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WAVE INFORMATION STUDIES
OF US COASTLINES

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WIS REPORT 27

USER'S GUIDE TO THE WAVE INFORMATION
STUDIES (WIS) WAVE MODEL, VERSION 2.0

by

J. M. Hubertz

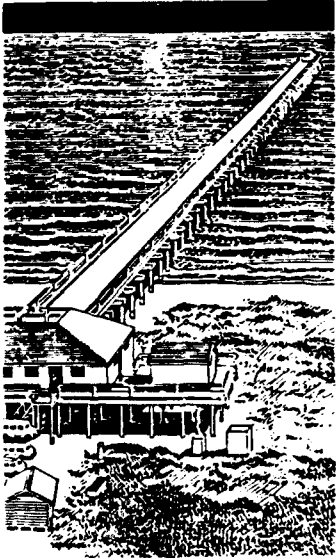
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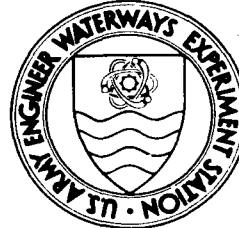
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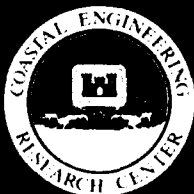


June 1992

Final Report

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13. ABSTRACT (Maximum 200 words)

This report provides guidance on application of the Wave Information Studies Wave Model, Version 2.0 (WISWAVE 2.0), and a description of the upgrades from Version 1.0. The present version operates in all water depths, while the previous version operated only in depths sufficient not to affect wave propagation. The present version also allows for changing water depths during a simulation as would be the case in storm surge applications or regions of large tidal amplitude. The structure and operation of the model are described. Input necessary to operate the model is described and an example input data set is provided. The theory, equations, and solution techniques contained within the model are described in the references provided. The theory, equations, and solution techniques associated with the upgrade to include shallow-water effects are described in Appendix A. Documented subroutines associated with the upgrade are provided in Appendix B.

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Comparisons of model results to measurements are provided in WIS reports on the Great Lakes (Reports 22-26) and the Atlantic hindcast (WIS Report 30). WISWAVE 1.0 was used to produce the Great Lakes wave hindcasts described in WIS Reports 22-26. WISWAVE 2.0 was used to produce the Atlantic hindcast, WIS Report 30.

PREFACE

The Wave Information Studies (WIS) were authorized by Headquarters, US Army Corps of Engineers (HQUSACE) in 1976 at the US Army Engineer Waterways Experiment Station (WES) to produce a wave climatology for US coastal waters. The WIS is part of the Coastal Field Data Collection Program managed by the WES Coastal Engineering Research Center (CERC). The WIS Project Manager is Dr. J. M. Hubertz, the Program Manager is Ms. C. M. Holmes, and the HQUSACE Technical Monitors are Messrs. John H. Lockhart, J. Housley, F. Campbell, and J. Crews.

This report, the 27th in a series, provides guidance on the operation of the latest version of the WIS wave model (WISWAVE 2.0) developed under contract to Dr. Donald T. Resio of Offshore and Coastal Technology Incorporated (OCTI). The structure and operation of the model are described and example input is provided. The following members of the WIS group in the Coastal Oceanography Branch (COB), CERC, were instrumental in documenting and verifying the computer code: Dr. J. M. Hubertz, Mr. D. B. Driver, Meses. B. A. Tracy, R. D. Reinhard, and W. A. Brandon. Dr. Resio provided valuable assistance during documentation and testing of the model.

The work was conducted under the direct supervision of Dr. Martin C. Miller, Chief, COB, and Mr. H. L. Butler, Chief, Research Division, CERC; and under general supervision of Dr. J. R. Houston and Mr. C. C. Calhoun, Jr., Director and Assistant Director, CERC, respectively. The word processing of this report was done by Ms. M. J. Stauble, COB. The report was edited by Ms. Janean C. Shirley, Information Technology Laboratory, WES.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard J. Hassell, EN.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u> Multiply </u>	<u> By </u>	<u> To Obtain </u>
degrees (angle)	0.01745329	radians

USER'S GUIDE TO THE WAVE INFORMATION STUDIES (WIS) WAVE MODEL

VERSION 2.0

PART I: INTRODUCTION

1. A number of numerical wave models have been used under the Wave Information Studies (WIS) to produce hindcast wave information along US coastlines. The earliest version (Resio and Vincent 1977, 1978), was used to produce hindcasts of storms on the Great Lakes. The next version (Resio 1981) was used for the Atlantic Coast Phases I and II hindcasts. The Pacific Coast hindcasts, Phases I and II, were produced by a version described by Resio and Tracy (1983) and the Gulf of Mexico, Phase II hindcast by a version described by Resio (1987 and 1988).

2. Each successive model improved in some way over its predecessor. However, each model was more a separate entity than an improvement to a basic model framework. The present version (Resio and Perrie 1989) is structured to allow improvements to a basic framework so that users see little change in applying the model as improved versions are developed.

3. The first version of the present model (hereafter referred to as WISWAVE 1.0) was used to produce the Great Lakes hindcasts and is described in each of the WIS reports on the Great Lakes (e.g., Hubertz, Driver, and Reinhard 1991). The present version (hereafter referred to as WISWAVE 2.0) operates in all water depths, while WISWAVE 1.0 only operated in depths deep enough not to affect wave propagation. The WISWAVE 2.0 also allows for changing water depths during a simulation as would be the case in a storm surge application or regions of large tidal amplitude.

4. The WISWAVE 2.0 was used to re-hindcast wave conditions along the Atlantic Coast (Hubertz et al., in preparation) for the period 1956-75 to improve previous hindcast results. The winds developed for the original WIS hindcasts (Corson, Resio, and Vincent 1980; Resio, Vincent, and Corson 1982) were used in the re-hindcast since they provide an accurate representation of the wind climatology. Present computer technology allowed greater resolution

(1.0-deg* and 0.25-deg spacing for Phases I and II, respectively, versus the 2.0-deg and 0.5-deg spacing used in the original hindcasts).

5. The WISWAVE model is written using standard FORTRAN commands. It can be executed on computers ranging from microcomputers to super computers. However, the model employs multi-dimensioned arrays dependent on the number of grid points covering a geographical area, and the number of frequency and angle bands specified to describe the directional wave spectra. Thus, super computers are needed to perform simulations on large bodies of water due to the large number of calculations involved. The version of WISWAVE that WIS uses has been optimized for execution on the CRAY YM-P super computer at the US Army Engineer Waterways Experiment Station. The structure and flow control of the model are discussed next.

4

*A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

PART II: STRUCTURE AND OPERATION

6. There are two main DO loops in the model. One (the inner) is contained within the other (the outer). The inner loop steps through time steps from the beginning of a simulation to the end and calculates wave conditions at each point on a latitude-longitude grid as a function of input conditions. The outer loop reads input as a function of time. This input can consist of winds over the model grid, wave conditions on the grid boundary, or water level information over the grid. This information is specified at time intervals during the simulation to update changing wind, wave, and water level conditions.

7. Prior to entering these loops, a number of subroutines read required options for the particular application and initialize values of constants and variables. Information is output as simulated time progresses and information is saved if subsequent runs of the same application are required. A simple flow diagram is shown in Figure 1.

Description of Subroutines

8. Subroutine RDOPT (Read Options) reads the model input options describing an application from unit 20. This includes a land/water matrix which identifies each point in the latitude-longitude grid as land (0) or water (1), and identifies boundaries of a nested grid if used. A nested grid is a subarea within the original grid boundary. It is defined by grid lines of the first level grid, but has a higher density of grid lines, which allows greater resolution of wave information in space. The initial depths at each grid point, if depths are used, are also read from this file. Updates to the depth field as a function of time are read from unit 14 when wind fields are updated.

9. Subroutine CKSTR (Check Start) either reads (from unit 23) or writes (to unit 16) information to be used in a warm start. A warm start is a run which uses results from the end of a previous run to initialize variables in the model. This allows computations to proceed from where they left off without a "spin-up." If a warm start is not used, there will be some time involved for wave conditions to develop for the given winds. The length of

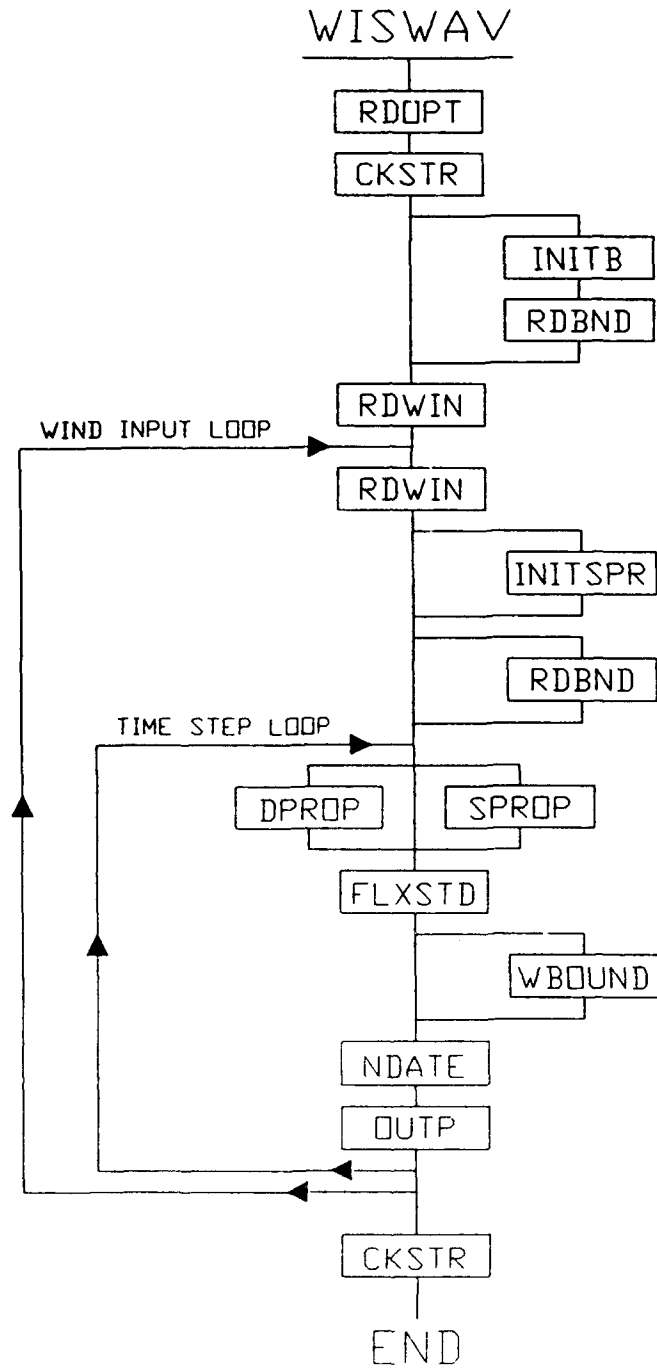


Figure 1. Flow diagram of WISWAVE 2.0

time is related to the size of the water body, and can be on the order of a few days for an ocean.

10. Subroutine `INITB` (Initialize Boundary Information) is only used when the present run is using boundary information saved from a previous run.

That is, a grid nested within a previously used larger grid is being used. It checks the land/water matrix to identify the location of points where boundary information was saved and interpolates and extrapolates this information to the grid points along the boundary of the present grid being used.

11. Subroutine RDBND (Read Boundary Information) is only used when the present run is using boundary information saved from a previous run. It reads (from unit 25) the previously saved boundary information (written by subroutine WBOUND on unit 17) and, using the weighting factors calculated in INITB, calculates boundary conditions along the model input boundary.

12. Subroutine RDWIN (Read Wind Input) is used to read wind speeds and directions (from unit 21) for all grid points at fixed time intervals during the simulation. Wind speeds and directions are interpolated to the timestep interval, from times when wind fields are supplied. The time step is the interval in time between which wave conditions are calculated over the grid. It must be less than the time needed for wave energy to travel between adjacent grid points.

13. Subroutine INITSPR (Initialization for Shallow-Water Propagation) is used to initialize all parameters dependent on depth. It is called once for a shallow-water application. It is also called every time the depths are updated as in a hurricane surge or application with a large tide range.

14. Subroutine DPROP (Deep-Water Propagation) is used to propagate wave energy over the grid assuming deep water. Water depths are set at 999 m everywhere, and refraction and shoaling do not take place.

15. Subroutine SPROP (Shallow-Water Propagation) is used to propagate wave energy over the grid accounting for the effects of shallow water (refraction, shoaling).

16. Subroutine FLXSTD (Flux of Energy through the Spectrum) is the subroutine that calculates the two-dimensional spectrum at each grid point based on the wind input and transfer of energy within the spectrum due to the wave interaction source term.

17. Subroutine WBOUND (Write Boundary Information) writes information to a file (on unit 17) for later use in a nested grid application. This is the same file subroutine RDBND accesses (on unit 25) when it is reading in information on the boundary of a nested grid.

18. Subroutine NDATE (Calculate Date) calculates the date used on output information from the beginning date and length and number of time steps between specified output times.

19. Subroutine OUTP (Write Output Information) writes out the results of the calculations (on unit 93) at the times specified in the options file by the parameter NTMS.

Model Input

20. The grid system used by the model is the system of latitude and longitude lines on the Earth's surface. Lines of latitude are denoted by rows, referenced by values of J, and lines of longitude are columns, referenced by values of I. The origin of a grid is in the lower left-hand corner (Figure 2). For small geographical areas on the Earth's surface, such as one of the Great Lakes, the distance between specified grid lines can be approximated as equal over the grid. For larger areas, the curvature of the Earth is taken into account to calculate the distance between grid lines so that waves are propagated over the proper distances.

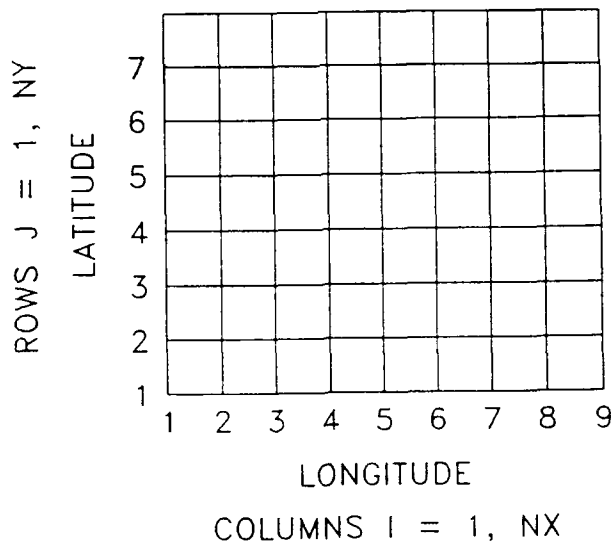


Figure 2. Schematic of model grid

21. The dimensions of the arrays in the model are specified by two parameter files PARA1.INC and PARA2.INC which are included in the program

during compilation. Thus, they must be prepared and available in the same directory as the source code before the program is compiled. Examples of these files are shown below for the sample case discussed later.

```
PARA1.INC      parameter (idmn=18,jdmn=35,if=20,ia=16,nobpts=10,nbn=30)
PARA2.INC      parameter (idmn=18,jdmn=35,if=20,ig=16,nobpts=10,nbn=30)
```

The dimensions for the grid size, columns and rows, are set with (idmn) and (jdmn) respectively. The dimensions for frequency and direction increments are set with parameters (if) for frequency and both (ia) and (ig) for direction. If boundary information is saved, (nobpts) sets the dimensions for the number of save boundary points. If an application is making use of previously saved boundary information, (nbn) specifies the number of boundary points in the present application which will be made up of interpolated and extrapolated points determined from those previously saved.

22. There are a number of parameters that specify the details of a particular application. These are given in an options file which is made up of a number of lines or records. Values of parameters need to be specified in the order shown below for each record and separated by at least one space. Note that some parameters are integers while others are real numbers. A summary of input and output unit numbers and associated information is provided in Table 1.

LOGICAL RECORD 1

NX NY NANG NFRQ DL DT MSTA INPLEV

NX	The number of columns in the grid.
NY	The number of rows in the grid.
NANG	The number of angle bands in the discrete spectrum.
NFRQ	The number of frequency bands in the discrete spectrum.
DL	The distance between grid points in kilometers.
DT	The time step in seconds.
MSTA	The number of points at which results should be saved.
INPLEV	Option to specify input level of winds. 0 = 10 m above sea surface. 1 = 20 m above sea surface.

Table 1
Input and Output Unit Numbers and Associated Information

<u>Input Files</u>	
<u>Unit Number</u>	<u>Data</u>
20	Options file (see page 8)
23	Warm start information (see page 8)
25	Boundary data for nested grid (see page 10)
21	Wind fields (see p. 10)
<u>Output Files</u>	
<u>Unit Number</u>	<u>Data</u>
93	One record summary at output times (see page 11 for description)
16	Warm start information (see page 8)
17	Nested grid boundary information (see page 10)

LOGICAL RECORD 2

NSTR NORD NTMS NHR MXHR IBND ISTDEP

NSTR Option to specify whether results from a previous run will be used to start present run (warm start).
 0 = Cold start, no restart data read.
 1 = Cold start, but save results for a warm start.
 2 = Warm start, but do not save results for another warm start.
 3 = Warm start, and save results for another warm start.

NORD Option to read in windfields or not.
 0 = Read in windfields.
 1 = Do not read in windfields, but specify fixed speeds and directions.

NTMS Number of time steps between output of results. For example, output is desired every 3 hr and time step is 30 min (0.5 hr), NTMS = $3/0.5 = 6$

NHR Number of hours between input of winds.

MXHR Maximum number of wind inputs in run. This value should be consistent with information in record 6.

IBND Option to read and write results on boundary of grid for use in nested grid applications.
 0 = No boundary data read or written.
 1 = Boundary data written, but none read.
 2 = Boundary data read, but none written.
 3 = Boundary data read and written.

ISTDEP Option to use depths or assume uniform value.
 0 = Depths input (meters)
 1 = Depth assumed constant (999 m).

LOGICAL RECORD 3

DLAT XLATO ICURV IUPDAT

DLAT Number of degrees of latitude between rows of grid.

XLATO Southernmost latitude (degrees) of grid. Negative if in Southern Hemisphere.

ICURV Option to include curvature effects of Earth in propagation.
 0 = Do not include.
 1 = Include.

IDPRP Option to choose deep or shallow-water propagation.
 0 = Shallow water
 1 = Deep water

IUPDAT Option to update still-water level during simulation.
 0 = Do not update.
 1 = Update water levels at frequency of wind input.

LOGICAL RECORD 4

FREQ(K) Mid-band values of frequency for NFRQ bands. Can be on more than one line.

LOGICAL RECORD 5 (Only needed if MSTA > 0)

K IOUT(K), JOUT(K)

K Sequential number of output point (station number)

IOUT(K) Grid column at station K.

JOUT(K) Grid row at station K.

LOGICAL RECORD 6

IDFIRST IDLAST IDBND1 IDBND2

IDFIRST The date/time code to start a simulation (for example, 90010100 signifies 1990 January 1, 00 hr).

IDLAST The date/time code to end a simulation.

IDBND1 The date/time code to begin saving boundary information.

IDBND2 The date/time code to end saving boundary information.

LOGICAL RECORD 7 (Only needed if ISTDEP=0)

DEP(I,J) This array contains the depth at each grid point if ISTDEP=0. Values should be positive, in meters, and arranged for all columns starting with row NY (see example in sample application). Format statement 401 in RDOPT can be adjusted to meet the user's needs.

LOGICAL RECORD 8

IBOUND(I,J) A matrix of values defining whether a grid point is land, water, or a boundary point for a nested grid application. Values are arranged for input in the same manner as the depths. The following numerical values are used to designate each grid point. Examples are shown in the sample application. Format is 80I1.

- 0 - Land Point
- 1 - Water Point
- 2 - Extrapolated Boundary Point (at beginning of boundary line)
- 3 - Input Boundary Point (coincident point in large and nested grid)
- 4 - Interpolated Boundary Point (interpolated at points on boundary of nested grid between (3) type points)
- 5 - Extrapolated Points (at end of boundary line)

LOGICAL RECORD 9 Only needed if IBND is 1 or 3.

NBPO The number of boundary points at which information is output for a nested grid run.

LOGICAL RECORD 10 (Only needed if IBND is 1 or 3)

IBPO(K), K=1,NBPO Ordered I locations of boundary output points
from beginning of boundary curve to end.

LOGICAL RECORD 11 (Only needed if IBND is 1 or 3)

JBPO(K), K=1,NBPO Ordered J locations of boundary output points
from beginning of boundary curve to end.

LOGICAL RECORD 12 (Only needed if IBND is 2 or 3)

ILS, JLS The I,J location (in the nested grid coordinates) of the boundary
point at the beginning of the offshore boundary curve in the
nested grid. It will usually be an IBOUND(I,J)=2 type point.

LOGICAL RECORD 13 (Only needed if NORD=1)

IUWS, IUDIR, ISHFT, NSHFT, IWNDN, IDEGN

IUWS A constant value of wind speed (m/sec) over the whole
grid.

IUDIR The wind direction in degrees. The wind angle is defined in
the compass sense, i.e., from North = 0 deg, from East = 90
deg, etc.

ISHFT Option to change wind speed and direction in test case.

NSHFT Number of hours in simulation prior to shift in wind.

IWNDN Wind speed after shift.

IDEGN Wind direction after shift.

23. Two files need to be prepared by the user. One is the options
file, and the other the wind input file. The parameters in the options file
are described above. The wind speed and direction at every grid point in the
grid are read in every NHR hours in the simulation. The wind file is composed
of a series of wind fields, each consisting of a header record containing the
date/time code for the following winds. Next the wind speeds (meters/second)
are read, in the same order as the depths and land/water boundary matrix, and
then the wind directions, also in the same order.

24. Wind directions should be in the meteorological or compass sense,
i.e., 0 deg is a wind blowing from the north, 90 deg, from the east, etc.
Winds are read in by subroutine RDWIN. The present formats for the header

record and speed and direction are I 10, F5.1, and F5.0, respectively. The user may adjust the format and make speed and direction conversions as needed in this subroutine, or reformat existing wind fields to conform to the above format and conventions.

25. Wind speeds (m/sec) should be representative of either a 10- or 20-m elevation above the sea surface. The particular level is specified by the parameter INPLEV in record 1 of the options file. If the winds are not at one of these levels, but at some other level between 0 and 20 m, they can be adjusted to one of these levels using Equation 3-26, page 3-26 of the Shore Protection Manual (SPM) (US Army Engineer Waterways Experiment Station 1984).

Model Output

26. The model calculates the discretized two-dimensional (frequency by direction) wave spectrum at every time step at every grid point during the simulation. Potentially, all of this information could be output, but would be overwhelming to comprehend. Generally a user is interested in the basic wave parameters as a function of time at particular points. These parameters are: (a) wave height, (b) peak or mean wave period, and (c) mean wave direction. These values, along with a station number (location identifier), the date/time code, the wind speed and direction, and water level with respect to a datum are output on unit 93.

27. Other information which describes the wave conditions in more detail is also provided on this output record. This consists of the percent of total energy in each frequency band and the mean direction of each frequency band. Additional space is also available on this record for the speed and direction of flow of currents at the chosen output location. This is in anticipation of a future upgrade to add currents to the wave model.

28. An example of the output record is shown below.

```
001 90102806 024 13 10 165 06 165 00 00 00 003446 0 0 0 0 0 0 1 3 61311 7 5 8101312 6 3 1 0 0 0 0 0 0 04646466 0 0 0 0 0 0 0 0 0
```

The first three digits are the station number. The next eight are the date/time group, which, taken in four groups of two represent the year, month, day, and hour. The example above represents 0600 on October 28, 1990. The next

three digits represent the significant wave height in meters times ten. In this example, the value is 2.4 m. The next two values are the peak and mean wave periods to the closest second. In this example, they are 13 and 10 sec, respectively. The next three digits represent the mean wave direction in degrees from which the waves are coming with respect to compass directions. That is, 0 deg is from the north, 90 deg, from the east, etc. In this example, the waves are coming from 165 deg or from a direction between SSE and S. The next two digits are the wind speed in m/sec, 6 m/sec in this case. The next three are the wind direction in degrees in the same convention as the waves. In this example, both the wind and waves are coming from 165 deg. The next two digits represent the water level above a datum. There will be a non-zero value here only if the water level is changed during the simulation as in a hurricane surge or large tidal range case. The value is in meters with respect to the datum chosen; for example, mean sea level or mean low water, or some other datum. The next two digits represent the speed of current flow along a fixed latitude or in the x direction (see Figure 2). Values are in meters/second times 10. The next two digits are the similar quantity for flow in the y direction. Positive values are toward the east and north, respectively. The effect of currents on wave propagation and source terms is not accounted for in WISWAVE 2.0, but is planned for the future. The next six digits represent the total energy in the discrete part of the spectrum multiplied by 10,000 and in units of meters squared.

29. The next 40 spaces contain the percent of total energy in the discrete part of the spectrum contained in each of the 20 frequency bands for all directions. The center frequencies associated with each of these bands are given in record 4 of the input options file. The hindcast frequency spectrum is obtained using these frequencies, the total discrete energy, and the percentages in each band.

30. The last 40 spaces contain the mean directions in each frequency band, expressed as a percent of 360 deg. In the example above, in frequency band eight, the 46 represents 46 percent of 360 deg or approximately 165 deg. Thus, in this frequency band, the mean direction from which waves are coming is about 165 deg or from the SSE. The mean across all frequency bands should agree with the mean direction of the spectrum given by the sixth group of numbers in the record. There may be some difference due to rounding off in

the averaging process and the resolution of 4 deg imposed by expressing the directions as a percentage of 360 deg.

31. Additional output may be obtained by referring to subroutine OUTF and modifying the coding to obtain what is desired. Examples are the complete two-dimensional frequency by direction spectrum, or values of wave parameters such as height, period, and direction over the whole grid at particular times.

Sample Input Files

32. The following sample input files are provided for the user to help in understanding input to the model. The example is for Lake Michigan. The numerical model grid for this application is shown in Figure 3. An explanation of each of the input parameters is provided below for this application. A general description is provided above in the section titled "Model Input."

```

18 35 16 20 16.1 1800 1 0
1 0 6 3 40 1 0
0.145 41.55 0 0 0
.07 .08 .09 .10 .11 .12 .13 .14 .15 .16
.17 .18 .19 .20 .21 .22 .23 .25 .33 .50
1 6 7
00000000 99999999 00000000 99999999

  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  18 48 49  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  62 112 84 43  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  59 124 120 40 31 93 24  0  0  0  0
  0  0  0  0  0  0  18 105 148 137 137 157 95  0  0  0  0  0
  0  0  0  0  0  0  55 130 173 137 70 106  0  0  0  0  0  0
  0  0  0  0  0  31 133 166 192 55 49  0  0  0  0  0  0  0
  0  0  0  0  0  68 185 209 165 81  0  0  0  0  0  0  0  0
  0  0  0  0  37 155 229 218 128 42  0  0  0  0  0  0  0  0
  0  0  0  0  84 203 265 254 188  0  0  0  0  0  0  0  0

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0	0	0	0	137	229	249	223	165	0	0	0	0	0	0	0	0	0
0	0	0	66	174	233	122	236	113	0	0	0	0	0	0	0	0	0
0	0	0	48	110	203	205	105	22	0	0	0	0	0	0	0	0	0
0	0	0	71	157	170	158	135	0	0	0	0	0	0	0	0	0	0
0	0	15	70	95	101	161	70	0	0	0	0	0	0	0	0	0	0
0	0	42	82	93	163	172	66	0	0	0	0	0	0	0	0	0	0
0	0	24	110	115	143	124	86	0	0	0	0	0	0	0	0	0	0
0	0	81	137	119	88	128	93	0	0	0	0	0	0	0	0	0	0
0	0	106	143	68	59	124	119	40	0	0	0	0	0	0	0	0	0
0	0	102	82	93	86	110	117	59	0	0	0	0	0	0	0	0	0
0	0	82	95	84	82	95	106	91	20	0	0	0	0	0	0	0	0
0	0	46	88	93	82	101	97	82	49	0	0	0	0	0	0	0	0
0	0	22	91	119	149	152	102	82	60	0	0	0	0	0	0	0	0
0	0	15	82	126	150	163	106	80	53	0	0	0	0	0	0	0	0
0	0	40	88	119	141	159	91	69	42	0	0	0	0	0	0	0	0
0	0	33	79	106	121	130	80	51	29	0	0	0	0	0	0	0	0
0	0	15	53	79	95	102	91	33	0	0	0	0	0	0	0	0	0
0	0	0	24	59	70	84	69	22	0	0	0	0	0	0	0	0	0
0	0	0	13	29	48	55	42	0	0	0	0	0	0	0	0	0	0
0	0	0	0	11	23	22	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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3 4 5 6 6 6 6 6 6 6
7 7 7 7 6 5 4 3 2 1

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33. The first two numbers in the first line or record of input are 18 and 35. For this application, these numbers indicate that there are 18 columns (NX=18) or values of the I index and 35 rows (NY=35) or values of the J index (see Figure 3). There are 16 direction bands (NANG=16), each of which is 22.5 deg in width. These correspond to the points of the compass, i.e., N, NNE,

NE, ENE, E, etc., and are typically the number of direction bands specified in an application. There are 20 frequency bands specified (NFRQ=20), which is a typical number to use. The spacing between grid lines (DL) is 16.1 km, which corresponds to 10 miles. The time step (DT) is 1,800 sec or 30 min. Information at one grid intersection point is being output (MSTA=1). The winds being input are applicable to an elevation 10 m above the sea surface (INPLEV=0).

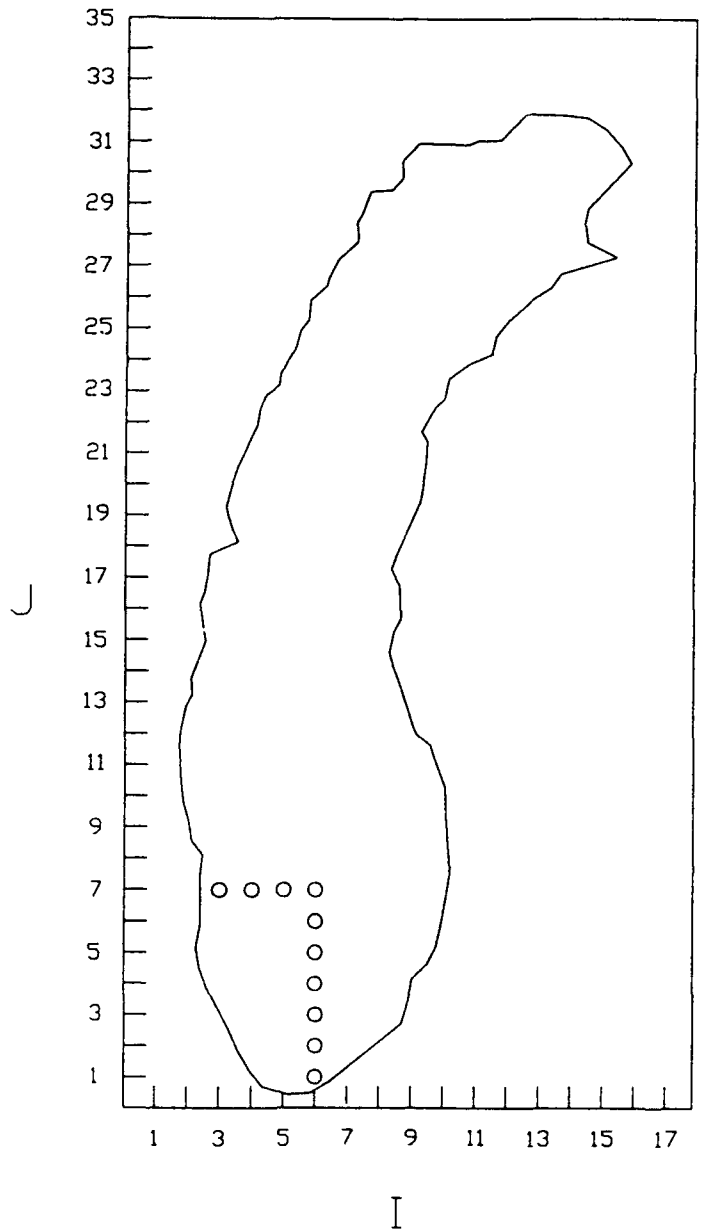


Figure 3. Example of model grid for Lake Michigan

34. The first value in the second line or record of input indicates that this is the initial run for this application (NSTR=1); that is, no previous results are available as a warm start, but information for a warm start will be saved at the end of this run. Wind speeds and directions will be read in for each grid point for successive times (NORD=0). Results will be output every 6 time steps (NTMS=6) or in this case every 3 hr, since a time step equals 0.5 hr. New wind information will be input every 3 hr (NHR=3) and a total of 40 wind fields (MXHR=40) will be input. This corresponds to 120 hr of simulation, or 5 days. Boundary information will be written at a number of grid points defining the outer boundary of a grid nested within this grid (IBND=1). Depths will be input (ISTDEP=0) to account for refraction, shoaling, and depth limitation of wave energy.

35. The third record begins with the increment in degrees of latitude (DLAT) between rows of the grid, whose value in this case is 0.145 deg. The southern-most latitude of the grid (XLAT0) is 41.55 deg. The size of the grid on the Earth's surface is relatively small, so curvature effects of the Earth's surface are not included (ICURV=0). Shallow water is present, so IDPRP=0. Water levels are not being changed during the simulation, so IUPDAT=0).

36. The fourth record contains the NFRQ values of frequency of the discretized frequency spectrum. These are the values at the center of the bands. The band widths are determined by the adjacent midband values.

37. The fifth record contains the list of station numbers with I,J locations of the stations in the grid where model output will be saved. In this case, only one station (MTSA=1) is specified at location I=6, J=7.

38. The sixth record contains optional beginning and ending dates for model execution and saving of boundary conditions. In this example, values are set at 00000000 and 99999999, so the beginning and ending dates are not determined by these values, but by the header records on the first and last input wind fields, respectively. If, for example, one had a year of wind fields for 1991 in a file and only wanted to model the month of March, the dates 91030100 and 91033121 could be specified for the first and last dates, respectively. The model would read the wind input file and begin when it reached the first date and quit when it reached the last.

39. The next group of data is the depths at each grid point if the parameter ISTDEP=0. If ISTDEP=1, deep water (999 m) is assumed at every grid point and no depths are read in. Depths are read in for all columns from the top row to the bottom row. The READ statement is in Subroutine READOPT and uses FORMAT statement 401. The format of the depths in the input options file must conform to the format specified by statement 401. In this example, it is 18F4.0.

40. The next group of data is the land-water boundary matrix. This set of data is always needed to specify which grid points are land and which are water. It is also used to designate grid points at which boundary information is expected from a previous model application. This example is for an initial application and so no boundary points are designated for input of information. A value of 0 represents land and a value of 1 water. Values are read in for all columns from the top row to the bottom using FORMAT statement 957 in subroutine READOPT. In this example, the format is 18I1.

41. If the present model application is being used to generate boundary information for a smaller grid nested within the larger, the number of points defining the boundary of the smaller grid within the larger is needed. In this example, 10 water points in the present grid define the water boundary of a finer grid over the southwestern portion of the lake. These points are shown by circles in Figure 3.

42. The next two records contain the column (I) and row (J) locations of these points, respectively. The order in which the points are specified can be either clockwise from the western boundary of the lake to the southern boundary, or counterclockwise from the southern boundary to the west side of the lake. Either way, the I values must be in the same order as the J's, so that paired I's and J's define the proper grid points.

43. The only other input needed for this application is the input wind fields. An example of the winds for one time period is shown below. The first record is the date/time group given as four groups of two digits defining the year, month, day, and hour (from 00 to 23). The next group of records contain the wind speed at all grid points ordered the same as the depths and land-water matrix; that is, values for all columns starting with the top row and ending with the bottom. The wind directions follow the wind

speeds. Successive sets of wind fields are supplied every NHR hours during the simulation.

88010100

22	22	22	22	22	21	21	21	21	21	21	21	21	20	20	19	19	18
22	22	22	22	22	21	21	21	21	21	21	21	21	20	20	19	19	18
22	22	22	22	22	21	21	21	21	21	21	21	20	20	20	19	18	17
22	22	22	22	21	21	20	20	20	21	21	20	20	19	18	18	17	17
22	22	22	21	21	20	20	19	20	20	19	18	18	17	17	16	16	16
21	21	21	21	20	19	18	18	18	17	17	17	16	16	15	15	15	15
22	22	21	21	20	18	17	16	15	14	14	14	14	14	14	14	14	14
22	22	22	21	20	18	15	13	12	12	11	11	11	12	12	12	13	13
22	22	22	21	20	17	14	12	11	11	11	11	11	11	11	11	12	12
22	22	22	22	20	16	13	11	11	11	11	11	11	11	11	11	11	12
22	22	22	21	19	15	12	11	11	11	11	11	11	11	11	11	11	11
22	22	21	20	18	14	12	11	11	11	11	11	11	11	11	10	10	11
21	21	21	19	17	13	11	11	11	11	11	11	11	10	10	10	10	11
20	20	20	18	16	13	12	11	11	11	11	11	10	10	10	10	10	11
20	20	19	18	16	14	12	11	11	11	11	11	10	10	10	10	10	11
20	20	19	18	16	14	13	11	11	10	10	10	10	10	10	10	11	12
20	20	19	19	17	15	14	12	11	10	10	10	11	11	12	12	12	12
20	20	20	19	18	16	15	13	12	12	12	13	14	14	14	14	14	14
20	20	20	20	19	17	16	14	14	14	15	16	17	17	16	16	15	15
20	20	20	20	19	17	16	15	16	16	17	18	18	18	18	17	17	16
20	20	20	20	19	18	16	16	16	17	18	19	19	19	19	18	17	16
20	20	20	19	18	17	17	17	17	18	19	19	20	20	20	19	19	18
20	20	20	19	18	17	17	17	18	19	19	20	20	20	20	19	19	18
20	20	19	19	18	17	16	17	18	19	19	20	20	20	19	19	17	16
19	19	19	18	17	16	16	16	17	17	18	19	19	19	19	18	16	14
19	18	18	17	16	16	16	16	16	17	18	18	19	19	18	16	14	12
18	17	17	16	16	15	15	15	15	16	16	17	17	17	16	15	13	11
17	17	16	15	15	14	14	14	14	14	14	14	14	14	12	10	8	5
16	16	15	14	14	13	13	12	12	12	11	10	9	7	4	1	2	4
15	15	14	13	13	12	11	10	10	9	7	6	3	1	3	5	8	9
14	14	13	12	11	10	9	8	7	5	3	2	3	5	8	10	12	12
13	13	12	11	10	9	8	6	4	3	2	4	7	9	12	13	14	14
13	12	11	10	9	7	6	4	3	3	4	7	10	12	14	15	15	15
12	11	10	9	8	6	5	3	3	4	6	9	11	13	14	15	15	15
11	10	9	8	6	5	4	3	4	6	8	10	12	14	15	15	15	15
0	0	0	0	2	6	15	21	23	23	23	22	21	20	19	17	15	14
0	0	0	0	1	6	15	21	23	23	23	22	21	20	18	17	15	13
0	0	0	0	1	6	14	20	23	23	23	22	21	19	17	15	14	12
0	0	0	1	2	6	13	18	21	22	22	21	19	18	15	13	12	10
0	0	1	1	2	5	10	14	18	19	19	18	16	14	12	10	9	8
0	0	0	1	1	3	5	8	11	12	12	11	10	8	7	6	5	5
0	360	360	360	360	359	359	359	358	358	358	358	359	359	359	360	0	1
360	360	360	359	358	356	351	345	340	336	336	339	342	346	349	352	355	357
360	360	360	359	358	353	343	330	320	316	316	320	326	333	339	345	349	353
360	0	360	359	357	349	333	316	307	304	305	309	315	323	331	339	345	350
360	360	360	359	356	345	324	308	302	300	301	304	309	317	326	335	342	348
360	360	359	358	353	341	320	305	301	300	300	303	308	315	324	334	342	348
359	359	359	357	351	338	320	306	301	300	301	304	309	317	326	336	344	351
359	359	358	355	350	339	324	311	305	303	304	307	313	322	332	342	350	356
359	359	358	356	351	343	332	321	313	311	312	316	324	334	344	352	358	3
359	359	358	357	354	349	342	334	328	326	328	334	343	352	360	5	9	11
360	360	359	357	357	355	351	348	346	348	353	0	7	13	17	19	20	20
360	360	360	360	359	359	359	1	4	10	17	23	27	29	30	30	29	27
0	0	0	0	1	2	5	11	18	25	32	35	37	38	38	36	35	33
0	0	0	0	2	4	10	18	27	35	39	41	42	42	42	40	39	37
0	0	0	1	3	7	14	24	33	39	43	44	44	44	44	43	41	39
0	0	0	1	4	9	18	28	37	42	44	45	45	45	44	44	42	40
0	1	1	3	6	12	21	31	38	43	44	45	45	45	45	44	43	41
1	1	2	4	8	14	23	32	39	43	44	45	45	45	45	44	43	41
1	2	3	6	10	16	25	32	38	42	44	44	45	45	44	44	42	41
2	3	5	7	12	18	25	32	37	41	43	44	44	44	44	43	42	40
3	4	6	9	13	18	25	31	36	39	41	42	43	43	42	41	40	37
4	5	7	10	13	18	24	29	33	37	39	40	41	41	40	38	34	23
4	6	7	10	13	17	22	26	30	34	36	37	37	36	32	9	253	237
5	6	8	10	12	16	19	23	26	28	30	29	24	334	242	232	229	228
5	6	7	9	11	13	15	17	19	18	12	333	250	233	229	227	227	226
4	5	6	7	8	9	10	9	4	347	286	244	233	228	227	226	226	225
4	4	5	5	5	4	1	354	332	280	246	234	229	227	226	225	225	225
3	3	2	2	0	356	348	328	287	252	237	231	228	226	226	225	225	225
1	1	360	358	354	347	331	299	263	243	234	230	227	226	225	225	225	225

Figure 4. Example of wind field input

General Guidance on Model Use

44. The application of this model begins with a definition of what is needed from the model and why it is being used. The model can be used over a range of applications; e.g., from hindcasting wave information on an oceanic scale over decades to short-term simulation of events in a bay. Defining the problem will help set the regional coverage and other input options. Note that waves arriving at the coast may have been generated by storms hundreds or even thousands of miles away. If the model coverage does not extend to these generation areas, this wave energy will not be represented. Thus the first step is to define the boundaries of the region which needs to be modeled.

45. Once these boundaries are established, a grid of latitude and longitude lines is overlaid to define the points (crossings of lines of latitude and longitude) at which calculations will be made. The spacing between lines should be small enough to resolve geographic or bathymetric features of interest near land, but not so small that a large number (on the order of 100) of grid lines in each direction results. Very large grids require large amounts of computer memory and computational time. The nested grid feature of the model should be used when it is required to cover a large region and to also have fine resolution of land boundaries or bathymetry near land.

46. The time step is the next parameter to specify after the grid spacing is determined. The time step should generally be as large as possible without exceeding the time it takes for the fastest traveling wave energy to cross one grid cell. Since the fastest traveling waves are those of the lowest frequency, a first estimate of the time is obtained by dividing the grid cell size by the group speed of the wave in the lowest frequency band. The resulting time in seconds is a safe value to use. Typically a value close to this which is an even multiple of the output time is used. A common symptom of choosing too large a time step is excessive growth of wave energy resulting in unrealistic wave heights. This is generally obvious, but can be checked by using Figure 3.23 or 3.24 in the SPM (US Army Engineer Waterways Experiment Station 1984, pages 3-49 or 3-50) with an estimate of wind speed and fetch.

47. The mid-band values of frequency for the frequency bands should be chosen to represent all periods of expected wave energy. If, for example, the problem concerns wave energy on a small lake, long-period (> 12 sec) waves will probably not be present; thus, there would be no need to have bands in this low-frequency part of the spectrum. However, it is desirable to have 2-3 bands lower than the lowest band in which the peak energy is expected in order to define the shape of the spectrum in the low frequency or forward face region.

48. The program has a set format for reading the required input. Generally there is no reason to change this for the options file. Sometimes it is more convenient to change the format for input of wind information than to reformat input wind fields. If formats are changed or data reformatted for input, the user needs to be sure that the input data are consistent with the read statements and formats in the program. Input read errors or misinterpretation of input parameters are generally the result of inconsistency between input data and read statements or formats.

49. In a nested grid application, it is assumed that the time interval between input wind fields for the sub-grid is the same as that at which boundary information was saved in the large grid application. This is checked in the program by comparing dates in the header records of wind fields and boundary information, and will stop execution if the dates don't match. Consistency of this input should be checked prior to application to avoid this error. Also note that the time step will change in a nested grid application since the grid spacing will be reduced for the same climate of waves.

50. When forming the land/sea matrix, it is required that all boundary points on the circumference of the grid be zeros. This is naturally the case when a water body is surrounded by land. If land does not form a natural boundary, the grid boundary should be chosen to realistically represent the fetch length to the region of interest. Likewise, if wave generation and propagation from a water region will not affect the region of interest, it can be considered land and thus reduce the number of calculations.

51. Parameter statements are used in the FORTRAN Code to set the limits on the dimensioned arrays in the program. These values need to be changed to be appropriate for each application. The values set are the maximum number of

grid columns, grid rows, frequency bands, angle bands, output boundary points, and input boundary points.

52. After an application is completed, the results should be examined to see if they are reasonable as judged by nearby measurements or approximations for typical wind speeds and fetches. Generally, a numerical model is applied as an interpolation tool to provide information in space and time where it is lacking. An attempt should be made to verify the model results against other available information in order to validate the results and provide some indication of accuracy. Assistance in application of the model and interpretation of results is available from the WIS project office.

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APPENDIX A: GENERAL DESCRIPTION OF SUBROUTINES INITSPR AND SPROP

1. The upgrade of WISWAVE 1.0 to include the effects of refraction and shoaling in shallow water was accomplished by adding two subroutines. The first is subroutine INITSPR, which calculates variables dependent on depth that are used in subroutine SPROP to propagate wave energy from point to point. Subroutine INITSPR is called from the main part of the program when depths are defined initially, or when subsequently updated as in a storm surge or large tidal amplitude case.

2. Calculations in INITSPR are done within four nested DO LOOPS. The outermost loop is related to the frequencies in the discrete spectrum ($k=1, nfrq$), the two intermediate loops give position ($i=2, nx-1, j=2, ny-1$), and the inner loop is related to the angle bands in the discrete spectrum ($l=1, nang$). Notation of variables and symbols below is the same as that used in the subroutines. Values are calculated for five variables, each a function of frequency, position, and angle.

3. The concept of "backtracking" wave rays is used to calculate these variables. For a given frequency and position (value of k, i, j), a wave ray, with a specified angle, can be backtracked from the point using the ray trajectory equation

$$\frac{d\theta}{ds} = \frac{1}{ca(i,j,k)} \left[\frac{dc}{dx}(i,j) \sin(l) - \frac{dc}{dy}(i,j) \cos(l) \right] \quad (A1)$$

for one time step. The phase velocity is represented by "c," and "l" references the backtracking ray. The values dc/dx and dc/dy are calculated using the average value of c over two grid cells in the x and y directions respectively. This ray path is determined by the initial angle, with respect to the coordinate system, of a tangent to the ray at the (i,j) point, and the slope of the bathymetry defined by the differential in depth of points on either side of (i,j) in the north-south and east-west directions. The arc length traced by the ray is part of a circular path.

4. For a given frequency and position, the ray arrival angle is varied through all direction bands relative to the bottom slope angle (angsl) to allow computation of the change in angle (dth), component displacements (dpx, dpy) in the x, y directions, and combined component refraction, shoaling coefficients (ccgrjx, ccgrjy). These are the variables transferred to subroutine SPROP.

5. Subroutine SPROP examines the amount of energy, in x, y component form, leaving the point (i,j) and arriving at (i,j) from the upstream grid point accounting for refraction and shoaling. A more detailed description of the calculations is provided by comments in the coding of these two subroutines (see Appendix B).

APPENDIX B: SUBROUTINES ADDED IN UPGRADE TO WISWAVE 2.0

subroutine initspr

c This subroutine is called once from the main program if the shallow water
c option, IDRP=0 is input. It is not called if depths are set to 999 m by
c setting ISTDEP=1, or if depths are input but IDPRP=1. If depths are updated
c to reflect changing water levels, it is called from the main program each
c time an update occurs.

include 'paral.inc'

c The include statement reads a file (paral.inc) which is a fortran parameter
c statement used to set the values of idmn,jdmn,if,ia for dimensioning
c arrays.

```
common /smod/ dpx(idmn,jdmn,if,ia), dpy(idmn,jdmn,if,ia),
2dth(idmn,jdmn,if,ia),ccgrjx(idmn,jdmn,if,ia),ccgrjy(idmn,
3jdmn,if,ia)
```

c dpx, dpy are component distances, normalized by the grid cell size,
c traveled by a backtracked ray in one time step.
c dth is the change in refraction angle from upstream to point (i,j).
c ccgrjx, ccgrjy are related to refraction, shoaling coefficients.

```
common /ccg/ ca(idmn,jdmn,if),cga(idmn,jdmn,if),delx(jdmn)
```

c ca, cga are respectively the phase and group velocities at grid points.
c delx is latitude dependent due to the convergence of meridians.

```
common /a3/ g,pi,dl,nang,nfrq,nx,ny,twopi,dt,raddeg
```

c $g=9.8$ m/sec**2, $\pi=3.14159$, dl=distance between grid points (km), nang=# of
c angle bands, nfrq=# of frequency bands, nx=# of columns in grid, ny=# of
c rows in grid, twopi=2*pi, dt=time step (sec), raddeg=360/twopi.

```
dimension dcdx(idmn,jdmn),dcdy(idmn,jdmn),dcdx(idmn,jdmn),
2dcdy(idmn,jdmn)
```

c dcdx, dcdy are respectively the change in group velocity in the x,y
c directions about point (i,j) using centered differences. dcdx,dcdy are
c equivalent values for the phase velocity.

```
common /o5/ ibound(idmn,jdmn)
```

c ibound is the land-water boundary matrix, which can include boundary
c extrapolation, interpolation, or coincident point (same point in parent and
c nested grids) indicators.

```
common /angs/ ang(ia),sina(ia),cosa(ia),islp(idmn,jdmn)
```

c ang(l) is the center angle in radians of angle band l, sina and cosa are
c respectively the sine and cosine of ang(l), islp(i,j) is an index (either 0
c or 1) indicating which way the bottom slopes at i,j, more details below.

```
common /depth/ dep(idmn,jdmn)
```

c The values of depth (m) at each grid point.

```
common /band/ iua(ia),juaa(ia)
```

c Indices (0 or +, - 1) used to locate the appropriate upstream grid point
c from i,j for each angle band.

```
ep=0.0000001
```

c A small value added to the denominator to avoid dividing by zero.

```
ainc=twopi/nang
```

c The increment between angle bands in radians

```
alim=2*ainc
```

c A limit on the change in angle due to refraction between an upstream point
c and i,j.

```
do 80 l=1,nang  
ang(l)=(l-1)*ainc  
sina(l)=sin(ang(l))  
cosa(l)=cos(ang(l))
```

```
80 continue
```

c Calculate angles (radians) and sines, cosines for all angle bands

```
do 86 i=1,nang  
x=cosa(i)  
y=sina(i)  
iua(i)=-sign(1.0,x)  
juaa(i)=-sign(1.0,y)  
if (abs(x).lt.0.0001) iua(i)=0.0  
if (abs(y).lt.0.0001) juaa(i)=0.0
```

```
86 continue
```

c calculate the closest upstream i,j point from (i,j) for each angle band.

```
curvlim=1./(2.*dl)
```

c This is a limit on the arc length generated by the change in refraction
c angle. It is equal to 1/radius of curvature which is taken as 2*dl.

```
do 50 k=1,nfrq  
do 60 i=1,nx  
do 60 j=1,ny  
do 60 l=1,nang  
dpx(i,j,k,l)=0.  
dpy(i,j,k,l)=0.  
dth(i,j,k,l)=0.  
ccgrjx(i,j,k,l)=1.  
ccgrjy(i,j,k,l)=1.
```

```
60 continue
```

c Initialize values of arrays

```
do 1 i=2,nx-1  
do 1 j=2,ny-1  
dcgdx(i,j)=(cga(i+1,j,k)-cga(i-1,j,k))/(2.*delx(j))  
dcgdy(i,j)=(cga(i,j+1,k)-cga(i,j-1,k))/(2.*dl)  
dcdx(i,j)=(ca(i+1,j,k)-ca(i-1,j,k))/(2.*delx(j))  
dcdy(i,j)=(ca(i,j+1,k)-ca(i,j-1,k))/(2.*dl)
```

```

1 continue
c Calculate differentials of group and phase velocity.

do 2 i=2,nx-1
do 2 j=2,ny-1
if (ibound(i,j).ne.1) go to 2
c Skip to end of loop if not a water point. Depths are set to 0 for land
c points in subroutine rdopt

dhx=dep(i-1,j)-dep(i+1,j)
dhy=dep(i,j-1)-dep(i,j+1)
angsl=atan2(dhy,dhx+0.0000001)
c angl is the slope angle (positive toward shallow water)

islp(i,j)=0
if (abs(cos(angsl)).gt.abs(sin(angsl))) islp(i,j)=1
c islp=1 for angles > 315 and < 45, and > 135 and < 225 deg cartesian system,
c otherwise, islp=0.

do 3 l=1,nang
ll=1+nang/2
if (ll.gt.nang) ll=ll-nang
c l and ll are indices for opposite angle bands, ll references the
c "backtracking" ray.

cgav=cga(i,j,k)+ 0.5*dcdgdx(i,j)*cga(i,j,k)*cosa(ll)*dt
2 + 0.5*dcdgdy(i,j)*cga(i,j,k)*sina(ll)*dt
c cgav is the average group velocity calculated from points around i,j.

dels=cgav*dt
c distance energy will travel in one time step at the average group speed.

dthds=(dcdx(i,j)*sina(ll)-dcdy(i,j)*cosa(ll))/(ca(i,j,k)+ep)
c This is the ray trajectory equation. It calculates the change in angle due
c to refraction along an arc length.

if (abs(dthds).gt.curvlim) dthds=curvlim*dthds/abs(dthds)
c Limit dthds to curvlim, retaining the appropriate sign (+ or -).

thtav=ang(ll)+0.5*dthds*dels
c An average angle, based on initial value + 1/2 the change

phi=1.0/(sqrt(1.0-(0.5*dels*dthds)**2))
c 1/ratio of arc length to chord length. Chord length approximated with a
c Taylor expansion of 2r sin (1/2 theta)

dpx(i,j,k,l)=dels*cos(thtav)/phi
dpy(i,j,k,l)=dels*sin(thtav)/phi
dpx(i,j,k,l)=abs(dpx(i,j,k,l))/delx(j)
dpy(i,j,k,l)=abs(dpy(i,j,k,l))/dl
c Calculate fraction of cell size in x,y direction traveled by ray in one
c time step

```

```

ii=i+iuua(1)
cgupx=cga(ii,j,k)
cgrx=cgupx/cga(i,j,k)
jj=j+juua(1)
cgupy=cga(i,jj,k)
cgry=cgupy/cga(i,j,k)

```

c Ratio of component upstream group speeds to group speed at (i,j)

c Solve for intersection with boundary
c Following section considers rays backtracked from (i,j) at angles of each
c angle band and determines the originating angle based on the bottom slope
c and phase speeds using Snell's Law. Then the change in angle, dth, is
c calculated along with the proper ratios of group speed for use in
c subroutine sprop.

```

c1=ca(i,j,k)
c2=ca(ii,j,k)
rx=c1/c2
c3=ca(i,jj,k)
ry=c1/c3

```

c Ratio of phase speed at (i,j) to components of phase speed upstream.

```

angz=ang(1)-angsl

```

c Difference between band angle and slope angle.

```

if (angz.gt.pi) angz=angz-twopi
if (angz.lt.-pi) angz=angz+twopi

```

c Express angle as value between + or - 180 deg.

```

if (abs(angz).gt.pi/2.) rx=1./rx
if (abs(angz).gt.pi/2.) ry=1./ry

```

c Invert ratio of phase speeds if angle > 90 deg.

```

if (angz.gt.pi/2.) angz=pi - angz
if (angz.lt.-pi/2.) angz=-pi - angz

```

c Express angle as value between + or - 90 deg.

```

sinz=sin(angz)
if (rx.gt.2.0) rx=2.0

```

c Limit max. ratio of phase speeds to 2

```

if (rx.gt.1.) go to 76

```

c Two options for x component.

c If speed increasing as approaching (i,j) go to 76,
c otherwise speed decreasing, do section below.

```

ang0=asin(rx *sinz)

```

c Snell's Law $\sin(\text{shallow})/\sin(\text{deep})=c(\text{shallow})/c(\text{deep})$.

```

bx=abs(cos(angz)/(cos(ang0)+ep))

```

c Ratio of ray separation in deep to shallow water.

c bx and by are related to refraction coefficient

```

        if(abs(sinz).gt.0.99985) bx=1.0
c   Set bx for 90 or 270 deg incidence.
        if (islp(i,j).eq.1) dth(i,j,k,l)=ang0-angz
c   Calculate change in angle.

        go to 61
c   Do y component

c   Arrive here if speed increasing as approaching (i,j)
76 ang0=asin(sinz/rx)
        bx=abs(cos(ang0)/(cos(angz)+ep))
        if (islp(i,j).eq.1) dth(i,j,k,l)=angz-ang0

c   Two options for y component
61 if (ry.gt.2.0) ry=2.0
        if (ry.gt.1.) go to 62
        ang0=asin(ry*sinz)
        by=abs(cos(angz)/(cos(ang0)+ep))
        if(abs(sinz).gt.0.99985) by=1.0
c   Set by for 90 or 270 deg incidence
        if (islp(i,j).ne.1) dth(i,j,k,l)=ang0-angz
        go to 63

c   Arrive here if speed increasing as approaching (i,j)
62 ang0=asin(sinz/ry)
        by=abs(cos(angz)/(cos(ang0)+ep))
        if(abs(sinz).gt.0.99985) by=1.0
c   Set by for 90 or 270 deg incidence
        if (islp(i,j).ne.1) dth(i,j,k,l)=angz-ang0

63 if (dth(i,j,k,l).gt.alim) dth(i,j,k,l)=alim
        if (dth(i,j,k,l).lt.-alim) dth(i,j,k,l)=-alim
c   Limit change in angle to two angle increments.

        if (bx.gt.1.) bx = 1./cgrx
        if (by.gt.1.) by = 1./cgry
        ccgrjx(i,j,k,l)=cgrx *bx
        ccgrjy(i,j,k,l)=cgry *by
c   ccgrjx, ccgrjy are related to combined shoaling, refraction coefficient.

        3 continue
c   End of angle loop

        2 continue
c   End of space loop

        50 continue
c   End of frequency loop

c   The following variables are calculated above and used in subroutine sprop
c   Variable      Function of
c-----

```

```

c ispl          i,j
c dpx, dpy      i,j,k,l
c ccgrjx, ccgrjy i,j,k,l
c dth          i,j,k,l

```

```

    return
end

```

```

    subroutine sprop(k)

```

```

c This subroutine is called from the main program within loop 2000, which is
c a loop on frequency. It, in turn, is in loop 1001, which is a loop on time
c steps. Loops in this subroutine are on space and angles, thus computations
c in this subroutine are done for every time step, frequency, grid point and
c angle. The purpose of the subroutine is to propagate energy in shallow
c water accounting for refraction and shoaling. The equivalent subroutine
c for deep water is dprop.

```

```

    include 'paral.inc'

```

```

c The include statement reads a file (paral.inc) which is a fortran parameter
c statement used to set the values of idmn,jdmn,if,ia for dimensioning
c arrays.

```

```

    common /smod/ dpx(idmn,jdmn,if,ia), dpy(idmn,jdmn,if,ia),
    2 dth(idmn,jdmn,if,ia),ccgrjx(idmn,jdmn,if,ia),ccgrjy(idmn,
    3 jdmn,if,ia)

```

```

c dpx, dpy are component distances, normalized by the grid cell size,
c dth is the change in refraction angle from upstream to point (i,j).
c ccgrjx, ccgrjy are related to refraction, shoaling coefficients.

```

```

    common /ccg/ ca(idmn,jdmn,if),cga(idmn,jdmn,if),delx(jdmn)

```

```

c ca, cga are respectively the phase and group velocities at grid points.

```

```

    common /a3/ g,pi,xn,dl,nang,nfrq,nx,ny,twopi,fac,dt,raddeg

```

```

c g=9.8 m/sec**2, pi=3.14159,dl=distance between grid points (km), nang=# of
c angle bands, nfrq=# of frequency bands, nx=# of columns in grid, ny=# of
c rows in grid, twopi=2*pi, dt=time step (sec), raddeg=360/twopi.

```

```

    dimension eoutx(idmn,jdmn,ia),eouty(idmn,jdmn,ia),
    leinx(idmn,jdmn,ia),einy(idmn,jdmn,ia),einx(idmn,jdmn,ia),
    2einy(idmn,jdmn,ia)

```

```

c eoutx,eouty are components of energy leaving point (i,j) at angle l.
c einx,einy are components of energy entering point (i,j) at angle l.
c einfx,einy are components of energy for all angles.

```

```

    common /angs/ ang(ia),sina(ia),cosa(ia),islp(idmn,jdmn)

```

```

c ang(l) is the center angle in radians of angle band l, sina and cosa are
c respectively the sine and cosine of ang(l), islp(i,j) is an index (either 0
c or 1) indicating which way the bottom slopes at i,j, more details below.

```

```

    common /cen/ e(idmn,jdmn,if,ia),enxt(nbn,if,ia),elst(nbn,if,ia)

```

```

c e is the frequency spectrum at (i,j) after propagation.  enx and elst are
c not used in this subroutine, see main program.

```



```

      common /o5/ ibound(idmn,jdmn)
c  ibound is the land-water boundary matrix.

      common /band/ iua(ia),juaa(ia)
c  Indices (0 or +, - 1) used to locate the appropriate upstream grid point
c  from i,j.

      ainc=twopi/nang
c  The increment between angle bands in radians

c  Entering x-component propagation section
c  Determine x component of energy leaving (i,j) and arriving at (i,j) from
c  point upstream for all angle bands at one frequency
      do 1 i=1,nx
      do 1 j=1,ny
      if (ibound(i,j).ne.1) go to 1
      do 2 l=1,nang
      eoutx(i,j,l)=e(i,j,k,l)*dpx(i,j,k,l)
      ii=i+iua(l)
      einx(i,j,l)=e(ii,j,k,l)
      2 continue
      1 continue

c  Entering theta-propagation, x component
      do 5 i=2,nx-1
      do 5 j=2,ny-1

      if (ibound(i,j).ne.1) go to 5
c  If not a water point go to next point

      do 6 l=1,nang
      einfx(i,j,l)=0.
      6 continue
c  Initialize energy summation array at all angles to zero

      do 7 l=1,nang
      angz=ang(l)+dth(i,j,k,l)*islp(i,j)
      if(abs(angz).lt.0.02) angz=0.0
      if(angz.gt.twopi) angz=angz-twopi
      if(angz.lt.0.0) angz=angz+twopi
      ll=angz/ainc+l
      if(ll.lt.1) angz=angz+twopi
      if(ll.lt.1) ll=ll+nang
      if(ll.gt.nang) ll=ll-nang
      lh=ll+1
      if(lh.gt.nang) lh=lh-nang
      xl=(angz-(ll-1)*ainc)/ainc
      einfx(i,j,ll)=einfx(i,j,ll)+ccgrjx(i,j,k,l)*einx(i,j,l)*(1.-xl)
      2 * dpx(i,j,k,ll)
      einfx(i,j,lh)=einfx(i,j,lh)+ccgrjx(i,j,k,l)*einx(i,j,l)*xl
      2 * dpx(i,j,k,lh)
      7 continue

```

```

c Determine the amount of energy arriving at (i,j) from adjacent upstream
c angle bands.

      do 8 l=1,nang
        e(i,j,k,l)=e(i,j,k,l)-eoutx(i,j,l)+einx(i,j,l)
        if (e(i,j,k,l).lt.0.) e(i,j,k,l)=0.
      8 continue
c Calculate new energy after propagation in each angle band at frequency k
c and point (i,j)

      5 continue
c Completion of space loop

c Entering y-component propagation section
c Determine y component of energy leaving (i,j) and arriving at (i,j) from
c point upstream for all angle bands at one frequency

      do 17 i=1,nx
        do 17 j=1,ny

          if (ibound(i,j).ne.1) go to 17
c If not a water point go to next point

          do 9 l=1,nang
            eouty(i,j,l)=e(i,j,k,l)*dpy(i,j,k,l)
            jj=j+juaa(l)
            einy(i,j,l)=e(i,jj,k,l)
          9 continue
        17 continue

c Entering theta-propagation, y component
      do 3 i=2,nx-1
        do 3 j=2,ny-1
          if (ibound(i,j).ne.1) go to 3
          do 16 l=1,nang
            einfy(i,j,l)=0.
          16 continue
          do 27 l=1,nang
            angz=ang(l)+dth(i,j,k,l)*(1-islp(i,j))
            if(abs(angz).lt.0.0z) angz=0.
            if(angz.gt.twopi) angz=angz-twopi
            if(angz.lt.0.) angz=angz+twopi
            ll=angz/ainc+l
            if(ll.lt.1) ll=ll+nang
            if(ll.gt.nang) ll=ll-nang
            lh=ll+l
            if(lh.gt.nang) lh=lh-nang
            xl=(angz-(ll-1)*ainc)/ainc
            einfy(i,j,ll)=einfy(i,j,ll)+ccgrjy(i,j,k,l)*einy(i,j,l)*(1.-xl)
            2*dpy(i,j,k,ll)
            einfy(i,j,lh)=einfy(i,j,lh)+ccgrjy(i,j,k,l)*einy(i,j,l)*xl
            2* dpy(i,j,k,lh)

```

```

27 continue
c Determine the amount of energy arriving at (i,j) from adjacent upstream
c angle bands.

      do 18 l=1,nang
      e(i,j,k,l)=e(i,j,k,l)-eouty(i,j,l)+einfy(i,j,l)
      if (e(i,j,k,l).lt.0.) e(i,j,k,l)=0.
18 continue
c Calculate new energy after propagation in each angle band at frequency k
c and point (i,j)

      3 continue
c Completion of space loop

      return
      end

```

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