CHAPTER 5

AN APPROACH TO AN OFF-SHORE WAVE CLIMATOLOGY

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ABSTRACT

A project to derive a wave climatology for that portion of the Atlantic Ocean between 30° and 60° N. and west of 30° W, recently begun by the Atmospheric Environment Service of Environment Canada, is described. The data base is produced from isolines of significant wave height and from plotted ship data. Details of the preparation of the basic analysis as well as the design of the remainder of the project are presented. Intermediate results will provide guidance to potential users of the wave climatology until sufficient data have been accumulated to lend statistical reliability to the analysis.

INTRODUCTION

In his opening address to the Thirteenth International Conference on Coastal Engineering, Mr. M.P. O'Brien, Chairman of the Coastal Engineering Research Council of American Society of Civil Engineers stated, inter alia, that knowledge of wave climate is primitive, and that this fact has created a " . . . most frustrating gap in the kit of tools available to the coastal engineer." A major cause of this unfortunate situation is the lack of a suitable data base for many areas of interest. This paper describes a project designed to reveal the wave climate of the portion of the Atlantic Ocean between 30° and 60° north latitude, and west of 30° west longitude, but the approach is potentially applicable to any ocean area.

Measurements are ordinarily the raw material for any statistical study. Unfortunately, in the area under consideration, few deep-water wave measurements exist, and those are strongly biased in position and time. Visual estimates of wave conditions are made by ships crossing the area, but like any visual estimate, accuracy depends strongly on the individual, the conditions to which he is exposed at the moment, and other unquantifiable variables. Furthermore, most such estimates are also biased in space and time. Hindcasts based on the surface wind field are possible, but the derivation of the latter from surface pressure gradients and isobar curvature is tedious and can produce misleading results. Perhaps within the decade, satellite-borne instruments will relieve the problem.

Faced with the immediate problem of wave statistics for the continental shelf areas of Canada's Atlantic Coast, H.J.A. Neu, an engineer on the staff of the Bedford Institute, Marine Sciences Directorate of the Canada Department of the Environment, recognized the potential of routine analyses of significant wave height (H_S) at 0001 and 1200 GMT over the northwest Atlantic made by the Atmospheric Environment Service (AES) of the Canada Department of Environment. He undertook a feasibility study (Neu, 1971), and demonstrated to the AES the desirability of undertaking a similar program on an operational basis.

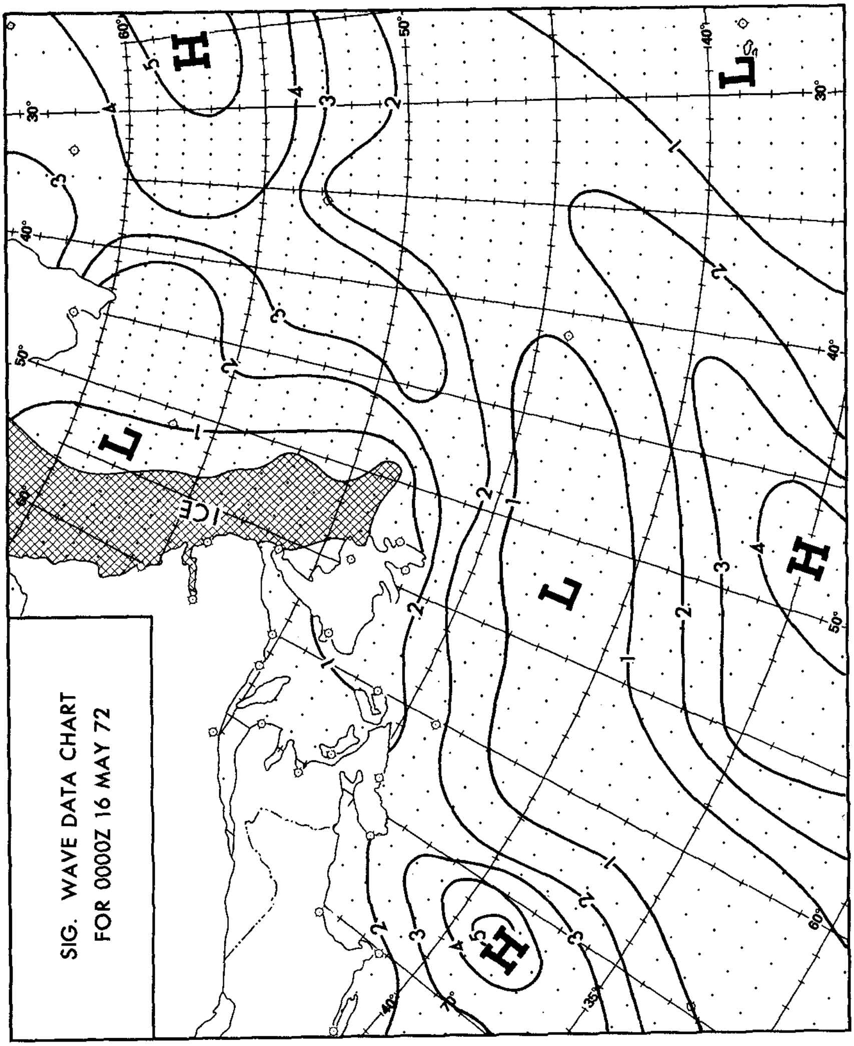

*Figure 1: A sample analysis of significant wave height.
The chart actually used in this project also contain plotted ship observations.*

In the following sections of this paper, the procedures used in the preparation of the basic wave-height analysis are presented, Neu's pilot project is briefly described, and the AES project which has evolved is discussed in detail. While many years of data will be required to determine the wave climate, intermediate results will be of interest to those for whom alternative guidance does not exist. However, in such cases, the user of the intermediate results must recognize the limitations of the program and the hazards of using samples of insufficient size for statistical reliability.

THE BASIC ANALYSIS

To meet a portion of the requirements of maritime units of the Canadian Armed Forces, the Meteorology and Oceanography (METOC) Centre in Halifax has undertaken a program of the analysis and prognosis of significant wave height. Isolines of significant wave height at one-metre intervals are analysed twice daily (fig. 1), and are used as the base charts for 12-, 24- and 36-hour prognostics. The method of analysis combines observations from ships and offshore drilling platforms with hindcasting, while imposing spatial and temporal continuity for the control of quality.

The 12-hour prognostic of the 0001 GMT analysis becomes the first-guess field for the 1200 GMT analysis. This prognostic is prepared using extrapolation, including simple trends, as well as compatability with the forecast surface weather map.

When the observational data arrive, they are plotted on a blank chart. With the earlier prognostic chart as an underlay, discrepancies between the expected pattern and the observational data become obvious. Resolution of these may require several approaches. Prime suspect must be the first guess field, for errors in judgement about the intensification of a weather system (and thus, a wave system), or about the speed or direction of movement of such systems must be expected. However, observing, transmission or plotting crrors must not be overlooked. For example, a ten-degree error in latitude or longitude of the ship can be caused by the mistaking of a dot for a dash during communication; ordinarily, this can be detected on the weather chart since wind, pressure, previous position and water temperature could singly or collectively provide evidence. The forcing of temporal and spatial continuity and compatability with the weather map on the resulting analysis provide the best quality controls possible in these circumstances.

Once the large discrepancies are resolved, the first-guess field is adjusted to account for the observed data and unexpected developments in the wind field. In general, adjustments are mainly in the location, strength or shape of troughs, ridges or centres of low or high significant wave height.

While only one set of isolines is produced, many observations show sea and swell separately. Such observations are used to calculate a combined wave whose H_s is the square-root of the sum of the squares of the significant wave height of each train.

Large portions of the area analyzcd lie off regualar sea lanes; observed data in these sections are scarce. To makc the "analyses" more mcaningful in such regions, hindcasts based on the current wcather map and its recent history are made. The nomograms used in this task are those due to Suthons (1945) as modified by Morgan (1971).

The resulting isolines of combined significant wave height (in metres) are transmitted by radio-facsimile to Canadian naval vessels and merchant ships of all nations with appropriate receiving equipment. Figure 1 demonstrates an analysis with the plotted data (which are usually transmitted as well) missing. At the same time, the prognostic patterns of significant wave height for 12-, 24- and 36-hours are also transmitted. As a measure of the quality of the analyses, the prognostics which are based upon them are routinely verified against subsequent observations and analyses. During 1971, the AES products at 24- and 36-hours had a lower monthly root-mean-square error (over a ten-point grid which includes the ocean weather ships) than the other forecast available for the area, the U.S. N.W.S. computer-derived prognostics. This applied to all twelve months at 24 hours and to eleven of the twelve at 36 hours. It is reasoned that this fact is evidence that the analysis is a useful representation of the actual conditions.

THE PILOT PROJECT

Neu recognized the potential of the routine analysis described above to serve as a data base for a wave climatology of the shelf areas off Canada's Atlantic coast. He undertook a pilot project (Neu, 1971) to establish the feasibility of the approach. A grid system 2.5 degrees latitude by 2.5 degrees longitude (termed Neu-Squares by this writer and his colleagues) was established. From each analysis, and from a linear interpolation between them providing a time scale of six hours, Neu abstracted the average significant wave height in each grid square along with an appropriate direction and period. The latter two quantities were inferred from the plotted data.

In the report on this pilot project, (Neu, 1971), the data are presented in several ways:

(a) for each month of 1970, and for each Neu-square, the total energy per metre of wave crest is presented graphically;

(b) for each month of 1970, for each Neu-square, and for each of eight directions, graphs of total energy per metre of wave crest as functions of wave period are given;

(c) for each month of 1970, for each Neu-square and for each of eight directions, the number of occurrences by height and period class is shown in tables.

The graphs and tables contained in this report are the only readily available wave statistics for the whole area in print at the present time. Because the AES required time to adapt and take over the program on an operational basis, Neu continued the project through 1971 and it is hoped that he will publish those data as well.

As an interesting sidelight, Neu's 1971 analysis brought to light an unexpected flaw in the operational wave information service of the AES. Unknown to the forecasters at the METOC Centre, the various drill rigs had been reporting maximum waves over differing time intervals. It had been assumed that the heights being reported were significant wave heights. In the higher wave situations where the difference between the maximum and the significant waves was large, the quality control procedures outlined in the section above detected the discrepancy and the data were modified. However, a bias toward higher values remained, especially since one reaches the stage where present techniques cannot determine with certainty that a particular value of significant wave height is inconsistent with history and weather. This bias resulted in an anomalous bulge of high energy in all months into the Neu-squares occupied by the rigs, signalling very clearly the existence of an observational problem. Once identified the problem was resolved through consultations with the operators.

PROGRAM MODIFICATIONS

Neu reasoned, quite justifiably, that the concept had been proven valid and should be carried on by an operational agency. The AES concurred and began a modified program on May 1, 1972 after the completion of a further, but relatively small, feasibility study. The modifications were necessary to permit the program to be undertaken within existing resources.

The relationships between the space and time scales chosen by Neu was deemed suitable. However, Neu was interested mainly in the shelf areas, while the AES had to consider a much large portion of the northwest Atlantic Ocean. To keep the activity to a size such that it could be undertaken within existing resources, it was decided to consider areas five degrees latitude by five degrees longitude with a time base of 12 hours. No time resolution was being sacrificed because the 6-hour "data" used by Neu were simply linear interpolations between the basic analyses. Considerable spatial resolution is sacrificed, but intelligent interpretation of the results will offset this to some extent. Doubling both the space and time scales reduces the effort involved by about one order of magnitude.

The other major change from Neu's design is the quantity being abstracted. When one considers a point, at any time there is a single significant wave height. However, when one is dealing with an area, unless circumstances are exceptional there is a variation of H_s across this area at any one time. The problem resolves itself into determining what quantity one should abstract. Neu chose an average H_s over his areas. The AES felt that the following types of questions are the ones that would be asked:

(a) What is the probability that the significant wave height at a point will equal or exceed a particular value in a particular month; or

(b) What is the significant wave height that will be exceeded, say, five percent of the time in a given month at a particular place? Using standard statistical results, the above questions could treat the average wave, or the maximum wave instead of the significant wave.

On the reasoning outlined above, the AES has chosen to abstract the highest significant wave height occurring at analysis time within each of the grid squares. This quantity will permit the derivation of a climatology of extremes (such as those for temperatures, humidities and winds used by heating and cooling engineers) so that questions similar to those posed above may be answered. Furthermore, the highest significant wave in an area at map time is easier to determine and is less affected on a percentage basis by irregularities in the analysis than is the average over the area.

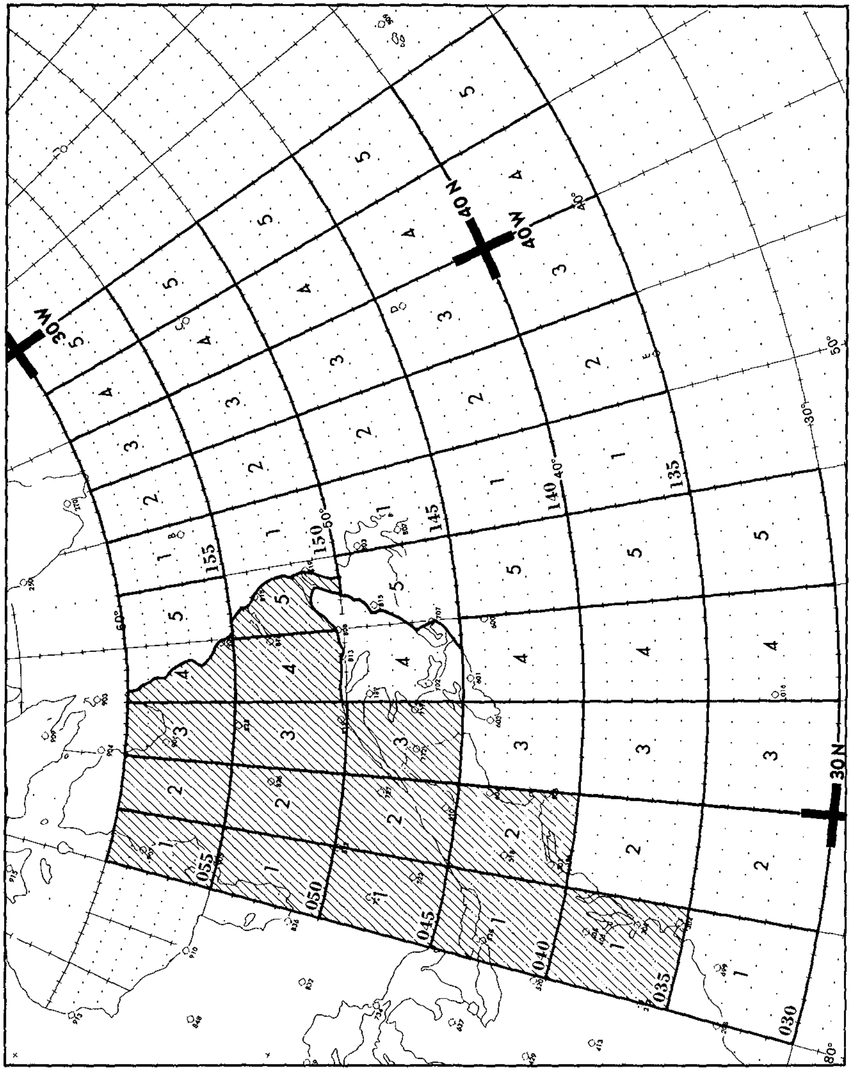

Figure 2: Area of interest and grid square identification. The hatched areas are invalid.

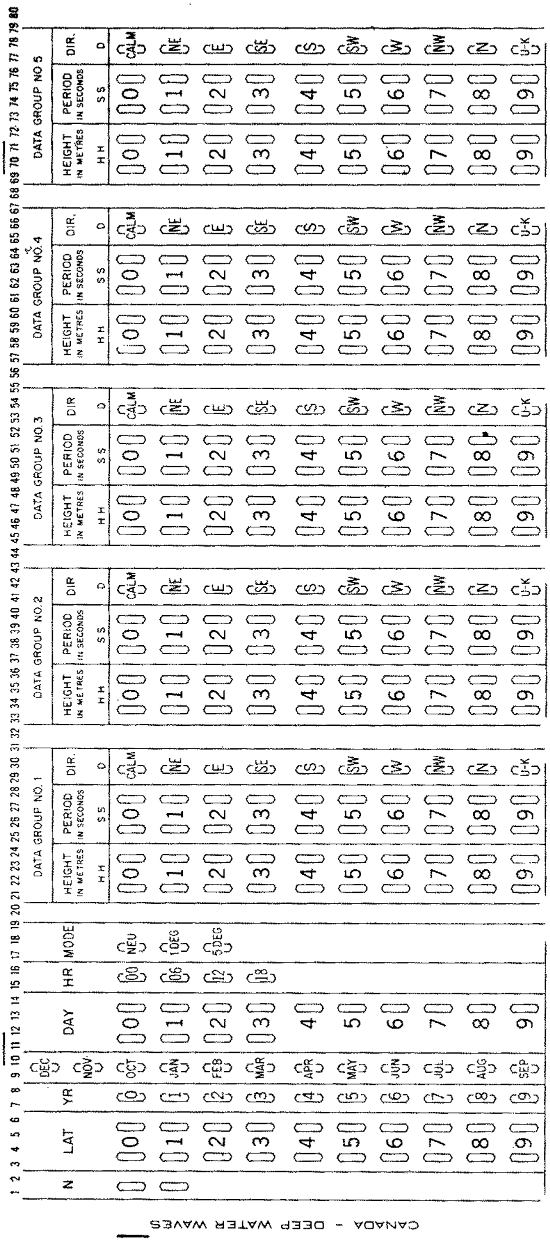

Figure 3: The optical mark recognition (OMR) card used for communicating the data to the computer.

THE AES PROJECT

Figure 2 shows the area covered by this project along with the system of identification of each grid square. The squares are grouped in fives, with the group identification consisting of the latitude of the southern boundary prefixed by a "O" or "1". For those groups whose western boundary is 80° W. longitude, the prefix is "O". If the western boundary of the group is 55° W longitude, the prefix is "1". Within each group, the squares are numbered one through five.

It should be noted that some squares are invalid because they are largely or completely land. Furthermore, some boundaries have been distorted to conform to the coastline. For example, the western boundary of square number five in group 055 has been extended to the coastline of Labrador, and all other squares in that group are invalid. Similarily, square one of group 150 has been extended westward to the coastline, and group 050 is completely invalid. Square four of group 045 constitutes the Gulf of St. Lawrence.

Data are recorded by the analyst on optical mark recognition (OMR) cards such as the one illustrated in figure 3. The first several columns are for the identifying information of the group (identifier, date/time, and mode – in this case, 5-degrees), and the remainder for the data for each square in the group. Ten such cards are produced from each chart. At the end of each month, the accumulated cards and copies of the analyses from which they were produced are forwarded to the AES headquarters for processing.

The first pass through the computer is to detect and note reading or coding errors. These are corrected on the original cards by headquarters staff, referring where necessary to the copies of the base charts. Second pass is for sorting and punching cards (as a permanent archive because the contents of two OMR cards can be recorded on one standard 80-column punched card).

Sorting is by month, area, wave direction, and classes of height and period. Initially, the height and period classes described in table 1 will be used because of the number of data available. After several years have passed, it may prove necessary to increase the resolution in height and period, but this may be easily accomplished at that time because the original data are still available on the punched cards.

TABLE 1:

Limits of Height and Period Classes

Height Classes – Metres		Period Classes – Seconds	
H1	0.5 – 1.4*	S1	<4
H2	1.5 – 3.4	S2	5 to 7
H3	3.5 – 5.4	S3	8 to 9
H4	5.5 – 7.4	S4	10 to 12
H5	7.5 – 10.4	S5	>12
H6	$\geqslant 10.5$		

*Waves with height less than 0.5m are classed as "calm", and the total of such cases listed in the area summary.

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PERIOD OF RECORD 1972 - 1972 MONTH 5 SQNO= 9 SW-CORNER= 55N, 40W MODE= 5 DEG.

NW

	H1	H2	H3	H4	H5	H6	SH
S1	0	0	0	0	0	0	0
S2	0	6	4	0	0	0	10
S3	0	0	3	0	0	0	3
S4	0	0	1	0	0	0	1
S5	0	0	0	0	0	0	0
SI	0	0	0	0	0	0	0
SV	0	6	8	0	0	0	14

EXTR. HH(SS)=05(09),SS(HH)=10(04)
YR/DA/HR 72/29/00 , 72/28/12

N

	H1	H2	H3	H4	H5	H6	SH
S1	0	0	0	0	0	0	0
S2	0	6	0	0	0	0	6
S3	0	0	1	0	0	0	1
S4	0	0	0	0	0	0	0
S5	0	0	0	1	0	0	1
SI	0	0	0	0	0	0	0
SV	0	6	1	1	0	0	8

EXTR. HH(SS)=06(12),SS(HH)=12(06)
YR/DA/HR 72/26/00 , 72/26/00

NE

	H1	H2	H3	H4	H5	H6	SH
S1	0	0	1	0	0	0	1
S2	0	1	0	0	0	0	1
S3	0	1	1	0	0	0	2
S4	0	0	1	0	0	0	1
S5	0	0	0	0	0	0	0
SI	0	0	0	0	0	0	0
SV	0	2	3	0	0	0	5

EXTR. HH(SS)=05(08),SS(HH)=11(04)
YR/DA/HR 72/25/12 , 72/25/00

W

	H1	H2	H3	H4	H5	H6	SH
S1	0	0	0	0	0	0	0
S2	1	2	1	0	0	0	4
S3	0	1	3	0	0	0	4
S4	0	0	1	1	0	0	2
S5	0	0	0	0	0	0	0
SI	0	0	0	0	0	0	0
SV	1	3	5	1	0	0	10

EXTR. HH(SS)=06(10),SS(HH)=11(04)
YR/DA/HR 72/28/00 , 72/18/12

T O T A L S

	ICE	CLM	H1	H2	H3	H4	H5	H6	HI	SH
ICE	0									0
S1		0	0	1	1	0	0	0	0	2
S2		0	2	22	12	2	0	0	0	38
S3		0	0	3	13	0	0	0	0	16
S4		0	0	1	3	1	0	0	0	5
S5		0	0	0	0	1	0	0	0	1
SI		0	0	0	0	0	0	0	0	0
SV	0	0	2	27	29	4	0	0	0	62

EXTR. HH(SS,D)=06(12, N),SS(HH,D)=12(06, N)
YR/DA/HR 72/26/00 , 72/26/00

E

	H1	H2	H3	H4	H5	H6	SH
S1	0	0	0	0	0	0	0
S2	0	1	2	0	0	0	3
S3	0	0	0	0	0	0	0
S4	0	0	0	0	0	0	0
S5	0	0	0	0	0	0	0
SI	0	0	0	0	0	0	0
SV	0	1	2	0	0	0	3

EXTR. HH(SS)=05(05),SS(HH)=06(02)
YR/DA/HR 72/07/12 , 72/23/12

SW

	H1	H2	H3	H4	H5	H6	SH
S1	0	0	0	0	0	0	0
S2	1	3	3	1	0	0	8
S3	0	0	2	0	0	0	2
S4	0	0	0	0	0	0	0
S5	0	0	0	0	0	0	0
S1	0	0	0	0	0	0	0
SV	1	3	5	1	0	0	10

EXTR. HH(SS)=06(06),SS(HH)=09(05)
YR/DA/HR 72/03/00 , 72/13/12

S

	H1	H2	H3	H4	H5	H6	SH
S1	0	0	0	0	0	0	0
S2	0	1	1	1	0	0	3
S3	0	1	2	0	0	0	3
S4	0	0	0	0	0	0	0
S5	0	0	0	0	0	0	0
S1	0	0	0	0	0	0	0
SV	0	2	3	1	0	0	6

EXTR. HH(SS)=06(06),SS(HH)=08(03)
YR/DA/HR 72/02/00 , 72/01/12

SE

	H1	H2	H3	H4	H5	H6	SH
S1	0	1	0	0	0	0	1
S2	0	2	1	0	0	0	3
S3	0	0	1	0	0	0	1
S4	0	1	0	0	0	0	1
S5	0	0	0	0	0	0	0
SI	0	0	0	0	0	0	0
SV	0	4	2	0	0	0	6

EXTR. HH(SS)=05(08),SS(HH)=10(02)
YR/DA/HR 72/15/00 , 72/19/12

WAVE HEIGHT IN METERS		PERIOD IN SEC.	
CLM	0 - 0.4	S1	0- 4
H1	0.5- 1.4	S2	5- 7
H2	1.5- 3.4	S3	8- 9
H3	3.5- 5.4	S4	10-12
H4	5.5- 7.4	S5	GE 12
H5	7.5-10.4	SI	INDETER.
H6	GE 10,5		
HI	INDETER.	ICE	MORE THAN 75% COVERED

SH=HOR. SUM
SV=VERT.SUM

Figure 4: A sample print-out.

During the sorting program, the extreme significant wave height for the area for the month for each direction is flagged along with its associated period and date of occurrence. Similarily, the longest period is noted along with the accompanying height and date.

Printer output will be in the form of tabulations of actual occurrences of height and period classes for each of the eight directions, and for the whole area regardless of direction. This will exist for actual and for collective month (all Januarys grouped together, for example). A model of the printer output is presented in fig. 4.

The project will be continued until the frequency of occurrence of the various classes for the collective month becomes stable, and thus can be used as a predictor of the probability of occurrence of the classes in the future. It is not possible to estimate at this time how long it will require to reach that stage.

If an area is more than 75 % ice covered, no attempt is made to abstract the wave information. Instead, a code "88" is used in the position reserved for wave height. The number of such occurrences will provide a very rough guide to the temporal extent of ice cover.

SUMMARY

In response to a long-standing need, the Atmospheric Environment Service of Environment Canada has embarked on a project that ultimately should provide a definitive wave climatology for the northwest Atlantic Ocean. In place of "measurements" the data base will be drawn from analyses of significant wave height based on a combination of observations and hindcasting within the constraints of continuity both in space and time.

Both the data base and the study design contain flaws, but the best compromises possible under the circumstances have been made. With suitable care by the user, the intermediate results may be used as interim guidance in the absence of other sources. Even inshore interests may find these results useful provided they take bottom and other boundary processes into account.

It must be emphasized that:

(a) the wave height parameter being abstracted is the highest significant wave height at map time anywhere within the grid square, in order that an extremes climatology could be produced. Since these are significant wave heights, they may be interpreted in terms of maximum wave heights using standard techniques.

(b) the period and direction are the values which, in the judgement of the analyst, are representative of the height chosen. These quantities are not analyzed separately but are deduced from the surrounding plotted data and the analyst's knowledge of how the present wave situation has evolved.

ACKNOWLEDGEMENTS

The writer is spokesman for persons too numerous to mention who have participated in the development of the program. Special mention is due Mr. B.S.V. Cudbird, Chief of the Data Processing Division of AES, Mr. M.R. Morgan, OIC of the METOC Centre at Halifax, and the staffs of both organizations. Mr. M.S. Webb also played a major role in the development of the project.

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