NOAA NWSTM PR-17

NOAA Technical Memorandum NWSTM PR-17

AN OPERATIONAL SWELL AND SURF PROGRAM USING THE N.W.S. AUTOMATIC DATA ACQUISITION SYSTEM (ADAS) COMPUTER SYSTEM

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DEPARTMENT OF COMMERCE
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noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / National Weather Service

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- continued on inside back cover -

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

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TABLE OF CONTENTS

I - INTRODUCTION

WSFO Honolulu has long operated a major marine forecast program. One of the tasks of this program is the production of surf and swell forecasts for the Hawaiian Islands, Johnston Island and Wake Island. The latter two locations have WSOs and the WSFO forecasts provide guidance for these WSOs. Swell and surf forecasts for the Hawaiian Islands are issued to the public.

Surf and swell forecasting techniques were first developed at the Scripps Institution of Oceanography during World War II for the U. S. Navy. It is believed that the first widely used operational techniques came from the Scripps effort under Sverdrup and Munk. The S-M method (6) was based on single wave theory and empirical data. The resulting method was simple to use and gave surprisingly good results, considering the nature of sea waves and the underlying assumptions of the system. Bretschneider (1) added data to the S-M system and the result was a revised forecasting system we shall refer to hereafter as the Sverdrup-Munk-Bretschneider system or SMB method.

Now, the waves in the sea are complex and the variety of wave amplitudes and periods in any given "sea" is better described as by a spectrum of amplitudes and periods. Thus, more sophisticated wave forecast techniques deal with spectra of wave groups. A typical system of this type is the Pierson-Neumann-James (5) or PNJ system.

Unfortunately for operational meteorologists, spectral methods are hard to use and even harder to program on a computer. When a technically better wave forecasting model is used it often provides a "deluge" of data of heights and periods in many spectral bands inundating the forecaster with numbers. Finally, the public user wants these forecast wave data "distilled" to reasonable size and the circle is complete. We arrive back to providing a forecast resembling the significant height and period, such as produced by the SMB method of old. Happily, the SMB method can be programmed on a computer or reduced to nomograms with relative ease.

To provide ocean-wide forecasts, large computer centers (the National Meteorological Center (NMC) and the Navy Fleet Numerical Weather Central (FNWC)) prepare areal charts of significant wind waves and swell. The approach is quasi-Eulerian and forecasts are valid up to 48 hours. Such products are quite valuable for high seas shipping. We feel that a somewhat better approach for localized (point) wave forecasting is to follow the older quasi-Lagrangian SMB approach and "track" generated wave trains to a desired point or a very few points. We feel that this is not really competitive with the products of the large computer centers as it can be done for only a few points and not over the entire ocean.

WSFO Honolulu recently received an Automatic Data Acquisition System (ADAS) built around a NOVA 1200, 24K memory computer. The system comes with rather sophisticated time-sharing software which can be used for many purposes in addition to its primary mission of automatic raingage query and upper air sounding reduction. One of the uses we have made of the ADAS system is computation of forecast swell heights and periods along with related arrival times along with the computation of resulting surf. The program should run in any interactive time-sharing system having the facility to load 8-level ASCII paper tapes and operating with the Business BASIC language interpreter. Specifically, the program will run on any NWS ADAS where it can be disc resident. While the program is designed for use with a KCRT, the programmed instructions to the operator can be substantially reduced and run on the ADAS through a common Model 33 ASCII teletype. Further, the program must be modified for local use elsewhere. This is not a difficult task.

II - <u>DESCRIPTION</u>

The operator "calls" the program through his peripheral device (KCRT, teletype, etc.), enters required data and makes certain decisions. A sample of the forecast swell output from a generating area fetch during the storm of November 8-10, 1976 is shown below. The leading edge of the wave generation fetch was located 1667 nm. northwest of Hawaii at that time.

```
NOV 12, 1976   8:43:00

                           FORECAST SWELL ARRIVAL TIME PLOT
SWELL ARRIVAL TIME                 SWELL HEIGHTS IN FEET              PAGE 1
(N=N'LY,S=S'LY)   0 . . . . 5 . . . . 10. . . . 15. . . . 20. . . . 25
 11 12 1100 FRI   I         .         .         .⊗        .         N
 11 12 1900 FRI   I         .         .         .N⊗       .         I
 11 12 2000 FRI   I         .         .         .         .  ⊗      N
 11 13 0100 FRI   I         .     N ? .         .         ⊗         I
 11 13 0300 FRI   I         .         .         .  ⊗ N    .         I
 11 13 0800 FRI   I         .         .         .  N      .         I
 11 13 1100 SAT   I         .         .N        .         .         I
 11 14 0100 SAT   I         .         .    N    .         .         I
 11 14 0300 SAT   I       N .         .         .         .         I
 11 14 0300 SAT   I         .         .   N     .         .         I
 11 14 0500 SAT   I         .         N         .         .         I
 11 14 0600 SAT   I         .         . N       .         .         I
 11 14 0300 SAT   I         .     N   .         .         .         I
 11 14 0800 SAT   I         .         . N       .         .         I

(N.B.:THE DAY OF THE WEEK IS LOCAL(HST) DAY.)
```

⊗ -Observed swell heights measured by Mokuleia wave gage.Gage inoperative after 11/12/0800Z.

III - METHODOLOGY

A. Wind Wave and Swell Generation

The SMB method is based on relatively unsophisticated single wave theory. Ocean waves do not normally consist of a single wave train at a point but rather a spectrum of single wave trains. The simpler SMB method is related to "reality" by tracking a single "significant" wave train. This train represents the average of the highest one third waves in the wind wave spectrum. In the theory, these waves decay in height, disperse somewhat and increase in period as they travel away from the generating area. This approach to describing wave systems is generally disdained by more modern investigators. One of these has said privately "The SMB method gives the right answers for all the wrong reasons." This is likely to be true, but we still use the system because of its simplicity of use. And we do need the "right" answers.

The WSFO Honolulu program (named "HISW") uses observed sea conditions (height, period and local direction) or indicated surface wind speed, fetch length, direction and duration time. If wind data are input, the wind waves are computed by two methods; fetch limited waves of Liu spectrum (3) or duration limited waves (Pore and Richardson (4)). For duration limited waves,

$$H_{1/3} = .0176(U/2)^2 + Td/_6 + .5 \quad \text{(Ft.)}$$

and

$$\bar{T}\text{ (sec)} = 2\,U^{.4} + T_d(U/180)$$

where

U = Wind speed (knots)
T_d = Duration time (hours)

For fetch limited waves, $H_{1/3}$ and $\bar{T}$ are given by:

$$H_{1/3} = .0211(F^{.237})(U^{1.526}) \quad \text{(Ft.)}$$

$$\bar{T} = 8 + (H_{1/3} - 8)/4 \quad \text{(Approximation)}$$

where

F = Fetch length, nm.
U = Wind speed (knots)

The program takes the lesser of the two since the lesser values would properly represent the wind waves generated under the greater restraint, fetch or duration time.

The generated waves are presumed to leave the generating area and become swell. Dispersion, and consequent lowering of wave heights, are handled by the following relationship based on usage and observed results:

$$F = (\cos 4\theta)^{\frac{1}{2}} \quad (0 < \theta < 22.5°)$$

Thus, waves more than 22.5° from the <u>sides</u> of the fetch area "box" will not be forecast to reach the point for which we are forecasting. Lesser angles result in reduced (dispersed) wave heights.

B. <u>Swell Propagation</u>

Swell propagation is computed in accordance with SMB theory. The travel time as the waves move along a great circle from leading edge of the generating area to the destination is given by

$$t = \frac{.66\ D}{T_{ave.}}$$

where D is the travel distance in nm.

$T_{ave.}$ is the <u>mean</u> period of the waves as they travel.

Using a $T_{ave.}$ rather than the final period suggested by Bretschneider (1) has proved to be a key improvement in forecasting arrival time. $T_{ave.}$ must be found by an iterative process as it is, in turn, dependent on travel time, t.

In our program, $T_{ave.} = (T_o + T_f)/2$.

So, T_f is computed first using the relationship from FNWC and NMC

$$T_f = (T_o^{\ 2} + K\ t_1)$$

where

K is a "tuneable factor"
t_1 is the "first guess" as a travel time given by

$$t_1 = .66\ D/T_o$$

Then a final travel time t_f is computed from

$$t_f = .66D/\overline{(T_o + T_1)}$$

This procedure produces a later arrival time when K = 1.2 is used. This was empirically determined from reviewing arrival times of southerly swell from southern hemisphere storms. Waves from these storms often travel 4000 or more miles to reach Hawaii and a useful value for K is required to make reasonably good forecast arrival times. K = 1.2 appears to be a good value.

The wave height decay relationship used by NMC (4) is

$$H_F = H_o \left(\frac{T_F}{T_o}\right)^{-k}$$

where k = 2.65.

Experience in verifying average heights from visual observations and measured from wave gages indicates that k = 2.65 is an averaged factor that gives good results for waves traveling less than 1200 miles. When waves travel greater distances, k should be 3, 4 or greater to give results comparable with observation. As a result, Bretschneider's (2) wave decay data indicates this factor ranges from 1.9 to 5 depending on travel distance for an average fetch; assumed to be 300 miles.

A cubic polynomial was fitted to the Bretschneider data. This relationship is

$$k = .0947(\hat{D})^3 - .818(\hat{D})^2 + 2.54(\hat{D}) + 1.69$$

where $\hat{D} = D \times 10^{-3}$ (nm)

D was scaled simply to avoid large negative exponents.

Using a variable k as a function of travel distance D seems to give quite realistic results in the final swell height forecasts.

Using the above relationships, the system produces a swell forecast for any selected arrival point.

C. Surf Forecasts

After the forecasted swell arrives at the destination point, an idea of the resulting surf may be desired. Using the U. S. Navy (7) surf computation scheme, Dr. Arthur Hull, formerly of this station and now MIC of WSFO Seattle, wrote a BASIC program adapted from the USN system. Input is the swell height, period and direction. Direction of the normal to the beach underwater contours and average slope are internal parameters and are usually unique to each beach.

The WSFO Honolulu program system provides the forecaster with a beach list from which to select a desired beach. The beach list can be modified easily for any locale where representative beaches exist (i.e., a reasonably long beach front along with a fairly even slope). A sample program run using swell from the forecast given earlier follows:

```
      LIST OF BEACHES FOLLOWS:
SLOPE-NORMAL DIR.-NAME
 1. 1/40    145  SANDY BEACH
 2. 1/40    020  NORTH BEACH
 3. 1/50    315  SUNSET BEACH
 4. 1/30    360  MOKULEIA BEACH
 5. 1/50    245  MAKAHA BEACH
 6. 1/50    260  MAILE BEACH
 7. 1/40    170  EWA BEACH
 8. 1/70    200  ALA MOANA
 9. 1/50    280  BARKING SANDS

TYPE IN THE NUMBER REPRESENTING THE BEACH FOR WHICH YOU WISH
TO COMPUTE THE SURF.

? 3

BEACH SELECTED IS     SUNSET BEACH


THE DIRECTION IOF THE BEACH NORMAL IS  315 DEG.
THE DIRECTION OF THE OCEAN SWELL APPROACHING THE BEACH IS 303.931 DEG


*****************************************************************

        SURF AT   SUNSET BEACH

SIGNIFICANT BREAKER HEIGHT  18.6 FEET.

AVERAGE PERIOD OF SURF IS  16.7  SECONDS.

DEPTH AT BREAKING IS 23.3 FEET

WIDTH OF BREAKER ZONE IS 389.1 FEET

EFFECTIVE AFTER  11 / 12 / 1000 Z

*****************************************************************
```

D. Special Data Presentation

The HISW program provides the user with an option to save forecast swell data. The data file will allow saving up to 48 swell forecasts at a given time.

A special program, SWLST, will call the data file, eliminate old data and duplicates and print out a list of the forecast swell data in chronological order using a graphic format. These listings are printed out twice daily and provide a hard copy of the swell forecasts for archival purposes.

A sample of this output is as follows:

```
#SWLST1

PLEASE WAIT WHILE NUMERICAL SORT TAKES PLACE.

 1




DEC 21, 1976  11:33:26

                       FORECAST SWELL ARRIVAL TIME PLOT
SWELL ARRIVAL TIME             SWELL HEIGHTS IN FEET              PAGE 1
 (N=N'LY, S=S'LY)   0 . . . . 5 . . . . 10. . . . 15. . . . 20. . . . 25
  12 21 2000 TUE    I     N   .         .         .         .         I
  12 22 0100 TUE    I         . N       .         .         .         I
  12 22 0300 TUE    I        N.         .         .         .         I
  12 22 0500 TUE    I         .      N  .         .         .         I
  12 22 0600 TUE    I        N.         .         .         .         I
  12 22 0700 TUE    I         .         . N       .         .         I
  12 22 1400 WED    I    N    .         .         .         .         I
  12 23 0500 WED    I      N  .         .         .         .         I

(N.B.: THE DAY OF THE WEEK IS LOCAL(HST) DAY.)
```

E. Program Operation and Responses

Operating the HISW program produces a number of requests for data, progress statements, instructions and output. The program seems "vocal" because use of a KCRT permits rapid input/output response.

Since a teletype is slower than a KCRT, the program responses should be shortened to save I/O time. This can be rather easily done. Also, versions for use elsewhere in the ADAS system need to have references to Hawaii eliminated and references to own area incorporated. This can be accomplished easily using BASIC.

The following is a listing on a teletype of a sample KCRT run of a real case in November, 1976.

```
#HISW

     BE SURE TO HIT 'RETURN' KEY AFTER EACH DATA ENTRY!

PLEASE TYPE IN MONTH/DAY/TIME(Z) OF INITIAL WAVE DATA
THERE ARE THREE ENTRIES;MONTH(1 OR 2 DIGITS),DATE(1 OR 2
DIGITS) AND 'Z' TIME(4 DIGITS).FORMAT EXAMPLE: ?7?14?0350

? 11? 9? 1200
TYPE IN 'W' IF YOU ARE OBTAINING WAVES FROM WIND DATA
TYPE IN 'H' IF YOU ALREADY KNOW WAVE HT. AND PD.

? W

   NOW, TYPE IN THE FOLLOWING:
        * AVERAGE WIND SPEED IN FETCH
        * MEAN WIND DIRECTION IN FETCH
        * FETCH LENGTH (NM.)
        * DURATION TIME (HRS.)
  FORMAT: /35?240?400?12

? 47? 290? 700? 18
 TYPE IN LATITUDE OF WAVE POINT DISTANT FROM HAWAII.
 USE NEGATIVE VALUES FOR SOUTH LATITUDE AND EAST LONGITUDE.
 EXAMPLES: 24S IS -24. 155E IS -155. 25.7N IS 25.7.

TYPE IN LATITUDE(RETURN) FOLLOWED BY LONGITUDE(RET)

? 34.5? -174
 IF YOU WISH TO COMPUTE WAVE ARRIVAL AT SOME OTHER  PLACE
 THAN HAWAII(OAHU), TYPE IN 0
 IF DESTINATION IS HAWAII, TYPE IN 1

? 1
```

```
HERE IS A RESUME OF DATA YOU HAVE ENTERED

MONTH            DAY              TIME
 11               9               1200

FETCH FACTORS: WIND SPEED- WIND DIR.-FETCH LEN.-DUR.TM.
               47 KTS.  290 DEG   700 NM.   18 HRS

SIGNIF HT.     AVE.PERIOD     LOCAL WAVE DIR
 29.6           14             290

 INPUT LAT.    INPUT LONG.
 34.5          -174
 NOTE: WAVE HEIGHTS AND PERIOD ARE DURATION LIMITED.


DESTINATION IS HAWAII

PLEASE EXAMINE DATA. IF OKAY, TYPE IN 1. IF NOT,
TYPE IN 0. PROGRAM WILL START OVER.
? 1
 THERE WILL BE A SHORT WAIT WHILE ANOTHER PROGRAM IS FETCHED


 THANKS FOR WAITING. COMPUTATION HAS RESUMED.

DIRECTION OF G.C. AT DESTINATION POINT IS 303 DEG.
DIRECTION OF G.C. AT POINT OF ORIGIN IS  290 DEG

ANGLE BETWEEN G.C. DIR. AND LOCAL WAVE DIR. IN GENERATING
AREA IS  0 DEG.THE RESULTING WAVE HTS. WILL BE REDUCED
BY A SPREADING FACTOR OF  .99

PLEASE WAIT FOR ANOTHER PROGRAM TO BE FETCHED


 THANKS FOR WAITING. COMPUTATION HAS RESUMED
**********************************************************************

INITIAL DTG.           INITIAL HT. & PD.       INITIAL SWELL DIR.
 11 / 9 /1200Z          29.6 FT. 14 SEC.             290 DEG.

INITIAL WAVE HTS. REDUCED BY SPEADING FACTOR TO   29.3 FT.

ARRIVAL POINT LAT./LONG IS 21.5  158

 DECAY    TRAVEL   ARRIVAL     FINAL     FINAL      ARRIVAL DTG AND DAY
  DIST.    TIME     DIR.        PD.       HT.
1667 NM.  70 HRS.  303 DEG.  16.7 SEC.  14.2 FT.   11 / 12 / 1000 Z(FRI

**********************************************************************
DO YOU WISH TO SAVE THIS SWELL FORECAST FOR LISTING?(Y OR N)
? N      DATA NOT SAVED
THE FOLLOWING OPTIONS ARE AVAILABLE AT THIS TIME:
     1.COMPUTE SURF AT SELECTED HAWAIIAN BEACHES.
     2.MAKE ANOTHER SWELL COMPUTATION WITH NEW DATA.
     3.COMPUTE SWELL AT A DIFFERENT ARRIVAL POINT USING
       PRESENT INPUT DATA.
     4.GENERATE  PLOT OF SWELL HTS. VS. ARRIVAL TIMES.
     5.QUIT.
```

BIBLIOGRAPHY

1. Bretschneider, C. L., "Revised Wave Forecasting Relationships", Proceedings of Second Conference on Coastal Engineering, 1952.

2. Bretschneider, C. L., "The Generation and Decay of Wind Waves in Deep Water", Trans. Amer. Geophysics Union, pp 381-389, 33 (June 1952).

3. Liu, P. C., "Normalized and Equilibrium Spectra of Wind Waves in Lake Michigan", Journal of Physical Oceanography, 1:249-257, 1971.

4. Pore, A. and Richardson, W., "Weather Service Program in Objective Wind Wave and Swell Forecasting", Technical Memo TDLM-30, 1970.

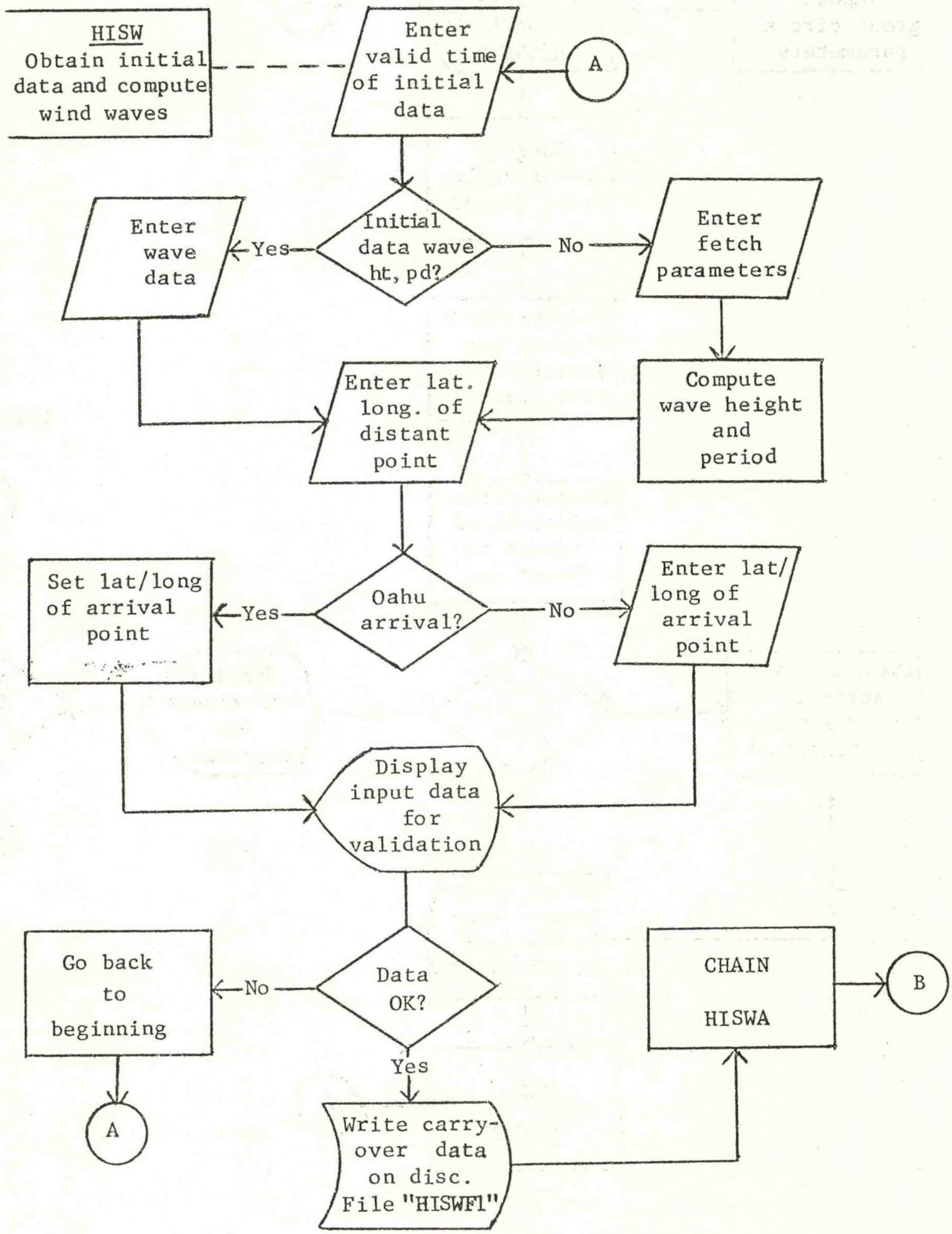
5. U. S. Navy Hydrographic Office, "Observing and Forecasting Ocean Waves", H. O. Publication 603, 1955.

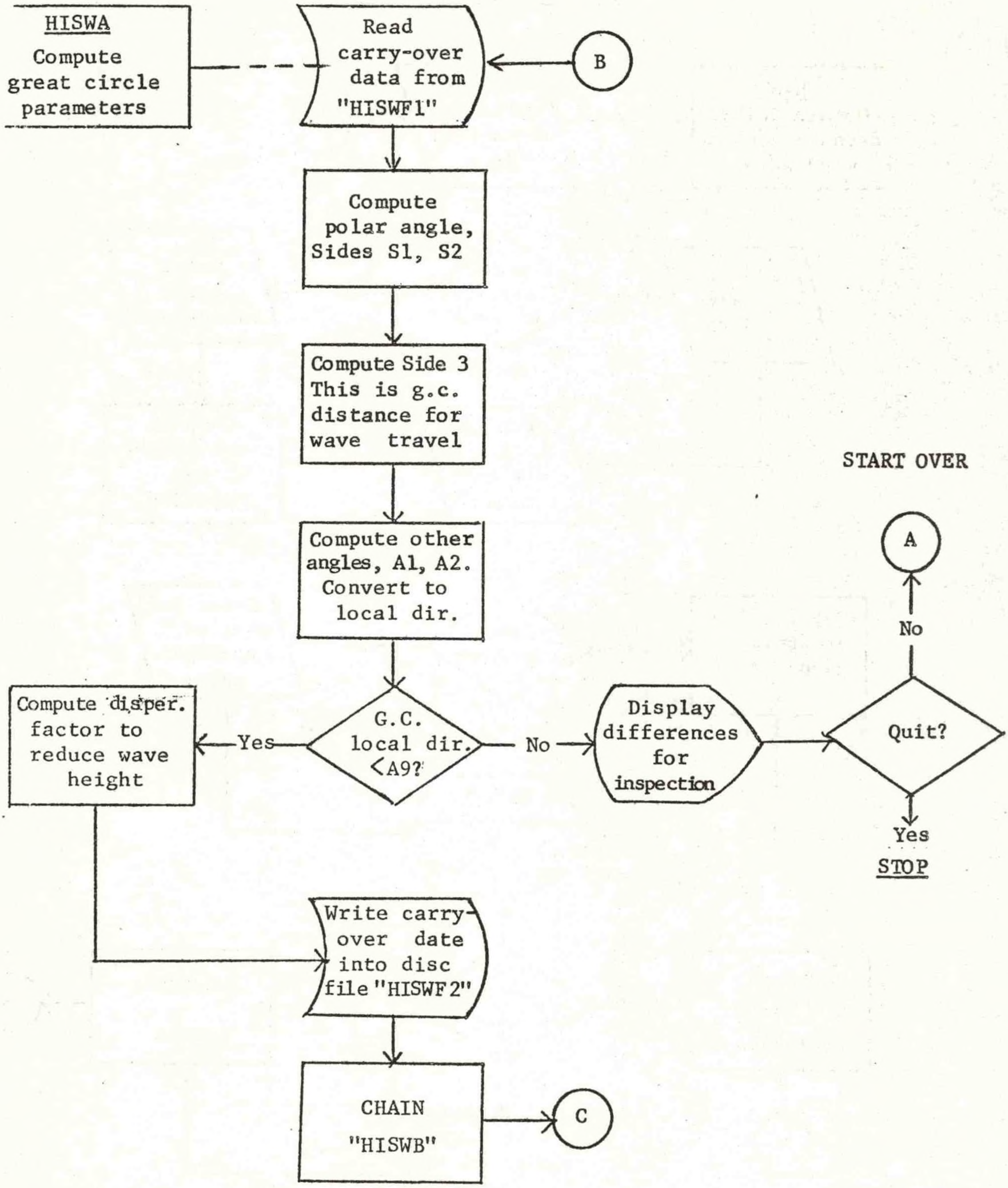
6. U. S. Navy Hydrographic Office, "Technique for Forecasting Wind Waves and Swell", H. O. Publication 604, Washington, D. C., 1951.

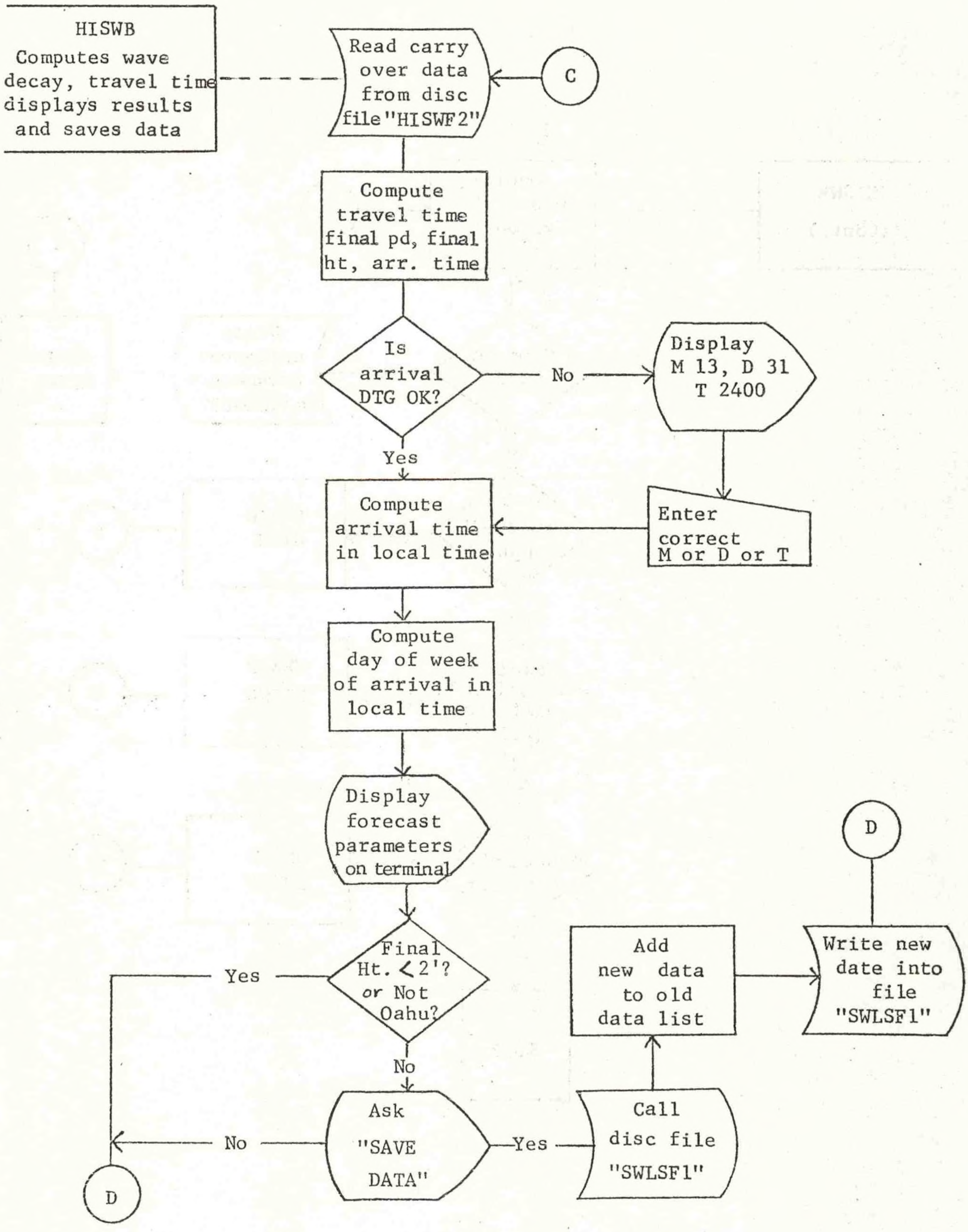
7. U. S. Navy Weather Research Facility, "Surf Forecast", Griswold, NWRF 36-1264-099, 1964.

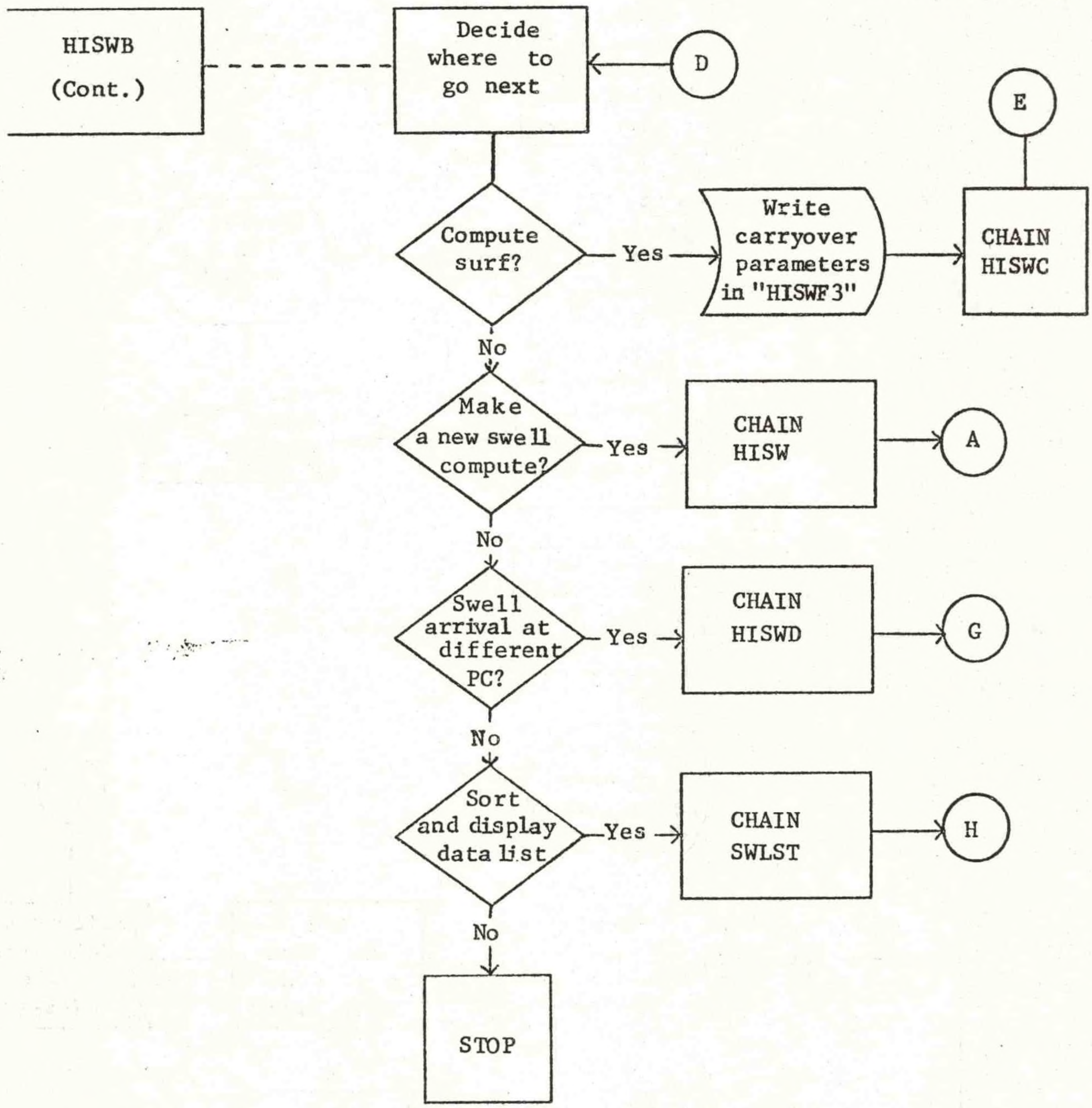
APPENDIX I

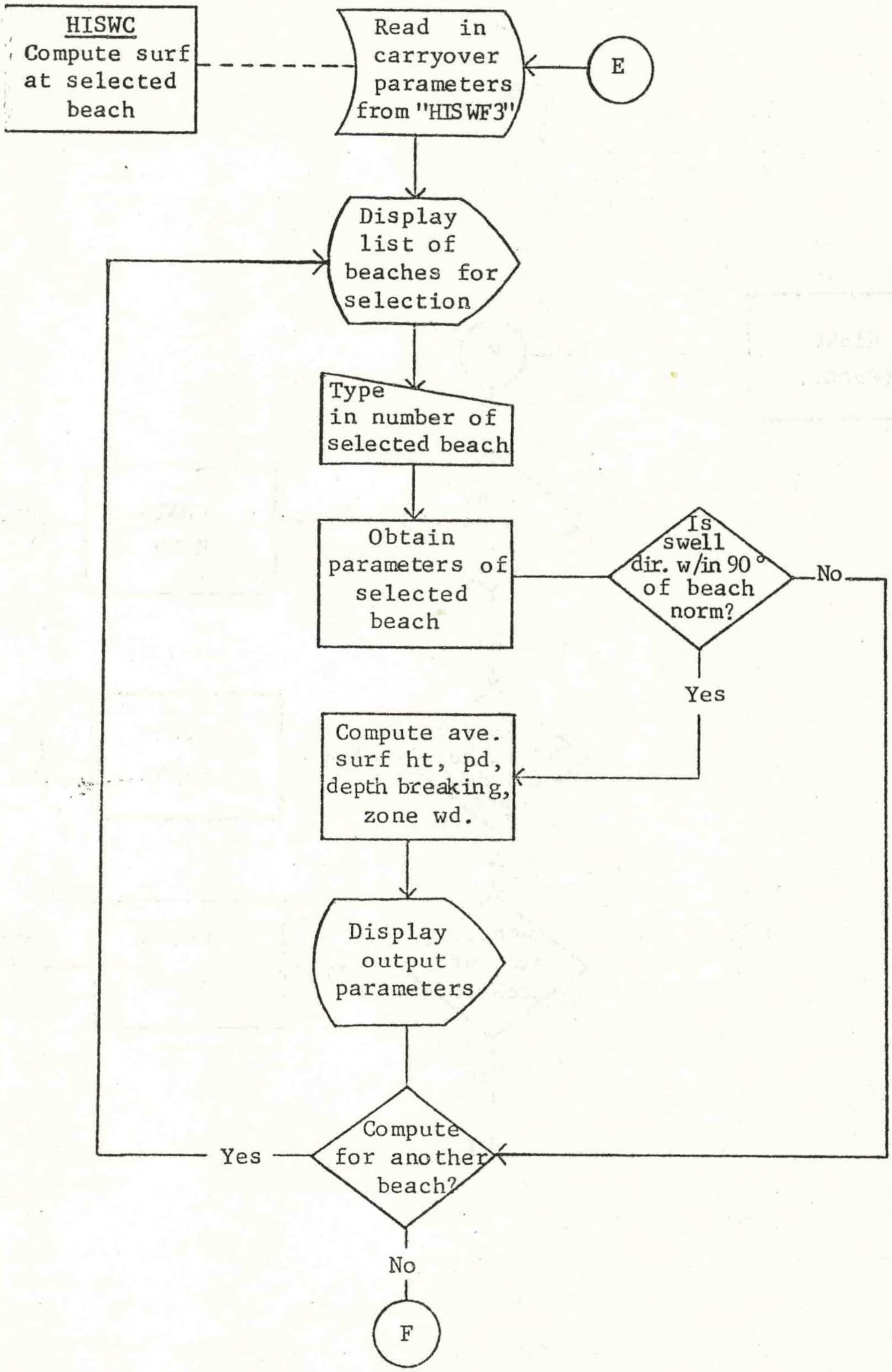
FUNCTIONAL FLOW DIAGRAMS

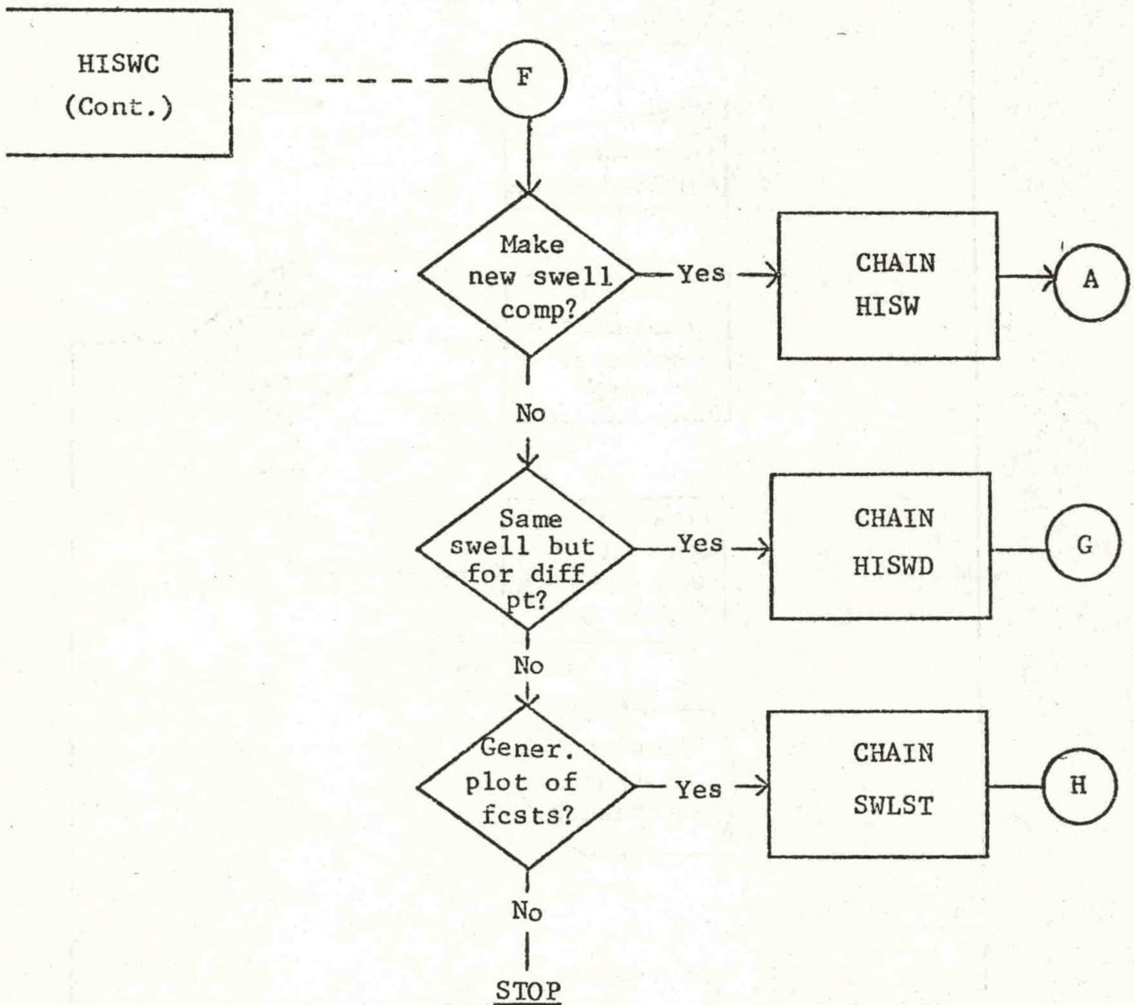


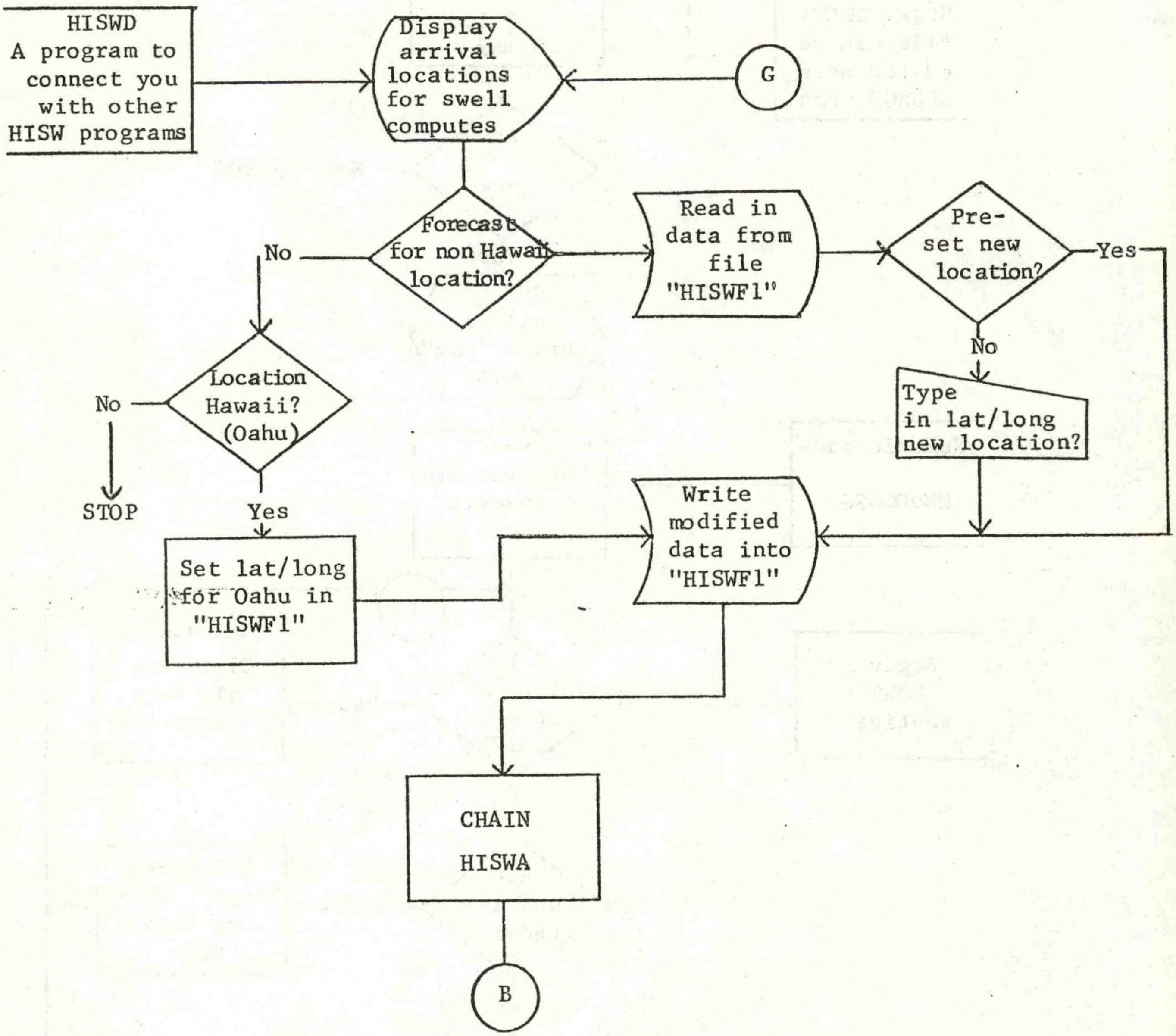

HISWA
Compute great circle parameters
Read carry-over data from "HISWF1"
B
Compute polar angle, Sides S1, S2
Compute Side 3 This is g.c. distance for wave travel
Compute other angles, A1, A2. Convert to local dir.
G.C. local dir. <A9?
Yes
No
Compute disper. factor to reduce wave height
Display differences for inspection
Quit?
No
Yes
START OVER
A
STOP
Write carry-over date into disc file "HISWF2"
CHAIN "HISWB"
C

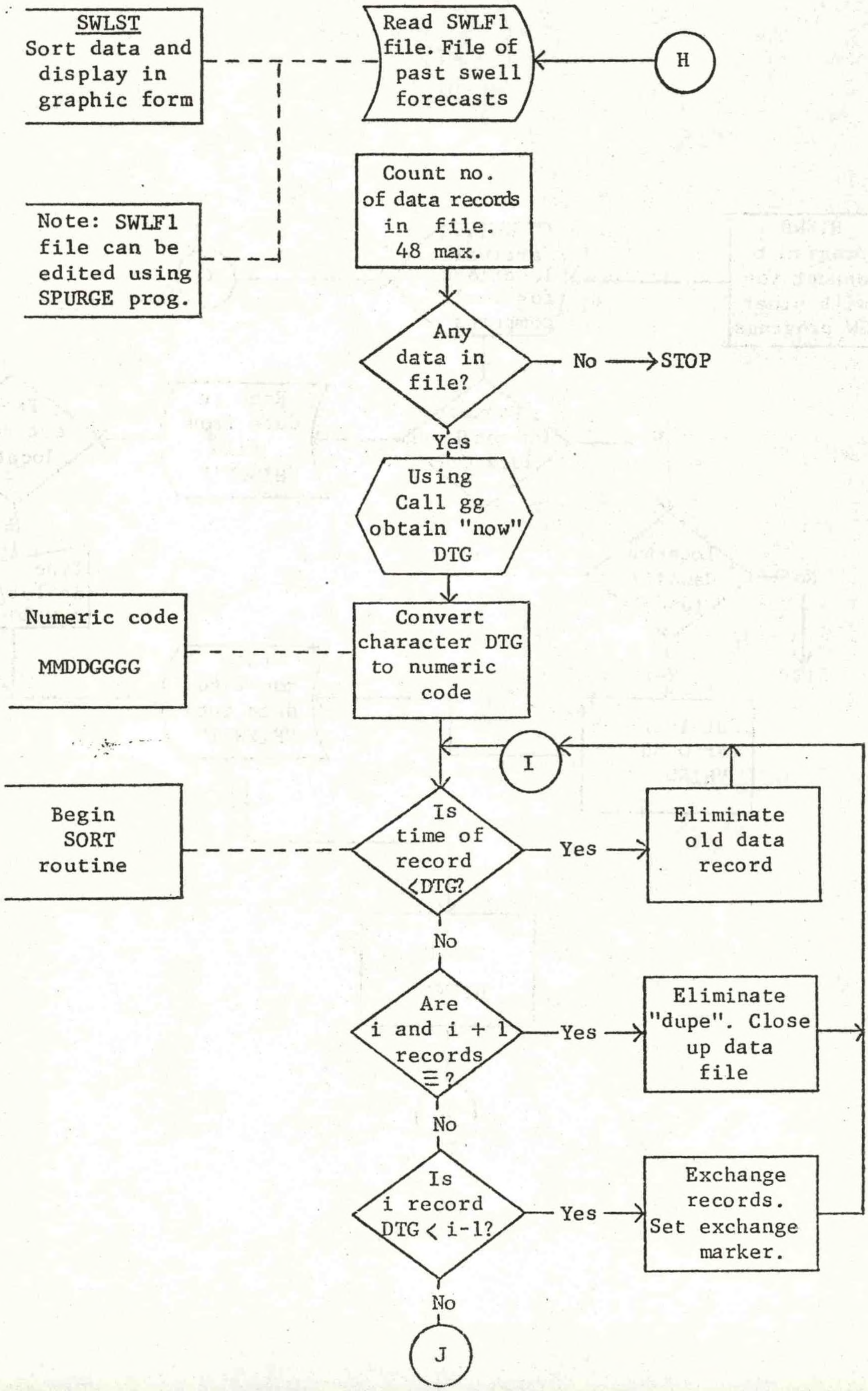

HISWB
Computes wave decay, travel time displays results and saves data
Read carry over data from disc file "HISWF2"
C
Compute travel time final pd, final ht, arr. time
Is arrival DTG OK?
No
Display M 13, D 31 T 2400
Yes
Compute arrival time in local time
Enter correct M or D or T
Compute day of week of arrival in local time
Display forecast parameters on terminal
D
Final Ht. < 2'? or Not Oahu?
Yes
Add new data to old data list
Write new date into file "SWLSF1"
No
Ask "SAVE DATA"
No
Yes
Call disc file "SWLSF1"
D

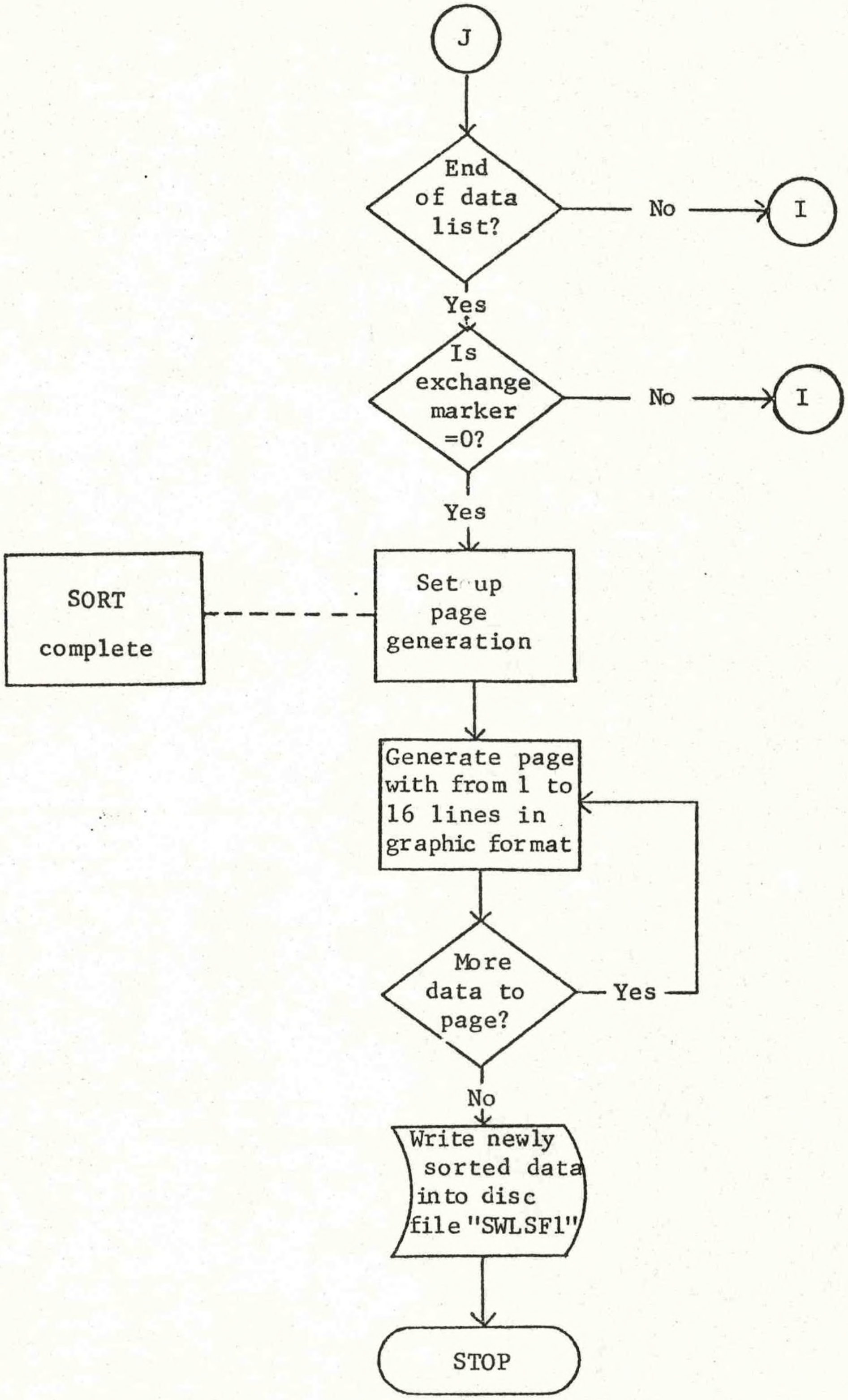

HISWB
(Cont.)
Decide where to go next
D
E
Compute surf?
Yes
Write carryover parameters in "HISWF3"
CHAIN HISWC
No
Make a new swell compute?
Yes
CHAIN HISW
A
No
Swell arrival at different PC?
Yes
CHAIN HISWD
G
No
Sort and display data list
Yes
CHAIN SWLST
H
No
STOP


HISWC
Compute surf at selected beach
Read in carryover parameters from "HISWF3"
E
Display list of beaches for selection
Type in number of selected beach
Obtain parameters of selected beach
Is swell dir. w/in 90° of beach norm?
No
Yes
Compute ave. surf ht, pd, depth breaking, zone wd.
Display output parameters
Compute for another beach?
Yes
No
F


HISWC
(Cont.)
F
Make new swell comp?
Yes
CHAIN
HISW
A
No
Same swell but for diff pt?
Yes
CHAIN
HISWD
G
No
Gener. plot of fcsts?
Yes
CHAIN
SWLST
H
No
STOP


HISWD
A program to connect you with other HISW programs
Display arrival locations for swell computes
G
Forecast for non Hawaii location?
No
Read in data from file "HISWF1"
Pre-set new location?
Yes
No
Type in lat/long new location?
Location Hawaii? (Oahu)
No
STOP
Yes
Set lat/long for Oahu in "HISWF1"
Write modified data into "HISWF1"
CHAIN HISWA
B


SWLST
Sort data and display in graphic form
Read SWLF1 file. File of past swell forecasts
H
Note: SWLF1 file can be edited using SPURGE prog.
Count no. of data records in file. 48 max.
Any data in file?
No
STOP
Yes
Using Call gg obtain "now" DTG
Numeric code
MMDDGGGG
Convert character DTG to numeric code
I
Begin SORT routine
Is time of record <DTG?
Yes
Eliminate old data record
No
Are i and i + 1 records ≡ ?
Yes
Eliminate "dupe". Close up data file
No
Is i record DTG < i-1?
Yes
Exchange records. Set exchange marker.
No
J


J
End of data list?
No
I
Yes
Is exchange marker =0?
No
I
Yes
SORT complete
Set up page generation
Generate page with from 1 to 16 lines in graphic format
More data to page?
Yes
No
Write newly sorted data into disc file "SWLSF1"
STOP

NOAA Technical Memoranda NWS

No. 9 Tropical Numerical Weather Prediction in Hawaii - 1971. E. M. Carlstead. March 1971. (COM-71-00494)

No. 10 Climatology of Rainfall Probabilities for Oahu, Hawaii. A. N. Hull and Jon Pitko. April 1972. (COM-73-10242)

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