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Technical Note No. 181

COMPUTER PROGRAM FOR IONOSPHERIC MAPPING BY NUMERICAL METHODS

MARTHA E. HINDS AND WILLIAM B. JONES

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NBS Boulder Laboratories

Boulder, Colorado

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COMPUTER PROGRAM FOR IONOSPHERIC MAPPING BY NUMERICAL METHODS

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A solution has recently been given to the problem of representing the complex variations of ionospheric characteristics on a world-wide scale, including their diurnal variation, by numerical analysis of ionospheric data as measured at a network of stations [Jones and Gallet, 1962a]. The present paper describes the IBM 7090 (FAP) program of the methods of numerical mapping referred to above. Included are detailed flow charts of the program logic, and all necessary information for applying the program. Thus it fills the gap between the publications giving the scientific bases for the methods of mapping and the practical problem of producing ionospheric maps. This program, applied to ionospheric characteristics foF2 and F2-M3000, forms the basis for the new series, Central Radio Propagation Laboratory Ionospheric Predictions.

1. INTRODUCTION

A solution has recently been given to the problem of representing the complex variations of ionospheric characteristics by numerical analysis of ionospheric data as measured at a network of stations [Jones and Gallet, 1962a].[1] The methods employed consist of well-defined mathematical operations which are readily adapted to high-speed automatic computing.[2] The principal output of these methods is a set of numerical coefficients defining a continuous function of latitude, longitude and time which represents the ionospheric characteristic on a world-wide scale, including its diurnal variation. The ionospheric representation thus obtained is called a numerical map.

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[1]For a brief summary of the problem and its solution the reader can refer to [Jones and Gallet, 1960].

[2]The need for world-wide mapping methods based on numerical analysis and the use of high-speed computers has been felt for many years [C.C.I.R., 1959].

An integral part of the work in forming and testing the mapping methods referred to above was the parallel development and application of computer programs. This work evolved over a period of several years, beginning with an IBM 650 computer (in SOAP language), then with an IBM 704 (in SAP language) for its increased size and speed, and finally with the IBM 7090 (in FAP language). The present paper describes the 7090 program, referred to here as the Numerical Map Program.[1] The 7090 FAP listing of the Numerical Map Program is contained in [Hinds and Jones, 1962], which has been revised and condensed to form the present NBS Technical Note.

The numerical methods of mapping and computer programs referred to above, together with extensive applications made with the ionospheric characteristics foF2 and F2-M3000, form the basis for the new series,[2] Central Radio Propagation Laboratory Ionospheric Predictions, commencing in January 1963 [Ostrow, 1962; CRPL, 1963]. Among the advantages of this new series is that it is based on objective methods of mapping which are repeatable and well-defined in the mathematical sense, so that anyone starting with the same data will obtain an identical map. Although most of the mapping methods appear in published papers, there are many details of the mapping process which can be given only in a description of the computer program; for example, detailed flow charts of the program and all necessary information for applying the Numerical Map Program.

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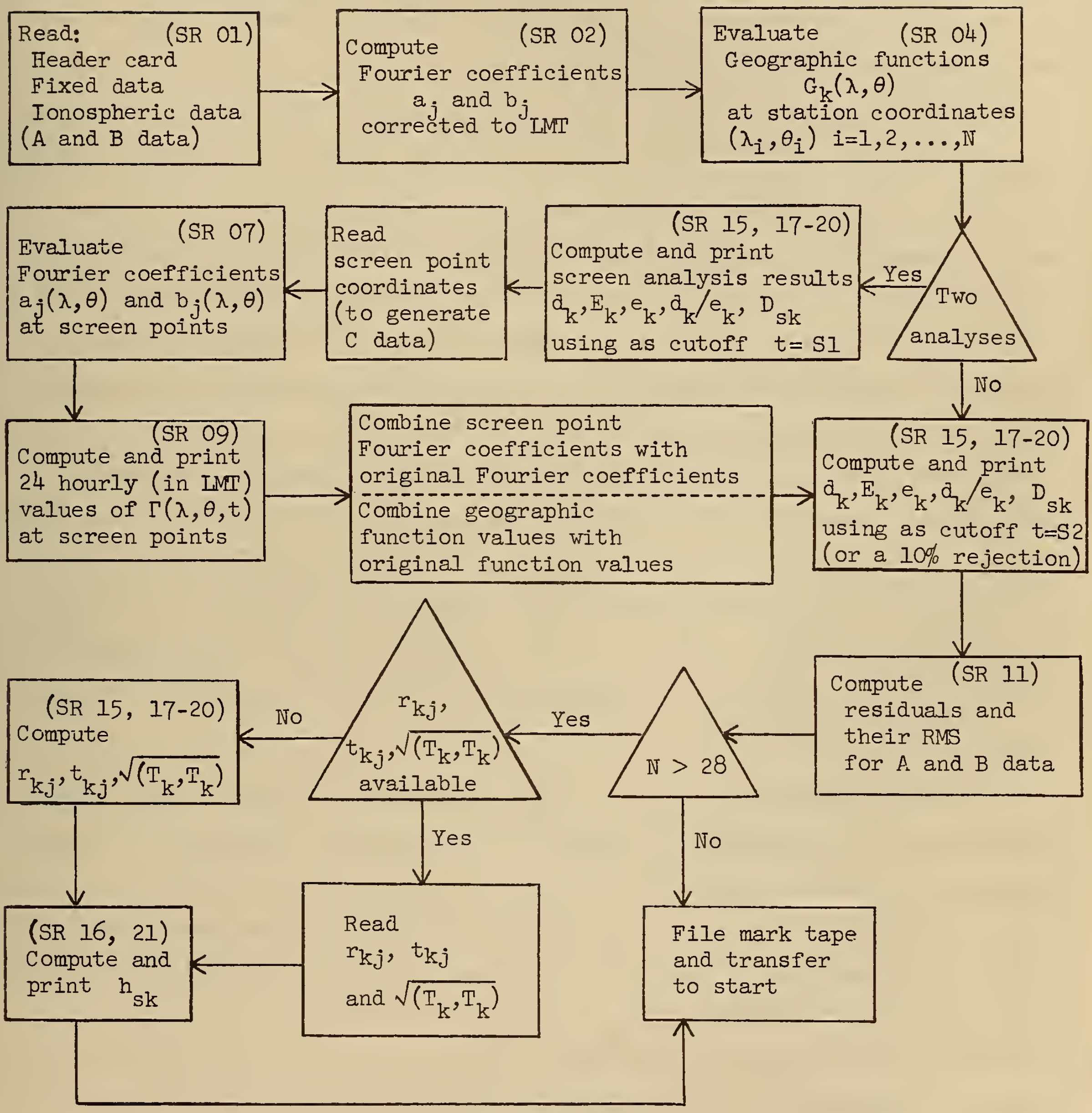
[1]Other 7090 computer programs (closely related to the one given here) have also been developed and extensively used. These include: (a) a Numerical Predictions Program for computing predicted numerical maps of ionospheric characteristics for future months (or days) and (b) a Contour Map Program for computing world-wide or polar contour maps in either universal time or local mean time.

[2]This series replaces the former CRPL Series D, "Basic Radio Propagation Predictions".

Flow Chart 1

NUMERICAL MAP PROGRAM

SUMMARY FLOW DIAGRAM OF MAIN PROGRAM STEPS



Thus, the purpose of the present paper is to fill the gap between the publications which give the scientific basis for the methods of mapping and the practical problem of producing ionospheric maps. Moreover, it is designed to complement the research papers already available by an overall treatment of the mapping processes, several of which are discussed here for the first time.

The backbone of the Numerical Map Program is an "executive program" (see section 2), which first enters the data using the routine 01 (SR 01) and then directs the operations until the final output is obtained. The main steps of the operations themselves are performed by 17 routines at the command of the executive program (see Flow Chart 1).[1] Each of these 17 routines forms a logical unit, which often is a relatively large problem in itself (for example, SR 17--the Gram-Schmidt Orthogonalization; see flow chart 8, second sheet). Even more, several routines are sometimes linked in a quasi-independent loop, with a loop executive program of their own (for instance, SR 20--Executive General Data Fitting). The 17 main routines are discussed in sections 3 through 9. For the executive program and each routine, a detailed program writeup is given to describe the input, output, storage, card formats, program logic, and other necessary information. Sample printouts of input and output are given in the appendices.

Input to the Numerical Map Program consists of the 24 hourly measurements of an ionospheric characteristic from all available stations for a given month (or day) together with such basic information as station coordinates and various parameters defining the mathematical functions to be used (section 2.3a). The principal output of the program is a set of numerical coefficients D_{sk}, defining a function $\Gamma(\lambda, \theta, t)$, of latitude, longitude, and local mean hour angle, which represents the ionospheric characteristic, including its diurnal variation, on a world-wide scale (section 2.3b).

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[1]It will be noticed that in the numbering of the subroutines, numbers 3, 12, 13, and 14 are missing. These subroutines are not included since they are no longer used in the Numerical Map Program.

Although the basic theory for the methods of numerical mapping has been published [Jones and Gallet, 1962a], some essential procedures used in the Numerical Map Program have not been justified in scientific literature. In particular, the problem of the "stability" of the geographic representation in areas where no stations are available appears to be solved by a method of "screen points", which has been extensively applied and tested. While the method is described in section 2.2, further justification and illustrations will be given in a subsequent paper.

Section 9.1 describes a method for generating a special set of coefficients, h_{sk}, for intercomparing numerical maps from month to month or from day to day. Explanations of other new procedures and formulas are included in the text where they occur. It should also be mentioned that many of the routines in the present program were originally written for the 704 and are now retained with only slight modifications for purposes of economy. This is at no loss of program efficiency and accounts for certain differences of techniques appearing in the program.

This paper is intended for two types of users: (a) those who wish to apply the program as it stands, and (b) those who wish to use the program with modifications. For the former, a reading of only sections 2 and 3 will largely suffice. The remaining sections are included mainly for the latter. The terminology and notation used conform, whenever possible, with the reference papers [Jones and Gallet, 1962a and 1962b] so that most of the formulas and definitions are not repeated here. As a result, some knowledge of the above references will be needed for a thorough understanding of the program.

2. NUMERICAL MAP EXECUTIVE PROGRAM

2.1 Introduction

The primary function of the numerical map executive program is to direct the operation of the various subroutines. Section 2.2 discusses the concept and application of "screen points". Section 2.3 describes input, output, intermediate output on magnetic tape, storage requirements, and subroutines used. Section 2.3 also includes: (1) a summary list of sense switch settings, (2) a storage plan for the Numerical Map Program, (3) card formats for input and output, and (4) a flow chart of the numerical map executive program. Sample printouts of input and output are contained in appendices A and B, respectively. Before proceeding to these sections, however, it is desirable to review briefly the choice of time and geographic functions [Jones and Gallet, 1962a, chapter 3].

A number of options are available with regard to input, output, and types of analyses (section 2.3). The choice of the time and geographic functions to be used is considered here. A particular set of functions is specified by the following parameters entered on the header card (section 2.3a): (1) The total number of harmonics H used in the diurnal analysis. (2) The numbers k_0, k_1, and $k_2 = K$ (referred to in the program by the symbols PP1, PP2, and PP3 = P, respectively) which determine a particular set of geographic functions (table 1, section 5). Note that k_0 = PP1 must be greater than or equal zero. (3) In the geographic analyses, the residuals arrive at the noise level at a much lower degree for the high order harmonics than for the low order ones. Therefore, it is frequently necessary to truncate automatically the series of geographic functions for all harmonics of order higher than a certain value, e. g., H1. This can be done by entering H1 and a special cutoff, k = PH2, for the geographic series on the header card. (An example of values commonly used are H1 = 4 and PH2 = 4.)
(4) Finally, a numerical code, FNCD, is used to identify the choice of time and geographic functions.

2.2 Screen Points

An important modification included in the present program is the use of "screen points" for stabilizing the geographic representations in areas where few or no measurements are available. As was pointed out in chapter 5 of Jones and Gallet [1962a], the heavy grouping of stations in some regions, such as Europe, and the absence of stations in other regions tends to produce a sort of mathematical instability in the representation function--that is, unrealistic behavior in areas where no data are available. The best representation that can be expected for such a region is a smooth continuation of the variations from surrounding stations. The instability is alleviated by computing smooth continuations at "screen points" chosen inside the gaps.[1] The "screen point values" for the ionospheric characteristic are obtained from a deliberately oversmoothed geographic representation of all the data. A second analysis is then made using both the original data and the screen point values (see flow chart 2).[2]

The oversmoothed representation in the first analysis is effected by a radical truncation of the orthonormal series of geographic functions [see section 4.2 of Jones and Gallet, 1962a]. By using a rejection criterion considerably higher than 5 percent, all but the most significant terms are rejected. For example, the value $t = 4.0$ or 6.0 (for the variable in Student's distribution) has been found to give a satisfactory cutoff in the first analysis, whereas $t = 2.0$ is generally

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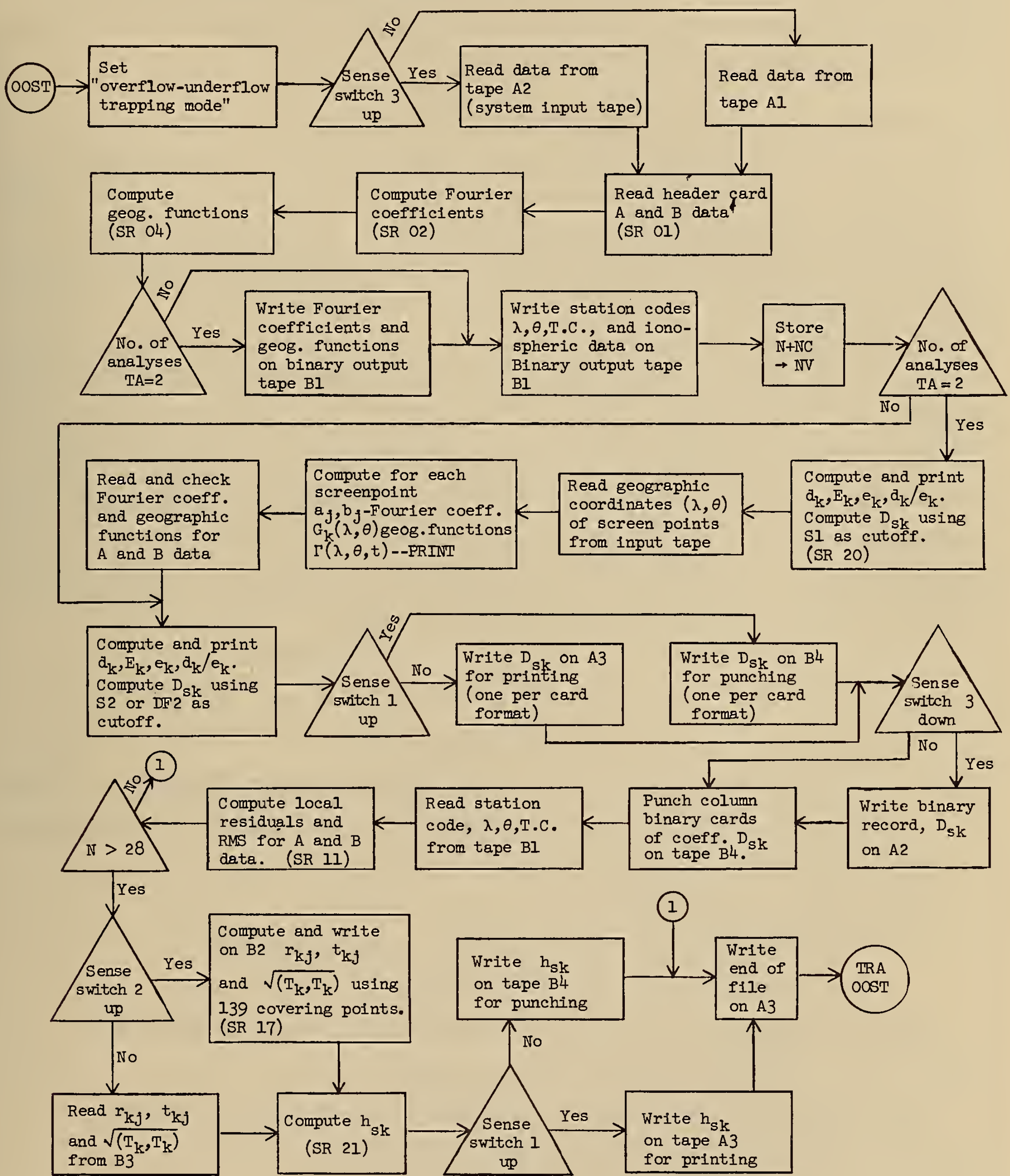
[1]The set of screen points for the data of a given month is selected, prior to using the program, in such a way as to fill all large gaps where no stations are available and where consequently unacceptable instabilities would be produced (section 2.3a, input (4)). In practice, the set of screen points remains essentially unchanged from one month to the next.

[2]A slight variation in the method of defining the screen analysis will be described in a later paper entitled "Representation of diurnal and geographic variations of ionospheric data by numerical methods, II. Control of instability." The screen analysis given there is made by including only the main geographic variation.

Flow Chart 2

NUMERICAL MAP EXECUTIVE PROGRAM



used in the second analysis. These values of t are denoted in the header card by S1 and S2, respectively. When it is not desired to use screen points, it is possible to make only one analysis. This option is also specified in the header card.

When the number of stations N is so small that the number of degrees of freedom (DF = (N - k - 1), where (k + 1) is the number of geographic functions) is less than or equal 28, it is assumed that only one analysis will be made, and the value of t is for a two tail, 10 percent rejection, depending on the number of degrees of freedom (see section 8.2d).

In addition to screen points described above, it has also been found helpful, in filling large gaps in the data, to use "predicted data" at certain stations for which data were not available for the given month or day being analyzed. Such "predictions" are made from correlations of measurements with a solar index. For purposes of identification in the present paper, we shall refer to measurements as A data, to predictions as B data, and to screen point values as C data.

2.3 Program Description

(a) Input (see sample printout, appendix A)

The following list gives the different types of input, ordered as they follow the program. Card formats and sample printouts are given for each type of card input.

(1) Header card (card format 1).

(2) Fixed data cards (card format 2)--see section 3. A data cards precede B data cards.

(3) Ionospheric data cards (card format 3)--see section 3. A data cards precede B data cards.

(4) Optional screen point coordinates on cards if a second analysis is to be made (card format 4).

(5) Optional input (on binary tape 3, channel B) r_{kj}, t_{kj}, and $\sqrt{(T_k, T_k)}$. In this case, these numbers can be computed in the first analysis and then entered as input in tape 3, channel B in each subsequent analysis by having sense switch 2 down.

The IBM 1401 is used to convert the binary program deck and the input data deck to magnetic tape.

If it is desired to use the Fortran monitor system, sense switch 3 must be up. In this case, tape 1, channel A is the system tape and the program and data are read from tape 2, channel A (the system input tape). There are two program options if the Fortran monitor system is not used: (1) if sense switch 3 is up, the self-loading program must be on tape 1, channel A and the input data must be on tape 2, channel A; (2) if sense switch 3 is down, the self-loading program followed by the input data must be on tape 1, channel A.

(b) Output. The following are regular and optional types of output:

(1) Tape 3, channel A, BCD output (see sample printout, appendix B).

First analysis:

d_k, E_k, e_k, d_k/e_k, $k = 0, 1, \ldots, K$ (for each Fourier coefficient).

Second analysis (optional):

Γ values at screen points and d_k, E_k, e_k, d_k/e_k. (The following are output from analysis 1 when there is no second analysis.) Coefficients D_{sk} (if sense switch 1 is down); residuals and their root mean square; intercomparison coefficients h_{sk} (if sense switch 1 is down).

(2) Tape 4, channel B, binary output to be punched into column binary cards by 1401 (see card formats 6 and 7). These cards contain the coefficients D_{sk} and are stored for permanent records and later use in predictions. First card is binary identification followed by the coefficients D_{sk}. These cards are punched in absolute locations for use in prediction programs.

(3) Optional binary output of coefficients D_{sk} is obtained on tape 2, channel A, when sense switch 3 is down. This output is generally used for immediate applications such as the computation of contour maps. (Note: if sense switch 3 is up, tape 2, channel A is used for input).

(4) Optional BCD tape 4, channel B will contain the coefficients D_{sk} and h_{sk} when sense switch 1 is up. These coefficients are then punched one per card for later use (see card format 5). Note: if sense switch 1 is down, these coefficients will be included in output 1 above.

(5) Optional binary output r_{kj}, t_{kj}, and $\sqrt{(T_k, T_k)}$ will be written on tape 2, channel B if sense switch 2 is up (see input 5 and also section 9).

(c) <u>Intermediate output</u>

(1) The geographic functions and Fourier coefficients for A and B data are written on tape 1, channel B if two analyses are used. This is done so that corresponding screen point results can be combined for the second analysis.

(2) Geographic latitudes and longitudes, time corrections, and ionospheric data (A and B data) are written on tape 1, channel B for subsequent use in the residual subroutine (SR 11).

(3) Tape 2, channel B is used to write the intermediate triangular matrices a_{kj}, b_{kj}, for use in SR 17 and SR 18 (see section 8). This tape is subsequently rewound and used for output if the option is chosen to compute the r_{kj}, t_{kj} (see output 5) rather than read them from input.

(d) <u>Storage</u>

At most instances during the operation of the program, the computer storage capacity of 32,000 + storage locations is used. See <u>storage plan</u> (h) for matrix limits and locations.

(e) Share subroutines used

Punch B, UA-SPHI, and UA-BDCI, along with those share subroutines incorporated in each of the seventeen subroutines.

(f) Remarks

Trapping mode is set for use in controlling underflow. End of file is written on tape 3, channel A after each set of data.

If consecutive months of data are to be run, push start at the program halt or return to system.

If at any time during the computation it is desired to see the off-line BCD output written on the on-line printer, put sense switch 6 down. The printing may again be suppressed by putting sense switch 6 up.

(g) Sense switch settings for Numerical Map Program

1 up writes coefficients D_{sk} and h_{sk} (as above) on tape 4, channel B.

down writes coefficients D_{sk} and h_{sk} in BCD one per card format on tape 3, channel A.

2 up computes r_{kj}, t_{kj}, and $\sqrt{(T_k, T_k)}$ and writes output on tape 2, channel B. Computed values are used as input to SR 21.

down assumes tape 3, channel B contains 3 binary records r_{kj}, t_{kj}, and $\sqrt{(T_k, T_k)}$ (see input (5)) for input to SR 21.

3 up reads data (monitor system) from tape 2, channel A. Omits writing binary record of coefficients D_{sk} on tape 2, channel A.

down reads program and data from tape 1, channel A. Writes binary record of coefficients D_{sk} on tape 2, channel A.

6 up normal operating procedure.

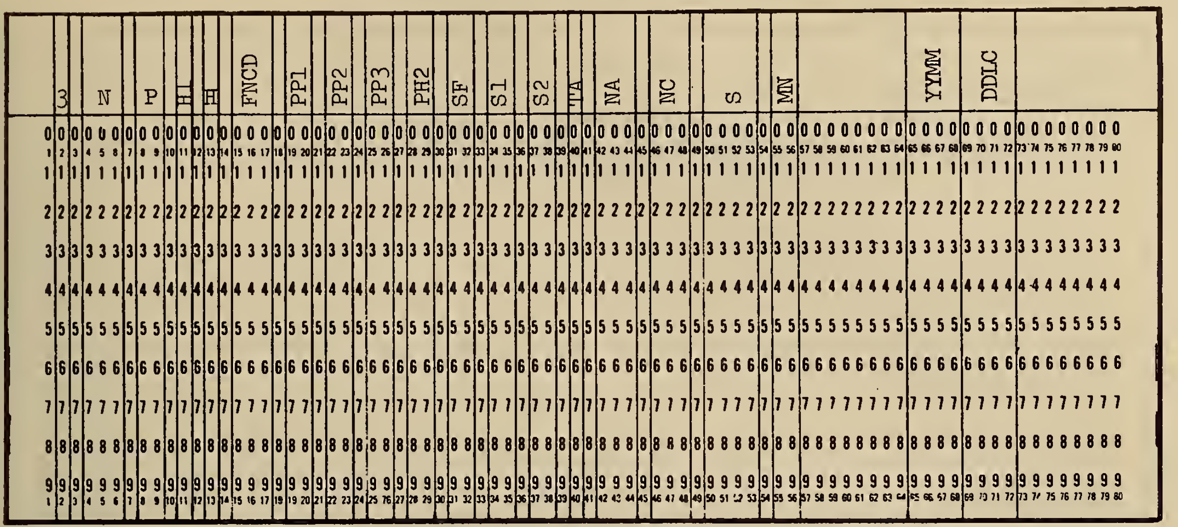
down BCD records are written on tape and the on-line printer.

(h) Storage Plan for Numerical Map Program

Analysis 1. Max(N_A+N_B)=180 Max H=8 Max P=80	Analysis 2. MAX($N_A+N_B+N_C$)=220 Max H=8 Max P=80
Fixed Data 5101(1st Loc) Station code 5101 ... +N Geog. long. 5281 ... +N Geog. lat. 5461 ... +N Time correction 5641 ... +N Ionospheric Data 5821 Hour 0 5821 ... +N Hour 1 6001 ... +N ⋮ ⋮ Hour 23 9961 ... +N Maximum elements 5040 (=28 x 180)	Fourier Coefficients 5101(1st Loc) a_0 5101 ... +(N+NC) b_1 5101+(N+NC) ... +(N+NC) a_1 ⋮ ⋮ b_H a_H 5101+2H(N+NC) ... +(N+NC) Maximum elements 3740 (=17 x 220)
Fourier Coefficients 11581(1st Loc) a_0 11581 ... +N b_1 (11581+N) ... +N a_1 ⋮ ⋮ b_H a_H (11581+2HN) ... +N Maximum elements 3060 (=17 x 180)	Geographic Functions [M=5101+(2H+1)(N+NC)] (1st Loc) G_0 M ... +(N+NC) G_1 M+(N+NC) ... +(N+NC) ⋮ ⋮ G_P M+P(N+NC) ... +(N+NC) Maximum elements 17820(=81 x 220) Intermediate Storage 27228 Same order as Analysis 1
Geographic Functions [M=11581+(2H+1)N] (1st Loc) G_0 M ... +N G_1 (M+N) ... +N ⋮ ⋮ G_P (M+PN) ... +N Maximum elements 14580 (=81 x 180) Intermediate Storage 27228(1st Loc) P(P+1)/2 Maximum elements 3240 Coefficients D_{sk}, 30468(1st Loc) Maximum elements 1377	Residual Subroutine (restored from tape B1 as in Analysis 1) Fixed Data 5101(1st Loc) Station code 5101 ... +N Geog. long. 5281 ... +N Geog. lat. 5461 ... +N Time correction 5641 ... +N Ionospheric Data 5821 Hour 0 5821 ... +N Hour 1 6001 ... +N ⋮ ⋮ Hour 23 9961 ... +N Maximum elements 5040 (=28 x 180) Program Origin 101

Card Format 1

NUMERICAL MAP HEADER CARD

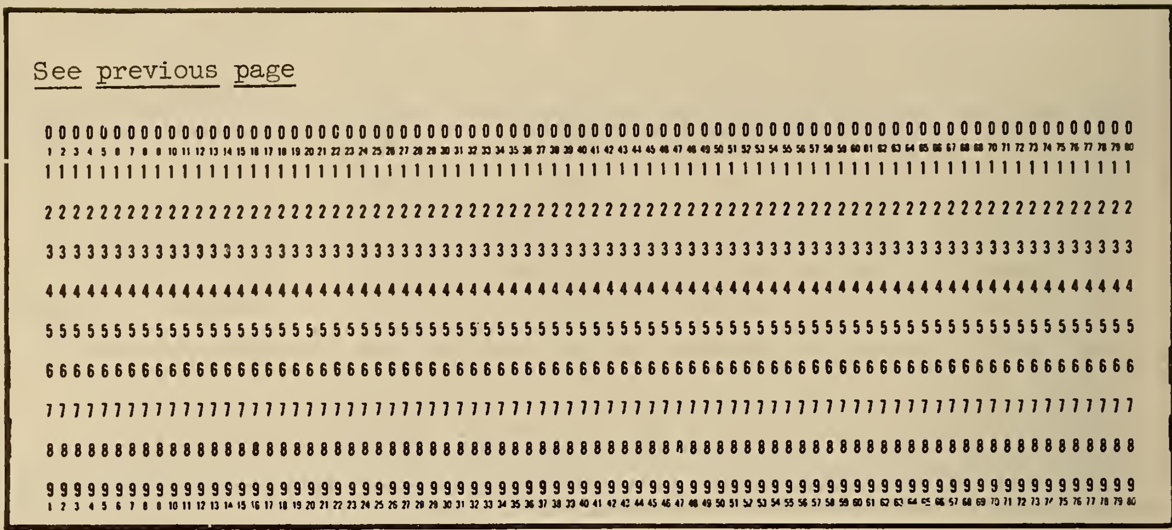


CARD COLUMN	DESCRIPTION		REMARKS
2	3		Header card
4-6	N	(xxx)	Number of stations (A and B data)
8-9	P	(xx)	P+1 = K+1 = Number of geographic functions
11	H1	(x)	Highest harmonic for which the geographic analysis is made with P+1 functions
13	H	(x)	Number of harmonics for diurnal analysis
15-17	FNCD	(xxx)	Function identification code
19-20	PP1	(xx)	k_0: Highest term for main latitudinal variation
22-23	PP2	(xx)	k_1: Highest term for first order longitudinal variation
25-26	PP3	(xx)	k_2=K: Highest term for second order longitudinal variation
28-29	PH2	(xx)	Highest term used in geographic analysis of harmonics $H1 < j \leq H$.
31-32	SF	(± n)	Scale factor
34-35	S1	(xx)[1]	Student's t cutoff in first analysis
37-38	S2	(xx)[1]	Student's t cutoff in second analysis
40	TA	(x)	Option of 1 or 2 analyses
42-44	NA	(xxx)	Number of stations with A data

[1] Program automatically places a decimal point between the first and second digits.

Card Format 1 (Cont.)

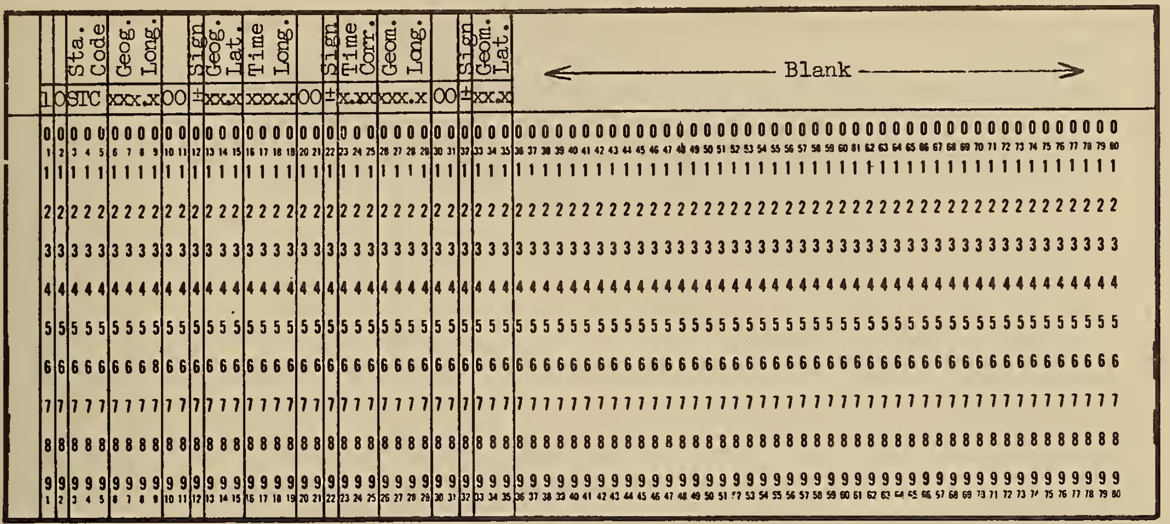
NUMERICAL MAP HEADER CARD



CARD COLUMN	DESCRIPTION		REMARKS
46-48	NC	(xxx)	Number of screen points
50-53	S	(xxx.x)	Sunspot number
55-56	MN	(xx)	Order of months (or days) for use in prediction program
65-68	YYMM	(xxxx)	Year and month
69-72	DDLC	(xxxx)	Date, layer, and characteristic (see card format for ionospheric data)

Card Format 2

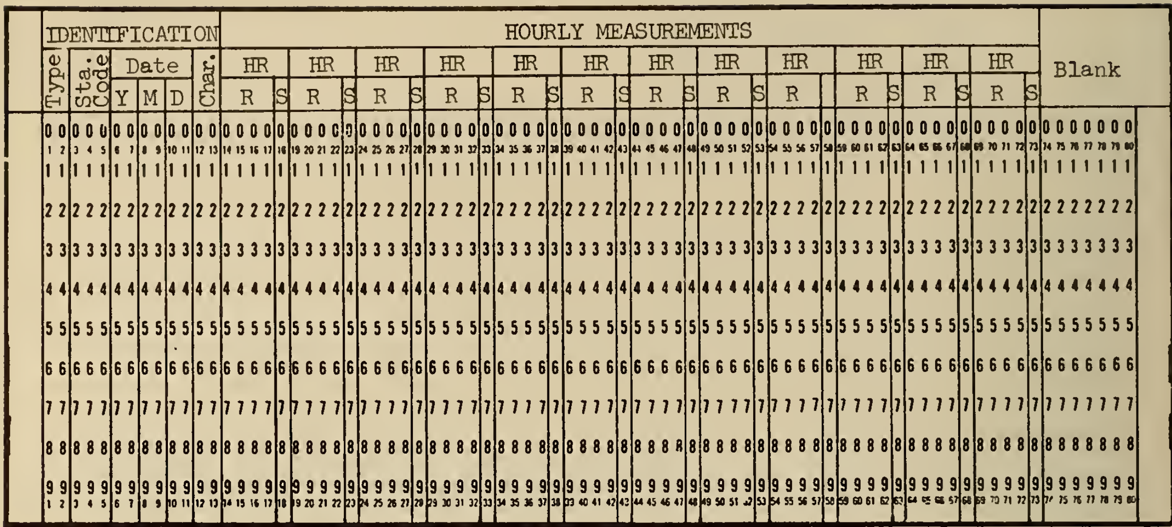
FIXED STATION DATA



CARD COLUMN	DESCRIPTION	REMARKS
1	1	Ionospheric data
2	0	Fixed station data
3-5	STC	Station code
6-9	000.0≤xxx.x<360.0	Geographic longitude (θ) in degrees east of Greenwich.
10-11	00	Constants
12	11 or 12 Punch	Sign of geographic latitude. 11 indicates southern latitude, 12 indicates northern latitude.
13-15	00.0≤xx.x≤90.0	Geographic latitude (λ) in degrees
16-19	000.0≤xxx.x< 360.0	Reference longitude (θ_R) for time zone See [Jones and Gallet, 1962a, section 3.1.]
20-21	00	Constants
22	11 or 12 Punch	Sign of time correction. 11 indicates negative correction, 12 indicates positive correction.
23-25	x.xx	Time correction (in hours). T.C. = $(\theta - \theta_R)/15$.
26-29	000.0≤xxx.x < 360.0	Geomagnetic longitude: see Smithsonian Physical Tables, Ninth Revised Edition, pp. 493-501.
30-31	00	Constants
32	11 or 12 Punch	Sign of geomagnetic latitude. 11 indicates south, 12 indicates north.
33-35	xx.x	Geomagnetic latitude: see Smithsonian Physical Tables, Ninth Revised Edition, pp. 493-501.

Card Format 3

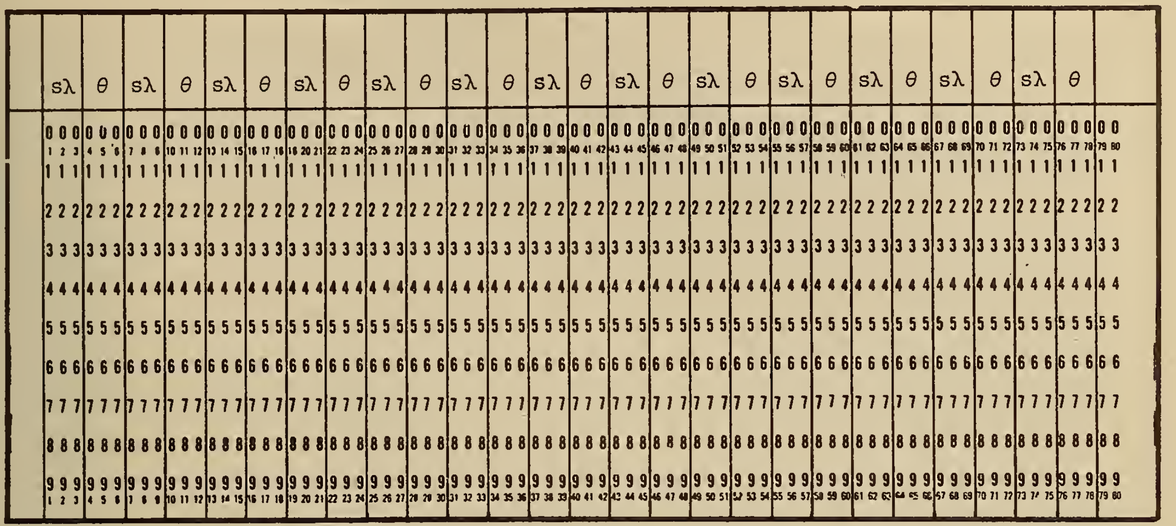
IONOSPHERIC DATA



CARD COLUMN	DESCRIPTION	REMARKS
1	1	Ionospheric data
2	1 or 2	1 refers to hours from 00:00 to 11:00 2 refers to hours from 12:00 to 23:00
3-5	STC	Station code
6-7	YY	Year
8-9	MM	Month
10-11	DD	Date: $01 \leq DD \leq 31$ indicates day of month DD = 45 indicates monthly median
12	L	Ionospheric layer: L = 0, F2-layer; L = 1, F1-layer; L = 2, E-layer; L = 3, E_s-layer
13	C	Ionospheric characteristic; C = 0, fo; C = 1, fx; C = 3, M3000; C = 4, h′; C = 5, h_p
14-73	Hourly Readings	Twelve readings of five positions each
		First four positions--numerical reading (R) Fifth position--qualifying symbol (S)

Card Format 4

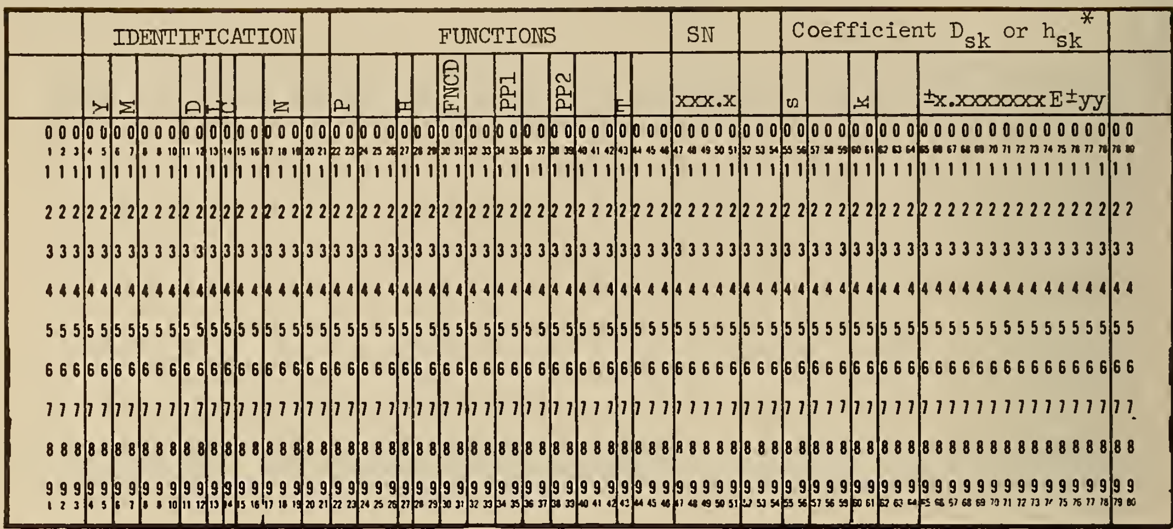
SCREEN POINT INPUT



CARD COLUMN	DESCRIPTION	REMARKS
1, 7, ..., 73	s	Sign of geographic latitude
		(blank for plus and – for minus)
2-3, 8-9, ...,74-75	λλ	Geographic latitude (degrees)
4-6, 10-12, ...,76-78	θθθ	Geographic longitude (degrees east of Greenwich)

Card Format 5

COEFFICIENTS D_{sk} AND h_{sk} DEFINING NUMERICAL
MAPS OF IONOSPHERIC CHARACTERISTICS

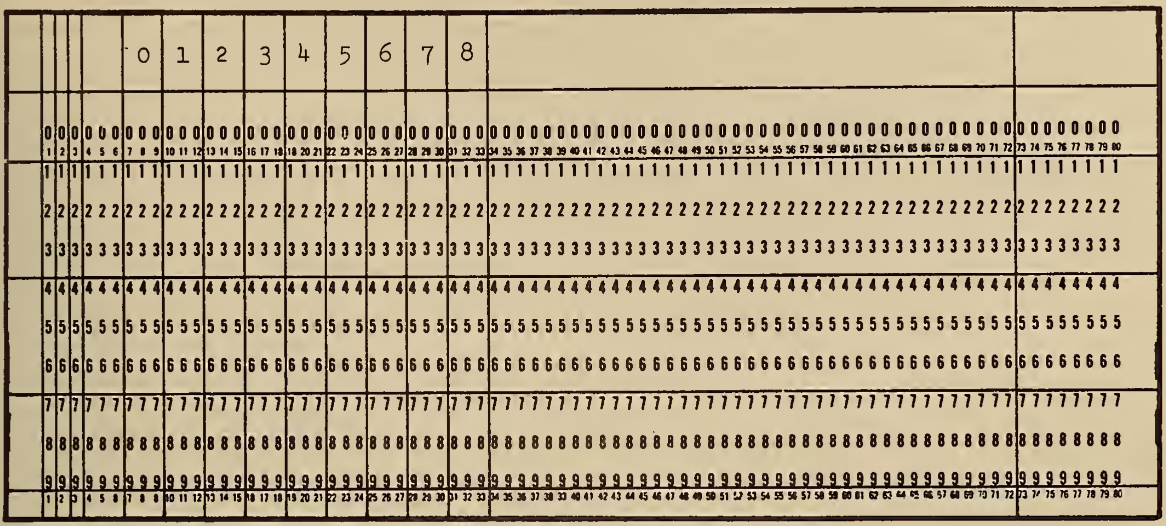


*For D_{sk} or h_{sk}, the number given by the first eight digits and sign is multiplied by 10 raised to the power given by the last two digits and sign.

CARD COLUMN	DESCRIPTION	REMARKS
4-5	YY	Year
6-7	MM	Month
11-12	DD	Date: See Ionospheric Data Card Format.
13	L	Ionospheric layer: See Ionospheric Data Card Format.
14	C	Ionospheric Characteristic: See Ionospheric Data Card Format.
17-19	NNN	Number of stations used in the analysis
22-23	P	P+1 = K+1 = Number of geographic functions
27	H	Number of harmonics for diurnal analysis
30-31	FNCD	Function identification code
34-35	PP1	k_0 = Highest term for main latitudinal variation
38-39	PP2	k_1 = Highest term for first order longitudinal variation
43	T	T = 1 for coefficients D_{sk} T = 2 for coefficients h_{sk}
47-51	xxx.x	Sunspot number
55-56 60-61	ss kk	Indices for coefficients D_{sk} or h_{sk} [Jones and Gallet, 1962a, chapter 7]
65-78	±x.xxxxxxxE±yy	Coefficient D_{sk} or h_{sk} in floating decimal form

Card Format 6

NUMERICAL MAP BINARY IDENTIFICATION



CARD COLUMN	DESCRIPTION	REMARKS
1	7 and 9 Punch	Column binary
2-3		Absolute binary location $(100)_{10}$
4-6	Check Sum	
7-9	YYMM	Year, month
10-12	DDLC	Date, layer, characteristic
13-15	N	Number of stations (A and B data)
16-18	P	P+1 = K+1 = Number of geographic functions
19-21	H	Number of harmonics for diurnal analysis
22-24	FNCD	Function identification code
25-27	PP1	k_0: Highest term for main latitudinal variation
28-30	PP2	k_1: Highest term for first order longitudinal variation
31-33	PP3	k_2 = K: Highest term for second order longitudinal variation

3. DATA READ SUBROUTINE 01

The data read subroutine (SR 01) is employed by the numerical map executive program for reading and storing the header card, fixed data, and ionospheric (A and B) data. Although most of the necessary information concerning input is given in section 2, certain additional information is necessary, in particular, the discussion of the scale factor and the list of stops resulting from improper input (section 3g). Other topics include: output, storage, calling sequence, subroutines used, general remarks, and program logic (flow chart 3).

(a) Input (see sample printout, appendix A)

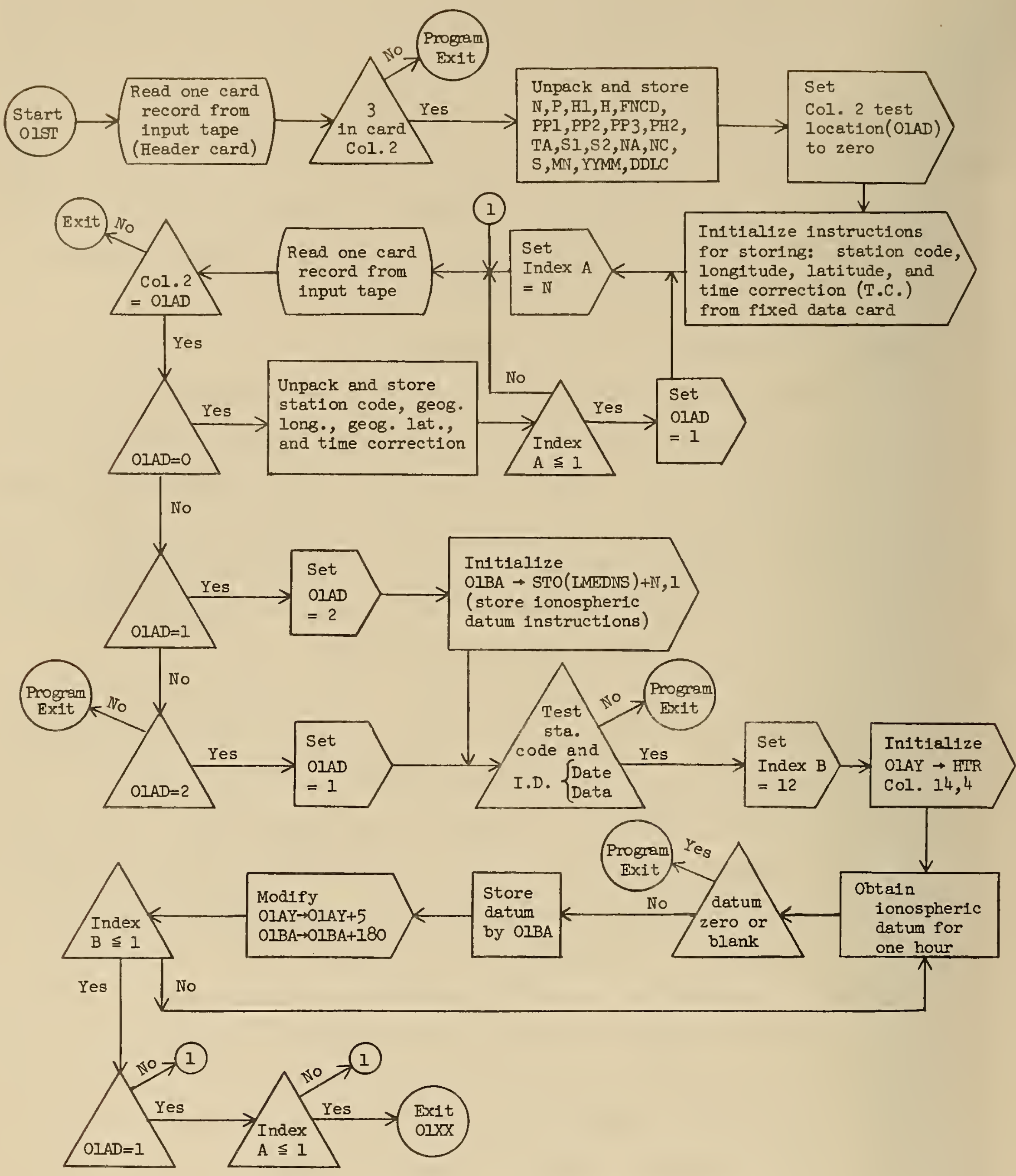
Input card formats and sample printouts were discussed in section 2. One fixed data card and two ionospheric data cards must be read for each station (for A and B data). All fixed data cards precede the ionospheric data cards, and the latter must be paired by stations in the same order as the fixed data. In each pair, the type 1 card (col. 2) must precede the type 2 card (col. 2). Also, the stations with A data must precede those with B data.

For ionospheric data other than foF2, a special scale factor must be inserted in the header card. The ionospheric data are assumed to be given by four digit numbers (XXXX) (see card format 3). If no scale factor (blank) is punched on the header card, the program places a decimal point between the second and third digits (XX.XX). For other characteristics, however, (such as M3000) the position of the decimal point is specified by the scale factor. A scale factor of plus (or minus) n ($n \neq 0$) moves the decimal point n places to the right (or left) from the position at the right of the fourth digit. "Minus zero" places the decimal point to the right of the fourth digit. For example, for M3000 the scale factor is -3 so that each ionospheric reading is taken as X.XXX.

(b) Output includes: station code, geographic longitude (θ) and latitude (λ), time correction, and ionospheric data.

Flow Chart 3

DATA READ SUBROUTINE 01



(c) Storage (see storage plan in section 2)

The input uses maximum storage of 5040 locations starting at $(5101)_{10}$. SR 01 itself takes 157 locations.

(d) Calling sequence

```
          C L A  (EXTIN)
          S T O   01XX
          T R A   01ST
(EXTIN)   T R A  (NEXT)
(NEXT)   (CONTINUE)
```

(e) Subroutines used

Modified share subroutine PE-CSMO, which includes: READT, FLOAT, FIXED, SCALE, and BCDPK.

(f) Remarks

(1) Index registers A, B, and C are used with no provision to restore them.

(2) In order to read data on tapes other than A1 or A2, a modification must be made in READT.

(g) Stops

SR 01 stops at 01AC for the following conditions:

(1) An ionospheric datum is zero or blank.

(2) Input cards not in proper order with respect to column 2. Proper order requires: (i) first card has 3 in column 2, (ii) the following N cards have 0 in column 2, and (iii) the following 2N cards have alternately 1 and 2 in column 2.

(3) Column 2 contains a number other than 3, 0, 1, 2.

(4) Identification of ionospheric data cards does not match identification on header card or ionospheric data cards (in pairs) are in different order from fixed data cards.

4. FOURIER ANALYSIS SUBROUTINE 02

SR 02 is used to compute Fourier coefficients for the diurnal analysis of the ionospheric data. The coefficients are then corrected to local mean time [Jones and Gallet, 1962a, section 3.1]. SR 02 is entered one time for each set of (A and B) ionospheric data (i.e., N times). This section gives a general description of the subroutine including the program logic (flow chart 4).

(a) Input

(1) Hourly values $y_1, y_2, \ldots, y_{24}$ of ionospheric data from one station.

(2) Number H of harmonics.

(3) Time correction T.C. (in hours).

(b) Output

Fourier coefficients a_0, a_j, and b_j, amplitudes c_j and phase angles ψ_j corrected to local mean time (LMT) for $j = 1, 2, \ldots, H$ (see [Jones and Gallet, 1962a], section 3.1). Note: the c_j and ψ_j are merely intermediate results and hence are not permanently stored.

(c) Storage

There are 4 (H+1) storage locations required for output: AO to AO + H, BO to BO + H, CO to CO + H, and PSIO to PSIO + H. The routine itself (not including subroutines) takes 328 storage locations.

(d) Calling sequence

```
          C L A  (EXTIN)
          S T O   02XX
(EXTIN)   T R A  (NEXT)
(NEXT)   (CONTINUE)
```

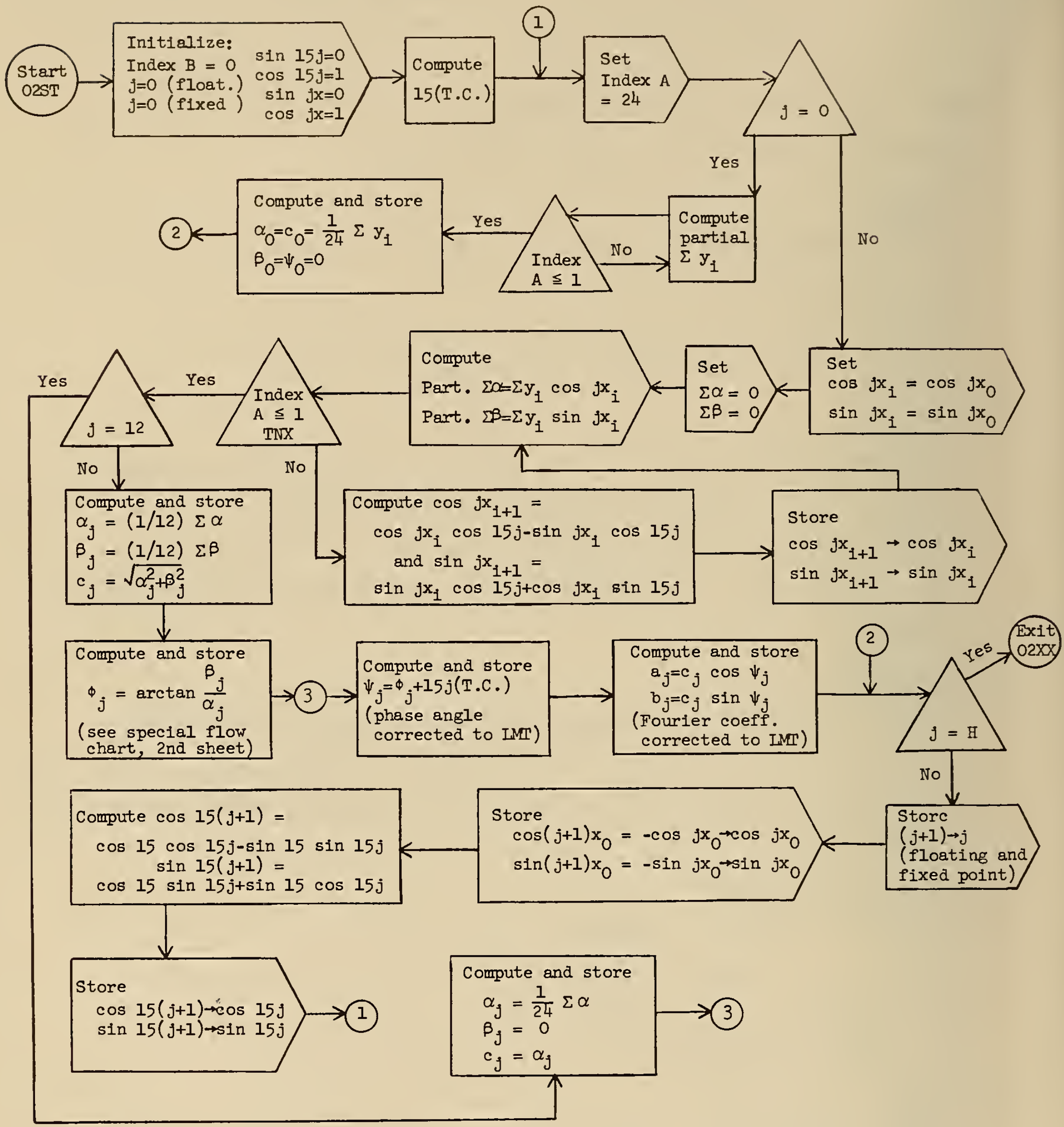
(e) Subroutines used

Share subroutines: UASQR4, NA0331, UA-S+CL, and UA-SPHI

Flow Chart 4

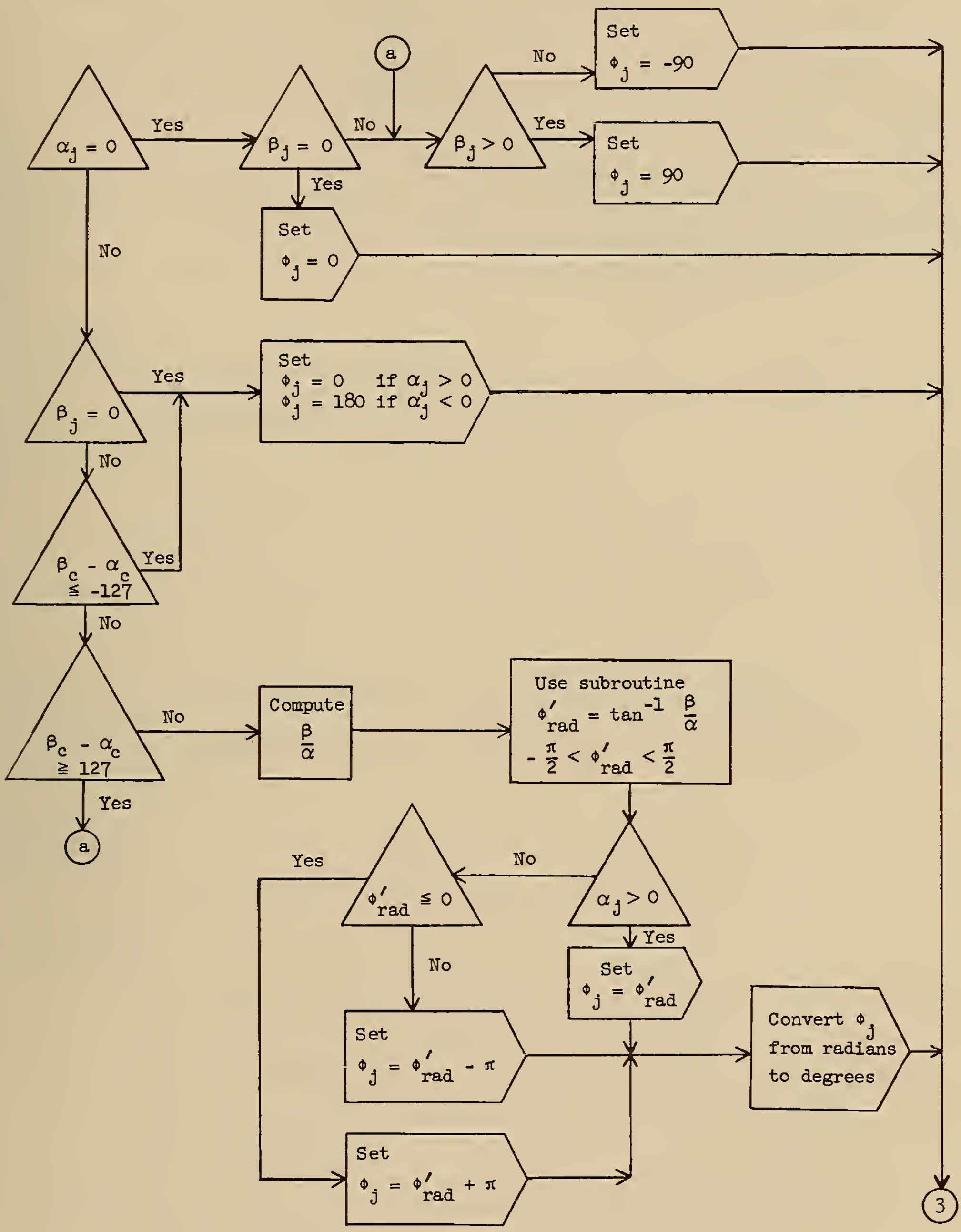
FOURIER ANALYSIS SUBROUTINE 02

(x = zone time hour angle; x_i = (15°i-180°); i = 0,1,..., 23)



Special Flow Chart for Computing ϕ_j

(Second Sheet)



(f) <u>Remarks</u>

(1) The AC and MQ overflow indicators should be off at entry to SR 02.

(2) Index registers A, B, and C are used with no provision to restore them.

(g) <u>Stops</u>

A halt will occur at 02BM + 2 if an attempt is made to take the square root of a negative number.

5. GEOGRAPHIC FUNCTIONS SUBROUTINE 04

SR 04 is used to evaluate the geographic functions $G_k(\lambda,\theta)$ at station coordinates and at screen point coordinates (see table 1). These functional values are subsequently used in the geographic analyses. For this purpose, SR 04 is entered one time for each of the N stations and once for each screen point. SR 04 is again entered once for each of the N stations for computing residuals (section 7). A general description of the subroutine is given, including the program logic (flow chart 5).

(a) Input

(1) Geographic coordinates (λ_i,θ_i) for one station (λ_i = latitude, θ_i = longitude).

(2) Parameters PP1 (≥ 1), PP2, and PP3 = P defining the choice of geographic functions $G_k(\lambda,\theta)$. If no longitude terms are desired, we set PP1 = PP2 = PP3 = P. See table 1 (this section) and the discussion of the choice of functions in section 2.1.

(3) Function identification code FNCD (see header card).

(4) If 04ST entry is used, N, N-1, ..., 1 must be in index register A.

(b) Output

Geographic function values $G_k(\lambda_i,\theta_i)$, $k = 0, 1, \ldots, K$.

(c) Storage

(1) Entry through 04ST causes the $G_k(\lambda_i,\theta_i)$ to be stored in matrix form involving $N(K+1)$ elements.

(2) Entry through 04ST2 causes the $G_k(\lambda_i,\theta_i)$ to be stored in consecutive locations starting at FUNCT. This involves $(K+1)$ elements.

(3) SR 04 (not including subroutines) itself requires 286 storage locations.

TABLE 1

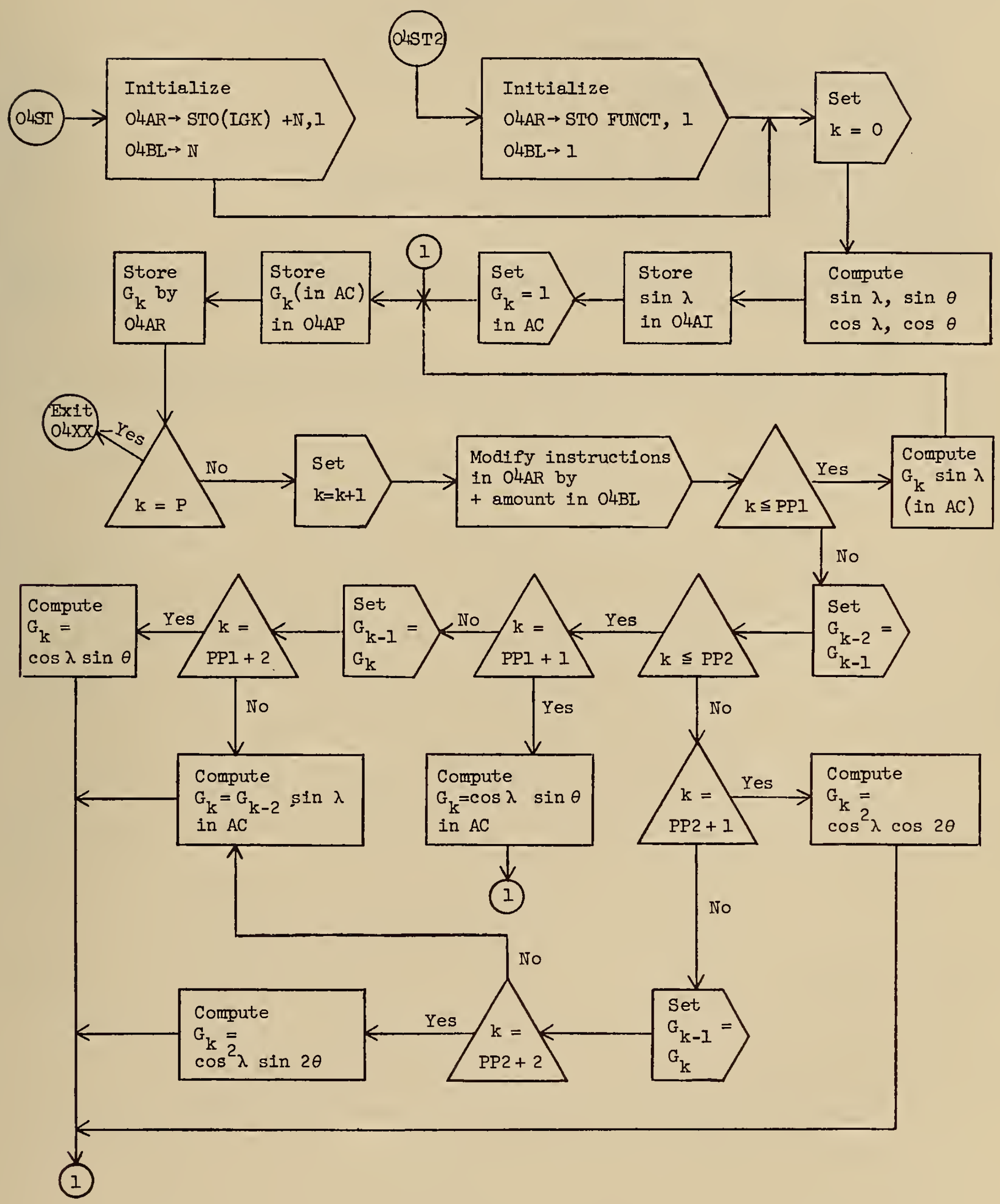
GEOGRAPHIC FUNCTIONS $G_k(\lambda,\theta)$

		k	$G_k(\lambda,\theta)$
Main Latitudinal Variation		0	1
		1	$\sin \lambda$
		2	$\sin^2 \lambda$
		...	...
		k_0	$\sin^{q_0} \lambda$
Mixed Latitudinal and Longitudinal Variation	First Order in Longitude	k_0+1	$\cos \lambda \cos \theta$
		k_0+2	$\cos \lambda \sin \theta$
		k_0+3	$\sin \lambda \ \cos \lambda \cos \theta$
		k_0+4	$\sin \lambda \ \cos \lambda \sin \theta$
		...	... ...
		...	... ...
		k_1-1	$\sin^{q_1} \lambda \cos \lambda \cos \theta$
		k_1	$\sin^{q_1} \lambda \cos \lambda \sin \theta$
	Second Order in Longitude	k_1+1	$\cos^2 \lambda \cos 2\theta$
		k_1+2	$\cos^2 \lambda \sin 2\theta$
		k_1+3	$\sin \lambda \ \cos^2 \lambda \cos 2\theta$
		k_1+4	$\sin \lambda \ \cos^2 \lambda \sin 2\theta$
		...	... ...
		...	... ...
		$K-1$	$\sin^{q_2} \lambda \cos^2 \lambda \cos 2\theta$
		K	$\sin^{q_2} \lambda \cos^2 \lambda \sin 2\theta$

Flow Chart 5

GEOGRAPHIC FUNCTIONS SUBROUTINE 04

(LGK = Loc. of $G_k(\lambda_i,\theta_i)$, i = 1,2, ..., N, k = 0,1, ..., P.
FUNCT = Loc. of $G_k(\lambda,\theta)$, k = 0,1, ..., P.)



(d) Calling sequence

```
                CLA    EXTIN
                STO    04XX
                TRA    04ST  (or 04ST2)
     EXTIN      TRA   (NEXT)
    (NEXT)    (CONTINUE)
```

(e) Subroutines used

Share subroutines: UA - S + CL and UA-SPHI

(f) Remarks

(1) The AC and MQ overflow indicators should be off at entry to SR 04.

(2) Index registers A, B, and C are used with no provision to restore them.

6. SYNTHESIS SUBROUTINES 05-10

6.1 Explanatory Remarks

Six subroutines are described in the present section. These subroutines are used to compute the value of the function $\Gamma(\lambda,\theta,t)$. One frequently needs to evaluate $\Gamma(\lambda,\theta,t)$, (a) at many locations for a fixed instant of time, or (b) at a fixed location for several different instants of time. In such cases, considerable savings in computer time can be gained by use of the following subroutines. The techniques employed are described in detail in section 3.1 of [Jones and Gallet, 1962b].

(a) SR 08 should be used when, for successive computations, Γ is evaluated for a fixed t and varying λ and θ. The entry for the first of such computations is 08ST, and for all following 08ST2 until t changes.

(b) SR 09 should be used for fixed λ and θ and varying t. The entry for the first of such computations is 09ST and for subsequent computations 09ST2 (until λ and θ change).

(c) SR 10 should be used for successive computations of Γ for fixed T and θ and for varying λ. SR 10 is entered initially at 10ST and then at 10ST2 until T and θ are changed.

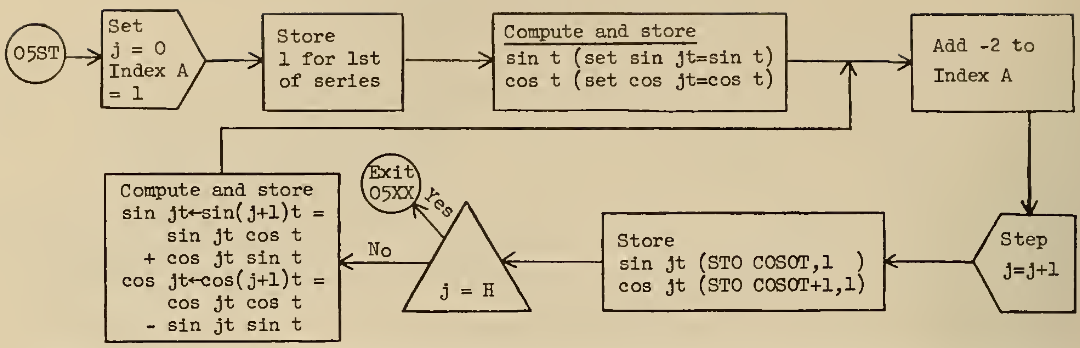
The following three subroutines are used in connection with the above:

(d) SR 05 computes $\sin jt$ and $\cos jt$ for $j = 1, 2, \ldots, H$, given t, H, and TRA exit instruction in 05XX.

(e) SR 06 computes $D_k(t)$ for $k = 0, 1, \ldots, K$, given the matrix of coefficients D_{sk}, $\sin jt$ and $\cos jt$ $(j = 1, 2, \ldots, H)$, H, K, and TRA exit instruction in 06XX. For an explanation of $D_k(t)$, see section 3.1a of [Jones and Gallet, 1962b].

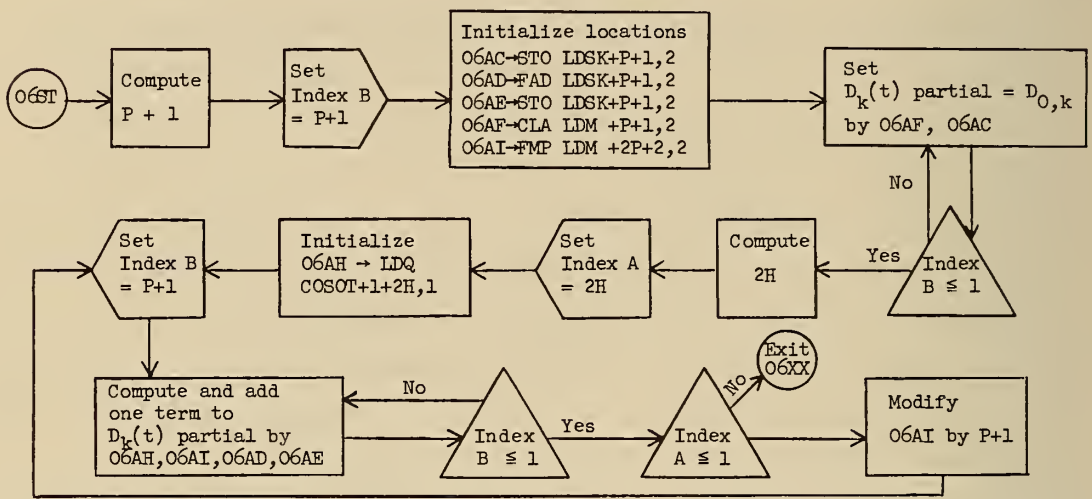
Flow Chart 6

SYNTHESIS SUBROUTINES 05-10



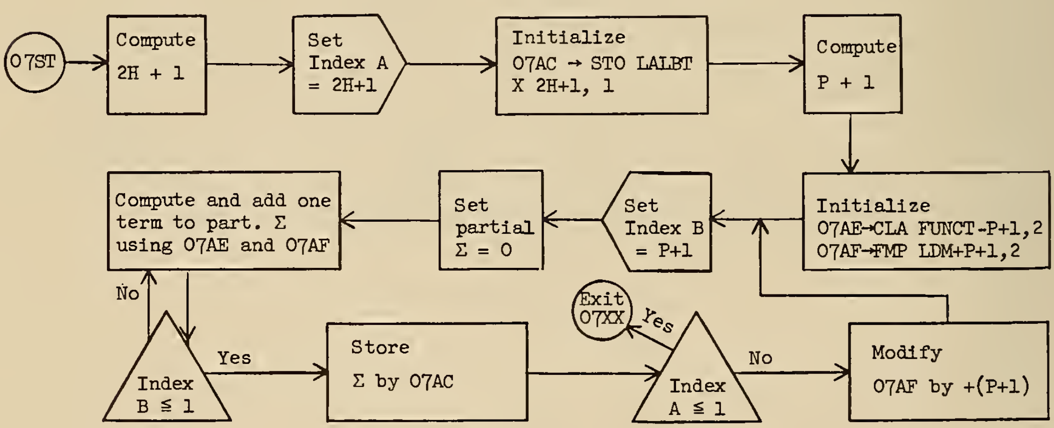
LDSK = Loc. of $D_k(t)$

LDM = Loc. of D_{sk} coefficients.

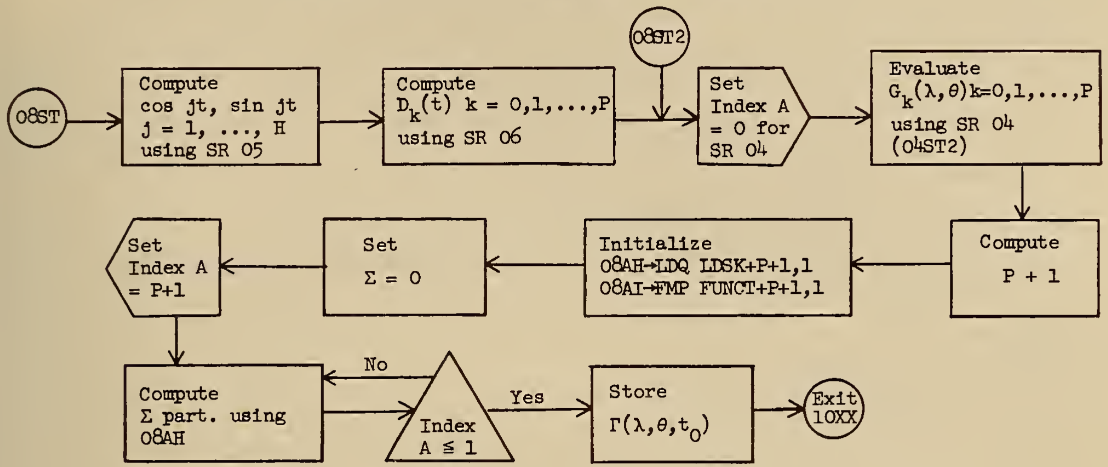


FUNCT = Loc. of $G_k(\lambda,\theta)$, k = 0,1, ..., P.

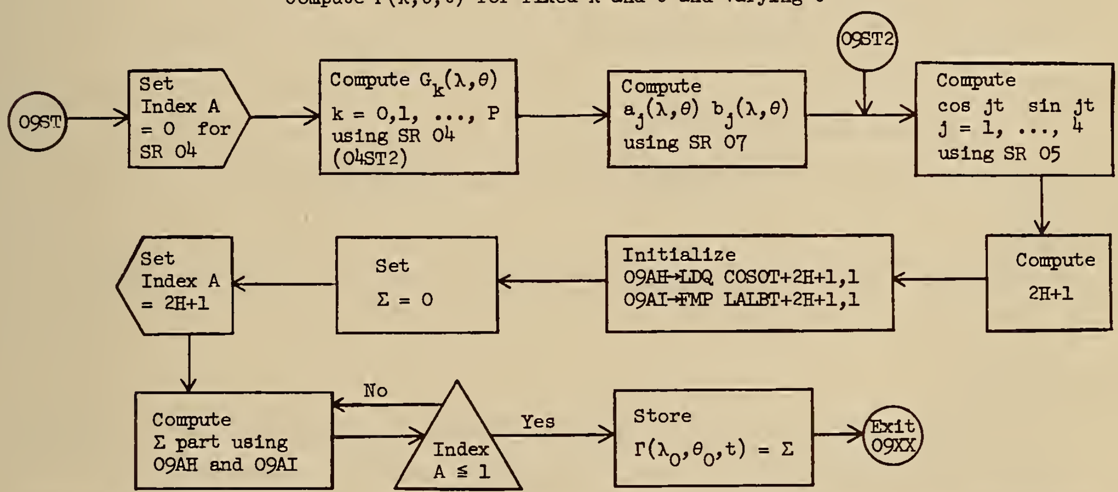
LALBT = Loc. of $a_j(\lambda,\theta)$ and $b_j(\lambda,\theta)$.



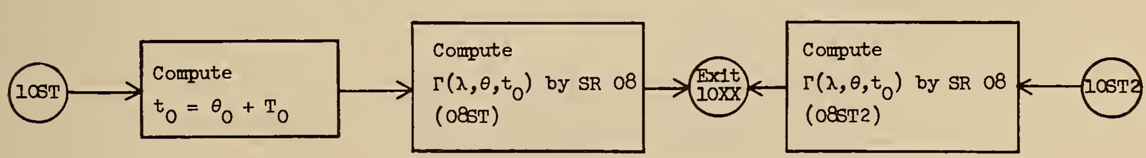
Compute $\Gamma(\lambda,\theta,t)$ for fixed t and varying λ and θ



Compute $\Gamma(\lambda,\theta,t)$ for fixed λ and θ and varying t



Compute $\Gamma(\lambda,\theta,t)$ for fixed T = t-θ and varying λ



(f) SR 07 computes $a_0(\lambda,\theta)$, $a_j(\lambda,\theta)$ and $b_j(\lambda,\theta)$ ($j = 1, 2, \ldots, H$), given the matrix of coefficients D_{sk}, the functional values $G_k(\lambda,\theta)$ ($k = 0, 1, \ldots, K$) from SR 04, H, K, and TRA exit instruction in 07XX. For an explanation of $a_j(\lambda,\theta)$ and $b_j(\lambda,\theta)$, see section 3.1c of [Jones and Gallet, 1962b]. (Entrance to SR 04 is through 04ST2.)

6.2 Program Description (for subroutines 08, 09 and 10)

(a) Input

(1) λ = geographic latitude,

(2) θ = geographic longitude,

(3) t = local mean hour angle, or
T = universal hour angle.

(4) Matrix of coefficients D_{sk}, $s = 0, 1, \ldots, 2H$ and $k = 0, 1, \ldots, K$.

(5) PP1, PP2, and PP3 = P.

(6) H = number of harmonics for the diurnal analysis.

(b) Output

The desired functional value, $\Gamma(\lambda,\theta,t)$ or $\Gamma(\lambda,\theta,\theta+T)$ where $t = \theta + T$.

(c) Storage

Subroutine 08 and 09 each take 72 storage locations, not including other subroutines used. SR 10 takes 11 storage locations in addition to the locations used in SR 08 and other subroutines.

(d) Calling sequence

```
            C L A  EXTIN
            S T O  08XX  (or 09XX or 10XX)
            T R A  08ST  (or 08ST2 or 09ST or 09ST2 or
                          10ST or 10ST2)
(EXTIN)     T R A (NEXT)
(NEXT)    (CONTINUE)
```

(e) Subroutines used

SR 08 uses subroutines 04, 05 and 06 (see remarks) and hence all subroutines used by these. SR 09 uses subroutines 04, 05, and 07 (see remarks). SR 10 uses SR 08 and all subroutines used by it.

(f) Remarks

The AC and MQ overflow indicators should be off at entry to subroutines 08, 09, and 10. They, along with their included subroutines, use index registers A, B, and C, making no provision to restore them.

7. RESIDUAL SUBROUTINE 11

SR 11 is used to compute residuals between the original ionospheric data (A and B) and the values computed from $\Gamma(\lambda,\theta,t)$ and their root mean square. Examples of such results are given in the sample printout in appendix B. These results are used to test the "goodness of fit" of the function $\Gamma(\lambda,\theta,t)$ and to spot undue irregularities in the data. Separate results are obtained for the A and B data, since the residuals for the latter are in general systematically higher than for the former. The program description is followed by a logical diagram (flow chart 7).

(a) Input

(1) Matrix of coefficients D_{sk},

(2) Ionospheric data (A and B),

(3) Station latitudes λ_i $(i = 1, 2, \ldots, N)$,

(4) Station longitudes θ_i $(i = 1, 2, \ldots, N)$,

(5) Time corrections,

(6) Station codes,

(7) N = number of stations (A and B data),

(8) PP1, PP2, and PP3 = P,

(9) H = number of harmonics for diurnal analysis, and

(10) Exit instruction TRA, in 11XX.

(b) Output (see sample printout 2, appendix B)

(1) For each station (A and B data) the 24 hourly residuals (original ionospheric data minus values computed from $\Gamma(\lambda,\theta,t)$,

(2) Root mean square (RMS) of the 24 residuals from each station,

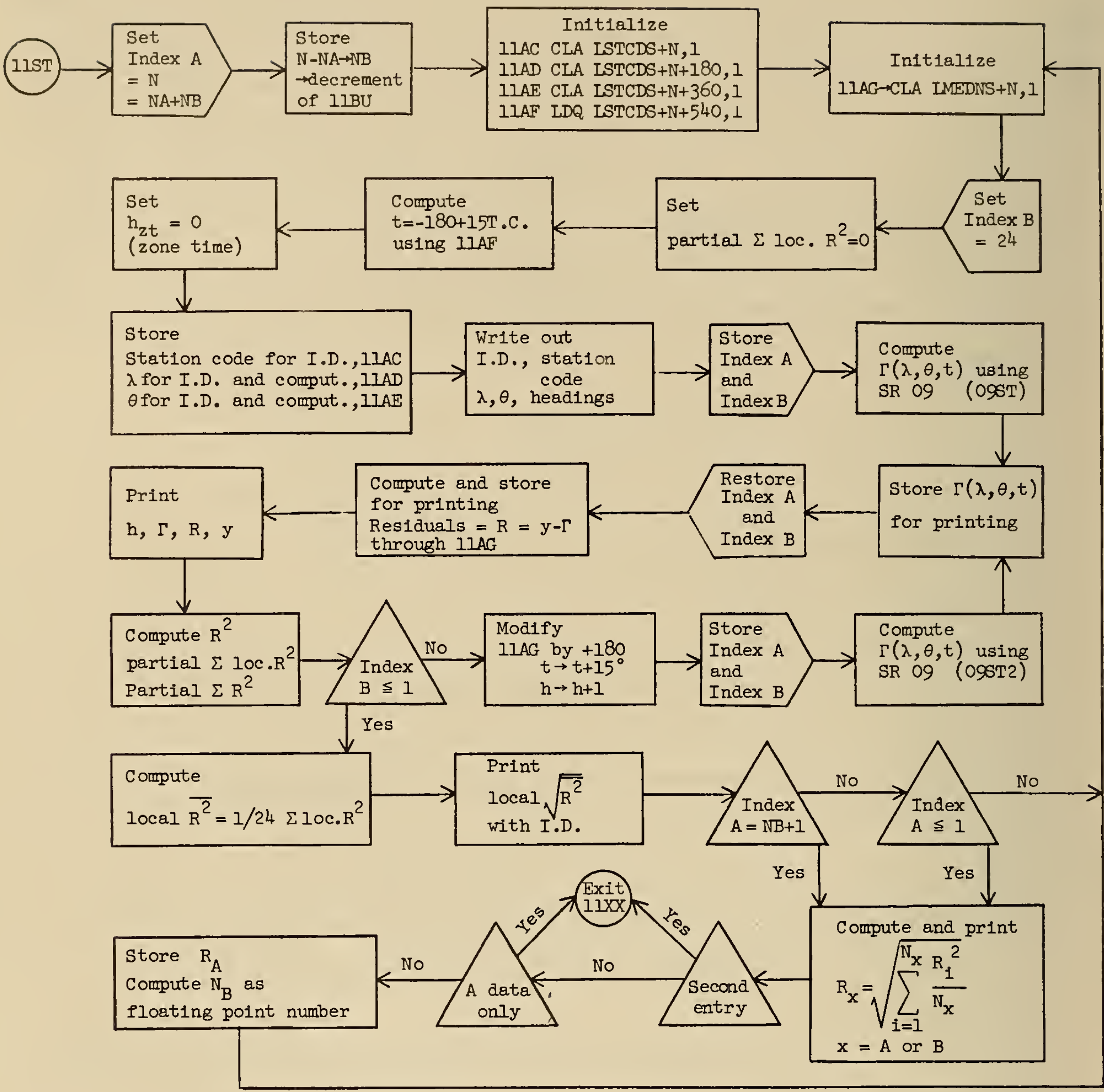
(3) RMS of residuals from A data stations taken together,

(4) RMS of residuals from B data stations taken together, and

(5) RMS of residuals from all stations (A and B data) taken together.

Flow Chart 7

RESIDUAL SUBROUTINE 11



(c) Storage

SR 11 uses 185 storage locations (not including other subroutines employed).

(d) Calling sequence

```
           C L A  (EXTIN)
           S T O   11XX
           T R A   11ST
   (EXTIN) T R A  (NEXT)
   (NEXT)  (CONTINUE)
```

(e) Subroutines used

Share subroutine UA-SPHI, SR 09, and all included subroutines.

(f) Remarks

(1) AC and MQ overflow indicators should be off at entry to SR 11.

(2) Index registers A, B, and C are used making no provision to restore them.

(g) Stops

(1) 11BM - 4)
) if an attempt is made to take the square root of a negative number
(2) 11BQ - 4)

8. GENERAL DATA FITTING SUBROUTINES 15, 17-20

8.1 Explanatory Remarks

The general data fitting method described in chapters 2 and 6 of Jones and Gallet [1962a] is performed in the present program by five subroutines:

SR 20 Executive general data fitting,

SR 15 Inner products,

SR 17 Gram-Schmidt orthogonalization,

SR 19 Least squares fitting, and

SR 18 Coefficients D_{sk}.

SR 20 sets up the necessary requirements for input, output, storage, and number of entries to each of the other subroutines, and restores all index registers. Input, output, storage and calling sequences for SR 20 are included in section 8.2. The descriptions of the other subroutines are given in section 8.2e. The program logic for each of the five subroutines is given in flow chart 8.

8.2 Program Description

(a) Input (to SR 20)

(1) First of $N(K+1)$ consecutive storage locations used successively to store the functional values $G_k(\lambda_i,\theta_i)$, $A_k(\lambda_i,\theta_i)$, and $B_k(\lambda_i,\theta_i)$, $i = 1, 2, \ldots, N$, and $k = 0, 1, \ldots, K$.

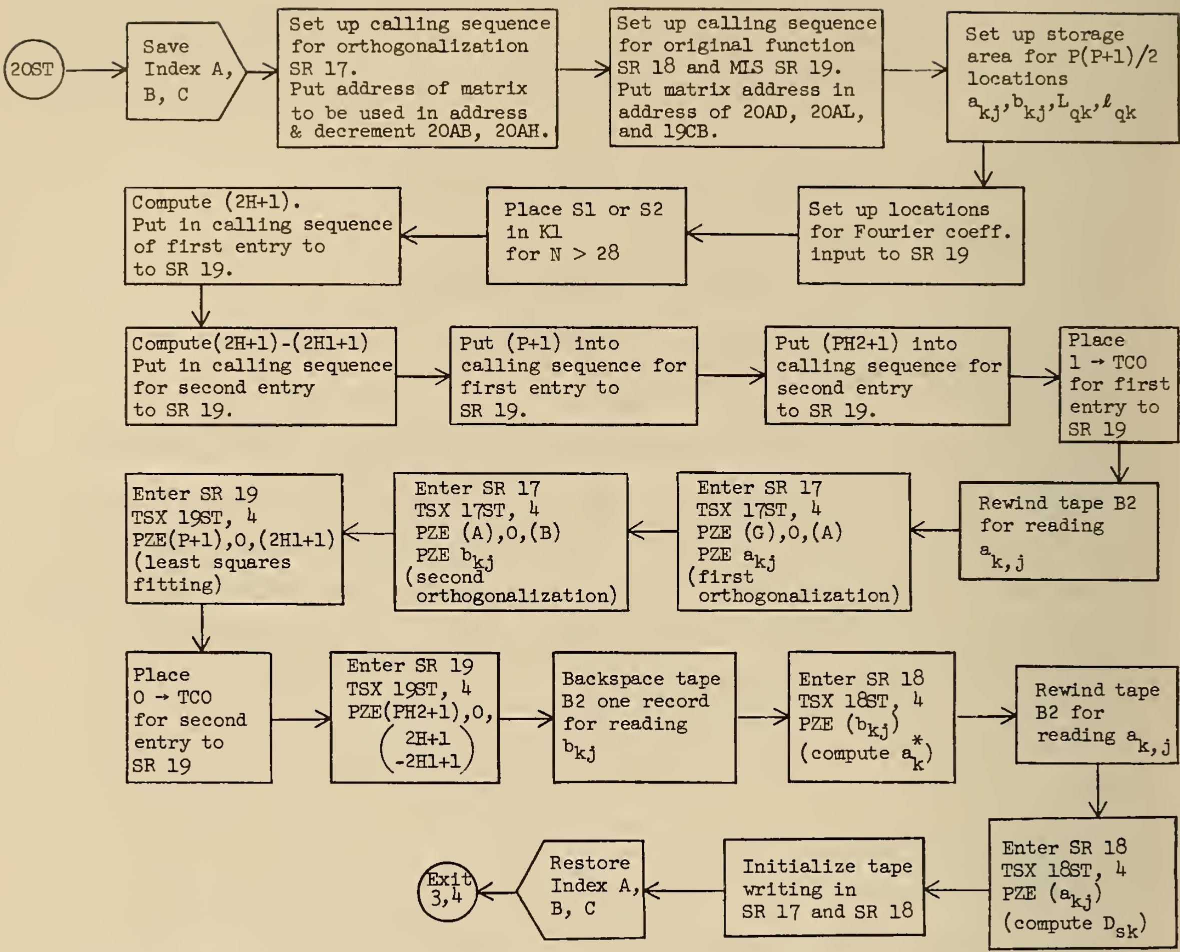
(2) First of $N(2H+1)$ consecutive storage locations used for the $(2H+1)$ sets of N Fourier (time series) coefficients for geographic analysis.

(3) First of $K(K+1)/2$ consecutive storage locations used successively to store the triangular matrices of coefficients a_{kj}, b_{kj}, ℓ_{kj}, L_{kj} $(k = 1, 2, \ldots, K$ and $j = 0, 1, \ldots, k-1)$.

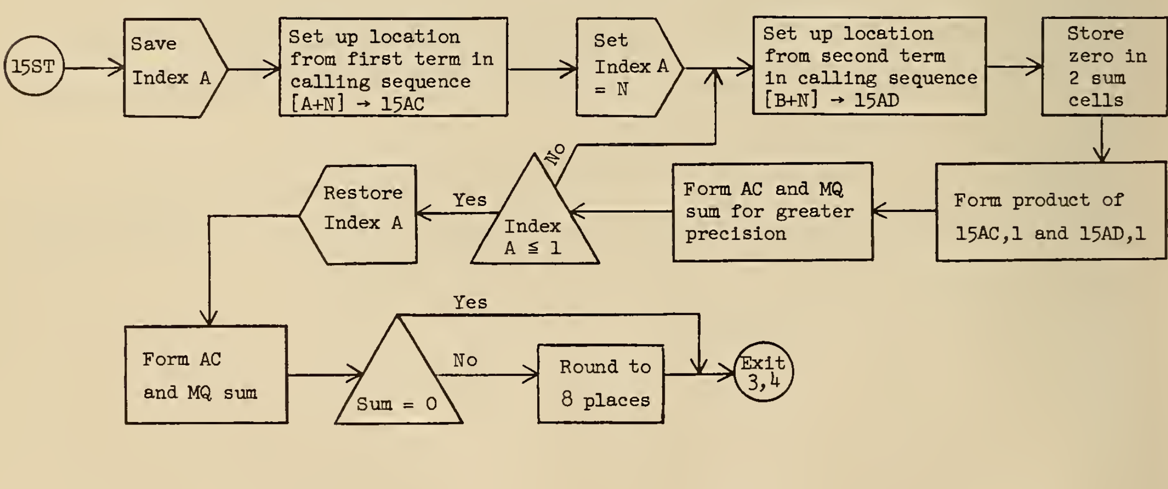
Flow Chart 8

GENERAL DATA-FITTING SUBROUTINE 15, 17-20

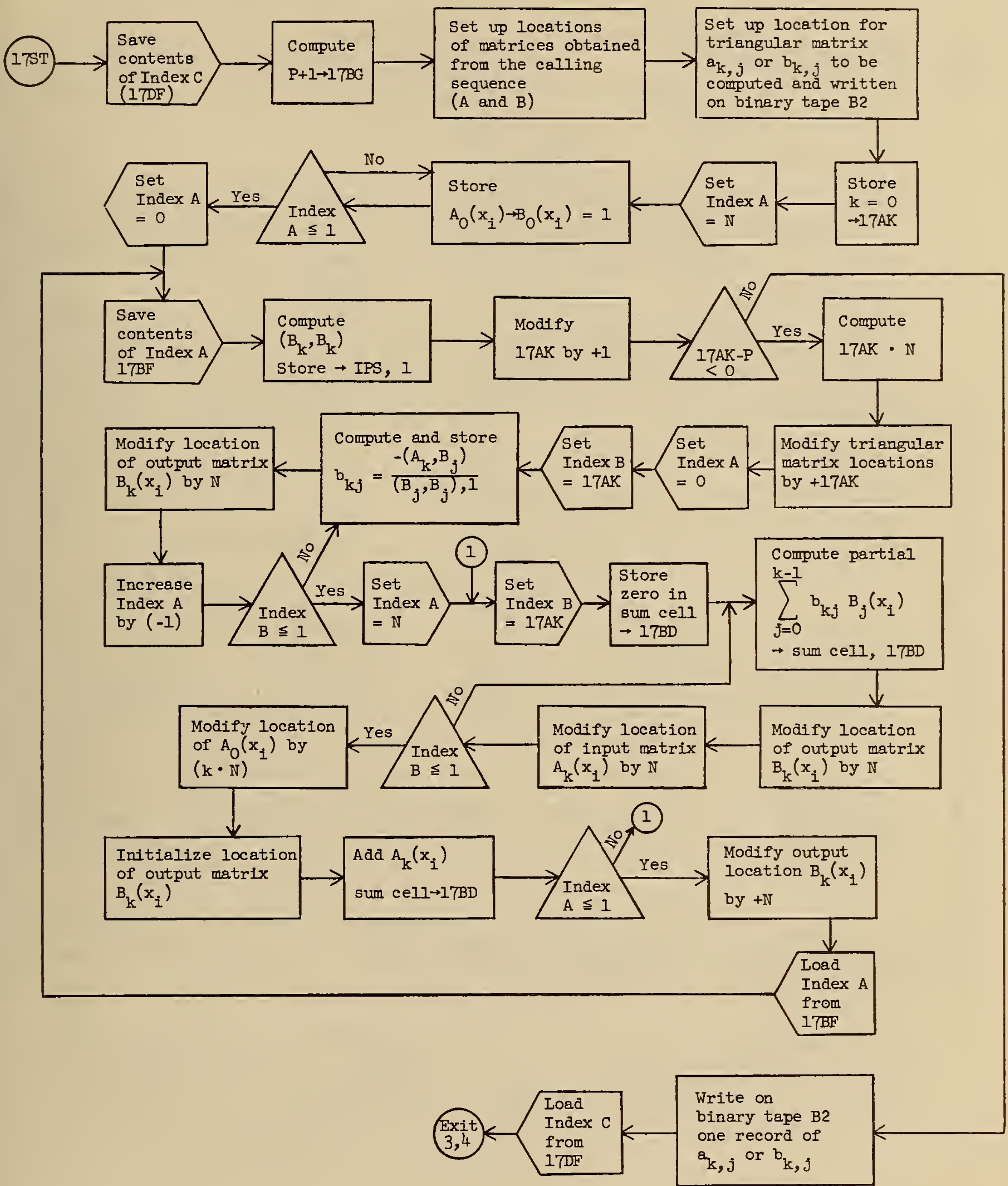
SR 20 Executive General Data-Fitting



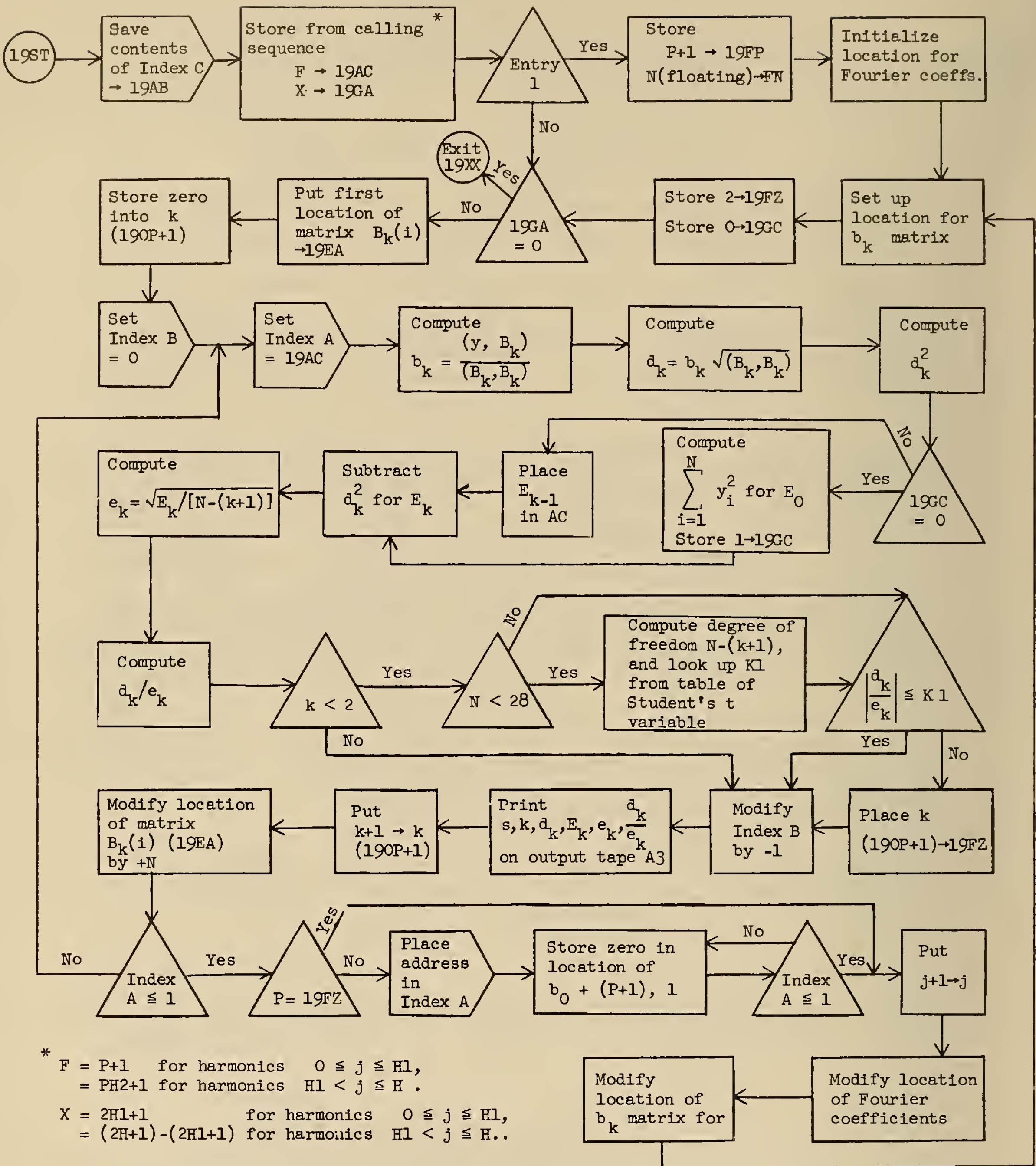
SR 15 Inner Products



SR 17 Gram-Schmidt Orthogonalization



SR 19 Least Squares Fitting

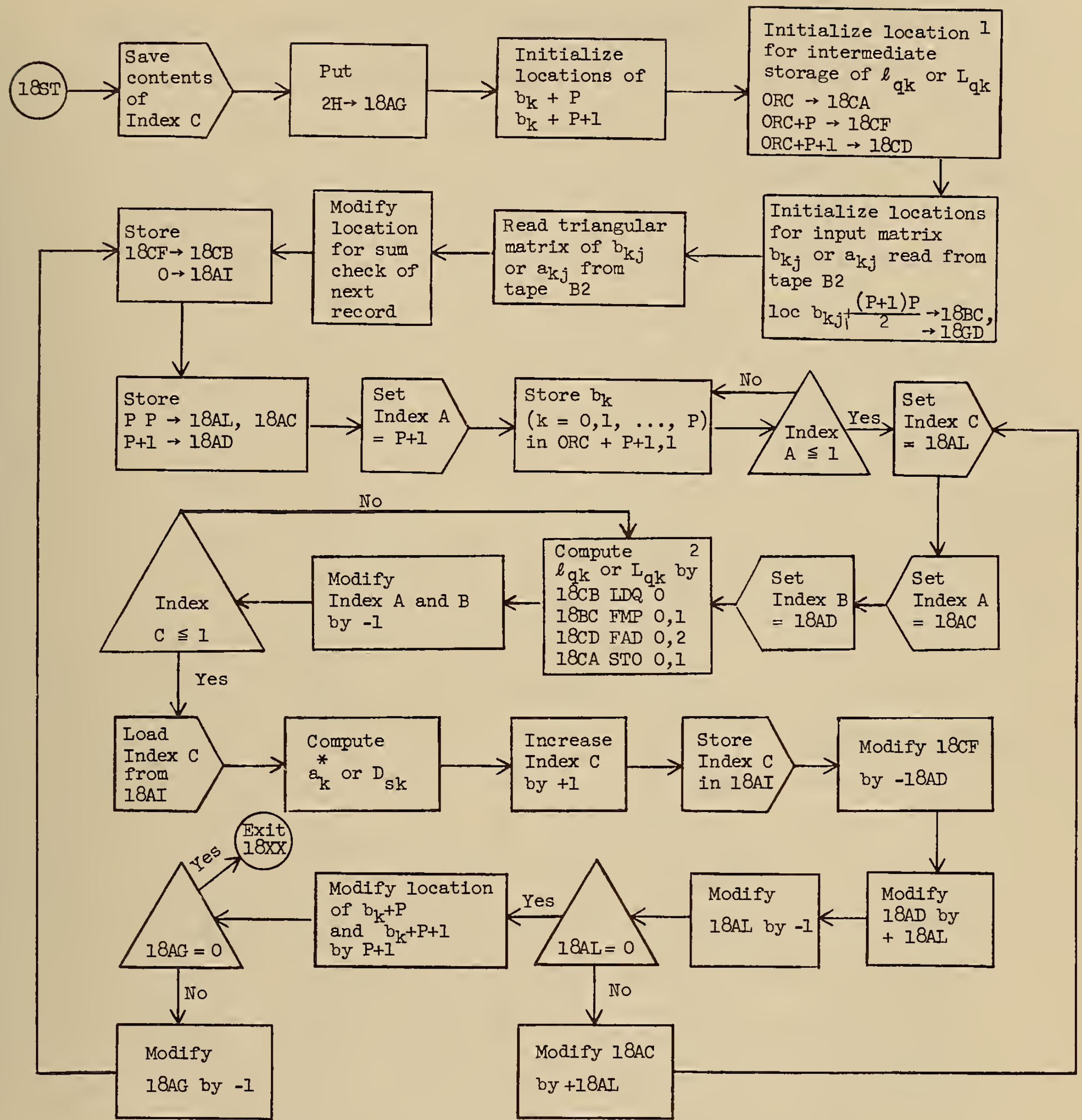


* F = P+1 for harmonics $0 \leq j \leq H1$,
 = PH2+1 for harmonics $H1 < j \leq H$.

X = 2H1+1 for harmonics $0 \leq j \leq H1$,
 = (2H+1)-(2H1+1) for harmonics $H1 < j \leq H$..

Flow Chart 8 (Cont.) (Fourth Sheet)

SR 18 Obtaining Y_P in terms of $\Sigma D_k G_k$



[1] ORC+k = location of $\ell_{0,k}$, k = 0,1, ..., P .

ORC-(k+1) = location of $\ell_{1,k}$ k = 0,1, ..., P-1.

ORC - $\sum_{j=2}^{q}$ (P+2-ℓ)-(k+1) = location of $\ell_{q,k}$, k = 0,1,...., P-q, for 2 ≤ q ≤ P.

[2] Computation starts with $\ell_{1,P-1}$ (or $L_{1,P-1}$) followed by $\ell_{1,P-2}$, $\ell_{1,P-3}$, ..., etc.

Note: The matrix ℓ_{kj} is used after second orthogonalization to transfer $\Sigma\, b_k\, B_k$ to the form $\Sigma\, a_k^*\, A_k$, see section 6.2 of Jones and Gallet [1962a]. Then the matrix L_{kj} is used to transfer $\Sigma\, a_k^*\, A_k$ to the form $\Sigma\, D_{sk}\, G_k$ (see section 2.2 [Jones and Gallet, 1962a]).

(b) Output (for each of the (2H + 1) sets of Fourier coefficients written on tape 3, channel A) (see printout in appendix B)

(1) Orthonormal coefficients d_k, k = 0, 1, ..., K.

(2) Sums of squares of residuals E_k, k = 0, 1, ..., K.

(3) Root mean squared residual e_k, k = 0, 1, ..., K.

(4) Ratios d_k/e_k, k = 0, 1, ..., K.

(5) Coefficients D_{sk}, k = 0, 1, ..., K.

(c) Storage

(1) N (K+ 1) locations for input (1) above.

(2) K (K+ 1)/2 location for input (3) above.

(3) (2H + 1) (K+ 1) locations for the coefficients D_{sk} (s = 0, 1, ..., 2H and k = 0, 1, ..., K).

(d) Calling sequence

```
        T S X   2OST, 4
        P Z E  (G), 0, (ADFC)
               (LFC), 0, (K1)
```

Note: K1 denotes the value of Student's t variable used for truncating the orthonormal series $\Sigma\, d_k\, F_k$. All terms are rejected after the last term for which $|d_k/e_k| \geq$ K1. The number K1 is either S1 or S2 (see header card) for the first or second analysis, respectively. K1 could also be the value of t for a two tail, 10 percent rejection depending upon the number of degrees of freedom

$$DF = N - (k + 1),$$

Table 2

STUDENT'S t VARIABLE FOR
TWO TAIL 10% REJECTION[1]

[Degrees of Freedom (D.F.) = N - (k+1).]

D.F.	t
1	6.314
2	2.920
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.860
9	1.833
10	1.812
11	1.796
12	1.782
13	1.771
14	1.761
15	1.753
16	1.746
17	1.740
18	1.734
19	1.729
20	1.725
21	1.721
22	1.717
23	1.714
24	1.711
25	1.708
26	1.706
27	1.703
28	1.701

[1] Reference: [C.R.C., 1957].

where N is the number of Fourier coefficients being analyzed and k+ 1 is the number of functions used at this point in the analysis (see section 2.1). Table 2 contains the values of t for a 10 percent cutoff.

A different percent can be used for the rejection criterion by replacing the values of t in table 2 by a different set, as follows. The program must be reassembled with the new table of values in locations DF2 to DF2 + 27. The following card format should be used.

Table 3

Card Format for Change in the Rejection Criterion

Card Column	2	8	12	18	...	72
	DF2	DEC	X.XXX,X.XXX,...,X.XXX,...			
		DEC	X.XXX,X.XXX,...,X.XXX,...			
		DEC	X.XXX,X.XXX,			
		.				
		.				

Note: No columns after 72 can be used. A blank after column 11 causes all remaining information on that card to be ignored.

(e) Description of subroutines used

(1) SR 15 is used to form inner products of two N dimensional vectors. Suppose U is a vector whose components are stored in locations A, A+1, ..., A+N-1 and V is a vector with corresponding components in B, B+1, ..., B+N-1. Then given N and the locations A+N and B+N, SR 15 computes the inner product (U, V) and leaves it in the accumulator.

The calling sequence is:

```
T S X   15ST, 4
P Z E  (A+N), 0, (N)
P Z E  (B+N)
```

(2) SR 17 is used to orthogonalize a set of $K+1$ linearly independent vectors of dimension N. The method employed is the Gram-Schmidt orthogonalization and reorthogonalization process described in sections 2.2 and 6.2 by Jones and Gallet, [1962a]. SR 17 forms the orthogonal functions $B_k(\lambda,\theta)$ from the geographic functions $G_k(\lambda,\theta)$ (table 1). Given the locations for input (1) and input (3), SR 17 first computes the values $A_k(\lambda_i,\theta_i)$ and stores them in place of the $G_k(\lambda_i,\theta_i)$. Following this, it computes the values $B_k(\lambda_i,\theta_i)$ (from the second orthogonalization process) and stores them in place of the $A_k(\lambda_i,\theta_i)$. The intermediate coefficients a_{kj} and b_{kj} are also computed, the b_{kj} being stored in place of the a_{kj}. (Note: in order to conserve storage space the input and output locations determined by SR 20 are the same as used here). The triangular matrices of coefficients a_{kj} and b_{kj} are written on tape 2, channel B for later use in SR 18. The same storage locations are also used by SR 18 for intermediate storage of matrices ℓ_{kj} and L_{kj}. The calling sequence is:

```
T S X   17ST, 4
P Z E   (C+W), 0, (C+N)
P Z E   (D)
```

where C is input (1) and D is input (3) above.

(3) SR 19 is used to fit successively, by least squares, the orthogonal functions generated by SR 17 to each of the $2H+1$ sets of N Fourier coefficients (input (2)). Output from SR 19 includes output (1), (2), (3), and (4) listed above. The orthonormal coefficients d_k are set equal to zero for all k greater than the last k for which $|d_k/e_k| \geqq K1$. When fitting Fourier coefficients for harmonics less than or equal H1, the calling sequence is:

```
T S X   19ST, 4
P Z E   (P+1), 0, (2H1+1).
```

For harmonics j such that $H1 < j \leq H$, the calling sequence is:

```
T S X   19ST, 4
P Z E   (PH2 + 1), 0, 2(H - H1).
```

(4) SR 18 is used to compute the coefficients D_{sk} (output (5) above). Input to SR 18 are the orthonormal coefficients d_k from SR 19, and the triangular matrices of coefficients a_{kj} and b_{kj} on tape 2, channel B. SR 20 determines the number of entries to SR 18 and the position of tape 2, channel B. The calling sequence for SR 18 is:

```
T S X   18ST, 4
P Z E   (LGK), 0, 0
```

Note: location LGK which was used in SR 17 for storage of the matrices of orthogonal values is now free to be used for the storage of the triangular matrices b_{kj} and a_{kj} as they are read from tape 2, channel B.

9. INTERCOMPARISON COEFFICIENTS SUBROUTINES 16 AND 21

9.1 Summary of Method and Formulas

For intercomparing numerical maps of ionospheric characteristics from month to month, it is desirable to use series of orthonormal functions, since the terms in such series are independent. The orthonormal functions $F_k(\lambda,\theta)$ used for a given month (or day) depend, for their construction, on the particular set of stations available [Jones and Gallet, 1962a, chapter 2]. Therefore, since the set of available stations changes from day to day and month to month, one cannot use the orthonormal coefficients d_k for intercomparison purposes. For this reason we have made use of a special set of orthonormal functions $H_k(\lambda,\theta)$, constructed relative to a fixed set of 139 points which cover the globe approximately uniformly. The coordinates of these points are given in table 4. Thus, it is possible to represent the function $\Gamma(\lambda,\theta,t)$ in terms of a fixed set of orthonormal functions,and the resulting coefficients h_{sk} can be intercompared from one month (or day) to the next.[1]

The construction of the functions $H_k(\lambda,\theta)$ is completely analogous to the construction of the orthonormal functions $F_k(\lambda,\theta)$ [Jones and Gallet, 1962a, chapters 2 and 6]. One begins with the same set of geographic functions $G_k(\lambda,\theta)$, with the station coordinates (λ_i,θ_i) replaced by the set of 139 covering points in table 4. The first orthogonalization provides:

$$R_0 = G_0$$

$$R_k = \sum_{j=0}^{k-1} r_{kj} R_j + G_k \qquad k = 1, 2, \ldots, K \tag{9.1}$$

---

[1]Note: The index s in h_{sk} is used here in the same sense as (56) in [Jones and Gallet, 1962a].

Table 4

COORDINATES OF THE 139 COVERING POINTS

λ = Latitude	θ = Longitude
$\pm 90^\circ$	0°
$\pm 80^\circ$	$25^\circ + 90^\circ i, \quad i = 0,1,2,3$
$\pm 70^\circ$	$10^\circ (1+6i), \quad i = 0,1,2,3,4,5$
$\pm 10^\circ (1+2k), \quad k = 0,1,2$	$20^\circ (1+2i), \quad i = 0,1,\ldots,8$
$\pm 20^\circ k, \quad k = 0,1,2,3$	$40^\circ i, \quad i = 0,1,\ldots,8$

where

$$r_{kj} = - \frac{(G_k, R_j)}{(R_j, R_j)} \ .^{1} \tag{9.2}$$

A second orthogonalization yields:

$$T_0 = R_0$$

$$T_k = \sum_{j=0}^{k-1} t_{kj} \, T_j + R_k \qquad k = 1, 2, \ldots, K, \tag{9.3}$$

$$t_{kj} = - \frac{(R_k, T_j)}{(T_j, T_j)} \ . \tag{9.4}$$

The orthogonal functions $T_k(\lambda, \theta)$ are then normalized by

$$H_k = \frac{T_k}{\sqrt{(T_k, T_k)}} \qquad k = 0, 1, \ldots, K. \tag{9.5}$$

Consider now the problem of transforming the expression

$$Y_k = \sum_{k=0}^{K} D_k \, G_k \tag{9.6}$$

to the form

$$Y_k = \sum_{k=0}^{K} h_k \, H_k \ . \tag{9.7}$$

The first step is:

$$Y_k = \sum_{k=0}^{K} r_k \, R_k \ , \tag{9.8}$$

---

[1] The inner product notation (G_k, R_j) is used here to denote a summation $\Sigma \, G_k(\lambda, \theta) \; R_j(\lambda, \theta)$ over the set of 139 covering points (table 4).

which from (9.1) and (9.6) provides:

$$r_k = D_k - \sum_{j=k+1}^{K} r_{jk} D_j, \qquad k = 0, 1, \ldots, K-1, \quad \text{and}$$

$$r_K = D_K . \tag{9.9}$$

This gives

$$Y_k = \sum_{k=0}^{K} t_k T_k , \tag{9.10}$$

where from (9.3) and (9.8)

$$t_k = r_k - \sum_{j=k+1}^{K} t_{jk} r_j , \qquad k = 0, 1, \ldots, K-1, \quad \text{and}$$

$$t_K = r_K = D_K . \tag{9.11}$$

Finally, the desired coefficients in (9.7) are obtained from

$$h_k = t_k \sqrt{(T_k, T_k)} , \qquad k = 0, 1, \ldots, K . \tag{9.12}$$

Two subroutines are described in this section. SR 21 is an executive subroutine which employs SR 16 to compute the coefficients r_k and t_k, the numbers r_{kj}, t_{kj} and $\sqrt{(T_k, T_k)}$ being obtained from the numerical map executive program (see input 5, section 2.3). The program description is given in section 9.2.

9.2 Program Description

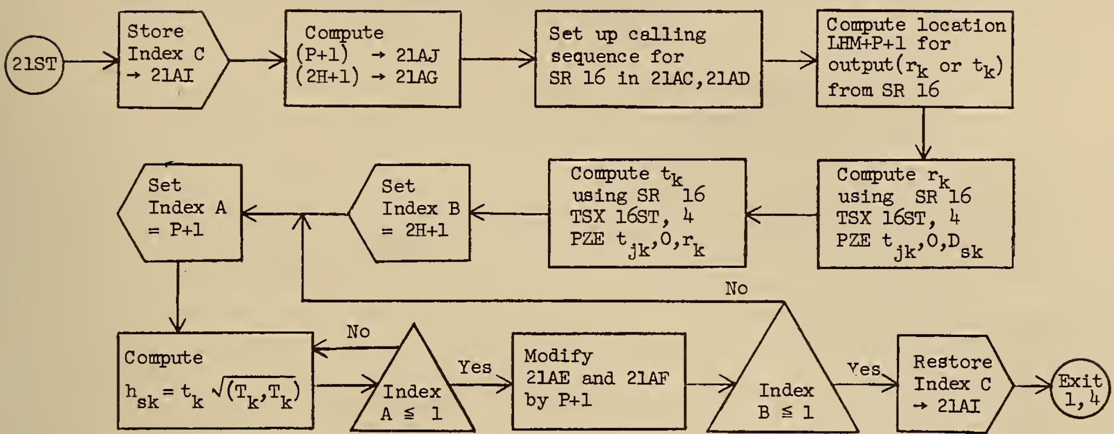
(a) <u>Input</u>

(1) Triangular matrices r_{kj} and t_{kj}, $k = 1, 2, \ldots, K$ and $j = 0, 1, \ldots, k-1$ defining orthogonal functions for the 139 covering points. (Note: these numbers are either computed by the numerical map executive program (section 2) or else read in from tape 3, channel B. See input 5 and output 5, section 2.3).

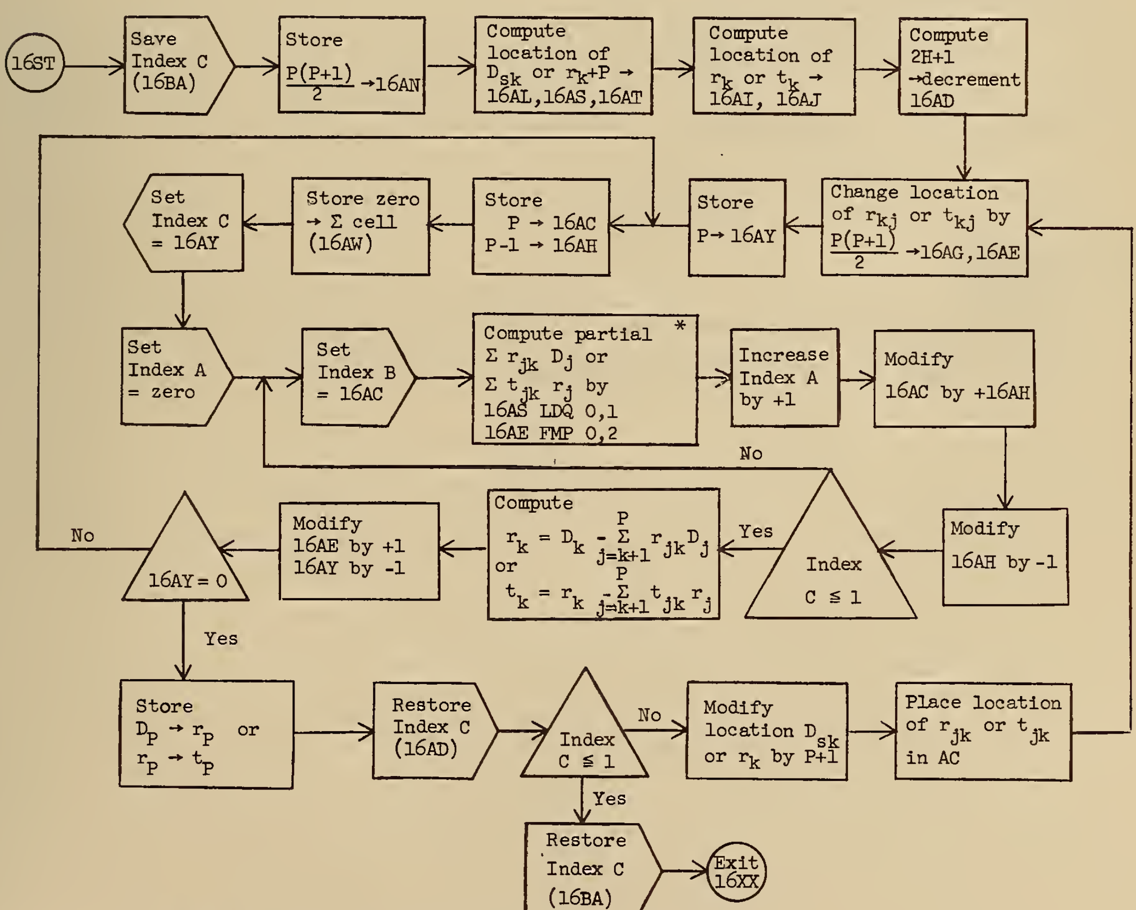
Flow Chart 9

INTERCOMPARISON COEFFICIENTS SUBROUTINES 16 AND 21

SR 21 Intercomparison Coefficients Executive Subroutine



SR 16 (Computes r_k or t_k)



* Compute r_0 first, starting with the term $r_{P0} D_P$.

(2) Square roots of inner products $\sqrt{(T_k, T_k)}$, $k = 0, 1, \ldots, K$. (Note: these numbers are also either computed by the numerical map executive program (section 2) or else read in from tape 3, channel B.

(3) Matrix of coefficients D_{sk}, $k = 0, 1, \ldots, K$, $s = 0, 1, \ldots, 2H$.

(b) Output

Matrix of intercomparison coefficients h_{sk}, $s = 0, 1, \ldots, 2H$ and $k = 0, 1, \ldots, K$.

(c) Calling sequence

T S X 21ST, 4

(d) Subroutines used

SR 16 computes the coefficients r_k and t_k. The r_k are computed when entering SR 16 by

```
        T S X   16ST, 4
                (LT1), 0, 0
```

The t_k are computed when entering SR 16 by

```
        T S X   16ST, 4
                (LT2), 0, 0
```

(e) Remarks

(1) The index registers are restored after they are used.

(2) Underflow is checked internally in the code.

ACKNOWLEDGEMENTS

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Jones, W. B., and R. M. Gallet (Nov.-Dec. 1962b), Methods for applying numerical maps of ionospheric characteristics, J. Res. NBS 66D (Radio Prop.), No. 6, 649-662.

Ostrow, S. M. (Dec. 21, 1962), Handbook for the Central Radio Propagation Laboratory ionospheric predictions based on numerical methods of mapping, National Bureau of Standards Handbook 90.

APPENDIX A

SAMPLE PRINTOUT OF INPUT TO NUMERICAL MAP PROGRAM

Header Card Fixed Data

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 3 154 52 4 8 100 12 36 52  4 -2 60 2  2 142  59 1868  4        58064500
10687219900+868210000+066201000+790                                           5806
10483141700+823045000+645191000+700                                           5806
10982243900+799285000-274239000+810                                           5806
10J82297400+826285000+083170000+850                                           5806
10280058000+806045000+087                                                     5806
10980274100+800285000-073235000+860                                           5806
10178015700+782015000+005012900+744                                           5806
10J76291300+766285000+042355000+870                                           5806
10974265100+747270000-033289400+830                                           5806
10373080400+735105000-164162000+640                                           5806
10771203200+713210000-045241200+685                                           5806
10J70291400+705285000+043000700+819                                           5806
10169019000+697015000+027116200+669                                           5806
10J69306500+693315000-057032700+798                                           5806
10168033000+690030000+020126000+630                                           5806
10167020300+678015000+035115700+652                                           5806
10166026600+674030000-023120000+640                                           5806
10266066700+665060000+045148000+570                                           5806
10165022100+656015000+047114700+629                                           5806
10164018800+646015000+025111000+630                                           5806
10664186600+644180000+044237000+680                                           5806
10764212200+649210000+015256600+646                                           5806
10964264000+643270000-040315500+737                                           5806
10A64338200+641345000-045071100+701                                           5806
10J63291400+638285000+043360000+750                                           5806
10462129600+620135000-036194000+510                                           5806
10761210100+612210000+001258200+609                                           5806
10J61314600+612315000-003036900+712                                           5806
10160030700+600030000+005                                                     5806
10059011100+600015000-026100000+595                                           5806
10159024600+605030000-036113000+560                                           5806
10158017600+598015000+017106000+585                                           5806
10958265800+588270000-028322800+687                                           5806
10056355800+574360000-028083400+607                                           5806
10156044300+561045000-005126000+502                                           5806
10256061100+567060000+007140800+484                                           5806
10356084900+565090000-034159700+459                                           5806
10055013400+546015000-011099000+550                                           5806
10155037300+555030000+049120600+508                                           5806
10855246700+546255000-055301000+620                                           5806
10053005200+521000000+035089500+537                                           5806
10052014600+500000000+097097500+500                                           5806
10352104000+525105000-007174000+410                                           5806
10452113500+520120000-043182100+405                                           5806
10051359400+515360000-004083300+543                                           5806
10651183400+519180000+023240100+472                                           5806
10050010100+516015000-033093900+521                                           5806
10049004600+501000000+031088000+520                                           5806
10149039700+472045000-035120000+420                                           5806
10949262600+499270000-049322900+588                                           5806
10048007600+481000000+051090000+494                                           5806
10848236600+484240000-023294300+533                                           5806
10147019200+474000000+128101000+470                                           5806
10547143000+470150000-047208500+370                                           5806
```

```
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10046000300+466000000+002079500+499          5806
10045007300+468015000-051088700+480          5806
10145020500+448015000+037100000+440          5806
10545141700+454135000+045206100+352          5806
10945284100+454285000-006351500+569          5806
10044009000+446015000-040                    5806
10144034100+448030000+027113000+390          5806
10343076900+432075000+013150500+337          5806
10041012500+418015000-017092100+425          5806
10040000300+408000000+002                    5806
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10237058300+379060000-011133000+300          5806
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10431130600+312135000-029197900+203          5806
10929279400+284285000-037347000+390          5806
10328077200+286075000+015149000+188          5806
10426127800+263135000-048195700+152          5806
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10424121500+250120000+010189000+140          5806
10[illegible]23072600+230075000-016144000+140          5806
10022005500+228000000+037080000+260          5806
10422113600+222120000-043278000+110          5806
10720203500+208210000-043268200+208          5806
10219072800+190075000-015143900+098          5806
10J18292800+185300000-048002100+299          5806
10416120600+164120000+004189300+050          5806
10A14342600+148360000-116054700+215          5806
10313080300+131075000+035150100+030          5806
10311078700+108075000+025148500+010          5806
10310077500+102075000+017014800+006          5806
10909280100+094285000-033348600+206          5806
10308077000+085075000+013146000-014          5806
10007003900+074000000+026074800+106          5806
10J06304800+058360000-368015000+170          5806
10J05285800+045285000+005345000+160          5806
10104018600+046015000+024089000+050          5806
10102030200+015000000+201991800-019          5806
10301103800+013105000-008172800-101          5806
1010K028800-023030000-008097300-038          5806
1050K140800-025000000+939211000-120          5806
1010M015200-044000000+101083600-029          5806
1090M278700-046285000-042350000+066          5806
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1090P280200-068285000-032349000+040          5806
1090R281400-091285000-024350000+020          5806
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10J3M301500-345300000+010009500-231                                    5806
1053N149000-353150000-007224400-439                                    5806
10J30287000-366285000+013356000-250                                    5806
1054K147200-429150000-019224500-516                                    5806
1064L172800-436180000-048252800-480                                    5806
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10J5J302200-517300000+015009300-403                                    5806
1065K169200-525165000+028253300-572                                    5806
1055M159000-545150000+060243300-610                                    5806
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10J6M296500-648300000-023004000-533                                    5806
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10560140000-667135000+033                                              5806
10170023300-704030000-045063000-068                                    5806
1067K170300-723165000+035277000-750                                    5806
10A70333400-755330000+023017500-675                                    5806
10A7P318900-777315000+026147000-670                                    5806
1C67Q166800-778165000+012295000-790                                    5806
1077Q197800-782195000+019312000-740                                    5806
10880240000-800240000+000336000-710                                    5806
10090000000-900000000+000000000-780                                    5806
10471128900+716128900+000                                              5806
10919260500+193260500+000000000+000                                    5806
10513144900+136144900+000213000+040                                    5806
10111043200+116043200+000114000+069                                    5806
10411125000+110125000+000193800-001                                    5806
10705197900+059197900+000265900+051                                    5806
10701202700+019202700+000271400+022                                    5806
1050R147100-094147100+000
1061Q178200-180178200+000251200-220                                    5806
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1016R039600-690039600+000780000-700
1047P106900-784106900+000129000-880
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Ionospheric Data

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12687580645000540 0530 0500 0500 0550U0500 0510 0500 0530 0560 0560 0590
11483580645000520 0520 0510 0520 0550 0560 0600 0580 0600 0530 0500 0550
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11J6958064500052 5 0520U0520U0500 0500U0485 0475U0480 0530U0560 0555U0620U
12J69580645000610U0600 0590U0560U0580 0575U0580 0610U0590U0590 0555 0520
1116858064500062O 0620 0630 0620 0620 0640 0630 0650 0640 0660 0680 0680
1216858064500066O 0660 0650 0630 0630 0640 0640 0640 0620 0620 0640 0600
1116758064500056O 0600 0590 0610 0610 0600 0600 0610 0630 0640 0650 0630
1216758064500063O 0630 0630 0620 0630 0640 0630 0620 0610 0600 0600 0600
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1216658064500066O 0650 0650 0650 0650 0650 0650 0660 0660 0650 0600 0620
1126658064500060O 0600 0620 0640 0640 0660 0670 0640 0670 0690 0680 0700
1226658064500070O 0710 0700 0680 0660 0670 0670 0680 0660 0650 0660 0620
1116558064500062O 0620 0610 0640 0650 0630 0640 0670 0680 0690 0670 0670
1216558064500067O 0660 0660 0650 0650 0660 0660 0650 0660 0640 0620 0630
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12090580645000500U0490U0520U0490U0500U0550U0470U0440U0450U0470I0480U0500U
11471580645000640P0640P0640P0630P0610P0590P0580P0580P0580P0580P0590P0600P
```

```
12471580645000600P0610P0620P0640P0650P0660P0670P0670P0660P0650P0650P0640P
11919580645000960P0910P0850P0810P0760P0700P0760P0860P0940P1020P1080P1140P
12919580645001190P1230P1240P1220P1190P1160P1130P1090P1040P1000P0980P0960P
11513580645000970P0930P0890P0830P0760P0700P0830P0940P0990P1030P1090P1150P
12513580645001190P1230P1260P1290P1310P1330P1300P1230P1150P1080P1040P1010P
11111580645000800P0760P0720P0680P0630P0570P0790P0980P1090P1130P1150P1140P
12111580645001150P1170P1200P1220P1240P1240P1210P1150P1050P0960P0890P0850P
11411580645000990P0950P0890P0800P0700P0610P0840P1030P1120P1160P1160P1160P
12411580645001180P1190P1190P1190P1190P1190P1180P1120P1030P0990P0990P1000P
11705580645001160P1110P1040P0950P0810P0630P0710P0890P0990P1060P1100P1130P
12705580645001150P1170P1200P1210P1200P1180P1150P1080P1050P1080P1130P1160P
11701580645001090P1050P0990P0900P0780P0590P0700P0870P0990P1050P1090P1120P
12701580645001130P1150P1160P1180P1170P1140P1090P1050P1020P1030P1070P1100P
1150R580645000850P0750P0600P0460P0370P0320P0530P0960P1190P1270P1230P1190P
1250R580645001160P1160P1130P1080P1060P1040P1040P1050P1010P0920P0880P0860P
1161Q580645000770P0690P0580P0510P0440P0400P0530P1040P1280P1360P1370P1360P
1261Q580645001340P1310P1290P1270P1280P1260P1190P1080P0960P0900P0870P0830P
1162R580645000520P0520P0520P0520P0510P0480P0450P0730P1000P1140P1210P1180P
1262R580645001150P1130P1110P1090P1060P0990P0850P0730P0640P0580P0540P0530P
1116R580645000400P0400P0390P0380P0380P0400P0430P0450P0460P0470P0560P0710P
1216R580645000810P0880P0890P0820P0730P0610P0470P0360P0340P0360P0380P0390P
1147P580645000340P0330P0310P0310P0320P0350P0380P0420P0460P0510P0560P0620P
1247P580645000660P0670P0660P0630P0580P0550P0510P0490P0450P0420P0380P0360P
```

Screen Point Coordinates

```
 90000 80337 65157 40210 40330 35030 35105 35185 35310 30165 25050 25325 20030
 20232 15175 10240 05160 05345 00060 00180 00225 00255-05080-05125-05200-10165
-10350-15105-15240-20075-20265-25345-30095-30225-35050-35075-35200-35265-40345
-45095-45120-45240-45325-50015-50045-50200-50270-55105-60000-60330-65210-65240
-65265-75067-75277-80037-80300-85140-85225
```

APPENDIX B

SAMPLE PRINTOUT OF OUTPUT FROM NUMERICAL MAP PROGRAM

DATE=5806 DATA=4500 N=154 P=52 H=8 FN=100
PP1= 12 PP2= 36 PP3= 52 PH2= 4 H1=4 TA=2 S1= 6.0 S2= 2.0
NA=142 NC= 59 S=186.8 MN=4

First Analysis

s	k	d_k ORTHO COEFF.	E_k SUMS EK	e_k RMS (EK)	d_k/e_k ORTHO COEFF/RMS
0	0	9.7796171E 01	6.6465771E 02	2.0842668E 00	4.6921139E 01
0	1	-7.9743505E-01	6.6402160E 02	2.0901111E 00	-3.8152758E-01
0	2	-2.3183237E 01	1.2655933E 02	9.1550053E-01	-2.5323018E 01
0	3	-7.2388791E-01	1.2603531E 02	9.1664355E-01	-7.8971581E-01
0	4	1.4358329E 00	1.2397369E 02	9.1216128E-01	1.5740999E 00
0	5	1.2821402E 00	1.2232981E 02	9.0914947E-01	1.4102634E 00
0	6	-1.1086683E-01	1.2231752E 02	9.1219074E-01	-1.2153909E-01
0	7	-1.1094761E 00	1.2108658E 02	9.1069211E-01	-1.2182779E 00
0	8	5.1708630E-01	1.2081920E 02	9.1281754E-01	5.6647279E-01
0	9	-2.9567594E-01	1.2073178E 02	9.1565011E-01	-3.2291367E-01
0	10	1.9614815E-01	1.2069330E 02	9.1869968E-01	2.1350628E-01
0	11	9.0033002E-01	1.1988271E 02	9.1882774E-01	9.7986813E-01
0	12	1.1211874E 00	1.1862565E 02	9.1723313E-01	1.2223582E 00
0	13	-3.1900162E-02	1.1862463E 02	9.2049918E-01	-3.4655285E-02
0	14	4.2415078E 00	1.0063424E 02	8.5087444E-01	4.9848809E 00
0	15	1.8129360E 00	9.7347503E 01	8.3989086E-01	2.1585376E 00
0	16	4.5197838E 00	7.6919057E 01	7.4930165E-01	6.0319949E 00
0	17	-1.3758838E 00	7.5026000E 01	7.4273936E-01	-1.8524449E 00
0	18	-1.4438721E-01	7.5005152E 01	7.4538158E-01	-1.9370911E-01
0	19	4.2654412E-01	7.4823126E 01	7.4724931E-01	5.7095284E-01
0	20	-2.0292717E 00	7.0705182E 01	7.2912132E-01	-2.7831743E 00
0	21	-8.5872000E-01	6.9967782E 01	7.2805147E-01	-1.1794771E 00
0	22	1.8782378E 00	6.6440004E 01	7.1216262E-01	2.6373720E 00
0	23	9.8311927E-02	6.6430339E 01	7.1484445E-01	1.3752912E-01
0	24	-2.1768287E 00	6.1691756E 01	6.9154223E-01	-3.1477884E 00
0	25	-6.1193166E-01	6.1317295E 01	6.9212813E-01	-8.8413059E-01
0	26	-1.3842770E 00	5.9401072E 01	6.8390421E-01	-2.0240802E 00
0	27	6.5889627E-01	5.8966928E 01	6.8409902E-01	9.6315920E-01
0	28	3.2180943E 00	4.8610796E 01	6.2360753E-01	5.1604480E 00
0	29	4.1557774E-01	4.8438091E 01	6.2500380E-01	6.6492034E-01
0	30	7.0715965E-01	4.7938016E 01	6.2429157E-01	1.1327394E 00
0	31	2.0153300E-01	4.7897401E 01	6.2657931E-01	3.2164004E-01
0	32	-3.1065224E 00	3.8246920E 01	5.6221903E-01	-5.5254663E 00
0	33	-8.8725764E-01	3.7459693E 01	5.5871648E-01	-1.5880284E 00
0	34	-6.5550982E-01	3.7030000E 01	5.5783193E-01	-1.1751027E 00
0	35	1.6988062E 00	3.4144057E 01	5.3791859E-01	3.1581103E 00
0	36	1.9383783E 00	3.0386747E 01	5.0962317E-01	3.8035522E 00
0	37	5.3007979E-02	3.0383936E 01	5.1179144E-01	1.0357340E-01
0	38	1.4382064E-01	3.0363252E 01	5.1383681E-01	2.7989555E-01
0	39	1.4322262E 00	2.8311980E 01	4.9834797E-01	2.8739480E 00
0	40	-1.2305239E 00	2.6797791E 01	4.8697904E-01	-2.5268517E 00
0	41	-6.1052668E-01	2.6425048E 01	4.8573442E-01	-1.2569146E 00
0	42	-5.9274504E-01	2.6073701E 01	4.8466299E-01	-1.2230045E 00
0	43	2.8318019E-01	2.5993510E 01	4.8611175E-01	5.8254132E-01
0	44	8.3273214E-01	2.5300067E 01	4.8177869E-01	1.7284537E 00
0	45	2.4392665E-01	2.5240567E 01	4.8343453E-01	5.0457017E-01
0	46	3.4209192E-01	2.5123540E 01	4.8456107E-01	7.0598308E-01
0	47	-1.1776633E 00	2.3736649E 01	4.7321311E-01	-2.4886532E 00
0	48	-6.9790944E-01	2.3249571E 01	4.7055763E-01	-1.4831540E 00
0	49	4.8534400E-01	2.3014013E 01	4.7041320E-01	1.0317398E 00
0	50	1.8633364E-01	2.2979292E 01	4.7233454E-01	3.9449505E-01
0	51	-2.8886722E-01	2.2895848E 01	4.7378169E-01	-6.0970533E-01
0	52	1.5939509E 00	2.0355168E 01	4.4892796E-01	3.5505716E 00
1	0	1.1545718E 01	1.2457914E 02	9.0235400E-01	1.2795110E 01

Hourly Values of Ionospheric Characteristics at Screen Points

LAMBDA= 90.0 THETA= 0. (Geographic Coordinates of Screen Point)

6.13	6.08	6.08	6.33	6.36	6.13	6.00	6.00	5.87	5.77	5.77	5.76
5.88	5.55	5.53	5.72	5.98	6.23	6.34	6.23	6.16	6.25	6.22	6.12

LAMBDA= 80.0 THETA= 337.0

5.71	5.63	5.62	5.79	5.81	5.58	5.44	5.43	5.38	5.35	5.39	5.42
5.42	5.40	5.48	5.70	5.93	6.10	6.15	6.03	5.95	5.99	5.90	5.75

LAMBDA= 65.0 THETA= 157.0

6.03	5.87	5.76	5.72	5.60	5.96	6.04	6.08	6.21	6.35	6.42	6.49
6.51	6.49	6.53	6.57	6.57	6.62	6.68	6.64	6.59	6.53	6.39	6.21

LAMBDA= 40.0 THETA= 210.0

6.97	6.72	6.48	6.18	6.07	6.44	7.07	7.55	7.79	8.01	8.24	8.36
8.35	8.27	8.07	7.75	7.43	7.30	7.36	7.47	7.45	7.37	7.32	7.21

LAMBDA= 40.0 THETA= 330.0

7.51	7.05	6.53	6.13	5.95	6.33	7.04	7.64	8.01	8.31	8.60	8.76
8.80	8.79	8.71	8.51	8.31	8.26	8.38	8.51	8.48	8.35	8.21	7.94

LAMBDA= 35.0 THETA= 30.0

9.62	9.23	8.66	8.03	7.62	7.78	8.49	9.08	9.25	9.43	9.84	10.27
10.64	10.97	11.12	11.09	10.96	10.80	10.61	10.32	9.92	9.68	9.72	9.77

LAMBDA= 35.0 THETA= 105.0

9.88	9.64	9.16	8.57	8.16	8.29	8.91	9.38	9.41	9.49	9.89	10.38
10.84	11.24	11.43	11.39	11.23	10.97	10.64	10.18	9.66	9.41	9.57	9.82

LAMBDA= 35.0 THETA= 185.0

8.34	8.23	7.99	7.64	7.37	7.52	8.12	8.60	8.68	8.78	9.12	9.43
9.64	9.76	9.68	9.41	9.10	8.85	8.70	8.53	8.27	8.13	8.22	8.34

LAMBDA= 35.0 THETA= 310.0

7.96	7.62	7.26	6.85	6.58	6.78	7.50	8.17	8.45	8.70	9.05	9.27
9.35	9.37	9.24	8.97	8.72	8.59	8.66	8.73	8.65	8.52	8.44	8.26

LAMBDA= 30.0 THETA= 165.0

9.53	9.34	8.92	8.40	7.86	7.73	8.31	8.88	8.89	9.00	9.57	10.20
10.75	11.19	11.33	11.25	11.07	10.82	10.53	10.09	9.54	9.26	9.33	9.49

Second Analysis

s	k	d_k ORTHO COEFF.	E_k SUMS EK	e_k RMS (EK)	d_k/e_k ORTHO COEFF/RMS
0	0	1.1586693E 02	9.1748523E 02	2.0803270E 00	5.5696498E 01
0	1	2.7317004E 00	9.1002303E 02	2.0767536E 00	1.3153705E 00
0	2	-2.7691270E 01	1.4321663E 02	8.2582319E-01	-3.3531717E 01
0	3	-1.0710768E 00	1.4206942E 02	8.2447437E-01	-1.2991025E 00
0	4	1.8120750E 00	1.3878580E 02	8.1684725E-01	2.2183768E 00
0	5	1.3887605E 00	1.3685715E 02	8.1310862E-01	1.7079643E 00
0	6	2.1874004E-02	1.3685667E 02	8.1507837E-01	2.6836688E-02
0	7	-9.0152808E-01	1.3604391E 02	8.1463417E-01	-1.1066662E 00
0	8	4.1653732E-01	1.3587041E 02	8.1610746E-01	5.1039518E-01
0	9	-1.6968181E-01	1.3584162E 02	8.1802843E-01	-2.0742777E-01
0	10	-2.5998666E-01	1.3577402E 02	8.1984670E-01	-3.1711619E-01
0	11	1.2061595E 00	1.3431920E 02	8.1746848E-01	1.4754813E 00
0	12	1.7125742E 00	1.3138629E 02	8.1051307E-01	2.1129507E 00
0	13	-4.7527678E-01	1.3116040E 02	8.1184818E-01	-5.8542568E-01
0	14	3.4918428E 00	1.1896743E 02	7.7514232E-01	4.5047764E 00
0	15	2.8463537E 00	1.1086570E 02	7.5018002E-01	3.7942275E 00
0	16	5.8259827E 00	7.6923630E 01	6.2647226E-01	9.2996657E 00
0	17	-1.0570359E 00	7.5806304E 01	6.2349841E-01	-1.6953306E 00
0	18	5.7026108E-02	7.5803052E 01	6.2508989E-01	9.1228651E-02
0	19	2.1162752E-01	7.5758265E 01	6.2652204E-01	3.3778145E-01
0	20	-1.7289138E 00	7.2769122E 01	6.1563450E-01	-2.8083445E 00
0	21	-9.5828191E-01	7.1850817E 01	6.1333700E-01	-1.5624068E 00
0	22	1.2780304E 00	7.0217456E 01	6.0791903E-01	2.1023037E 00
0	23	2.9435686E-01	7.0130810E 01	6.0914898E-01	4.8322638E-01
0	24	-1.4432488E 00	6.8047842E 01	6.0162829E-01	-2.3989044E 00
0	25	-7.1608432E-01	6.7535064E 01	6.0095763E-01	-1.1915721E 00
0	26	-1.4521510E 00	6.5426322E 01	5.9308887E-01	-2.4484543E 00
0	27	2.4560481E-01	6.5366000E 01	5.9441544E-01	4.1318712E-01
0	28	2.0283353E 00	6.1251855E 01	5.7696665E-01	3.5155157E 00
0	29	8.5172019E-01	6.0526428E 01	5.7510477E-01	1.4809826E 00
0	30	1.1125955E 00	5.9288559E 01	5.7075503E-01	1.9493397E 00
0	31	2.0158679E-01	5.9247922E 01	5.7213335E-01	3.5234231E-01
0	32	-2.1212865E 00	5.4748065E 01	5.5150332E-01	-3.8463712E 00
0	33	-9.7172962E-01	5.3803806E 01	5.4825169E-01	-1.7724152E 00
0	34	-9.4321649E-01	5.2914149E 01	5.4522518E-01	-1.7299577E 00
0	35	1.3584320E 00	5.1068811E 01	5.3714463E-01	2.5289873E 00
0	36	1.4552336E 00	4.8951106E 01	5.2738153E-01	2.7593565E 00
0	37	7.0770034E-01	4.8450266E 01	5.2617360E-01	1.3449940E 00
0	38	2.7800587E-01	4.8372979E 01	5.2726238E-01	5.2726285E-01
0	39	9.6084980E-01	4.7449746E 01	5.2371365E-01	1.8346854E 00
0	40	-9.1351080E-01	4.6615244E 01	5.2059472E-01	-1.7547447E 00
0	41	-3.0404171E-01	4.6522802E 01	5.2159674E-01	-5.8290569E-01
0	42	-8.6670141E-01	4.5771630E 01	5.1888812E-01	-1.6703050E 00
0	43	1.9961724E-01	4.5731783E 01	5.2019445E-01	3.8373581E-01
0	44	1.2900269E-01	4.5715141E 01	5.2164540E-01	2.4729959E-01
0	45	6.7134166E-01	4.5264441E 01	5.2061940E-01	1.2895056E 00
0	46	1.2942037E 00	4.3589478E 01	5.1243264E-01	2.5256074E 00
0	47	-1.3200679E 00	4.1846898E 01	5.0360457E-01	-2.6212389E 00
0	48	-1.0531998E 00	4.0737668E 01	4.9839785E-01	-2.1131709E 00
0	49	-8.8752718E-01	3.9949963E 01	4.9506747E-01	-1.7927399E 00
0	50	-1.6098626E-01	3.9924047E 01	4.9643200E-01	-3.2428662E-01
0	51	1.0323948E 00	3.8858207E 01	4.9127927E-01	2.1014417E 00
0	52	1.5491854E 00	3.6458232E 01	4.7735097E-01	3.2453802E 00
1	0	1.5186295E 01	1.6917869E 02	8.9331555E-01	1.6999922E 01
1	1	-5.2349702E 00	1.4177378E 02	8.1970338E-01	-6.3864201E 00
1	2	-8.2212824E 00	7.4184297E 01	5.9435557E-01	-1.3832262E 01
1	3	2.3026811E 00	6.8881957E 01	5.7408948E-01	4.0110143E 00
1	4	-3.1106774E-01	6.8785193E 01	5.7506351E-01	-5.4092762E-01
1	5	1.9968812E 00	6.4797658E 01	5.5949277E-01	3.5690922E 00

Residuals and their RMS

Station Code

00687 A DATA
LAMBDA= 86.8 THETA= 219.9 (Geographic coordinates)

H LZT	GAMMA	RESIDUAL	Y
0	6.13	-0.23	5.90
1	6.06	-0.06	6.00
2	6.13	-0.13	6.00
3	6.22	-0.32	5.90
4	5.96	-0.06	5.90
5	5.64	-0.14	5.50
6	5.63	0.07	5.70
7	5.63	-0.03	5.60
8	5.51	-0.01	5.50
9	5.56	-0.06	5.50
10	5.68	-0.08	5.60
11	5.70	-0.20	5.50
12	5.67	-0.27	5.40
13	5.58	-0.28	5.30
14	5.51	-0.51	5.00
15	5.61	-0.61	5.00
16	5.77	-0.27	5.50
17	5.86	-0.86	5.00
18	5.85	-0.75	5.10
19	5.81	-0.81	5.00
20	5.92	-0.62	5.30
21	6.10	-0.50	5.60
22	6.14	-0.54	5.60
23	6.14	-0.24	5.90

LZT = Zone time

Y = Observed value

Gamma = Computed value

Residual = Y – Gamma

LOCAL RMS RESIDUAL
4.105988E-01

00483 A DATA
LAMBDA= 82.3 THETA= 141.7

H LZT	GAMMA	RESIDUAL	Y
0	5.37	-0.17	5.20
1	5.39	-0.19	5.20
2	5.27	-0.17	5.10
3	5.29	-0.09	5.20
4	5.49	0.01	5.50
5	5.63	-0.03	5.60
6	5.67	0.33	6.00
7	5.57	0.23	5.80
8	5.37	0.63	6.00
9	5.30	0.00	5.30
10	5.39	-0.39	5.00
11	5.54	-0.04	5.50
12	5.62	-0.02	5.60
13	5.63	0.17	5.80
14	5.68	0.12	5.80
15	5.79	0.21	6.00
16	5.81	0.09	5.90
17	5.80	-0.10	5.70
18	5.81	-0.01	5.80
19	5.75	0.05	5.80
20	5.75	-0.05	5.70
21	5.85	-0.15	5.70
22	5.71	0.09	5.80
23	5.41	0.39	5.80

LOCAL RMS RESIDUAL
2.144553E-01

00982 A DATA

LAMBDA= 79.9 THETA= 243.9

H LZT	GAMMA	RESIDUAL	Y
0	5.61	0.09	5.70
1	5.66	-0.06	5.60
2	5.65	0.15	5.80
3	5.67	0.18	5.85
4	5.63	0.22	5.85
5	5.61	-0.01	5.60
6	5.71	-0.21	5.50
7	5.67	-0.17	5.50
8	5.45	0.15	5.60
9	5.43	-0.03	5.40
10	5.56	-0.06	5.50
11	5.53	-0.03	5.50
12	5.47	0.13	5.60
13	5.50	-0.00	5.50
14	5.49	0.21	5.70
15	5.45	0.10	5.55
16	5.41	0.14	5.55
17	5.36	0.04	5.40
18	5.40	0.30	5.70
19	5.54	0.11	5.65
20	5.64	-0.24	5.40
21	5.64	0.06	5.70
22	5.55	0.05	5.60
23	5.52	-0.02	5.50

LOCAL RMS RESIDUAL
1.416085E-01

0009- A DATA

LAMBDA=-90.0 THETA= 0.

H LZT	GAMMA	RESIDUAL	Y
0	4.68	0.12	4.80
1	4.80	0.40	5.20
2	5.08	0.02	5.10
3	5.32	-0.12	5.20
4	5.23	0.77	6.00
5	5.03	0.37	5.40
6	4.96	0.14	5.10
7	4.70	0.50	5.20
8	4.45	0.85	5.30
9	4.77	0.53	5.30
10	5.23	-0.03	5.20
11	5.23	-0.03	5.20
12	5.08	-0.08	5.00
13	5.03	-0.13	4.90
14	4.95	0.25	5.20
15	4.88	0.02	4.90
16	4.61	0.39	5.00
17	3.94	1.56	5.50
18	3.35	1.35	4.70
19	3.29	1.11	4.40
20	3.58	0.92	4.50
21	4.00	0.70	4.70
22	4.39	0.41	4.80
23	4.60	0.40	5.00

LOCAL RMS RESIDUAL
6.320838E-01

RMS RESIDUAL A DATA
6.318335E-01

00471 B DATA
LAMBDA= 71.6 THETA= 128.9

H LZT	GAMMA	RESIDUAL	Y
0	5.77	0.63	6.40
1	5.73	0.67	6.40
2	5.66	0.74	6.40
3	5.66	0.64	6.30
4	5.72	0.38	6.10
5	5.68	0.22	5.90
6	5.64	0.16	5.80
7	5.68	0.12	5.80
8	5.72	0.08	5.80
9	5.76	0.04	5.80
10	5.90	0.00	5.90
11	6.08	-0.08	6.00
12	6.21	-0.21	6.00
13	6.26	-0.16	6.10
14	6.20	0.00	6.20
15	6.06	0.34	6.40
16	5.96	0.54	6.50
17	5.93	0.67	6.60
18	5.90	0.80	6.70
19	5.84	0.86	6.70
20	5.80	0.80	6.60
21	5.82	0.68	6.50
22	5.83	0.67	6.50
23	5.80	0.60	6.40

LOCAL RMS RESIDUAL
5.112251E-01

0047P B DATA
LAMBDA=-78.4 THETA= 106.9

H LZT	GAMMA	RESIDUAL	Y
0	4.25	-0.85	3.40
1	3.90	-0.60	3.30
2	3.59	-0.49	3.10
3	3.40	-0.30	3.10
4	3.33	-0.13	3.20
5	3.48	0.02	3.50
6	3.76	0.04	3.80
7	3.94	0.26	4.20
8	4.19	0.41	4.60
9	4.88	0.22	5.10
10	5.73	-0.13	5.60
11	6.25	-0.05	6.20
12	6.49	0.11	6.60
13	6.55	0.15	6.70
14	6.43	0.17	6.60
15	6.37	-0.07	6.30
16	6.33	-0.53	5.80
17	6.06	-0.56	5.50
18	5.65	-0.55	5.10
19	5.34	-0.44	4.90
20	5.05	-0.55	4.50
21	4.77	-0.57	4.20
22	4.62	-0.82	3.80
23	4.50	-0.90	3.60

LOCAL RMS RESIDUAL
4.569347E-01

RMS RESIDUAL B DATA
6.237257E-01

RMS RESIDUAL OF A AND B DATA
6.312054E-01

One Per Card Coefficients D_{sk} (See Card Format 5)

Y M	DLC	N	P	H	FNCD	PP1	PP2	T	SN	s	k	D_{sk}
5806	4500	213	52	8	100	12	36	1	186.8	0	0	1.0847341E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	1	6.0068659E-01
5806	4500	213	52	8	100	12	36	1	186.8	0	2	-2.4230472E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	3	1.7365042E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	4	1.8869887E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	5	-1.1593593E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	6	-7.6300942E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	7	2.6676274E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	8	1.4264726E 03
5806	4500	213	52	8	100	12	36	1	186.8	0	9	-2.5996887E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	10	-1.2412525E 03
5806	4500	213	52	8	100	12	36	1	186.8	0	11	9.1843662E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	12	4.0777261E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	13	1.4352705E-01
5806	4500	213	52	8	100	12	36	1	186.8	0	14	9.6570256E-01
5806	4500	213	52	8	100	12	36	1	186.8	0	15	-8.4557281E-01
5806	4500	213	52	8	100	12	36	1	186.8	0	16	-4.7783220E 00
5806	4500	213	52	8	100	12	36	1	186.8	0	17	-1.3976016E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	18	-2.3884222E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	19	4.4348199E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	20	1.1777619E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	21	1.1766320E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	22	1.5439476E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	23	-2.9505143E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	24	-5.8452889E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	25	-3.3965383E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	26	-3.8447369E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	27	7.7576793E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	28	1.2218275E 03
5806	4500	213	52	8	100	12	36	1	186.8	0	29	3.9903615E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	30	4.1502135E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	31	-8.8033071E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	32	-1.1519065E 03
5806	4500	213	52	8	100	12	36	1	186.8	0	33	-1.6575612E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	34	-1.6211853E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	35	3.6065598E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	36	4.0243153E 02
5806	4500	213	52	8	100	12	36	1	186.8	0	37	2.8422108E-01
5806	4500	213	52	8	100	12	36	1	186.8	0	38	3.9405910E-01
5806	4500	213	52	8	100	12	36	1	186.8	0	39	-1.9527271E 00
5806	4500	213	52	8	100	12	36	1	186.8	0	40	-3.6131784E 00
5806	4500	213	52	8	100	12	36	1	186.8	0	41	-5.2786767E 00
5806	4500	213	52	8	100	12	36	1	186.8	0	42	-4.8036404E 00
5806	4500	213	52	8	100	12	36	1	186.8	0	43	2.1448102E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	44	3.3071747E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	45	1.8113526E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	46	9.1406965E 00
5806	4500	213	52	8	100	12	36	1	186.8	0	47	-4.7457672E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	48	-8.1269085E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	49	-1.5238267E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	50	-3.3477439E 00
5806	4500	213	52	8	100	12	36	1	186.8	0	51	2.9248889E 01
5806	4500	213	52	8	100	12	36	1	186.8	0	52	5.5277724E 01
5806	4500	213	52	8	100	12	36	1	186.8	1	0	1.5654446E 00
5806	4500	213	52	8	100	12	36	1	186.8	1	1	-1.7650886E 00

One Per Card Coefficients h_{sk} (See Card Format 5)

Y M	DLC	N	P	H	FNCD	PP1	PP2	T	SN	s	k	h_{sk}
5806	4500	213	52	8	100	12	36	2	186.8	0	0	9.4565125E 01
5806	4500	213	52	8	100	12	36	2	186.8	0	1	4.0170246E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	2	-2.1605705E 01
5806	4500	213	52	8	100	12	36	2	186.8	0	3	-7.8164387E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	4	1.4642438E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	5	1.3993547E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	6	-3.2498074E-02
5806	4500	213	52	8	100	12	36	2	186.8	0	7	-3.7577779E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	8	1.3522217E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	9	-3.9923328E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	10	-6.4115469E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	11	7.1357547E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	12	1.5940220E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	13	-9.0769068E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	14	1.8921489E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	15	2.6680483E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	16	5.1834916E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	17	-6.0173756E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	18	2.8737972E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	19	7.5293761E-02
5806	4500	213	52	8	100	12	36	2	186.8	0	20	-1.5618081E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	21	-8.1786337E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	22	1.0628657E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	23	3.9685505E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	24	-7.7826549E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	25	-3.5562921E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	26	-1.2530024E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	27	1.6143535E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	28	1.2648626E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	29	7.4794657E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	30	1.2934358E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	31	6.1983575E-02
5806	4500	213	52	8	100	12	36	2	186.8	0	32	-1.8562712E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	33	-9.3592011E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	34	-9.1538558E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	35	1.0113917E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	36	1.1285386E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	37	3.4079790E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	38	3.2231821E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	39	8.8341281E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	40	-9.1879728E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	41	-9.5740420E-02
5806	4500	213	52	8	100	12	36	2	186.8	0	42	-6.3193738E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	43	1.1002588E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	44	-9.0577019E-02
5806	4500	213	52	8	100	12	36	2	186.8	0	45	5.0261891E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	46	1.2591517E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	47	-1.0611030E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	48	-1.1026031E 00
5806	4500	213	52	8	100	12	36	2	186.8	0	49	-8.0437840E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	50	-1.7631563E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	51	8.2920978E-01
5806	4500	213	52	8	100	12	36	2	186.8	0	52	1.4233196E 00
5806	4500	213	52	8	100	12	36	2	186.8	1	0	1.4133058E 01
5806	4500	213	52	8	100	12	36	2	186.8	1	1	-3.7146698E 00

GPO 835-527

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

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Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Research. Radiodetermination.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. High Latitude Ionosphere Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

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