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RANDOM-ACCESS TECHNIQUE FOR MODULAR BATHYMETRY DATA STORAGE IN A CONTINENTAL-SHELF WAVE-REFRACTION PROGRAM

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16. Abstract

A study was conducted of an alternate method for storage and use of bathymetry data in the Langley Research Center and Virginia Institute of Marine Science mid-Atlantic continental-shelf wave-refraction computer program. The regional bathymetry array was divided into 105 indexed modules which can be read individually into memory in a non-sequential manner from a peripheral file using special random-access subroutines. In running a sample refraction case, a 75-percent decrease in program field length was achieved by using the random-access storage method in comparison with the conventional method of total regional array storage. This field-length decrease was accompanied by a comparative 5-percent increase in central processing time and a 477-percent increase in the number of operating-system calls. A comparative Langley Research Center computer-system cost savings of 68 percent was achieved by using the random-access storage method.

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RANDOM-ACCESS TECHNIQUE FOR MODULAR BATHYMETRY

DATA STORAGE IN A CONTINENTAL-SHELF

WAVE-REFRACTION PROGRAM

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SUMMARY

A study has been conducted of an alternate method for storage and use of bathymetry data in the Langley Research Center (LRC)-Virginia Institute of Marine Science (VIMS) mid-Atlantic continental-shelf wave-refraction computer program. The method involves dividing the regional bathymetry array, which in the conventional method is stored in its entirety, into a number of indexed modules. The data modules are read into computer memory in a nonsequential manner from a peripheral disk file by using special random-access subroutines. Based on computer resources expended in running a sample refraction case, it was found that, in comparison with the conventional regional array storage method, a 75-percent reduction in program field length accompanied by only a 5-percent increase in central processing time was achieved by using the alternate random-access storage method with modules of dimensions 23 by 43. An increase of 477 percent in the number of operating-system calls was experienced in running the sample case by using the random-access method; however, since operating-system calls are weighted very lightly in the Langley Research Center computer-system cost formula, a cost reduction of 68 percent was achieved in comparison with the cost incurred with the use of the conventional storage method. Comparable cost savings could be expected in general use of the LRC-VIMS program with random-access storage on the Langley computer system. For other computer systems in which the computer-system cost formula is similar to that of the Langley system, substantial cost savings could be expected with the use of random-access techniques in programs where only a small part of a large data field is required in central memory at any one time.

INTRODUCTION

One key objective of the NASA Earth and Ocean Physics Application Program (EOPAP) is the development and validation of methods for monitoring and predicting transient ocean surface phenomena, with the emphasis being on identifying existing and potential hazards to the coastline and to shipping on the continental shelf. A necessary ingredient of such an

effort is an analytical model to predict on a broad scale the influence of irregular shelf bathymetry on the properties of waves propagating across the shelf toward the coastline. Such analytical models have existed for some time, but have been limited to small regions around harbors or inlets.

In a cooperative effort, the Langley Research Center (LRC) and the Virginia Institute of Marine Science (VIMS) have recently developed a computerized analytical model of wave refraction on the mid-Atlantic continental shelf beginning with deep-ocean conditions. This model is the first known application of linear wave theory to such a large geographical area. As such, it offers the opportunity for a broad-scale study of hazards and other coastal-zone problems such as the location of offshore port facilities and waste disposal sites.

A prelude to continuous use of any computer program is a phase to maximize the efficiency of computations and the storage and use of input data. Such a phase is of particular importance to a continental-shelf wave-refraction program, since bathymetry data must be supplied in fine detail over a large geographical area. For this reason, a study has been conducted of a method for storage and use of the bathymetry data in the LRC-VIMS wave-refraction program alternative to the conventional method in which the entire regional bathymetry array is stored continually. The new method involves the use of random-access subroutines developed by the Control Data Corporation (CDC) and available through the Langley computer system library. A brief discussion of the wave-refraction program and its internal use of the bathymetry data is presented along with the reasoning behind the adoption of the random-access storage method. A typical case is computed by use of the random-access method and compared with an identical case computed by using the conventional regional array method of storage. Computer resource requirements for running the case by using each storage method are compared and discussed.

SYMBOLS

a,b   any general numbers

$[f]$ largest integer less than or equal to the function f

I_n regional row index of point p_n

$I_{n,L}$ local row index of point p_n

$I_{n,L}^*$ local row index of point p_n in overlapping sections

J_n regional column index of point p_n

2

$J_{n,L}$ local column index of point p_n

$J_{n,L}^*$ local column index of point p_n in overlapping sections

K   module row number in random-access module arrangement

M   module column number in random-access module arrangement

N   index number of module currently required from random-access file

p_i local point of interest having regional coordinates (x_i, y_i)

p_n any of 12 nodal points in grouping surrounding point p_i (see fig. 2)

X   alongshore axis

x   alongshore coordinate

x_i regional x-coordinate of point p_i, grid units

Y   offshore axis

y   offshore coordinate

y_i regional y-coordinate of point p_i, grid units

WAVE-REFRACTION-PROGRAM DISCUSSION

The basic computational routines of the LRC-VIMS mid-Atlantic continental shelf wave-refraction program are described in reference 1. Basically, the program computes the change in direction of wave rays (orthogonals to a wave crest) as they are propagated from deep water across the continental shelf toward the coastline. The relative convergence or divergence of adjacent rays leads to a focus or diffusion of wave energy and, thus, changes in wave height, particle velocity, and other properties. Changes in the direction of ray propagation are due to changes in the speed of propagation of the wave. The propagation speed is influenced strongly by the local depth of the ocean for waters of relatively shallow depth such as those on the continental shelf.

It is obvious upon viewing the bathymetry contours of the mid-Atlantic shelf region shown in figure 1 that the bathymetry field as a whole cannot be represented mathematically by any single algebraic equation as a function of local position. Consequently, the basic program, as described in reference 1, calculates the depth at any point by an interpolation

procedure in which actual depth values are supplied for each nodal point in a square grid pattern covering the entire region of interest. In order to minimize error when applying the program to a region of irregular bathymetry, a relatively fine grid pattern must be used. As a consequence, application of the program to a large geographical area such as the mid-Atlantic shelf region involves a large number of actual depth values. The LRC-VIMS wave-refraction program employs a 1/2-nautical-mile square grid pattern of depth values which was developed from original hydrographic soundings and other data. Consequently, for the 100-nautical-mile (185-km) by 210-nautical-mile (389-km) region of interest, a total of approximately 200 by 420, or 84 000, depth values are required.

The LRC-VIMS program, as originally developed, handled these depth values in the same manner as did the original program described in reference 1. This technique involved storing the entire array of values in the central memory of the computer and using individual values in computations as needed. However, the only routine in the program in which the depth array is needed is the routine which performs the interpolation procedure. The specific procedure involved approximates the actual ocean bottom in a local region by using a quadratic least-squares polynomial. The coefficients of this polynomial are calculated by using actual depth values at only the 12 nodal points surrounding the local region of interest depicted in figure 2. Thus, with the LRC-VIMS program as a specific example, storing 84 000 values in central memory while using only 12 of the values at any one time in a computation constitutes inefficient use of computer space and resources. Some technique was clearly needed by which the entire array would be available to central memory, but by which as few values as necessary, or feasible, would actually be stored in central memory at any one time.

RANDOM-ACCESS MODULAR DATA STORAGE

A typical wave-refraction case run using the LRC-VIMS mid-Atlantic shelf program consists of a set of rays for which is prescribed an initial propagation direction, wave period, and height. The calculations for each ray are initiated at some deep-water (x,y) location (see fig. 1) near either the northern, eastern, or southern boundary of the rectangular region. As ray paths are computed on an individual basis (rather than as a set), it is logical that the regional bathymetry array could be divided into a number of small data modules, which could be supplied to central memory as needed as the individual ray progresses shoreward. A procedure which has been used in similar programs involves assigning module coordinates to each data module and writing the modules in order on a peripheral magnetic tape. A specific module is then retrieved by moving the tape sequentially forward or backward to the position of the required module.

This sequential modular technique is nearly optimal with respect to computer storage, but, in general, can be very inefficient in terms of computer time and computer-system operations necessary to move the tape to the position of the required module. Much more efficient module retrieval can be achieved by the use of random-access data storage. By using random-access techniques, logical records (data modules) can be retrieved individually from a peripheral disk file without the time-consuming steps of sequentially skipping unwanted records in either a forward or a backward manner. An identifying index number or name which is assigned by the user to each logical record on the random-access file is used by the operating system to locate and retrieve individual records.

The random-access procedure on the Langley computer system involves the use of several subroutines developed by Control Data Corporation and available through the Langley computer system library. These subroutines (appendix A) include subroutine OPENMS, which opens a random-access file and establishes the mode of indexing and the length of the index array; subroutine WRITMS, which is used to write records on the random-access file; and subroutine READMS, which is used to read records which have been written on the random-access file. In addition to the option of named or numbered indexing, the Langley random-access package allows for either single-level or multiple-level indexing. For simplicity in application of the random-access techniques to the LRC-VIMS wave-refraction program, it was decided that only single-level numbered indexing would be employed. With single-level indexing, the maximum number of records (and thus the minimum size of the data modules) that can feasibly be used is limited in that the array of index numbers must be stored in central memory. Consideration must also be given to the fact that the operating system is called each time a new record is read from the random-access file into central memory.

The first step, then, in applying the random-access modular data storage techniques to the LRC-VIMS program was the selection of module size. It was decided that modules of equal size would be used, although modules of unequal size and unequal grid spacing could be handled with little difficulty. For convenience, a nominal module size of 20 rows (in the x-direction) and 40 columns (in the y-direction) was selected as a base. This module size corresponds to a geographical area of 10 nautical miles (18.5 km) by 20 nautical miles (37 km). The region shown in figure 1 was thus divided into a total of 105 modules (21 rows and 5 columns of modules). The module arrangement and the index system used to identify individual modules are shown in figure 3.

Procedures for determining the index of the current module required from the random-access file and for properly utilizing the data within that module can now be developed. The first step is to calculate indices which denote the regional location of nodal point p_1 in the 12-point grouping about the point of interest p_i. (See fig. 4.) The regional row and column indices of point p_1 can be calculated as

$$I_1 = [x_i + 1.] \tag{1}$$

$$J_1 = [y_i + 1.] \tag{2}$$

where x_i and y_i are measured in 1/2-nautical-mile grid units and $[f]$ is the largest integer $\leq f$. It should be noted that, in accordance with Control Data FORTRAN convention, indices are numbered beginning with 1 rather than 0. In other words, row 1 is the Y-axis (x = 0) and column 1 is the X-axis (y = 0).

Within each 20 by 40 module, local indices indicate the location of point p_1 with respect to the northwest corner of the module. Equations for calculating these local indices can be determined by using modular arithmetic. The modular function can be defined as

$$a(\text{mod } b) = a - \left[\frac{a}{b}\right] b \tag{3}$$

The local indices of point p_1, for the 20 by 40 module size, are then

$$I_{1,L} = I_1(\text{mod } 20) \tag{4}$$

$$J_{1,L} = J_1(\text{mod } 40) \tag{5}$$

Local indices of nodal points p_2 to p_{12} can then be calculated by considering the orientation of these points with respect to point p_1. For example, $I_{4,L} = I_{1,L}$ and $J_{4,L} = J_{1,L} + 1.$ (See fig. 4.)

The module in which nodal point p_1 lies can then be identified by module row K and module column M numbers. These numbers can be calculated for the 20 by 40 module size as

$$K = \begin{cases} \left[\dfrac{I_1}{20}\right] + 1 & (I_{1,L} \neq 0) \tag{6} \\[2em] \left[\dfrac{I_1}{20}\right] & (I_{1,L} = 0) \tag{7} \end{cases}$$

$$M = \begin{cases} \left[\dfrac{J_1}{40}\right] + 1 & (J_{1,L} \neq 0) \tag{8} \\[2em] \left[\dfrac{J_1}{40}\right] & (J_{1,L} = 0) \tag{9} \end{cases}$$

A problem arises in the basic module configuration when nodal point p_1 lies near any of the edges of a 20 by 40 module. If point p_1 lies in the 1st row ($I_{1,L} = 1$), the 19th row ($I_{1,L} = 19$), or the 20th row ($I_{1,L} = 0$) of a module, at least two of the nodal points in the required grouping (p_2 to p_{12}) would lie outside the basic module. The same problem occurs if point p_1 lies in the 1st column ($J_{1,L} = 1$), the 39th column ($J_{1,L} = 39$), or the 40th column ($J_{1,L} = 0$) of a module. These problems can be avoided by allowing an overlap of three rows and three columns in adjacent modules. The particular overlapping config-uration which has been selected involves the addition of three rows at the southern edge and three columns at the eastern edge of each module and, thus, results in a module size of 23 by 43. In this configuration, local rows 21 to 23 of a module located in module row K are identical to local rows 1 to 3 of the adjacent module located in module row K + 1; local columns 41 to 43 of a module located in module column M are identical to local columns 1 to 3 of the adjacent module located in module column M + 1. The overlapping configuration is illustrated in figure 5 for modules 1, 2, 22, and 23 (as numbered in fig. 3). It should be noted that there is no overlapping near the boundaries of the region, the X- and Y-axes. In practice, computations are halted when the point of interest lies less than one grid unit from either axis.

With the overlapping configuration, then, if nodal point p_1 lies in any of rows 2 to 20 of a basic 20 by 40 module situated in module row K, the entire 12-point grouping lies in that same module row. Similarly, if point p_1 lies in any of columns 2 to 40 of a basic module situated in module column M, the entire 12-point grouping lies in that module column. If point p_1 should lie in row 1 of a module situated in module row K (with K $\neq$ 1 or $I_1 > 1$), the 12-point grouping lies in module row K - 1. Likewise, if point p_1 should lie in column 1 of a module situated in module column M (with M $\neq$ 1 or $J_1 > 1$), the 12-point grouping lies in module column M - 1. Equations for calculating the module row and module column numbers for these special cases are identical to equations (7) and (9). Restating these equations, with extended limits of application, yields

$$K = \left\lceil \frac{I_1}{20} \right\rceil \qquad (I_1 > 1; I_{1,L} < 2) \qquad\qquad (10)$$

$$M = \left\lceil \frac{J_1}{40} \right\rceil \qquad (J_1 > 1; J_{1,L} < 2) \qquad\qquad (11)$$

For either of the special cases mentioned, the local indices of point p_1 must be calculated by alternatives to the general equations (4) and (5). These alternate equations are as follows:

$$I_{I,L}^{*} = I_{1,L} + 20 \qquad (I_{1,L} < 2) \qquad (12)$$

$$J_{1,L}^{*} = J_{1,L} + 40 \qquad (J_{1,L} < 2) \qquad (13)$$

The local indices $(I_{n,L}^{*}, J_{n,L}^{*}, n = 2, 3, \ldots, 12)$ for nodal points p_2 to p_{12} for these special cases can again be calculated by considering the orientation of these points with respect to point p_1. (See fig. 4.)

The equations for calculating the indices of nodal point p_1 and module row and column numbers then can be summarized as follows:

Regional indices of nodal point p_1:

$$I_1 = [x_i + 1]$$

$$J_1 = [y_i + 1]$$

Local indices of nodal point p_1:

$$I_{1,L} = I_1 \,(\mathrm{mod}\ 20) \qquad (I_{1,L} \geqq 2)$$

$$I_{1,L}^{*} = I_{1,L} + 20 \qquad (I_{1,L} < 2)$$

$$J_{1,L} = J_1 \,(\mathrm{mod}\ 40) \qquad (J_{1,L} \geqq 2)$$

$$J_{1,L}^{*} = J_{1,L} + 40 \qquad (J_{1,L} < 2)$$

Module row number:

$$K = \begin{cases} \left[\dfrac{I_1}{20}\right] + 1 & (I_{1,L} \geqq 2) \\[3ex] \left[\dfrac{I_1}{20}\right] & (I_1 > 1;\ I_{1,L} < 2) \end{cases}$$

Module column number:

$$M = \begin{cases} \left[\dfrac{J_1}{40}\right] + 1 & (J_{1,L} \geqq 2) \\[20pt] \left[\dfrac{J_1}{40}\right] & (J_1 > 1; J_{1,L} < 2) \end{cases}$$

For all cases, the index number of the module required to be read from the random-access file can be calculated as follows:

$$N = 21(M - 1) + K \tag{14}$$

SAMPLE CASE COMPARISON

The LRC-VIMS wave-refraction program was altered to incorporate the random-access modular data storage techniques described in the previous section. The regional 420 by 200 bathymetry data array was divided into the 105 overlapped modules of dimensions 23 by 43 which were then copied in a proper manner onto a data cell for input to the random-access file. In order to verify that calculations were being performed properly with random-access data storage and to compare computer resource requirements, a sample refraction case was run by using the program with both the random-access modular storage method and the conventional regional array storage method. The refraction pattern calculated for the sample case (rays propagated from the southeast with a period of 8 sec) using the random-access method is shown in figure 6. An identical refraction pattern and other identical results were calculated for the sample case using the regional array storage method.

Computer resource requirements can be measured in terms of three variables: the program field length (FL) or the number of locations required for storing a program and its accompanying data in the central memory of the computer; the central processing time (CPT) required for the program to run to completion; and the number of operating-system (OS) calls, which include input/output operations such as reading a peripheral file, made during the run. The specific formula used to calculate job cost (JC) for a batch (non-priority) run on the Langley computer system is as follows:

$$JC = \frac{4 FL}{1000} \left(\frac{2}{60} + \frac{CPT}{1800} + \frac{0.001 OS}{60} \right) \tag{15}$$

where JC is measured in dollars, FL is measured in decimal locations, and CPT is measured in seconds. Comparative field lengths, central processing times, operating-system calls, and Langley computer-system costs for running the sample wave-refraction case with the random-access and regional array storage methods are given in table I.

TABLE I.- COMPUTER RESOURCE REQUIREMENTS FOR SAMPLE
REFRACTION CASE

Item	Random-access storage method	Regional array storage method	Ratio of random-access requirements to regional array requirements
Total field length, decimal	27 200	107 600	0.25
Central processing time, sec (CDC 6600 computer systems)	288	274	1.05
Operating-system calls	3289	570	5.77
Langley computer-system cost, $	27	84	.32

It is evident from table I that, for the Langley computer system, the random-access method is a significant improvement over the regional array method for data storage in the LRC-VIMS wave-refraction program. In comparison with the regional array storage method, there is a 75-percent reduction in total field length by using the random-access method, accompanied by only a 5-percent penalty in central processing time for this sample case. There is a 477-percent increase in operating-system calls for the sample case, but, since operating-system calls are weighted very lightly in the Langley system cost formula, this increase has only a small effect on the resultant cost. For the sample case, a cost reduction of 68 percent is achieved by using the random-access storage method as opposed to the regional array storage method. As this cost reduction is primarily due to the field-length reduction, which would vary only with module size, a comparable cost reduction can be expected in general use of the random-access method in the LRC-VIMS program or in similar programs on computer systems whose cost formula is similar to that of the Langley cost formula. For computer systems on which cost is a much stronger function of operating system calls, very different comparative results could be expected. In such situations, choice of a larger module size (and, thus, fewer modules) would be recommended in order to reduce the number of operating-system calls.

CONCLUSIONS

A study has been conducted of a new method for storage and use of bathymetry data in the Langley Research Center (LRC)-Virginia Institute of Marine Science (VIMS) mid-Atlantic continental-shelf wave-refraction computer program. The new method involves dividing the regional bathymetry array, which in the conventional method is stored in its entirety, into a number of indexed modules which can be read in a nonsequential manner from a designated random-access disk file. Special random-access subroutines are used which were developed by the Control Data Corporation and are available through the Langley computer-system library. A sample refraction case was run that used both the conventional regional array data storage method and the random-access modular data storage method, and identical computed results were obtained. Based on a comparison of computer resources required to run the sample case using each of the data storage methods, the following conclusions can be made:

1. A 75-percent reduction in total program field length was achieved by using the random-access storage method, with modules of dimensions 23 by 43, as opposed to using the conventional regional array storage method.

2. Central processing time required by using the random-access method was only 5 percent greater than that required by using the regional array storage method.

3. Operating-system calls required by use of the random-access method increased by 477 percent over the number required by use of the regional array storage method. This increase had only a slight effect on the Langley computer-system cost.

4. A Langley computer-system cost savings of 68 percent was achieved by using the random-access method as opposed to using the conventional regional array method. Comparable cost savings can be expected in general use of the LRC-VIMS program with random-access data storage.

5. For computer systems on which the cost formula is similar to that of the Langley system, substantial cost savings could be expected by using random-access methods in other programs where only a small part of a large data field is needed in central memory at any one time.

Langley Research Center,
    National Aeronautics and Space Administration,
        Hampton, Va., March 13, 1974.

APPENDIX A

LANGLEY LIBRARY SUBROUTINES

Subroutine OPENMS

Language: COMPASS

Purpose: To open a random-access file.

Use: CALL OPENMS(IU, IX, L, IP) where

IU   The logical unit number.

IX   The first word address of the index.

L   The length of the index.

IP $\begin{cases} = 0 & \text{for numbered indexing.} \\ = 1 & \text{for named indexing.} \end{cases}$

Restrictions: OPENMS must be the first operation on a random-access file. The file must be a disk file. For n index entries, the length of the index must be at least $2n + 1$ for named indexing, whereas the index length must be at least $n + 1$ for numbered indexing.

Method: OPENMS sets the first word in the index to a positive number for numbered indexing or to a negative number for named indexing. The random-access bit, index address, and index length are set by OPENMS into the FET of the file for system communication. If the file already exists, the master index is read into central memory.

Storage: 103_8 locations.

Subroutine date: March 22, 1972.

Subroutine WRITMS

Language: COMPASS

Purpose: To write a record on a random-access file.

Use: CALL WRITMS(IU, FWA, N, I) where

IU   The logical unit number.

FWA   The central memory address of the first word of the record.

N   The number of central memory words to be transferred.

I   The record number or record name depending upon the indexing mode set by the initial call to OPENMS.

Restrictions: The file must have been opened by a call to OPENMS.

Method: The specified record is written on the file and an address entered in the index to reference the record.

Storage: 102_8 locations.

Subroutine date: March 22, 1972.

Subroutine READMS

Language: COMPASS

Purpose: To read a record on a random-access file.

Use: CALL READMS(IU, FWA, N, I) where

IU   The logical unit number.

FWA   The central memory address of the first word of the record.

N   The number of words of the record to be transferred.

I   The record number or record name depending upon the indexing mode set by
        the initial call to OPENMS.

Restrictions: The file must have been opened by a call to OPENMS.

Method: The disk address of the record is determined using the index. If n words
    are requested to be transferred and there are m words in the record, where $m \leq n$,
    m words are transferred. If $m > n$, n words are transferred.

Storage: 131_8 locations.

Subroutine date: March 22, 1972.

REFERENCE

1. Dobson, R. S.: Some Applications of a Digital Computer to Hydraulic Engineering Problems. Rep. No. TR-80 (Contract Nonr-225(85)), Dep. Civil Eng., Stanford Univ., June 1967. (Available from DDC as AD 659 309.)
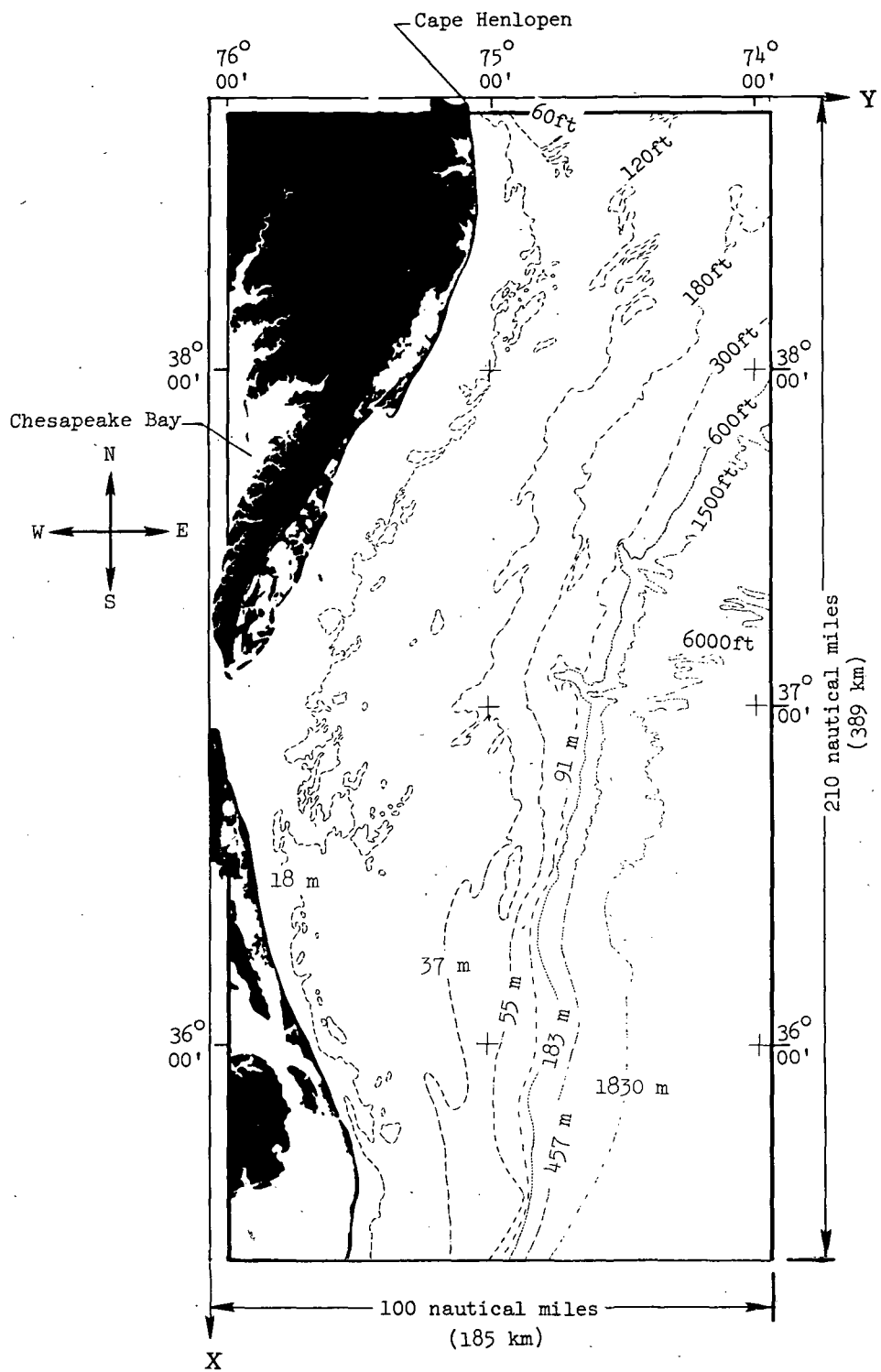
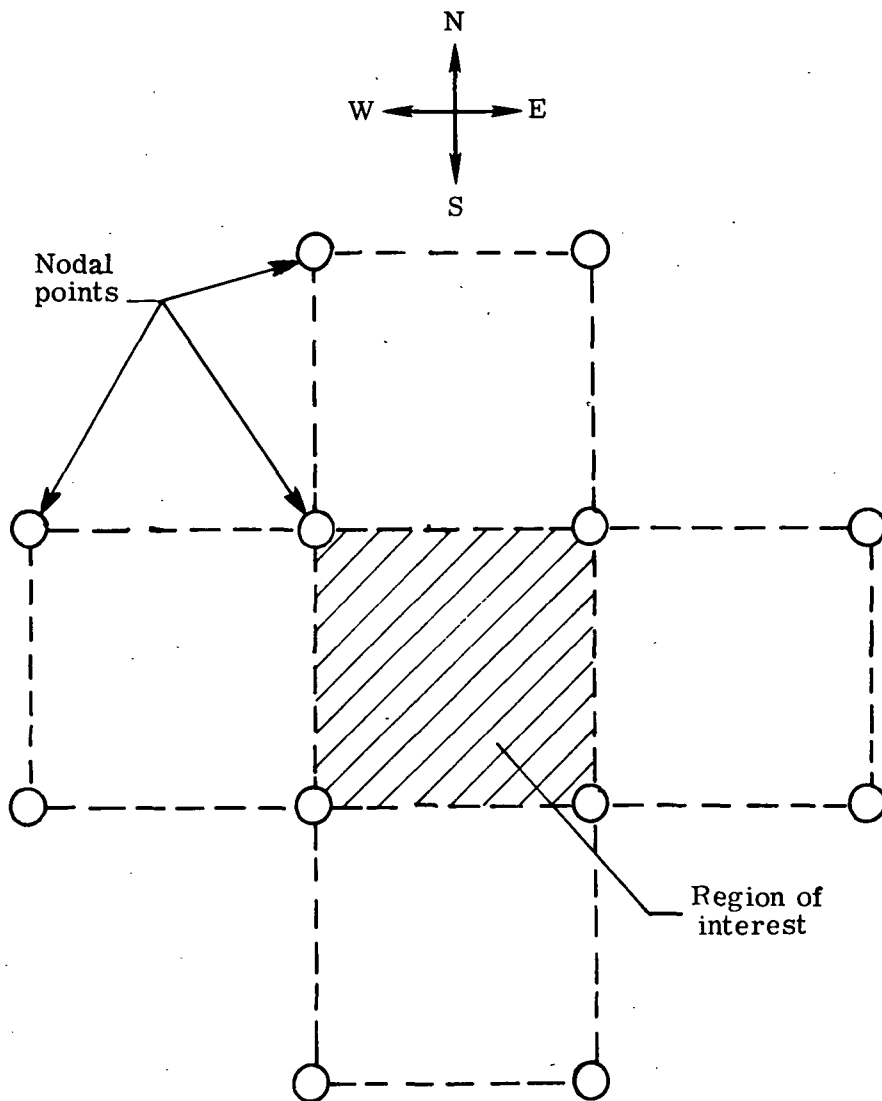Figure 1.- Bathymetry of the mid-Atlantic continental-shelf region.

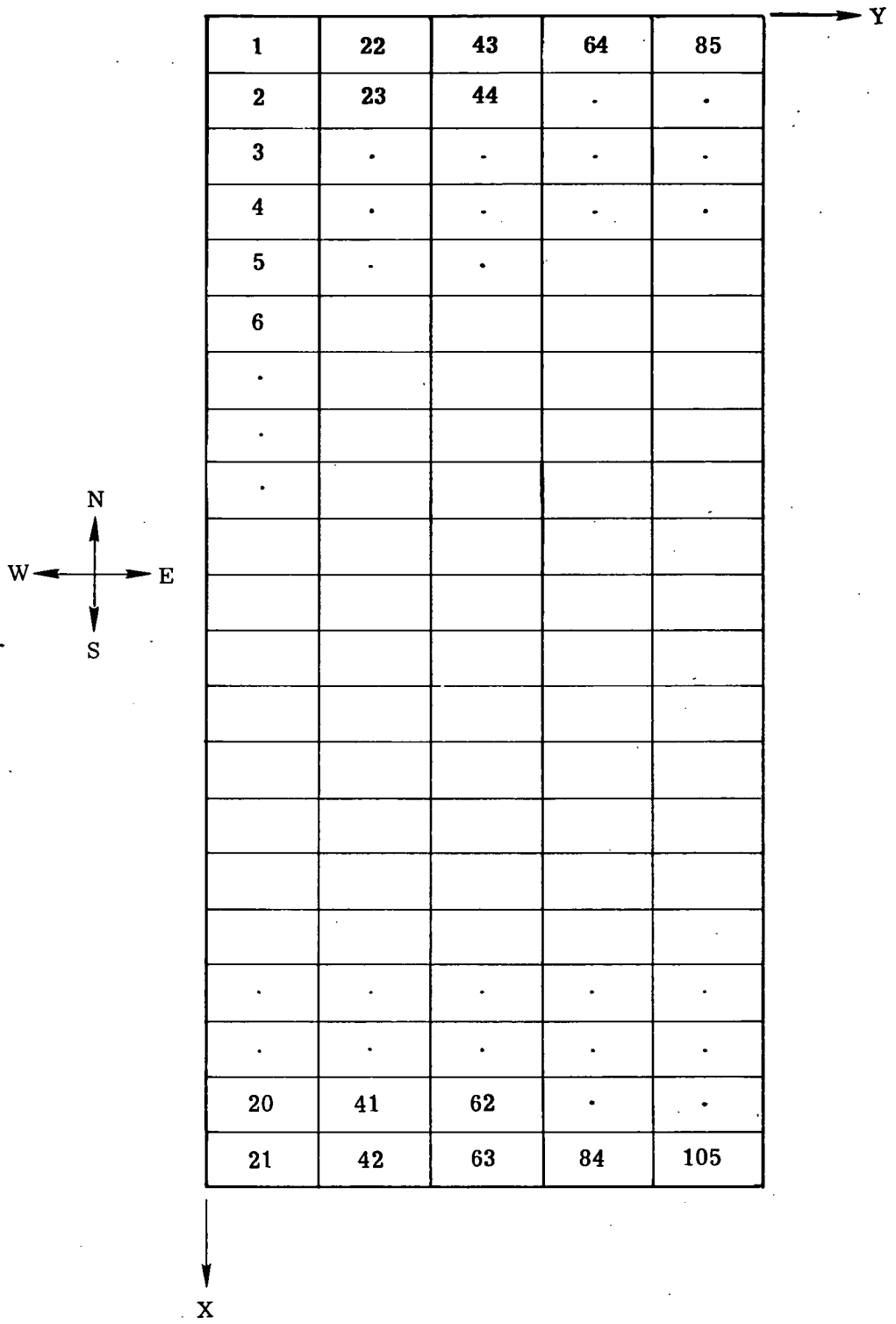Figure 2.- Nodal-point grouping used in least-squares surface fit.

1	22	43	64	85
2	23	44	.	.
3	.	.	.	.
4	.	.	.	.
5	.	.		.
6				
.				
.				
.				
.	.	.	.	.
.	.	.	.	.
20	41	62	.	.
21	42	63	84	105

Y

N
W ← → E
S
X

Figure 3.- Module arrangement and index system.

18
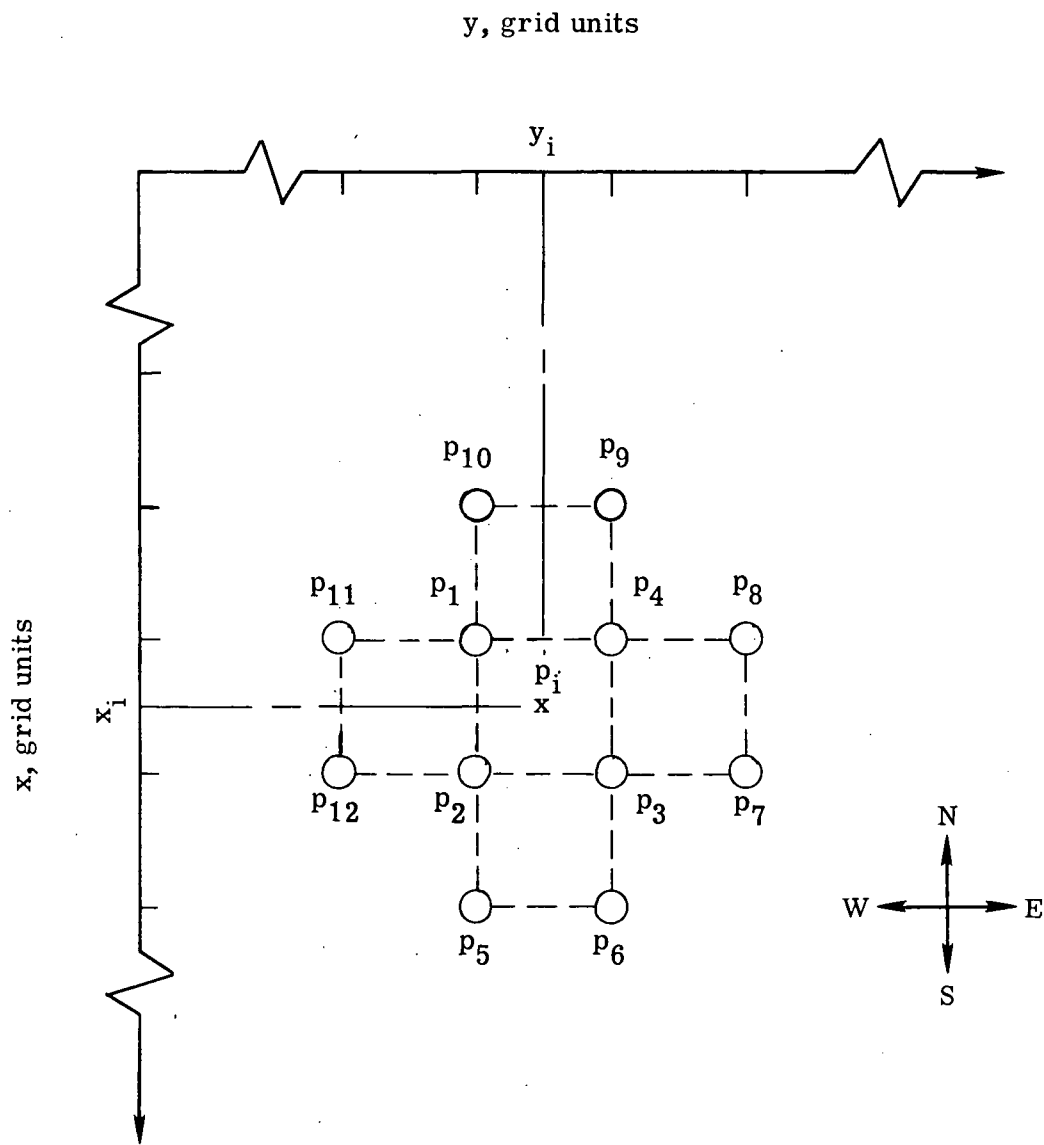
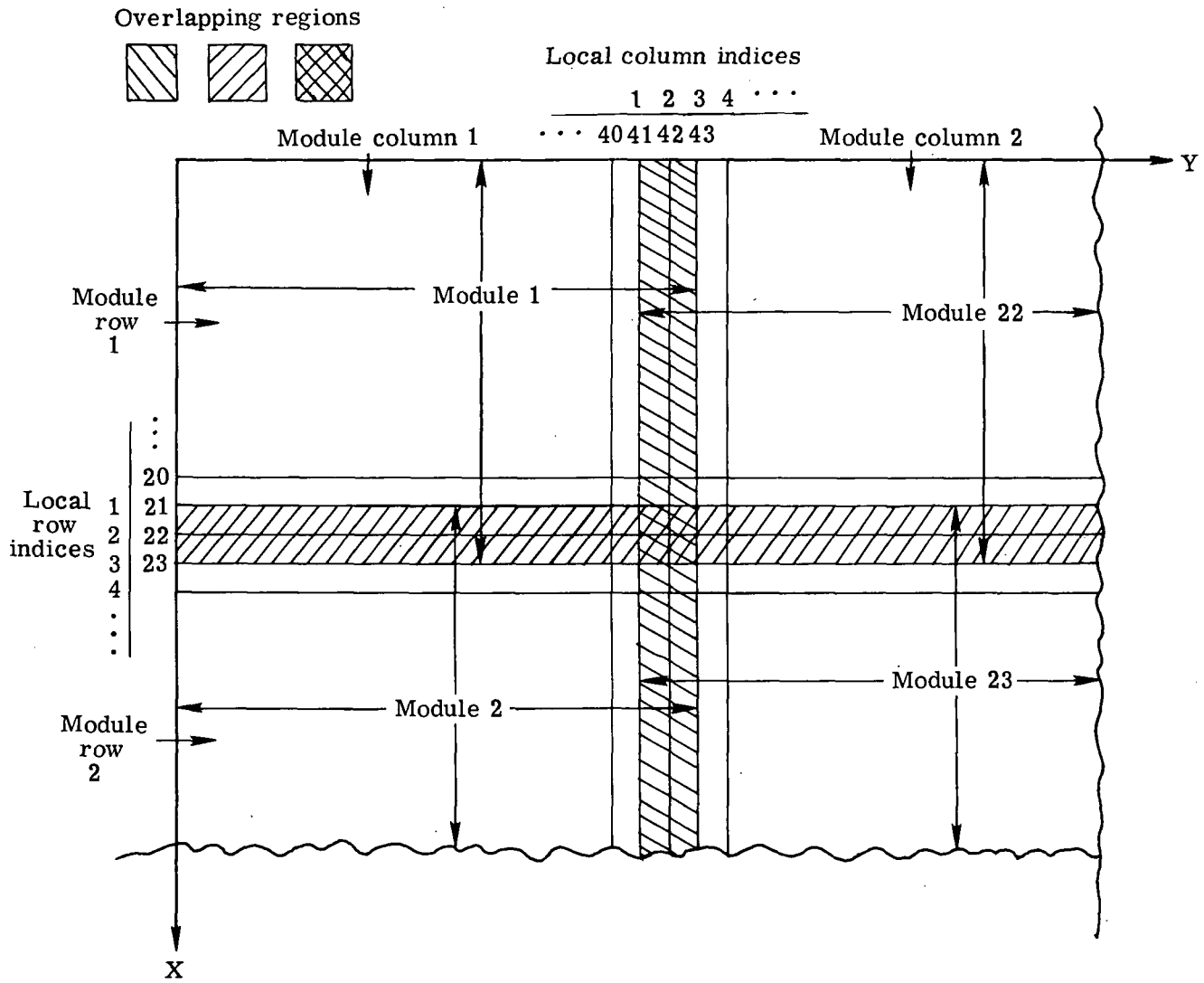Figure 4.- Twelve nodal-point grouping about point of interest p_i.

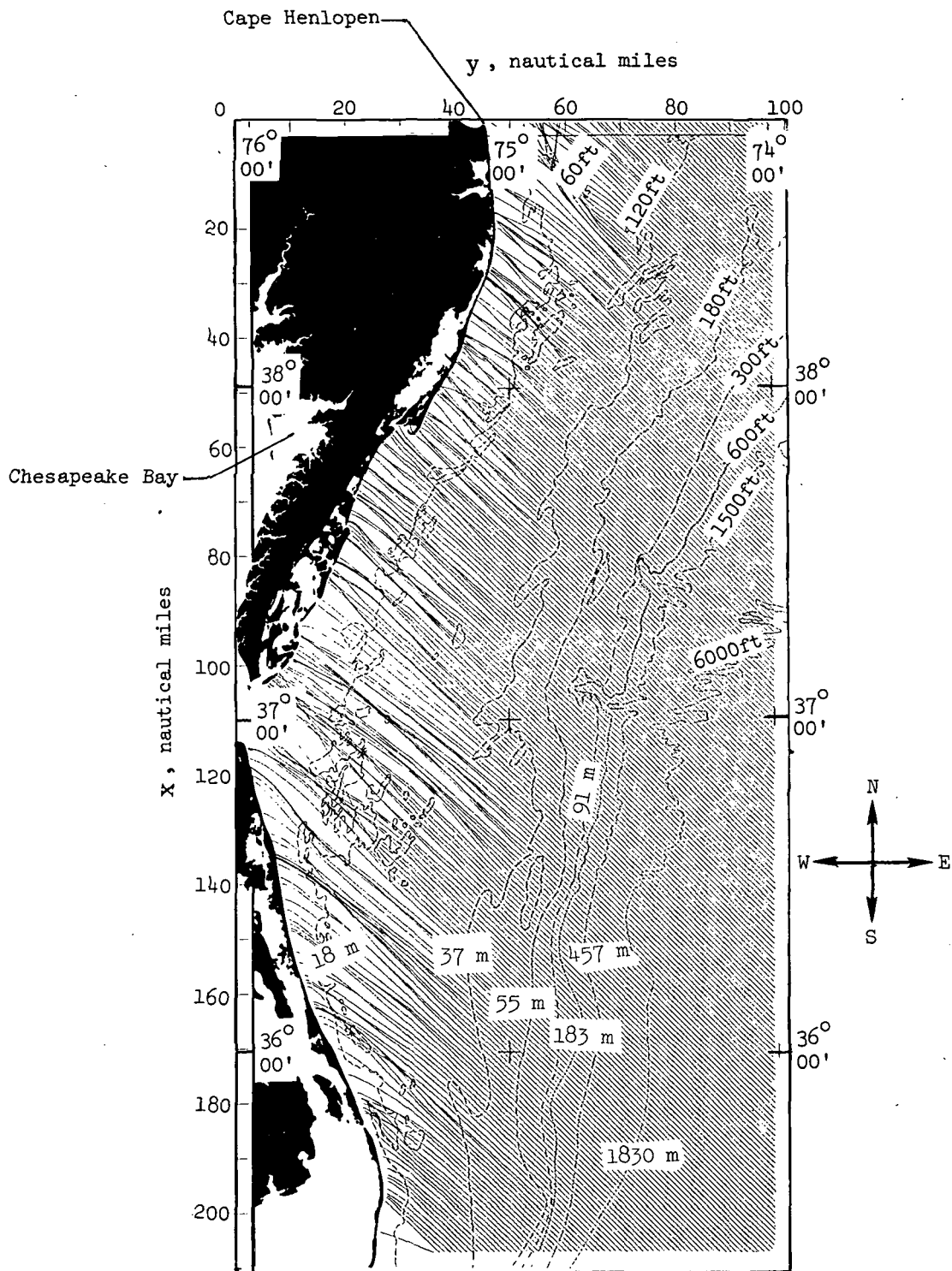Figure 5.- Overlapped configuration of adjacent modules.

Figure 6.- Refraction pattern for sample case (rays propagated from southeast with a period of 8 sec) calculated by using random-access storage method.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."
—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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