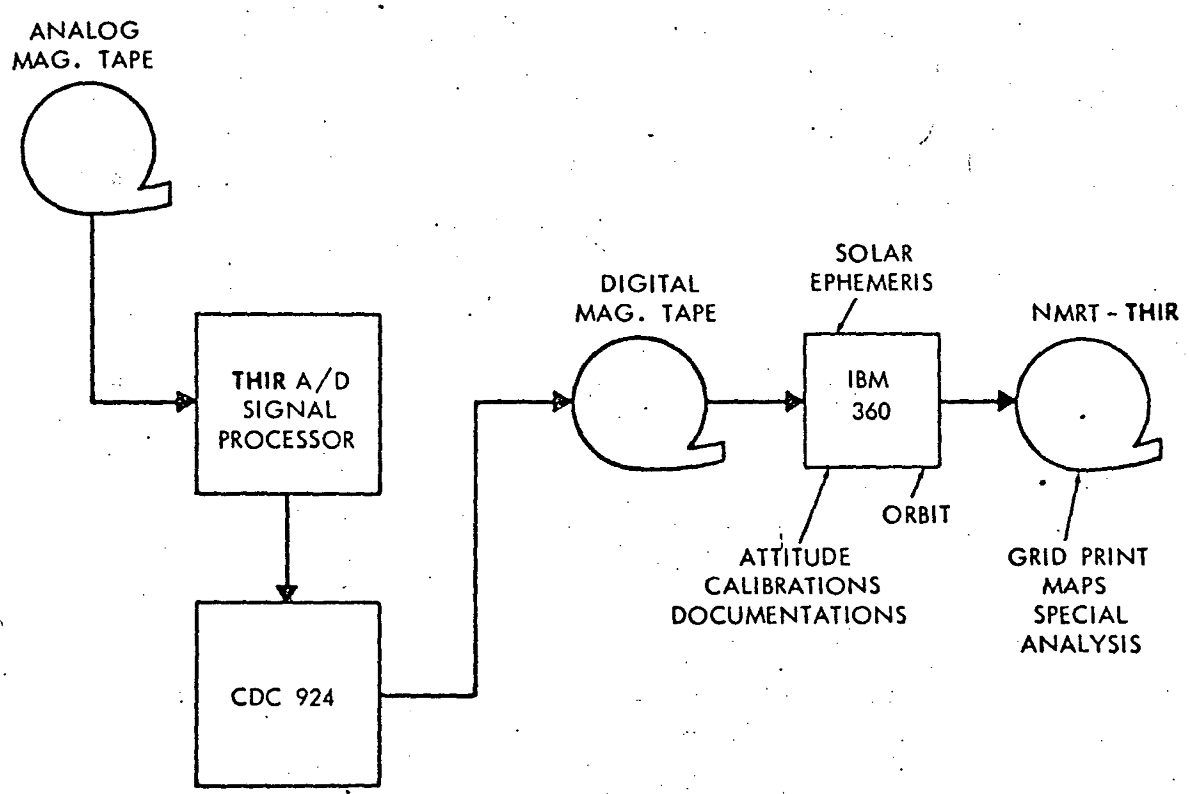


Figure 3-3. Simplified Block Diagram of the A/D Processing System
(From Nimbus IV User's Guide)

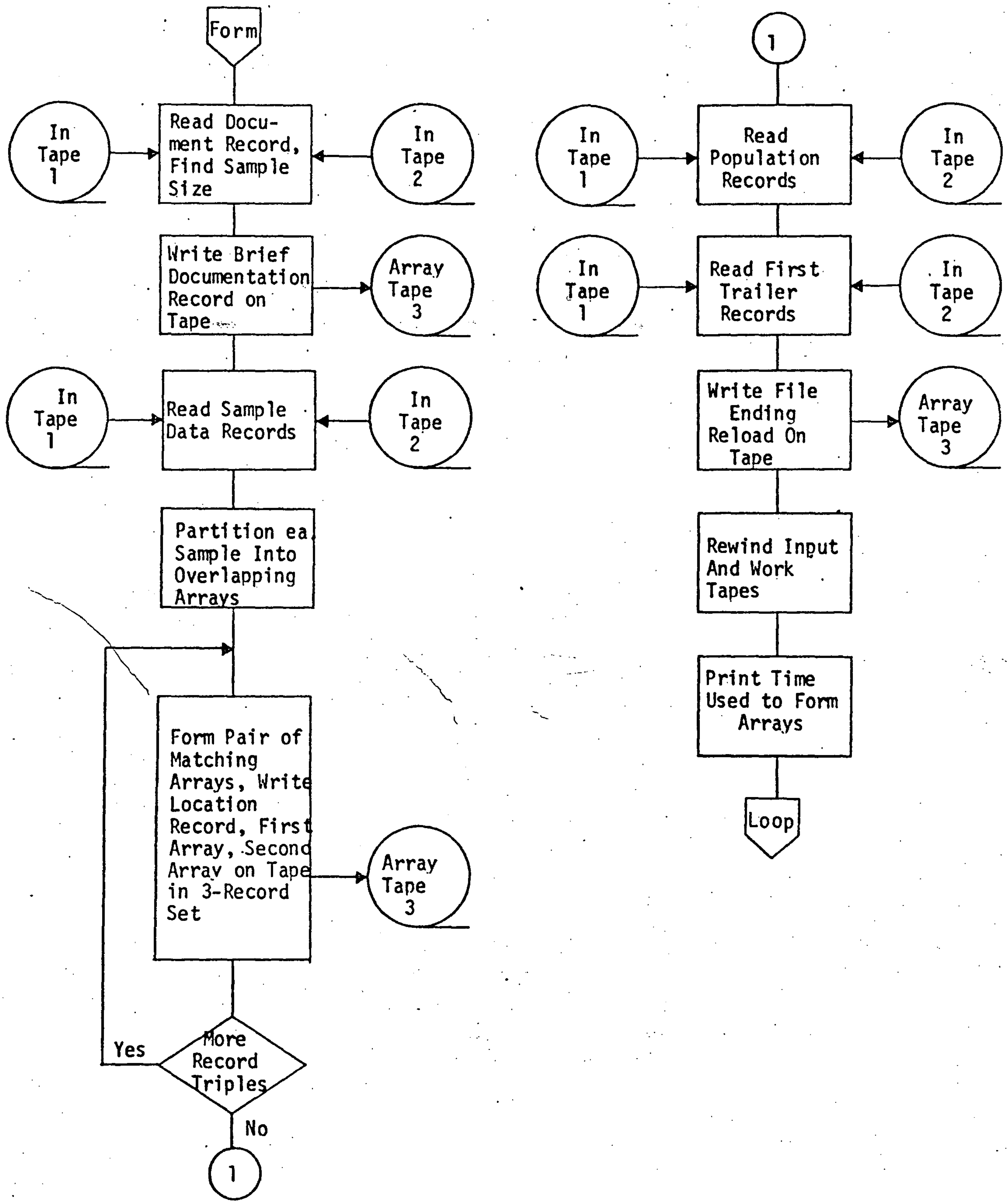


Figure 3-4. ARRAY FORMATION PROGRAM FLOW

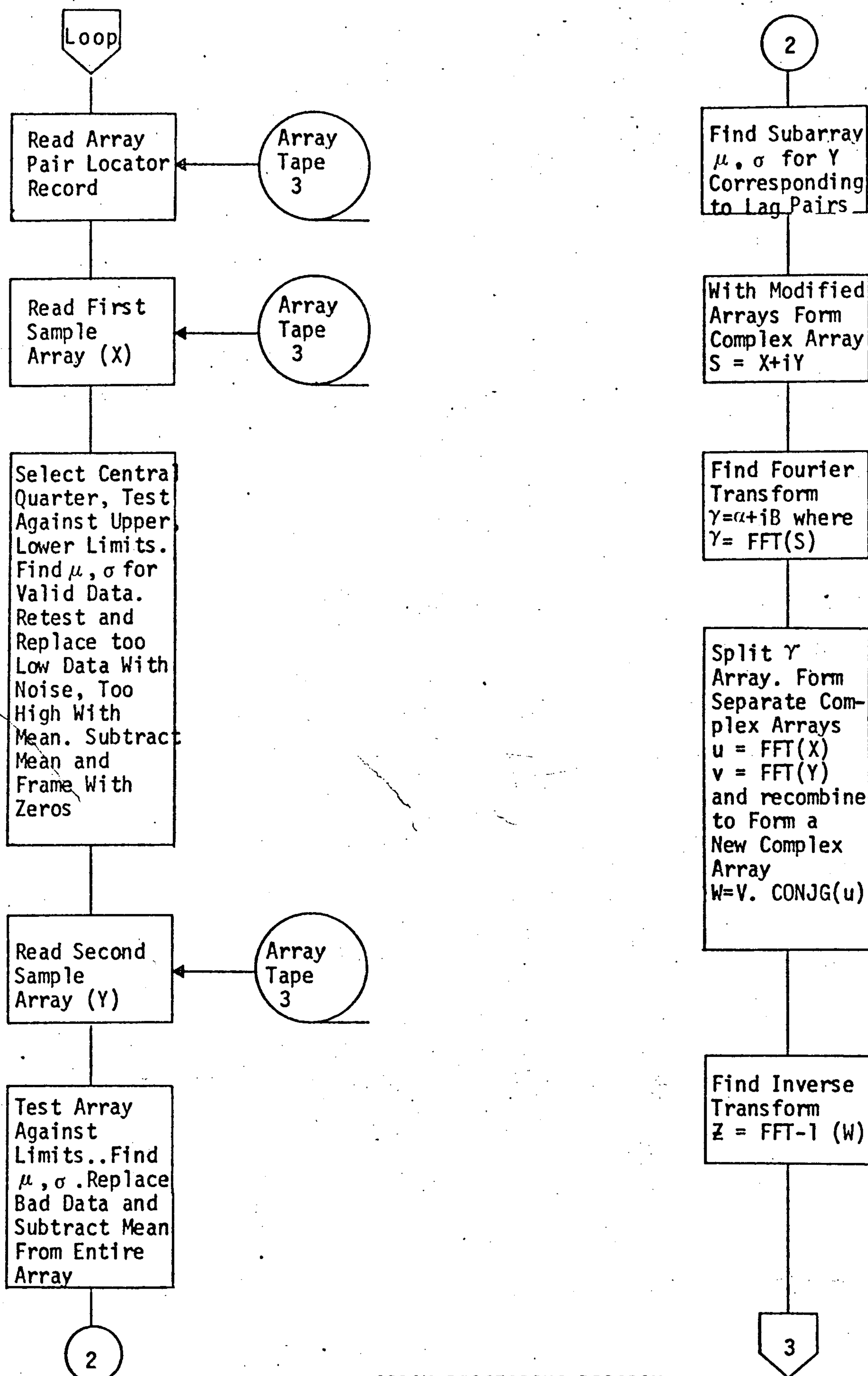


Figure 3-5. ARRAY PROCESSING PROGRAM, Part 1

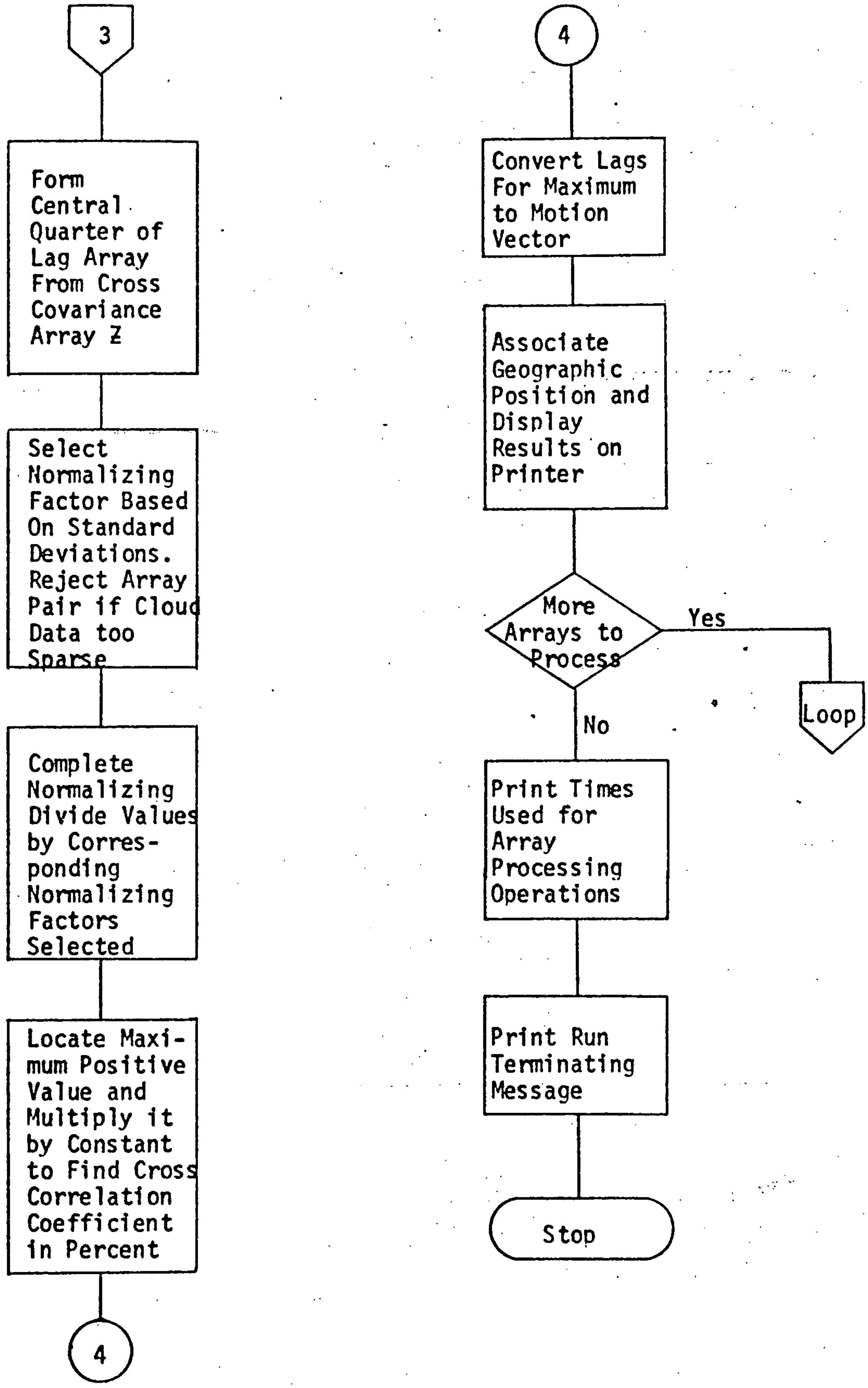


Figure 3-6. ARRAY PROCESSING PROGRAM, Part 2

## Section 4

## IMPLEMENTATION

The overall approach to the study included the selection of several previously developed computer programs, some incomplete, testing them with artificial image pairs, evaluating their various approaches and evolving therefrom a single procedure for deducing pattern motion. A type of experimental data was to be selected from polar orbiting satellite experiments and the necessary routines developed to prepare that data in format suitable for input to the motion computation procedure. Actual data samples would then be used to evaluate the procedure and it would be modified accordingly. If resources permitted, statistical experimentation would then be undertaken using a larger sample of data.

### 4.1 Initial Technique Development

Three experimental programs developed within IBM to compute pattern motion for meteorological satellite data had been used at three IBM System/360 Model 50 computer installations which used different compilers and operating systems. Other programs provided by Dr. J. A. Leese and Mr. C. S. Novak of the National Environmental Satellite Service (NESS) had been used at their Control Data Corporation system 6600 installation which, due to the different word length of the machine, had a slightly different language. All programs had been written in FORTRAN IV. The three IBM programs were adjusted to the Goddard Space Flight Center computer system and debugged. One of the NESS programs was converted to the IBM System/360 FORTRAN IV language and executed with data samples which were provided with them.

The three IBM programs had been designed to serve distinct purposes:

1. The first was to test the Fast Fourier Transform method of cross-correlation computation using small synthesized arrays.

2. The second was a streamlined program which would perform only those functions necessary to derive a pattern motion vector and print a minimum amount of information.

3. The third was a more general program which would perform both cross-correlation and spectrum analysis and offer a more comprehensive printing capability.

The first program was intended to test only the essential features which would be needed in the array processing program. Prewhitening of arrays before power spectrum computation, smoothing of the cross transform array before computing the cross-covariance, and filtering for selected wave numbers were not included as candidate functions. Inputs were constructed as 16 x 16 complex word arrays and a simple standard output format was used. Arrays were bounded with uniform strips equal to the array mean, wide enough to permit the assigned motion without loss of points whose value differed from the mean, and elements vacated during motion were reset equal to the mean.

Features of the program were:

a. Constructed one of five types of initial array and moved this with the specified vector to produce a second array.

b. Transformed each array and computed a cross-transform array by multiplying each transform element of the second array by the complex conjugate of the transform element of the initial array.

c. Formed the cross-covariance array by taking the inverse transform of the cross-transform array.

d. Computed the power spectra of both the input arrays.

e. Located the highest cross-covariance value, found its lag coordinates and formed a relative cross-covariance array by dividing each cross-covariance by this maximum.

f. Printed the array resulting from each of the nine array computations as well as the input type and motion vector.

The second program was designed to perform the basic functions required to arrive at a motion vector from two input data arrays associated with the same geographic location but separated by a known interval of time. Features of the program were:

a. Read in the data for each array and computed the mean and standard deviation of each then subracted the mean from each element of the respective array.

b. Transformed these arrays and computed a cross-transform array by multiplying each transform element of the second array by the complex conjugate of the corresponding element in the first array.

c. Smoothed the cross transform array with Hanning coefficients and formed the cross-covariance array by taking the inverse transform of the smoothed cross-transform array.

d. Formed the cross-correlation array by dividing the cross-covariance array by the product of the two single-array standard deviations.

e. Located the highest cross-correlation value and computed the motion vector corresponding to its location.

f. Printed the time and identification for each input array, their arithmetic means, the lag coordinates and value of the peak cross-covariance and the motion vector expressed in degrees and knots.

The third program was designed to analyze each input array, compute a motion vector and print those results chosen from among the output options available, from a pair of arrays such as is processed by the second program. This program included all of the features of the second program and in addition, on option:

a. Prewhitened each input array by making a least squares fit.

b. Computed the power spectrum for each prewhitened array.

c. Computed the cross-power spectrum of the pair of arrays.

d. Printed those detailed results requested from these options.

   1) Print input arrays for both observation times in integer format.

   2) Print Fourier transform array for both observation times in complex format.

   3) Print power spectrum arrays for both observation times in integer format.

   4) Print the cross power spectrum relating both observation times in integer format.

   5) Print the smoothed cross covariance array in integer format.

   6) Print the cross correlation coefficient as a percentage in integer format.

The program developed at NESS processed 32 x 32 element arrays altering the array for the second time by keeping the central square, which contained one fourth of the input data for that time, and replacing the remainder of that array by the mean value of the array. It then performed the correlation analysis for the two resulting arrays. After this step it zeroed the portion of the transformed arrays corresponding to specified wave numbers, found the resulting filtered array and completed the analysis cycle for this new pair. The cycle could be repeated for up to five sets of wave numbers specified in input parameter cards.

## 4.2 Preliminary Timing Evaluation

A preliminary timing evaluation was made using the second IBM program (referred to as the short program) and the third IBM program (long). The two programs were modified to allow the cross-correlation computation itself to be bypassed but to permit the remainder of the processing to be completed in the customary manner. Those functions which were bypassed were the performance of the Fourier transform of the input arrays, the cross product of one transform with the complex conjugate of the other, smoothing of the result using Hanning coefficients and taking the inverse Fourier transform of the smoothed array. The same set of input array pairs was then processed first by the original programs then by the modified by-pass programs to measure the performance in three ways:

1. Using the short program
2. Using the long program with output limited
3. Using the long program with full output

The average times required for the computations, not including data selection and array formation (since the input was preselected arrays in card format) were per pair of 64 x 64 element arrays:

| Program Option | Cross-Correlation | Input Output | Other CPU Time | Total Time |
|---|---|---|---|---|
| Short | 1.2 sec | 0.7 sec | 0.6 sec | 2.5 sec |
| Long (limited) | 1.2 sec | 1.2 sec | 1.2 sec | 3.6 sec |
| Long (full) | 1.2 sec | 2.1 sec | 3.9 sec | 7.2 sec |

This indicated that for the best case the cross correlation portion used about 48% of the total computation time for an array pair.

4.3 Technique Modifications

1. Suppression of Spurious Products

In computing a cross-covariance for two arrays of equal size for non-zero lags the sum of cross-products may be in error, if using the lagged-product method because there are non-overlapping portions, or if using the Fourier transform because of its implicit interpretation of both data arrays as repeating sets in each direction with period corresponding to their respective dimensions. Since this study involves cross-correlation analysis using the Fast Fourier Transform this error is eliminated by using an array for the second time (search area) which is twice the desired size and modifying the array for the initial time (window area) by embedding it in a frame of zeros, after the mean has been subtracted from each element. The resulting cross-covariance array for lags corresponding to the interior of the zero-frame will have that error suppressed.

2. Restricting the Range of Data Values

Experimental two-dimensional image data may be missing over certain data points or it may have values outside a reasonable range which would tend to distort cross-correlation computations. In the case of data from the Nimbus IV THIR Experiment, there is further risk possible because values which appear to be reasonable may have been measured over areas free of clouds. Missing data will be represented as zeroes and the lowest valid values are large; however, it is not always obvious that a value is too high. It was therefore necessary to provide means of screening out the effects of missing data and unwanted high data separately. This was done by accepting as program input parameters an upper and a lower threshold.

In each array of a pair to be considered the individual data values which will enter into the cross-correlation computation are tested against the upper and lower bounds or thresholds. (In the case of the array for the initial picture only the central quarter or window area of the array is involved whereas for the second picture the entire search area is considered.) Those which lie within bounds are used to compute a mean and standard deviation for the array. On a second search through each array,

a. Data values which are too low are replaced by uniformly distributed random numbers whose mean is equal to and whose standard deviation is a multiple of those of the corresponding array. This tends to eliminate the adverse effect of missing data.

b. Data values which exceed the upper threshold are replaced by the mean value of the corresponding array. They thus do not contribute to the cross-covariance.

While the lower threshold value is likely to be a function of the sensor, the upper threshold may vary with season, time of day, or geographic location. In fact, the threshold approach offers the opportunity to consider slicing even an image of valid information into distinct subsets for special analysis.

3. Normalization for Subsamples

Investigation of the subsample means and variances for each window-sized subarray of a search area array revealed significant variation in values, sometimes by as much as a factor of 3 or 4 between the highest and lowest values of standard deviation. Since these standard deviations enter as divisors in computing the cross-correlation coefficient it is necessary to provide for effective normalization for each subsample and actual computation of the correlation coefficient prior to seeking the maximum value corresponding to the best pattern fit. A very efficient subroutine was programmed to accomplish this computation for all subsamples of the array for the second observation time.

When the use of thresholds was coupled with the improved normalization for subsamples very dramatic effects occurred which complicated the process of completing the cross-correlation computations and seeking their maximum value. In cases where there are very few clouds in the window area or in any search area subarray, the standard deviation computation may result in floating point underflow or division by zero. To remedy this, it was necessary to reject computations for such occurrences. The first fallback position in such a case is to use a constant subarray standard deviation equal to that of the search area; if that still fails computation is abandoned.

4. Deletion of Non-essential Computations

Several computer routines which had been considered in the program development were found non-essential to the cross-correlation analysis and were deleted from the program package in the interest of reducing storage requirements and computation time. Among these were the computation of power spectra for individual arrays or the cross spectrum for an array-pair, smoothing, which was useful in the spectrum computation but tends to dampen the extrema if applied to cross-correlation analysis, and the printing of information not needed operationally.

5. Simplification of Printing

A new print routine was prepared to reduce printer output. The original output routine used four pages of printer output to display the array of cross-covariance or cross correlation values for the range of E-W lags from -32 to +31 increments and N-S lags from +32 to -32 increments. The revised routine produces a 32 x 32 element page which is the window array extracted from the larger 64 x 64 array. It also prints the 32 x 32 subarray of the search area centered about the peak value of cross correlation.

### 4.4 Conversion of Input Sample Tape Pairs into Sets of Array Pairs for Analysis

Routines were programmed to read in each sample tape in a pair and subdivide its data into as many 64 x 64 element arrays as can be formed starting from the Northernmost row and Westernmost column and incrementing each starting row or column by 16 (a value which could be changed) before proceeding to the next pair. The largest array which may be provided on the sample tapes would be 200 x 200 data points; such a sample would yield at most 9 x 9 data arrays with three-fourths of the data elements being common in adjacent arrays.

## 4.5 Organization into Program Modules

The main control program, CMXC, and the tape reading and array formation subprogram, RDTAPE, are necessarily written with dimensions which are specific to this study, computer system and type of data used as input. All of the remaining 20 subprograms have been prepared in modular form with variable dimensions to permit their adaptation to similar use with different data.

## 4.6 Timing

Clock reading is introduced at the beginning and ending of each major operation and times used are printed out at each intermediate point. Summaries by each operator are also printed at the completion of the job.

## 4.7 Characteristics of the Computer System Used in the Study

The IBM System/360 Model 91 is an information-processing system designed for ultra high-speed, large-scale scientific and business applications. It provides a major-machine-cycle time of 60 nanoseconds. Data flow is eight bytes (one double word) in parallel. The storage cycle time is 780 nanoseconds. (The cycle time of storage itself is 750 nanoseconds.) Minimum total storage access time is 600 or 900 nanoseconds, as determined by the way in which the processor storage is attached.

Because floating-point overflow and underflow cause imprecise interruptions on the Model 91, it is possible that subsequent instructions will be executed using the overflow or underflow results. For this reason, the results are made to differ from the standard System/360 results, which produce the correct fraction and a wraparound exponent. On the Model 91, overflow produces the correct sign and the maximum fraction and exponent; underflow produces a true zero result.

The GSFC computer uses operating System/360 with MVT (Multi-programming with a variable number of tasks). Programs were compiled using FORTRAN IV, H Compiler, Option 2.

## 4.8 Program Options

To indicate the necessary parameters to the main program, there are nine input control card types. The options permitted are:

1. Number of Input Tapes

   2 indicates run is to process two NMR print tapes and generate an array tape before completing array processing.
   1 indicates an array tape is used as the input tape.

2. Number of Threshold Values

   The number of upper thresholds to be processed is entered. All computations will be repeated for each new one.

3. Number of Replications

   For timing runs the number of repetitions of computations for each array pair may be specified. Normally it is 1.

4. Noise Scaling

   The number of sixths of array standard deviation to be used in computing random noise to replace missing data may be specified. Normally it is set at 6.

5. Print Option

   1 indicates array printouts are requested
   0 indicates they are bypassed.

6. Initial Values

   The first upper and lower thresholds and an odd value for use in starting the random number generator are specified.

7. The run number and orbital description are entered to permit subsequent identification of results.

8. Time between orbits (in minutes) if the run includes array tape generation.

9. Additional upper threshold cards if the number of threshold values to process exceeds 1.

Section 5

RESULTS

## 5.1 Vector Computations

The data sets used as input to the vector computation programs are summarized in Figure 5-1. As the figure shows, eight sample pairs were provided as test cases. From these eight cases, a total of 32 array pairs were formed, as described in Appendix E.

The 32 array pairs were processed using a value of 190 as the threshold for rejecting missing data. Three values (263, 268, and 273) of the threshold used to discriminate between cloud and ground target returns were used for each array pair. In addition, the five array pairs of Case IV-2 were processed against themselves as a control.

Results of the vector computations may be classified according to whether a vector was apparently computed successfully; a warning appeared because the motion appeared to go to, or possibly beyond, the picture boundaries; or the computation was rejected because of the floating point underflow condition discussed on pages 4-7 and 4-8. Such a classification is shown in Figure 5-2. The results may be summarized as follows:

| | Array Pairs | Control Pairs |
|---|---|---|
| Vector Found (V) | 53 | 5 |
| Warning (W) | 7 | 0 |
| Rejection (R) | 36 | 10 |

As Figure 5-2 shows, there were a total of 21 array pairs (not including control cases) for which at least one apparently valid vector was computed. For four of these array pairs the results were considered untrustworthy because less than 30% of the data values were considered

| Case And No. | Date Sensed | | | Data Orbit No. | Image Boundaries | | | | Extent of Image | | No. of Arrays | Geographic Vicinity Sensed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Latitudes - N | | Longitudes - W | | | | | |
| | Mo. | Da. | Yr. | | Lower | Upper | Left | Right | Rows | Cols | | |
| I-1<br>I-2 | 5 | 8 | 70 | 402<br>403 | 40 | 52 | 309 | 293 | 71 | 65 | 1 | Aral Sea |
| II-1<br>II-2 | 5 | 9 | 70 | 416<br>417 | 42 | 62 | 324 | 308 | 134 | 65 | 5 | Caspian - Black Seas |
| III-1<br>III-2 | 5 | 9 | 70 | 417<br>418 | 42 | 62 | 351 | 335 | 134 | 65 | 5 | Poland |
| IV-1<br>IV-2 | 5 | 10 | 70 | 430<br>431 | 42 | 62 | 340 | 324 | 134 | 65 | 5 | Ukraine |
| V-1<br>V-2 | 5 | 13 | 70 | 470<br>471 | 42 | 62 | 332 | 316 | 134 | 65 | 5 | Ukraine |
| VI-1<br>VI-2 | 5 | 15 | 70 | 493<br>494 | 40 | 60 | 230 | 214 | 128 | 65 | 5 | Sakhalin |
| VII-1<br>VII-2 | 5 | 17 | 70 | 520<br>521 | 44 | 55 | 233 | 217 | 69 | 65 | 1 | SE Siberia |
| VIII-1<br>VIII-2 | 5 | 30 | 70 | 702<br>703 | 40 | 60 | 73 | 57 | 128 | 65 | 5 | Quebec |

Figure 5-1. THIR DATA SAMPLES SELECTED FOR USE IN CLOUD MOTION STUDY

| Case | Array Pair | Upper Threshold 263 | 268 | 273 | Comments |
|---|---|---|---|---|---|
| I | 1 | V | V | V | Data too sparse |
| II | 1 | R | R | R | |
| | 2 | R | R | R | |
| | 3 | R | R | R | |
| | 4 | R | V | V | Data too sparse |
| | 5 | R | V | V | Data too sparse |
| III | 1 | V | V | V | |
| | 2 | V | V | V | |
| | 3 | W | W | V | |
| | 4 | V | V | V | |
| | 5 | R | R | R | |
| IV | 1 | V | V | V | |
| | 2 | R | R | R | |
| | 3 | R | R | R | |
| | 4 | R | R | R | |
| | 5 | R | R | R | |
| V | 1 | V | V | V | Insufficient ground truth |
| | 2 | V | V | V | Insufficient ground truth |
| | 3 | R | R | R | |
| | 4 | R | R | R | |
| | 5 | R | R | R | |
| VI | 1 | V | V | V | Data too sparse |
| | 2 | V | V | W | |
| | 3 | V | V | V | |
| | 4 | V | V | V | |
| | 5 | V | V | V | |
| VII | 1 | V | W | W | |
| VIII | 1 | R | W | V | |
| | 2 | V | V | V | |
| | 3 | V | V | V | |
| | 4 | V | V | V | |
| | 5 | V | V | W | |
| Control | 1 | V | V | V | |
| | 2 | R | V | V | |
| | 3 | R | R | R | |
| | 4 | R | R | R | |
| | 5 | R | R | R | |

V = Vector Found W = Warning R = Rejection

Figure 5-2. CLASSIFICATION OF VECTOR COMPUTATION RESULTS valid. For two additional array pairs available ground truth was insufficent to permit evaluation of the results. The five vectors computed in the control trials showed no motion (as expected), and all but one of the rejections occurred with less than 10 percent of the data values acceptable.

The computed results for the remaining fifteen array pairs were compared to rawinsonde data for the nearest observation time which could be found in the archives of the Atmospheric Sciences Library of the National Oceanographic and Atmospheric Administration. Observing stations within the image area for each case were identified and data obtained for each station. Those stations lying within the array boundaries were examined and based upon the approximate elevation in that area of the center of coldest equivalent black body temperature found in the image a representative wind observation was selected. These are presented in Figure 5-3. Because of the breadth of the image area, and the large difference between the times of the image sensing and the rawinsonde observation, it is difficult to evaluate this comparison; it is significant that in several examples there appeared fairly close agreement. In most examples visual inspection of the image photographs substantiated the computed vectors; in several cases the photographs revealed strongly circulating patterns which would have both rotational and translational components.

In the sample display of test results shown in Appendix G are included four samples of results obtained from Case VIII. Figure G-2 shows that for the subarray centered at 45.0 N latitude and 65.0 W longitude, over Newfoundland, the window area had a standard deviation of 0.577. For one or more subarrays of the search area the subarray standard deviation was either zero or so small that its product with that of the window area resulted in a value less than 0.01. The subarray standard deviation was then reset equal to the search area standard deviation and the problem still existed. Apparently for the upper threshold of 263 there are so few data that depart significantly from their mean value that no valid cross correlation array can be determined. On the other hand, for the same sample pair the array pair centered at 50.0 N latitude and 65.0 W longitude

| Case No. | Array Pair | Upper Limit | Computed Vector Degrees | Computed Vector MPS | | Ground Truth Vector Degrees | Ground Truth Vector MPS | Time Diff.(Hrs.) |
|---|---|---|---|---|---|---|---|---|
| III | 1 | 263 | 350 | 2 | * | 235 | 5 | 11 |
| | 1 | 268 | 351 | 5 | | 235 | 5 | 11 |
| | 1 | 273 | 331 | 8 | | 235 | 5 | 11 |
| | 2 | 263 | 350 | 2 | | 200 | 5 | 11 |
| | 2 | 268 | 352 | 5 | | 200 | 5 | 11 |
| | 2 | 273 | 313 | 6 | | 200 | 5 | 11 |
| | 3 | 273 | 51 | 16 | | 150 | 15 | 11 |
| | 4 | 263 | 52 | 10 | * | 30 | 5 | 11 |
| | 4 | 268 | 44 | 8 | | 30 | 5 | 11 |
| | 4 | 273 | 44 | 6 | | 30 | 5 | 11 |
| IV | 1 | 263 | 275 | 17 | | 300 | 17 | 10 |
| | 1 | 268 | 275 | 17 | | 300 | 17 | 10 |
| | 1 | 273 | 275 | 17 | | 300 | 17 | 10 |
| VI | 2 | 263 | 321 | 22 | * | 325 | 10 | 3 |
| | 2 | 268 | 330 | 23 | * | 325 | 10 | 3 |
| | 3 | 263 | 324 | 19 | | 340 | 18 | 3 |
| | 3 | 268 | 326 | 16 | | 340 | 18 | 3 |
| | 3 | 273 | 315 | 19 | | 340 | 18 | 3 |
| | 4 | 263 | 224 | 9 | | 220 | 20 | 3 |
| | 4 | 268 | 251 | 7 | | 220 | 20 | 3 |
| | 4 | 273 | 242 | 9 | | 220 | 20 | 3 |
| | 5 | 263 | 222 | 6 | | 200 | 10 | 3 |
| | 5 | 268 | 230 | 10 | | 200 | 10 | 3 |
| | 5 | 273 | 180 | 4 | | 200 | 10 | 3 |
| VII | 1 | 263 | 7 | 34 | | 260 | 55 | 3 |
| | 1 | 268 | 7 | 36 | | 260 | 55 | 3 |
| | 1 | 273 | 7 | 36 | | 260 | 55 | 3 |
| VIII | 1 | 273 | 24 | 36 | | 15 | 26 | 4 |
| | 2 | 263 | 254 | 24 | | 345 | 17 | 4 |
| | 2 | 268 | 23 | 36 | | 345 | 17 | 4 |
| | 2 | 273 | 264 | 24 | | 345 | 17 | 4 |
| | 3 | 263 | 258 | 23 | | 320 | 29 | 4 |
| | 3 | 268 | 258 | 23 | | 320 | 29 | 4 |
| | 3 | 273 | 258 | 23 | | 320 | 29 | 4 |
| | 4 | 263 | 246 | 28 | | 320 | 35 | 4 |
| | 4 | 268 | 246 | 28 | | 320 | 35 | 4 |
| | 4 | 273 | 244 | 26 | | 320 | 35 | 4 |
| | 5 | 263 | 270 | 30 | | 277 | 40 | 4 |
| | 5 | 268 | 254 | 16 | | 277 | 40 | 4 |

* The density of valid data points in this window was less than 30 percent.

Figure 5-3. RESULTS OBTAINED FOR THE FIFTEEN SELECTED ARRAY PAIRS determines the same vector for the three thresholds tested. In those cases the window subarray contains over 97% accepted data points for the three tests. The window area appears to cover the southern and colder half of a cyclonic circulation which sweeps across the search area from West to East. These examples show the great differences in computational results that can be obtained from different array pairs drawn from the same sample pair.

## 5.2 Timing Results

Timing was estimated by making a run using a five array-pair sample with the same four threshold values and replicating the computations 20 times each. This provided 400 vector computations, many of which would find subarray standard deviations too small and result in recycling to attempt to find a vector assuming a constant scaling in place of the subarray standard deviations. The largest variation in the operations was found in operation 1. Tape reading and array formation need be done only once for a picture pair so its timing was measured independently.

The typical times required

| | |
|---|---|
| Tape reading and array formation | |
| for a 1-array pair | 0.3 to 0.5 sec |
| for a 5-array pair | 0.4 to 0.7 sec |
| Operations per array pair | |
| 1. Initialize to process one pair | 0.58 sec |
| 2. Fourier transform array pair and form cross-product | 0.27 sec |
| 3. Inverse Fourier transform | 0.21 sec |
| 4. Rearrange cross covariance and find motion vector | 0.02 sec |
| 5. Printing (only if requested) | 0.40 sec |
| Pair total with printout | 1.48 sec |
| Pair total without printout | 1.08 sec |

The initializing to process one pair which includes the threshold testing and subarray standard deviation computation uses about 54% of the time required to process a single array pair.

## 5.3 System Versus Cloud Motion

The geographic scale of data points used in the study leads to a situation which had not been anticipated originally. At leas three of the picture pairs, making up 11 of the 16 useful arrays, though chosen because they were in overlapped portions of successive orbits and between selected latitudes because they would otherwise have been severely truncated on the corners, were found to have apparent closed circulation patterns lying within their central portions. One instance, Case VII, proved to be a remarkable case which occasioned the issuance of two of the warnings because the cross correlation peak appeared at a boundary.

Case VII is a single array pair case located over Southeast Siberia. The motion computations, one of which is presented as Figure 5-4, showed vectors from 7 degress with speeds of 41, 43 and 43 mps. The motion was measured between pictures completed at about 01:14 and 03:02 Greenwich Mean Time.

Ground truth 400 mb level data taken at 000:00 Greenwich Mean Time showed a wind of 260 degrees at 55 mps at the center of the picture area. However, other winds in the picture area were:

| | |
|---|---|
| NW Corner | 360/65 mps |
| N Center | 045/22 mps |
| NE Corner | 195/24 mps |
| SE Corner | 255/15 mps |
| S Center | 285/23 mps |
| SW Center | 295/56 mps |
| W Center | 325/47 mps |

The ground truth temperature, humidity, height and wind data for the 400 mb constant pressure surface was plotted and contours of constant height drown. This is presented as Figure 5-5 where the computed motion vector appears as a dashed vector of 42 mps. Apparently intense northerly flow swept into the picture by the time the satellite passed overhead in its second orbit.

This case is a good example of the difficulty encountered in comparing computed vectors with ground truth data. Significant changes in the direction and intensity of motion over an image area can occur without being detected in the time between successive satellite orbits; to be aware of these it is necessary to study a synoptic analysis of the area and its environs. Motion such as was computed for this case could be valuable in making upper air analysis but there is a risk in an automated procedure that such results will be rejected as inconsistent and the information thus lost. The motion detected in this instance revealed short term changes which could be missed in the conventional observation system.

```
347   CMXC MAIN PROGRAM TEST USING PASSES 520 AND 521 NIMBUS IV THIR DATA
TAPE READING AND ARRAY FORMATION TOOK   0.05000SECONDS
LATITUDE= 49.10144N  LONGITUDE=225.00000W  E-W MESH SIZE= 0.25000DEG  N-S MESH SIZE= 0.15942DEG TIME BETWEEN FRAMES=.  108.MINUTES
THRESHOLDS ARE MIN= 190 MAX= 263 VALID POINTS NUMBER     436 FOR A PERCENTAGE OF  42.58 THE MEAN=  254.2 STANDARD DEVIATION=    6.1
THRESHOLDS ARE MIN= 190 MAX= 263 VALID POINTS NUMBER    1645 FOR A PERCENTAGE OF  40.16 THE MEAN=  249.8 STANDARD DEVIATION=    9.5
FOR THE SEARCH AREA SUBARRAYS THE FOLLOWING STATISTICS WERE FOUND AFTER THE SEARCH AREA MEAN WAS SUBTRACTED FROM THE DATA
  MEAN OF                MEANS=   0.975      STANDARD DEVIATION OF                MEANS=   0.912
  MEAN OF STANDARD DEVIATIONS=   5.411      STANDARD DEVIATION OF STANDARD DEVIATIONS=   1.611
TIME IN SECONDS FOR OPERATION   1 WAS       0.48333329
TIME IN SECONDS FOR OPERATION   2 WAS       0.25000000
TIME IN SECONDS FOR OPERATION   3 WAS       0.21666664
 ONE PAIR VALUE IN CROSS-CORRELATION APPEARS AT ILAG=  -2   JLAG= -15  WITH PERCENTAGE=   57. WHICH WAS SELECTED AS THE BEST FIT.
 THE PEAK VALUE AT I=  -2  AND J= -15  IS       57% MOTION WAS FROM   7 DEGREES AT   80  KNOTS
TIME IN SECONDS FOR OPERATION   4 WAS       0.01666667
```

Figure 5-4. DISPLAY FOR CASE VII, A SINGLE ARRAY CASE, UPPER THRESHOLD = 263

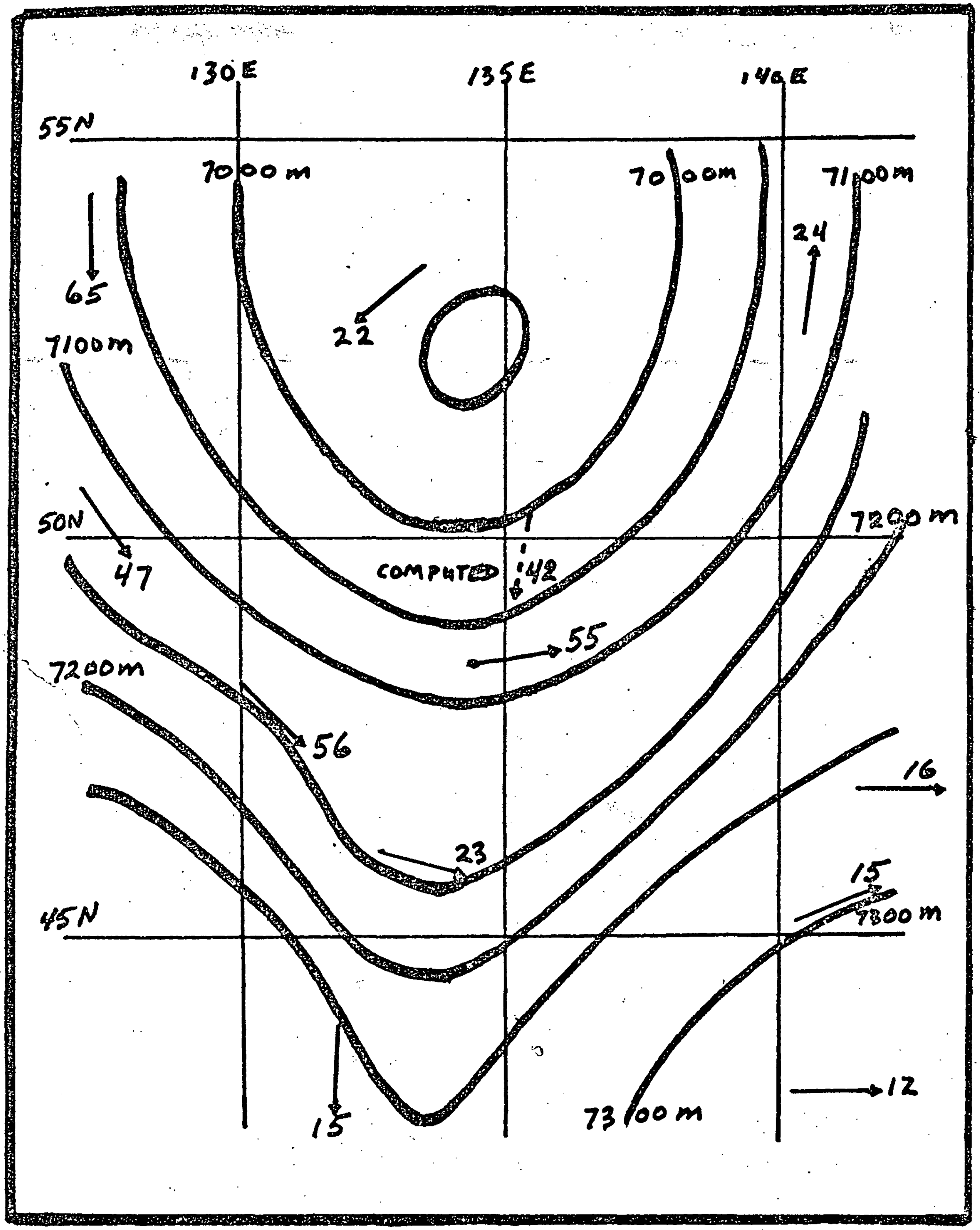


Figure 5-5. HEIGHT AND WINDS (IN MPS) AT 400 mb SURFACE AT 0000 GMT, 17 MAY 1970 - CASE VII.

# Section 6

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 General

The primary conclusion to be drawn from this study is that the basic technique of cross-correlation using the Fast Fourier Transform can be applied to data from a sensor such as the THIR to determine cloud motions. Unfortunately, the small number of cases for which both computed wind vectors and ground truth measurements were obtained makes this conclusion somewhat tentative. It is felt, however, that the results presented in Section 5 do support the validity of the process.

The great difficulty in obtaining useful data leads to another, perhaps more important, conclusion: the combination of a polar orbiting satellite and a sensor such as the THIR is not practical for wind velocity determination. The sensor characteristics, limited sidelap of successive orbits, and present NASA procedures for generating geographically registered data sets make it quite difficult to obtain a sufficient sample population to support the required computations. Excessive manual involvement in sample selection and the number of steps needed to obtain digital output clearly show that it would not be economical to make cloud motion computations with this type of data on an operational basis.

A problem, common to all cloud motion determination techniques, which was observed during this study is that of discriminating between data samples that represent clouds and those that arise from ground targets such as ice or water. Simple thresholding was used in this study to accomplish the required discrimination. Multispectral signature analysis and change detection are examples of alternate techniques which might be used for this function.

## 6.2 Program Changes

During the course of the study, the following changes were found to greatly improve the usefulness of the program in processing THIR data:

a. Suppression of spurious cross covariance products by bounding the window area with neutral values (the window mean). In the experimental programs window and search area sizes were equal, which had the effect of moving false clouds over the search area. The revised version measures the motion of only those clouds which lie within the window area initially.

b. Replacement of missing data with noise on the basis of a lower threshold test. Missing data appears on the sample tapes as zero values. Since the lowest value expected in the samples would be about 190, missing data would have biased results toward the low side. By replacing missing data with random noise within the expected range this effect is neutralized.

c. Normalization of cross correlations according to the subsample scale (standard deviation). The variation in subsample standard deviation is very large. The original program found the cross covariance which is the cross correlation before it has been normalized to fit the scale of the two subsamples (the window and the search area subarray for that lag pair). Searching for the maximum of cross covariance would yield a good fit only if the search area subarrays had about the same scale.

d. Exclusion, using an upper threshold test, of data which while valid to the sensor constitutes noise to the cloud motion computation. The most difficult aspect of objective interpretation of the THIR data is in determining what is valid data for the interpretation. It is possible to receive measurements throughout the range of the sensor, but for motion study there must be some way of determining what is moving and what is fixed.

Temperature may be a good indicator, though its effectiveness does depend upon sensor and geographic location. The upper threshold provides a means of screening out data which is obviously too high. A summary of the effects of using three different threshold values appears in Figure 6-1.

| | Array Pair | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Upper Threshold = 263 | Case I | 2 | Single Array Pair | | | |
| | II | 0 | 0 | * | 3 | 13 |
| | III | 27 | 31 | 17 | 16 | 5 |
| | IV | 57 | 28 | 4 | 0 | 0 |
| | V | 32 | 42 | 27 | * | 0 |
| | VI | 5 | 20 | 64 | 94 | 82 |
| | VII | 43 | Single Array Pair | | | |
| | VIII | 16 | 64 | 98 | 99 | 96 |
| | Control | 68 | 38 | 5 | 0 | 0 |
| Upper Threshold = 268 | Case I | 2 | Single Array Pair | | | |
| | II | 0 | 1 | 4 | 8 | 21 |
| | III | 33 | 40 | 31 | 30 | 11 |
| | IV | 62 | 35 | 8 | 0 | 0 |
| | V | 38 | 49 | 30 | * | 0 |
| | VI | 7 | 25 | 71 | 99 | 88 |
| | VII | 51 | Single Array Pair | | | |
| | VIII | 20 | 70 | 99 | 99 | 99 |
| | Control | 76 | 43 | 8 | 0 | 0 |
| Upper Threshold = 273 | Case I | 3 | Single Array Pair | | | |
| | II | * | 3 | 8 | 14 | 28 |
| | III | 43 | 53 | 45 | 19 | 25 |
| | IV | 66 | 40 | 11 | 0 | * |
| | V | 46 | 56 | 32 | 1 | 0 |
| | VI | 16 | 36 | 78 | 100 | 94 |
| | VII | 59 | Single Array Pair | | | |
| | VIII | 30 | 77 | 99 | 100 | 100 |
| | Control | 81 | 48 | 10 | 0 | * |

Figure 6-1. DENSITY IN PERCENT OF WINDOW ARRAY POINTS QUALIFYING AS CLOUDS FOR THRESHOLDS SHOWN (* INDICATES LESS THAN 1% BUT NOT 0)

### 6.3 Timing

It appears reasonable to compute motion vectors using a 32 x 32 window over a 64 x 64 search area. Time required for one such computation is about 1.1 seconds.

## 6.4 Recommendations

The obvious recommendation arising from this study is to apply cloud motion determination techniques to data gathered by geosynchronous satellites. Use of such data should greatly reduce, if not eliminate, the problems of obtaining timely ground truth measurements and sufficient data sample population in overlapped areas. Data from both the visible and infra-red ranges of the spectrum should be used in such an investigation.

Another area recommended for investigation is that of separating returns from clouds and ground targets. A simple approach that might be tried is that of differencing successive data sets and filtering out all areas for which no appreciable change has occurred. An alternate approach is that of examining spectral and thermal signatures in order to arrive at an algorithm which will accurately detect clouds and reject ground targets in a single data set.

A final recommendation is that a cloud motion determination scheme based on the Sequential Similarity Detection Algorithm (SSDA) be investigated. Recent experiments have shown that, especially for low-resolution data of the type used in cloud motion studies, use of the SSDA may produce results which are computationally much less expensive than those produced with cross correlation and the FFT with no less in accuracy.

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1. Barnea, D.I., and Silverman, H.F., "The Class of Sequential Similarity Detection Algorithms (SSDA's) for Fast Digital Image Registration," IBM Research Report RC-3356, May 10, 1971.

2. Bernstein, R., and Silverman, H., "Digital Techniques for Earth Resource Image Data Processing," IBM Report FSC 71-6017, September 30, 1971.

3. Barnea, D.I., and Silverman, H.F., "A Class of Algorithms for Fast Digital Image Registration," IEEE Transactions on Computers, Feb. 1972.

## Section 7

## NEW TECHNOLOGY

No reportable items, as defined in Section I(a) (i) of NASA Form 1162, NEW TECHNOLOGY (May 1966), have been identified during the performance under this contract.

## Appendix A

## SENSOR DESCRIPTION

(Condensed From Nimbus IV User's Guide)

The THIR is a two channel high resolution scanning radiometer designed to perform two major functions. First, a 10.5-12.5$\mu$ window channel provides both day and night cloud top or surface temperatures. Second, a water vapor channel at 6.7$\mu$ gives information on the moisture content of the upper troposphere and stratosphere and the location of jet streams and frontal systems. The ground resolution at the subpoint is 8 Km for the window channel and 22 Km for the water vapor channel. The window channel will operate day and night while the water vapor channel will operate mostly at night. (Data from the window channel was used in this study.)

The THIR radiometer consists of an optical scanner and an electronic module. A blackened collar near the scan mirrow serves as a sun shield to prevent sunlight contamination during spacecraft sunrise and sunset. The other side of the sun shield is painted white. The end of the scanner opposite the sun shield contains the optical system and preamplifiers.

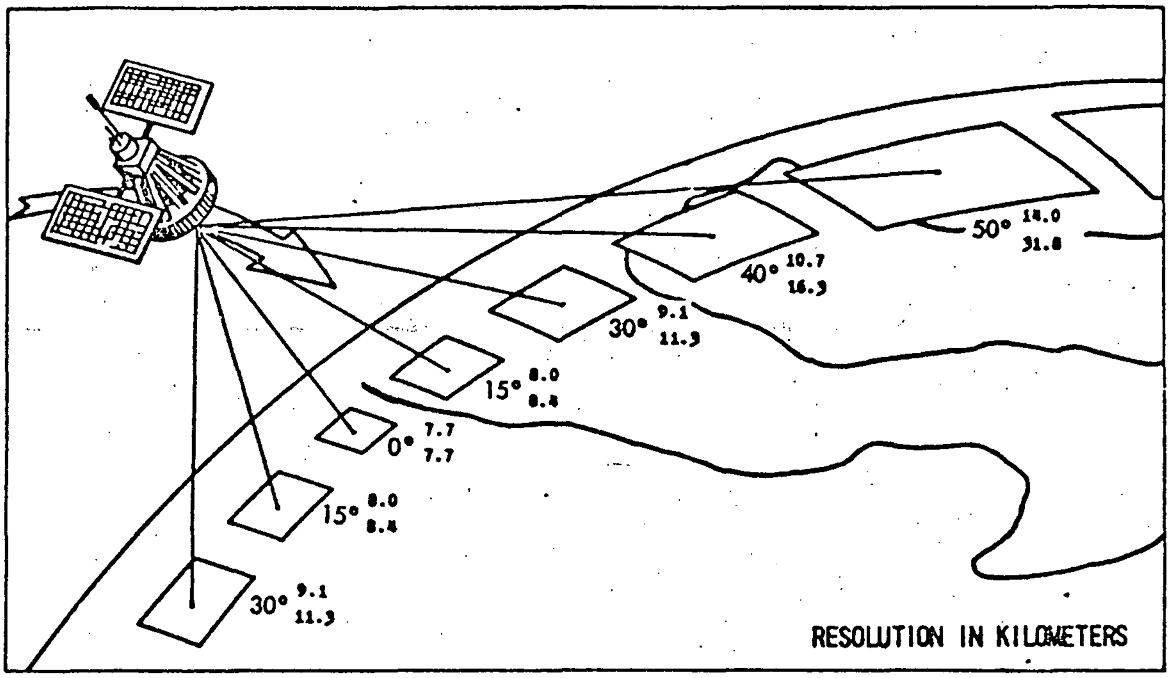
The optical system consists of a scan mirrow, a telescope (comprised of primary and secondary mirrors) and a dichroic beamsplitter. The scan mirrow, inclined at 45° to the optical axis, rotates at 48 rpm and scans in a plane perpendicular to the direction of the motion of the satellite. The scan mirror rotation is such that, when combined with the velocity vector of the satellite, a right-hand spiral results. Therefore, the field of view scans across the earth from east to west in daytime and west to east at night, when the satellite is traveling northward and southward respectively.

The telescope focuses the energy at the dichroic beamsplitter which divides the energy spectrally and spatially into two (2) channels. A 21-milliradian channel detects energy in the 6.7 micron band. A 7.0 milliradian channel detects energy in the 10.5-12.5 micron band. It consists of a bandpass filter (transmission portion of the dichroic), an Itran-2 relay lens which also serves as a long wavelength blocking filter, a folding mirror, and a germanium immersed thermistor bolometer.

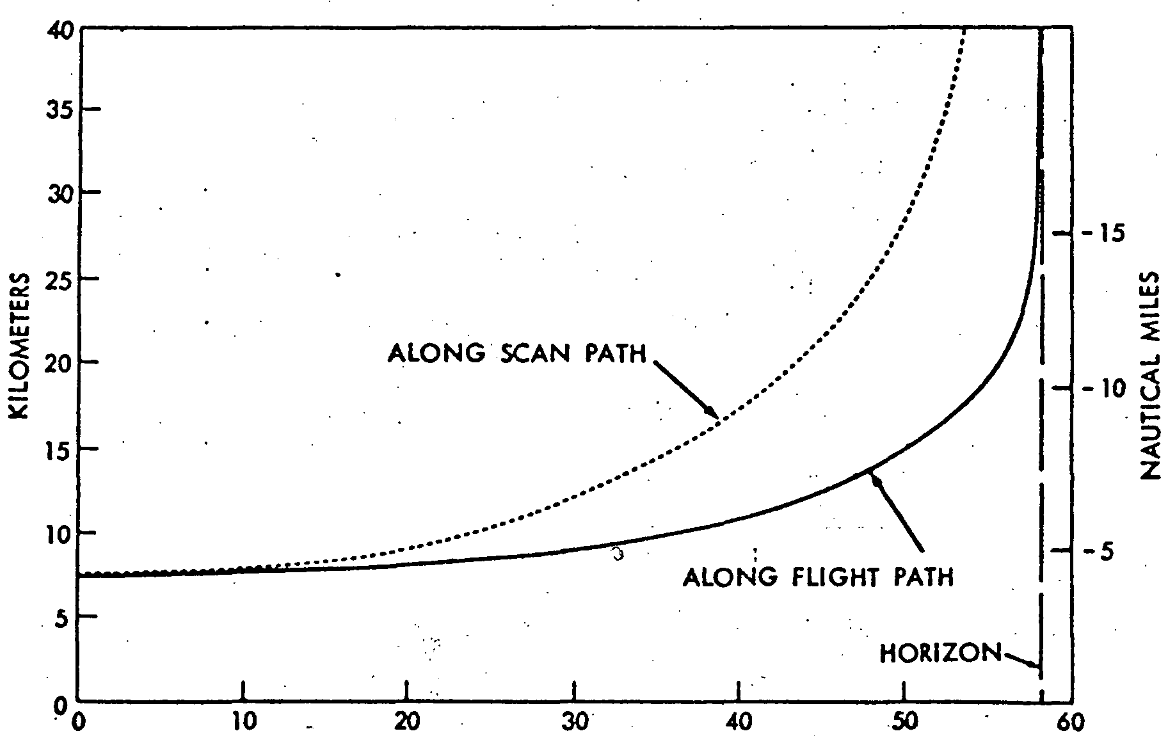
The signals from the detectors are capacitively coupled to the preamplifiers, amplified and sent to the electronic module. In the electronic module, the signals are further amplified and corrected for detector time constant to provide the overall frequency response as required by the subsystem optical resolution. The signals are processed out of the electronic module through buffer amplifiers. The 6.7 micron channel output is available on a full time basis as the shifted level channel. The offset of the shifted level channel is provided in the buffer of that channel. A second video output selects either the 6.7 micron or the 11.5 micron channel by means of a command relay. In addition to the two video output signals, there are fourteen telemetry channels: ten analog and four digital.

The instantaneous field of view (IFOV) of the window channel is approximately 7 milliradians. At an altitude of 1112 kilometers (600 nautical miles) this results in a subsatellite ground resolution of 6.67 kilometers (4.1 nautical miles). The scan rate of 48 rpm produces contiguous coverage along the subsatellite track. Due to the earth-scan geometry of the THIR, as nadir angle increases, overlapping occurs between consecutive scans, reaching 350 percent overlap at the horizons, and resulting in a loss of ground resolution in the direction of the satellite motion. Even greater loss of resolution occurs along the scan line (perpendicular to the line of motion of the satellite) because of the expansion, with increasing nadir angle, of the target area viewed.

Figure A-1 shows, for the window channel, the relationship between nadir angle and ground resolution element size along the path of the satellite and




(a)




(b)

Figure A-1. Relationship between Nadir Angle and Ground Resolution for the THIR 11.5μ Channel at 600 N. Miles (a) Pictorial (b) Graphical perpendicular to it. The numbers under each resolution element are nadir angle (in degrees), resolution along the scan line (in kilometers), and resolution parallel to the satellite line of motion (in kilometers).

No image is formed within the radiometer: the THIR sensor merely transforms the received radiation into an electrical (voltage) output with an information bandwidth of 0.5 to 360 Hz for the 10.5-12.5 micron channel and 0.5 to 120 Hz for the 6.7 micron channel. The radiometer scan mirror continuously rotates the field of view of the detector through 360 degrees in a plane normal to the spacecraft velocity vector. The detector views in sequence the in-flight black body calibration target (which is a part of the radiometer housing), outer space, Earth, outer space, and returns again to intercept the calibration target. The space and housing-viewed parts of the scan, which can be identified without difficulty, serve as part of the in-flight check of calibration. Information on housing temperature, which is monitored by thermistors, is telemetered to the ground stations and for calibration purposes is constantly compared with the temperature obtained from the radiometer housing scan. Even though the first stages of amplification are capacitor-coupled, the low frequency cutoff is so low that a dc restore circuit is necessary to provide a zero signal reference. This occurs during that portion of the scan when the optics are receiving zero radiation (space). The dc restore circuitry also provides additional gain to raise the signal to the desired output level and filtering to establish proper frequency characteristics.

## Appendix B

## DATA GENERATION PROCEDURE

Following are summary descriptions of the three programs used at the Goddard Space Flight Center computer facility to generate the standard sample products provided for this study from the Nimbus Meteorological Radiation Tape.

1. Program Number - L00240 (NHM)

   Title - Nimbus HRIR Mapping Program

   Abstract -

   This program is used to generate maps of the Earth showing high resolution infrared radiation measurements taken by the NIMBUS NMRT-HRIR scanning equipment. Up to three maps can be made during a single pass of the NMRT-HRIR tape: - one mercator map and two polar maps. Thus, the entire Earth or any portion of it can be mapped at one time.

   Restrictions -

   Maps are limited to a width of 100 horizontal grids (25 grids per page). There is no limit to the number of vertical grids.

   The only limit to the overall map size is available memory space. Four bytes are required per map grid for each of the maps.

2. Program Number - S00009 (PCITG)

   Title - Pseudo Color Input Tape Generation Program

   Abstract -

   This program is to be included as an additional job step following a job step using program L00240. The HRIR (and THIR) grid print mapping program (L00240) generates a two dimensional matrix containing temperature data geographically located on a mercator map projection and places it (the matrix) on disc for passage to another step (L00244) which formats the matrix for printer (Class M or A) output. S00009 accesses the matrix on disc and copies it with necessary documentation, on magnetic tape (using an unformatted write).

Restrictions -

Limitations are set by L00240, and S00010.
Current limit is 200 by 200 for Data and Population Matrices.

3. Program Number - S00010 (PCMM)

Title - Pseudo Color Mercator Mapping Program

Abstract -

S00010 is a program for producing pseudo-color maps of data from the NIMBUS 3 HRIR and the NIMBUS 4 THIR experiments (or any compatible data source). The program accepts a data matrix from magnetic tape (see S00009) and reformats the output magnetic tape line by line to produce the pseudo-color map containing a title, an annotated color scale, geographical gridding, and the pseudo-color data map in a mercator projection. The gridding and associated annotations may be omitted if a non-mercator projection data matrix is used. A variable number of colors (up to 20) are available in the color scale.

Restrictions -

Data Array maximum size (MRCAT Tape) is 200 x 200 (I*4) Words. Data Values are limited to range of 1 to 350. Values $\leq$ 0 are not contoured and represented as Black on Color Picture (output). Values > 350 are revalued to 0. Maximum of 20 colors can be selected.

## Appendix C

## COMPUTER SYSTEM DESCRIPTION

The portion of the Goddard Space Flight Center computing facility which was used for the cloud motion program development and testing during the study was the IBM System/360 Model 91K located in Building I. Supporting services at the computing facility were also available when needed. The system hardware, on-line and off-line peripheral devices and supporting services are described in the SESD Computing Center User's Guide, including a diagram of the system configuration.

The main system components include:

a. Model 2091K Processing Unit, including one Model 2250-1 Display Unit serving as the operator's console.

b. One Model 2395-1 Processor Storage, 2048K (2,097,152) bytes of high-speed storage.

c. One 2150/1052 typewriter console.

d. Three 2860 selector channels with:

    1. Two 2314 Direct Access Storage Facilities, containing 233,408K bytes each.

    2. Two 2301 Drum Storage, containing 4000K bytes.

    3. One 2321 Data Cell, containing 400,000K bytes.

e. One 2870-1 multiplexer channel, including three selector subchannels with:

    1. One 2250-1 Display Unit

2. Six 2401-3 7-track tape drives

3. Eight 2401-6 9-track tape drives

4. Two 2540 Card Read Punch

5. Four 1403 N-1 Printers

6. One 2702-1 remote communications device for attaching Model-1050 CRBE terminals.

# Appendix D

## CONSIDERATION OF AN ALTERNATE EXPERIMENT

Early in the second quarter of the study (the summer of 1971) upon instructions from the Technical Monitor, consideration was undertaken of the design of a comparative experiment in which the digital technique being investigated under this contract would be compared to another method of estimating cloud motion by means of cross-correlation analysis, both using ATS data.

The instructions followed in this consideration initially were to consider the design of a comparative experiment, using ATS data, in which two methods of estimating cloud motion by means of cross-correlation analysis would be compared. One technique was to be optical/analog and the other the digital technique being investigated by IBM under Contract NAS5-11859. Subsequently these instructions were changed; instead of a comparative experiment, a comparative test would be considered and the work would include recommending a suitable set of test ATS data and reorienting the conduct of the contract performance to the use of ATS data instead of polar-orbiting data.

Investigation suggested that the most serious problem in such a test might be that of registration relative to a frame of reference. It seemed unlikely that registration for ATS pictures will be automated in the near future. Manual performance of the task at the National Environmental Satellite Service had indicated that the validity of the result diminishes with distance from the landmarks used for reference. Solution of that problem was considered well beyond the scope of contract NAS5-11859.
A second problem would be that of data selection, availability and format. ATS meteorological data processing was being conducted by NESS so NASA did

not maintain complete data catalogs.

To address these two problem areas it appeared possible that test data be selected from that previously registered and processed by the National Environmental Satellite Service for the GARP month of June, 1970. In this way it would have been possible to eliminate the registration portion of the task which seemed likely to remain largely manual in the immediate future, independent of the method used to perform cross-correlation analysis.

It was concluded that while consideration of the conduct of a comparative experiment or test using ATS data and the reorientation of the contract performance toward the use of ATS data as input would have been consistent with the broad aspects of the Statement of Work, it would have rendered some details of that statement inappropriate and would have called for a substantial departure from the proposed approach to this investigation.

It was therefore recommended that the cloud motion study be completed as originally planned using HRIR data obtained from polar-orbiting NIMBUS satellites, that any comparative experiment or test conducted under the existing contract be based upon such HRIR data and that adaptation of programs and techniques to ATS data be considered separately.

## Appendix E

## DATA SAMPLES SELECTED BY NASA

Selection of data samples to be used in the study was accomplished by the Technical Monitor. The objectives of the selection process were that the sample pairs selected would:

- number between 15 and 50
- include about 100 by 100 data points each
- be selected from higher latitudes from overlapping frames of successive NIMBUS orbits of either HRIR or THIR data.

The selection process included investigation of the NIMBUS IV Data Catalog and examination of enlarged photographic prints of the Temperature-Humidity Infrared Radiometer montages. Selections were made from NIMBUS IV 11.5$\mu$ THIR daytime data.

As pointed out in Volume 2 of the NIMBUS IV Data Catalog, the quality of THIR data from the window channel (11.5 $\mu$m) was excellent. Data recorded after orbit 450 did contain periodic noise which could be filtered out. However, difficulties in processing to obtain the mercator tapes, sparsity of data which forced use of a coarse scaling and failure to find satisfactory data from both orbits chosen in the overlapped area which had been demarked resulted in degradation of the twenty sample sets (from forty orbits) into only eight useful sample pairs. These are identified as Cases I through VIII which are described in Figure E-1.

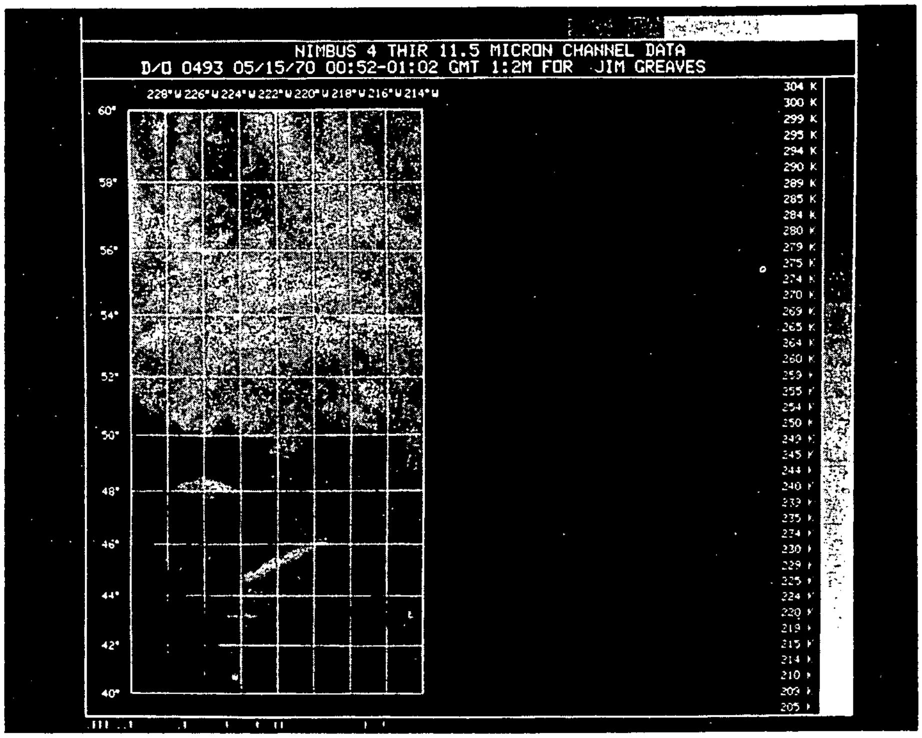
Three samples have been pictured to identify some of the limitations encountered in the available sample data. Figure E-2 shows the data selected for Case VI. As will be noted, a substantial field of cyclonic circulation is nearly centered in the overlapped area; the limit of the East-West range to one array width restricts the analysis of variations in the field to those in the North-South direction. A central array pair is likely to provide information about motion of the field itself rather than within the field

Figure E-3 portrays the data selected for Case I. Examination of the data values contained in this overlapped area reveal that only a very small portion of the central quarter of the area contains any cloud cover at all. This case was limited to a single array in both latitudinal and longitudinal directions so no significant conclusions could be made for this case.

Figure E-4 portrays the data selected for Case VIII. In this case, the cloud features seem fairly well distributed with less prominent circulation features than were found in Case VI. Here the lower left corner of the image from orbit 702 and portions of the right side of the image from orbit 703 are characterized by missing data values.

| Case And No. | Date Sensed | | | Data Orbit No. | Image Boundaries | | | | Extent of Image | | No. of Arrays | Geographic Vicinity Sensed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Latitudes - N | | Longitudes - W | | | | | |
| | Mo. | Da. | Yr. | | Lower | Upper | Left | Right | Rows | Cols | | |
| I-1<br>I-2 | 5 | 8 | 70 | 402<br>403 | 40 | 52 | 309 | 293 | 71 | 65 | 1 | Aral Sea |
| II-1<br>II-2 | 5 | 9 | 70 | 416<br>417 | 42 | 62 | 324 | 308 | 134 | 65 | 5 | Caspian - Black Seas |
| III-1<br>III-2 | 5 | 9 | 70 | 417<br>418 | 42 | 62 | 351 | 335 | 134 | 65 | 5 | Poland |
| IV-1<br>IV-2 | 5 | 10 | 70 | 430<br>431 | 42 | 62 | 340 | 324 | 134 | 65 | 5 | Ukraine |
| V-1<br>V-2 | 5 | 13 | 70 | 470<br>471 | 42 | 62 | 332 | 316 | 134 | 65 | 5 | Ukraine |
| VI-1<br>VI-2 | 5 | 15 | 70 | 493<br>494 | 40 | 60 | 230 | 214 | 128 | 65 | 5 | Sakhalin |
| VII-1<br>VII-2 | 5 | 17 | 70 | 520<br>521 | 44 | 55 | 233 | 217 | 69 | 65 | 1 | SE Siberia |
| VIII-1<br>VIII-2 | 5 | 30 | 70 | 702<br>703 | 40 | 60 | 73 | 57 | 128 | 65 | 5 | Quebec |

Figure E-1. THIR DATA SAMPLES SELECTED FOR USE IN CLOUD MOTION STUDY



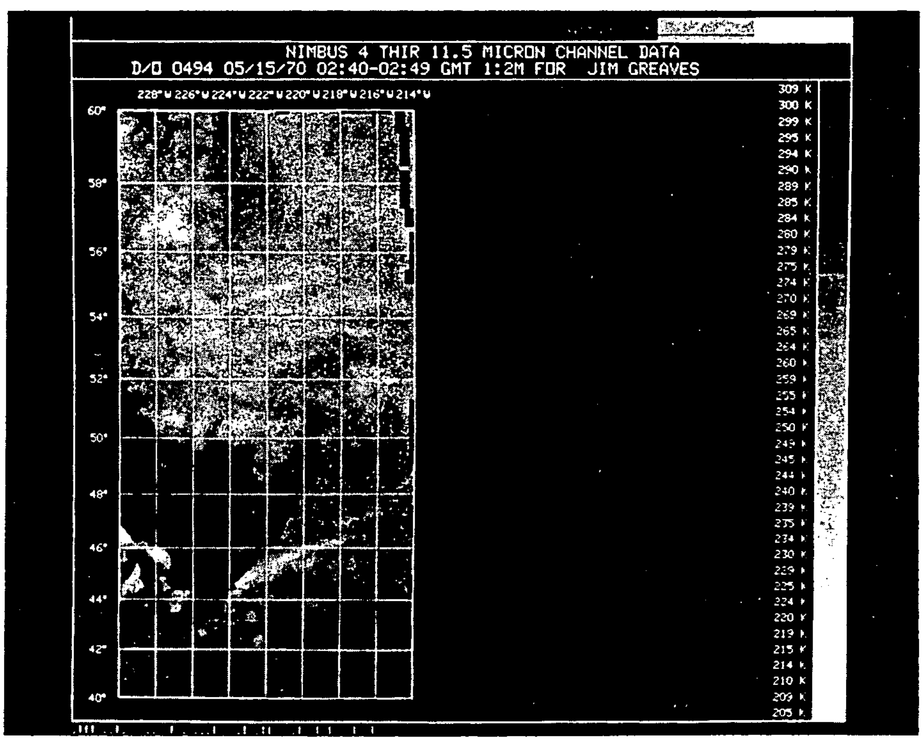




Figure E-2. Black and White Presentations of THIR Data Selected for Case VI

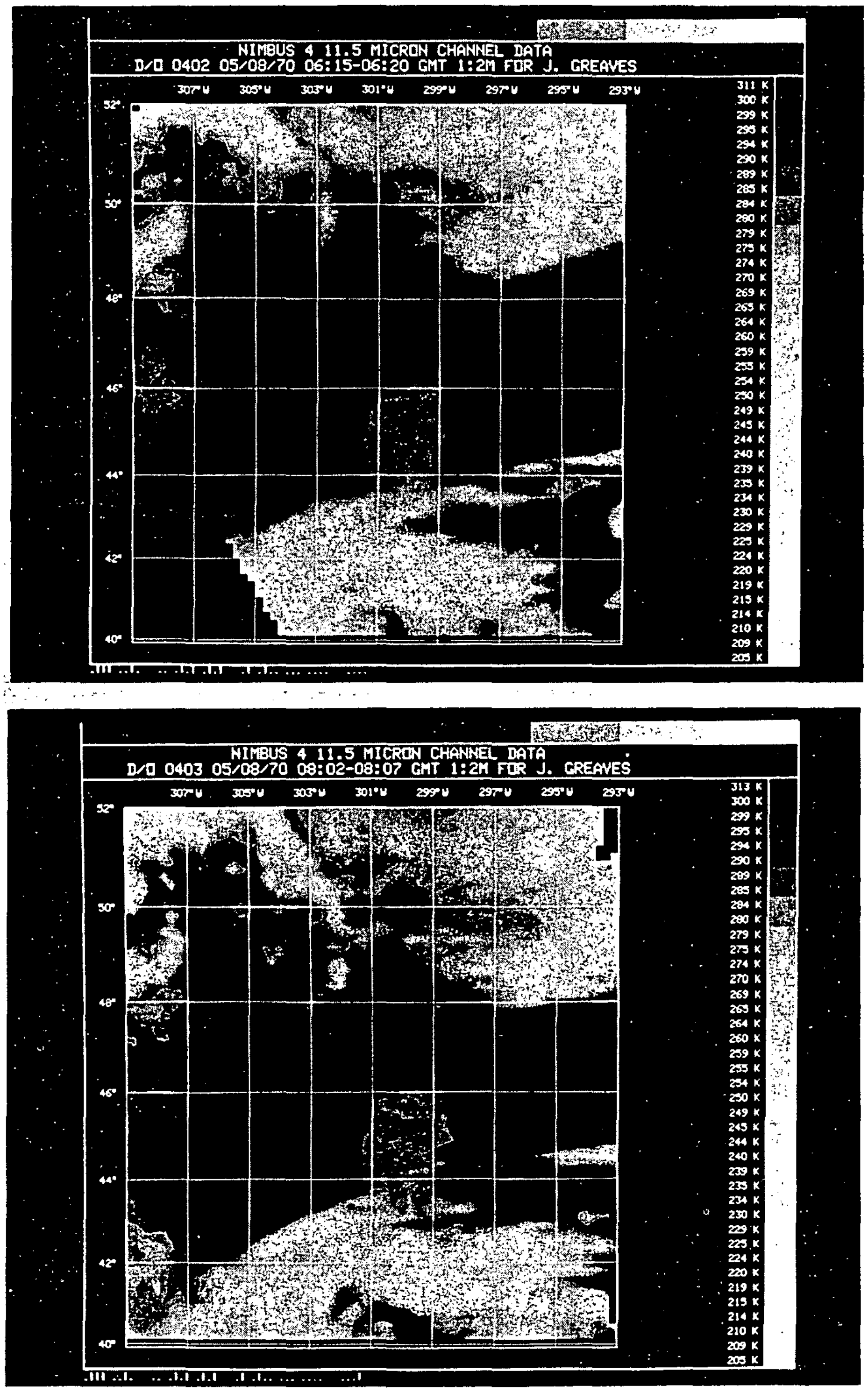
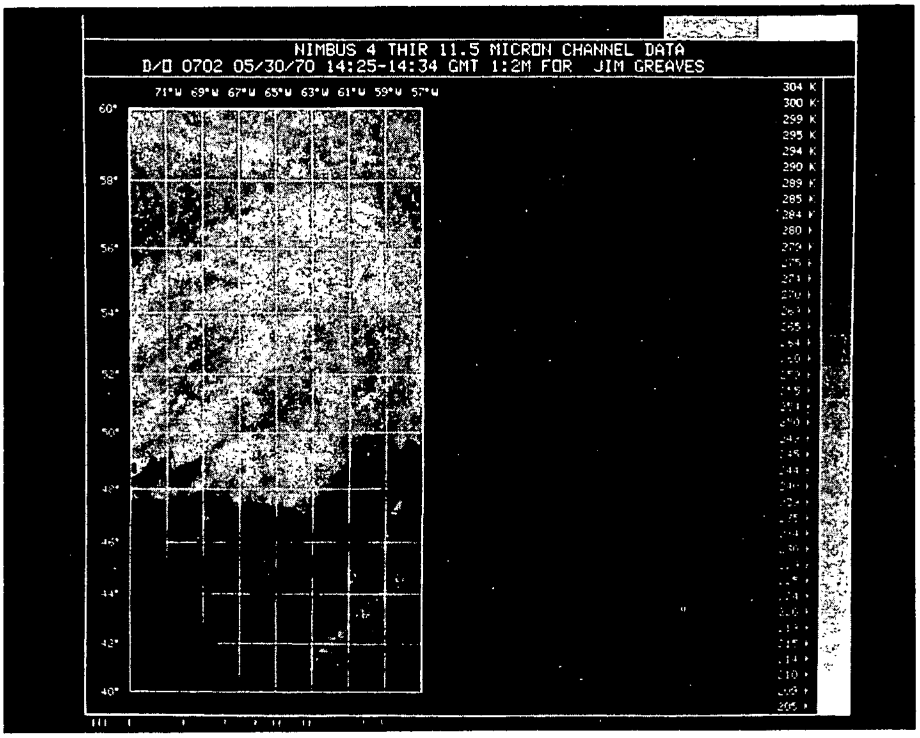



Figure E-3. Black and White Presentations of THIR Data Selected for Case I



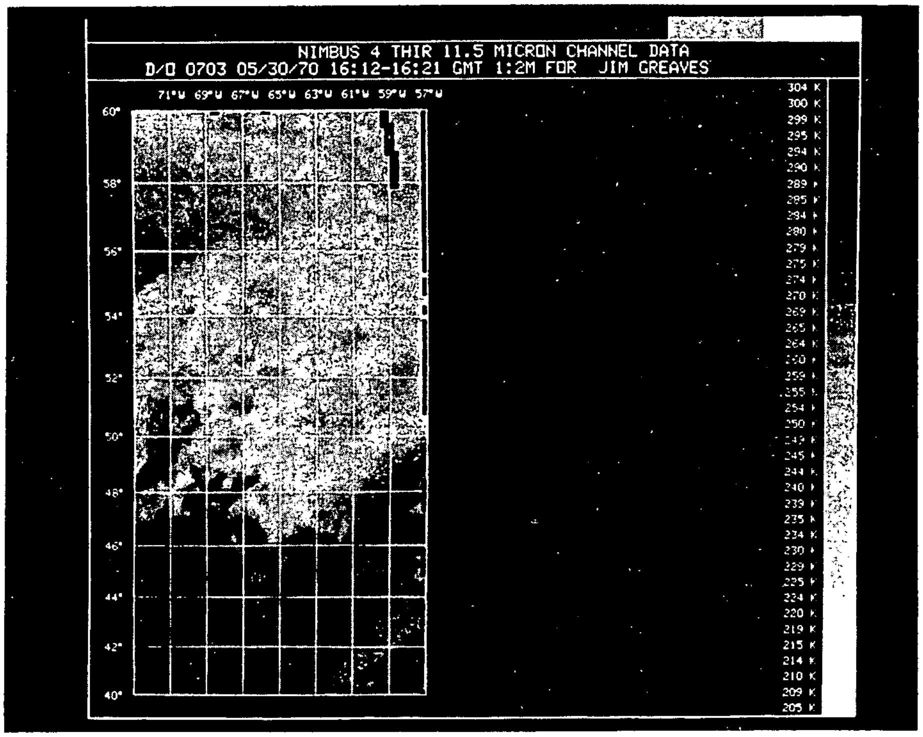




Figure E-4. Black and White Presentations of THIR Data Selected for Case VIII

## Appendix F

## COMPUTER PROGRAM

The MAIN program which controls the flow of processing in the cloud motion cross correlation problem has been assigned the identifying label CMXC for use in referring to it as a subprogram. On subsequent pages of this appendix are the detailed source code (in FORTRAN IV Language) of the 22 subprograms developed in this study. Activity is actually divided into six basic operations each of whose central processor usage is timed by CMXC using the internal clock. Several subprograms are used in more than one operation.

1. Tape Reading and Array Formation Operation

The first time a pair of image tapes is processed an array pair tape is generated for use in subsequent operations using the subprograms RDTAPE, RDREC, RDPIK and RAYSET. For all computer runs the subprogram HARM is here initialized to process the appropriate size of arrays using subprograms SETHRM, HARM and IFEXIT.

2. Operation 1

Working storage is initialized to process one pair of arrays and each of these arrays undergoes single array analysis and, if necessary, modification to assure its data content meets the boundary conditions set for this pass through the loop. The subprograms used are NULOOP, SETRAY, ZFRAME, ZNORM, TIMNSD, THRESH and BKGRND.

3. Operation 2

The two modified input arrays undergo a Fourier transform and the resulting transformed arrays are combined into a product array W using subprograms HARM, IFEXIT and SPLITV.

4. Operation 3

The inverse Fourier transform of array W is taken to determine the cross covariance array for the pair of arrays using subprograms HARM and IFEXIT.

5. Operation 4

The cross covariance array is rearranged in lag form and the corresponding array of cross correlation coefficients is computed. This array is searched for a peak positive value which, if found, is then converted into the motion vector which it signifies. Subprograms LAGWS, WINDOW, XCMAX, XIJMAX and VECTOR are used in this operation.

6. Operation 5

If requested in the run parameters, selected arrays of input and computed data are printed using subprogram OUTLAG.

```
C     MAIN PROGRAM FOR COMPUTATION OF CLOUD MOTION                        CMXC0001
      COMMON INTEGR(88192)                                                CMXC0002
      DIMENSION U(64,64),V(64,64),W(64,64),Z(64,64),WT(65,65)             CMXC0003
      DIMENSION A(64,64),B(64,64),C(64,64),TARA(64,64),TARB(64,64)        CMXC0004
      DIMENSION YWMN(33,33),YWSD(33,33),XCVP(33,33),VARA(32,32)           CMXC0005
      DIMENSION XCV(33,33),S(64),RL(5)                                    CMXC0006
      DIMENSION MA(64,64),MB(64,64),KARA(64,64),KARB(64,64),LARA(32,32)   CMXC0007
      DIMENSION INV(64),LIST(32),MH(3)                                    CMXC0008
      DIMENSION LAGRAY(33,33),AXCLD(18),TIM(5,500)                        CMXC0009
      DIMENSION REPL(18),THR(18),TAPEN(18),PRNTN(18),SDEVN(18),RN(18)     CMXC0010
      COMPLEX U,V,W,Z,WT,ZUVW                                             CMXC0011
      COMPLEX ZI                                                          CMXC0012
      EQUIVALENCE (    U(1,1),INTEGR(     1)),(    V(1,1),INTEGR( 8193))  CMXC0013
      EQUIVALENCE (    W(1,1),INTEGR(16385)),(    Z(1,1),INTEGR(24577))   CMXC0014
      EQUIVALENCE (   WT(1,1),INTEGR(32769)),(    A(1,1),INTEGR(41219))   CMXC0015
      EQUIVALENCE (    B(1,1),INTEGR(45315)),(    C(1,1),INTEGR(49411))   CMXC0016
      EQUIVALENCE (TARA(1,1),INTEGR(53507)),(TARB(1,1),INTEGR(57603))     CMXC0017
      EQUIVALENCE (YWMN(1,1),INTEGR(61699)),(YWSD(1,1),INTEGR(62788))     CMXC0018
      EQUIVALENCE (XCVP(1,1),INTEGR(63877)),(VARA(1,1),INTEGR(64966))     CMXC0019
      EQUIVALENCE (XCV (1,1),INTEGR(65990)),(TIM (1,1),INTEGR(67079))     CMXC0020
      EQUIVALENCE (    S(1)   ,INTEGR(69579)),(  RL(1)   ,INTEGR(69643))  CMXC0021
      EQUIVALENCE (MA   (1,1),INTEGR(69648)),(   MB(1,1),INTEGR(73744))   CMXC0022
      EQUIVALENCE (KARA(1,1),INTEGR(77840)),(KARB(1,1),INTEGR(81936))     CMXC0023
      EQUIVALENCE (LARA(1,1),INTEGR(86032)),( INV(1)   ,INTEGR(87056))    CMXC0024
      EQUIVALENCE (LIST(1)   ,INTEGR(87120))                              CMXC0025
    1 FORMAT (7X,I4,9X,I4,26X,I10)                                        CMXC0026
    2 FORMAT (10HOLATITUDE=,F9.5,13HN  LONGITUDE=,F9.5,17HW  E-W MESH SICMXC0027
     1ZE=,F8.5,19HDEG  N-S MESH SIZE=,F8.5,25HDEG TIME BETWEEN FRAMES=,   CMXC0028
     2F6.0, 8HMINUTES   )                                                 CMXC0029
    3 FORMAT (1H1)                                                        CMXC0030
    4 FORMAT (38HOTAPE READING AND ARRAY FORMATION TOOK,F10.5,7HSECONDS)CMXC0031
    5 FORMAT (30HOTIME IN SECONDS FOR OPERATION ,I4,6H WAS  ,F15.8)       CMXC0032
    6 FORMAT (54HOFOLLOWING ARE TOTALS FOR ALL ARRAY PAIRS IN THIS RUN )CMXC0033
    7 FORMAT (I3,18A4)                                                    CMXC0034
    8 FORMAT (1HO,I8,2H  ,18A4 )                                          CMXC0035
      CALL COUNTV                                                         CMXC0036
      PRINT 3                                                             CMXC0037
      READ (5,7) NTAPE,TAPEN                                              CMXC0038
      PRINT 8,NTAPE,TAPEN                                                 CMXC0039
      READ (5,7) NTHR ,THR                                                CMXC0040
      PRINT 8,NTHR,THR                                                    CMXC0041
      READ (5,7) NREPL,REPL                                               CMXC0042
      PRINT 8,NREPL,REPL                                                  CMXC0043
      READ (5,7) NDEV,SDEVN                                               CMXC0044
      PRINT 8,NDEV,SDEVN                                                  CMXC0045
```

```
      READ (5,7) NPRN,PRNTN
      PRINT 8,NPRN,PRNTN
      READ (5,1) MINCLD,MAXCLD,IXZED
      INITIX=IXZED
      ISIZE =88192
C
C
C
      AMAX=0
      IMAX=0
      JMAX=0
      IBM=0
      JBM=0
      TIM1=0
      TIM2=0
      TIM3=0
      TIM4=0
      TIM5=0
      ZI=(0.0,1.0)
C     SET MH ARRAY WITH EXPONENTS OF 2 FOR 64,64,1 TO USE WITH HARM
      MH(1)=6
      MH(2)=6
      MH(3)=0
      MH1=2**MH(1)
      MH2=2**MH(2)
      MHF1=MH1/2
      MHF2=MH2/2
      MHW1=MHF1+1
      MHW2=MHF2+1
      MWT=MH1+1
      NWT=MH2+1
      MPT=MHW1
      NPT=MHW2
      NHARM=0
      IFS=0
      PRINT 3
      IF (NTAPE.NE.2) GO TO 100
      CALL RDTAPE
      GO TO 101
  100 READ (5,7) NRN,RN
      PRINT 8,NRN,RN
  101 DO 102 I=1,ISIZE
  102 INTEGR(I)=0
      CALL SETHRM  (NHARM,IFERR,IFS,MH,MH1,MH2,U,INV,S)
      CALL TIMEV(RDTIM)
```

```
C     PRINT TIME USED TO READ DATA AND SET UP PROGRAM
      PRINT 4,RDTIM
      DO 5000 ITHRUN=1,NTHR
C     INCREMENT COUNTER OF MAXIMUM CLOUD DATA THRESHOLDS USED
      DO 3000 ITHREP=1,NREPL
C     INCREMENT COUNTER OF REPLICATIONS FOR ONE ARRAY PAIR
      READ (15) LIST
      IR=LIST(30)
      JR=LIST(31)
      NTOT=IR*JR
C
C     FIRST READ IN THE NUMBERS  OF ARRAY PAIRS E-W AND N-S
C     THEN COMPUTE THE TOTAL NUMBER TO BE PROCESSED
C
      DO 500 ITRY=1,NTOT
C  BEGINNING  OF  OPERATION  1
      CALL COUNTV
      CALL NULOOP (U,V,W,TARA,TARB,MB,MH1,MH2)
      READ (15) RL
      READ (15) KARA
      READ (15) KARB
      PRINT 2,RL
      CALL SETRAY (RL,DELI,DELJ,TIMEK)
      CALL ZFRAME (KARA,MH1,MH2,LARA,MHF1,MHF2,MINCLD,MAXCLD,NFRQA,
     1PCNTA,AMEN,SDEVA,VARA,INITIX,TARA,NDEV)
      CALL ZNORM (KARB,MH1,MH2,MINCLD,MAXCLD,NFRQB,PCNTB,BMEN,SDEVB,
     1INITIX,TARB,NDEV)
      CALL TIMNSD (TARB,YWMN,YWSD,MH1,MH2,MHW1,MHW2,YMNMN,YMNSD,YSDMN,
     1YSDSD,ZTEST)
      DO 200 IUV=1,MH1
      DO 200 JUV=1,MH2
      Z(IUV,JUV)=TARA(IUV,JUV)+(ZI*TARB(IUV,JUV))
  200 CONTINUE
C TERMINATION OF  OPERATION  1
      CALL TIMEV(TIM(1,ITRY))
C  BEGINNING  OF  OPERATION  2
      CALL COUNTV
      NOPN=1
      PRINT 5,NOPN,TIM(NOPN,ITRY)
      IFS=-2
      NHARM=4
      CALL HARM (Z,MH,INV,S,IFS,IFERR)
      IF (IFERR.EQ.0) GO TO 201
      CALL IFEXIT (NHARM,IFERR,IFS,MH,MH1,MH2,Z,INV,S)
      GO TO 5001
```

```
  201 CONTINUE
      MMNN=MH1*MH2
      CALL SPLITV (MH1,MH2,MMNN,MHF1,W,Z)
C TERMINATION OF  OPERATION  2
      CALL TIMEV(TIM(2,ITRY))
C  BEGINNING  OF  OPERATION  3
      CALL COUNTV
      NOPN=2
      PRINT 5,NOPN,TIM(NOPN,ITRY)
      IFS=2
      NHARM=3
      CALL HARM (W,MH,INV,S,IFS,IFERR)
      IF (IFERR.EQ.0) GO TO 211
      CALL IFEXIT (NHARM,IFERR,IFS,MH,MH1,MH2,W,INV,S)
      GO TO 5001
  211 CONTINUE
C TERMINATION OF  OPERATION  3
      CALL TIMEV(TIM(3,ITRY))
C  BEGINNING  OF  OPERATION  4
      CALL COUNTV
      NOPN=3
      PRINT 5,NOPN,TIM(NOPN,ITRY)
      CALL LAGWS (W,WT,MH1,MH2,MWT,NWT)
      MXSWCH=0
      IF (ZTEST.NE.0) GO TO 214
      MXSWCH=1
      GO TO 215
  214 CONTINUE
      CALL WINDOW (WT,MWT,NWT,XCV,MHW1,MHW2,XCVP,MPT,NPT,YWSD,MHW1,MHW2,
     1SDEVA,MXSWCH)
      IF (MXSWCH.NE.0) GO TO 215
      CALL XCMAX (XCVP,AMAX,MPT,NPT,IMAX,JMAX,MXSWCH)
  215 IF(MXSWCH.EQ.0) GO TO 220
      CALL WINDOW (WT,MWT,NWT,XCV,MHW1,MHW2,XCVP,MPT,NPT,YWSD,MHW1,MHW2,
     1SDEVA,MXSWCH)
      IF (MXSWCH.NE.0) GO TO 230
      CALL XCMAX (XCVP,AMAX,MPT,NPT,IMAX,JMAX,MXSWCH)
      IF (MXSWCH.NE.0) GO TO 230
  220 CALL XIJMAX (MPT,NPT,IMAX,JMAX,IBM,JBM,AMAX,MAXA)
      CALL VECTOR (IBM,JBM,DELI,DELJ,TIMEK,AMAX)
C TERMINATION OF  OPERATION  4
  230 CONTINUE
      CALL TIMEV(TIM(4,ITRY))
C  BEGINNING  OF  OPERATION  5
      CALL COUNTV
```

```
      NOPN=4
      PRINT 5,NOPN,TIM(NOPN,ITRY)
C     BY-PASS TO 390 IF NO ARRAY PRINT-OUTS ARE SPECIFIED
      IF (NPRN.EQ.0) GO TO 390
C     PROCEED TO PRINT-OUT OF REQUESTED ARRAYS
      DO 300 K=1,33
      LAGRAY(K,1)=11111
  300 LAGRAY(33,K)=11111
      DO 305 I=1,32
      DO 305 J=2,33
      K=J-1
  305 LAGRAY(I,J)=LARA(I,K)
      CALL OUTLAG(LAGRAY,1,IBM,JBM)
      DO 310 K=1,33
      LAGRAY(K,1)=11111
  310 LAGRAY(1,K)=11111
      DO 311 K=1,32
      KI=16+K+IBM
      DO 311 L=2,33
      LJ=15+L+JBM
  311 LAGRAY(K,L)=KARB(KI,LJ)
      CALL OUTLAG (LAGRAY,2,IBM,JBM)
      DO 320 K=1,33
      DO 320 L=1,33
      LAGRAY(K,L)=YWMN(K,L)
  320 CONTINUE
      CALL OUTLAG(LAGRAY,3,IBM,JBM)
      DO 330 K=1,33
      DO 330 L=1,33
      LAGRAY(K,L)=YWSD(K,L)*10.0
  330 CONTINUE
      CALL OUTLAG(LAGRAY,4,IBM,JBM)
      DO 340 K=1,33
      DO 340 L=1,33
      LAGRAY(K,L)=XCVP(K,L)*400.0
  340 CONTINUE
      CALL OUTLAG(LAGRAY,5,IBM,JBM)
C TERMINATION OF  OPERATION  5
      CALL TIMEV(TIM(5,ITRY))
      NOPN=5
      PRINT 5,NOPN,TIM(NOPN,ITRY)
C     ARRAY PRINT-OUTS COMPLETED IF SPECIFIED
  390 CONTINUE
      PRINT 3
C     ALL PROCESSING FOR THIS ARRAY PAIR IS COMPLETED
```

```
  500 CONTINUE                                                          CMXC0226
C       ALL ARRAY PAIRS IN REPLICATION COMPLETED. CUMULATE OPERATION TIMESCMXC0227
        DO 400 J=1,NTOT                                                 CMXC0228
        TIM1=TIM1+TIM(1,J)                                              CMXC0229
        TIM2=TIM2+TIM(2,J)                                              CMXC0230
        TIM3=TIM3+TIM(3,J)                                              CMXC0231
        TIM4=TIM4+TIM(4,J)                                              CMXC0232
        TIM5=TIM5+TIM(5,J)                                              CMXC0233
  400 CONTINUE                                                          CMXC0234
        REWIND 15                                                       CMXC0235
C       THIS REPLICATION COMPLETED. RETURN IF MORE SPECIFIED            CMXC0236
 3000 CONTINUE                                                          CMXC0237
C       REPLICATIONS COMPLETED. READ NEW MAX THRESHOLD IF ANY           CMXC0238
        NNTH=ITHRUN-1                                                   CMXC0239
        IF (NNTH.EQ.0) GO TO 4000                                       CMXC0240
        READ (5,7) MAXCLD,AXCLD                                         CMXC0241
 4000 CONTINUE                                                          CMXC0242
C       REITERATE THROUGH MAIN LOOP IF NEW THRESHOLD READ IN            CMXC0243
 5000 CONTINUE                                                          CMXC0244
        PRINT 3                                                         CMXC0245
        PRINT 6                                                         CMXC0246
        LX=1                                                            CMXC0247
        PRINT 5,LX,TIM1                                                 CMXC0248
        LX=2                                                            CMXC0249
        PRINT 5,LX,TIM2                                                 CMXC0250
        LX=3                                                            CMXC0251
        PRINT 5,LX,TIM3                                                 CMXC0252
        LX=4                                                            CMXC0253
        PRINT 5,LX,TIM4                                                 CMXC0254
        LX=5                                                            CMXC0255
        PRINT 5,LX,TIM5                                                 CMXC0256
 5001 CONTINUE                                                          CMXC0257
        STOP                                                            CMXC0258
        END                                                             CMXC0259
```

```
      SUBROUTINE BKGRND (IX,SDEV,AMEAN,V)
C
C     FOR INITIAL ENTRY TO BKGRND,SET IX=AN ODD INTEGER OF LESS THAN 10 D
C       WE CHOOSE THIS NUMBER TO BE 451798973
C
C   SDEV AND AMEAN ARE STANDARD DEVIATION AND MEAN OF PORTION OF SAMPLE
C   WHICH IS NOT BACKGROUND (I. E., REFLECTIVITY EXCEEDS THRESHHOLD VALU
C
C   V IS THE NEXT UNIFORMLY DISTRIBUTED RANDOM VALUE WITH THE SAME MEAN
C   STANDARD DEVIATION AS THE NON-BACKGROUND PART OF THIS SAMPLE.
C   USE IT TO REPLACE THE BACKGROUND VALUE
C
      A=0.0
      DO 50 I=1,12
      IY=IX*65539
      IF(IY)5,6,6
5     IY=IY+2147483647+1
6     Y = IY
      Y = Y* .4656613E-9
      IX=IY
50    A=A+Y
      V=(A-6.0)*SDEV+AMEAN
      RETURN
      END
```

```
C      HARM  DISCRETE FOURIER TRANSFORM. BASIC FORTRAN IV
C
C     INPUT PARAMETERS TO BE SET BY USER BEFORE ENTERING HARM-
C
C     A IS A 3-DIMENSIONAL ARRAY OF COMPLEX COEFFICIENTS,
C     OF DIMENSION(N(1),N(2),N(3)).
C     THE A'S ARE STORED WITH REAL PART OF A(I1,I2,I3) IN THE LOCATION
C     WITH INDEX  2*(I3*N(1)*N(2)+I2*N(1)+I1)+1  AND THE IMAGINARY PART
C     IN THE LOCATION IMMEDIATELY FOLLOWING
C     IF THE FOURIER  SERIES   IS REQUESTED,  ARRAY  A  IS REPLACED BY
C     X(J1,J2,J3)=SUM A(K1,K2,K3)*W1**(K1*J1)*W2**(K2*J2)*W3**(K3*J3)
C     SUMMED OVER K1=0,N(1)-1,    K2=0,N(2)-1,    K3=0,N(3)-1
C     WHERE WI=N(I)-TH ROOT OF UNITY.
C
C     M(I),I=1,2,3,WHERE N(I)=2**M(I) IS THE NO.OF PTS.IN THE I-TH.DIM.
C     THE DIMENSION OF  A  IN THE CALLING PROGRAM SHOULD BE TWICE THE
C     NUMBER OF COMPLEX ELEMENTS OF THE LARGEST  A  ARRAY TO BE PROCESS-
C     ED
C     THE COMPLEX X'S ARE STORED IN THE SAME MANNER AS A.
C
C     IF THE FOURIER TRANSFORM IS REQUESTED, THE ARGUMENT  A  IS TAKEN
C     TO BE  X  AND IS REPLACED BY THE ARRAY  A  SATISFYING THE FOURIER
C     SERIES.
C
C     LET MT=MAX(M(1),M(2),M(3))-2, NT=2**MT, WITH  M  BEING THE  M
C     GIVEN WHEN THE TABLES ARE SET.
C
C     S(J)=SIN(J*PI/(2*NT ) ), J = 1,2,3,...NT-1.
C
C     INV(J+1)=WORD CONTAINING BITS OF J IN INVERTED ORDER IN ITS
C     RIGHTMOST MT BIT POSITIONS, FOR J = 0,1,2,...,NT-1.
C
C     LET  IFS=0 TO SET UP SIN AND INV TAB3ES.
C          IFS=+1 TO SET UP SIN AND INV TABLES AND DO FOURIER SERIES.
C          IFS=-1 TO SET UP SIN AND INV TABLES AND DO FOURIER TRANSFORM.
C          IFS=+2  TO DO FOURIER SERIES ONLY.
C          IFS=-2 TO DO FOURIER TRANSFORM ONLY.
C
C     ONE DOES NOT HAVE TO REPEAT THE CALL TO 'HARM' WITH IFS=0,+1,-1
C     IF ONE DOES NOT CHANGE THE MAXIMUM  M.
C
C     IFERR=0 IF THE ARGUMENTS M ARE O.K.
C
C     IFERR=1 IF THERE IS AN ERROR IN CALLING 'HARM'
C     IF IFS=0,+1,-1,  IT MEANS THAT THE MAXIMUM M IS GREATER THAN 20
```

```
C     OR LESS THAN 3                                                    HARM0046
C     IF IFS=+-2, IT MEANS THAT A SUFFICIENTLY LARGE SIN AND INV TABLE  HARM0047
C     HAS NOT BEEN COMPUTED.  ONE MUST CALL  'HARM' WITH  IFS=0,+-1 AND HARM0048
C     WITH A MAX M(I) GREATER THAN OR EQUAL TO THE MAX M(I) FOR WHICH A HARM0049
C     FOURIER TRANSFORM IS TO BE COMPUTED.                              HARM0050
C                                                                       HARM0051
C     IFERR=-1 IF ONE IS CALLING ON 'HARM' WITH IFS=0,+-1  TO COMPUTE   HARM0052
C     SIN, INV TABLES WHICH IT ALREADY HAS COMPUTED ON A PREVIOUS       HARM0053
C     CALL TO HARM WITH THE SAME MAXIMUM M                              HARM0054
C                                                                       HARM0055
C     REFERENCE- AN ALGORITHM FOR THE MACHINE CALCULATION OF COMPLEX    HARM0056
C     FOURIER SERIES, BY J.W.COOLEY AND J.W. TUKEY, MATH. OF COMP.      HARM0057
C     VOL. 19, P.297-301, APRIL 1965.                                   HARM0058
C                                                                       HARM0059
C                                                                       HARM0060
      SUBROUTINE HARM(A,M,INV,S,IFS,    IFERR)                          HARM0061
      DIMENSION A(1),INV(1),S(1),N(3),M(3),NP(3),W(2),W2(2),W3(2)       HARM0062
      EQUIVALENCE (N1,N(1)),(N2,N(2)),(N3,N(3))                         HARM0063
   10 IF (IABS(IFS)-1) 900,900,12                                       HARM0064
   12 MTT=MAX0(M(1),M(2),M(3)) -2                                       HARM0065
      ROOT2 = SQRT(2.)                                                  HARM0066
      IF (MTT-MT ) 14,14,13                                             HARM0067
   13 IFERR=1                                                           HARM0068
    1 RETURN                                                            HARM0069
   14 IFERR=0                                                           HARM0070
      M1=M(1)                                                           HARM0071
      M2=M(2)                                                           HARM0072
      M3=M(3)                                                           HARM0073
      N1=2**M1                                                          HARM0074
      N2=2**M2                                                          HARM0075
      N3=2**M3                                                          HARM0076
      IF (IFS) 16,1,20                                                  HARM0077
C     TO CALCULATE TRANSFORM REPLACE A BY CONJG(A)/N                    HARM0078
   16 NTOT = N1*N2*N3                                                   HARM0079
      FN = NTOT                                                         HARM0080
      DO 18 I=1,NTOT                                                    HARM0081
      A(2*I-1) = A(2*I-1)/FN                                            HARM0082
   18 A(2*I) = -A(2*I)/FN                                               HARM0083
   20 NP(1)=N1*2                                                        HARM0084
      NP(2)= NP(1)*N2                                                   HARM0085
      NP(3)=NP(2)*N3                                                    HARM0086
      DO 250 ID=1,3                                                     HARM0087
      IL = NP(3)-NP(ID)                                                 HARM0088
      IL1 = IL+1                                                        HARM0089
      MI = M(ID)                                                        HARM0090
```

```
      IF (MI)250,250,30
   30 IDIF=NP(ID)
      KBIT=NP(ID)
      MEV = 2*(MI/2)
      IF (MI - MEV )60,60,40
C     M IS ODD. DO L=1 CASE
   40 KBIT=KBIT/2
      KL=KBIT-2
      DO 50 I=1,IL1,IDIF
      KLAST=KL+I
      DO 50 K=I,KLAST,2
      KD=K+KBIT
C     DO ONE STEP WITH L=1,J=0
C     A(K)=A(K)+A(KD)
C     A(KD)=A(K)-A(KD)
C
      T=A(KD)
      A(KD)=A(K)-T
      A(K)=A(K)+T
      T=A(KD+1)
      A(KD+1)=A(K+1)-T
   50 A(K+1)=A(K+1)+T
      IF (MI - 1)250,250,52
   52 LFIRST =3
C     DEF - JLAST = 2**(L-2) -1
      JLAST=1
      GO TO 70
C     M IS EVEN
   60 LFIRST = 2
      JLAST=0
   70 DO 240 L=LFIRST,MI,2
      JJDIF=KBIT
      KBIT=KBIT/4
      KL=KBIT-2
C     DO FOR J=0
      DO 80 I=1,IL1,IDIF
      KLAST=I+KL
      DO 80 K=I,KLAST,2
      K1=K+KBIT
      K2=K1+KBIT
      K3=K2+KBIT
C
C     DO TWO STEPS WITH J=0
C     A(K)=A(K)+A(K2)
C     A(K2)=A(K)-A(K2)
```

```
C       A(K1)=A(K1)+A(K3)
C       A(K3)=A(K1)-A(K3)
C
C       A(K)=A(K)+A(K1)
C       A(K1)=A(K)-A(K1)
C       A(K2)=A(K2)+A(K3)*I
C       A(K3)=A(K2)-A(K3)*I
C
        T=A(K2)
        A(K2)=A(K)-T
        A(K)=A(K)+T
        T=A(K2+1)
        A(K2+1)=A(K+1)-T
        A(K+1)=A(K+1)+T
C
        T=A(K3)
        A(K3)=A(K1)-T
        A(K1)=A(K1)+T
        T=A(K3+1)
        A(K3+1)=A(K1+1)-T
        A(K1+1)=A(K1+1)+T
C
        T=A(K1)
        A(K1)=A(K)-T
        A(K)=A(K)+T
        T=A(K1+1)
        A(K1+1)=A(K+1)-T
        A(K+1)=A(K+1)+T
C
        R=-A(K3+1)
        T = A(K3)
        A(K3)=A(K2)-R
        A(K2)=A(K2)+R
        A(K3+1)=A(K2+1)-T
   80   A(K2+1)=A(K2+1)+T
        IF (JLAST) 235,235,82
   82   JJ=JJDIF    +1
C
C       DO FOR J=1
        ILAST= IL +JJ
        DO 85 I = JJ,ILAST,IDIF
        KLAST = KL+I
        DO 85 K=I,KLAST,2
        K1 = K+KBIT
        K2 = K1+KBIT
```

```
      K3 = K2+KBIT                                                      HARM0181
C     LETTING W=(1+I)/ROOT2,W3=(-1+I)/ROOT2,W2=I,                       HARM0182
C     A(K)=A(K)+A(K2)*I                                                 HARM0183
C     A(K2)=A(K)-A(K2)*I                                                HARM0184
C     A(K1)=A(K1)*W+A(K3)*W3                                            HARM0185
C     A(K3)=A(K1)*W-A(K3)*W3                                            HARM0186
C                                                                       HARM0187
C     A(K)=A(K)+A(K1)                                                   HARM0188
C     A(K1)=A(K)-A(K1)                                                  HARM0189
C     A(K2)=A(K2)+A(K3)*I                                               HARM0190
C     A(K3)=A(K2)-A(K3)*I                                               HARM0191
C                                                                       HARM0192
      R =-A(K2+1)                                                       HARM0193
      T = A(K2)                                                         HARM0194
      A(K2) = A(K)-R                                                    HARM0195
      A(K) = A(K)+R                                                     HARM0196
      A(K2+1)=A(K+1)-T                                                  HARM0197
      A(K+1)=A(K+1)+T                                                   HARM0198
C                                                                       HARM0199
      AWR=A(K1)-A(K1+1)                                                 HARM0200
      AWI = A(K1+1)+A(K1)                                               HARM0201
      R=-A(K3)-A(K3+1)                                                  HARM0202
      T=A(K3)-A(K3+1)                                                   HARM0203
      A(K3)=(AWR-R)/ROOT2                                               HARM0204
      A(K3+1)=(AWI-T)/ROOT2                                             HARM0205
      A(K1)=(AWR+R)/ROOT2                                               HARM0206
      A(K1+1)=(AWI+T)/ROOT2                                             HARM0207
      T= A(K1)                                                          HARM0208
      A(K1)=A(K)-T                                                      HARM0209
      A(K)=A(K)+T                                                       HARM0210
      T=A(K1+1)                                                         HARM0211
      A(K1+1)=A(K+1)-T                                                  HARM0212
      A(K+1)=A(K+1)+T                                                   HARM0213
      R=-A(K3+1)                                                        HARM0214
      T=A(K3)                                                           HARM0215
      A(K3)=A(K2)-R                                                     HARM0216
      A(K2)=A(K2)+R                                                     HARM0217
      A(K3+1)=A(K2+1)-T                                                 HARM0218
   85 A(K2+1)=A(K2+1)+T                                                 HARM0219
      IF(JLAST-1) 235,235,90                                            HARM0220
   90 JJ= JJ + JJDIF                                                    HARM0221
C                                                                       HARM0222
C     NOW DO THE REMAINING J'S                                          HARM0223
      DO 230 J=2,JLAST                                                  HARM0224
C                                                                       HARM0225
```

```
      FETCH W'S                                                       HARM0226
C     DEF- W=W**INV(J), W2=W**2, W3=W**3                              HARM0227
 [illegible] I=INV(J+1)                                                  HARM0228
 [illegible] IC=NT-I                                                     HARM0229
      W(1)=S(IC)                                                      HARM0230
      W(2)=S(I)                                                       HARM0231
      I2=2*I                                                          HARM0232
      I2C=NT-I2                                                       HARM0233
      IF(I2C)120,110,100                                              HARM0234
C                                                                     HARM0235
C     2*I IS IN FIRST QUADRANT                                        HARM0236
  100 W2(1)=S(I2C)                                                    HARM0237
      W2(2)=S(I2)                                                     HARM0238
      GO TO 130                                                       HARM0239
  110 W2(1)=0.                                                        HARM0240
      W2(2)=1.                                                        HARM0241
      GO TO 130                                                       HARM0242
C                                                                     HARM0243
C     2*I IS IN SECOND QUADRANT                                       HARM0244
  120 I2CC = I2C+NT                                                   HARM0245
      I2C=-I2C                                                        HARM0246
      W2(1)=-S(I2C)                                                   HARM0247
      W2(2)=S(I2CC)                                                   HARM0248
  130 I3=I+I2                                                         HARM0249
      I3C=NT-I3                                                       HARM0250
      IF(I3C)160,150,140                                              HARM0251
C                                                                     HARM0252
C     I3 IN FIRST QUADRANT                                            HARM0253
  140 W3(1)=S(I3C)                                                    HARM0254
      W3(2)=S(I3)                                                     HARM0255
      GO TO 200                                                       HARM0256
  150 W3(1)=0.                                                        HARM0257
      W3(2)=1.                                                        HARM0258
      GO TO 200                                                       HARM0259
C                                                                     HARM0260
  160 I3CC=I3C+NT                                                     HARM0261
      IF(I3CC)190,180,170                                             HARM0262
C                                                                     HARM0263
C     I3 IN SECOND QUADRANT                                           HARM0264
  170 I3C=-I3C                                                        HARM0265
      W3(1)=-S(I3C)                                                   HARM0266
      W3(2)=S(I3CC)                                                   HARM0267
      GO TO 200                                                       HARM0268
  180 W3(1)=-1.                                                       HARM0269
      W3(2)=0.                                                        HARM0270
```

```
      GO TO 200
C
C     3*I IN THIRD QUADRANT
  190 I3CCC=NT+I3CC
      I3CC = -I3CC
      W3(1)=-S(I3CCC)
      W3(2)=-S(I3CC)
  200 ILAST=IL+JJ
      DO 220 I=JJ,ILAST,IDIF
      KLAST=KL+I
      DO 220 K=I,KLAST,2
      K1=K+KBIT
      K2=K1+KBIT
      K3=K2+KBIT
C
C     DO TWO STEPS WITH J NOT 0
C     A(K)=A(K)+A(K2)*W2
C     A(K2)=A(K)-A(K2)*W2
C     A(K1)=A(K1)*W+A(K3)*W3
C     A(K3)=A(K1)*W-A(K3)*W3
C
C     A(K)=A(K)+A(K1)
C     A(K1)=A(K)-A(K1)
C     A(K2)=A(K2)+A(K3)*I
C     A(K3)=A(K2)-A(K3)*I
C
      R=A(K2)*W2(1)-A(K2+1)*W2(2)
      T=A(K2)*W2(2)+A(K2+1)*W2(1)
      A(K2)=A(K)-R
      A(K)=A(K)+R
      A(K2+1)=A(K+1)-T
      A(K+1)=A(K+1)+T
C
      R=A(K3)*W3(1)-A(K3+1)*W3(2)
      T=A(K3)*W3(2)+A(K3+1)*W3(1)
      AWR=A(K1)*W(1)-A(K1+1)*W(2)
      AWI=A(K1)*W(2)+A(K1+1)*W(1)
      A(K3)=AWR-R
      A(K3+1)=AWI-T
      A(K1)=AWR+R
      A(K1+1)=AWI+T
      T=A(K1)
      A(K1)=A(K)-T
      A(K)=A(K)+T
      T=A(K1+1)
```

```
      A(K1+1)=A(K+1)-T                                                  HARM0316
      A(K+1)=A(K+1)+T                                                   HARM0317
      R=-A(K3+1)                                                        HARM0318
      T=A(K3)                                                           HARM0319
      A(K3)=A(K2)-R                                                     HARM0320
      A(K2)=A(K2)+R                                                     HARM0321
      A(K3+1)=A(K2+1)-T                                                 HARM0322
  220 A(K2+1)=A(K2+1)+T                                                 HARM0323
C     END OF I AND K LOOPS                                              HARM0324
  230 JJ=JJDIF+JJ                                                       HARM0325
C     END OF J-LOOP                                                     HARM0326
  235 JLAST=4*JLAST+3                                                   HARM0327
  240 CONTINUE                                                          HARM0328
C     END OF  L  LOOP                                                   HARM0329
  250 CONTINUE                                                          HARM0330
C     END OF  ID  LOOP                                                  HARM0331
C                                                                       HARM0332
C     WE NOW HAVE THE COMPLEX FOURIER SUMS BUT THEIR ADDRESSES ARE      HARM0333
C     BIT-REVERSED.  THE FOLLOWING ROUTINE PUTS THEM IN ORDER           HARM0334
      NTSQ=NT*NT                                                        HARM0335
      M3MT=M3-MT                                                        HARM0336
  350 IF(M3MT) 370,360,360                                              HARM0337
C     M3 GR. OR EQ. MT                                                  HARM0338
  360 IGO3=1                                                            HARM0339
      N3VNT=N3/NT                                                       HARM0340
      MINN3=NT                                                          HARM0341
      GO TO 380                                                         HARM0342
C     M3 LESS THAN MT                                                   HARM0343
  370 IGO3=2                                                            HARM0344
      N3VNT=1                                                           HARM0345
      NTVN3=NT/N3                                                       HARM0346
      MINN3=N3                                                          HARM0347
  380 JJD3 = NTSQ/N3                                                    HARM0348
      M2MT=M2-MT                                                        HARM0349
  450 IF (M2MT)470,460,460                                              HARM0350
C     M2 GR. OR EQ. MT                                                  HARM0351
  460 IGO2=1                                                            HARM0352
      N2VNT=N2/NT                                                       HARM0353
      MINN2=NT                                                          HARM0354
      GO TO 480                                                         HARM0355
C     M2 LESS THAN MT                                                   HARM0356
  470 IGO2 = 2                                                          HARM0357
      N2VNT=1                                                           HARM0358
      NTVN2=NT/N2                                                       HARM0359
      MINN2=N2                                                          HARM0360
```

```
 480 JJD2=NTSQ/N2
     M1MT=M1-MT
 550 IF(M1MT)570,560,560
C    M1 GR. OR EQ. MT
 560 IGO1=1
     N1VNT=N1/NT
     MINN1=NT
     GO TO 580
C    M1 LESS THAN MT
 570 IGO1=2
     N1VNT=1
     NTVN1=NT/N1
     MINN1=N1
 580 JJD1=NTSQ/N1
 600 JJ3=1
     J=1
     DO 880 JPP3=1,N3VNT
     IPP3=INV(JJ3)
     DO 870 JP3=1,MINN3
     GO TO (610,620),IGO3
 610 IP3=INV(JP3)*N3VNT
     GO TO 630
 620 IP3=INV(JP3)/NTVN3
 630 I3=(IPP3+IP3)*N2
 700 JJ2=1
     DO 870 JPP2=1,N2VNT
     IPP2=INV(JJ2)+I3
     DO 860 JP2=1,MINN2
     GO TO (710,720),IGO2
 710 IP2=INV(JP2)*N2VNT
     GO TO 730
 720 IP2=INV(JP2)/NTVN2
 730 I2=(IPP2+IP2)*N1
 800 JJ1=1
     DO 860 JPP1=1,N1VNT
     IPP1=INV(JJ1)+I2
     DO 850 JP1=1,MINN1
     GO TO (810,820),IGO1
 810 IP1=INV(JP1)*N1VNT
     GO TO 830
 820 IP1=INV(JP1)/NTVN1
 830 I=2*(IPP1+IP1)+1
     IF (J-I) 840,845,845
 840 T=A(I)
     A(I)=A(J)
```

```
      A(J)=T                                                            HARM0406
      T=A(I+1)                                                          HARM0407
      A(I+1)=A(J+1)                                                     HARM0408
      A(J+1)=T                                                          HARM0409
  845 CONTINUE                                                          HARM0410
  850 J=J+2                                                             HARM0411
  860 JJ1=JJ1+JJD1                                                      HARM0412
C     END OF JPP1 AND JP2                                               HARM0413
  870 JJ2=JJ2+JJD2                                                      HARM0414
C     END OF JPP2 AND JP3 LOOPS                                         HARM0415
  880 JJ3 = JJ3+JJD3                                                    HARM0416
C     END OF JPP3 LOOP                                                  HARM0417
      IF(IFS) 882,1,1                                                   HARM0418
C                                                                       HARM0419
C     DOING TRANSFORM. REPLACE A BY CONJG(A).                           HARM0420
  882 DO 884 I=1,NTOT                                                   HARM0421
  884 A(2*I) = -A(2*I)                                                  HARM0422
      GO TO 1                                                           HARM0423
C     RETURN                                                            HARM0424
C                                                                       HARM0425
C     THE FOLLOWING PROGRAM COMPUTES THE SIN AND INV TABLES.            HARM0426
C                                                                       HARM0427
  900 MT=MAX0(M(1),M(2),M(3)) -2                                        HARM0428
      MT = MAX0(2,MT)                                                   HARM0429
  904 IF (MT-20)906,906,905                                             HARM0430
  905 IFERR = 1                                                         HARM0431
      GO TO 1                                                           HARM0432
C     RETURN                                                            HARM0433
  906 IFERR=0                                                           HARM0434
      NT=2**MT                                                          HARM0435
      NTV2=NT/2                                                         HARM0436
C     SET UP SIN TABLE                                                  HARM0437
C     THETA=PIE/2**(L+1) FOR L=1                                        HARM0438
  910 THETA=.7853981634                                                 HARM0439
C     JSTEP=2**(MT-L+1) FOR L=1                                         HARM0440
      JSTEP=NT                                                          HARM0441
C     JDIF=2**(MT-L) FOR L=1                                            HARM0442
      JDIF=NTV2                                                         HARM0443
      S(JDIF)=SIN(THETA)                                                HARM0444
      DO 950 L=2,MT                                                     HARM0445
      THETA=THETA/2.                                                    HARM0446
      JSTEP2=JSTEP                                                      HARM0447
      JSTEP=JDIF                                                        HARM0448
      JDIF=JSTEP/2                                                      HARM0449
      S(JDIF)=SIN(THETA)                                                HARM0450
```

```
      JC1=NT-JDIF                                                       HARM0451
      S(JC1)=COS(THETA)                                                 HARM0452
      JLAST=NT-JSTEP2                                                   HARM0453
      IF(JLAST - JSTEP) 950,920,920                                     HARM0454
  920 DO 940 J=JSTEP,JLAST,JSTEP                                        HARM0455
      JC=NT-J                                                           HARM0456
      JD=J+JDIF                                                         HARM0457
  940 S(JD)=S(J)*S(JC1)+S(JDIF)*S(JC)                                   HARM0458
  950 CONTINUE                                                          HARM0459
C                                                                       HARM0460
C     SET UP INV(J) TABLE                                               HARM0461
C                                                                       HARM0462
  960 MTLEXP=NTV2                                                       HARM0463
C     MTLEXP=2**(MT-L). FOR L=1                                         HARM0464
      LM1EXP=1                                                          HARM0465
C     LM1EXP=2**(L-1). FOR L=1                                          HARM0466
      INV(1)=0                                                          HARM0467
      DO 980 L=1,MT                                                     HARM0468
      INV(LM1EXP+1) = MTLEXP                                            HARM0469
      DO 970 J=2,LM1EXP                                                 HARM0470
      JJ=J+LM1EXP                                                       HARM0471
  970 INV(JJ)=INV(J)+MTLEXP                                             HARM0472
      MTLEXP=MTLEXP/2                                                   HARM0473
  980 LM1EXP=LM1EXP*2                                                   HARM0474
      IF(IFS) 12,1,12                                                   HARM0475
C     RETURN                                                            HARM0476
      END                                                               HARM0477
```

```
      SUBROUTINE IFEXIT (NHARM,IFERR,IFS,M,MM,NN,U,INV,S)               IFEX0001
      DIMENSION M(3),U(MM,NN),INV(MM),S(MM)                             IFEX0002
      COMPLEX U                                                         IFEX0003
    6 FORMAT (49H0 AN ERROR WAS DETECTED BY HARM AT ENTRY NUMBER  ,I3,  IFEX0004
     112H  IFERR WAS ,I3,10H  IFS WAS ,I3 )                             IFEX0005
   16 FORMAT (119H0PROGRAM HAS BEEN RESET FOR A 64X64 COMPLEX ARRAY AND IFEX0006
     1A SECOND ATTEMPT IS BEING MADE TO INITIALIZE SIN AND INV TABLES. )IFEX0007
   26 FORMAT (54H0 SECOND TRY WITH 64X64 ARRAY ALSO FAILED. JOB STOPPED)IFEX0008
      PRINT 6, NHARM, IFERR, IFS                                        IFEX0009
      IFERR=0                                                           IFEX0010
      IF (NHARM.GE.1) GO TO 1                                           IFEX0011
C   NHARM=0 SO ERROR OCCURRED IN TRYING TO INITIALIZE INV AND SIN TABLES IFEX0012
C   PROGRAM WILL SET HARM FOR 64X64 COMPLEX ARRAY AND PROCEED           IFEX0013
      PRINT 16                                                          IFEX0014
      M(1)=6                                                            IFEX0015
      M(2)=6                                                            IFEX0016
      M(3)=0                                                            IFEX0017
      CALL HARM (U,M,INV,S,0,IFERR)                                     IFEX0018
      IF (IFERR.EQ.0) GO TO 3                                           IFEX0019
      PRINT 26                                                          IFEX0020
    1 CONTINUE                                                          IFEX0021
      NHARM =99                                                         IFEX0022
    3 CONTINUE                                                          IFEX0023
      RETURN                                                            IFEX0024
      END                                                               IFEX0025
```

```
      SUBROUTINE LAGWS (WS,WT,MWS,NWS,MWT,NWT)
C
C   THIS REORGANIZES DATA OF COMPLEX  ARRAY WS(MWS,NWS) AND GENERATES A
C   NEW ARRAY WT(MWT,NWT) WHERE MWT=MWS+1 AND NWT=NWS+1 WHICH CONTAINS TH
C   SAME DATA AS IT WOULD APPEAR IN LAG COORDINATES. FOR MWS=64 AND NWS=6
C   THE RANGE OF ILAGS AND JLAGS IN WT WILL BE FROM -32 TO +32. THE POSIT
C   OF DATA CORRESPONDING TO ILAG= -32, -16, -08,   0, +08, +16, +32
C   WIL HAVE THE COORDINATE        I=  01,  17,  25,  33,  41,  49,  65
C   AND
C   OF DATA CORRESPONDING TO  JLAG= +32, +16, +08,   0, -08, -16, -32
C   WILL HAVE THE COORDINATE      J=  65,  49,  41,  33,  25,  17,  01
C
      DIMENSION WS(MWS,NWS), WT(MWT,NWT)
      COMPLEX WS,WT
      KIT=MWS/2
      LIT =KIT+1
      MIT=MWS+1
      KIS=KIT
      LIS=KIS
      KJT=NWS/2+1
      LJT=KJT+1
      MJT=NWS+1
      KJS=KJT+1
      LJS=NWS+KJS
      DO 30 IT=1,KIT
      IS=IT+KIS
      DO 10 JT=1,KJT
      JS=KJS-JT
      WT(IT,JT)=WS(IS,JS)
   10 CONTINUE
      DO 20 JT=LJT,MJT
      JS=LJS-JT
      WT(IT,JT)=WS(IS,JS)
   20 CONTINUE
   30 CONTINUE
      DO 60 IT=LIT,MIT
      IS=IT-LIS
      DO 40 JT=1,KJT
      JS=KJS-JT
      WT(IT,JT)=WS(IS,JS)
   40 CONTINUE
      DO 50 JT=LJT,MJT
      JS=LJS-JT
      WT(IT,JT)= WS(IS,JS)
   50 CONTINUE
```

```
60 CONTINUE                                                                    LAGW0046
   RETURN                                                                      LAGW0047
   END                                                                         LAGW0048
```

```
      SUBROUTINE NULOOP (U,V,W,A,B,MS,MM,NN)
      DIMENSION U(MM,NN),V(MM,NN),W(MM,NN),A(MM,NN),B(MM,NN),MS(MM,NN)
      COMPLEX U,V,W
      DO 20 I=1,MM
      DO 20 J=1,NN
      U(I,J)=0
      V(I,J)=0
      W(I,J)=0
      A(I,J)=0
      B(I,J)=0
      MS(I,J)=0
   20 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE OUTLAG (LAGRAY,NDATA,IBM,JBM)
C
C
C     THIS PRINTS OUT THE CONTENTS OF AN ARRAY ORGANIZED IN LAG FORMAT WITH
C     LAGS RANGING FROM -16 TO +16 IN THE ARRAY AND WITH THE HEADER FORMAT
C     NUMBERED NDATA. DATA IN THE ARRAY MUST BE IN INTEGER FORMAT AND MUST
C     NOT EXCEED 999 IN VALUE. ONLY THOSE ELEMENTS CORRESPONDING TO ILAGS
C     OF -16 THROUGH +15 WILL BE PRINTED ACROSS THE PAGE, THOUGH VERTICALLY
C     ALL ROWS CORRESPONDING TO ILAGS OF +16 DOWN THROUGH -16 WILL APPEAR
C
C     IF ONE ELEMENT OF THE ARRAY HAS SPECIAL MEANING ITS LAG COORDINATES
C     MUST BE INCLUDED IN THE CALL AS IBM,JBM.
C
C
C     FOR NDATA = 1  PRINTS DATA VALUES OF WINDOW ARRAY (AXES TRANSLATED)
C
C                 2  PRINTS DATA VALUES OF SEARCH AREA SUBARRAY SELECTED AS
C                      BEST MATCH (WITH AXES TRANSLATED)
C
C                 3  PRINTS MEAN VALUES OF SUBARRAYS OF SEARCH AREA BY LAGS
C
C                 4  PRINTS STANDARD DEVIATIONS OF SUBARRAYS OF SEARCH AREA
C
C                 5  PRINTS CROSS-CORRELATIONS IN PERCENTAGES FOR ALL LAGS
C
C
      DIMENSION LAGRAY(33,33),ILAG(32),JLAG(33)
C
    1 FORMAT ( 86H1DATA USED AS WINDOW ARRAY WITH COORDINATE AXES MOVED
     1SO COORDINATES APPEAR AS LAGS      )
    2 FORMAT (128H1DATA CONTAINED IN THE SEARCH AREA SUBARRAY IDENTIFIED
     1 AS THE BEST MATCH. COORDINATE AXES MOVED SO COORDINATES APPEAR AS
     2 LAGS      )
    3 FORMAT (116H1TRUNCATED MEANS OF SUBARRAYS OF SEARCH AREA CORRESPON
     1DING TO THE LAG VALUES OF WINDOW AREA RELATIVE TO SEARCH AREA     )
    4 FORMAT (119H1STANDARD DEVIATION (TENTHS) OF SEARCH AREA SUBARRAY C
     2ORRESPONDING TO LAG VALUES OF WINDOW AREA RELATIVE TO SEARCH AREA)
    5 FORMAT (129H1CROSS-CORRELATIONS (IN PERCENTAGE) BETWEEN WINDOW AND
     1 SEARCH AREA SUBARRAY ARRANGED BY LAG COORDINATES RELATIVE TO SEAR
     2CH AREA    )
   10 FORMAT (5H0LAGS,I3,31I4)
   11 FORMAT (1H0,I3,32I4)
      DO 100 I=1,32
      ILAG(I)=I-17
      JLAG(I)=I-17
```

```
  100 CONTINUE
      JLAG(33)=16
      GO TO (21,22,23,24,25),NDATA
      GO TO 30
   21 PRINT 1
      GO TO 30
   22 PRINT 2
      GO TO 30
   23 PRINT 3
      GO TO 30
   24 PRINT 4
      GO TO 30
   25 PRINT 5
   30 CONTINUE
      PRINT 10,(ILAG(I),I=1,32)
      DO 200 I=1,33
      J=34-I
      PRINT 11, JLAG(J),(LAGRAY(K,J),K=1,32)
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RAYSET (L,R,I,J,P,N,IR,JR)
      DIMENSION R(IR,JR,5),L(32),P(5)
      IN=(I+1)*N
      JN=(J+1)*N
      R(I,J,3)=P(5)
      R(I,J,4)=(P(1)-P(2))/L(11)
      R(I,J,1)=P(2)+JN*R(I,J,4)
      R(I,J,2)=P(3)+(P(4)-IN-1)*P(5)
      R(I,J,5)=L(29)
      RETURN
      END
```

```
      SUBROUTINE RDPIK (INA,INB,KOA,KOB,L,N,R,IA,JA,IB,JB,IK,JK,IR,JR,P
     1,JDISP)
      DIMENSION INA(IA,JA),INB(IB,JB),KOA(IK,JK),KOB(IK,JK)
      DIMENSION L(32),R(IR,JR,5),P(5)
      DO 400 J=1,JR
      DO 300 I=1,IR
      CALL     RAYSET (L,R,I,J,P,N,IR,JR)
      WRITE (15) (R(I,J,K),K=1,5)
      JDL=(J-1)*N+JDISP
      IDL=(I-1)*N
      DO 200 JX=1,JK
      JY=JDL+JX
      DO 100 IX=1,IK
      IY=IDL+IX
      IF (IX.GT.L(10)) GO TO 20
      IF (JX.GT.L(11)) GO TO 20
   10 CONTINUE
      KOA(IX,JX)=INA(IY,JY)
      KOB(IX,JX)=INB(IY,JY)
      GO TO 30
   20 CONTINUE
      KOA(IX,JX)=0
      KOB(IX,JX)=0
   30 CONTINUE
  100 CONTINUE
  200 CONTINUE
      WRITE (15) KOA
      WRITE (15) KOB
  300 CONTINUE
  400 CONTINUE
      READ (13) INA
      READ (14) INB
      RETURN
      END
```

```
      SUBROUTINE RDREC (M,N,I,J)                                        RDRE000
      DIMENSION M(I),N(J)                                               RDRE000
      READ (13) M                                                       RDRE000
      READ (14) N                                                       RDRE000
      RETURN                                                            RDRE000
      END                                                               RDRE000
```

```
      SUBROUTINE RDTAPE                                                 RDTA0001
C     SUBROUTINE   FOR READING TAPES FOR SUCCESSIVE ORBITS AND SAME AREARDTA0002
C     AND FORMING PAIRS OF 64X64 ARRAYS. RESULTS ARE OUTPUT ON A SINGLE RDTA0003
C     TAPE IN THE SEQUENCE OF ONE RECORD CONTAINING TITLE, LOCATION AND RDTA0004
C     NUMBER OF ARRAY PAIRS FOLLOWED BY TRIPLES OF ONE RECORD WITH TITLERDTA0005
C     I,J, AND APPROXIMATE COORDINATES,ONE RECORD OF DATA FOR THE 64X64 RDTA0006
C     POINTS FOR THE FIRST PASS, AND ONE RECORD OF DATA FOR THE SECOND  RDTA0007
C     PASS. THE LAST TRIPLE IS FOLLOWED BY A RECORD OF THE TITLE, PLACE RDTA0008
C     NUMBER OF PAIRS AND THE NMR TAPE DDNAME, STARTING AND ENDING TIMESRDTA0009
C     FOR EACH OF THE TAPES AND OTHER DATA                              RDTA0010
      COMMON INTEGR(88192)                                              RDTA0011
      DIMENSION INDATA(40000),INDATB(40000)                             RDTA0012
      DIMENSION KOUTA(4096),KOUTB(4096)                                 RDTA0013
      DIMENSION INBUFA(26),BUFA(7),PICTA(5),NGRIDA(4),TNMRA(8),XNMRA(7) RDTA0014
      DIMENSION INBUFB(26),BUFB(7),PICTB(5),NGRIDB(4),TNMRB(8),XNMRB(7) RDTA0015
      DIMENSION ABF(18),BBF(18),LIST(32),TITLE(3),PLACE(5),NPRS(3)      RDTA0016
      DIMENSION PARM(20),RAYS(500)                                      RDTA0017
      EQUIVALENCE (INDATA(1),INTEGR(1)), (INDATB(1),INTEGR(40001))      RDTA0018
      EQUIVALENCE (KOUTA(1),INTEGR(80001)),(KOUTB(1),INTEGR(84097))     RDTA0019
      EQUIVALENCE (INBUFA(1),BUFA(1)),(INBUFA(8),XNDRA),(INBUFA(9),MRCA)RDTA0020
      EQUIVALENCE (INBUFA(10),PICTA(1)),(INBUFA(15),NGRIDA(1))          RDTA0021
      EQUIVALENCE (INBUFB(1),BUFB(1)),(INBUFB(8),XNDRB),(INBUFB(9),MRCB)RDTA0022
      EQUIVALENCE (INBUFB(10),PICTB(1)),(INBUFB(15),NGRIDB(1))          RDTA0023
      EQUIVALENCE (INBUFA(19),TNMRA(1)),(INBUFB(19),TNMRB(1))           RDTA0024
      EQUIVALENCE (LIST(1),KEY),(LIST(2),TITLE(1)),(LIST(5),PLACE(1))   RDTA0025
      EQUIVALENCE (LIST(10),NPRS(1)),(LIST(13),XNMRA(1)),(LIST(32),KEND)RDTA0026
      EQUIVALENCE (LIST(20),XNMRB(1)),(LIST(27),XNADIR),(LIST(28),MERC) RDTA0027
      EQUIVALENCE (LIST(29),NTDIF),(INBUFA(1),ABF(1)),(INBUFB(1),BBF(1)))RDTA0028
      EQUIVALENCE (LIST(30),IRAYS),(LIST(31),JRAYS)                     RDTA0029
    1 FORMAT (20A4)                                                     RDTA0030
    2 FORMAT (75H1RUN QUESTIONED BECAUSE AT LEAST ONE INPUT TAPE WAS NOTRDTA0031
     1MERCATOR PROJECTION. )                                            RDTA0032
    3 FORMAT (71H1RUN QUESTIONED BECAUSE PICTURE LOCATIONS OR SCALES WERRDTA0033
     1E NOT IDENTICAL. )                                                RDTA0034
    4 FORMAT (65H1RUN TERMINATED BECAUSE INPUT AREA LARGER THAN 40000 DARDTA0035
     1TA POINTS. )                                                      RDTA0036
    5 FORMAT (46H0 THE TIME DIFFERENCE FOR THIS PICTURE PAIR IS,I8,10H  RDTA0037
     1MINUTES.        )                                                 RDTA0038
    6 FORMAT (36H0 ARRAY ORGANIZATION STEP COMPLETED.    )              RDTA0039
    7 FORMAT (16X,I4,60X)                                               RDTA0040
    8 FORMAT (1H1,20A4)                                                 RDTA0041
    9 FORMAT (16HONUMBER OF ROWS=  ,I6, 20H NUMBER OF COLUMNS= ,I6)     RDTA0042
  100 CONTINUE                                                          RDTA0043
      REWIND 13                                                         RDTA0044
      REWIND 14                                                         RDTA0045
```

```
      NDISP=16
      READ (5,1) PARM
      READ (5,7) NTIME
      PRINT 8,PARM
      DO 110 L=1,3
      TITLE(L)=PARM(L)
  110 CONTINUE
      READ (13) ABF
      READ (14) BBF
      IF (MRCA.EQ.MRCB) GO TO 120
      PRINT 2
  120 CONTINUE
      DO 130 LA=1,5
      IF (PICTA(LA).NE.PICTB(LA)) GO TO 150
  130 CONTINUE
      DO 140 LB=2,3
      IF (NGRIDA(LB).NE.NGRIDB(LB)) GO TO 150
  140 CONTINUE
C  PROJECTIONS, LOCATIONS AND SCALES OF TWO SAMPLES MATCH. FORM MATCHING
      GO TO 200
  150 PRINT 3
  200 CONTINUE
      KEY=1
      DO 210 LC=1,5
      PLACE(LC)=PICTA(LC)
  210 CONTINUE
      NPRS(1)=NGRIDA(2)
      NPRS(2)=NGRIDA(3)
      NPRS(3)=NPRS(1)*NPRS(2)
      PRINT 9,NPRS(2),NPRS(1)
      XNADIR=XNDRA
      MERC=MRCA
      IRAYS=(NPRS(1)/NDISP)-3
      JRAYS=(NPRS(2)/NDISP)-3
      IF (IRAYS.LT.1) IRAYS=1
      IF (JRAYS.LT.1) JRAYS=1
      IF (NPRS(3).LE.40000) GO TO 220
      PRINT 4
      STOP
  220 CONTINUE
      JDISP=NPRS(2)-(JRAYS+3)*NDISP
      KEND=1
      WRITE (15) LIST
      IA=LIST(10)
      JA=LIST(11)
```

```
      IB=LIST(10)
      JB=LIST(11)
      IK=NDISP*4
      JK=NDISP*4
      IR=LIST(30)
      JR=LIST(31)
      IRD=IA*JA
      JRD=IB*JB
      CALL RDREC (INDATA,INDATB,IRD,JRD)
  300 CONTINUE
  310 CONTINUE
      NTDIF=NTIME
      PRINT 5, NTDIF
      CALL RDPIK (INDATA,INDATB,KOUTA,KOUTB,LIST,NDISP,RAYS,IA,JA,IB,JB,
     1IK,JK,IR,JR,PLACE,JDISP)
      REWIND 13
      REWIND 14
      LIST(1)=9999
      WRITE (15) LIST
      END FILE 15
      REWIND 15
      PRINT 6
 5000 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SETHRM (NHARM,IFERR,IFS,M,MM,NN,U,INV,S)               SETH0001
      DIMENSION U(MM,NN),M(3),INV(MM),S(MM)                             SETH0002
      COMPLEX U                                                         SETH0003
      DO 600 I=1,MM                                                     SETH0004
      S(I)=0                                                            SETH0005
      INV(I)=0                                                          SETH0006
  600 CONTINUE                                                          SETH0007
      CALL HARM (U,M,INV,S,0,IFERR)                                     SETH0008
      IF (IFERR) 601,602,601                                            SETH0009
  601 CALL        IFEXIT (0     ,IFERR,IFS,M,MM,NN,U,INV,S)             SETH0010
  602 CONTINUE                                                          SETH0011
      RETURN                                                            SETH0012
      END                                                               SETH0013
```

```
      SUBROUTINE SETRAY (RL,DELI,DELJ,TIMEK)
C
C      INPUT TO THIS SUBROUTINE IS THE FIVE-WORD RECORD READ FROM ARRAY
C      TAPE PRECEDING THIS ARRAY PAIR. IT CONTAINS ARRAY-PAIR VALUES OF
C            LATITUDE IN DEGREES NORTH LATITUDE
C            LONGITUDE IN DEGREES WEST LONGITUDE
C            LATITUDINAL SCALE IN DEGREES
C            LONGITUDINAL SCALE IN DEGREES
C            TIME BETWEEN DATA MEASUREMENTS OF WINDOW AND SEARCH DATA
C              (TIME IS IN MINUTES)
C
C     OUTPUT FROM THE SUBROUTINE ARE THE THREE CONVERSION PARAMETERS
C      NEEDED TO CONVERT THE LAG COORDINATES OF THE CROSS-CORRELATION
C      PEAK INTO A MOTION VECTOR FOR THE WINDOW USED
C            DELI = THE EAST-WEST SPACING UNITS IN NAUTICAL MILES
C            DELJ = THE NORTH-SOUTH SPACING UNITS IN NAUTICAL MILES
C            TIMEK= THE TIME BETWEEN DATA MEASUREMENTS IN HOURS
C
      DIMENSION RL(5)
      RADS=RL(1)/57.295
      DELI= (RL(3) * 60.0) * COS(RADS)
      DELJ=RL(4) * 60.0
      TIMEK= RL(5)/60.0
      RETURN
      END
```

```
      SUBROUTINE SPLITV (MM,NN,MMNN,KII,UU,VV)
      DIMENSION UU(MMNN),VV(MMNN)
      COMPLEX UU,VV,UP,UM,UX,UY
      UU(1)=REAL(VV(1))*AIMAG(VV(1))
      III=MM+2
      DO 3001 I=2,MM
      II=III-I
      UP=VV(I)
      UM=VV(II)
      UX=CONJG(UP)+UM
      UY=UP-CONJG(UM)
      UU(I)=(0.,-0.25)*UX*UY
 3001 CONTINUE
      MMNN=MM*NN
      JB=MM+1
      JE=MMNN-MM+1
      JJJ=MMNN+2
      DO 3002 J=JB,JE,MM
      JJ=JJJ-J
      UP=VV(J)
      UM=VV(JJ)
      UX=CONJG(UP)+UM
      UY=UP-CONJG(UM)
      UU(J)=(0.,-0.25)*UX*UY
 3002 CONTINUE
      JB=JB+1
      JE=JE+1
      MMM=KII-1
      III=MMNN+III
      DO 3004   J=JB,JE,MM
      IE=MMM+J
      DO 3003 I=J,IE
      II=III-I
      UP=VV(I)
      UM=VV(II)
      UX=CONJG(UP)+UM
      UY=UP-CONJG(UM)
      UU(I)=(0.,-0.25)*UX*UY
 3003 CONTINUE
 3004 CONTINUE
      JB=JB+KII
      JE=JE+KII
      MMM=MMM-1
      DO 3006 J=JB,JE,MM
      IE=MMM+J
```

```
      DO 3005 I=J,IE
      II=III-I
      UU(I)=CONJG(UU(II))
 3005 CONTINUE
 3006 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE THRESH (MARRAY,MM,NN,MINCLD,MAXCLD,NFREQ,PRCENT,XMEAN,
     1SDEV,TARRAY,INITIX,NDEV)
      DIMENSION TARRAY(MM,NN),MARRAY(MM,NN)
    1 FORMAT (20HOTHRESHOLDS ARE MIN=,I4,5H MAX=,I4,21H VALID POINTS NUM
     1BER   ,I7,21H FOR A PERCENTAGE OF ,F6.2,10H THE MEAN=,F7.1,20H STA
     2NDARD DEVIATION=,F7.1)
      MSUM=0
      MSQSUM=0
      NFREQ=0
      PRCENT=0
      DO 20 J=1,NN
      DO 10 I=1,MM
      IF (MARRAY(I,J).LT.MINCLD) GO TO 10
      IF (MARRAY(I,J).GT.MAXCLD) GO TO 10
      NFREQ=NFREQ+1
      MSUM=MSUM + MARRAY(I,J)
      MSQSUM=MSQSUM + MARRAY(I,J)**2
   10 CONTINUE
   20 CONTINUE
      XFREQ=NFREQ
      XSUM=MSUM
      XSQSUM=MSQSUM
      XMEAN = XSUM/XFREQ
      PRCENT = (XFREQ*100.0)/(MM*NN)
      XVAR=((XSQSUM/XFREQ)-(XMEAN**2))*(XFREQ/(XFREQ-1.0))
      SDEV = SQRT (XVAR)
      DO 60 J=1,NN
      DO 50 I=1,MM
      IF (MARRAY(I,J).LT.MINCLD) GO TO 30
      IF (MARRAY(I,J).GT.MAXCLD) GO TO 31
      TARRAY(I,J) = MARRAY(I,J)
      GO TO 40
   30 CONTINUE
      DEVN=NDEV/(6.0)
      ADEV=SDEV*DEVN
      GO TO 32
   31 ADEV=0
   32 CALL BKGRND (INITIX,ADEV,XMEAN,V)
      TARRAY(I,J)=V
   40 CONTINUE
   50 CONTINUE
   60 CONTINUE
      NSUBS=(MM*NN)-NFREQ
      PRINT 1,MINCLD,MAXCLD,NFREQ,PRCENT,XMEAN,SDEV
      RETURN
```

END THRE0046

```
      SUBROUTINE T1MNSD(Y,YWMN,YWSD,MM,NN,MW,NW,YMNMN,YMNSD,YSDMN,YSDSD,T1MN0001
     1ZTEST)                                                            T1MN0002
      DIMENSION YWMN(MW,NW),YWSD(MW,NW),Y(MM,NN)                        T1MN0003
C     MUST HAVE MW=(MM/2)+1, NW=(NN/2)+1 UPON CALLING                   T1MN0004
    1 FORMAT (123H0FOR THE SEARCH AREA SUBARRAYS THE FOLLOWING STATISTICT1MN0005
     1S WERE FOUND AFTER THE SEARCH AREA MEAN WAS SUBTRACTED FROM THE DAT1MN0006
     2TA     )                                                          T1MN0007
    2 FORMAT (31H0  MEAN OF                  MEANS=,F8.3,48H       STANDARD T1MN0008
     1DEVIATION OF              MEANS=,F8.3)                            T1MN0009
    3 FORMAT (31H0  MEAN OF STANDARD DEVIATIONS=,F8.3,48H      STANDARD T1MN0010
     1DEVIATION OF STANDARD DEVIATIONS=,F8.3)                           T1MN0011
      ZTEST=1                                                           T1MN0012
      YMNMN=0                                                           T1MN0013
      YMNSD=0                                                           T1MN0014
      YSDMN=0                                                           T1MN0015
      YSDSD=0                                                           T1MN0016
      YSUM=0                                                            T1MN0017
      YSQSUM=0                                                          T1MN0018
      MWN=MW*NW                                                         T1MN0019
      M=MM/2                                                            T1MN0020
      N=NN/2                                                            T1MN0021
      MN=M*N                                                            T1MN0022
      Z=MN                                                              T1MN0023
      ZW=MWN                                                            T1MN0024
      ZS=Z*Z                                                            T1MN0025
      ZWS=ZW*ZW                                                         T1MN0026
      DO 10 I=1,M                                                       T1MN0027
      DO 10 J=1,N                                                       T1MN0028
      YSUM=YSUM+Y(I,J)                                                  T1MN0029
      YSQSUM=YSQSUM+Y(I,J)*Y(I,J)                                       T1MN0030
   10 CONTINUE                                                          T1MN0031
      YWMN (1,1)=YSUM                                                   T1MN0032
      YWSD  (1,1)=YSQSUM                                                T1MN0033
C     SQUARE IN LOWER LEFT QUADRANT PROCESSED AND STORED                T1MN0034
C     NOW PROCEED  UP  THE COLUMN ALONG THE LEFT SIDE                   T1MN0035
      DO 30 J=1,N                                                       T1MN0036
      JM=J                                                              T1MN0037
      JP=J+N                                                            T1MN0038
      JW=J+1                                                            T1MN0039
      YSUM=YWMN (1,J)                                                   T1MN0040
      YSQSUM=YWSD  (1,J)                                                T1MN0041
      DO 20 I=1,M                                                       T1MN0042
      YSUM=YSUM+Y(I,JP)-Y(I,JM)                                         T1MN0043
      YSQSUM=YSQSUM+Y(I,JP)*Y(I,JP)-Y(I,JM)*Y(I,JM)                     T1MN0044
   20 CONTINUE                                                          T1MN0045
```

```
      YWMN (1,JW)=YSUM
      YWSD  (1,JW)=YSQSUM
   30 CONTINUE
C   PROCESSING LEFTMOST COLUMN OF M ROWS COMPLETED
C   CONTINUE PROCESSING SHIFTING ONE COLUMN TO RIGHT AT A TIME
CC   AND GETTING RESULTS FOR A NEW STRIP M WIDE BY N ROWS EACH TIME
      DO 70 ISTEP=1,M
      IM=ISTEP
      IP=ISTEP+M
      IW=ISTEP+1
      YSUM=YWMN (ISTEP,1)
      YSQSUM=YWSD  (ISTEP,1)
      DO 40 J=1,N
      YSUM=YSUM+Y(IP,J)-Y(IM,J)
      YSQSUM=YSQSUM+Y(IP,J)*Y(IP,J)-Y(IM,J)*Y(IM,J)
   40 CONTINUE
      YWMN(IW,1)=YSUM
      YWSD(IW,1)=YSQSUM
C   BOTTOM M BY N BOX OF COLUMN PROCESSED
C   NOW COMPLETE PROCESSING REMAINDER OF COLUMN
      DO 60 J=1,N
      JM=J
      JP=J+N
      JW=J+1
      YSUM=YWMN(IW,J)
      YSQSUM=YWSD(IW,J)
      ILO=ISTEP+1
      IHI=ISTEP+M
      DO 50 I=ILO,IHI
      YSUM=YSUM+Y(I,JP)-Y(I,JM)
      YSQSUM=YSQSUM+Y(I,JP)*Y(I,JP)-Y(I,JM)*Y(I,JM)
   50 CONTINUE
      YWMN (IW,JW)=YSUM
      YWSD  (IW,JW)=YSQSUM
   60 CONTINUE
C   THIS COLUMN HAS BEEN PROCESSED. GO BACK TO START A NEW ONE.
C   COLUMN INCREMENTED TO RIGHT BY ONE ELEMENT-COLUMN
   70 CONTINUE
C   ALL (M+1) BY (N+1) M BY N ARRAYS ARRAYS PROCESSED
C   ALL (M+1)X(N+1) M BY N ARRAYS PROCESSED TO THE EXTENT OF GETTING
C   SUMS AND SUMS OF SQUARES. CONVERT THESE TO MEANS AND SIGMAS
      DO 80 I=1,MW
      DO 80 J=1,NW
      XS=Z*YWSD(I,J)
      SXS=YWMN(I,J)*YWMN(I,J)
```

```
      YWV=(XS-SXS)/(ZS-Z)
      YWM=YWMN(I,J)/Z
      YMNMN=YMNMN+YWM
      YWMN(I,J)=YWM
      YMNSD=YMNSD+(YWM*YWM)
      IF(YWV.LE.0) GO TO 75
      YWSD(I,J)=SQRT(YWV)
      YSDMN=YSDMN+YWSD(I,J)
      YSDSD=YSDSD+YWV
      GO TO 80
   75 YWSD(I,J)=-1.0
      ZTEST=0
   80 CONTINUE
      XMM=YMNMN/ZW
      XMN=YMNMN*YMNMN
      XMV=YMNSD*ZW-XMN
      XMV=XMV/(ZWS-ZW)
      IF (XMV.LE.0) GO TO 85
      XMS=SQRT(XMV)
      GO TO 86
   85 XMS=-1.0
   86 YMNSD=XMS
      YMNMN=XMM
      XSM=YSDMN/ZW
      XSN=YSDMN*YSDMN
      XSV=YSDSD*ZW-XSN
      XSV=XSV/(ZWS-ZW)
      IF (XSV.LE.0) GO TO 87
      XSS=SQRT(XSV)
      GO TO 88
   87 XSS=-1.0
   88 YSDSD=XSS
      YSDMN=XSM
      PRINT 1
      PRINT 2,YMNMN,YMNSD
      PRINT 3,YSDMN,YSDSD
      RETURN
      END
```

```
      SUBROUTINE VECTOR (IBM,JBM,DELI,DELJ,TIMEK,AMAX)                  VECT0001
    7 FORMAT (23H0 THE PEAK VALUE AT I= ,I3,9H  AND J= ,I3,4H  IS,I9,18HVECT0002
     1% MOTION WAS FROM ,I3,12H DEGREES AT ,I4,9H  KNOTS  )             VECT0003
      ZI=IBM                                                            VECT0004
      ZJ=JBM                                                            VECT0005
      WI=ZI*DELI                                                        VECT0006
      WJ=ZJ*DELJ                                                        VECT0007
      WSQ=WI*WI+WJ*WJ                                                   VECT0008
      WVEL=SQRT(WSQ)/TIMEK                                              VECT0009
      MVEL=WVEL                                                         VECT0010
      IF (JBM) 44,40,44                                                 VECT0011
   40 IF (IBM) 41,42,43                                                 VECT0012
   41 MPHI=90                                                           VECT0013
      GO TO 70                                                          VECT0014
   42 MPHI=0                                                            VECT0015
      GO TO 70                                                          VECT0016
   43 MPHI=270                                                          VECT0017
      GO TO 70                                                          VECT0018
   44 WPHI=WI/WJ                                                        VECT0019
      APHI=ABS(WPHI)                                                    VECT0020
      BPHI=ATAN(APHI)                                                   VECT0021
      PHI=BPHI*(57.295)                                                 VECT0022
      NPHI=PHI                                                          VECT0023
      IF (JBM) 45,51,51                                                 VECT0024
   45 IF (IBM) 46,47,48                                                 VECT0025
   46 MPHI=NPHI                                                         VECT0026
      GO TO 70                                                          VECT0027
   47 MPHI=360                                                          VECT0028
      GO TO 70                                                          VECT0029
   48 MPHI=360-NPHI                                                     VECT0030
      GO TO 70                                                          VECT0031
   51 IF (IBM) 52,53,54                                                 VECT0032
   52 MPHI=180 -NPHI                                                    VECT0033
      GO TO 70                                                          VECT0034
   53 MPHI=180                                                          VECT0035
      GO TO 70                                                          VECT0036
   54 MPHI=180+NPHI                                                     VECT0037
   70 CONTINUE                                                          VECT0038
      MPK=AMAX*400.0                                                    VECT0039
      PRINT 7,IBM,JBM,MPK,MPHI,MVEL                                     VECT0040
      RETURN                                                            VECT0041
      END                                                               VECT0042
```

```
      SUBROUTINE WINDOW (WT,MWT,NWT,XCV,MVT,NVT,XCVP,MPT,NPT,YSDLAG,MW,
     1NW,SDEVA,MXSWCH)
C
C  INPUTS ARE WT, INVERSE TRANSFORM OF W IN LAG FORM AND ITS DIMENSIONS
C             YSDLAG, THE STANDARD DEVIATIONS OF SEARCH AREA SUBARRAYS
C             SDEVA, THE STANDARD DEVIATION OF THE WINDOW SUBARRAY
C             WORK AREA XCV AND OUTPUT ARRAY AREA AND THEIR DIMENSIONS
C
C  OUTPUT WILL BE A CROSS-CORRELATION ARRAY XCVP FOR LAGS OF THE WINDOW
C
C  TO CALL THIS SUBROUTINE SET  MVT= (MWT-1)/2, NVT= (NWT-1)/2 ,
C                          AND  MPT= MVT+1      NPT= NVT+1
C
      DIMENSION WT(MWT,NWT), XCV(MVT,NVT), XCVP(MPT,NPT), YSDLAG(MW,NW)
      COMPLEX WT
    1 FORMAT (83HOCROSS CORRELATIONS RECOMPUTED USING UNIFORM STANDARD D
     1EVIATION OVER SEARCH AREA.     )
      INC=MVT/2
      JNC=NVT/2
C
C  FORM XCV BY SELECTING REAL PARTS OF WT FOR CENTRAL FOURTH ONLY
      DO 100 I=1,MVT
      DO 100 J=1,NVT
      IW=I+INC
      JW=J+JNC
      XCV(I,J)=REAL(WT(IW,JW))
      XCVP(I,J)=XCV(I,J)
  100 CONTINUE
C
C  COMPUTE CROSS-CORRELATION COEFFICIENT S FOR NORMALIZED SUBARRAYS BY
C  DIVIDING CROSS-COVARIANCE FOR EACH LAG PAIR BY STANDARD DEVIATION
C  OF WINDOW SUBARRAY AND THE STANDARD DEVIATION OF THE SEARCH AREA
C  SUBARRAY FOR THAT PAIR OF LAGS
C
      IF (MXSWCH.NE.0) GO TO 500
      DO 400 I=1,MPT
      DO 400 J=1,NPT
      DEN=SDEVA*YSDLAG(I,J)
      IF (DEN.LT.0.01) GO TO 500
  400 XCVP(I,J)=XCVP(I,J)/DEN
      RETURN
  500 DEN=SDEVA*SDEVB
      IF (DEN.LT.0.01) GO TO 700
      DO 600 I=1,MPT
      DO 600 J=1,NPT
```

```
600 XCVP(I,J)=XCVP(I,J)/DEN                                             WIND0046
    PRINT 1                                                             WIND0047
    RETURN                                                              WIND0048
700 PRINT 1                                                             WIND0049
    PRINT 2                                                             WIND0050
    RETURN                                                              WIND0051
  2 FORMAT (53HOCOMPUTATION REJECTED BECAUSE CLOUD DATA TOO SPARSE     )WIND0052
    END                                                                 WIND0053
```

```
      SUBROUTINE XCMAX (A,AMAX,MM,NN,IMAX,JMAX,MXSWCH)                  XCMA0001
      DIMENSION A(MM,NN),VMAX(6),MAXI(6),MAXJ(6),MAXV(6)                XCMA0002
    1 FORMAT (58H0EXTREME MAXIMA NOTED WERE FOR ILAG=   JLAG=   THE VALUXCMA0003
     1E    )                                                            XCMA0004
    2 FORMAT (1H ,30X,I5,3X,I5,8X,I5)                                   XCMA0005
    3 FORMAT (132H0THIS MOTION COMPUTATION WAS REJECTED BECAUSE MORE THAXCMA0006
     1N FIVE LAG PAIRS HAD GREATER THAN 0.99 CROSS CORRELATION COEFFICIEXCMA0007
     2NT.                       )                                       XCMA0008
    4 FORMAT (105H0THIS MOTION COMPUTATION WAS REJECTED BECAUSE COMPUTEDXCMA0009
     1 CROSS CORRELATION COEFFICIENT EXCEEDED 1.005.      )             XCMA0010
      NMAX=0                                                            XCMA0011
      MXSWCH=0                                                          XCMA0012
      ATST=0.2475                                                       XCMA0013
      ALIMIT=0.25125                                                    XCMA0014
      DO 10 K=1,6                                                       XCMA0015
      VMAX(K)=0                                                         XCMA0016
      MAXI(K)=0                                                         XCMA0017
      MAXJ(K)=0                                                         XCMA0018
      MAXV(K)=0                                                         XCMA0019
   10 CONTINUE                                                          XCMA0020
      IMX=0                                                             XCMA0021
      JMX=0                                                             XCMA0022
      AM=0                                                              XCMA0023
      BM=0                                                              XCMA0024
      DO 23 I=1,MM                                                      XCMA0025
      DO 23 J=1,NN                                                      XCMA0026
      IF (A(I,J)) 13,13,11                                              XCMA0027
   11 IF (A(I,J) - AM ) 13,13,12                                        XCMA0028
   12 AM=A(I,J)                                                         XCMA0029
      IMX=I                                                             XCMA0030
      JMX=J                                                             XCMA0031
      IF (AM.LE.ATST) GO TO 130                                         XCMA0032
      IF (AM.GE.ALIMIT) GO TO 128                                       XCMA0033
      NMAX=NMAX+1                                                       XCMA0034
      VMAX(NMAX)=AM                                                     XCMA0035
      MAXI(NMAX)=I-1-(MM/2)                                             XCMA0036
      MAXJ(NMAX)=J-1-(NN/2)                                             XCMA0037
      MAXV(NMAX)=VMAX(NMAX)*400.00                                      XCMA0038
      IF (NMAX.LE.5) GO TO 130                                          XCMA0039
      PRINT 3                                                           XCMA0040
      GO TO 129                                                         XCMA0041
  128 PRINT 4                                                           XCMA0042
  129 MXSWCH=1                                                          XCMA0043
      GO TO 100                                                         XCMA0044
  130 CONTINUE                                                          XCMA0045
```

```
 13 CONTINUE                                                    XCMA0046
    BIJ=ABS(A(I,J))                                             XCMA0047
    IF (BM-BIJ) 21,23,23                                        XCMA0048
 21 BM=BIJ                                                      XCMA0049
 22 IF (BM.GT.ALIMIT) GO TO 128                                 XCMA0050
 23 CONTINUE                                                    XCMA0051
    IMAX=IMX                                                    XCMA0052
    JMAX=JMX                                                    XCMA0053
    AMAX=A(IMX,JMX)                                             XCMA0054
100 CONTINUE                                                    XCMA0055
    IF (NMAX.EQ.0) GO TO 110                                    XCMA0056
    PRINT 1                                                     XCMA0057
    DO 121 KK=1,NMAX                                            XCMA0058
    PRINT 2,MAXI(KK),MAXJ(KK),MAXV(KK)                          XCMA0059
121 CONTINUE                                                    XCMA0060
110 CONTINUE                                                    XCMA0061
    RETURN                                                      XCMA0062
    END                                                         XCMA0063
```

```
      SUBROUTINE XIJMAX (MM,NN,IMAX,JMAX,IBM,JBM,AMAX,MAXA)             XIJM000
C      INPUTS TO THIS ROUTINE ARE COORDINATES AND MAGNITUDE OF PEAK VALUE  XIJM000
C     AS FOUND IN THE WINDOW AREA CROSS-CORRELATION MATRIX XCVP(MPT,NPT)   XIJM000
C    WHEN IT WAS SEARCHED BY SUBROUTINE XCMAX                           XIJM000
C                                                                       XIJM000
C     OUTPUTS OF ROUTINE ARE LAG COORDINATES OF PEAK VALUE AND          XIJM000
C     MAGNITUDE OF CROSS-CORRELATION EXPRESSED IN PERCENTAGE UNITS      XIJM000
C                                                                       XIJM000
    1 FORMAT (54H0 ONE PAIR VALUE IN CROSS-CORRELATION APPEARS AT ILAG=,XIJM000
     1I4, 8H   JLAG=,I4,18H  WITH PERCENTAGE=,I5,37H, WHICH WAS SELECTEDXIJM001
     2 AS THE BEST FIT.    )                                            XIJM001
    2 FORMAT (106H0**** WARNING PEAK CROSS CORRELATION VALUE WAS FOUND AXIJM001
     1T EDGE OF CORRELATION ARRAY SO MAY BE INVALID *****      )        XIJM001
      IBM=IMAX -1-(MM/2)                                                XIJM001
      JBM=JMAX -1-(NN/2)                                                XIJM001
      IMA=IABS(IBM)                                                     XIJM001
      JMA=IABS(JBM)                                                     XIJM001
      IF ((IMA.GE.(MM/2)).OR.(JMA.GE.(NN/2))) PRINT 2                   XIJM001
      MAXA=AMAX*400.0                                                   XIJM001
      PRINT 1,IBM,JBM,MAXA                                              XIJM002
      RETURN                                                            XIJM002
      END                                                               XIJM002
```

```
      SUBROUTINE ZFRAME (KARA,MM,NN,LARA,M,N,MINCLD,MAXCLD,NFRQA,PCNTA,
     1AMEN,SDEVA,VARA,INITIX,TARA,NDEV)
      DIMENSION KARA(MM,NN),LARA(M,N),VARA(M,N),TARA(MM,NN)
C     ACCEPTS AN MM BY NN ARRAY FOR TIME T-ZERO AND IDENTIFIES CENTER QUAR
C     TER.  THEN IT PROCESSES THAT SUBARRAY. IT NORMALIZES THE WHOLE ARRAY
C     BY SUBTRACTING MEAN FROM CENTRAL PART AND REPLACING FRAMING PART BY
C     ZEROES. NOTES STANDARD DEVIATION OF THE CENTRAL PART AND USES THAT
C               VALUE AS STANDARD DEVIATION FOR TIME T-ZERO.M=MM/2, N=NN/2
      MH=MM/4
      NH=NN/4
      DO 10 I=1,M
      DO 10 J=1,N
      IL=MH+I
      JL=NH+J
      LARA(I,J)=KARA(IL,JL)
   10 CONTINUE
      CALL THRESH (LARA,M,N,MINCLD,MAXCLD,NFRQA,PCNTA,AMEN,SDEVA,VARA,
     1INITIX,NDEV)
      DO 20 I=1,MM
      DO 20 J=1,NN
      TARA(I,J)=0
   20 CONTINUE
      DO 30 I=1,M
      DO 30 J=1,N
      IT=I+MH
      JT=J+NH
      TARA(IT,JT)=VARA(I,J)-AMEN
   30 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ZNORM (KARB,MM,NN,MINCLD,MAXCLD,NFROB,PCNTB,BMEN,SDEVB,ZNOR0001
     1INITIX,TARB,NDEV)                                                 ZNOR0002
      DIMENSION KARB(MM,NN),TARB(MM,NN)                                 ZNOR0003
C   ACCEPTS MM BY NN ARRAY FOR TIME T-ONE, PROCESSES WITH THRESHOLDS    ZNOR0004
C  MINCLD AND MAXCLD, NORMALIZES ENTIRE ARRAY BY SUBTRACTING MEAN FROM  ZNOR0005
C   EACH VALUE, NOTES STANDARD DEVIATION AND KEEPS IT FOR TIME T/ONE    ZNOR0006
      CALL THRESH (KARB,MM,NN,MINCLD,MAXCLD,NFROB,PCNTB,BMEN,SDEVB,TARB,ZNOR0007
     1INITIX,NDEV)                                                      ZNOR0008
      DO 10 I=1,MM                                                      ZNOR0009
      DO 10 J=1,NN                                                      ZNOR0010
      TARB(I,J)=TARB(I,J)-BMEN                                          ZNOR0011
   10 CONTINUE                                                          ZNOR0012
      RETURN                                                            ZNOR0013
      END                                                               ZNOR0014
```

## Appendix G

## TESTS PERFORMED

As described in Section 5, tests were made for the 32 array pairs and five control array pairs with lower threshold value of 190 and upper threshold values of 263, 268, and 273. Typical pages of output for such runs where array output printing was to be bypassed are shown in Figures G-1 through G-5. Appendix H presents the display produced when the array output printing is not bypassed.

A comprehensive timing run, whose results are summarized in Section 5, was conducted using Case III data. Typical pages of output from that run appear as Figures G-6 through G-8.

```
1    INPUT ARRAY TAPE IS USED FOR THIS RUN CASES ARE    VIII-A1 ANDVIII-B1
4    MAXIMUM THRESHOLDS ARE TO BE CONSIDERED FOR THIS CASE
1    REPLICATIONS WILL BE MADE FOR EACH VALUE OF THE MAXIMUM THRESHOLD VALUE
6    SIXTHS OF ARRAY STANDARD DEVIATIJN USED FOR RANDOMIZING NOISE COMPUTED
0    PRINTING OF ARRAY OUTPUT WILL     BE BYPASSED FOR THIS CASE
```

Figure G-1. DISPLAY OF RUN PARAMETERS FOR CASE VIII

```
    348   CMXC MAIN PROGRAM TEST USING PASSES 702 AND 703 NIMBUS IV THIR DATA
TAPE READING AND ARRAY FORMATION TOOK    0.05000SECONDS
LATITUDE= 45.00000N  LONGITUDE= 65.00000W  E-W MESH SIZE= 0.25000DEG  N-S MESH SIZE= 0.15625DEG TIME BETWEEN FRAMES=.  108.MINUTES
THRESHOLDS ARE MIN= 190 MAX= 263 VALID POINTS NUMBER     165 FOR A PERCENTAGE OF  16.11 THE MEAN=  247.3 STANDARD DEVIATION=    9.2
THRESHOLDS ARE MIN= 190 MAX= 263 VALID POINTS NUMBER    1068 FOR A PERCENTAGE OF  26.07 THE MEAN=  245.6 STANDARD DEVIATION=   10.0
FOR THE SEARCH AREA SUBARRAYS THE FOLLOWING STATISTICS WERE FOUND AFTER THE SEARCH AREA MEAN WAS SUBTRACTED FROM THE DATA
  MEAN OF                 MEANS=  -0.046      STANDARD DEVIATION OF                 MEANS=   0.577
  MEAN OF STANDARD DEVIATIONS=    4.180      STANDARD DEVIATION OF STANDARD DEVIATIONS=   2.463
TIME IN SECONDS FOR OPERATION   1 WAS       0.54999995
TIME IN SECONDS FOR OPERATION   2 WAS       0.26666665
TIME IN SECONDS FOR OPERATION   3 WAS       0.19999999
CROSS CORRELATIONS RECOMPUTED USING UNIFORM STANDARD DEVIATION OVER SEARCH AREA.
COMPUTATION REJECTED BECAUSE CLOUD DATA TOO SPARSE
TIME IN SECONDS FOR OPERATION   4 WAS       0.01666667
```

Figure G-2. DISPLAY FOR ONE CASE VIII ARRAY PAIR FOR WHICH COMPUTATION WAS REJECTED

```
LATITUDE= 50.00000N  LONGITUDE= 65.00000W  E-W MESH SIZE= 0.25000DEG  N-S MESH SIZE= 0.15625DEG TIME BETWEEN FRAMES=.  108.MINUTES
THRESHOLDS ARE MIN= 190 MAX= 263 VALID POINTS NUMBER    1001 FOR A PERCENTAGE OF   97.75 THE MEAN=  243.9 STANDARD DEVIATION=    8.4
THRESHOLDS ARE MIN= 190 MAX= 263 VALID POINTS NUMBER    3033 FOR A PERCENTAGE OF   74.05 THE MEAN=  246.0 STANDARD DEVIATION=    8.4
FOR THE SEARCH AREA SUBARRAYS THE FOLLOWING STATISTICS WERE FOUND AFTER THE SEARCH AREA MEAN WAS SUBTRACTED FROM THE DATA
  MEAN OF                MEANS=  -1.001     STANDARD DEVIATION OF               MEANS=   1.455
  MEAN OF STANDARD DEVIATIONS=   8.042      STANDARD DEVIATION OF STANDARD DEVIATIONS=   0.519
TIME IN SECONDS FOR OPERATION   1 WAS       0.28333330
TIME IN SECONDS FOR OPERATION   2 WAS       0.28333330
TIME IN SECONDS FOR OPERATION   3 WAS       0.18333328
 ONE PAIR VALUE IN CROSS-CORRELATION APPEARS AT ILAG=  10   JLAG=   2  WITH PERCENTAGE=   37. WHICH WAS SELECTED AS THE BEST FIT.
 THE PEAK VALUE AT I=  10  AND J=   2  IS       37% MOTION WAS FROM 258 DEGREES AT   54  KNOTS
TIME IN SECONDS FOR OPERATION   4 WAS       0.03333333
```

Figure G-3.  DISPLAY FOR CASE VIII, ARRAY PAIR 3, UPPER THRESHOLD = 263

```
LATITUDE= 50.00000N  LONGITUDE= 65.00000W  E-W MESH SIZE= 0.25000DEG  N-S MESH SIZE= 0.15625DEG TIME BETWEEN FRAMES=.  108.MINUTES
THRESHOLDS ARE MIN= 190 MAX= 268 VALID POINTS NUMBER     1019 FOR A PERCENTAGE OF  99.51 THE MEAN=  244.3 STANDARD DEVIATION=    8.8
THRESHOLDS ARE MIN= 190 MAX= 268 VALID POINTS NUMBER     3223 FOR A PERCENTAGE OF  78.69 THE MEAN=  247.2 STANDARD DEVIATION=    9.4
FOR THE SEARCH AREA SUBARRAYS THE FOLLOWING STATISTICS WERE FOUND AFTER THE SEARCH AREA MEAN WAS SUBTRACTED FROM THE DATA
  MEAN OF             MEANS=  -1.402      STANDARD DEVIATION OF               MEANS=   1.838
  MEAN OF STANDARD DEVIATIONS=   8.808      STANDARD DEVIATION OF STANDARD DEVIATIONS=   0.921
TIME IN SECONDS FOR OPERATION   1 WAS       0.31666666
TIME IN SECONDS FOR OPERATION   2 WAS       0.28333330
TIME IN SECONDS FOR OPERATION   3 WAS       0.19999999
 ONE PAIR VALUE IN CROSS-CORRELATION APPEARS AT ILAG=  10   JLAG=   2  WITH PERCENTAGE=   39. WHICH WAS SELECTED AS THE BEST FIT.
 THE PEAK VALUE AT I=  10  AND J=   2  IS       39% MOTION WAS FROM 258 DEGREES AT   54  KNOTS
TIME IN SECONDS FOR OPERATION   4 WAS       0.03333333
```

Figure G-4. DISPLAY FOR CASE VIII, ARRAY PAIR 3, UPPER THRESHOLD = 268

```
LATITUDE= 50.00000N  LONGITUDE= 65.00000W  E-W MESH SIZE= 0.25000DEG  N-S MESH SIZE= 0.15625DEG TIME BETWEEN FRAMES=.  108.MINUTES
THRESHOLDS ARE MIN= 190 MAX= 273 VALID POINTS NUMBER    1023 FOR A PERCENTAGE OF  99.90 THE MEAN=  244.4 STANDARD DEVIATION=    8.9
THRESHOLDS ARE MIN= 190 MAX= 273 VALID POINTS NUMBER    3481 FOR A PERCENTAGE OF  84.99 THE MEAN=  248.9 STANDARD DEVIATION=   11.0
FOR THE SEARCH AREA SUBARRAYS THE FOLLOWING STATISTICS WERE FOUND AFTER THE SEARCH AREA MEAN WAS SUBTRACTED FROM THE DATA
  MEAN OF               MEANS=  -2.362      STANDARD DEVIATION OF               MEANS=   2.390
  MEAN OF STANDARD DEVIATIONS=   9.649      STANDARD DEVIATION OF STANDARD DEVIATIONS=   1.498
TIME IN SECONDS FOR OPERATION   1 WAS       0.29999995
TIME IN SECONDS FOR OPERATION   2 WAS       0.25000000
TIME IN SECONDS FOR OPERATION   3 WAS       0.19999999
 ONE PAIR VALUE IN CROSS-CORRELATION APPEARS AT ILAG=  10   JLAG=   2  WITH PERCENTAGE=   41. WHICH WAS SELECTED AS THE BEST FIT.
 THE PEAK VALUE AT I=  10  AND J=   2  IS        41% MOTION WAS FROM 258 DEGREES AT   54  KNOTS
TIME IN SECONDS FOR OPERATION   4 WAS       0.02333333
```

Figure G-5.  DISPLAY FOR CASE VIII, ARRAY PAIR 3, UPPER THRESHOLD = 273

```
1    INPUT ARRAY TAPE IS USED FOR THIS RUN CASES ARE      III-A1 AND III-B1
4    MAXIMUM THRESHOLDS ARE TO BE CONSIDERED FOR THIS CASE
20   REPLICATIONS WILL BE MADE FOR EACH VALUE OF THE MAXIMUM THRESHOLD VALUE
6    SIXTHS OF ARRAY STANDARD DEVIATION USED FOR RANDOMIZING NOISE COMPUTED
0    PRINTING OF ARRAY OUTPUT WILL    BE BYPASSED FOR THIS CASE
```

Figure G-6. DISPLAY OF RUN PARAMETERS FOR TIMING RUN FOR CASE III.

```
     343   CMXC MAIN PROGRAM TEST USING PASSES 417 AND 418 NIMBUS IV THIR DATA
TAPE READING AND ARRAY FORMATION TOOK    0.06667SECONDS
LATITUDE= 46.77611N  LONGITUDE=343.00000W  E-W MESH SIZE= 0.25000DEG  N-S MESH SIZE= 0.14925DEG TIME BETWEEN FRAMES=.  108.MINUTES
THRESHOLDS ARE MIN= 190 MAX= 263 VALID POINTS NUMBER      272 FOR A PERCENTAGE OF  26.55 THE MEAN=  250.4 STANDARD DEVIATION=    8.3
THRESHOLDS ARE MIN= 190 MAX= 263 VALID POINTS NUMBER      994 FOR A PERCENTAGE OF  24.27 THE MEAN=  250.5 STANDARD DEVIATION=    8.3
FOR THE SEARCH AREA SUBARRAYS THE FOLLOWING STATISTICS WERE FOUND AFTER THE SEARCH AREA MEAN WAS SUBTRACTED FROM THE DATA
  MEAN OF               MEANS=  -0.208      STANDARD DEVIATION OF               MEANS=   0.416
  MEAN OF STANDARD DEVIATIONS=   3.844      STANDARD DEVIATION OF STANDARD DEVIATIONS=   1.259
TIME IN SECONDS FOR OPERATION   1 WAS       0.58333331
TIME IN SECONDS FOR OPERATION   2 WAS       0.26666665
TIME IN SECONDS FOR OPERATION   3 WAS       0.21666664
 ONE PAIR VALUE IN CROSS-CORRELATION APPEARS AT ILAG=   0   JLAG=  -1  WITH PERCENTAGE=   28. WHICH WAS SELECTED AS THE BEST FIT.
 THE PEAK VALUE AT I=   0  AND J=  -1  IS       28% MOTION WAS FROM 360 DEGREES AT    4  KNOTS
TIME IN SECONDS FOR OPERATION   4 WAS       0.01666667
```



Figure G-7.   DISPLAY FOR ONE CASE III ARRAY PAIR

```
FOLLOWING ARE TOTALS FCR ALL ARRAY PAIRS IN THIS RUN
TIME IN SECONDS FOR OPERATION   1 WAS     232.58081055
TIME IN SECONDS FOR OPERATION   2 WAS     108.99810791
TIME IN SECONDS FOR OPERATION   3 WAS      82.59822083
TIME IN SECONDS FOR OPERATION   4 WAS       8.59988308
TIME IN SECONDS FOR OPERATION   5 WAS       0.0
```

Figure G-8. DISPLAY OF SUMMARY RESULTS FOR TIMING RUN FOR CASE III

# Appendix H

## SAMPLE OUTPUT RESULTS

Figures H-1 through H-7 show the types of output which are obtained when the printing of array output is not bypassed.

```
1    INPUT ARRAY TAPE IS USED FOR THIS RUN CASES ARE      VI-A1 AND   VI-B1
4    MAXIMUM THRESHOLDS ARE TO BE CONSIDERED FOR THIS CASE
1    REPLICATIONS WILL BE MADE FOR EACH VALUE OF THE MAXIMUM THRESHOLD VALUE
6    SIXTHS OF ARRAY STANDARD DEVIATION USED FOR RANDOMIZING NOISE COMPUTED
1    PRINTING OF ARRAY OUTPUT WILL NOT BE BYPASSED FOR THIS CASE
```

Figure H-1. DISPLAY OF RUN PARAMETERS FOR CASE VI.

```
LATITUDE= 55.00000N  LONGITUDE=222.00000W  E-W MESH SIZE= 0.25000DEG  N-S MESH SIZE= 0.15625DEG TIME BETWEEN FRAMES=.  108.MINUTES
THRESHOLDS ARE MIN= 190 MAX= 273 VALID POINTS NUMBER      957 FOR A PERCENTAGE OF  93.46 THE MEAN=  252.3 STANDARD DEVIATION=    8.9
THRESHOLDS ARE MIN= 190 MAX= 273 VALID POINTS NUMBER     3627 FOR A PERCENTAGE OF  88.55 THE MEAN=  256.4 STANDARD DEVIATION=    9.2
FOR THE SEARCH AREA SUBARRAYS THE FOLLOWING STATISTICS WERE FOUND AFTER THE SEARCH AREA MEAN WAS SUBTRACTED FROM THE DATA
  MEAN OF               MEANS=  -1.854      STANDARD DEVIATION OF                 MEANS=   3.380
  MEAN OF STANDARD DEVIATIONS=   7.897      STANDARD DEVIATION OF STANDARD DEVIATIONS=   0.771
TIME IN SECONDS FOR OPERATION   1 WAS       0.33333331
TIME IN SECONDS FOR OPERATION   2 WAS       0.26666665
TIME IN SECONDS FOR OPERATION   3 WAS       0.19999999
 ONE PAIR VALUE IN CROSS-CORRELATION APPEARS AT ILAG=   0   JLAG=   2  WITH PERCENTAGE=   62. WHICH WAS SELECTED AS THE BEST FIT.
 THE PEAK VALUE AT I=   0  AND J=   2  IS        62% MOTION WAS FROM 180 DEGREES AT   10  KNOTS
TIME IN SECONDS FOR OPERATION   4 WAS       0.03333333
```

Figure H-2.   DISPLAY FOR CASE VI, ARRAY PAIR 5, UPPER THRESHOLD = 273

DATA USED AS WINDOW ARRAY WITH COORDINATE AXES MOVED SO COORDINATES APPEAR AS LAGS

| LAGS | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 266 | 263 | 273 | 278 | 276 | 277 | 280 | 282 | 278 | 278 | 277 | 277 | 276 | 276 | 274 | 272 | 266 | 264 | 262 | 261 | 262 | 256 | 249 | 256 | 253 | 253 | 251 | 246 | 251 | 255 | 254 | 255 |
| 15 | 262 | 268 | 278 | 282 | 278 | 277 | 282 | 279 | 279 | 278 | 279 | 280 | 277 | 276 | 275 | 273 | 263 | 264 | 263 | 264 | 262 | 257 | 252 | 249 | 254 | 254 | 253 | 251 | 251 | 255 | 253 | 256 |
| 14 | 260 | 263 | 272 | 275 | 276 | 278 | 279 | 277 | 277 | 278 | 282 | 280 | 277 | 276 | 277 | 271 | 267 | 264 | 263 | 264 | 265 | 262 | 259 | 250 | 252 | 250 | 253 | 252 | 255 | 260 | 257 | 258 |
| 13 | 263 | 264 | 263 | 269 | 273 | 279 | 293 | 281 | 281 | 281 | 278 | 276 | 275 | 276 | 274 | 270 | 267 | 267 | 263 | 263 | 263 | 262 | 256 | 254 | 251 | 254 | 251 | 251 | 257 | 256 | 257 | 257 |
| 12 | 268 | 271 | 267 | 270 | 272 | 273 | 276 | 280 | 281 | 281 | 277 | 275 | 273 | 270 | 269 | 268 | 267 | 270 | 264 | 261 | 263 | 259 | 257 | 252 | 252 | 255 | 251 | 255 | 254 | 253 | 254 | 256 |
| 11 | 271 | 268 | 265 | 269 | 276 | 275 | 271 | 277 | 278 | 275 | 276 | 273 | 271 | 269 | 271 | 268 | 269 | 269 | 262 | 264 | 262 | 260 | 261 | 254 | 254 | 251 | 252 | 252 | 251 | 252 | 249 | 251 |
| 10 | 262 | 261 | 265 | 270 | 276 | 274 | 267 | 265 | 273 | 274 | 273 | 271 | 270 | 270 | 271 | 269 | 267 | 264 | 262 | 263 | 259 | 261 | 258 | 259 | 254 | 252 | 252 | 252 | 253 | 253 | 249 | 251 |
| 9 | 270 | 266 | 271 | 270 | 271 | 273 | 272 | 267 | 271 | 273 | 276 | 270 | 269 | 273 | 269 | 267 | 267 | 266 | 264 | 260 | 261 | 257 | 260 | 260 | 258 | 255 | 252 | 249 | 253 | 246 | 247 | 250 |
| 8 | 269 | 270 | 267 | 259 | 262 | 269 | 274 | 269 | 268 | 274 | 274 | 269 | 271 | 269 | 268 | 268 | 263 | 265 | 262 | 263 | 261 | 257 | 261 | 261 | 259 | 258 | 252 | 253 | 252 | 250 | 245 | 244 |
| 7 | 267 | 269 | 272 | 274 | 267 | 266 | 266 | 254 | 265 | 267 | 266 | 266 | 268 | 262 | 261 | 263 | 264 | 263 | 263 | 263 | 261 | 260 | 259 | 260 | 258 | 253 | 253 | 251 | 250 | 249 | 246 | 248 |
| 6 | 260 | 269 | 271 | 267 | 263 | 264 | 264 | 256 | 265 | 262 | 260 | 258 | 257 | 257 | 255 | 262 | 262 | 259 | 262 | 263 | 261 | 263 | 260 | 258 | 260 | 254 | 250 | 250 | 252 | 251 | 248 | 249 |
| 5 | 255 | 261 | 263 | 267 | 255 | 250 | 251 | 269 | 266 | 256 | 258 | 255 | 255 | 254 | 254 | 261 | 256 | 258 | 262 | 261 | 265 | 263 | 258 | 250 | 253 | 253 | 251 | 252 | 252 | 253 | 251 | 250 |
| 4 | 254 | 249 | 249 | 251 | 252 | 250 | 266 | 270 | 262 | 256 | 255 | 251 | 252 | 252 | 256 | 258 | 258 | 257 | 254 | 261 | 264 | 263 | 260 | 255 | 255 | 255 | 254 | 254 | 251 | 254 | 254 | 253 |
| 3 | 245 | 251 | 252 | 246 | 248 | 259 | 262 | 262 | 258 | 254 | 253 | 254 | 251 | 251 | 252 | 258 | 260 | 258 | 255 | 256 | 258 | 261 | 259 | 255 | 253 | 252 | 254 | 254 | 253 | 252 | 255 | 254 |
| 2 | 236 | 240 | 243 | 250 | 258 | 258 | 264 | 252 | 251 | 252 | 253 | 253 | 253 | 254 | 251 | 254 | 259 | 256 | 255 | 253 | 255 | 259 | 256 | 255 | 249 | 252 | 254 | 254 | 253 | 251 | 253 | 253 |
| 1 | 242 | 243 | 240 | 248 | 252 | 249 | 255 | 247 | 248 | 251 | 251 | 253 | 255 | 252 | 251 | 250 | 254 | 254 | 256 | 258 | 256 | 254 | 254 | 252 | 251 | 253 | 252 | 256 | 255 | 253 | 253 | 254 |
| 0 | 255 | 249 | 252 | 257 | 259 | 249 | 248 | 245 | 245 | 245 | 250 | 252 | 252 | 254 | 252 | 250 | 251 | 252 | 253 | 257 | 255 | 259 | 257 | 254 | 254 | 252 | 255 | 255 | 255 | 255 | 254 | 254 |
| -1 | 244 | 247 | 255 | 260 | 259 | 252 | 246 | 244 | 244 | 243 | 245 | 243 | 244 | 249 | 247 | 246 | 250 | 248 | 251 | 248 | 249 | 253 | 252 | 252 | 254 | 252 | 255 | 255 | 256 | 255 | 253 | 253 |
| -2 | 242 | 246 | 257 | 257 | 253 | 245 | 242 | 241 | 240 | 236 | 239 | 235 | 240 | 239 | 238 | 243 | 242 | 244 | 248 | 249 | 252 | 247 | 250 | 255 | 254 | 250 | 254 | 253 | 254 | 255 | 254 | 251 |
| -3 | 251 | 255 | 258 | 257 | 254 | 246 | 246 | 247 | 247 | 246 | 244 | 246 | 245 | 237 | 240 | 240 | 236 | 240 | 236 | 242 | 247 | 248 | 249 | 247 | 245 | 247 | 246 | 248 | 252 | 254 | 254 | 252 |
| -4 | 258 | 255 | 255 | 254 | 251 | 246 | 254 | 253 | 251 | 250 | 244 | 243 | 243 | 242 | 242 | 244 | 242 | 238 | 242 | 248 | 247 | 242 | 236 | 241 | 242 | 244 | 244 | 245 | 245 | 248 | 247 | 253 |
| -5 | 262 | 258 | 259 | 255 | 255 | 256 | 254 | 253 | 251 | 246 | 244 | 238 | 239 | 241 | 239 | 245 | 243 | 244 | 244 | 248 | 246 | 244 | 243 | 245 | 247 | 246 | 247 | 248 | 246 | 247 | 247 | 247 |
| -6 | 262 | 261 | 258 | 253 | 254 | 253 | 253 | 255 | 252 | 252 | 248 | 243 | 243 | 242 | 245 | 247 | 244 | 242 | 246 | 244 | 240 | 236 | 241 | 242 | 244 | 245 | 240 | 240 | 241 | 242 | 246 | 249 |
| -7 | 256 | 252 | 249 | 247 | 251 | 251 | 251 | 252 | 254 | 253 | 247 | 249 | 241 | 241 | 244 | 246 | 244 | 242 | 241 | 242 | 236 | 232 | 233 | 234 | 231 | 234 | 233 | 237 | 233 | 235 | 236 | 241 |
| -8 | 248 | 252 | 257 | 254 | 252 | 254 | 252 | 248 | 252 | 247 | 250 | 243 | 238 | 239 | 240 | 243 | 240 | 239 | 238 | 231 | 229 | 231 | 234 | 238 | 240 | 240 | 244 | 241 | 238 | 241 | 243 | 246 |
| -9 | 248 | 254 | 256 | 256 | 256 | 254 | 253 | 252 | 247 | 247 | 245 | 243 | 240 | 237 | 233 | 235 | 229 | 232 | 236 | 236 | 238 | 237 | 239 | 243 | 241 | 242 | 247 | 249 | 253 | 250 | 250 | 247 |
| -10 | 249 | 252 | 254 | 256 | 250 | 245 | 248 | 247 | 246 | 245 | 244 | 243 | 240 | 236 | 235 | 233 | 233 | 241 | 247 | 244 | 243 | 246 | 249 | 244 | 246 | 249 | 252 | 256 | 252 | 251 | 250 | 251 |
| -11 | 253 | 257 | 252 | 247 | 242 | 242 | 245 | 244 | 243 | 243 | 245 | 244 | 241 | 242 | 242 | 246 | 250 | 249 | 249 | 254 | 250 | 246 | 243 | 246 | 251 | 253 | 255 | 254 | 254 | 252 | 246 | 247 |
| -12 | 259 | 255 | 249 | 243 | 246 | 245 | 245 | 244 | 241 | 245 | 245 | 247 | 245 | 247 | 246 | 248 | 248 | 246 | 253 | 252 | 250 | 247 | 244 | 248 | 248 | 248 | 247 | 250 | 254 | 249 | 239 | 236 |
| -13 | 256 | 258 | 253 | 246 | 246 | 245 | 244 | 246 | 243 | 246 | 251 | 249 | 250 | 248 | 248 | 248 | 246 | 251 | 251 | 249 | 249 | 245 | 248 | 248 | 248 | 247 | 244 | 247 | 250 | 244 | 237 | 233 |
| -14 | 257 | 258 | 250 | 248 | 245 | 249 | 247 | 247 | 251 | 255 | 248 | 248 | 249 | 250 | 250 | 246 | 248 | 248 | 248 | 251 | 246 | 241 | 239 | 236 | 241 | 239 | 240 | 241 | 246 | 247 | 246 | 244 |
| -15 | 252 | 252 | 251 | 248 | 251 | 257 | 256 | 254 | 252 | 244 | 246 | 246 | 243 | 251 | 248 | 247 | 247 | 246 | 250 | 253 | 251 | 249 | 241 | 235 | 237 | 235 | 237 | 238 | 240 | 244 | 247 | 249 |
| -16 | ****************************************************************************************** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Figure H-3. WINDOW AREA DISPLAY FOR CASE VI, ARRAY PAIR 5, UPPER THRESHOLD = 273

DATA CONTAINED IN THE SEARCH AREA SUBARRAY IDENTIFIED AS THE BEST MATCH. COORDINATE AXES MOVED SO COORDINATES APPEAR AS LAGS

| LAGS | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 264 | 266 | 270 | 277 | 276 | 280 | 280 | 292 | 281 | 283 | 276 | 275 | 274 | 277 | 275 | 273 | 273 | 273 | 270 | 266 | 260 | 256 | 254 | 255 | 254 | 256 | 253 | 248 | 248 | 248 | 248 | 254 |
| 15 | 262 | 259 | 266 | 276 | 275 | 279 | 279 | 282 | 282 | 279 | 279 | 277 | 277 | 278 | 276 | 275 | 275 | 273 | 268 | 263 | 259 | 257 | 252 | 252 | 250 | 254 | 252 | 250 | 251 | 245 | 246 | 247 |
| 14 | 263 | 261 | 258 | 272 | 273 | 275 | 281 | 292 | 275 | 280 | 277 | 279 | 278 | 277 | 278 | 276 | 273 | 272 | 271 | 266 | 263 | 258 | 252 | 251 | 251 | 251 | 249 | 252 | 247 | 248 | 243 | 247 |
| 13 | 260 | 260 | 257 | 262 | 274 | 275 | 277 | 275 | 277 | 274 | 279 | 280 | 279 | 281 | 277 | 277 | 276 | 274 | 270 | 263 | 258 | 255 | 253 | 253 | 253 | 250 | 248 | 247 | 249 | 249 | 248 | 248 |
| 12 | 258 | 257 | 259 | 259 | 271 | 273 | 277 | 279 | 279 | 279 | 283 | 279 | 277 | 278 | 280 | 279 | 276 | 271 | 269 | 267 | 263 | 260 | 258 | 251 | 252 | 249 | 247 | 251 | 252 | 252 | 250 | 247 |
| 11 | 261 | 255 | 258 | 255 | 258 | 264 | 270 | 275 | 280 | 280 | 280 | 278 | 279 | 274 | 274 | 274 | 271 | 273 | 272 | 271 | 262 | 257 | 257 | 253 | 252 | 249 | 249 | 252 | 251 | 252 | 253 | 250 |
| 10 | 268 | 268 | 269 | 265 | 259 | 255 | 260 | 269 | 273 | 276 | 281 | 284 | 278 | 270 | 271 | 271 | 269 | 270 | 270 | 267 | 261 | 258 | 256 | 255 | 251 | 250 | 251 | 254 | 252 | 255 | 256 | 253 |
| 9 | 265 | 272 | 270 | 271 | 269 | 265 | 265 | 267 | 269 | 274 | 278 | 277 | 275 | 272 | 272 | 273 | 267 | 267 | 268 | 265 | 259 | 259 | 255 | 256 | 260 | 253 | 251 | 254 | 254 | 250 | 256 | 255 |
| 8 | 272 | 276 | 270 | 272 | 277 | 275 | 270 | 269 | 273 | 276 | 275 | 273 | 269 | 271 | 273 | 271 | 270 | 266 | 263 | 260 | 259 | 258 | 259 | 257 | 256 | 250 | 253 | 254 | 256 | 255 | 254 | 254 |
| 7 | 273 | 275 | 271 | 273 | 275 | 274 | 272 | 274 | 278 | 278 | 277 | 276 | 272 | 270 | 274 | 271 | 270 | 266 | 258 | 261 | 259 | 261 | 258 | 259 | 253 | 248 | 249 | 253 | 259 | 258 | 258 | 255 |
| 6 | 265 | 269 | 274 | 276 | 269 | 263 | 263 | 274 | 276 | 275 | 273 | 272 | 273 | 272 | 273 | 271 | 265 | 259 | 262 | 263 | 260 | 260 | 256 | 253 | 253 | 249 | 253 | 258 | 259 | 258 | 255 | 252 |
| 5 | 258 | 267 | 271 | 264 | 263 | 266 | 267 | 271 | 275 | 271 | 274 | 274 | 276 | 271 | 269 | 267 | 264 | 260 | 261 | 259 | 258 | 255 | 255 | 257 | 255 | 254 | 253 | 253 | 255 | 253 | 254 | 254 |
| 4 | 248 | 261 | 258 | 256 | 267 | 268 | 271 | 270 | 272 | 273 | 269 | 271 | 269 | 265 | 266 | 269 | 267 | 266 | 263 | 256 | 258 | 255 | 256 | 256 | 256 | 255 | 255 | 253 | 254 | 253 | 253 | 254 |
| 3 | 250 | 261 | 259 | 261 | 263 | 259 | 268 | 275 | 270 | 264 | 266 | 269 | 267 | 265 | 263 | 265 | 263 | 261 | 256 | 256 | 255 | 254 | 253 | 254 | 252 | 255 | 252 | 255 | 254 | 254 | 254 | 253 |
| 2 | 257 | 271 | 264 | 253 | 245 | 254 | 268 | 271 | 267 | 263 | 265 | 265 | 262 | 258 | 259 | 258 | 259 | 256 | 257 | 256 | 254 | 253 | 255 | 256 | 254 | 254 | 255 | 254 | 255 | 255 | 256 | 254 |
| 1 | 262 | 260 | 265 | 259 | 261 | 261 | 259 | 268 | 271 | 266 | 263 | 257 | 255 | 256 | 257 | 260 | 258 | 256 | 257 | 259 | 253 | 254 | 255 | 255 | 256 | 252 | 251 | 252 | 252 | 254 | 253 | 254 |
| 0 | 258 | 259 | 269 | 261 | 263 | 263 | 258 | 254 | 266 | 261 | 263 | 259 | 256 | 254 | 257 | 259 | 258 | 260 | 259 | 258 | 255 | 253 | 255 | 255 | 256 | 254 | 253 | 253 | 255 | 253 | 253 | 255 |
| -1 | 263 | 265 | 267 | 264 | 264 | 262 | 259 | 262 | 263 | 259 | 258 | 256 | 258 | 262 | 264 | 261 | 255 | 256 | 257 | 258 | 257 | 254 | 253 | 252 | 250 | 248 | 249 | 251 | 253 | 249 | 251 | 250 |
| -2 | 264 | 266 | 268 | 267 | 266 | 258 | 257 | 261 | 260 | 255 | 259 | 260 | 259 | 260 | 258 | 262 | 259 | 258 | 255 | 256 | 251 | 253 | 254 | 253 | 253 | 252 | 253 | 255 | 254 | 253 | 251 | 248 |
| -3 | 267 | 272 | 267 | 260 | 254 | 255 | 254 | 252 | 250 | 254 | 260 | 262 | 257 | 255 | 256 | 256 | 257 | 255 | 257 | 253 | 251 | 247 | 248 | 248 | 250 | 250 | 249 | 250 | 251 | 252 | 253 | 255 |
| -4 | 267 | 266 | 263 | 265 | 260 | 254 | 250 | 249 | 248 | 245 | 245 | 247 | 252 | 253 | 249 | 250 | 254 | 255 | 257 | 248 | 245 | 243 | 246 | 245 | 247 | 244 | 244 | 245 | 242 | 244 | 249 | 250 |
| -5 | 261 | 256 | 261 | 264 | 261 | 254 | 252 | 252 | 249 | 250 | 251 | 251 | 248 | 244 | 248 | 249 | 253 | 254 | 249 | 246 | 243 | 244 | 243 | 242 | 242 | 242 | 247 | 246 | 246 | 247 | 242 | 244 |
| -6 | 260 | 256 | 258 | 258 | 259 | 251 | 248 | 254 | 253 | 253 | 253 | 254 | 254 | 251 | 250 | 252 | 255 | 252 | 252 | 248 | 248 | 249 | 248 | 246 | 247 | 241 | 243 | 244 | 244 | 245 | 248 | 248 |
| -7 | 257 | 253 | 253 | 256 | 253 | 256 | 256 | 258 | 262 | 258 | 258 | 255 | 251 | 251 | 251 | 250 | 247 | 249 | 245 | 244 | 240 | 237 | 238 | 241 | 240 | 243 | 247 | 248 | 249 | 253 | 249 | 250 |
| -8 | 253 | 252 | 250 | 252 | 256 | 260 | 260 | 257 | 258 | 253 | 250 | 253 | 249 | 246 | 240 | 237 | 237 | 236 | 233 | 231 | 232 | 238 | 241 | 244 | 248 | 252 | 257 | 256 | 254 | 250 | 248 | 248 |
| -9 | 246 | 243 | 249 | 259 | 259 | 264 | 260 | 258 | 257 | 254 | 252 | 253 | 250 | 244 | 234 | 234 | 234 | 233 | 236 | 239 | 243 | 246 | 247 | 247 | 251 | 252 | 251 | 249 | 250 | 247 | 249 | 245 |
| -10 | 241 | 241 | 246 | 256 | 269 | 273 | 269 | 262 | 257 | 255 | 255 | 249 | 244 | 235 | 232 | 235 | 238 | 242 | 241 | 247 | 248 | 246 | 246 | 247 | 249 | 248 | 247 | 245 | 244 | 243 | 243 | 246 |
| -11 | 251 | 244 | 241 | 243 | 259 | 265 | 264 | 255 | 248 | 249 | 244 | 239 | 242 | 245 | 242 | 245 | 248 | 244 | 246 | 243 | 246 | 246 | 246 | 247 | 247 | 245 | 243 | 241 | 239 | 237 | 240 | 239 |
| -12 | 252 | 238 | 240 | 247 | 244 | 250 | 252 | 247 | 242 | 243 | 245 | 249 | 253 | 250 | 247 | 251 | 248 | 243 | 241 | 243 | 240 | 242 | 242 | 240 | 239 | 238 | 238 | 238 | 237 | 234 | 235 | 234 |
| -13 | 245 | 241 | 248 | 251 | 246 | 245 | 243 | 242 | 245 | 252 | 257 | 256 | 252 | 249 | 244 | 241 | 237 | 237 | 239 | 239 | 239 | 237 | 236 | 238 | 236 | 235 | 236 | 238 | 237 | 236 | 239 | 242 |
| -14 | 250 | 244 | 243 | 243 | 242 | 238 | 245 | 251 | 256 | 255 | 255 | 251 | 249 | 243 | 236 | 240 | 243 | 241 | 240 | 238 | 236 | 234 | 234 | 236 | 236 | 237 | 237 | 239 | 242 | 243 | 248 | 248 |
| -15 | 249 | 246 | 245 | 243 | 240 | 241 | 244 | 247 | 249 | 252 | 251 | 250 | 248 | 246 | 246 | 245 | 244 | 238 | 234 | 233 | 238 | 236 | 239 | 238 | 235 | 238 | 236 | 237 | 237 | 241 | 246 | 249 |
| -16 | ****************************************************************************** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Figure H-4. SEARCH AREA SUBARRAY DISPLAY FOR CASE VI, ARRAY PAIR 5, UPPER THRESHOLD = 273

TRUNCATED MEANS OF SUBARRAYS OF SEARCH AREA CORRESPONDING TO THE LAG VALUES OF WINDOW AREA RELATIVE TO SEARCH AREA

| LAGS | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 15 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| 14 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 13 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 7 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 6 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -2 | -2 | -2 | -2 | -2 | -2 | -2 | -2 |
| 5 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -2 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -3 | -3 | -3 |
| 4 | 2 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -3 | -3 | -3 | -3 | -3 |
| 3 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -2 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -4 | -4 |
| 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -2 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -4 | -4 | -4 | -4 |
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -2 | -2 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 |
| 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -2 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 |
| -1 | 1 | 1 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -2 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 |
| -2 | 1 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -2 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 |
| -3 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -2 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -6 | -5 |
| -4 | 0 | 0 | 0 | 0 | -1 | -1 | -2 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -6 | -5 |
| -5 | 0 | 0 | 0 | -1 | -1 | -1 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -6 | -6 | -6 | -5 |
| -6 | 0 | 0 | 0 | -1 | -1 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -6 | -6 | -6 | -5 |
| -7 | 0 | 0 | 0 | -1 | -1 | -2 | -2 | -3 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -6 | -6 | -6 | -5 |
| -8 | 0 | 0 | -1 | -1 | -2 | -2 | -3 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -6 | -6 | -6 | -6 | -5 |
| -9 | 0 | 0 | -1 | -1 | -2 | -2 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -6 | -6 | -6 | -6 | -6 | -6 |
| -10 | 0 | 0 | -1 | -1 | -2 | -2 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -6 | -6 | -6 | -6 | -6 | -6 | -6 |
| -11 | 0 | 0 | -1 | -1 | -2 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -5 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 |
| -12 | 0 | 0 | -1 | -2 | -2 | -3 | -3 | -3 | -4 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -6 | -5 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 |
| -13 | 0 | 0 | -1 | -1 | -2 | -3 | -3 | -3 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -5 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 |
| -14 | 0 | 0 | -1 | -1 | -2 | -3 | -3 | -3 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 |
| -15 | 0 | 0 | -1 | -2 | -2 | -3 | -3 | -3 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -5 | -6 | -6 | -6 | -6 | -6 | -6 | -6 |
| -16 | 0 | 0 | -1 | -2 | -2 | -3 | -3 | -3 | -4 | -4 | -4 | -5 | -5 | -5 | -5 | -5 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 | -6 |



Figure H-5. SUBARRAY MEAN DISPLAY FOR CASE VI, ARRAY PAIR 5, UPPER THRESHOLD = 273

STANDARD DEVIATION (TENTHS) OF SEARCH AREA SUBARRAY CORRESPONDING TO LAG VALUES OF WINDOW AREA RELATIVE TO SEARCH AREA

| LAGS | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 75 | 74 | 74 | 73 | 72 | 71 | 71 | 70 | 69 | 68 | 68 | 67 | 66 | 64 | 63 | 62 | 62 | 62 | 63 | 63 | 63 | 63 | 64 | 64 | 65 | 66 | 67 | 69 | 69 | 70 | 70 | 70 |
| 15 | 75 | 74 | 74 | 73 | 72 | 71 | 70 | 69 | 69 | 68 | 68 | 67 | 66 | 64 | 63 | 62 | 62 | 62 | 63 | 62 | 62 | 62 | 63 | 64 | 64 | 65 | 66 | 68 | 68 | 69 | 69 | 68 |
| 14 | 75 | 74 | 74 | 73 | 72 | 71 | 70 | 69 | 69 | 68 | 68 | 67 | 66 | 65 | 63 | 62 | 62 | 63 | 63 | 63 | 62 | 62 | 63 | 64 | 64 | 65 | 66 | 67 | 68 | 68 | 68 | 68 |
| 13 | 76 | 75 | 75 | 74 | 73 | 72 | 71 | 71 | 70 | 70 | 69 | 69 | 68 | 67 | 65 | 65 | 65 | 65 | 65 | 64 | 64 | 64 | 64 | 65 | 65 | 65 | 66 | 67 | 68 | 68 | 68 | 67 |
| 12 | 76 | 76 | 75 | 74 | 73 | 73 | 72 | 72 | 71 | 71 | 71 | 71 | 70 | 69 | 67 | 67 | 67 | 67 | 67 | 66 | 66 | 65 | 66 | 66 | 66 | 67 | 67 | 68 | 68 | 69 | 68 | 68 |
| 11 | 76 | 76 | 75 | 75 | 74 | 73 | 73 | 72 | 72 | 72 | 72 | 72 | 71 | 70 | 69 | 68 | 68 | 68 | 68 | 67 | 67 | 66 | 67 | 67 | 67 | 67 | 67 | 68 | 68 | 68 | 68 | 67 |
| 10 | 76 | 76 | 75 | 75 | 74 | 74 | 74 | 73 | 73 | 73 | 74 | 73 | 73 | 72 | 71 | 70 | 70 | 70 | 70 | 69 | 68 | 67 | 67 | 67 | 67 | 67 | 67 | 68 | 68 | 68 | 68 | 67 |
| 9 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 74 | 73 | 73 | 73 | 73 | 72 | 72 | 70 | 70 | 70 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 68 |
| 8 | 78 | 78 | 78 | 78 | 78 | 78 | 79 | 78 | 78 | 78 | 78 | 78 | 78 | 76 | 76 | 75 | 75 | 75 | 74 | 73 | 72 | 71 | 71 | 71 | 70 | 70 | 70 | 70 | 69 | 70 | 69 | 69 |
| 7 | 80 | 80 | 81 | 81 | 81 | 81 | 81 | 81 | 81 | 81 | 81 | 81 | 80 | 79 | 78 | 78 | 78 | 77 | 77 | 76 | 74 | 74 | 74 | 73 | 72 | 72 | 72 | 72 | 71 | 71 | 70 | 68 |
| 6 | 81 | 82 | 82 | 82 | 82 | 82 | 83 | 83 | 83 | 83 | 83 | 82 | 82 | 81 | 81 | 80 | 80 | 80 | 79 | 78 | 76 | 76 | 76 | 75 | 75 | 74 | 74 | 74 | 73 | 73 | 72 | 70 |
| 5 | 82 | 82 | 83 | 83 | 83 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 83 | 83 | 83 | 83 | 82 | 81 | 80 | 79 | 78 | 78 | 77 | 77 | 76 | 76 | 75 | 74 | 74 | 73 | 72 |
| 4 | 83 | 84 | 84 | 84 | 84 | 85 | 85 | 86 | 86 | 86 | 87 | 86 | 86 | 86 | 86 | 86 | 86 | 85 | 84 | 83 | 81 | 81 | 80 | 80 | 79 | 78 | 77 | 76 | 75 | 75 | 74 | 73 |
| 3 | 84 | 85 | 85 | 85 | 85 | 86 | 87 | 87 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 87 | 86 | 84 | 83 | 82 | 82 | 81 | 80 | 78 | 78 | 77 | 76 | 76 | 75 | 73 |
| 2 | 85 | 85 | 86 | 86 | 87 | 87 | 88 | 89 | 89 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 89 | 88 | 86 | 85 | 84 | 83 | 82 | 81 | 80 | 79 | 78 | 77 | 77 | 76 | 74 |
| 1 | 85 | 86 | 86 | 86 | 86 | 87 | 88 | 89 | 89 | 90 | 91 | 91 | 91 | 90 | 90 | 90 | 91 | 90 | 89 | 87 | 86 | 84 | 84 | 82 | 81 | 79 | 78 | 77 | 76 | 76 | 75 | 73 |
| 0 | 86 | 86 | 87 | 87 | 87 | 88 | 89 | 89 | 90 | 91 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 91 | 90 | 88 | 87 | 86 | 85 | 83 | 82 | 80 | 79 | 78 | 77 | 76 | 75 | 73 |
| -1 | 86 | 87 | 87 | 87 | 87 | 88 | 89 | 90 | 91 | 91 | 92 | 92 | 92 | 93 | 93 | 93 | 93 | 92 | 90 | 89 | 87 | 86 | 85 | 83 | 82 | 80 | 79 | 78 | 76 | 75 | 74 | 72 |
| -2 | 88 | 88 | 89 | 89 | 88 | 89 | 90 | 91 | 92 | 92 | 93 | 93 | 93 | 93 | 93 | 93 | 93 | 92 | 91 | 89 | 88 | 86 | 85 | 83 | 82 | 80 | 79 | 78 | 76 | 75 | 73 | 71 |
| -3 | 89 | 89 | 89 | 89 | 88 | 89 | 90 | 91 | 91 | 92 | 93 | 93 | 93 | 93 | 93 | 93 | 93 | 92 | 91 | 89 | 87 | 86 | 85 | 83 | 82 | 80 | 79 | 78 | 76 | 75 | 73 | 71 |
| -4 | 89 | 89 | 89 | 88 | 88 | 88 | 89 | 90 | 91 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 91 | 90 | 88 | 87 | 86 | 85 | 83 | 81 | 80 | 78 | 77 | 76 | 75 | 73 | 70 |
| -5 | 89 | 89 | 88 | 87 | 87 | 87 | 88 | 89 | 89 | 90 | 91 | 91 | 90 | 90 | 91 | 91 | 91 | 90 | 88 | 87 | 86 | 85 | 84 | 82 | 80 | 79 | 78 | 76 | 75 | 74 | 72 | 70 |
| -6 | 88 | 88 | 87 | 86 | 86 | 86 | 87 | 87 | 88 | 89 | 89 | 89 | 89 | 89 | 89 | 89 | 89 | 89 | 87 | 86 | 85 | 84 | 84 | 82 | 81 | 79 | 78 | 77 | 75 | 74 | 73 | 71 |
| -7 | 87 | 86 | 85 | 85 | 84 | 84 | 85 | 85 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 88 | 88 | 87 | 86 | 85 | 84 | 83 | 83 | 81 | 80 | 79 | 78 | 76 | 75 | 74 | 73 | 72 |
| -8 | 85 | 85 | 84 | 83 | 82 | 83 | 83 | 84 | 85 | 86 | 86 | 86 | 85 | 86 | 86 | 86 | 87 | 86 | 85 | 84 | 84 | 83 | 82 | 81 | 80 | 78 | 77 | 76 | 75 | 74 | 73 | 72 |
| -9 | 84 | 83 | 82 | 81 | 81 | 81 | 81 | 82 | 83 | 83 | 84 | 84 | 84 | 84 | 84 | 85 | 85 | 85 | 84 | 83 | 82 | 82 | 81 | 80 | 79 | 78 | 77 | 76 | 75 | 75 | 74 | 73 |
| -10 | 82 | 82 | 81 | 80 | 79 | 79 | 79 | 80 | 81 | 82 | 82 | 82 | 82 | 83 | 83 | 84 | 84 | 84 | 83 | 82 | 82 | 81 | 81 | 80 | 80 | 79 | 78 | 77 | 76 | 76 | 76 | 75 |
| -11 | 81 | 80 | 79 | 78 | 77 | 77 | 77 | 78 | 78 | 79 | 80 | 80 | 80 | 80 | 81 | 81 | 82 | 82 | 81 | 80 | 80 | 79 | 79 | 79 | 79 | 78 | 78 | 78 | 78 | 78 | 78 | 78 |
| -12 | 80 | 79 | 78 | 77 | 76 | 76 | 76 | 75 | 77 | 78 | 78 | 79 | 78 | 79 | 80 | 80 | 81 | 81 | 80 | 79 | 79 | 79 | 79 | 79 | 79 | 78 | 79 | 79 | 79 | 79 | 79 | 79 |
| -13 | 79 | 78 | 78 | 77 | 76 | 76 | 76 | 76 | 77 | 77 | 78 | 78 | 78 | 78 | 79 | 79 | 80 | 80 | 79 | 79 | 78 | 78 | 78 | 78 | 78 | 78 | 79 | 79 | 79 | 79 | 79 | 79 |
| -14 | 79 | 79 | 78 | 77 | 76 | 76 | 76 | 76 | 77 | 77 | 77 | 77 | 77 | 77 | 78 | 79 | 79 | 79 | 79 | 78 | 77 | 77 | 77 | 78 | 78 | 78 | 78 | 79 | 79 | 79 | 79 | 79 |
| -15 | 80 | 79 | 79 | 78 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 78 | 79 | 79 | 79 | 79 | 78 | 78 | 78 | 78 | 78 | 78 | 78 | 79 | 79 | 79 | 80 | 80 | 80 |
| -16 | 80 | 79 | 79 | 78 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 78 | 78 | 79 | 79 | 80 | 79 | 79 | 79 | 79 | 79 | 79 | 80 | 80 | 80 | 81 | 81 | 81 | 81 | 81 |

Figure H-6. SUBARRAY STANDARD DEVIATION DISPLAY FOR CASE VI, ARRAY PAIR 5, UPPER THRESHOLD = 273

CROSS-CORRELATIONS (IN PERCENTAGE) BETWEEN WINDOW AND SEARCH AREA SUBARRAY ARRANGED BY LAG COORDINATES RELATIVE TO SEARCH AREA

| LAGS | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 11 | 12 | 11 | 10 | 7 | 6 | 6 | 8 | 9 | 6 | 3 | -1 | -5 | -9 | -13 | -17 | -22 | -26 | -30 | -32 | -36 | -39 | -42 | -45 | -47 | -49 | -47 | -44 | -43 | -42 | -40 | -39 |
| 15 | 16 | 19 | 19 | 17 | 15 | 13 | 12 | 13 | 12 | 9 | 7 | 5 | 2 | -1 | -4 | -8 | -12 | -17 | -20 | -23 | -26 | -32 | -37 | -41 | -44 | -45 | -45 | -43 | -41 | -39 | -39 | -36 |
| 14 | 23 | 26 | 26 | 25 | 22 | 20 | 18 | 16 | 15 | 13 | 12 | 10 | 8 | 6 | 3 | 0 | -4 | -8 | -12 | -14 | -18 | -22 | -27 | -33 | -35 | -37 | -37 | -35 | -34 | -32 | -31 | -29 |
| 13 | 27 | 28 | 28 | 29 | 27 | 26 | 24 | 22 | 19 | 16 | 14 | 12 | 11 | 9 | 9 | 7 | 5 | 0 | -4 | -8 | -11 | -14 | -16 | -20 | -23 | -25 | -25 | -24 | -24 | -24 | -24 | -24 |
| 12 | 28 | 30 | 30 | 31 | 30 | 29 | 30 | 28 | 25 | 22 | 18 | 16 | 13 | 11 | 11 | 12 | 10 | 6 | 2 | 0 | -2 | -3 | -5 | -7 | -8 | -9 | -9 | -11 | -12 | -13 | -14 | -15 |
| 11 | 29 | 31 | 32 | 32 | 32 | 32 | 33 | 34 | 32 | 29 | 25 | 22 | 18 | 16 | 16 | 16 | 15 | 13 | 9 | 6 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 0 | 0 | -1 | -3 |
| 10 | 30 | 33 | 35 | 35 | 35 | 36 | 37 | 39 | 39 | 37 | 33 | 30 | 26 | 24 | 24 | 25 | 25 | 22 | 17 | 13 | 11 | 11 | 11 | 11 | 10 | 10 | 10 | 9 | 8 | 7 | 6 | 4 |
| 9 | 34 | 36 | 37 | 36 | 37 | 38 | 40 | 43 | 42 | 41 | 39 | 36 | 34 | 32 | 33 | 34 | 33 | 31 | 28 | 24 | 22 | 20 | 20 | 20 | 19 | 17 | 16 | 16 | 15 | 14 | 12 | 9 |
| 8 | 36 | 37 | 37 | 37 | 38 | 39 | 39 | 42 | 43 | 43 | 43 | 42 | 40 | 39 | 39 | 41 | 41 | 40 | 38 | 34 | 33 | 31 | 30 | 30 | 29 | 29 | 26 | 23 | 21 | 19 | 16 | 14 |
| 7 | 35 | 36 | 37 | 37 | 36 | 35 | 36 | 39 | 41 | 41 | 42 | 43 | 42 | 43 | 44 | 45 | 47 | 47 | 45 | 43 | 42 | 40 | 38 | 37 | 36 | 34 | 32 | 31 | 28 | 26 | 23 | 22 |
| 6 | 34 | 34 | 34 | 34 | 33 | 32 | 34 | 39 | 40 | 41 | 43 | 44 | 44 | 47 | 50 | 51 | 51 | 50 | 50 | 49 | 48 | 47 | 45 | 42 | 41 | 40 | 38 | 37 | 36 | 34 | 31 | 29 |
| 5 | 33 | 34 | 33 | 32 | 31 | 30 | 32 | 34 | 37 | 40 | 42 | 45 | 47 | 50 | 53 | 53 | 55 | 55 | 54 | 53 | 52 | 50 | 49 | 46 | 45 | 43 | 42 | 41 | 40 | 39 | 36 | 34 |
| 4 | 30 | 31 | 31 | 30 | 29 | 29 | 30 | 32 | 33 | 37 | 40 | 44 | 48 | 52 | 55 | 57 | 58 | 58 | 57 | 56 | 55 | 54 | 53 | 51 | 49 | 47 | 45 | 45 | 44 | 43 | 41 | 38 |
| 3 | 25 | 26 | 28 | 29 | 29 | 29 | 30 | 29 | 30 | 34 | 37 | 43 | 47 | 53 | 58 | 60 | 60 | 60 | 59 | 60 | 59 | 58 | 57 | 56 | 53 | 51 | 50 | 49 | 49 | 46 | 44 | 42 |
| 2 | 20 | 23 | 26 | 27 | 28 | 28 | 30 | 29 | 30 | 33 | 36 | 40 | 46 | 53 | 58 | 60 | 62 | 62 | 61 | 61 | 60 | 59 | 58 | 57 | 55 | 55 | 54 | 53 | 52 | 50 | 46 | 45 |
| 1 | 17 | 20 | 23 | 25 | 26 | 27 | 30 | 30 | 32 | 33 | 37 | 41 | 46 | 51 | 55 | 58 | 60 | 60 | 60 | 59 | 58 | 57 | 56 | 55 | 55 | 56 | 56 | 55 | 54 | 51 | 49 | 46 |
| 0 | 19 | 22 | 23 | 25 | 27 | 28 | 29 | 29 | 31 | 35 | 40 | 44 | 48 | 52 | 54 | 55 | 57 | 58 | 58 | 58 | 55 | 52 | 50 | 50 | 50 | 49 | 48 | 48 | 48 | 47 | 45 | 44 |
| -1 | 20 | 22 | 23 | 24 | 26 | 27 | 27 | 29 | 32 | 35 | 41 | 46 | 49 | 52 | 54 | 55 | 55 | 55 | 56 | 53 | 51 | 49 | 46 | 44 | 43 | 41 | 40 | 40 | 39 | 39 | 38 | 38 |
| -2 | 21 | 22 | 23 | 23 | 25 | 26 | 27 | 28 | 32 | 35 | 39 | 43 | 47 | 50 | 53 | 55 | 55 | 54 | 54 | 51 | 49 | 46 | 44 | 41 | 39 | 38 | 36 | 35 | 33 | 32 | 32 | 32 |
| -3 | 22 | 23 | 23 | 22 | 22 | 23 | 24 | 27 | 29 | 32 | 36 | 39 | 43 | 45 | 49 | 49 | 49 | 49 | 50 | 49 | 47 | 45 | 43 | 40 | 37 | 35 | 34 | 33 | 30 | 30 | 29 | 27 |
| -4 | 25 | 25 | 26 | 24 | 23 | 24 | 25 | 26 | 29 | 30 | 33 | 36 | 39 | 41 | 42 | 43 | 43 | 42 | 44 | 45 | 44 | 44 | 43 | 40 | 38 | 36 | 34 | 33 | 32 | 31 | 29 | 27 |
| -5 | 27 | 28 | 26 | 25 | 24 | 24 | 25 | 25 | 29 | 30 | 31 | 33 | 35 | 36 | 37 | 36 | 36 | 36 | 36 | 38 | 38 | 39 | 38 | 36 | 36 | 35 | 34 | 34 | 33 | 31 | 29 | 26 |
| -6 | 28 | 27 | 26 | 25 | 25 | 23 | 23 | 24 | 26 | 28 | 29 | 30 | 32 | 33 | 32 | 31 | 30 | 31 | 30 | 30 | 31 | 31 | 32 | 31 | 30 | 31 | 31 | 31 | 30 | 28 | 26 | 24 |
| -7 | 28 | 28 | 26 | 24 | 24 | 21 | 21 | 22 | 22 | 23 | 26 | 28 | 30 | 28 | 28 | 28 | 27 | 27 | 25 | 25 | 24 | 24 | 24 | 25 | 25 | 26 | 26 | 26 | 25 | 24 | 22 | 19 |
| -8 | 28 | 26 | 24 | 22 | 21 | 19 | 17 | 19 | 18 | 19 | 22 | 24 | 25 | 25 | 25 | 25 | 23 | 22 | 22 | 20 | 19 | 19 | 20 | 21 | 22 | 24 | 23 | 22 | 22 | 19 | 17 | 16 |
| -9 | 28 | 27 | 22 | 18 | 16 | 15 | 13 | 12 | 13 | 15 | 17 | 19 | 20 | 22 | 22 | 22 | 21 | 19 | 20 | 18 | 16 | 16 | 17 | 18 | 20 | 22 | 24 | 24 | 22 | 19 | 19 | 17 |
| -10 | 28 | 25 | 21 | 16 | 13 | 11 | 8 | 9 | 10 | 10 | 12 | 15 | 17 | 19 | 20 | 19 | 19 | 18 | 19 | 17 | 15 | 14 | 13 | 15 | 18 | 21 | 23 | 24 | 23 | 22 | 21 | 20 |
| -11 | 25 | 21 | 18 | 14 | 10 | 7 | 4 | 3 | 5 | 5 | 7 | 11 | 14 | 16 | 16 | 16 | 18 | 19 | 18 | 16 | 14 | 14 | 14 | 14 | 17 | 21 | 23 | 25 | 25 | 26 | 25 | 24 |
| -12 | 21 | 18 | 14 | 9 | 4 | 1 | 0 | -1 | 0 | 2 | 4 | 7 | 11 | 12 | 14 | 15 | 15 | 17 | 15 | 15 | 14 | 13 | 13 | 14 | 16 | 20 | 23 | 25 | 26 | 28 | 28 | 26 |
| -13 | 17 | 12 | 9 | 4 | -1 | -5 | -7 | -6 | -5 | -4 | 0 | 2 | 5 | 9 | 12 | 13 | 13 | 14 | 14 | 14 | 13 | 14 | 14 | 15 | 17 | 21 | 24 | 28 | 29 | 30 | 31 | 30 |
| -14 | 15 | 11 | 6 | 3 | -3 | -8 | -9 | -8 | -7 | -6 | -4 | -1 | 2 | 4 | 8 | 8 | 9 | 11 | 12 | 12 | 12 | 13 | 14 | 16 | 19 | 22 | 27 | 29 | 31 | 33 | 33 | 34 |
| -15 | 11 | 9 | 5 | 1 | -4 | -8 | -10 | -9 | -8 | -7 | -5 | -3 | 0 | 2 | 3 | 5 | 8 | 12 | 12 | 12 | 12 | 14 | 16 | 19 | 21 | 24 | 27 | 31 | 33 | 35 | 36 | 37 |
| -16 | 8 | 7 | 4 | 0 | -4 | -7 | -8 | -9 | -9 | -8 | -5 | -2 | 0 | 1 | 4 | 5 | 7 | 9 | 12 | 11 | 12 | 14 | 17 | 20 | 23 | 25 | 28 | 33 | 35 | 38 | 38 | 39 |

TIME IN SECONDS FOR OPERATION 5 WAS 0.38333333

Figure H-7. CROSS-CORRELATION DISPLAY FOR CASE VI, ARRAY PAIR 5, UPPER THRESHOLD = 273

## Appendix I

## SOME SUPPORTING THEORY

1. The Cross-Covariance of Two Discrete Functions (from Stallard)

For two discrete functions x and y of one variable t, the cross-covariance function at lag $\tau$ is given by

$$(1) \quad C(\tau) = \frac{1}{N} \sum_{t=0}^{N-1} X(t)\, Y(t+\tau)$$

where N is the number of discrete values of X and Y. This definition of cross-covariance is different from the modified cross-covariance defined by

$$C(\tau) = \sum_{t+0}^{N-\tau} \frac{X(t)\, Y(t+\tau)}{N-\tau}$$

in that the unmodified form assumes that the data is cyclic, whereas the modified form does not. In the modified form the sum is defined only over those values of X and Y that overlap. This difference should be kept in mind when comparing the results obtained from the two different expressions.

Equation (1) can be written as

$$C(\tau) = \frac{1}{N} \sum_{t=0}^{N-1} \sum_{s=0}^{N-1} S(t)\, Y(s)\, \delta_N(s-t-\tau)$$

where $\delta_N$ is the Kronecker delta function with its argument being considered modulo N, i.e.

$$\delta_N(kN) = \begin{cases} 1, & \text{if } k \text{ is an integer} \\ 0, & \text{otherwise} \end{cases}$$

The orthogonality condition states that

$$\sum_{t=0}^{N-1} e^{\frac{2\pi i t u}{N}} = N\,\delta_N(u)$$

so that

$$C(\tau) = \frac{1}{N^2} \sum_{t=0}^{N-1} \sum_{s=0}^{N-1} X(t)\,Y(s) \sum_{r=0}^{N-1} e^{\frac{2\pi i r(s-t-\tau)}{N}}$$

$$= \sum_{r=0}^{N-1} \left( \frac{1}{N} \sum_{t=0}^{N-1} X(t) e^{\frac{-2\pi i r t}{N}} \right) \left( \frac{1}{N} \sum_{s=0}^{N-1} Y^*(s) e^{\frac{-2\pi i r s}{N}} \right) e^{\frac{-2\pi i r \tau}{N}}$$

where $Y^*(S)$ denotes the complex conjugate of $Y(S)$.

Since the expressions above in parenthesis are the inverse Fourier transforms of X and Y respectively,

$$C(\tau) = \sum_{r=0}^{N-1} A(r)\,B^*(r)\,e^{\frac{-2\pi i r \tau}{N}}$$

where $A(r)$ and $B(r)$ are the Fourier coefficients of $X(t)$ and $Y(t)$ respectively.

Then, by taking complex conjugates,

$$C(\tau) = \sum_{r=0}^{N-1} A^*(r)\,B(r)\,e^{\frac{2\pi i r \tau}{N}} = D(\tau).$$

where $D(\tau)$ is the Fourier transform of $A^*B$.

For two discrete functions X and Y of two variables $t_1$ and $t_2$, the cross-covariance function at lag $\tau_1$ and $\tau_2$ is given by

$$(2)\quad C(\tau_1, \tau_2) = \frac{1}{N_1 N_2} \sum_{t_1=0}^{N_1-1} \sum_{t_2=0}^{N_2-1} X(t_1, t_2)\,Y(t_1+\tau_1, t_2+\tau_2)$$

where $N_1$ is the number of discrete values of the variable $t_1$ and $N_2$ is the number of discrete values of the variable $t_2$. Then equation (2) can be written as

$$C(\tau_1,\tau_2) = \frac{1}{N_1N_2} \sum_{t_1=0}^{N_1-1} \sum_{t_2=0}^{N_2-1} \sum_{s_1=0}^{N_1-1} \sum_{s_2=0}^{N_2-1} X(t_1,t_2)\ Y(s_1,s_2 0.$$

$$\cdot\delta_{N_1N_2}\ (s_1 - t_1 - \tau_1,\ s_2 - t_2 - \tau_2)\ .$$

This, in turn, reduces to

$$C\ (\tau_1,\tau_2) = \sum_{r_1=0}^{N_1-1} \sum_{r_2=0}^{N_2-1} A(r_1,r_2)\ B^*\ (r_1,r_2)\ e^{-2\pi i \left[\frac{r_1\tau_1}{N_1} + \frac{r_1\tau_1}{N_2}\right]}$$

or $$C(\tau_1,\tau_2) = \sum_{r_1=0}^{N_1-1} \sum_{r_2=0}^{N_2-1} A^*\ (r_1,r_2)\ B\ (r_1,r_2^2)\ e^{2\pi i \left[\frac{r_1\tau_1}{N_1} + \frac{r_2\tau_2}{N_2}\right]}$$

which is $D\ (\tau_1,\tau_2)$, the Fourier transform of A*B.

2. Covariance Computation (From Stallard)

The classical means of computing the cross-covariance function had been lagged products. However, the advent of a fast Fourier transform allowed a new approach to computing the cross-covariance.

The cross-covariance of two functions f and g at lags $u_1$ and $u_2$ is approximated by

$$C(u_1,\ u_2) = T^{-1}\ [(T(f)\ )^*\ \ T(g)]$$

where T is the finite Fourier series representation of a function. For the case in which f and g are the same functions the function $C(u_1,\ u_2)$ is referred to as the auto-covariance.

If f represents one set of cloud data, and g represents a subsequent set of cloud data, then the motion required to move f with respect to g so as to produce a maximum covariance is the motion of the cloud pattern.

3. Simultaneous Fourier Analysis of Two Sets of Real Data (From Cooley)

Here we shall describe a procedure for calculating the Fourier transforms of two sets of real data by applying one complex Fourier transform. Letting $S_1(j)$ and $X_2(j)$ be two sets of real data with

$$X_1(j) \leftrightarrow A_1(n)$$

$$X_2(j) \leftrightarrow A_2(n),$$

we have

$$X(j) \leftrightarrow A(n)$$

where

$$X(j) = X_1(j) + i\ X_2(j)$$

and

$$A(n) = A_1(n) + i\ A_2(n).$$

Replacing n by N-n, taking conjugates of both sides we may obtain

$$A^*\ (N-n) = A_{11}^*(N-n) - i\ A_2^*\ (N-n) = A_1(n) - i\ A_2(n)$$

It then follows by addition that

$$A(n) + A^*(N-n) = 2A_1(n) \quad \text{and by subtraction}$$

$$A(n) - A^*(N-n) = 2i\ A_2(n)$$

hence $$A_1\ (n) = \frac{1}{2}\ [A(n) + A^*\ (N-n)]$$

and $$A_2\ (n) = \frac{1}{2i}\ [A(n) - A^*\ (N-n)]$$

For the special cases n=0 and n=N/2 we note that

$$A(0) = A_1(0) + i\ A_2(0)$$

$$A(\tfrac{N}{2}) = Ai\ (\tfrac{N}{2}) + i\ A_2\ (\tfrac{N}{2})$$

So $A_1(0)$ is the Real part of $A(0)$

$A_2(0)$ is the Imaginary part of $A(0)$

$A_1\ (\frac{N}{2})$ is the Real part of $A(\frac{N}{2})$

$A_2\ (\frac{N}{2})$ is the Imaginary part of $A(\frac{N}{2})$

Since $X_1(j)$ and $X_2(j)$ are postulated as two sets of real data their Fourier coefficients satisfy the symmetry property

$$A_1(n) = A_1^*\ (N-n) \text{ and } A_2(n) = A_2^*\ (N-n)$$

and therefore only one half of each array need be computed and stored. Thus one requires the same amount of storage for $A_1(n)$ and $A_2(n)$ as for $A(n)$ or $X(j)$. A suggested storage arrangement is to replace $A(n)$ by $A_1(n)$ and $A(N-n)$ by $A_2(N-n)$ for $n = 1, 2, \ldots, N/2-1$. We see that we can skip the indices $n = 0$ and $N/2$ since we already have the results in the real and imaginary parts of $A(0)$ and $A(N/2)$. To summarize the procedure when using the subroutine HARM:

Step 1. Let $X\ (j) = X_1(j) + i\ X_2(j)$ be the input to HARM

Step 2. Call HARM, requesting that a Fourier transform be computed, replacing the array $X(j)$ by $A(n)$.

Step 3. For $n = 1, 2, \ldots, (N/2 -1)$, let

$$A_1(n) = \frac{1}{2}\ [A(n) + A^*(N-n)]$$

$$A_2^*(N-n) = \frac{i}{2i}\ [A(n) - A^*(N-n)]$$

with $A_1(n)$ and $A_2(N-n)$ replacing $A(n)$ and $A(N-n)$, respectively, in storage.

4. Errors in Digital Fourier Transform Convolution/Correlation (From Silverman)

Errors in performing a DFT convolution or correlation may be considered as stemming from two sources. First is the error incurred in sampling continuous functions, which is easy to bound. Second is the error resulting from roundoff in fast Fourier transforms and in multiplications.

The error in approximation of a continuous Fourier Transform by the DFT has been shown to result from three sources. First, one assumes that the function is non-zero only over a finite interval. Should this not be the case, aliasing error occurs. The magnitude of this error can easily be bounded by comparing a norm for the function on the intervals, $(-\infty, 0)$, $(T, \infty)$ with the same norm over $(0,T)$. This is demonstrated for the square norm in

$$||X(t)||_{ab} = \left[ \int_a^b X^2(t)dt \right]^{1/2}$$

$$\% \text{ aliasing error} \leq 100 \times \frac{\left( ||X(t)||_{-\infty,0} + ||X(t)||_{T,\infty} \right)}{||X(t)||_{0,T}}$$

(Note: there are special cases when the region $(-\infty, \infty)$ need not be considered.)

A second aliasing error occurs as a result of saving only a finite number of frequencies. If an analytic solution for the continuous Fourier Transform for a function is known, the application of the above in equality for frequency domain functions may be applied to find this source of error by replacing T with F.

A third source of error in this approximation comes from the trapezoidal integration. This is proportional to the second derivative of the function being approximated.

$$\frac{N(\Delta t)^3}{12} f''(n\Delta t).$$

Therefore, the DFT is a reasonable approximation to the continuous Fourier Transform only if all three of these sources of error are small. These three error criteria severely influence the selection of the two parameters which may be selected, t and T. The integration interval T must be selected to optimize two criteria. First, it must cause the error due to

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