NASA CONTRACTOR REPORT

N72-18359

NASA CR-61373

AURORAL OVAL KINEMATICS PROGRAM

By R. H. Comfort

Northrop Services, Inc.
P. O. Box 1484
Huntsville, Alabama 35807

January 1972

CASE FILE COPY

Prepared for

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
NASA CR-61373		

4. TITLE AND SUBTITLE	5. REPORT DATE
AURORAL OVAL KINEMATICS PROGRAM	January 1972
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT #
R. H. Comfort	TR-241-1028
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NO.
Northrop Services, Inc. P. O. Box 1484 Huntsville, Alabama 35807	11. CONTRACT OR GRANT NO. NAS8-21810
	13. TYPE OF REPORT & PERIOD COVERED
12. SPONSORING AGENCY NAME AND ADDRESS	CONTRACTOR REPORT
NASA Washington, D. C. 20546	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Technical Coordinator: Robert E. Smith, Space Environment Branch, Aerospace Environment Division, Aero-Astrodynamics Laboratory, Marshall Space Flight Center.

16. ABSTRACT

A computer program which determines the geographic location of the auroral oval for given universal time and level of geomagnetic activity has been developed for use on the IBM 7094 computer. The program provides both printed output of geographic coordinates of auroral oval boundaries and polar plots of the auroral oval. In addition, there is available a time-integration option which indicates how long a given location is under the auroral oval during a specified period. This report describes the program and its use.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
	UNCLASSIFIED-UNLIMITED WWY E. D. Geissler E. D. GEISSLER Director, Aero-Astrodynamics Lab, MSFC

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	109	$3.00

MSFC - Form 3292 (May 1969)

FOREWORD

This report describes a computer program which determines the geographic position of the auroral oval as a function of universal time and geomagnetic activity. This program was developed by Northrop Services, Inc., Huntsville, Alabama, for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Aero-Astrodynamics Laboratory, under Contract NAS8-21810, Appendix A-1, Schedule Order 5. This work was under the direction of the Space Environment Branch with Mr. R. E. Smith as NASA/MSFC Technical Coordinator.

ACKNOWLEDGEMENTS

Thanks go to Mrs. E. Williams, MSFC Computation Laboratory for programming Subroutine POLAR in its original form and making it available for use in this program. Also thanks to Mrs. D. P. Conrad, formerly of Northrop Services, Inc. for considerable programming advice during development of this program.

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Section I

INTRODUCTION

At high latitudes, the energetics of the upper atmosphere are strongly influenced by phenomena in the region of the auroral oval (refs. 1, 2, and 3). For this reason the auroral oval is the natural frame of reference in which to study such energetics as well as auroral and related phenomena themselves (ref. 4). The upper atmosphere is, however, also dynamically coupled to the geographic coordinate frame of the rotating earth. So in order to use the auroral oval reference frame effectively in upper atmospheric studies, it must be possible to know where the auroral oval is, geographically, at a given time and for a given level of geomagnetic activity. The purpose of the Auroral Oval Kinematics (AOK) program is to provide this information in a convenient, easily usable form.

At present, no theoretical model provides a sufficiently detailed description of auroral morphology on a global scale to be used as a basis for such a program. However, extensive observations during the International Geophysical Year (IGY) have been used by Feldstein and Starkov (refs. 5 and 6) to formulate statistical models - from which the auroral oval concept resulted. Extensions of these models form the data base of the AOK program, permitting the necessary computations to be made.

The method of AOK is simple and direct. Models of the auroral oval are functions of geomagnetic activity alone in the coordinate frame of corrected geomagnetic (CG) latitude (ref. 7) and CG local time. For a given level of geomagnetic activity, boundaries of the auroral oval are determined by linear interpolation between the appropriate models. Transformation to the geographic coordinate frame is a function of universal time (UT) alone. For a given UT, the CG meridian of local midnight is determined and the computed auroral oval is oriented along this reference. Then boundaries of the oval are transformed point-by-point to geographic coordinates. Hence the desired output is obtained by specifying universal time and the level of geomagnetic activity.

A description of the physical problem is presented in Section II. In Section III the program is described in detail. Section IV provides information required to use the program: inputs, outputs and deck layout. The program is listed in Section V, and Section VI contains references. The appendixes contain the auroral oval models used in the program.

Section II
THE PROBLEM

2.1 AURORAL OVAL MODELS

The auroral oval is that region where aurora appear in the zenith at a given universal time. The location of the boundaries of this region have been investigated by Feldstein and Starkov (refs. 5 and 6) using observations made during the IGY period. They employed a statistical method, identifying the auroral oval region as locations where aurora occur in the zenith 60 percent of the time. With this method they examined the variation in location of the boundaries with geomagnetic activity in the coordinate frame of CG latitude and CG local time (for a discussion of the merits of this coordinate system, see reference 8). Their results form the basis for the auroral oval models used in AOK.

In particular, Feldstein and Starkov have presented graphs giving the CG latitudes of auroral oval boundaries as functions of the geomagnetic indices Q (ref. 5) and K_p (ref. 6) for six CG local times throughout the day. From these graphs a set of auroral oval reference models have been developed for both the 15 minute local index Q and the 3 hour planetary index K_p. These models are formulated in CG latitude and CG local time, in accordance with references 5 and 6. A reference model has been developed for each integral value of the geomagnetic indices (0 to 9). Corrected geomagnetic latitudes of both north and south boundaries of the auroral oval are specified at 20 minute (CG local time) intervals. To obtain this resolution and for complete coverage from the data in references 5 and 6, a considerable amount of interpolation and extrapolation has been required, particularly for the K_p index.

The same approach was used for both geomagnetic indices. In the graphs (refs. 5 and 6) showing the variation in position of the oval boundaries with geomagnetic activity, the ranges of the geomagnetic indices varied. In all cases, these have been extended by linear extrapolation to cover the range 0 to 8. For each model (integral value of the index), the six data points available have been plotted on a polar grid, each point being placed in the center of the

CG local time interval it represents. These points were then connected by a smooth curve. The resulting model ovals are displayed in Appendixes A and B, showing where extrapolation has been used. The required latitude values have been taken from the smooth curves. These then constitute the reference models which form the data base (Subroutines BLOCK DATA) of AOK. The models for Q and K_p equal to 8 have been repeated for the value 9, in order to have reference models for all values of the geomagnetic indices. This permits easy substitution of better data when it becomes available, without exaggerating the size of the oval in the meantime on the basis of questionable extrapolation to the highest levels of geomagnetic activity.

2.2 METHOD OF ATTACK

With the above models in the data base, it is a simple matter to interpolate between models for any given value of geomagnetic activity. In this coordinate frame of CG latitude and local time, the auroral oval is approximately invariant with respect to changes in universal time (UT). Although for a given level of geomagnetic activity, the oval is approximately fixed with respect to the sun, the earth is rotating under it. Since the oval is located asymmetrically about the rotation pole, its geographic position is continually changing. In addition, it is changing orientation in the CG coordinate system (CG latitude and longitude) because the CG longitude of local midnight changes continually.

So the next step in determining the geographic position of the oval for a given UT is to establish its orientation in the CG coordinate system. This is accomplished by computing the CG longitude of local midnight and converting the CG local time coordinates to CG longitude based on this identification. These steps are taken in Subroutine OVAL; details are presented in Section III. Once the auroral oval boundaries are specified in CG coordinates, the transformations of Comfort (ref. 9) are used to convert to geographic coordinates. Derivations of the transformations are contained in reference 9 and are not reviewed here. In AOK, the conversion is performed by Subroutine MC2GC. Use of the transformations introduces a limitation in the application of the program. The coordinate transformations of reference 9 were formulated empirically for the northern hemisphere. Hence AOK can be applied only to the auroral oval in the northern hemisphere.

In the geographic coordinate system, lines of constant CG latitude (circles, in polar plots of the CG coordinate system) appear approximately as ellipses. So in the transformation from CG to geographic coordinates, the shape of the auroral oval is distorted. It is basically this distortion of shape that makes simpler approaches to the problem less accurate than this one. A graphic approach to this same problem is presented by Whalen (ref. 8).

2.3 TIME-INTEGRATION

An additional feature has been incorporated into AOK, although it is presently at an intermediate stage of development with respect to its ultimate objective. This is a time-integration option, which now indicates how much time, during a specified period, a given location has been under the auroral oval. At such time as the distribution of energy deposition in the upper atmosphere can be specified in the auroral oval frame of reference, this option can be modified to give the time-integrated energy deposited in the upper atmosphere as a function of geographic location. Subroutine TIOVL performs the time integration; a detailed description of the method is given in Section III.

Section III
PROGRAM DESCRIPTION

3.1 PROGRAM SUBROUTINES

3.1.1 DRIVE Routine

This is the main routine of AOK; it performs all input operations and controls program execution. The initial input card designates one of three program options and indicates whether or not another case will follow. Control is then transferred to the appropriate part of the routine for the option specified. Input data for that option is read in and prepared for use in other subroutines. Time control is established, as required for the option, and the appropriate subroutines are called to perform the necessary computations. Output is then directed by a call to Subroutine OUT.

The three program options are independent and accessible only through the option designator. So each case must be preceded by an option card, and only one option may be employed for each case. There is no limit to the number of cases processed in a given run.

3.1.1.1 Option I: Production of Auroral Oval Tables. In this option the position of the auroral oval is determined at fixed intervals of one hour UT and one unit of geomagnetic activity. The lower and upper limits for both parameters are read in. The computation begins with the lower limits and continues at the fixed intervals until the upper limit is reached or passed.

All time-keeping and geomagnetic-activity bookkeeping for this program option take place in DRIVE. For each level of geomagnetic activity, the auroral oval for all time intervals is determined before the activity level is increased. Actual determination of the position of the auroral oval is performed in Subroutine OVAL and output is obtained by calling Subroutine OUT.

3.1.1.2 Option II: Position of the Auroral Oval for Specified Universal Time and Geomagnetic Activity. With this option, the position of the auroral oval is computed for any pair of universal time and geomagnetic activity values read in. The number of ovals which can be computed for a single case (one option card) is limited to 96, and this number (NC) must be specified in advance. Either the Q or K_p geomagnetic index may be used, but they may not be mixed in a single case. This option differs from Option I only in the manner in which UT and geomagnetic activity values are provided to the computer: in Option I they are generated automatically from base values; in this option each pair of values is read in. Outputs for both options are identical.

3.1.1.3 <u>Option III: Time-Integrated Position of the Auroral Oval</u>. The purpose of this option is treated in detail in subsection 3.1.4, Subroutine TIOVL. Basically it provides information on how long a given geographic location is under the auroral oval during a specified period of time. Since the geographic position of the auroral oval is a function of geomagnetic activity as well as universal time, the variation of the geomagnetic activity index must be specified throughout the time period of integration. This is done by reading in an array of index values and identifying the universal time corresponding to the initial value. At present the maximum period of integration is 24 hours which requires 9 K_p values or 96 (the array maximum) Q values.

DRIVE actually plays a very small role in this option. It causes the pertinent information to be read in and loads reference data arrays; but most initialization and bookkeeping functions, as well as performance of the computations are controlled and executed in TIOVL.

Inputs and outputs for this subroutine are defined in Tables 3-1 and 3-2.

3.1.2 Subroutine OUT(N)

This subroutine controls all printed output from AOK except for error messages. OUT is composed of seven independent parts. Entry to the appropriate portion is determined by the argument N through a computed GO TO statement. Upon completion of the designated portion, control is returned to the calling subroutine. All information available to OUT comes in through the COMMON BLOCKS. Optional plot output is controlled by testing the plot option parameter, NPOL. However, actual execution of plot output takes place in Subroutine POLAR.

Table 3-1. INPUTS TO DRIVE

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
GAT(I,J)	A two dimensional array of real values of the geomagnetic index and corresponding values of UT. IMAX = 96. J = 1 for UT; J = 2 for geomagnetic index.	READ IN	hours & minutes (UT)
GMAB	In Option I, the lower limit (real) of the geomagnetic activity index.	READ IN	
GMAE	In Option I, the upper limit (real) of the geomagnetic activity index.	READ IN	
IGAT(I)	In Option II, a one dimensional array containing integer values of UT. IMAX = 96.	READ IN	hours & minutes
IGM	An integer variable indicating geomagnetic index: IGM = 1 for K_p, IGM = 2 for Q. All other values are meaningless.	READ IN	
IØPT	Integer variable option designator. IOPT < 0 for Option I; IOPT = 0 for Option II; IOPT > 0 for Option III. If IOPT > 1 isointensity contours are computed (See Subroutine TIOVL).	READ IN	
ITGMB	In Option III, the universal time (integer) corresponding to the first value of the geomagnetic activity index read in.	READ IN	hours & minutes
IUTB	Initial value (integer) of UT in Options I and III.	READ IN	hours & minutes
IUTE	Final value (integer) of UT in Options I and III.	READ IN	hours & minutes
LAST	Integer variable last case indicator. LAST = 0 for last case (run terminates upon completion of the case). LAST ≠ 0 indicates another case follows.	READ IN	
NC	In Option II, an integer variable giving the number of auroral ovals to be computed.	READ IN	
NGMA	In Option III, an integer variable specifying the number of geomagnetic index values to be stored in array GAT.	READ IN	
NPØL	Integer variable plot option designator. NPOL > 0 for plots; NPOL ≤ 0 for no plots.	READ IN	
SØLD	Real value of the solar declination angle corresponding to the time frame for which auroral ovals are to be computed.	READ IN	degrees

Table 3-2. OUTPUTS FROM DRIVE

MNEMONIC SYMBOL	DEFINITION	UNITS
GMA	Real variable value of the geomagnetic activity index	
GMAB	In Option I, the lower limit (real) of the geomagnetic activity index.	
GMAE	In Option I, the upper limit (real) of the geomagnetic activity index.	
GAT(I,J)	In Option II, a one dimensional array containing integer values of UT. IMAX = 96.	hours & minutes
IERR	Integer variable giving the statement number immediately preceding a detected error condition	
IGM	An integer variable indicating geomagnetic index: IGM = 1 for K_p, IGM = 2 for Q. All other values are meaningless.	
IØPT	Integer variable option designator. IOPT < 0 for Option I; IOPT = 0 for Option II; IOPT > 0 for Option III. If IOPT > 1 isointensity contours are computed (See Subroutine TIOVL).	
IPØ1	Integer variable used with plot options for housekeeping purposes.	
ITGMB	In Option III, the universal time (integer) corresponding to the first value of the geomagnetic activity index read in.	hours & minutes
IUT	Integer variable for universal time	hours & minutes
IUTB	Initial value (integer) of UT in Options I and III.	hours & minutes
IUTE	Final value (integer) of UT in Options I and III.	hours & minutes
NC	In Option II, an integer variable giving the number of auroral ovals to be computed.	
NGMA	In Option III, an integer variable specifying the number of geomagnetic index values to be stored in array GAT.	
NPØL	Integer variable plot option designator. NPOL > 0 for plots; NPOL $\leq$ 0 for no plots.	
UT	Real variable for universal time	hours
UTGMB	Real value of ITGMB	hours & minutes

Inputs and outputs for this subroutine are defined in Tables 3-3 and 3-4.

3.1.3 Subroutine OVAL, (UT, GMA, IGM)

This subroutine is the heart of the program: it is here that the positions of the auroral oval boundaries are computed. Arguments in the call statement provide the UT and geomagnetic index information required by OVAL for a specific calculation.

The procedure for this calculation may be outlined as follows. First the geographic meridian of local solar midnight is computed from UT. From this, the CG meridian of local midnight is determined. Boundaries of the auroral oval are determined in the reference frame of the models by linear interpolation based on the value of the geomagnetic activity index. The computed oval is then oriented on the CG meridian of local midnight and boundary coordinates are transformed to the geographic coordinate system. Details of these steps are presented below.

3.1.3.1 Determination of Corrected Geomagnetic Midnight. In this program the following definition of corrected geomagnetic time by Montbriand (ref. 10) is used:

> "Corrected geomagnetic time is defined by the angle between the corrected geomagnetic meridian (nearly planar) surfaces, one passing through the axis of the earth's uniform magnetism and the station, and the other through the axis of uniform magnetism and the sun".

Although CG time is not a linear function of the earth's rotation, because the earth's rotation axis and magnetic field axis do not coincide, Montbriand notes that variations in the lengths of CG hours are not very large or important, so that the approximation of equal lengths may be used. This approximation is adopted here.

For present purposes, CG midnight is taken as the reference meridian. The problem then is to determine this meridian for a given universal time. First, the geographic meridian of local midnight (GGLG) is computed from the equation

$$GGLG = 360 - 15\ UT$$

Table 3-3. INPUTS TO OUT(N)

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
CØN(I,J,K)	A three dimensional array of real values of the geographic latitudes of isointensity contours at intervals of 5 degrees longitude (beginning with 0 degrees). Index I (IMAX = 4) labels different contours with the same intensity along a given meridian in order of decreasing latitude. Index J (JMAX = 72) relates to longitude. Index K (KMAX = 9) labels the intensity value of the contour.	TIØVL	degrees
GAT(I,J)	A two dimensional array of real values of the geomagnetic index and corresponding values of UT. IMAX = 96. J = 1 for UT; J = 2 for the geomagnetic index.	DRIVE	hours (UT)
GGLG	Real value of the geographic longitude of local solar midnight.	ØVAL	degrees
GGØVL (I,J,K)	A three dimensional array of real values of the geographic coordinates of auroral oval boundaries. Index I (MAX = 72) is related to CG local time. J = 1 for the north boundary; J = 2 for the south boundary. K = 1 for longitude; K = 2 for latitude.	ØVAL	degrees
GMA	Real value of the geomagnetic activity index.	DRIVE	
GMAB	Real value of the lower limit of the geomagnetic activity index in program Option I.	DRIVE	
GMAE	Real value of the upper limit of the geomagnetic activity index in program Option I.	DRIVE	
GMØVL (I,J,K)	A three dimensional array of real values of the CG coordinates of auroral oval boundaries. Indices have same meaning as for GGOVL, with the addition of K = 3 for which the array contains values of CG local time.	ØVAL	degrees hours (K = 3)
IGM	An integer variable indicating the geomagnetic index used: IGM = 1 for K_p, IGM = 2 for Q. All other values are meaningless.	DRIVE	
IGRID(I,J)	A two dimensional array of integer numbers which are proportional to the length of time the corresponding location is under the auroral oval during the integration period (Option III). Index I (MAX = 50) is related to geographic latitude; index J (MAX = 72) is related to geographic longitude.	TIØVL	

Table 3-3. INPUTS TO OUT(N) (Concluded)

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
IPØ1	Integer parameter for plot housekeeping purposes.	DRIVE	
ITGMB	Integer value of UT corresponding to the first value of the geomagnetic activity index read in under Option III.	DRIVE	hours & minutes
IUTB	Initial value (integer) of UT in Options I and III.	DRIVE	hours & minutes
IUTE	Final value (integer) of UT in Options I and III.	DRIVE	hours & minutes
N	Integer argument designating output	CALLING ROUTINE	
NC	An integer variable specifying the number of auroral ovals to be computed for a given case in Option II.	DRIVE	
NCØN	Integer parameter giving the maximum number of contour values in Option III.	TIØVL	
NGMA	An integer variable specifying the number of pairs of values actually stored in array GAT under Option III.	DRIVE	
NPØL	Integer variable plot option designator. NPOL > 0 for plots; NPOL $\leq$ for no plots.	DRIVE	
SØLD	Real value of the solar declination angle corresponding to the time frame for which auroral ovals are to be computed.	DRIVE	degrees
TT	Real value of the total integration time.	TIØVL	hours

Table 3-4. OUTPUTS FROM OUT(N)

MNEMONIC SYMBOL	DEFINITION	UNITS
	All entries in Table 3-3 are printed out except for N.	
INDEX(I)	A one dimensional field data array containing alphanumeric identifiers for the geomagnetic activity index: INDEX(1) = KP; INDEX(2) = Q.	

with UT in hours and GGLG in degrees. The CG meridian of local midnight is that which intersects GGLG at the geographic latitude of the anti-subsolar point.

Ideally, the CG coordinates could be obtained by the proper transformation of these two geographic coordinates. There are practical difficulties, however. First, Subroutine GC2MC, which transforms geographic coordinates to corrected geomagnetic coordinates, was designed empirically for high latitudes in the northern hemisphere (ref. 9); and it becomes increasingly inaccurate at lower latitudes. It provides a convenient first approximation, but must be corrected for low latitudes.

This presents a second problem. The tables of Hakura (ref. 7), on which the development of GC2MC was based, extend no lower than 20 degrees geographic latitude. In order to determine corrections to GC2MC, values of the CG coordinates corresponding to geographic coordinates down to the equator must be determined. The method used to accomplish this follows that of Montbriand (ref. 10). Lines of constant geographic longitude have been plotted on a grid of geographic latitude versus CG longitude, using the CG coordinates of Hakura (ref. 7). These lines have been extended graphically (smooth curves) across the equatorial region where the CG coordinates are not available. At the intersection of these lines with the geographic latitude grid lines, the value of CG longitude can be read. Since this is the only coordinate requiring correction in order to determine the CG meridian of local midnight, discrepancies in CG latitude are ignored.

Corrections to GC2MC have been determined by comparing the CG longitudes obtained from GC2MC from 0 degrees to 25 degrees north geographic latitude at 5-degree intervals with those obtained from the graph. The differences are roughly sinusoidal, but are longitudinally asymmetric, having different amplitudes in two longitudinal regions. Designated as Regions I and II, they are defined by:

Region I: $0 \leq \phi_c < 100,\ 245 < \phi_c \leq 360$ (degrees)

Region II: $100 \leq \phi_c \leq 245$ (degrees) where ϕ_c is the CG longitude computed by GC2MC. The corrected values of ϕ_c, designated as GMLGM in the CG midnight computation, are then given by

$$\text{GMLGM} = \phi_c + \Delta\phi_c$$

where the empirically determined corrections are

$$(\Delta\phi_c)_I = (10.9 - 0.18\theta)\sin[1.674\ (\phi_c + 0.1333\ \theta - 27)] - 0.02\theta + 0.4$$

$$(\Delta\phi_c)_{II} = 2.7 \cos\ (1.5\theta)\ \sin\ [2.483\ (\phi_c + 45)] + 0.6$$

Here θ is geographic latitude in the region

$$0 \leq \theta \leq 25$$

and $\Delta\phi_c$ is in degrees. (These equations, given here in terms of degrees, are programmed in terms of radians.)

Since GC2MC with low latitude corrections is usable only for the northern hemisphere, only positive values of latitude can be employed. When the solar declination is positive (summer), a negative value of θ is required in computing the CG midnight meridian. To avoid this, the CG meridian of local noon is computed and 180 degrees are added to obtain the midnight meridian. When the solar declination is negative (winter), a positive value of θ is required so the CG midnight meridian is computed directly.

In the above procedure, there are three sources of error: that associated with the graphic extension of Hakura's coordinates, that associated with the corrections to GC2MC, and that associated with the indirect determination of CG midnight in the summer. For the first, Montbriand (ref. 10), estimates maximum errors of about ± 0.5 degree CG longitude. For the second, direct comparison of the results of GC2MC-with-corrections with the graphically extended coordinates shows maximum errors of ± 2.1 degrees CG longitude for all latitudes below 25 degrees. So the maximum error in terms of CG time is about ± 10 minutes around local CG midnight during the fall and winter months. The error in the summer months results from the fact that the CG meridians of local noon and midnight are not exactly 180 degrees apart. Deviations increase with increasing magnitude of solar declination and may reach 5 or 6 degrees for certain longitudes during the period around summer solstice. This adds another possible error of up to 24 minutes in the location of CG midnight during this period.

3.1.3.2 <u>Determination of Auroral Oval Boundaries</u>. This procedure is simple and straightforward. CG latitude values for model auroral oval boundaries are stored in arrays at 5 degrees CG longitude (20 minutes of CG time) intervals. There is one model oval corresponding to each integral value of the geomagnetic activity indices (0 to 9). For a given level of geomagnetic activity, the auroral oval boundary latitude for each 20 minutes of CG time is determined by linear interpolation between the two models corresponding to geomagnetic index values bracketing the given value. The computed latitude values are stored in another array together with CG longitude values which are based on the CG longitude of local midnight corresponding to that latitude determined for 00 hours CG local time. When all latitude values of both boundaries have been determined, each pair of CG latitude-longitude coordinates is transformed by Subroutine MC2GC (ref. 9) to geographic coordinates. These coordinates define the auroral oval boundaries in geographic coordinates at roughly 5 degrees geographic longitude intervals (exact interval varies with longitude due to the difference in locations of the geographic and CG poles).

Inputs and outputs for this subroutine are defined in Tables 3-5 and 3-6.

3.1.4 Subroutine TIOVL

TIOVL integrates the position of the auroral oval in time. Eventually, it is expected that this subroutine can be modified to determine the time-integrated deposition of auroral-related energy in the upper atmosphere. From this viewpoint the present situation amounts to the assumption of a uniform energy density throughout the oval, one which vanishes outside the oval. That is, results of the present subroutine indicate only how long a given location is under the auroral oval relative to other locations during a specified period of time.

The method is straightforward, although the details are somewhat complicated. Data required for TIOVL are the begin and end times (UT) for the integration and the geomagnetic index values throughout this period. The position

Table 3-5. INPUTS TO OVAL (UT, GMA, IGM)

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
GMA	Real value of the geomagnetic activity index.	CALLING ROUTINE	
IGM	An integer variable indicating the geomagnetic index used: IGM = 1 for K_p, IGM = 2 for Q. All other values are meaningless.	CALLING ROUTINE	
UT	Real value of universal time	CALLING ROUTINE	hours
RØVL (I,J,K,L)	A four dimensional array containing real values of the CG latitudes of reference auroral oval boundaries. Index I (MAX = 72) identifies CG local time. Index J (MAX = 2) distinguishes north and south boundaries. Index K (MAX = 10) identifies the geomagnetic activity level associated with the model oval. Index L (MAX 2) identifies the geomagnetic activity index for the model oval.	BLØCK DATA	degrees
SØLD	Real value of the solar declination angle corresponding to the time frame for which the auroral oval is to be computed.	DRIVE	degrees

Table 3-6. OUTPUTS FROM OVAL (UT, GMA, IGM)

MNEMONIC SYMBOL	DEFINITION	UNITS
GGLG	Real value of the geographic longitude of local solar midnight.	degrees
GGØVL (I,J,K)	A three dimensional array of real values of the geographic coordinates of auroral oval boundaries. Index I (MAX = 72) is related to CG local time. J = 1 for the north boundary, J = 2 for the south boundary. K = 1 for longitude, K = 2 for latitude.	degrees
GMØVL (I,J,K)	A three dimensional array of real values of the CG coordinates of auroral oval boundaries. Indices have the same meanings as for GGOVL, with the addition of K = 3 for which the array contains values of CG local time.	degrees hours (K = 3)

of the auroral oval is computed for the initial time increment and the appropriate geomagnetic activity level. The oval is then projected onto a geographic latitude-longitude grid (1° x 5°) and each location which is under the oval receives one unit. Universal time is then increased by 20 minutes and the process is repeated until the end time is reached. The value in the accumulator associated with each location is then proportional to the length of time that location was under the auroral oval.

3.1.4.1 Initialization and Time Control. This part of TIOVL zeroes out the latitude-longitude grid (IGRID) and sets up the timing for the integration. If the integration begins one day and ends on the next, it is likely that the end time will "precede" the begin time, since days are not specified. A test is made for this, and when it happens, the end time is incremented by 2400. Total integration time is then computed in terms of hours and decimal fractions thereof.

Time is incremented by 20 minutes for each integration step. In evaluating the geomagnetic activity level and auroral oval position, the midpoint of this time period is used. The level of geomagnetic activity is determined by linear interpolation from the array (GAT) which covers the entire integration period. With UT and the value of the geomagnetic index determined, all data required for the specification of the auroral oval's location is available.

3.1.4.2 Integration Procedure. First, a call to OVAL brings in the boundaries of the auroral oval through array GGOVL, which is in COMMON. (All coordinates used in TIOVL are geographic.) To provide reference lines for programming purposes, the indices of the minimum longitudes for both north and south boundaries are obtained from program function MINT. This is required later so that proper interpolations can be made across the Greenwich meridian where the longitude drops from 360 degrees to 0 degrees. Dummy tables are established from GGOVL in order to have the indices in proper sequence for use in the interpolation routine.

With these preliminaries completed, the procedure begins. The integration takes place along geographic meridians at 5-degree intervals beginning with 0 degree. At each meridian, the north and south boundaries of the auroral oval are determined by linear interpolation between appropriate values from GGOVL. Then beginning with 39 degrees north latitude, the latitude is increased 1 degree. The new latitude is tested to see if it is either within 0.5 degree of one of the boundaries or lies wholly within the boundaries. If the former, program function AUGB computes the fractional area of the 1-degree-by-5-degree grid block which lies under the auroral oval. This fractional contribution is then allotted to the grid block. If the grid block lies entirely within the auroral oval boundaries, a full unit contribution is allotted to that block. Since integer arithmetic is used to minimize storage requirements for the large arrays, the unit contribution is given a value of 10 and the fractional contribution is truncated to the next lower tenth of a unit (values 1 to 9).

When the latitude is increased to the extent that the northern boundary of the oval is passed, the longitude is incremented by 5 degrees and the procedure repeats until 355 degrees is completed. Then time is increased by 20 minutes, and all is repeated. After the final time increment, the contents of the grid locations (array IGRID) are printed out.

3.1.4.3 Option to Compute Isointensity Contours at Grid Intervals of 100. This option gives the coordinates of contours of constant magnitude in IGRID. Contour intervals are 100, corresponding to the location being under the auroral oval for 10 integration increments, i.e., 3 hours and 20 minutes. It is optional because it is not very useful unless the total integration period is long compared with 3 hours. These contours are useful for indicating regions likely to receive most auroral energy, assuming that the longer a location is under the auroral oval, the more energy it receives.

Latitudes of isointensity contours are stored in array CON (I,J,K). Index J is related to longitude, a change of one unit corresponding to 5 degrees change in longitude. For each longitude, four latitude values can be stored, identified by index I. Normally only two values are stored, corresponding to a northern and a southern contour. When a contour curves back on itself, however, four or more values may be required. Pathological cases requiring the storage of more than four latitude values for a given meridian are beyond the present capability of TIOVL. The index K in CON relates to the intensity value. At present, 900 is the maximum value possible, consistent with other limits of AOK.

The following procedure is used in this part of TIOVL. After array elements of CON are initially zeroed out, the value of the maximum intensity contour is computed for the present case. For each intensity, contour latitudes are computed at 5-degree longitude intervals using linear interpolation between appropriate values of IGRID along the meridian (going north to south so that the highest latitude value corresponds to CON (1,J,K)). After all longitudes are completed, the next larger intensity value is treated in the same manner, until the maximum value is completed. Then the contents of CON are printed out.

Inputs and outputs for this subroutine are defined in Tables 3-7 and 3-8.

3.1.5 Subroutine PPLOT(LS)

This subroutine prepares data for polar plotting and calls Subroutine POLAR to execute the plots. PPLOT consists of two independent parts: one section prepares auroral oval boundary data for plotting in program Options I and II; the other prepares isointensity contour data for plotting in Option III. The former is direct, simple and short. The latter is long and complicated; hence, more attention will be directed toward this portion.

3.1.5.1 Auroral Oval Plots. For plotting of auroral oval boundaries, all that is required is to change latitude to colatitude and to extend the array containing the boundary coordinates so that the first point is repeated as the final point. This causes the plotted boundaries to close. Subroutine POLAR is then called and the plot executed.

3.1.5.2 Isointensity Contour Plots. If the Option III grid printout (IGRID in Subroutine TIOVL) were graphed as a topographical surface, the contours plotted here would represent lines of constant altitude. Preparing data for the plotting of these isointensity contours is complicated because of the difficulty of following the contour from point to point. Coordinates of the contours

Table 3-7. INPUTS TO TIOVL

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
GAT(I,J)	A two dimensional array of real values of the geomagnetic index and corresponding values of UT. IMAX = 96. J = 1 for UT, J = 2 for the geomagnetic index.	DRIVE	hours (UT)
GGØVL (I,J,K)	A three dimensional array of real values of the geographic coordinates of auroral oval boundaries. Index I (MAX = 72) is related to CG local time. J = 1 for the north boundary, J = 2 for the south boundary. K = 1 for longitude, K = 2 for latitude.	ØVAL	degrees
GMA	Real value of the geomagnetic activity index.	DRIVE	
IGM	An integer variable indicating the geomagnetic index used: IGM = 1 for K_p, IGM = 2 for Q. All other values are meaningless.	DRIVE	
IØPT	Integer variable option designator. In this subroutine if IOPT > 1, isointensity contours are computed, otherwise not.		
IUTB	Initial value (integer) of UT in time-integration.	DRIVE	hours & minutes
IUTE	Final value (integer) of UT in time-integration.	DRIVE	hours & minutes
NGMA	Integer variable specifying the number of pairs of values actually stored in array GAT.	DRIVE	

Table 3-8. OUTPUTS FROM TIOVL

MNEMONIC SYMBOL	DEFINITION	UNITS
CØN(I,J,K)	A three dimensional array of real values of the geographic latitudes of isointensity contours at intervals of 5 degrees longitude (beginning with 0 degrees). Index I (IMAX = 4) labels different contours with the same intensity along a given meridian in order of decreasing latitude. Index J (JMAX = 72) relates to longitude. Index K (KMAX = 9) labels the intensity value of the contour.	degrees
IGRID(I,J)	A two dimensional array of integer numbers which are proportional to the length of time the corresponding location is under the auroral oval during the integration period. Index I (MAX = 50) is related to geographic latitude; index J (MAX = 72) is related to geographic longitude.	
NCØN	Integer variable giving the maximum number of contour values.	
TT	Real value of the total integration time.	hours
IERR	Integer variable giving the statement number immediately preceding a detected error condition.	

are contained in array CON, produced in TIOVL. This array allows for four contours of a given value crossing each meridian. Normally as a meridian crosses the time-integrated auroral oval (IGRID), it passes through a single peak of intensity. In this case only two contours of a given value cross the meridian, one on either side of the peak. If there is a double peak of intensity, there are generally four such crossings, Figure 3-1 illustrates these two conditions. More than two such peaks cannot be adequately treated in this program; however, no example of this has yet been found in any test case (as could be seen in the grid printout).

In order to plot the contour, the coordinates of the contour must be stored sequentially in an array, SCP in this program. One difficulty arises when the next meridian has four latitude values stored in CON. The computer must select one as the next sequential point. To determine which is next, a form of quasi-linear extrapolation is used, based on the two preceding points. Since points are plotted at fixed longitude intervals of 5 degrees, that coordinate is known. The latitude of the next point is predicted in the following way. Let k be the index of the present point, k+1 that of the point to be predicted, and k-1 be that of the previous point. Denote by r the colatitude of a point. The prediction equation is then written

$$r_{k+1} = r_k + \Delta r_k$$

where

$$\Delta r_k = r_k - r_{k-1}$$

Hence

$$r_{k+1} = 2r_k - r_{k-1}$$

The values in CON corresponding to k+1 are then compared with $(90 - r_{k+1})$. The first value (starting with the highest latitude) to be within 1 degree of r_{k+1} is accepted as the next sequential point and is stored accordingly in SCP. For this approach, the first two points in the contour must be identified explicitly.

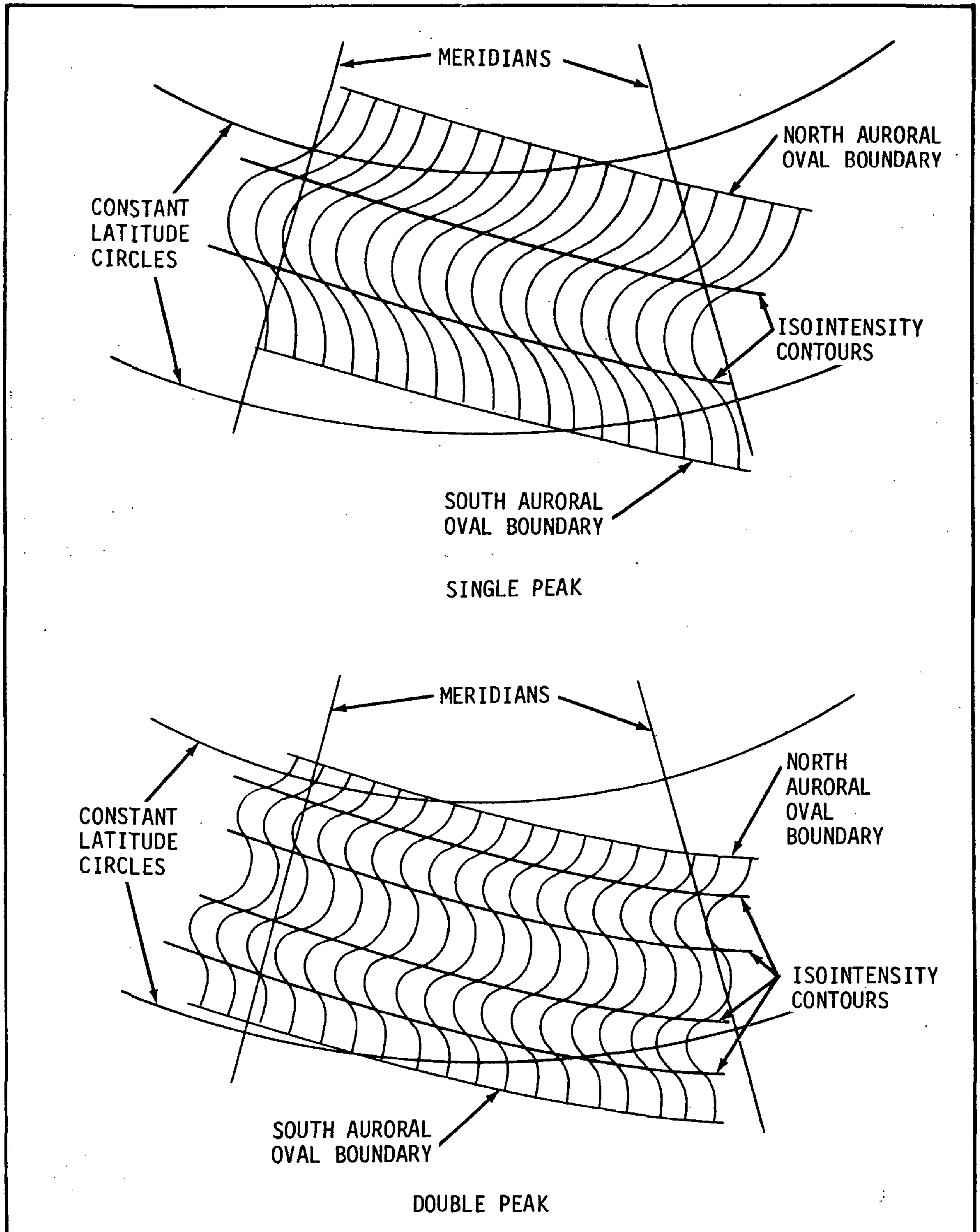

Figure 3-1. TOPOGRAPHIC ILLUSTRATIONS OF POSSIBLE DISTRIBUTIONS IN CONTENTS OF ARRAY IGRID, WHERE ALTITUDE IS PROPORTIONAL TO THE LENGTH OF TIME THAT POSITION IS UNDER THE AURORAL OVAL FOR THE PERIOD OF INTEGRATION

If no latitude value lies within 1 degree of the predicted r_{k+1}, the contour is assumed to have turned back on itself. That is, the next sequential point does not lie on the next meridian, rather it crosses the present meridian again. This is the other major area of complication in PPLOT. When this occurs, it is assumed that the latitude value which lies closest to the present one belongs to the contour doubling back; hence, that value is assigned to the next sequential point. A similar criterion is used in selecting the second point in the reverse direction. After that, the normal prediction procedure is resumed. A flag (L) is used to keep track of the direction of the contour so that proper meridian and array elements are used with each step.

Once a particular contour point in CON has been selected and stored in SCP, it is zeroed out of CON so that it cannot be selected again. This reduces the possibility of selecting the wrong point at a later time. The only exception to this procedure occurs with the initial point. Each time a sequential contour point is stored in SCP, it is compared with the first point. If it is the same, the contour is complete and POLAR is called to plot it. Otherwise the next sequential point is determined by the methods outlined above. The initial point must be retained in CON so that it can be selected in the normal manner; otherwise the computer thinks that the contour is reversing itself and the contour will never close. Following closure of a given contour line, the initial contour point is zeroed out so as not to interfere with the determination of other contour lines of the same value.

All contours for a given time-integration are plotted on the same graph. These contours are not labled by the plotter, so reference must be made to the printouts of IGRID and CON for manual labeling of contour values.

Inputs and outputs for this subroutine are defined in Tables 3-9 and 3-10.

3.1.6 Subroutine POLAR (L, FLD, NP, AMP, PHASE)

This subroutine provides polar plots on a polar grid. In its original form, POLAR was programmed as a system plot routine for the MSFC UNIVAC 1108 computer system. It has been modified for use on the 7094 computer and further adapted to the problem treated by this program. Basically POLAR takes data

Table 3-9. INPUTS TO PPLOT(LS)

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
CØN(I,J,K)	A three dimensional array of real values of the geographic latitudes of isointensity contours at intervals of 5 degrees longitude (beginning with 0 degrees). Index I (MAX = 4) labels different contours with the same intensity along a given meridian in order of decreasing latitude. Index J (MAX = 72) relates to longitude. Index K (MAX = 9) labels the intensity value of the contour.	TIØVL	degrees
GGØVL (I,J,K)	A three dimensional array of real values of the geographic coordinates of auroral oval boundaries. Index I (MAX = 72) is related to CG local time. J = 1 for the north boundary, J = 2 for the south boundary. K = 1 for longitude, K = 2 for latitude.	ØVAL	degrees
LS	Integer argument designating desired output: LS = 1 gives auroral oval plots, LS = 2 gives isointensity contour plots.	CALLING ROUTINE	
NCØN	Integer variable giving the maximum number of contour values in Option III.	TIØVL	

Table 3-10. OUTPUTS FROM PPLOT(LS)

MNEMONIC SYMBOL	DEFINITION	UNITS
FLD1	Field data array containing labeling information for plots.	
FLD2	Field data array containing labeling information for plots.	
IERR	Integer variable giving the statement number immediately preceding a detected error condition.	
PØVL(I,J)	A two dimensional array containing real values of the geographic latitudes of auroral oval boundary points to be plotted. Index I (MAX = 73) relates to longitude. J = 1 for the north boundary, J = 2 for the south boundary.	degrees
SCP(I,J)	A two dimensional array containing real values of the geographic coordinates of sequential contour points. IMAX = 150. J = 1 for longitude, J = 2 for latitude.	degrees

ready for plotting and executes the plots through calls to system plotting routines. Data manipulation consists primarily in setting upper and lower limits to the magnitude variable, and changing polar coordinates to cartesian coordinates, with appropriate scaling of the plot parameters.

The grid on the plots is logarithmic in the polar amplitude variable. This grid is produced by a slide, and this slide is the only polar grid available on the SC4020 plotter at MSFC. For this program the logarithmic portion of the grid should be ignored - the plots are actually linear in the polar amplitude variable.

Inputs and outputs for this subroutine are defined in Table 3-11.

3.1.7 Subroutine MC2GC (X, Y)

MC2GC transforms corrected geomagnetic coordinates to geographic coordinates. This subroutine is documented in reference 9 which should be consulted for derivations of equations and other details.

Inputs and outputs for this subroutine are defined in Tables 3-12 and 3-13.

3.1.8 Subroutine GC2MC (X, Y)

GC2MC transforms geographic coordinates to corrected geomagnetic coordinates. This subroutine is documented in reference 9, which should be consulted for derivations of the equations and other details.

Inputs and outputs for this subroutine are defined in Tables 3-14 and 3-15.

3.1.9 Subroutine ERROR (IFLAG, IERR)

ERROR prints out error messages which give the name of the subroutine and the statement number immediately preceding the error condition. The only inputs are the arguments IFLAG, which indicates the subroutine and IERR, which gives the statement number. Output is the error message described above.

Table 3-11. INPUTS TO POLAR (L, FLD, NP, AMP, PHASE)

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
AMP(I)	A one dimensional array of real values of the polar amplitude variable to be plotted.	CALLING ROUTINE	degrees
FLD	A field data array containing eight words of alphanumeric labeling data, placed at the lower right of the polar grid. Label is written as two words per line on four lines.	CALLING ROUTINE	
GGLG	Real value of the geographic meridian of local solar noon.	ØVAL	degrees
L	Integer frame-advance parameter. For L $\leq$ 0, plot frame is advanced, polar grid is plotted, and curve is plotted. For L > 0, curve is plotted on current frame using previous grid.	CALLING ROUTINE	
NP	Integer variables specifying the number of points to be plotted. Points plotted are always connected by straight line segments.	CALLING ROUTINE	
PHASE(I)	A one dimensional array of real values of the polar angle variable to be plotted.	CALLING ROUTINE	
	Outputs are polar plots		

Table 3-12. INPUTS TO MC2GC (X, Y)

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
ALPHC BETC DELC EPC RC	Real values of transformation constants	BLØCK DATA	radians radians radians radians
X	Real value of CG latitude	CALLING ROUTINE	degrees
Y	Real value of CG longitude	CALLING ROUTINE	degrees

Table 3-13. OUTPUTS FROM MC2GC (X, Y)

MNEMONIC SYMBOL	DEFINITION		UNITS
X	Real value of geographic latitude		degrees
Y	Real value of geographic longitude		degrees

Table 3-14. INPUTS TO GC2MC (X, Y)

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
ALPHC BETC DELC EPC RC	Real values of transformation constants	BLØCK DATA	radians radians radians radians
X	Real value of geographic latitude	CALLING ROUTINE	degrees
Y	Real value of geographic longitude	CALLING ROUTINE	degrees

Table 3-15. OUTPUTS FROM GC2MC (X, Y)

MNEMONIC SYMBOL	DEFINITION		UNITS
X	Real value of CG latitude		degrees
Y	Real value of CG longitude		degrees

3.2 PROGRAM FUNCTIONS

3.2.1 Function CYTAB (X, TABLE, NP, NI, CYC)

CYTAB is a table-lookup, linear interpolation function for a circular table, that is, for a table in which the final value is followed by the initial value and the table repeats. This function is used in determining the latitude of an auroral oval boundary on a given meridian from a table of boundary coordinates. In this case, longitude is the cyclic variable. The only difference between this function and the function SINGF is that provision must be made for interpolation between the final and initial values in the table. In order for this function to give correct results, the independent cyclic variable must be a monotonic increasing function from the beginning to the end of its cycle. The initial point of the cycle must be identified in the function arguments, since it is not usually the initial point in the array. CYTAB is written so that it should be applicable to cyclic tables generally (providing that the independent variable is monotonic increasing).

Inputs and outputs for this subroutine are presented in Table 3-16.

3.2.2 Function SINGF (X, TABLE, NP, ND)

This function is a single variable table-lookup and interpolation function. The table values must be stored in a monotonic increasing sequence of the independent variable. If X exceeds the last array value, SINGF is set equal to the last array value of the dependent variable. If X is less than the initial array value, SINGF is set equal to the initial array value of the dependent variable. Note: Normally NP and ND are the same and one could be deleted. However, in this program a partially filled table is used; and due to the way arrays are stored in core, both the table dimension and the number of locations actually used must be provided to the function to obtain the correct results.

Inputs and outputs for this subroutine are defined in Table 3-17.

Table 3-16. INPUTS TO CYTAB (X, TABLE, NP, NI, CYC)

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
CYC	Real value of the cycle length of the cyclic variable in units of the cyclic variable.	CALLING ROUTINE	
NI	Index of the minimum table value of the cyclic variable.	CALLING ROUTINE	
NP	Integer number of values of the cyclic variable in array TABLE.	CALLING ROUTINE	
TABLE(I,J)	A two dimensional array of real values of an independent (cyclic) variable and corresponding values of a dependent variable. Index I (MAX = 72) labels the values. J = 1 for the independent variable, J = 2 for the dependent variable.	CALLING ROUTINE	
X	Real value of the independent (cyclic) variable for which the corresponding value of the dependent variable is desired.	CALLING ROUTINE	

Table 3-17. INPUTS TO SINGF (X, TABLE, NP, ND)

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
ND	Dimension of first index of TABLE in calling subroutine.	CALLING ROUTINE	
NP	Integer value of the number of data points actually in TABLE.	CALLING ROUTINE	
TABLE(I,J)	A two dimensional array of real values of an independent variable and corresponding values of a dependent variable. Index I (MAX = ND) labels the values. J = 1 for the independent variable, J = 2 for the dependent variable.	CALLING ROUTINE	
X	Real value of the independent variable for which the corresponding value of the dependent variable is desired.	CALLING ROUTINE	

3.2.3 Function Y3 (Y2, Y1, X3, X2, X1)

Y3 is a linear interpolation function. The equation for Y3 is

$$Y3 = Y1 + (Y1 - Y2) * (X3 - X1)/(X1 - X2)$$

Inputs and outputs for this subroutine are defined in Table 3-18.

3.2.4 Function AUGB (GLGD, GLTP, TABLE, NI)

For a grid location lying on the border of the auroral oval, AUGB computes the fractional area of the grid which lies under (for the north boundary) or outside of (for the south boundary) the auroral oval. The grid area (1 degree latitude by 5 degrees longitude) is divided into 10 longitudinal strips, each 0.5 degrees wide. For the meridian running through the center of each strip, the latitude of the auroral oval boundary is determined. If this latitude lies within the strip, the fractional contribution is determined based on 0.0 at the south edge to 0.1 at the north edge. The values 0.0 (0.1) are taken if the boundary latitude lies entirely south (north) of the strip in question. These contributions are summed over the 10 strips to determine the fractional area of the grid which lies under (outside) the auroral oval for the north (south) boundary.

Inputs and outputs for this subroutine are defined in Table 3-19.

3.2.5 Function MINT (TABLE, NP)

MINT provides the index of the minimum array value for a cyclic monotonic increasing sequence.

Inputs and outputs for this subroutine are defined in Table 3-20.

3.2.6 Function MINIT (M)

MINIT is a universal time (e.g., UT = 2315) modulus function. When minutes exceed 60, it adds one hour and subtracts 60 minutes. The only input is the argument M, which is universal time expressed as a fixed point integer.

Table 3-18. INPUTS TO Y3 (Y2, Y1, X3, X2, X1)

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
X1, Y1	Real values of the independent and dependent variables for the lower interpolation point.	CALLING ROUTINE	
X2, Y2	Real values of the independent and dependent variables for the upper interpolation point.	CALLING ROUTINE	
X3	Real present value of the independent variable.	CALLING ROUTINE	

Table 3-19. INPUTS TO AUGB (GLGD, GLTP, TABLE, NI)

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
GLGD	Real value of the longitude of the center of the grid area.	CALLING ROUTINE	degrees
GLTP	Real value of the latitude of the center of the grid area.	CALLING ROUTINE	degrees
NI	Index of the minimum longitude coordinate (J = 1) in TABLE.	CALLING ROUTINE	
TABLE(I,J)	Real values of the geographic coordinates of an auroral oval boundary. Index I (MAX = 72) labels the values. J = 1 for longitude, J = 2 for latitude.	CALLING ROUTINE	degrees

Table 3-20. INPUTS TO MINT (TABLE, NP)

MNEMONIC SYMBOL	DEFINITION	SOURCE ROUTINE	UNITS
NP	Integer value of the number of array elements in TABLE.	CALLING ROUTINE	
TABLE(I)	A cyclic sequence of monotonic increasing (real) values; i.e., when the maximum value of the sequence is reached, the sequence begins again with the minimum value. IMAX = NP. NOTE: The first value in TABLE is usually not the first (minimum) value in the sequence.	CALLING ROUTINE	

3.2.7 Function TMIN (UT)

TMIN changes the minutes in universal time to a decimal fraction of an hour, so that universal time is in units of hours (e.g., converts 2345 to 23.75). The only input to TMIN is the argument UT, which is universal time expressed as a real variable.

3.2.8 Function IMIN (X, TABLE, N)

IMIN gives the index of the value in the array table which is closest to the value of X. N is the dimension of Table(I).

3.2.9 Function ELPS (X, Y, Z)

ELPS is a statement function given by the following equation:

$$\mathrm{ELPS} = \sqrt{\frac{1 - X^2 \cos^2 Y}{1 - X^2 \cos^2 Z}}$$

The only inputs are the floating point arguments X, Y, and Z.

3.2.10 Function RAD (X)

RAD converts X in degrees to radians from the equation:

$$\mathrm{RAD} = 0.0174533X$$

3.2.11 Function RADI (X)

RADI converts X in radians to degrees from the equation:

$$\mathrm{RADI} = 57.2957795X$$

3.2.12 Function AMAG (X, Y, Z)

AMAG is a statement function given by the following equation:

$$\mathrm{AMAG} = \sqrt{X^2 + Y^2 + 2XY \cos Z}$$

The only inputs are the real arguments X, Y, and Z.

3.3 BLOCK DATA

Two block data subroutines are required to meet working storage limitations during compilation. The bulk of the data consists of boundary coordinates of reference auroral ovals for geomagnetic indices Q (15 minute local index) and K_p (3 hour planetary index). These models were discussed in Section II.

Inputs and outputs for this subroutine are defined in Table 3-21.

Table 3-21. OUTPUTS FROM BLOCK DATA

MNEMONIC SYMBOL	DEFINITION	UNITS
ALPHC BETC DELC EPC RC	Real values of transformation constants in the conversion of geographic to CG coordinates and vice versa.	radians radians radians radians
IN	Integer input unit number	
ØUT	Integer output unit number	
PN0(I)- PN9(I)	One dimensional arrays containing real values of the CG latitudes for the north boundaries of the reference auroral ovals corresponding to integer values of the K_p geomagnetic activity index (see Appendix A). There are 72 values at 20 minute (CG local time) intervals beginning with 0000 hours.	degrees
PS0(I)- PS9(I)	Same for south boundaries	degrees
QN0(I)- QN9(I) QS0(I)- QS9(I)	Same as P-arrays but for the Q geomagnetic activity index (see Appendix B).	degrees degrees

3.4 SYSTEM SUBROUTINES AND FUNCTIONS

The following subroutines and functions in the MSFC system subroutine library are used:

MATHEMATICS

ATAN2 COS EXP SIN SQRT

Section IV

USING THE PROGRAM

4.1 COMPUTER CONFIGURATION

AOK is written in Fortran IV for the IBM 7094 computer at MSFC, which operates under IBSYS/Version 13. Plots require the Stromberg-Carlson 4020 plotter. Core storage required by AOK is approximately 60,000 words octal, about 25,000 words decimal.

4.2 RUN TIMES

Run times vary depending on the options used and the number of cases. For the time-integration option (III), run times are typically 3-5 minutes including compilation. Run times for the other two options are generally 1-3 minutes, including compilation.

4.3 PROGRAM INPUTS

For any use of AOK the first data card is the option designator card. The format of this card is shown in Figure 4-1. Names shown are the mnemonic symbols used in the program; their meanings are as follows (below each name is the input format):

IOPT (Col. 1-10) (I10)	Input Option Designator: IOPT < 0 For Option I, IOPT = 0 for Option II; IOPT > 0 for Option III. For Option III, IOPT > 1 also gives isointensity contours.
LAST (Col. 11-20) (I10)	Last case indicator: LAST = 0 for last case; LAST ≠ 0 for more cases to follow.

Other inputs depend on the option selected and are treated separately below. For each case, only one option may be selected. Each new option requires a new option designator card and different input data following it.

4.3.1 Option I: Production of Auroral Oval Tables

This option requires a single data card specifying limits to the tables and other pertinent data. The card format is shown in Figure 4-2. Data elements are:

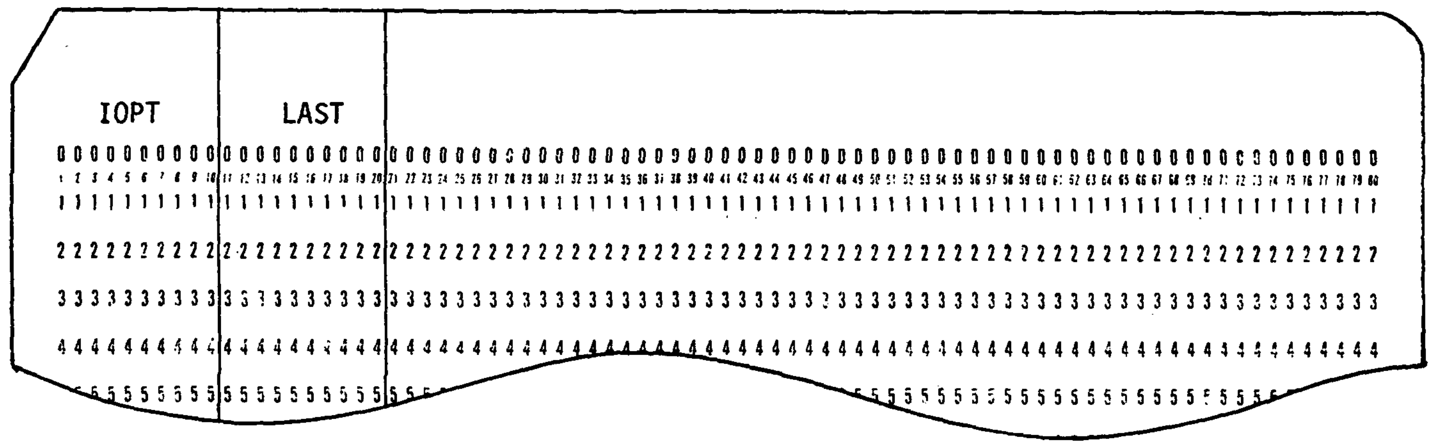

Figure 4-1. FORMAT OF OPTION DESIGNATOR CARD

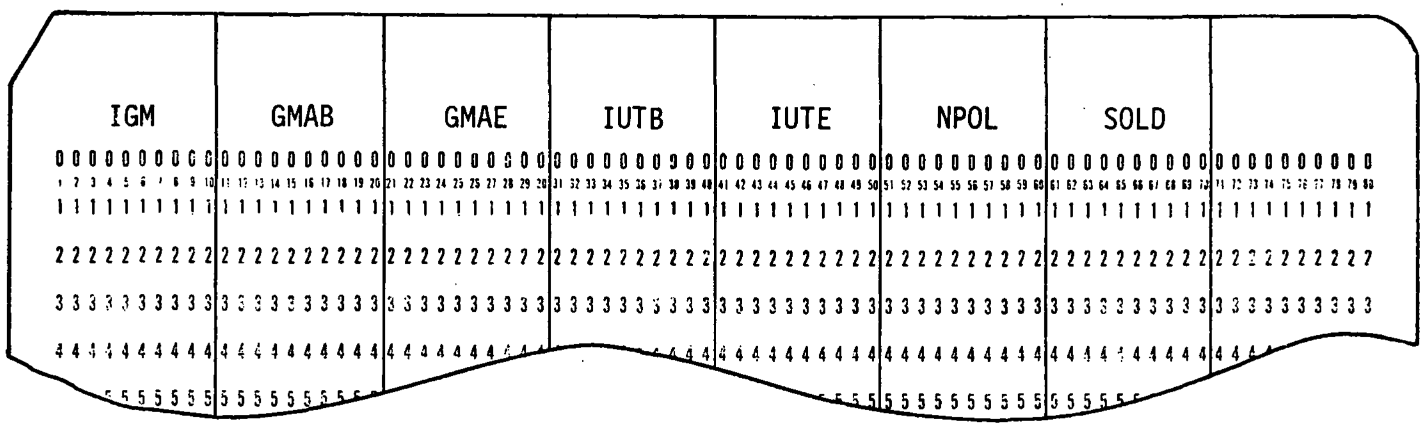

Figure 4-2. FORMAT OF DATA CARD FOR OPTION I

IGM (Col. 1-10) (I10)	Geomagnetic index indicator: IGM = 1 for K_p; IGM = 2 for Q.
GMAB (Col. 11-20) (F10.2)	Lowest value of geomagnetic index desired in tables ($0.0 \leq GMAB \leq 9.0$)
GMAE (Col. 21-30) (F10.2)	Highest value of geomagnetic index desired in tables ($0.0 \leq GMAE \leq 9.0$)
IUTB (Col. 31-40) (I10)	Initial UT desired in tables. ($0 \leq IUTB \leq 2400$)
IUTE (Col. 41-50) (I10)	Final UT desired in tables. ($0 \leq IUTE \leq 2400$)
NPOL (Col. 51-60) (I10)	Plot Option Designator: NPOL > 0 gives plots; NPOL $\leq$ 0 gives no plots.
SOLD (Col. 61-70) (F10.2)	Solar declination angle in degrees

4.3.2 Option II: Position of the Auroral Oval for Specified Universal Time and Geomagnetic Activity

In this option two types of cards are required, a single header card and a variable number of data cards. Formats for these cards are shown in Figure 4-3. All data cards for a single case must correspond to the same solar declination angle (SOLD). Each different value of SOLD constitutes a new case, requiring a new option card and a new header card.

Data elements for the header card are:

NC (Col. 1-10) (I10)	Number of data points to be read in
IGM (Col. 11-20) (I10)	See subsection 4.3.1
NPOL (Col. 21-30) (I10)	See subsection 4.3.1
SOLD (Col. 31-40) (F10.2)	See subsection 4.3.1

Data elements for the data card are:

IGAT (Col. 1-10) (I10)(Col. 21-30) (Col. 41-50)	Array of universal times for which auroral oval boundaries are desired.
GAT (Col. 11-20) (F10.2) (Col. 21-30) (Col. 51-60)	Array of values of the geomagnetic activity index corresponding to the universal times in IGAT.

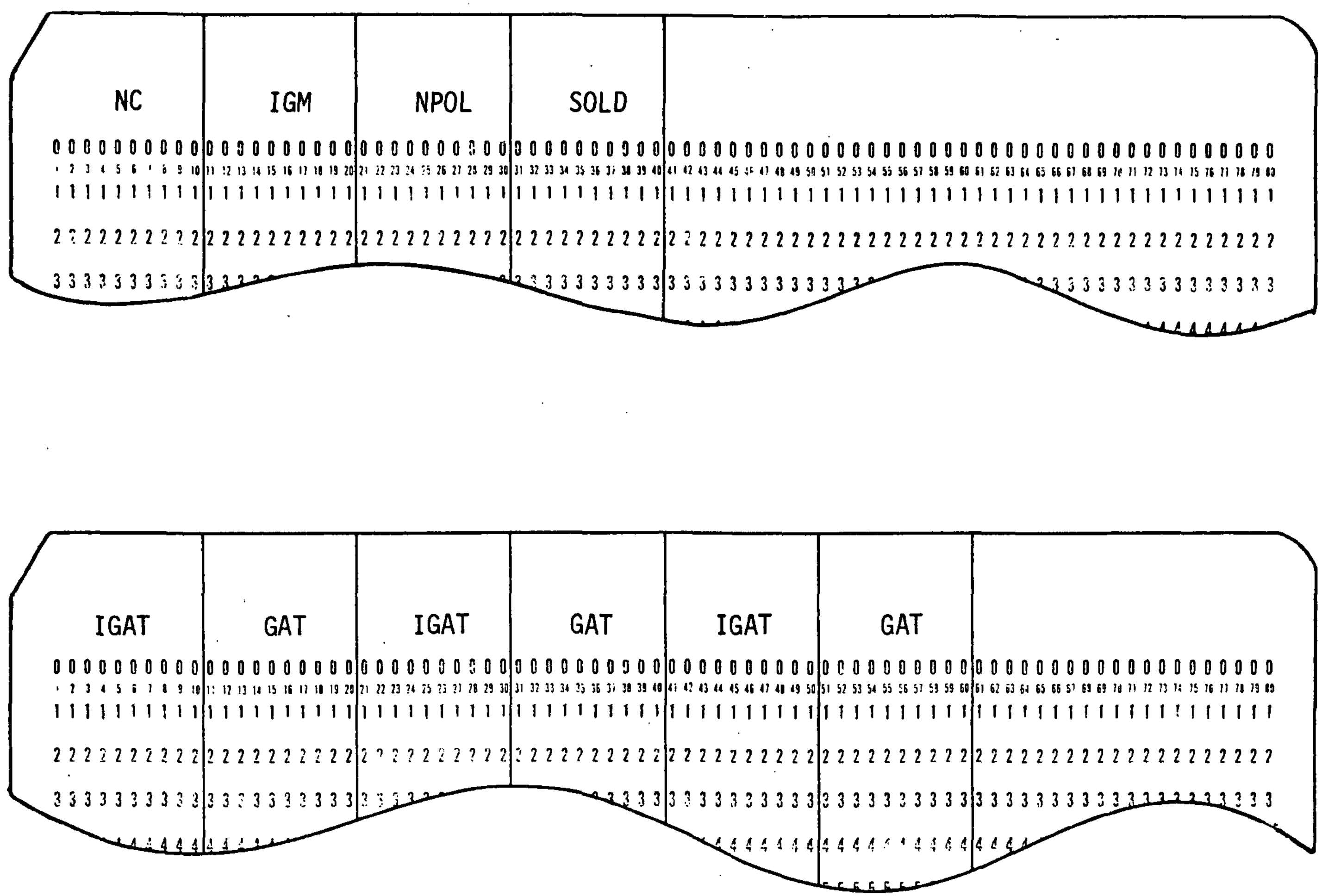

Figure 4-3. FORMATS FOR HEADER AND DATA CARDS FOR OPTION II

Note: These data are read in as pairs of coordinates (IGAT, GAT), three pairs to each card.

4.3.3 Option III: Time-Integrated Position of the Auroral Oval

Two types of cards are required for this option. The formats of the header and data cards are shown in Figure 4-4.

Data elements for the header cards are:

NGMA (Col. 1-10) (I10)	Number of values of the geomagnetic activity index to be read in
IGM (Col. 11-20) (I10)	See subsection 4.3.1
ITGMB (Col. 21-30) (I10)	Universal time corresponding to first value of geomagnetic activity index to be read in.
IUTB (Col. 31-40) (I10)	Universal time for start of time-integration
IUTE (Col. 41-50) (I10)	Universal time for end of time-integration
NPOL (Col. 51-60) (I10)	See subsection 4.3.1
SOLD (Col. 61-70) (F10.2)	See subsection 4.3.1

Data elements for the data card are:

GAT (Col. 1-10, etc.) (F10.2) (7 per card)	Array of values of geomagnetic activity index covering the period of integration

Note: In using this option, values of the geomagnetic activity index for the entire period of the integration must be read in. This means the value of ITGMB must be the same as or smaller than the value of IUTB. If the K_p index is used, a value is needed for every 3 hours, while for the Q index, one is needed for every 15 minutes. Times are generated by the program by adding 3 hours or 15 minutes, as appropriate, to ITGMB (initially). So ITGMB should correspond to the middle of the time period to which the first geomagnetic activity index belongs.

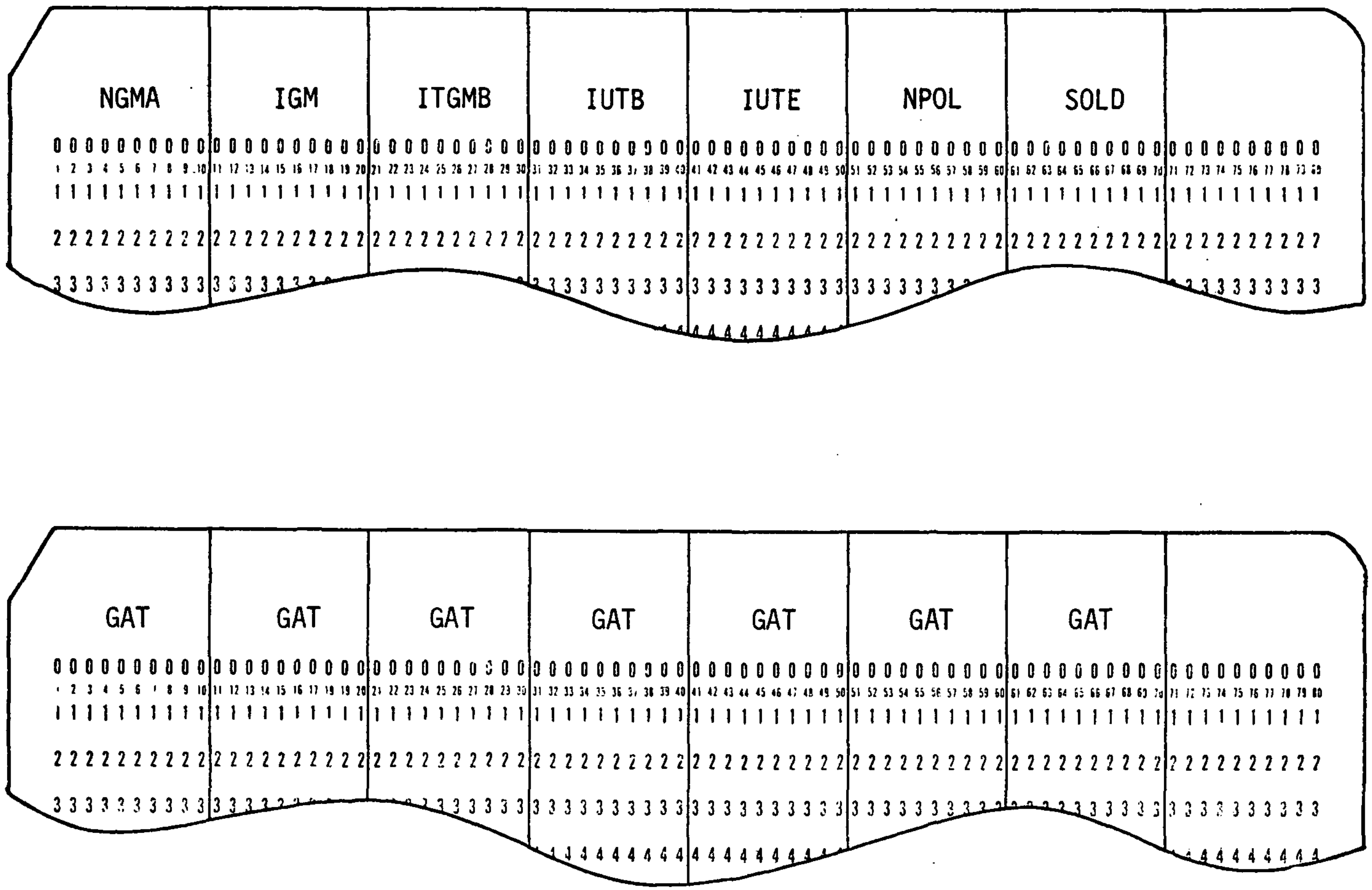

Figure 4-4. FORMATS FOR HEADER AND DATA CARDS FOR OPTION III

4.4 DECK LAYOUTS

Control cards required to run AOK on the IBM 7094 computer at MSFC are shown in Figure 4-5. On each control card the symbol $ goes in column 1. Sequencing of the control cards preceding the DRIVE routine must be as shown. The sequence of the subroutines and functions after the DRIVE routine is immaterial - but the required control card must precede each.

4.5 PROGRAM OUTPUTS

Outputs from AOK vary with the program options exercised. For each option, all input data is printed out. Since these were covered in detail in subsection 4.3, they are not repeated here. Print and plot outputs are covered option by option below.

4.5.1 Option I: Production of Auroral Oval Tables

In this option the auroral oval boundary coordinates are printed out at one hour UT intervals between the limits specified (IUTB and IUTE) and at one unit intervals of geomagnetic activity (Q or K_p) between the specified limits (GMAB and GMAE). In each case the first limit is the initial value, which is then incremented repeatedly until the last limit is exceeded. The preceding value is then the final value. For each pair of values of UT and geomagnetic activity a table of auroral oval boundary coordinates is printed out; a sample is shown in Figure 4-6. The lables are self-explanatory.

The interval of the coordinates in Figure 4-6 is 1 hour of CG local time, which is taken to correspond to 15 degrees CG longitude. In comparing tables in this option, it is seen that the CG longitudes, for a given CG local time, vary with UT, but not with geomagnetic activity, while for the CG latitudes the reverse is true. This corresponds to the idea introduced in Section II that the size of the auroral oval is controlled by the geomagnetic activity and the orientation by the sun (universal time).

It should be noted that for each value of CG longitude both north and south boundary CG latitudes are given. When these are transformed to geographic coordinates, the corresponding geographic longitudes differ, in general, because the center of reference has shifted from the CG pole to the rotational pole.

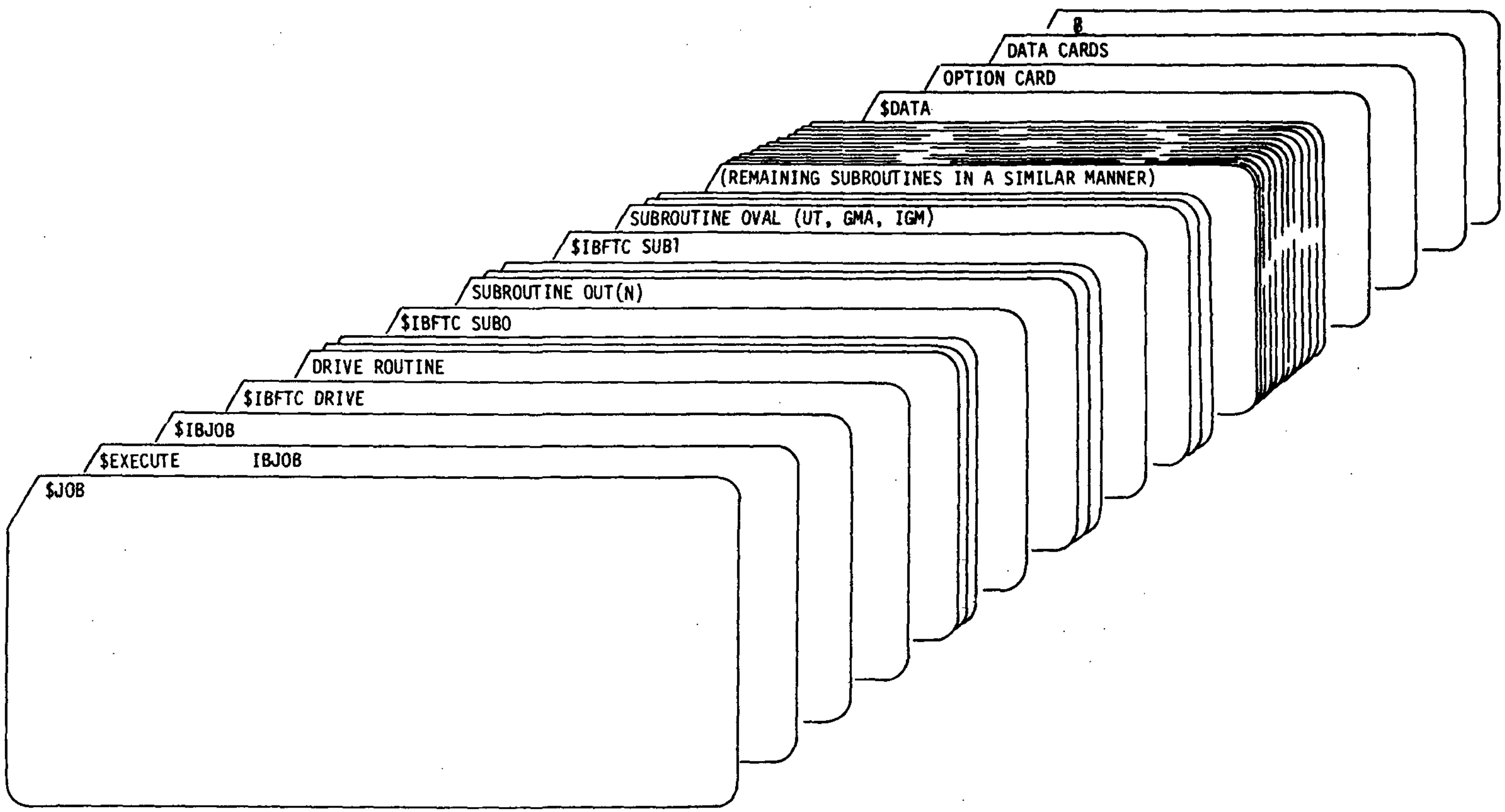

Figure 4-5. CONTROL CARDS AND DECK LAYOUT FOR AØK

AURORAL OVAL BOUNDARIES

UNIVERSAL TIME = 1455 GEOGRAPHIC LONGITUDE OF LOCAL MIDNIGHT = 136.25 KP = 7.0

CORRECTED GEOMAGNETIC LOCAL TIME	CORRECTED GEOMAGNETIC COORDINATES			GEOGRAPHIC COORDINATES			
	LONGITUDE	LATITUDE (NORTH)	LATITUDE (SOUTH)	LONGITUDE (NORTH)	LATITUDE (NORTH)	LONGITUDE (SOUTH)	LATITUDE (SOUTH)
0.	211.47	75.90	58.09	172.08	81.21	146.22	63.74
100.	226.47	75.66	58.42	191.29	79.13	165.54	63.71
200.	241.47	75.42	58.98	207.29	76.56	185.36	62.61
300.	256.47	74.98	59.68	220.76	73.60	204.31	60.64
400.	271.47	74.44	60.04	232.77	70.56	221.17	57.89
500.	286.47	73.44	61.64	243.20	67.28	234.29	56.27
600.	301.47	72.40	63.28	252.71	64.10	249.01	54.90
700.	316.47	71.14	64.60	261.37	60.83	259.72	53.91
800.	331.47	70.30	65.36	269.75	58.34	269.10	52.74
900.	346.47	70.38	66.10	278.06	57.64	277.95	52.66
1000.	1.47	71.14	66.76	286.23	58.81	286.61	53.76
1100.	16.47	72.04	67.28	294.33	61.02	295.37	55.77
1200.	31.47	72.82	67.36	302.69	63.58	304.77	57.95
1300.	46.47	73.28	66.86	311.98	66.08	315.66	59.93
1400.	61.47	73.78	65.60	322.42	68.83	326.93	61.51
1500.	76.47	73.56	64.10	335.22	71.22	344.84	63.15
1600.	91.47	73.00	62.76	350.70	73.48	3.09	64.84
1700.	106.47	72.52	62.90	8.70	75.63	21.97	67.23
1800.	121.47	72.40	63.10	28.69	77.46	41.58	68.69
1900.	136.47	72.70	63.02	49.87	78.66	60.98	68.83
2000.	151.47	73.24	62.10	71.76	79.87	79.35	67.37
2100.	166.47	74.26	60.74	94.31	81.14	96.19	65.39
2200.	181.47	75.12	59.30	119.69	82.07	112.20	63.91
2300.	196.47	75.74	58.42	147.32	82.25	128.56	63.62

Figure 4-6. SAMPLE PRINTED OUTPUT FOR OPTIONS I AND II

If the plot option is exercised, a plot such as shown in Figure 4-7 will result for each table of boundary coordinates. This plot is in geographic coordinates. As discussed under Subroutine POLAR, even though the grid is logarithmic in the polar amplitude variable, the plot is actually linear in this variable. The logarithmic part of the grid should be ignored. Each cycle corresponds to 10 degrees geographic latitude as the labels indicate. The letter "O" near the outer perimeter (40 degrees latitude circle) of the grid denotes the direction of the sun for the universal time for which the auroral oval is pictured.

4.5.2 Option II: Position of the Auroral Oval for Specified Universal Time and Geomagnetic Activity

Output under this option is exactly the same as under Option I; see Figures 4-6 and 4-7 and the discussion in subsection 4.5.1.

4.5.3 Option III: Time-Integrated Position of the Auroral Oval

Under this option the contents of IGRID (subsection 3.1.4) are printed out in tabular form. To cover all longitudes requires four pages; a sample is shown in Figure 4-8. Values in IGRID are proportional to the length of time the corresponding location is under the auroral oval during the integration period. Each 10 units in IGRID corresponds to one integration period of 20 minutes. Numbers less than 10 indicate that a fraction of the IGRID element (1 degree latitude by 5 degrees longitude) was under the oval for one or more integration periods.

Printout of the IGRID table is the only automatic output from this option; other output is available on an optional basis. If, on the input option card, IOPT > 1, isointensity contour coordinates are printed out. A sample of this printout is shown in Figure 4-9. Contour tables are printed out at intervals of 100 units, beginning with 100 and continuing to that contour just below the maximum value. As the sample shows, latitudes are printed out from highest to lowest. All coordinates are geographic.

Also available optionally are polar plots of the isointensity contours. These are obtained by specifying the plot option (NPOL $\neq$ 0) *in addition to* the

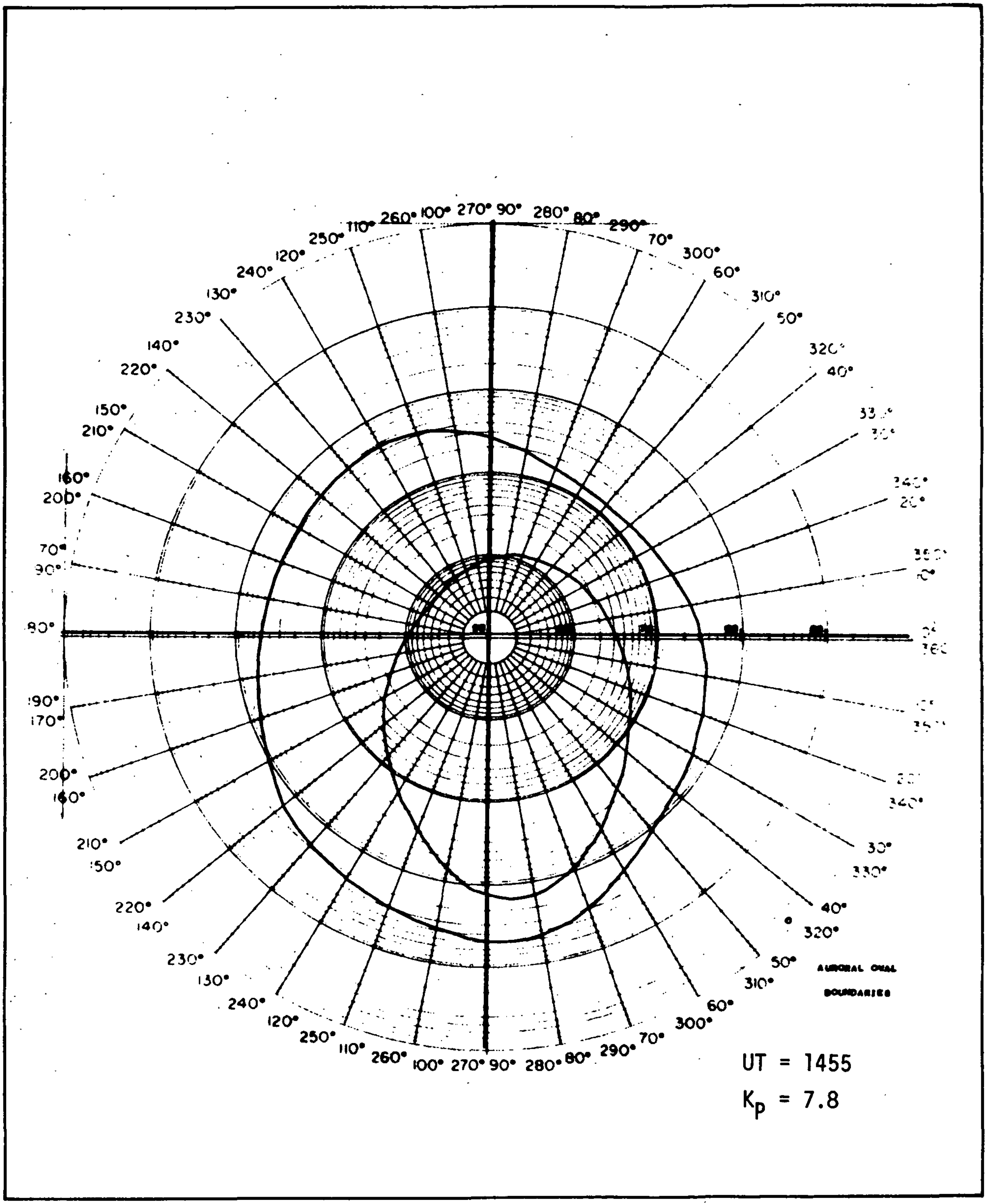

Figure 4-7. SAMPLE PLOT OUTPUT FOR OPTIONS I AND II

LATITUDE							LONGITUDE					INTEGRATION TIME = 23.75 HOURS						
	180	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	171	94	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	284	243	188	83	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	315	316	288	238	146	25	0	0	0	0	0	0	0	0	0	0	0	0
77	269	287	309	310	268	203	48	0	0	0	0	0	0	0	0	0	0	0
76	242	245	255	277	309	287	228	70	0	0	0	0	0	0	0	0	0	0
75	295	242	234	238	251	293	306	239	74	0	0	0	0	0	0	0	0	0
74	364	351	285	236	232	235	274	303	247	76	0	0	0	0	0	0	0	0
73	338	351	364	332	251	231	228	259	304	249	73	0	0	0	0	0	0	0
72	319	329	338	353	356	275	237	227	251	304	247	71	0	0	0	0	0	0
71	298	309	320	333	345	358	299	247	230	250	307	242	51	0	0	0	0	0
70	276	289	300	313	325	342	360	320	250	235	256	306	234	44	0	0	0	0
69	230	259	278	291	306	320	337	355	325	262	239	268	308	225	26	0	0	0
68	56	171	240	266	285	299	315	331	353	334	273	246	290	305	205	20	0	0
67	0	0	82	216	257	277	293	311	329	350	334	281	255	308	299	182	18	0
66	0	0	0	26	162	245	270	289	308	325	349	334	286	270	333	290	159	17
65	0	0	0	0	0	128	236	267	285	304	324	347	332	296	293	344	273	147
64	0	0	0	0	0	0	88	230	261	282	302	323	348	329	305	322	357	258
63	0	0	0	0	0	0	0	69	222	259	280	300	323	349	327	318	351	364
62	0	0	0	0	0	0	0	0	65	218	258	277	300	323	351	325	329	372
61	0	0	0	0	0	0	0	0	0	63	216	252	276	299	323	348	324	347
60	0	0	0	0	0	0	0	0	0	0	63	212	250	273	298	321	350	331
59	0	0	0	0	0	0	0	0	0	0	0	76	210	247	272	294	325	352
58	0	0	0	0	0	0	0	0	0	0	0	0	91	211	244	267	296	318
57	0	0	0	0	0	0	0	0	0	0	0	0	0	106	208	241	266	285
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	121	207	235	255
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	146	201	222
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	150	192
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	145
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4-8. SAMPLE PORTION OF NORMAL PRINTED OUTPUT FOR OPTION III

CONTOURS OF GRID VALUE 300

LONGITUDE	LATITUDES				LONGITUDE	LATITUDES			
0	73.34	68.14	0.00	0.00	5	74.08	68.50	0.00	0.00
10	74.94	69.20	0.00	0.00	15	75.66	69.83	0.00	0.00
20	76.46	70.35	0.00	0.00	25	77.39	70.79	0.00	0.00
30	78.50	71.23	0.00	0.00	35	79.10	71.66	0.00	0.00
40	79.38	71.97	0.00	0.00	45	79.72	72.30	0.00	0.00
50	80.04	72.56	0.00	0.00	55	80.21	72.81	0.00	0.00
60	80.31	73.03	0.00	0.00	65	80.38	73.14	0.00	0.00
70	80.43	73.36	0.00	0.00	75	80.46	73.50	0.00	0.00
80	80.51	73.63	0.00	0.00	85	80.53	73.74	0.00	0.00
90	80.53	73.82	0.00	0.00	95	80.52	73.86	0.00	0.00
100	80.54	73.89	0.00	0.00	105	80.52	73.85	0.00	0.00
110	80.53	73.79	0.00	0.00	115	80.54	73.76	0.00	0.00
120	80.52	73.69	0.00	0.00	125	80.50	73.67	0.00	0.00
130	80.44	73.57	0.00	0.00	135	80.41	73.52	0.00	0.00
140	80.37	73.43	0.00	0.00	145	80.30	73.28	0.00	0.00
150	80.25	78.00	76.85	73.16	155	80.15	78.22	76.72	72.91
160	80.03	78.33	76.57	72.61	165	79.55	78.28	76.35	72.33
170	79.31	78.21	75.71	72.00	175	79.12	77.88	75.48	71.55
180	78.48	77.67	74.93	71.10	185	78.22	77.45	74.47	70.55
190	77.43	76.83	73.81	70.00	195	77.14	76.70	73.33	69.41
200	76.22	75.84	72.53	68.71	205	71.70	68.06	0.00	0.00
210	75.08	74.81	70.98	67.32	215	74.05	73.93	70.27	66.50
220	73.07	72.92	69.33	65.65	225	72.07	71.93	68.47	64.82
230	71.12	70.86	67.56	63.91	235	70.09	69.84	66.64	63.00
240	69.11	68.56	65.70	62.00	245	68.06	66.79	64.88	61.04
250	66.97	65.17	64.42	60.08	255	65.81	59.22	0.00	0.00
260	64.68	58.14	0.00	0.00	265	63.60	57.45	0.00	0.00
270	62.66	56.71	0.00	0.00	275	62.13	56.09	0.00	0.00
280	61.73	55.67	0.00	0.00	285	62.06	55.50	0.00	0.00
290	62.29	55.58	0.00	0.00	295	63.22	62.43	59.83	56.15

Figure 4-9. SAMPLE PORTION OF OPTIONAL CONTOUR COORDINATES PRINTOUT FOR OPTION III

isointensity contour option above. An example of an unusually complicated case is shown in Figure 4-10. Normally the contours do not reverse direction as they do in this figure.

4.6 RUN REQUEST

A sample 7094 Run Request form (MSFC-Form 533) is shown completed for plot output in Figure 4-11. The top portion of the form is completed as shown for all cases. For the optional plot output, the bottom portion of the form should be completed as shown except for the number of frames. The number of frames will be the number of separate auroral ovals computed under Options I and II. For Option III there will be one frame for each case.

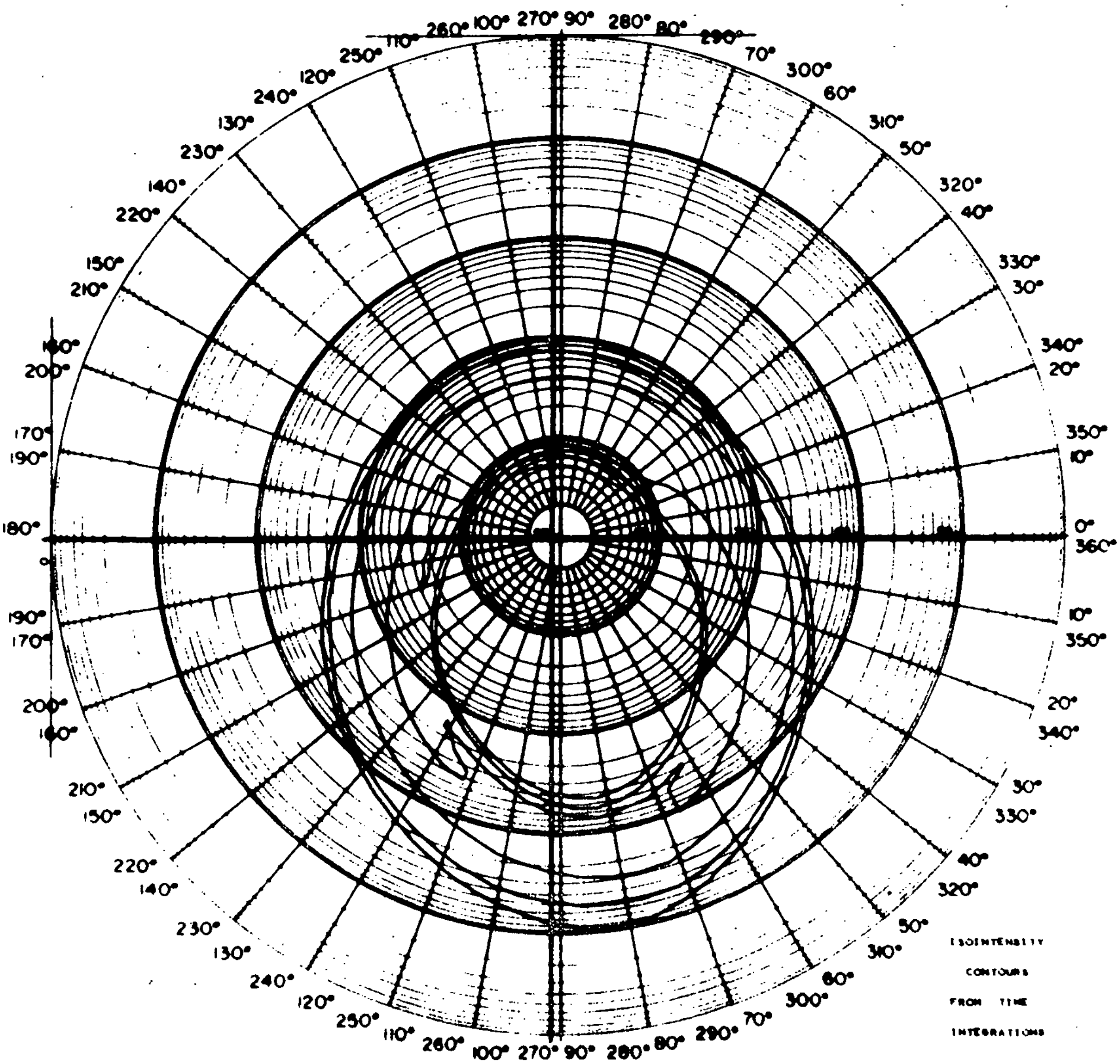

Figure 4-10. SAMPLE CONTOUR PLOT FOR OPTION III

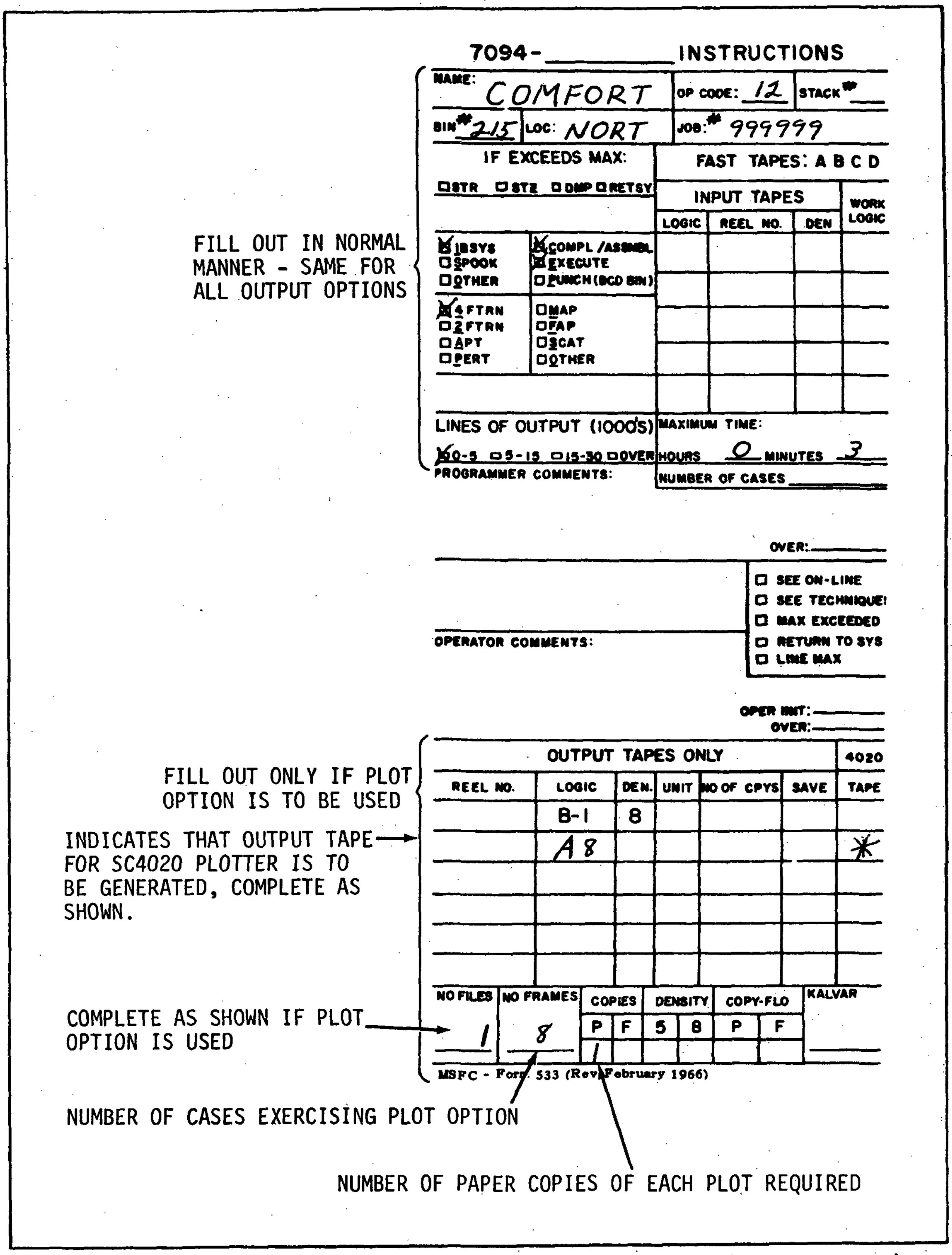

Figure 4-11. EXAMPLE OF COMPLETED 7094 RUN REQUEST FORM (MSFC-FORM 533)

Section V

PROGRAM LISTING

```
$JOB
$EXECUTE        IBJOB
$IBJOB COMFRT
$IBFTC DRIVE
C     AOK IS A TOOL FOR STUDYING AURORAL OVAL KINEMATICS.THE POSITION OF
C     THE AURORAL OVAL IS DETERMINED AS A FUNCTION OF GEOMAGNETIC
C     ACTIVITY AND UNIVERSAL TIME.
C
      DIMENSION IGAT(96)
      COMMON /TIME/ IUTB,IUTE,IUT,ITGMB,TT/GM/IGM,GMA
      COMMON /REDN/ GMAB,GMAE,NC,NGMA,GAT(96,2)
      COMMON /OPT/ IOPT,LAST
      COMMON /IPOUT/ IPO1,NPOL
      COMMON /INOUT/ IN,IO
      COMMON /SUN/ SOLD
C
C     2 READ IN OUTPUT OPTION DESIGNATOR
C
      IPO1=0
    2 READ (IN,36) IOPT,LAST
      IF (IOPT) 4,12,18
C
C     OPTION FOR PRODUCTION OF AURORAL OVAL TABLES
C
    4 READ (IN,38) IGM,GMAB,GMAE,IUTB,IUTE,NPOL,SOLD
      CALL OUT (1)
      IF (GMAB.LE.GMAE) GO TO 6
      IERR=10
      GO TO 32
    6 CONTINUE
      GMA=GMAB
      J=INT(GMAE-GMAB)+1
      DO 10 I=1,J
      IUT=IUTB
      L=(IUTE-IUTB)/100+1
      DO 8 K=1,L
      UT=IUT
      UT=TMIN(UT)
      CALL OVAL (UT,GMA,IGM)
      CALL OUT (7)
      IUT=IUT+100
      IUT=MINIT(IUT)
    8 CONTINUE
      GMA=GMA+1.0
   10 CONTINUE
      GO TO 34
C
C     OPTION TO COMPUTE THE POSITION OF THE AURORAL OVAL FOR SPECIFIED
C     TIME AND GEOMAGNETIC ACTIVITY.
C
   12 READ (IN,40) NC,IGM,NPOL,SOLD
      READ (IN,44) (IGAT(I),GAT(I,2),I=1,NC)
      DO 14 K=1,NC
      TEMP=IGAT(K)
   14 GAT(K,1)=TMIN(TEMP)
      CALL OUT (2)
      DO 16 J=1,NC
```

```
      CALL OVAL (GAT(J,1),GAT(J,2),IGM)
      IUT=IGAT(J)
      GMA=GAT(J,2)
      CALL OUT (7)
   16 CONTINUE
      GO TO 34
C
C     OPTION TO COMPUTE THE TIME-INTEGRATED POSITION OF THE AURORAL OVAL
C
   18 READ (IN,42) NGMA,IGM,ITGMB,IUTB,IUTE,NPOL,SOLD
      CALL OUT (3)
      DO 20 J=1,2
      DO 20 I=1,96
   20 GAT(I,J)=0.0
      UTGMB=ITGMB
      UTGMB=TMIN(UTGMB)
      IF (IGM.EQ.2) GO TO 26
      IF (IGM.EQ.1) GO TO 22
      IERR=82
      GO TO 32
   22 GAT(1,1)=UTGMB
      DO 24 K=2,NGMA
   24 GAT(K,1)=GAT(K-1,1)+3.0
      READ (IN,46) (GAT(K,2),K=1,NGMA)
      GO TO 30
   26 GAT(1,1)=UTGMB
      DO 28 K=2,NGMA
   28 GAT(K,1)=GAT(K-1,1)+.25
      READ (IN,46) (GAT(K,2),K=1,NGMA)
   30 CALL OUT (4)
      CALL TIOVL
      GO TO 34
   32 CALL ERROR (1,IERR)
   34 IF (LAST.NE.0) GO TO 2
      IF (IPO1.EQ.1) CALL ENDPLT
      STOP
C
C     INPUT FORMATS
C
C
   36 FORMAT (7I10)
   38 FORMAT (I10,2F10.2,3I10,F10.2)
   40 FORMAT (3I10,F10.2)
   42 FORMAT (6I10,F10.2)
   44 FORMAT (3(I10,F10.2))
   46 FORMAT (7F10.2)
      END
```

```
$IBFTC SUBO
      SUBROUTINE OUT (N)
C     SUBROUTINE OUT CONTAINS ALL OUTPUT STATEMENTS IN AOK.
      COMMON /TIME/ IUTB,IUTE,IUT,ITGMB,TT/GM/IGM,GMA
      COMMON /REDN/ GMAB,GMAE,NC,NGMA,GAT(96,2)
      COMMON /OVL/ GGLG,GGOVL(72,2,2),GMOVL(72,2,3)
      COMMON /GRID/ IGRID(50,72),NCON,CON(4,72,9)
      COMMON /IPOUT/ IPO1,NPOL
      COMMON /INOUT/ IN,IO
      COMMON /OPT/ IOPT,LAST
      COMMON /SUN/ SOLD
      DIMENSION LONG(18)
      DIMENSION INDEX(2)
      DATA INDEX/2HKP,1HQ/
      IF (NPOL.EQ.0.OR.IPO1.EQ.1) GO TO 2
      CALL PLOT1
      IPO1=1
    2 CONTINUE
      GO TO (4,6,8,10,12,20,26), N
C
C     PRINT OUT INPUT DATA FOR AURORAL OVAL TABLE OPTION.
C
    4 WRITE (IO,28) INDEX(IGM),GMAB,GMAE,IUTB,IUTE,NPOL,SOLD
      WRITE (IO,30) IOPT,LAST
      RETURN
C
C     PRINT OUT INPUT DATA FOR AURORAL OVAL OPTION SPECIFYING THE
C     UNIVERSAL TIME AND GEOMAGNETIC ACTIVITY.
C
    6 WRITE (IO,32) INDEX(IGM),INDEX(IGM),INDEX(IGM)
      WRITE (IO,34) (GAT(I,1),GAT(I,2),I=1,NC)
      WRITE (IO,36) NC,NPOL,SOLD
      WRITE (IO,30) IOPT,LAST
      RETURN
C
C     PRINT OUT INPUT DATA FOR TIME-INTEGRATED AURORAL OVAL OPTION.
C
    8 WRITE (IO,38) NGMA,INDEX(IGM),ITGMB,IUTB,IUTE,NPOL,SOLD
      WRITE (IO,30) IOPT,LAST
      RETURN
   10 WRITE (IO,40) INDEX(IGM)
      WRITE (IO,42) (GAT(K,1),GAT(K,2),K=1,NGMA)
      RETURN
C
C     PRINT OUT GRID CONTENTS FOR TIME-INTEGRATED AURORAL OVAL OPTION
C
   12 WRITE (IO,44)
      DO 18 I=1,4
      IL=18*(I-1)+1
      IU=IL+17
      DO 14 J=1,18
      LONG(J)=5*(J-2+IL)
   14 CONTINUE
      IF (I.NE.1) WRITE (IO,46)
      WRITE (IO,48) TT
      WRITE (IO,50) (LONG(K),K=1,18)
      DO 16 LT=1,50
```

```
      LTL=90-LT
      WRITE (IO,52) LTL,(IGRID(LT,LO),LO=IL,IU)
   16 CONTINUE
   18 CONTINUE
      RETURN
C
C     PRINT OUT GEOGRAPHIC COORDINATES OF CONTOURS OF CONSTANT MAGNITUDE
C     FOR TIME-INTEGRATED AURORAL OVAL OPTION.
C
   20 DO 24 K=1,NCON
      KT=100*K
      WRITE (IO,54) KT
      DO 22 L=1,72,2
      L1=5*(L-1)
      L2=5*L
      LP1=L+1
   22 WRITE (IO,56) L1,(CON(I,L,K),I=1,4),L2,(CON(J,LP1,K),J=1,4)
   24 CONTINUE
      IF (NPOL.GT.0) CALL PPLOT (2)
      RETURN
C
C     PRINT OUT COORDINATES OF AURORAL OVAL BOUNDARIES FOR TABLE OPTION
C     AND OPTION SPECIFYING TIME AND GEOMAGNETIC ACTIVITY.
C
   26 WRITE (IO,58) IUT,GGLG,INDEX(IGM),GMA
      WRITE (IO,60) (GMOVL(I,1,3),GMOVL(I,1,1),GMOVL(I,1,2),GMOVL(I,2,2)
     1,GGOVL(I,1,1),GGOVL(I,1,2),GGOVL(I,2,1),GGOVL(I,2,2),I=1,72,3)
      IF (NPOL.GT.0) CALL PPLOT (1)
      RETURN
C
   28 FORMAT (1H0//7X,9HGMA INDEX,8X,4HGMAB,11X,4HGMAE,13X,3HUTB,11X,3HU
     1TE,12X,4HNPOL,15X,4HSOLD//10X,A2,1X,2(5X,F10.2),3(5X,I10),10X,F10.
     22)
   30 FORMAT (1H0,10X,6HIOPT =,I3,10X,6HLAST =,I3)
   32 FORMAT (1H0//3(18X,2HUT,18X,A2)/)
   34 FORMAT (/,3(10X,F10.2,10X,F10.2))
   36 FORMAT (10X,4HNC =,I3,10X,6HNPOL =,I2,10X,6HSOLD =,F7.2)
   38 FORMAT (1H0//,11X,4HNGMA,9X,9HGMA INDEX,10X,5HITGMB,10X,4HIUTB,10X
     1,4HIUTE,12X,4HNPOL,10X,4HSOLD//9X,I5,14X,A5,3X,4(10X,I5),8X,F7.2)
   40 FORMAT (1H0,24X,2HUT,11X,A2/)
   42 FORMAT (1H ,20X,F7.2,10X,F5.2)
   44 FORMAT (1H1,46X,28HTIME INTEGRATED AURORAL OVAL//5X,5HNOTE-,1X,103
     1HVALUES IN THE TABLE BELOW ARE PROPORTIONAL TO THE LENGTH OF TIME
     2THE LOCATION IS UNDER THE AURORAL OVAL)
   46 FORMAT (1H1)
   48 FORMAT (1H0,1X,8HLATITUDE,30X,9HLONGITUDE,25X,19HINTEGRATION TIME
     1= ,F6.2,2X,5HHOURS)
   50 FORMAT (1H0,11X,18(I3,3X)/)
   52 FORMAT (1H ,3X,I3,5X,18(I3,3X))
   54 FORMAT (1H1,51X,23HCONTOURS OF GRID VALUE ,I4//2X,11HLONGITUDE *,2
     11X,9HLATITUDES,22X,13H* LONGITUDE *,21X,9HLATITUDES)
   56 FORMAT (1H ,12X,1H*,52X,1H*,11X,1H*/4X,I5,3X,1H*,4(3X,F7.2,3X),1H*
     1,3X,I5,3X,1H*,4(3X,F7.2,3X))
   58 FORMAT (1H1,54X,23HAURORAL OVAL BOUNDARIES//13X,16HUNIVERSAL TIME
     1=,I6,13X,40HGEOGRAPHIC LONGITUDE OF LOCAL MIDNIGHT =,F7.2,13X,A2,1
     2X,1H=,F4.1//18X,1H*,6X,33HCORRECTED GEOMAGNETIC COORDINATES,7X,1H*
     3,21X,22HGEOGRAPHIC COORDINATES//6X,9HCORRECTED,3X,1H*,46X,1H*/5X,1
```

```
     41HGEOMAGNETIC,6H   *    ,9HLONGITUDE,7X,8HLATITUDE,7X,8HLATITUDE,4X,
     51H*,4X,9HLONGITUDE,7X,8HLATITUDE,8X,9HLONGITUDE,7X,8HLATITUDE/5X,1
     61HLOCAL   TIME,3H   *,20X,7H(NORTH),8X,7H(SOUTH),4X,1H*,5X,7H(NORTH)
     7,9X,7H(NORTH),9X,7H(SOUTH),9X,7H(SOUTH))
   60 FORMAT (1H0,6X,F6.0,5X,1H*,3X,F7.2,9X,F7.2,8X,F7.2,5X,1H*,4X,F7.2,
     13F16.2)
      END
```

```
$IBFTC SUB1
      SUBROUTINE OVAL (UT,GMA,IGM)
C
C     OVAL COMPUTES THE POSITION OF THE AURORAL OVAL BOUNDARIES AS
C     FUNCTIONS OF UNIVERSAL TIME AND GEOMAGNETIC ACTIVITY IN BOTH
C     CORRECTED GEOMAGNETIC AND GEOGRAPHIC COORDINATES.
C
      DIMENSION TABLE(10,2)
      COMMON /OVL/ GGLG,GGOVL(72,2,2),GMOVL(72,2,3)
      COMMON /DUMMY/ ROVL(72,2,10,2)
      COMMON /SUN/ SOLD
C
C     COMPUTE THE CORRECTED GEOMAGNETIC MERIDIAN OF LOCAL MIDNIGHT
C
      UT=AMOD(UT,24.0)
      GGLG=360.0-15.0*UT
      IF (SOLD.GT.0.) GGLG=GGLG+180.
      GGLG=AMOD(GGLG,360.)
      GMLGM=GGLG
      SD=ABS(SOLD)
      CALL GC2MC (SD,GMLGM)
      T=RAD(GMLGM)
      SD=ABS(SOLD)
      SD=RAD(SD)
      IF ((T.GE.1.745).AND.(T.LE.4.276)) GO TO 2
      IF (T.LE.1.745) T=T+6.281853
      DELT=(.19-.18*SD)*SIN(1.674*(T+.1333*SD-.4712))-.02*SD+.007
      GO TO 4
    2 DELT=.047*COS(1.5*SD)*SIN(2.483*(T+.7854))+.01
    4 GMLGM=GMLGM+RADI(DELT)
      IF (SOLD.GT.0.) GMLGM=GMLGM+180.
      GMLGM=AMOD(GMLGM+360.,360.)
      IF (SOLD.GT.0.) GGLG=GGLG+180.
      GGLG=AMOD(GGLG,360.)
C
C     FROM THE REFERENCE AURORAL OVALS DETERMINE THE CGC BOUNDARIES FOR
C     THE SPECIFIED LEVEL OF GEOMAGNETIC ACTIVITY (LINEAR INTERPOLATION)
C
      DO 8 J=1,2
      LGMT=-20
      GMLG=GMLGM-5.0
      DO 8 I=1,72
      LGMT=LGMT+20
      LGMT=MINIT(LGMT)
      GMLG=GMLG+5.0
      GMLG=AMOD(GMLG+360.,360.)
      DO 6 K=1,10
      G=FLOAT(K)
      TABLE(K,1)=G-1.0
      TABLE(K,2)=ROVL(I,J,K,IGM)
    6 CONTINUE
      GGOVL(I,J,1)=GMLG
      GGOVL(I,J,2)=SINGF(GMA,TABLE,10,10)
      GMOVL(I,J,1)=GGOVL(I,J,1)
      GMOVL(I,J,2)=GGOVL(I,J,2)
      GMOVL(I,J,3)=LGMT
C
```

```
  TRANSFORM CGC AURORAL OVAL TO GEOGRAPHIC COORDINATES

  CALL MC2GC (GGOVL(I,J,2),GGOVL(I,J,1))
8 CONTINUE
  RETURN
  END
```

```
$IBFTC SUB2
      SUBROUTINE TIOVL
C
C     TIOVL TIME-INTEGRATES THE POSITION OF THE AURORAL OVAL
C
      COMMON /TIME/ IUTB,IUTE,IUT,ITGMB,TT/GM/IGM,GMA
      COMMON /REDN/ GMAB,GMAE,NC,NGMA,GAT(96,2)
      COMMON /OVL/ GGLG,GGOVL(72,2,2),GMOVL(72,2,3)
      COMMON /GRID/ IGRID(50,72),NCON,CON(4,72,9)
      COMMON /OPT/ IOPT,LAST
      DIMENSION IDD(3600)
      DIMENSION TABLE(72,2,2)
      EQUIVALENCE (IDD,IGRID)
C
C     INITIALIZATION AND TIME CONTROL
C
      DO 2 K1=1,72
      DO 2 K2=1,50
    2 IGRID(K2,K1)=0
      IF ((IUTE-IUTB).LE.0) IUTE=IUTE+2400
      TT=TMIN(FLOAT(IUTE))-TMIN(FLOAT(IUTB))
      IUT=IUTB-20
      DO 20 L=1,100
      IUT=MINIT(IUT+20)
      IF (IUT.GE.IUTE) GO TO 22
      UT=FLOAT(IUT+10)
      UT=TMIN(UT)
      GMA=SINGF(UT,GAT,NGMA,96)
C
C     INTEGRATION PROCEDURE
C
      CALL OVAL (UT,GMA,IGM)
      MN=MINT(GGOVL(1,1,1),72)
      IF (MN.GT.0) GO TO 4
      IERR=10
      GO TO 46
    4 MS=MINT(GGOVL(1,2,1),72)
      IF (MS.GT.0) GO TO 6
      IERR=14
      GO TO 46
    6 CONTINUE
      DO 8 I=1,72
      TABLE(I,1,1)=GGOVL(I,1,1)
      TABLE(I,2,1)=GGOVL(I,1,2)
      TABLE(I,1,2)=GGOVL(I,2,1)
      TABLE(I,2,2)=GGOVL(I,2,2)
    8 CONTINUE
      GLG=-5.0
      DO 18 I=1,72
      GLG=GLG+5.0
      GLTN=CYTAB(GLG,TABLE(1,1,1),72,MN,360.)
      GLTS=CYTAB(GLG,TABLE(1,1,2),72,MS,360.)
      GLT=39.
      LO=I
      DO 16 J=1,50
      GLT=GLT+1.
      DLT=GLT-GLTS
```

```
      IF (ABS(DLT).GT.0.5) GO TO 10
      AUG=1.0-AUGB(GLG,GLT,TABLE(1,1,2),MS)
      GO TO 14
   10 IF (DLT.LT.0.0) GO TO 16
      DLT=GLTN-GLT
      IF (ABS(DLT).GT.0.5) GO TO 12
      AUG=AUGB(GLG,GLT,TABLE(1,1,1),MN)
      GO TO 14
   12 IF (DLT.LT.0.0) GO TO 18
      AUG=1.0
C
C     COMPUTE GRID COORDINATES AND STORE VALUE OF AUGMENTATION
C
   14 CONTINUE
      LA=50-J+1
      IGRID(LA,LO)=IGRID(LA,LO)+INT(10.*AUG+.51)
   16 CONTINUE
   18 CONTINUE
   20 CONTINUE
      IERR=42
      GO TO 46
   22 CALL OUT (5)
C
C     OPTION TO COMPUTE ISOINTENSITY CONTOURS AT GRID INTERVALS OF 100
C
      IF (IOPT.LE.1) RETURN
      DO 24 K3=1,9
      DO 24 K2=1,72
      DO 24 K1=1,4
   24 CON(K1,K2,K3)=0.0
      IMAX=IDD(1)
      DO 26 I=2,3600
   26 IMAX=MAX0(IMAX,IDD(I))
      NCON=IMAX/100
      IF (NCON.LT.1) RETURN
      DO 44 K=1,NCON
      DO 42 LO=1,72
      DO 40 LA=1,49
      LAP1=LA+1
      IF (IGRID(LA,LO).EQ.100*K) GO TO 28
      IF ((IGRID(LA,LO).LT.100*K).AND.(IGRID(LAP1,LO).GT.100*K)) GO TO 3
     14
      IF ((IGRID(LA,LO).GT.100*K).AND.(IGRID(LAP1,LO).LT.100*K)) GO TO 3
     14
      GO TO 40
   28 DO 30 I=1,4
      IF (CON(I,LO,K).LT.0.1) GO TO 32
   30 CONTINUE
      IERR=66
      GO TO 46
   32 CON(I,LO,K)=FLOAT(90-LA)
      GO TO 40
   34 DO 36 I=1,4
      IF (CON(I,LO,K).LT.0.1) GO TO 38
   36 CONTINUE
      IERR=72
      GO TO 46
```

```
   38 Y1=FLOAT(90-LA)
      Y2=FLOAT(90-LAP1)
      X3=FLOAT(100*K)
      X2=IGRID(LAP1,LO)
      X1=IGRID(LA,LO)
      CON(I,LO,K)=Y3(Y2,Y1,X3,X2,X1)
   40 CONTINUE
   42 CONTINUE
   44 CONTINUE
      CALL OUT (6)
      RETURN
C
C     ERROR MESSAGE
C
   46 CALL ERROR (4,IERR)
      RETURN
      END
```

```
$IBFTC SUB3
      SUBROUTINE PPLOT (LS)
C
C     PPLOT PROVIDES POLAR PLOTS OF THE AURORAL OVAL BOUNDARIES OR OF
C     ISOINTENSITY CONTOURS IN THE TIME INTEGRATION OPTION. THE LATITUDE
C     GRID ON THE PLOTS IS LOGARITHMIC BECAUSE IT IS THE ONLY SLIDE NOW
C     AVAILABLE. THE LOGARITHMIC PART OF THE GRID SHOULD BE IGNORED--
C     THE PLOTS ARE ACTUALLY LINEAR. EACH CYCLE REPRESENTS 10 DEGREES OF
C     LATITUDE.
C
      COMMON /TIME/ IUTB,IUTE,IUT,ITGMB,TT/GM/IGM,GMA
      COMMON /REDN/ GMAB,GMAE,NC,NGMA,GAT(96,2)
      COMMON /OVL/ GGLG,GGOVL(72,2,2),GMOVL(72,2,3)
      COMMON /GRID/ IGRID(50,72),NCON,CON(4,72,9)
      DIMENSION POVL(73,2), DIFF(4), SCP(150,2)
      DIMENSION FLD1(8), FLD2(8)
      DATA FLD1/48HAURORAL OVAL BOUNDARIES                          /
      DATA FLD2/48HISOINTENSITY  CONTOURS  FROM  TIME  INTEGRATIONS/
      EQUIVALENCE (POVL,SCP)
      IFLAG=5
      GO TO (2,8), LS
C
C     PLOTTING OF AURORAL OVAL BOUNDARIES
C     (STRAIGHTFORWARD)
C
    2 ISUM=0
      DO 6 I=1,2
      DO 4 J=1,72
      POVL(J,2)=90.-GGOVL(J,I,2)
      POVL(J,1)=GGOVL(J,I,1)
    4 CONTINUE
      POVL(73,1)=POVL(1,1)
      POVL(73,2)=POVL(1,2)
      CALL POLAR (ISUM,FLD1,73,POVL(1,2),POVL(1,1))
      ISUM=ISUM+1
    6 CONTINUE
      RETURN
C
C     PLOTTING OF ISOINTENSITY CONTOURS FROM TIME INTEGRATION OPTION
C     (TRICKY)
C
C     INITIALIZATION
C
    8 ISUM=0
      IERR=0
      DO 40 J=1,NCON
      DO 38 I1=1,2
      DO 10 I=1,4
      IF (CON(I,1,J).LT.25.) GO TO 10
      SCP(1,1)=0.0
      SCP(1,2)=CON(I,1,J)
      TF=CON(I,1,J)
      ITF=I
      GO TO 12
   10 CONTINUE
      IERR=32
      GO TO 42
```

```
   12 DO 14 I=1,4
      IF (CON(I,2,J).LT.25.) GO TO 14
      SCP(2,1)=5.0
      SCP(2,2)=CON(I,2,J)
      CON(I,2,J)=0.0
      GO TO 16
   14 CONTINUE
      IERR=36
      GO TO 42
   16 L=3
      LP=2
      IX=0
      DO 30 K=3,150
C
C     LINEAR EXTRAPOLATION OF 2 PREVIOUS POINTS TO PREDICT POSITION OF
C     NEXT POINT
C
      IF (IX.GT.0) GO TO 18
      R1=90.-SCP(K-2,2)
      R2=90.-SCP(K-1,2)
      R3=2.*R2-R1
      PSCP=90.-R3
      GO TO 20
C
C     WHEN CONTOUR HAS JUST REVERSED ITS DIRECTION,LINEAR EXTRAPOLATION
C     CANNOT BE USED. THE NEXT POINT IS TAKEN TO BE THE ONE CLOSEST IN
C     LATITUDE TO THE PRESENT POINT.
C
   18 I=IMIN(SCP(K-1,2),CON(1,L,J),4)
      IF (I.EQ.0) CALL ERROR (5,40)
      PSCP=CON(I,L,J)
      IX=0
C
C     COMPARISON OF PREDICTED POSITION WITH ACTUAL DATA POINT POSITIONS-
C     -SELECTION OF NEXT SEQUENTIAL CONTOUR POINT.
C
   20 IF (MAX1(CON(1,L,J),CON(2,L,J),CON(3,L,J),CON(4,L,J)).LE.0) GO TO
     1132
      DO 22 I=1,4
      IF (ABS(PSCP-CON(I,L,J)).LT.1.) GO TO 24
   22 CONTINUE
      GO TO 26
   24 SCP(K,2)=CON(I,L,J)
      SCP(K,1)=5*(L-1)
      CON(I,L,J)=0.0
      L1=-1
      IF (L.GT.LP) L1=1
      LP=L
      L=L+L1
      L=MOD(L,72)
      IF (L.EQ.0) L=72
      GO TO 28
   26 I=IMIN(SCP(K-1,2),CON(1,LP,J),4)
      IF (I.EQ.0) CALL ERROR (5,48)
      SCP(K,2)=CON(I,LP,J)
      SCP(K,1)=5*(LP-1)
      CON(I,LP,J)=0.0
```

```
      L1=1
      IF (L.GT.LP) L1=-1
      L=LP+L1
      L=MOD(L,72)
      IF (L.EQ.0) L=72
      IX=1
      GO TO 30
   28 IF (ABS(SCP(K,1)).GT..001) GO TO 30
      IF (ABS(SCP(K,2)-TF).LT..001) GO TO 34
   30 CONTINUE
      CALL ERROR (5,60)
      K=150
   32 CALL ERROR (5,44)
   34 DO 36 K1=1,K
      SCP(K1,2)=90.-SCP(K1,2)
   36 CONTINUE
      CON(ITF,1,J)=0.
C
C     PLOT CONTOURS
C
      CALL POLAR (ISUM,FLD2,K,SCP(1,2),SCP(1,1))
      ISUM=ISUM+1
   38 CONTINUE
   40 CONTINUE
      RETURN
C
C     ERROR MESSAGE
C
   42 CONTINUE
      CALL ERROR (5,IERR)
      RETURN
C
      ENTRY PLOT1
      CALL CAMRAV (9)
      RETURN
C
      ENTRY ENDPLT
      CALL CLEAN
      RETURN
C
      END
```

```
$IBFTC SUB4
      SUBROUTINE POLAR (L,FLD,NP,AMP,PHASE)
      DIMENSION AMP(1), PHASE(1), FLD(8), HLABEL(5)
      DIMENSION FLDX(12), FLDY(12)
      EQUIVALENCE (FLDX,FLDY)
      DATA FLDX/12*6H      /
      DATA HLABEL/90.,80.,70.,60.,50./
      COMMON /OVL/ GGLG
      NPOINT=0
      IF (L.GT.0) GO TO 6
      CALL FRAMEV (0)
      CALL FORMV
      IY=100
      M=1
      DO 2 I=1,4
      CALL PRINTV (12,FLD(M),920,IY)
      M=M+2
    2 IY=IY-30
      IX=497
      DO 4 I=1,5
      CALL LABLV (HLABEL(I),IX,520,3,4,2)
    4 IX=IX+103
      CALL XAXISV (0,512)
      CALL YAXISV (512,0)
C     PLOT DIRECTION OF SUN. LETTER O INDICATES MERIDIAN OF LOCAL
C     SOLAR NOON.
      S=AMOD((GGLG+180.),360.)
      S=RAD(S)
      ISX=511.*(COS(S)+1.)+.5
      ISY=511.*(SIN(S)+1.)+.5
      CALL PLOTV (ISX,ISY,1HO)
    6 CONTINUE
      DO 10 I=1,NP
      PRAD=PHASE(I)/57.29577951
      C=AMP(I)
      IF (C.LT.0.0) C=0.0
      IF (C.GT.50.) C=50
      XK=10.24*C
      PCOS=COS(PRAD)
      PSIN=SIN(PRAD)
      NX=PCOS*XK+512.+.5
      NY=PSIN*XK+512.+.5
      IF (NPOINT.EQ.0) GO TO 8
      CALL LINEV (NX,NY,IX,IY)
    8 IX=NX
      IY=NY
      NPOINT=1
   10 CONTINUE
      CALL XAXISV (0,512)
      CALL YAXISV (512,0)
      RETURN
      END
```

```
$IBFTC SUB5
      SUBROUTINE MC2GC (X,Y)
C
C     MC2GC TRANSFORMS CORRECTED GEOMAGNETIC COORDINATES TO GEOGRAPHIC
C     COORDINATES (NORTHERN HEMISPHERE)
C     X = LATITUDE IN DEGREES
C     Y = LONGITUDE IN DEGREES
C
      COMMON /PAR/ ALPHC,BETC,DELC,EPC,RC
      R2=RAD(90.0-X)
      T2=RAD(Y)
      T1=T2-BETC
      T=T1-.13*ELPS(EPC,T1,ALPHC)*SIN(2.0*T1)
      R=R2*ELPS(EPC,ALPHC,T1)
      S=SIN(T)
      C=RC/R-COS(T)
      T2=ATAN2(S,C)
      T2=3.1415927+BETC-DELC-T2
      R2=AMAG(-RC,R,T)
      X=90.0-RADI(R2)
      Y=RADI(T2)
      Y=AMOD(Y+360.,360.)
      RETURN
      END
```

```
$IBFTC SUB6
      SUBROUTINE GC2MC (X,Y)
C
C     GC2MC TRANSFORMS GEOGRAPHIC COORDINATES TO CORRECTED GEOMAGNETIC
C     COORDINATES (NORTHERN HEMISPHERE)
C     X = LATITUDE IN DEGREES
C     Y = LONGITUDE IN DEGREES
C
      COMMON /PAR/ ALPHC,BETC,DELC,EPC,RC
      R1=RAD(90.0-X)
      T1=RAD(Y)
      T1=T1-BETC+DELC
      S=SIN(T1)
      C=RC/R1+COS(T1)
      T=ATAN2(S,C)
      T3=T+.13*ELPS(EPC,T,ALPHC)*SIN(2.0*T)
      R=AMAG(RC,R1,T1)*ELPS(EPC,T,ALPHC)
      X=90.0-RADI(R)
      T3=T3+BETC
      Y=RADI(T3)
      Y=AMOD(Y+360.,360.)
      RETURN
      END
```

```
$IBFTC SUB7
      SUBROUTINE ERROR (IFLAG,IERR)
      COMMON /INOUT/ IN,IO
C
C     PRINT OUT ERROR MESSAGE
C
      DIMENSION ISUB(5)
      DATA ISUB/5HDRIVE,3HOUT,4HOVAL,5HTIOVL,5HPPLOT/
    2 WRITE (IO,4) ISUB(IFLAG),IERR
      RETURN
C
    4 FORMAT (1H1,20HERROR IN SUBROUTINE ,A6,2X,20HFOLLOWING STATEMENT ,
     1I3)
      END
```

```
$IBFTC SUB8
      FUNCTION CYTAB (X,TABLE,NP,NI,CYC)

      CYTAB IS A TABLE-LOOKUP,LINEAR INTERPOLATION FUNCTION FOR THE CASE
      OF A CYCLIC TABLE.
      X IS THE INDEPENDENT VARIABLE
      NP IS THE CYCLE LENGTH OF THE DATA POINTS
      NI IS THE INDEX OF THE MINIMUM TABLE VALUE OF THE INDEPENDENT
      VARIABLE. THIS IS THE INITIAL POINT OF THE MONOTONIC INCREASING
      SEQUENCE REQUIRED FOR THIS ROUTINE TO GIVE CORRECT RESULTS.
      CYC IS THE CYCLE LENGTH IN UNITS OF THE INDEPENDENT VARIABLE X

      DIMENSION TABLE(72,2)
      NF=NI-1
      DO 2 I=NI,NP
      IF (X-TABLE(I,1)) 10,8,2
    2 CONTINUE
      DO 4 J=1,NF
      IF (X-TABLE(J,1)) 14,6,4
    4 CONTINUE
      K2=NI
      K1=NF
      T2=TABLE(NI,1)+CYC
      T1=TABLE(NF,1)
      GO TO 18
    6 I=J
    8 CYTAB=TABLE(I,2)
      RETURN
   10 IF (I.NE.NI) GO TO 12
      K2=NI
      K1=NF
      T2=TABLE(NI,1)
      T1=TABLE(NF,1)-CYC
      GO TO 18
   12 K2=I
      K1=I-1
      T2=TABLE(I,1)
      T1=TABLE(K1,1)
      GO TO 18
   14 IF (J.EQ.1) GO TO 16
      I=J
      GO TO 12
   16 K2=1
      K1=NP
      T2=TABLE(1,1)
      T1=TABLE(NP,1)
   18 CYTAB=Y3(TABLE(K2,2),TABLE(K1,2),X,T2,T1)
      RETURN
      END
```

```
$IBFTC SUB9
      FUNCTION SINGF (X,TABLE,NP,ND)
C
C     ****************************************************************
C     SINGLE VARIABLE TABLE LOOKUP AND INTERPOLATION                 *
C         SINGF=FUN(X)                                               *
C                                                                    *
C     INPUT                                                          *
C     X     =VALUE OF INDEPENDENT VARIABLE                           *
C     TABLE=DATA ARRAY STORED AS PAIRS OF INDEPENDENT-DEPENDENT POINTS *
C     NP    =NUMBER OF PAIRS OF POINTS IN TABLE - ADJUST DIMENSION TO  *
C                                             MAXIMUM REQUIRED       *
C     OUTPUT                                                         *
C     SINGF=VALUE OF DEPENDENT VARIABLE CORRESPONDING TO X            *
C                                                                    *
C     NOTE                                                           *
C     ROUTINE ASSUMES LINEAR POINT TO POINT FUNCTION                 *
C     IF X.GT.LAST  X POINT, SINGF= LAST DEPENDENT POINT IN TABLE    *
C     IF X.LT.FIRST X POINT, SINGF=FIRST DEPENDENT POINT IN TABLE    *
C     INPUT TABLE IN ASCENDING ORDER OF X'S.                         *
C     ****************************************************************
C
      DIMENSION TABLE(ND,2)
      DO 2 I=1,NP
      IF (X-TABLE(I,1)) 6,4,2
    2 CONTINUE
      I=NP
C
    4 SINGF=TABLE(I,2)
      RETURN
C
    6 I1=I-1
      IF (I1) 4,4,8
    8 SINGF=Y3(TABLE(I,2),TABLE(I1,2),X,TABLE(I,1),TABLE(I1,1))
      RETURN
      END
```

```
$IBFTC SUB10
      FUNCTION Y3 (Y2,Y1,X3,X2,X1)
C
C     **************************************************
C                                                      *
C     LINEAR INTERPOLATION BETWEEN POINTS              *
C         Y3=FUN(X3,X1,Y1,X2,Y2)                       *
C                                                      *
C     INPUT                                            *
C     X1,Y1=LOWER INTERPOLATION POINT                  *
C     X2,Y2=UPPER INTERPOLATION POINT                  *
C     X3   =PRESENT VALUE OF INDEPENDENT VARIABLE      *
C                                                      *
C     OUTPUT                                           *
C     Y3=VALUE OF DEPENDENT VARIABLE CORRESPONDING TO X3*
C     **************************************************
C                                                      *
      Y3=Y1+(Y1-Y2)*(X3-X1)/(X1-X2)
      RETURN
      END
```

```
$IBFTC SUB11
      FUNCTION AUGB (GLGD,GLTP,TABLE,NI)
C
C     FOR A GRID LOCATION LYING ON THE BORDER OF THE AURORAL OVAL,AUGB C
C     THE FRACTIONAL AREA OF THE GRID WHICH LIES UNDER (NORTH BOUNDARY)
C     OUTSIDE OF (SOUTH BOUNDARY) THE AURORAL OVAL
C
      DIMENSION TABLE(72,2)
      AUGB=0.0
C
C     GRID INTERVAL (5 DEGREES LONGITUDE BY 1 DEGREE LATITUDE) IS TO BE
C     CENTERED ON GEOGRAPHIC POSITION AT LONGITUDE GLG AND LATITUDE GLTP
C     NI IS THE INDEX OF THE MINIMUM TABLE VALUE, REQUIRED FOR THE
C     CYTAB FUNCTION CALL.
C
      GLG=GLGD
      GLG=GLG-2.75
      DO 8 I=1,10
      GLG=AMOD(GLG+.5,360.)
      GLT=CYTAB(GLG,TABLE,72,NI,360.)
      DAUG=GLT-GLTP
      IF (DAUG.LT.0.5) GO TO 2
      DAUG=.1
      GO TO 6
    2 IF (DAUG.GT.-0.5) GO TO 4
      DAUG=0.0
      GO TO 6
    4 DAUG=.1*(DAUG+.5)
    6 AUGB=AUGB+DAUG
    8 CONTINUE
      RETURN
      END
```

```
$IBFTC SUB12
      FUNCTION MINT (TABLE,NP)
C
C     MINT PROVIDES THE ARRAY INDEX OF THE MINIMUM TABLE VALUE FOR A
C     CYCLIC MONOTONIC INCREASING SEQUENCE.
C     NP=NUMBER OF POINTS IN THE CYCLIC SEQUENCE.
C
      DIMENSION TABLE(1)
      NP1=NP-1
      DO 4 I=1,NP1
      I1=I+1
      IF (TABLE(I1)-TABLE(I)) 6,2,4
    2 I1=0
      GO TO 6
    4 CONTINUE
      I1=1
    6 MINT=I1
      RETURN
      END
```

```
$IBFTC SUB13
      FUNCTION MINIT (M)
C
C     MINIT KEEPS UNIVERSAL TIME (EG UT=2315) CORRECT BY ADDING ONE HOUR
C     AND SUBTRACTING 60 MINUTES WHEN THE NUMBER OF MINUTES EQUALS OR
C     EXCEEDS 60.
C     M=UNIVERSAL TIME
C
      MINIT=M
      MH=M/100
      MM=M-MH*100
      IF (MM.GE.60) MINIT=(MH+1)*100+MM-60
      RETURN
      END
```

```
$IBFTC SUB14
      FUNCTION TMIN (UT)
C
C     TMIN CHANGES UNIVERSAL TIME (EG 2345.) TO HOURS AND DECIMAL
C     FRACTIONS THEREOF (EG 23.75)
C     UT=UNIVERSAL TIME
C
      IUT=IFIX(UT/100.)
      FUT=FLOAT(IUT)
      FUT=UT-FUT*100.
      TMIN=FUT/60.+(UT-FUT)/100.
      RETURN
      END
```

```
$IBFTC SUB15
      FUNCTION ELPS (X,Y,Z)
C
      ELPS=SQRT((1.0-X*X*COS(Y)*COS(Y))/(1.0-X*X*COS(Z)*COS(Z)))
      RETURN
      END
```

```
$IBFTC SUB16
      FUNCTION RAD (X)
C
C     RAD(X) CHANGES DEGREES TO RADIANS.
C
      RAD=.0174533*X
      RETURN
      END
```

```
$IBFTC SUB17
      FUNCTION RADI (X)
C
C     RADI(X) CHANGES RADIANS TO DEGREES.
C
      RADI=57.2957795*X
      RETURN
      END
```

```
$IBFTC SUB18
      FUNCTION AMAG (X,Y,Z)
      AMAG=SQRT(X*X+Y*Y+2.0*X*Y*COS(Z))
      RETURN
      END
```

```
$IBFTC SUB19
      FUNCTION IMIN (X,TABLE,N)
C
C     IMIN DETERMINES THE INDEX OF THE VALUE IN TABLE WHICH IS CLOSEST
C     TO THE VALUE OF X. N IS THE DIMENSION OF THE INPUT ARRAY.
C
      DIMENSION TABLE(1), DIFF(10)
      DO 2 J=1,N
    2 DIFF(J)=ABS(X-TABLE(J))
      DIMIN=DIFF(1)
      DO 4 J=2,N
    4 DIMIN=AMIN1(DIMIN,DIFF(J))
      DO 6 J=1,N
      IF (ABS(DIMIN-DIFF(J)).LT..01) GO TO 8
    6 CONTINUE
      J=0
    8 IMIN=J
      RETURN
      END
```

```
$*
$IBFTC SUB20
      BLOCK DATA
      DIMENSION PN0(72), PN1(72), PN2(72), PN3(72), PN4(72), PN5(72), PN
     16(72)
      DIMENSION PS0(72), PS1(72), PS2(72), PS3(72), PS4(72), PS5(72), PS
     16(72)
      DIMENSION PN7(72), PN8(72), PN9(72), PS7(72), PS8(72), PS9(72)
      DIMENSION QN0(72), QN1(72), QN2(72), QN3(72), QN4(72), QN5(72), QN
     16(72)
      DIMENSION QS0(72), QS1(72), QS2(72), QS3(72), QS4(72), QS5(72), QS
     16(72)
      DIMENSION QN7(72), QN8(72), QS7(72), QS8(72), QN9(72), QS9(72)
      COMMON /DUMMY/ PN0,PS0,PN1,PS1,PN2,PS2,PN3,PS3,PN4,PS4,PN5,PS5,PN6
     1,PS6,PN7,PS7,PN8,PS8,PN9,PS9,QN0,QS0,QN1,QS1,QN2,QS2,QN3,QS3,QN4,Q
     2S4,QN5,QS5,QN6,QS6,QN7,QS7,QN8,QS8,QN9,QS9
      COMMON /PAR/ ALPHC,BETC,DELC,EPC,RC
      COMMON /INOUT/ IN,IO
C     ALPHC=RAD(55.0)
C     BETC=RAD(170.0)
C     DELC=RAD(70.0)
C     RC=RAD(9.5)
      DATA ALPHC/.9599315/,BETC/2.9670610/,DELC/1.2217310/,EPC/.5913/
      DATA RC/.16580635/
      DATA IN/5/
      DATA IO/6/
C
C     QN DATA BLOCKS CORRESPOND TO CGC LATITUDE COORDINATES OF THE
C     NORTHERN BOUNDARY OF THE AURORAL OVAL FOR THE SPECIFIED Q LEVELS
C     (0-8) OF GEOMAGNETIC ACTIVITY. QS BLOCKS ARE FOR THE SOUTHERN
C     BOUNDARIES. PN AND PS BLOCKS ARE THE SAME FOR KP INDICES.
C
      DATA PN0/73.6,73.8,74.0,74.2,74.6,74.8,75.0,75.1,75.3,75.4,75.5,75
     1.6,75.5,75.2,75.1,74.9,74.8,74.7,74.6,74.5,74.5,74.5,74.5,74.5,74.
     25,74.9,75.3,76.1,76.8,77.3,78.0,78.5,78.9,79.2,79.5,79.7,79.9,80.0
     3,80.1,80.2,80.2,80.2,80.2,80.1,80.1,80.0,79.8,79.7,79.4,79.3,79.1,
     478.9,78.6,78.3,78.1,77.8,77.3,76.9,76.4,76.0,75.5,75.1,74,9,74.6,7
     54.3,74.1,73.9,73.8,73.8,73.7,73.6,73.6/
      DATA PS0/65.5,65.6,65.8,66.0,66.2,66.6,66.8,66.9,67.0,67.2,67.4,67
     1.7,68.0,68.6,69.0,69.6,70.0,70.2,70.6,70.9,71.1,71.3,71.8,72.0,72.
     25,72.8,73.1,73.6,74.0,74.3,74.8,75.0,75.4,75.7,76.0,76.1,76.2,76.4
     3,76.5,76.6,76.7,76.8,76.8,76.8,76.7,76.6,76.4,76.2,76.0,75.8,75.4,
     475.0,74.7,74.2,73.7,73.2,72.8,72.3,71.9,71.4,71.0,70.6,70.0,69.6,6
     59.0,68.4,67.8,67.2,66.8,66.2,65.9,65.7/
      DATA PN1/72.9,73.0,73.2,73.4,73.7,73.9,74.1,74.4,74.6,74.8,75.0,75
     1.1,75.2,75.3,75.4,75.4,75.4,75.3,75.2,75.1,75.0,74.9,74.8,74.7,74.
     26,74.8,75.0,75.5,76.0,76.5,77.0,77.5,78.0,78.3,78.7,78.9,79.0,79.1
     3,79.2,79.2,79.2,79.1,79.0,78.9,78.8,78.7,78.5,78.2,78.0,77.8,77.6,
     477.4,77.2,77.0,76.8,76.4,76.1,76.0,75.8,75.6,75.3,75.1,74.9,74.7,7
     54.4,74.2,74.0,73.8,73.4,73.3,73.1,73.0/
      DATA PS1/64.5,64.6,64.8,65.0,65.2,65.5,65.9,66.0,66.2,66.6,67.0,67
     1.2,67.6,68.0,68.5,69.0,69.4,69.9,70.1,70.5,70.8,70.9,71.1,71.3,71.
     27,72.0,72.4,72.9,73.2,73.7,74.0,74.3,74.6,74.8,75.0,75.1,75.2,75.2
     3,75.2,75.1,75.1,75.0,75.0,75.0,74.9,74.8,74.8,74.7,74.6,74.4,74.2,
     473.9,73.6,73.2,72.7,72.1,71.6,70.9,70.3,69.6,69.0,68.6,68.2,67.8,6
     57.3,67.0,66.4,66.0,65.4,65.0,64.8,64.7/
      DATA PN2/72.3,72.2,72.3,72.6,72.8,73.0,73.2,73.6,73.9,74.1,74.3,74
```

```
1.8,75.0,75.2,75.3,75.4,75.5,75.4,75.3,75.1,75.0,74.9,74.8,74.8,74.
29,75.1,75.6,76.0,76.4,76.8,77.2,77.4,77.8,77.9,78.0,78.0,78.0,77.9
3,77.8,77.7,77.6,77.5,77.4,77.2,77.0,76.9,76.8,76.7,76.5,76.4,76.3,
476.2,76.1,76.1,76.0,75.9,75.8,75.7,75.6,75.4,75.2,75.0,74.8,74.6,7
54.2,74.0,73.7,73.3,73.0,72.9,72.7,72.4/
 DATA PS2/63.5,63.6,63.8,64.0,64.2,64.5,64.7,64.8,64.8,64.8,64.9,65
1.0,65.0,65.0,65.1,65.3,65.8,66.2,66.8,67.4,68.0,68.6,69.1,69.7,70.
21,70.8,71.2,71.8,72.2,72.8,73.1,73.6,73.8,74.0,74.1,74.2,74.2,74.2
3,74.2,74.2,74.2,74.1,74.0,74.0,73.9,73.8,73.6,73.3,73.0,72.8,72.3,
472.0,71.5,71.0,70.4,69.9,69.1,68.5,68.0,67.6,67.1,66.8,66.3,66.0,6
55.8,65.3,65.0,64.4,64.0,63.9,63.7,63.6/
 DATA PN3/72.8,72.9,73.0,73.2,73.4,73.6,73.8,74.0,74.2,74.4,74.6,74
1.8,74.9,74.9,75.0,75.0,75.0,75.0,75.0,75.0,75.0,75.0,75.0,75.1,75.
21,75.2,75.4,75.6,75.8,76.0,76.1,76.2,76.4,76.6,76.7,76.8,76.9,77.0
3,77.0,77.0,76.9,76.8,76.6,76.4,76.2,76.1,76.0,75.9,75.8,75.7,75.6,
475.5,75.5,75.5,75.5,75.5,75.4,75.4,75.3,75.3,75.2,75.1,75.0,74.9,7
54.6,74.3,74.0,73.9,73.7,73.4,73.2,73.0/
 DATA PS3/62.5,62.5,62.5,62.6,62.7,62.8,62.9,62.9,63.0,63.1,63.3,63
1.6,63.8,63.9,64.2,64.8,65.4,66.1,66.9,67.6,68.2,68.9,69.4,70.0,70.
23,70.8,71.1,71.5,71.9,72.2,72.4,72.7,72.9,73.0,73.1,73.1,73.0,72.9
3,72.8,72.7,72.6,72.4,72.1,72.0,71.9,71.8,71.7,71.5,71.4,71.2,71.0,
470.8,70.3,70.0,69.5,69.0,68.3,67.6,66.9,66.0,65.2,64.8,64.3,64.0,6
53.8,63.7,63.6,63.5,63.3,63.1,63.0,62.8/
 DATA PN4/73.6,73.8,74.0,74.1,74.2,74.4,74.6,74.7,74.8,74.9,75.0,75
1.1,75.2,75.2,75.2,75.1,75.0,74.9,74.8,74.8,74.7,74.7,74.7,74.8,74.
28,74.9,75.0,75.1,75.2,75.3,75.5,75.6,75.7,75.8,75.9,75.9,76.0,76.0
3,76.0,76.0,76.0,75.9,75.8,75.7,75.6,75.5,75.3,75.2,75.1,75.0,75.0,
474.9,74.9,74.9,74.9,74.9,75.0,75.0,75.0,75.0,75.0,75.0,74.9,74.8,7
54.7,74.6,74.3,74.1,74.0,73.9,73.8,73.7/
 DATA PS4/61.4,61.4,61.3,61.2,61.2,61.1,61.2,61.3,61.4,61.6,61.8,62
1.0,62.3,63.0,63.7,64.3,65.1,66.0,66.8,67.3,68.1,68.8,69.1,69.6,69.
28,70.0,70.2,70.5,70.8,71.0,71.3,71.7,71.9,72.0,72.0,72.0,72.0,72.0
3,72.0,72.0,72.0,72.0,72.0,71.8,71.6,71.4,71.1,70.8,70.3,70.0,69.5,
469.0,68.4,67.9,67.3,66.7,66.0,65.8,65.2,64.9,64.5,64.1,64.0,63.8,6
53.5,63.2,63.0,62.8,62.5,62.0,61.9,61.6/
 DATA PN5/74.2,74.3,74.4,74.6,74.7,74.8,74.9,75.0,75.1,75.2,75.3,75
1.4,75.5,75.4,75.2,75.1,75.0,74.8,74.6,74.2,74.0,73.9,73.8,73.7,73.
26,73.7,73.8,73.9,74.0,74.2,74.5,74.9,75.0,75.1,75.2,75.2,75.2,75.2
3,75.1,75.1,75.0,75.0,75.0,74.9,74.8,74.8,74.7,74.7,74.7,74.7,74.7,
474.7,74.7,74.7,74.7,74.7,74.7,74.6,74.6,74.6,74.5,74.5,74.5,74.4,7
54.4,74.3,74.3,74.2,74.2,74.2,74.2,74.2/
 DATA PS5/60.5,60.5,60.4,60.3,60.2,60.1,60.1,60.2,60.3,60.4,60.8,61
1.0,61.5,62.0,62.9,63.6,64.4,65.1,65.9,66.4,67.0,67.5,68.0,68.2,68.
25,68.8,69.0,69.3,69.7,69.9,70.0,70.3,70.6,70.8,70.9,70.9,71.0,71.0
3,71.0,70.9,70.7,70.5,70.2,70.0,69.6,69.2,68.9,68.6,68.4,68.1,67.9,
467.7,67.4,67.1,66.8,66.4,66.0,65.5,65.0,64.4,63.6,63.0,62.5,62.0,6
51.7,61.3,61.0,60.9,60.9,60.8,60.7,60.6/
 DATA PN6/75.0,75.1,75.2,75.3,75.4,75.5,75.6,75.6,75.7,75.7,75.8,75
1.8,75.8,75.7,75.5,75.3,75.0,74.8,74.3,74.0,73.5,73.0,72.7,72.5,72.
25,72.6,72.8,73.0,73.2,73.4,73.6,73.8,74.0,74.1,74.2,74.2,74.2,74.2
3,74.2,74.2,74.2,74.2,74.2,74.2,74.2,74.1,74.1,74.1,74.1,74.0,74.0,
474.0,74.0,74.0,74.0,74.0,74.0,74.0,74.0,74.0,74.0,74.0,74.1,74.2,7
54.3,74.5,74.6,74.7,74.8,74.9,75.0,75.0/
 DATA PS6/59.6,59.7,59.6,59.6,59.5,59.4,59.4,59.5,59.6,59.8,60.0,60
1.2,60.8,61.3,62.0,62.8,63.5,64.2,64.9,65.4,66.0,66.4,66.8,67.1,67.
23,67.5,67.8,68.1,68.4,68.8,69.1,69.4,69.7,69.9,70.0,70.1,70.0,70.0
3,70.0,69.8,69.5,69.1,68.8,68.3,67.9,67.3,66.8,66.3,66.0,65.8,65.5,
```

```
     465.3,65.1,65.0,64.9,64.7,64.2,64.0,63.8,63.5,63.0,63.5,62.1,61.8,6
     51.4,61.0,60.7,60.2,59.9,59.7,59.6,59.6/
      DATA PN7/75.5,75.5,75.5,75.5,75.5,75.5,75.5,75.4,75.4,75.3,75.2,75
     1.1,75.0,75.0,74.9,74.8,74.7,74.4,74.0,73.5,73.0,72.5,72.0,71.7,71.
     25,71.6,71.8,71.9,72.0,72.2,72.5,72.7,72.8,73.0,73.1,73.2,73.3,73.4
     3,73.6,73.6,73.7,73.7,73.7,73.7,73.7,73.8,73.8,73.8,73.8,73.8,73.8,
     473.8,73.7,73.7,73.6,73.6,73.5,73.5,73.5,73.6,73.8,73.9,74.0,74.1,7
     54.3,74.6,74.8,74.9,75.0,75.1,75.3,75.4/
      DATA PS7/58.6,58.8,58.9,58.9,58.9,58.9,58.9,58.9,59.0,59.2,59.7,59
     1.9,60.2,60.7,61.2,61.8,62.2,62.8,63.2,63.9,64.5,65.0,65.5,66.0,66.
     24,66.8,67.0,67.3,67.8,68.0,68.2,68.3,68.6,68.8,68.9,68.9,68.8,68.7
     3,68.5,68.3,68.0,67.7,67.2,66.8,66.2,65.7,65.1,64.8,64.2,64.0,63.8,
     463.7,63.6,63.5,63.5,63.4,63.2,63.1,63.0,62.9,62.5,62.2,62.0,61.7,6
     51.2,60.9,60.5,60.0,59.8,59.3,59.0,58.8/
      DATA PN8/76.0,75.9,75.8,75.7,75.6,75.5,75.4,75.2,75.0,74.9,74.8,74
     1.5,74.3,74.0,73.6,73.1,72.9,72.4,72.0,71.6,71.1,70.8,70.4,70.0,70.
     20,69.9,69.9,70.0,70.2,70.4,70.8,71.0,71.3,71.8,72.0,72.3,72.7,73.0
     3,73.1,73.2,73.4,73.7,73.8,73.8,73.7,73.5,73.2,73.0,72.8,72.6,72.4,
     472.2,72.1,72.1,72.1,72.2,72.3,72.5,72.8,72.9,73.1,73.6,74.0,74.3,7
     54.7,75.0,75.2,75.4,75.8,75.9,76.0,76.0/
      DATA PS8/57.9,58.0,58.1,58.3,58.6,58.8,59.0,59.3,59.6,59.8,59.9,60
     1.0,60.0,60.4,61.0,61.6,62.1,62.8,63.3,63.8,64.1,64.6,64.9,65.0,65.
     21,65.3,65.6,65.8,66.0,66.2,66.4,66.7,66.8,66.9,67.0,67.0,67.0,67.0
     3,66.8,66.5,66.1,65.7,65.2,64.8,64.1,63.7,63.1,62.8,62.4,62.4,62.5,
     462.7,62.8,62.9,63.0,63.0,63.1,63.0,62.8,62.5,62.0,61.6,61.0,60.5,6
     50.0,59.4,59.0,58.6,58.3,58.2,58.1,58.0/
      DATA PN9/76.0,75.9,75.8,75.7,75.6,75.5,75.4,75.2,75.0,74.9,74.8,74
     1.5,74.3,74.0,73.6,73.1,72.9,72.4,72.0,71.6,71.1,70.8,70.4,70.0,70.
     20,69.9,69.9,70.0,70.2,70.4,70.8,71.0,71.3,71.8,72.0,72.3,72.7,73.0
     3,73.1,73.2,73.4,73.7,73.8,73.8,73.7,73.5,73.2,73.0,72.8,72.6,72.4,
     472.2,72.1,72.1,72.1,72.2,72.3,72.5,72.8,72.9,73.1,73.6,74.0,74.3,7
     54.7,75.0,75.2,75.4,75.8,75.9,76.0,76.0/
      DATA PS9/57.9,58.0,58.1,58.3,58.6,58.8,59.0,59.3,59.6,59.8,59.9,60
     1.0,60.0,60.4,61.0,61.6,62.1,62.8,63.3,63.8,64.1,64.6,64.9,65.0,65.
     21,65.3,65.6,65.8,66.0,66.2,66.4,66.7,66.8,66.9,67.0,67.0,67.0,67.0
     3,66.8,66.5,66.1,65.7,65.2,64.8,64.1,63.7,63.1,62.8,62.4,62.4,62.5,
     462.7,62.8,62.9,63.0,63.0,63.1,63.0,62.8,62.5,62.0,61.6,61.0,60.5,6
     50.0,59.4,59.0,58.6,58.3,58.2,58.1,58.0/
      END
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$IBFTC SUB21
      BLOCK DATA
      DIMENSION PN0(72), PN1(72), PN2(72), PN3(72), PN4(72), PN5(72), PN
     16(72)
      DIMENSION PS0(72), PS1(72), PS2(72), PS3(72), PS4(72), PS5(72), PS
     16(72)
      DIMENSION PN7(72), PN8(72), PN9(72), PS7(72), PS8(72), PS9(72)
      DIMENSION QN0(72), QN1(72), QN2(72), QN3(72), QN4(72), QN5(72), QN
     16(72)
      DIMENSION QS0(72), QS1(72), QS2(72), QS3(72), QS4(72), QS5(72), QS
     16(72)
      DIMENSION QN7(72), QN8(72), QS7(72), QS8(72), QN9(72), QS9(72)
      COMMON /DUMMY/ PN0,PS0,PN1,PS1,PN2,PS2,PN3,PS3,PN4,PS4,PN5,PS5,PN6
     1,PS6,PN7,PS7,PN8,PS8,PN9,PS9,QN0,QS0,QN1,QS1,QN2,QS2,QN3,QS3,QN4,Q
     2S4,QN5,QS5,QN6,QS6,QN7,QS7,QN8,QS8,QN9,QS9
C
C     QN DATA BLOCKS CORRESPOND TO CGC LATITUDE COORDINATES OF THE
C     NORTHERN BOUNDARY OF THE AURORAL OVAL FOR THE SPECIFIED Q LEVELS
C     (0-8) OF GEOMAGNETIC ACTIVITY. QS BLOCKS ARE FOR THE SOUTHERN
C     BOUNDARIES. PN AND PS BLOCKS ARE THE SAME FOR KP INDICES.
C
      DATA QN0/71.6,71.7,71.9,72.1,72.3,72.6,72.8,73.1,73.4,73.7,74.0,74
     1.1,74.4,74.5,74.6,74.7,74.8,74.8,74.8,74.6,74.5,74.4,74.3,74.2,74.
     21,74.4,74.8,75.0,75.6,76.0,76.5,76.9,77.1,77.4,77.7,77.8,77.9,78.0
     3,78.0,78.0,78.1,78.1,78.0,78.0,77.9,77.8,77.6,77.3,77.0,76.5,76.1,
     475.8,75.2,74.9,74.3,73.9,73.3,72.9,72.4,72.0,71.7,71.5,71.5,71.5,7
     51.6,71.7,71.7,71.7,71.6,71.5,71.5,71.5/
      DATA QS0/70.0,70.1,70.2,70.3,70.4,70.4,70.3,70.2,70.1,70.0,70.0,70
     1.0,70.0,70.2,70.6,70.9,71.0,71.2,71.4,71.7,71.9,72.0,72.2,72.7,73.
     20,73.3,73.8,74.1,74.5,74.8,75.0,75.3,75.5,75.8,75.9,76.0,76.0,76.0
     3,76.1,76.1,76.2,76.2,76.2,76.2,76.1,76.0,76.0,75.8,75.5,75.2,74.9,
     474.3,73.8,73.0,72.2,71.4,70.6,70.0,69.5,69.0,68.6,68.6,68.7,68.8,6
     59.0,69.1,69.3,69.6,69.8,69.9,70.0,70.0/
      DATA QN1/69.7,70.0,70.3,70.8,71.2,71.7,72.1,72.5,72.9,73.1,73.4,73
     1.6,73.7,73.8,73.9,74.0,74.0,74.1,74.2,74.2,74.2,74.2,74.2,74.2,74.
     23,74.5,74.8,75.0,75.3,75.6,75.8,76.0,76.1,76.3,76.6,76.7,76.9,77.1
     3,77.3,77.4,77.5,77.6,77.6,77.5,77.4,77.2,77.0,76.8,76.4,76.0,75.4,
     475.0,74.5,74.0,73.5,73.0,72.4,72.0,71.5,71.2,71.0,70.8,70.4,70.3,7
     50.1,70.0,69.9,69.8,69.6,69.6,69.6,69.7/
      DATA QS1/67.0,67.1,67.2,67.4,67.5,67.6,67.7,67.8,67.9,67.9,68.0,68
     1.0,68.3,68.7,69.0,69.5,70.0,70.3,70.7,71.0,71.3,71.6,71.8,72.0,72.
     24,72.7,73.0,73.4,73.8,74.1,74.4,74.7,74.9,75.1,75.2,75.4,75.5,75.6
     3,75.7,75.8,75.9,75.9,75.9,75.7,75.5,75.4,75.2,75.0,74.5,74.1,73.8,
     473.0,72.3,71.5,70.7,69.9,69.0,68.4,68.1,67.9,67.6,67.5,67.4,67.4,6
     57.4,67.3,67.2,67.2,67.1,67.1,67.0,67.0/
      DATA QN2/70.0,70.1,70.3,70.7,71.0,71.3,71.8,72.0,72.3,72.7,72.9,73
     1.1,73.4,73.7,73.9,74.0,74.2,74.3,74.4,74.4,74.4,74.4,74.4,74.3,74.
     23,74.3,74.4,74.7,74.8,75.0,75.1,75.3,75.6,75.8,76.0,76.1,76.2,76.4
     3,76.6,76.7,76.8,76.8,76.8,76.7,76.5,76.4,76.2,76.0,75.5,75.3,75.0,
     474.7,74.3,73.9,73.4,73.0,72.4,72.0,71.5,71.0,70.6,70.4,70.1,70.0,7
     50.0,70.0,70.0,70.0,70.0,70.0,70.0,70.0/
      DATA QS2/65.0,65.1,65.2,65.4,65.7,65.8,65.9,66.0,66.2,66.4,66.6,66
     1.8,66.9,67.1,67.6,68.0,68.4,69.0,69.7,70.1,70.6,71.0,71.4,71.7,72.
     20,72.1,72.3,72.6,72.9,73.0,73.3,73.7,73.9,74.0,74.3,74.5,74.7,74.8
     3,74.9,74.9,75.0,75.0,75.0,74.9,74.7,74.6,74.3,74.0,73.6,73.2,72.8,
     472.2,71.8,71.1,70.5,70.0,69.1,68.4,67.8,67.2,66.7,66.3,66.0,65.9,6
     55.7,65.6,65.5,65.4,65.3,65.2,65.1,65.0/
```

```
 DATA QN3/71.0,71.0,71.2,71.5,71.8,72.0,72.1,72.3,72.6,72.8,73.0,73
1.1,73.3,73.5,73.7,73.9,74.0,74.0,74.0,74.0,74.1,74.2,74.3,74.4,74.
25,74.7,74.9,75.0,75.2,75.4,75.6,75.8,75.9,76.0,76.0,76.0,76.0,76.0
3,76.0,76.0,76.0,76.0,75.9,75.8,75.7,75.6,75.4,75.2,75.0,74.6,74.4,
474.0,73.8,73.3,73.0,72.5,72.0,71.8,71.3,71.1,70.8,70.6,70.5,70.4,7
50.4,70.5,70.5,70.6,70.7,70.8,70.9,70.9/
 DATA QS3/64.0,64.0,64.0,64.0,64.0,64.0,64.0,64.0,64.1,64.4,64.8,65
1.0,65.5,66.0,66.8,67.3,68.0,68.8,69.2,69.8,70.0,70.4,70.8,71.0,71.
21,71.3,71.5,71.7,72.0,72.2,72.6,73.0,73.1,73.5,73.8,73.9,74.0,74.0
3,74.0,74.0,73.9,73.7,73.5,73.3,73.2,73.1,73.0,72.9,72.5,72.3,72.0,
471.5,71.0,70.5,70.0,69.0,68.4,67.7,67.0,66.2,65.7,65.2,64.9,64.7,6
54.5,64.4,64.3,64.2,64.1,64.1,64.1,64.1/
 DATA QN4/71.6,71.8,71.9,72.0,72.1,72.2,72.4,72.6,72.8,72.9,73.0,73
1.2,73.3,73.6,73.7,73.8,73.8,73.8,73.8,73.8,73.9,74.0,74.0,74.0,74.
20,74.1,74.3,74.5,74.7,74.8,75.0,75.1,75.2,75.3,75.5,75.5,75.5,75.6
3,75.6,75.6,75.5,75.3,75.1,75.0,74.9,74.7,74.4,74.1,74.0,73.9,73.7,
473.4,73.1,72.9,72.5,72.2,71.9,71.6,71.3,71.0,70.9,70.8,70.8,70.8,7
50.8,70.8,70.8,70.9,71.0,71.0,71.1,71.4/
 DATA QS4/63.5,63.5,63.6,63.7,63.8,63.8,63.8,63.9,63.9,63.9,64.0,64
1.2,64.7,65.0,65.2,65.8,66.1,66.9,67.5,68.1,68.8,69.2,69.8,70.1,70.
25,70.9,71.2,71.5,72.0,72.4,72.7,73.0,73.2,73.4,73.5,73.5,73.5,73.5
3,73.5,73.5,73.4,73.3,73.2,73.1,73.0,72.7,72.3,72.0,71.5,71.0,70.5,
469.9,69.2,68.5,67.9,67.0,66.5,66.0,65.5,65.2,65.0,65.0,64.9,64.8,6
54.7,64.5,64.3,64.1,63.9,63.8,63.7,63.5/
 DATA QN5/72.5,72.6,72.7,72.8,72.9,73.0,73.0,73.1,73.1,73.2,73.3,73
1.4,73.5,73.5,73.5,73.5,73.6,73.7,73.8,73.6,73.5,73.4,73.3,73.2,73.
21,73.3,73.6,73.8,74.0,74.0,74.2,74.6,74.8,74.9,75.0,75.2,75.3,75.4
3,75.4,75.3,75.2,75.1,74.0,74.8,74.4,74.1,73.9,73.4,73.1,72.9,72.5,
472.2,71.9,71.6,71.4,71.2,71.1,71.0,71.0,71.0,71.0,71.1,71.2,71.4,7
51.6,71.8,71.9,72.0,72.0,72.1,72.2,72.4/
 DATA QS5/62.9,63.0,63.0,63.0,63.1,63.2,63.3,63.5,63.6,63.7,63.7,63
1.8,63.9,64.1,64.5,64.9,65.2,66.0,66.8,67.2,67.8,68.2,68.8,69.0,69.
25,69.9,70.1,70.5,70.8,71.0,71.4,71.8,72.0,72.3,72.6,72.8,73.0,73.0
3,73.0,72.9,72.8,72.6,72.3,72.1,71.9,71.5,71.1,70.8,70.5,70.3,70.0,
469.8,69.2,68.8,68.1,67.5,66.9,66.1,65.5,64.9,64.3,63.9,63.5,63.1,6
53.0,62.9,62.8,62.7,62.6,62.6,62.7,62.8/
 DATA QN6/73.0,73.0,73.0,73.0,73.0,73.0,73.1,73.1,73.2,73.2,73.3,73
1.4,73.5,73.4,73.3,73.2,73.1,73.0,72.9,72.8,72.6,72.4,72.2,72.1,72.
20,72.2,72.7,73.0,73.6,74.0,74.4,74.8,75.0,75.1,75.2,75.2,75.2,75.1
3,75.0,74.9,74.7,74.3,74.0,73.9,73.6,73.2,73.0,72.8,72.5,72.3,72.1,
472.0,71.8,71.5,71.2,71.1,71.0,71.0,71.0,70.9,71.0,71.0,71.2,71.5,7
51.8,72.0,72.2,72.5,72.7,72.8,72.9,73.0/
 DATA QS6/61.6,61.5,61.2,61.1,61.1,61.3,61.6,61.8,62.0,62.2,62.6,62
1.9,63.5,63.9,64.1,64.8,65.0,65.1,65.5,65.8,66.0,66.2,66.7,67.0,67.
25,68.1,68.8,69.4,70.0,70.5,70.9,71.3,71.7,72.0,72.1,72.2,72.2,72.2
3,72.1,72.0,71.9,71.5,71.2,71.0,70.5,70.1,69.9,69.5,69.2,69.0,68.5,
468.0,67.5,67.0,66.3,65.8,65.2,64.8,64.3,64.0,63.5,63.0,62.9,62.7,6
52.5,62.4,62.3,62.2,62.2,62.1,62.0,61.9/
 DATA QN7/73.7,73.8,73.9,73.9,73.9,73.8,73.7,73.6,73.4,73.3,73.2,73
1.1,73.1,73.0,73.0,72.8,72.5,72.2,72.0,71.7,71.4,71.2,71.0,70.8,70.
26,70.7,71.0,71.5,72.0,72.6,73.3,73.9,74.2,74.6,74.9,75.0,75.1,75.2
3,75.1,75.0,74.9,74.5,74.2,73.7,73.2,72.7,72.2,71.8,71.5,71.4,71.3,
471.2,71.1,71.0,71.0,70.9,70.8,70.8,70.8,70.8,70.8,71.0,71.3,71.7,7
52.0,72.3,72.7,73.0,73.2,73.4,73.6,73.7/
 DATA QS7/60.5,60.8,61.0,61.2,61.4,61.7,61.9,62.0,62.0,62.1,62.3,62
1.7,62.9,63.0,63.3,63.7,64.0,64.2,64.5,64.6,64.7,64.8,64.9,65.1,65.
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466.5,66.0,65.8,65.2,64.9,64.5,64.2,64.0,63.5,63.0,62.8,62.3,62.0,6
51.6,61.2,61.0,60.8,60.6,60.5,60.4,60.4/
 DATA QN8/74.2,74.2,74.2,74.1,74.0,74.0,73.9,73.7,73.6,73.4,73.2,73
1.0,72.8,72.6,72.1,71.9,71.5,71.0,70.8,70.2,69.9,69.7,69.3,69.2,69.
20,69.1,69.6,70.2,71.0,71.8,72.7,73.1,73.8,74.1,74.6,74.8,75.0,74.9
3,74.9,74.8,74.6,74.3,74.0,73.7,73.1,72.5,72.2,71.3,70.6,70.2,70.1,
470.0,70.0,70.1,70.1,70.2,70.5,70.7,70.9,71.0,71.4,71.7,71.9,72.1,7
52.4,72.8,73.0,73.3,73.5,73.8,74.0,74.1/
 DATA QS8/58.9,58.7,58.8,59.0,59.2,59.6,59.9,60.1,60.6,60.9,61.4,62
1.0,62.5,63.1,63.8,64.0,64.5,65.0,65.1,65.3,65.6,65.7,65.8,65.9 66.
20,66.2,66.7,67.0,67.6,68.0,68.7,69.0,69.8,70.0,70.5,70.8,71.0,71.1
3,71.2,71.1,71.0,70.7,70.3,70.0,69.3,68.8,68.0,67.4,66.8,66.0,65.4,
465.0,64.8,64.3,64.2,64.1,64.0,63.9,63.5,63.1,62.4,62.0,61.5,61.0,6
50.8,60.5,60.1,59.9,59.8,59.4,59.1,59.0/
 DATA QN9/74.2,74.2,74.2,74.1,74.0,74.0,73.9,73.7,73.6,73.4,73.2,73
1.0,72.8,72.6,72.1,71.9,71.5,71.0,70.8,70.2,69.9,69.7,69.3,69.2,69.
20,69.1,69.6,70.2,71.0,71.8,72.7,73.1,73.8,74.1,74.6,74.8,75.0,74.9
3,74.9,74.8,74.6,74.3,74.0,73.7,73.1,72.5,72.2,71.3,70.6,70.2,70.1,
470.0,70.0,70.1,70.1,70.2,70.5,70.7,70.9,71.0,71.4,71.7,71.9,72.1,7
52.4,72.8,73.0,73.3,73.5,73.8,74.0,74.1/
 DATA QS9/58.9,58.7,58.8,59.0,59.2,59.6,59.9,60.1,60.6,60.9,61.4,62
1.0,62.5,63.1,63.8,64.0,64.5,65.0,65.1,65.3,65.6,65.7,65.8,65.9,66.
20,66.2,66.7,67.0,67.6,68.0,68.7,69.0,69.8,70.0,70.5,70.8,71.0,71.1
3,71.2,71.1,71.0,70.7,70.3,70.0,69.3,68.8,68.0,67.4,66.8,66.0,65.4,
465.0,64.8,64.3,64.2,64.1,64.0,63.9,63.5,63.1,62.4,62.0,61.5,61.0,6
50.8,60.5,60.1,59.9,59.8,59.4,59.1,59.0/
 END
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Section VI

REFERENCES

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Appendix A

REFERENCE AURORAL OVALS FOR GEOMAGNETIC ACTIVITY INDEX Q

NOTE: All graphs are in coordinates of corrected geomagnetic latitude and corrected geomagnetic local time.

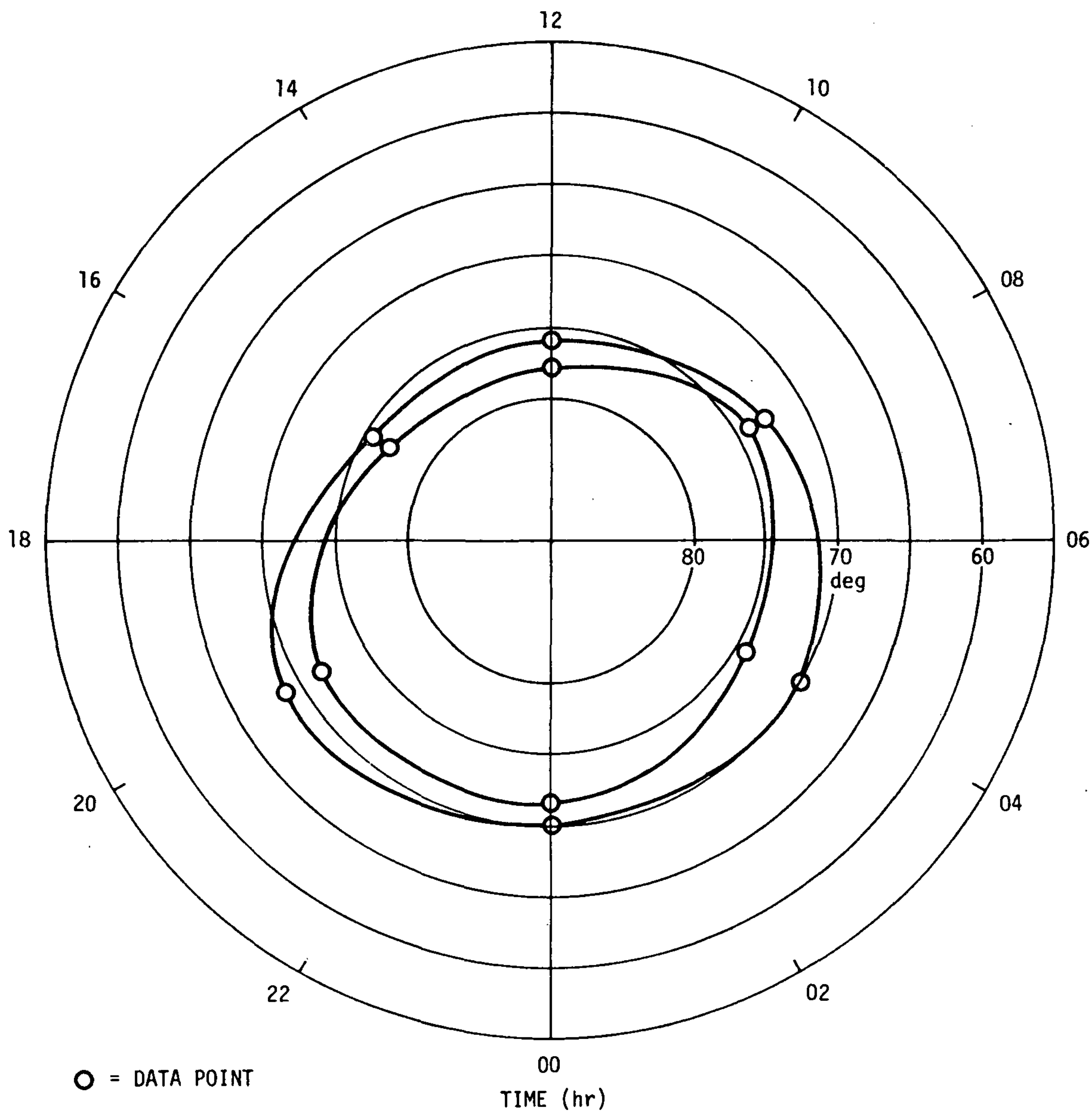

Figure A-1. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL Q = 0. DATA POINTS OBTAINED FROM REFERENCE 5

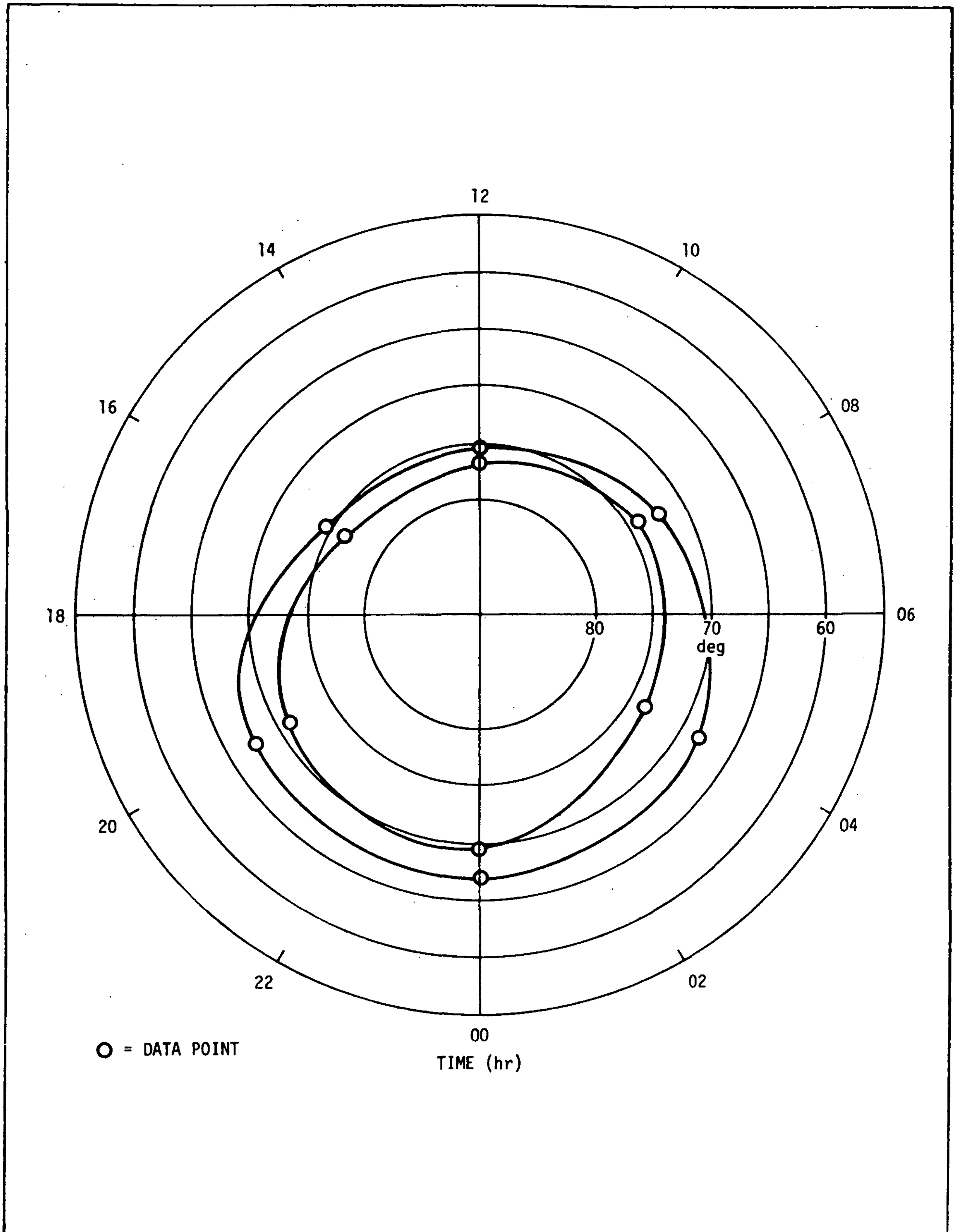

Figure A-2. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL Q = 1. DATA POINTS OBTAINED FROM REFERENCE 5

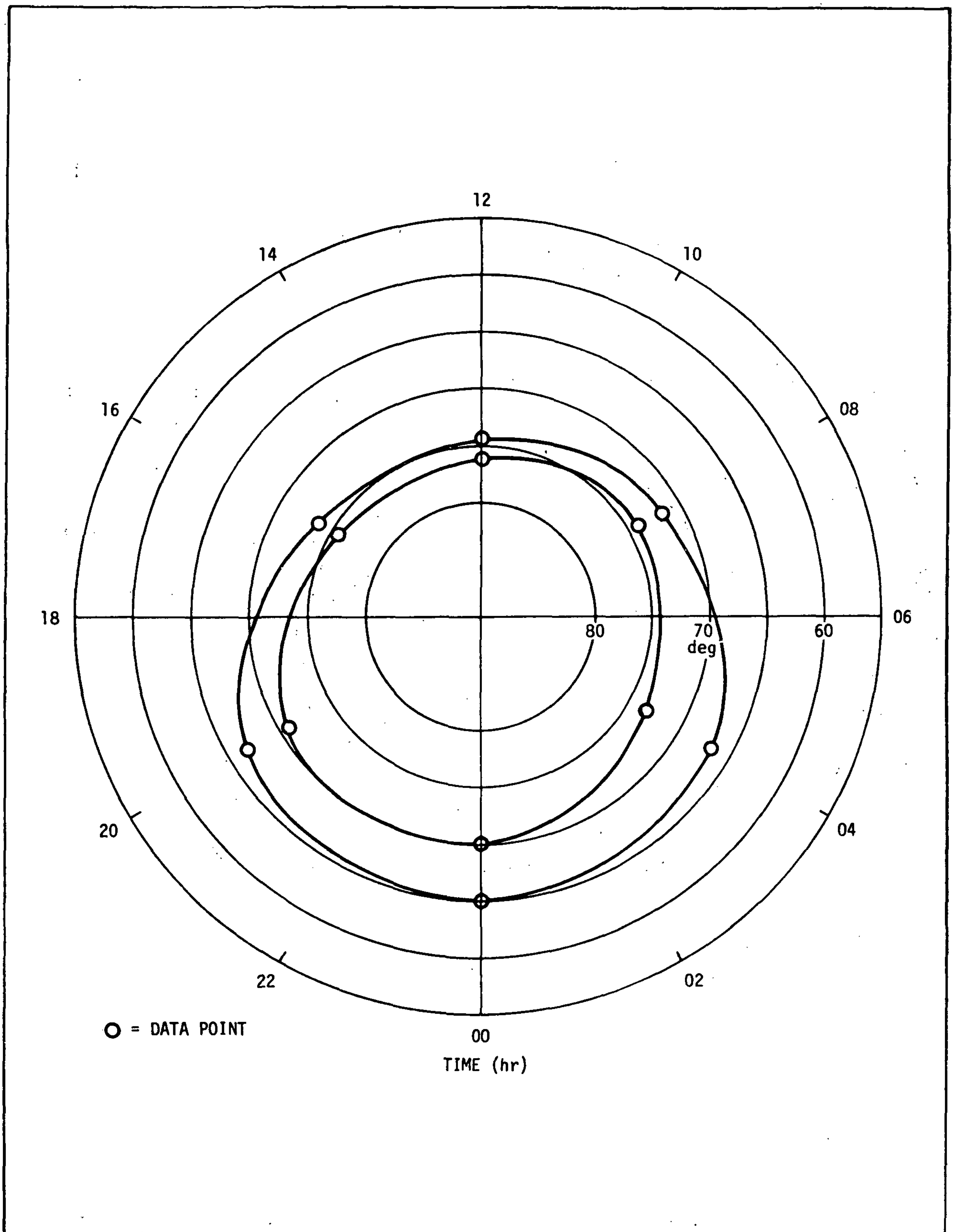

Figure A-3. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL Q = 2. DATA POINTS OBTAINED FROM REFERENCE 5

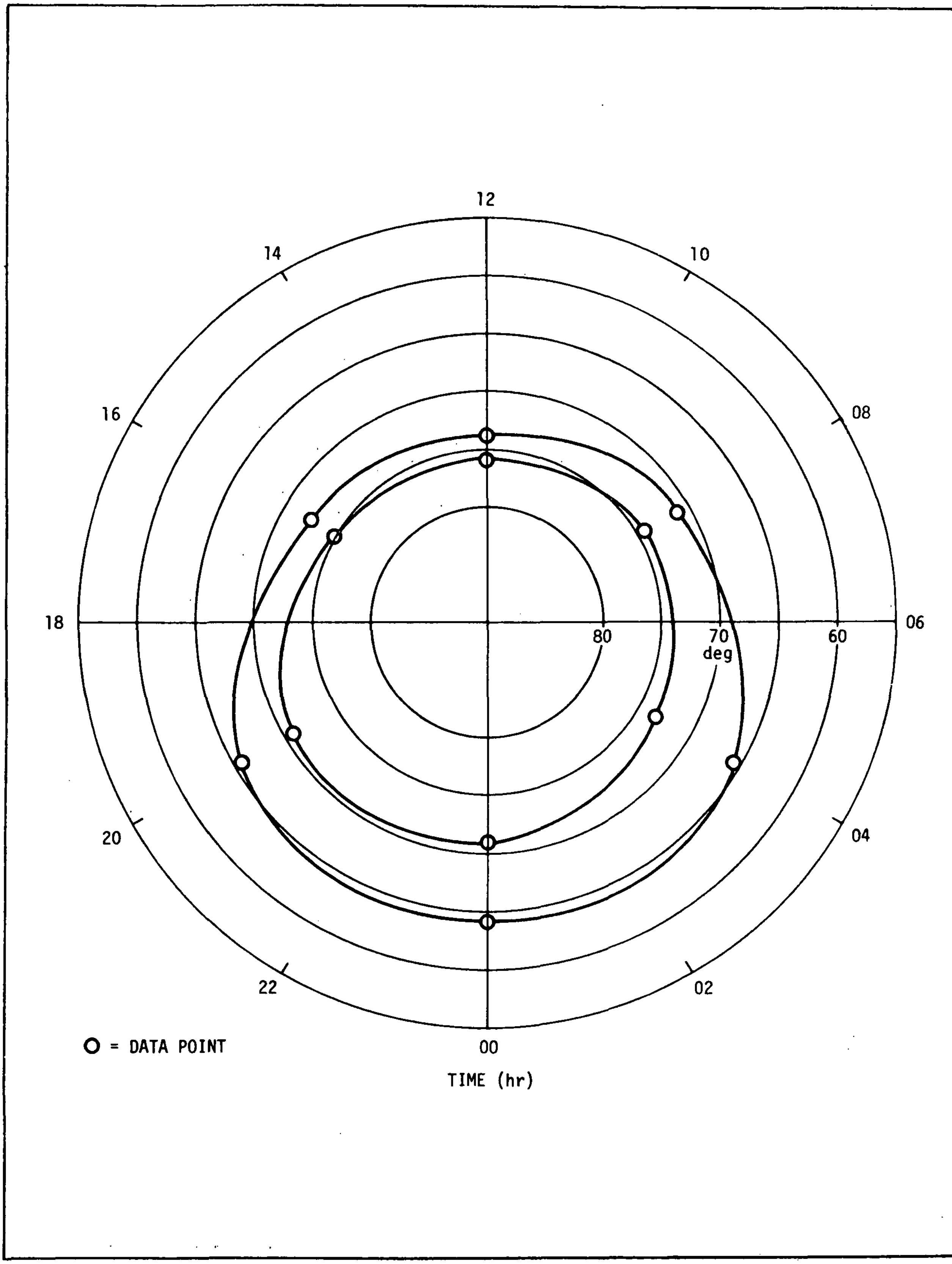

Figure A-4. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL Q = 3. DATA POINTS OBTAINED FROM REFERENCE 5

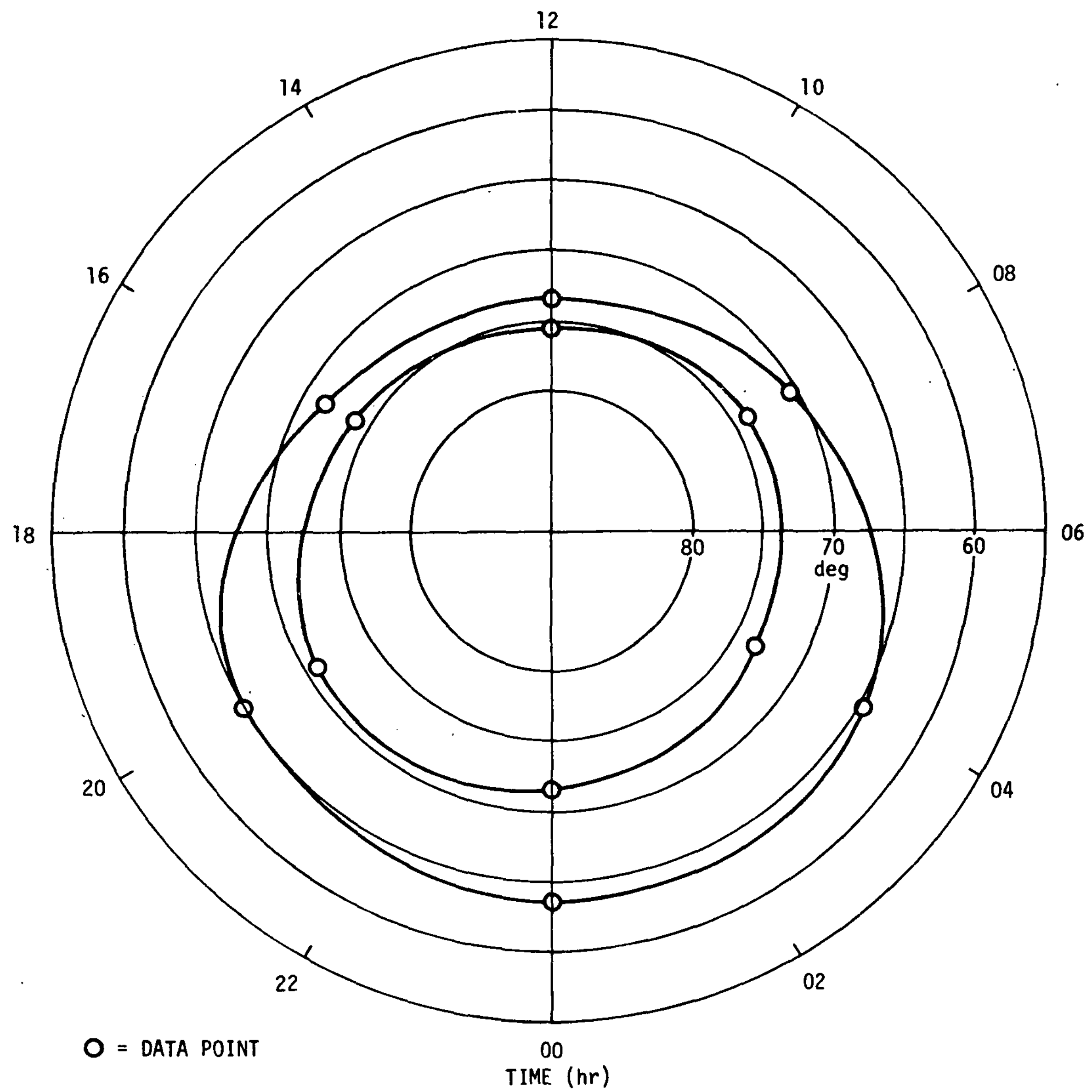

Figure A-5. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL Q = 4. DATA POINTS OBTAINED FROM REFERENCE 5

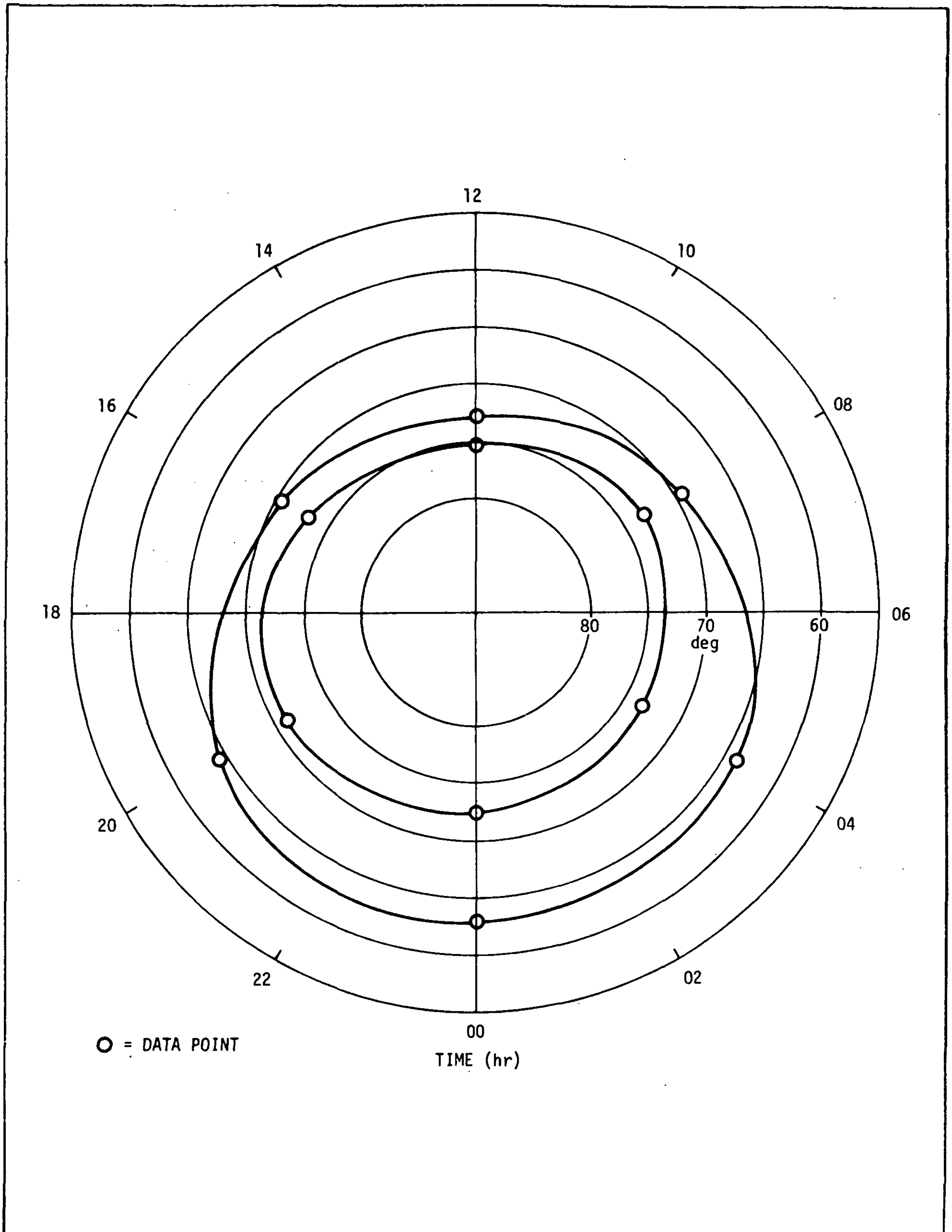

Figure A-6. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL Q = 5. DATA POINTS OBTAINED FROM REFERENCE 5

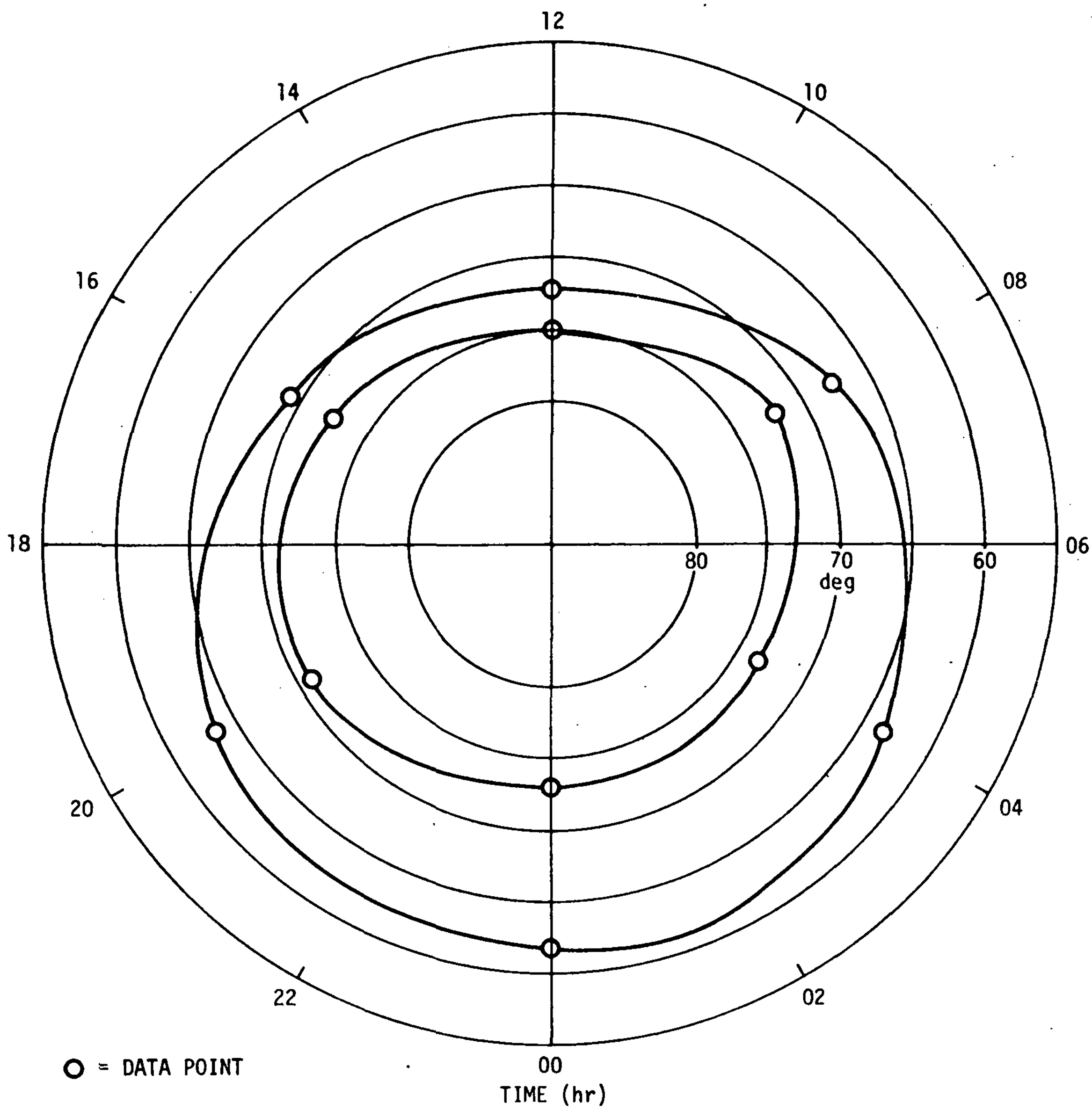

Figure A-7. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL Q = 6. DATA POINTS OBTAINED FROM REFERENCE 5

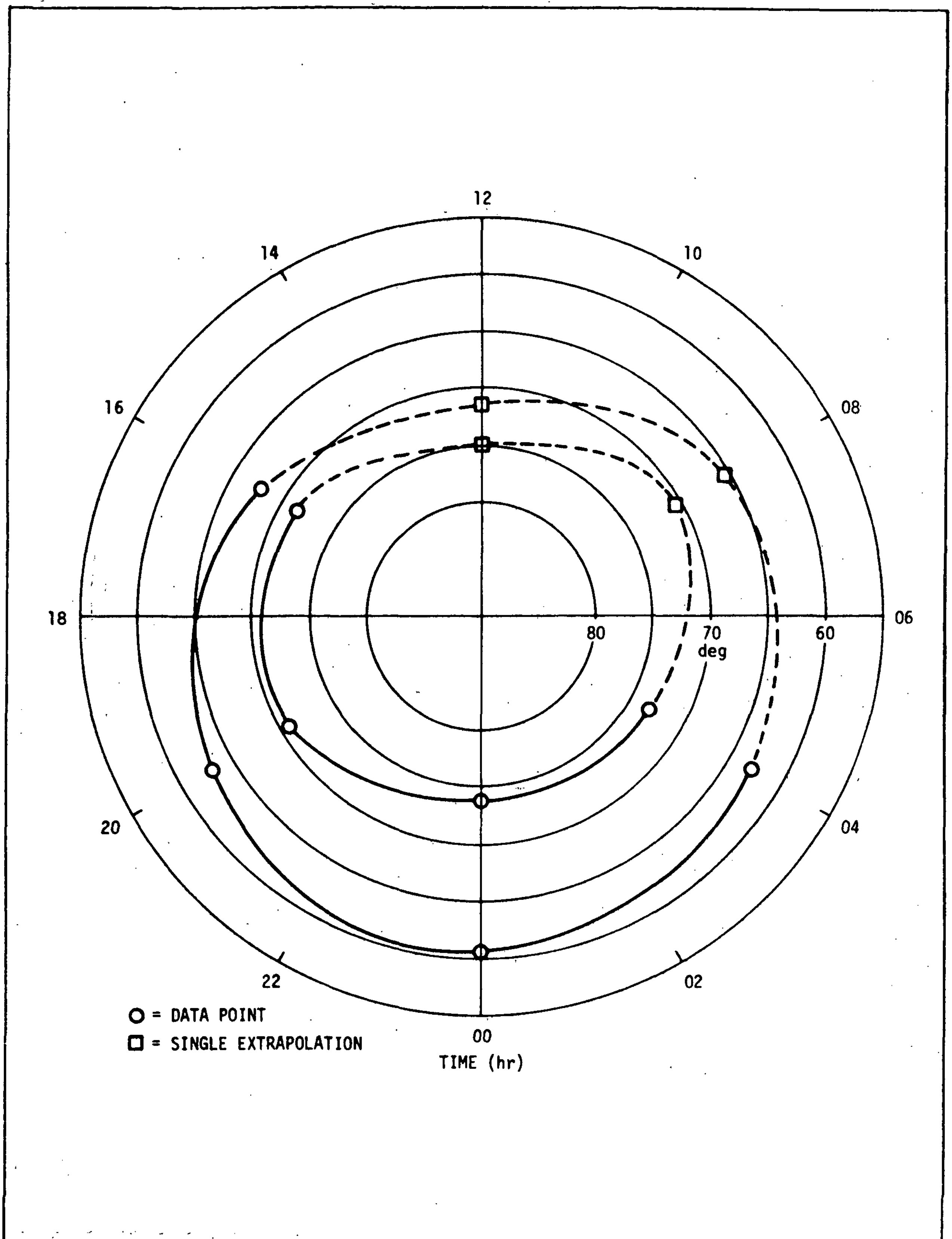

Figure A-8. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL Q = 7. DATA POINTS OBTAINED FROM REFERENCE 5

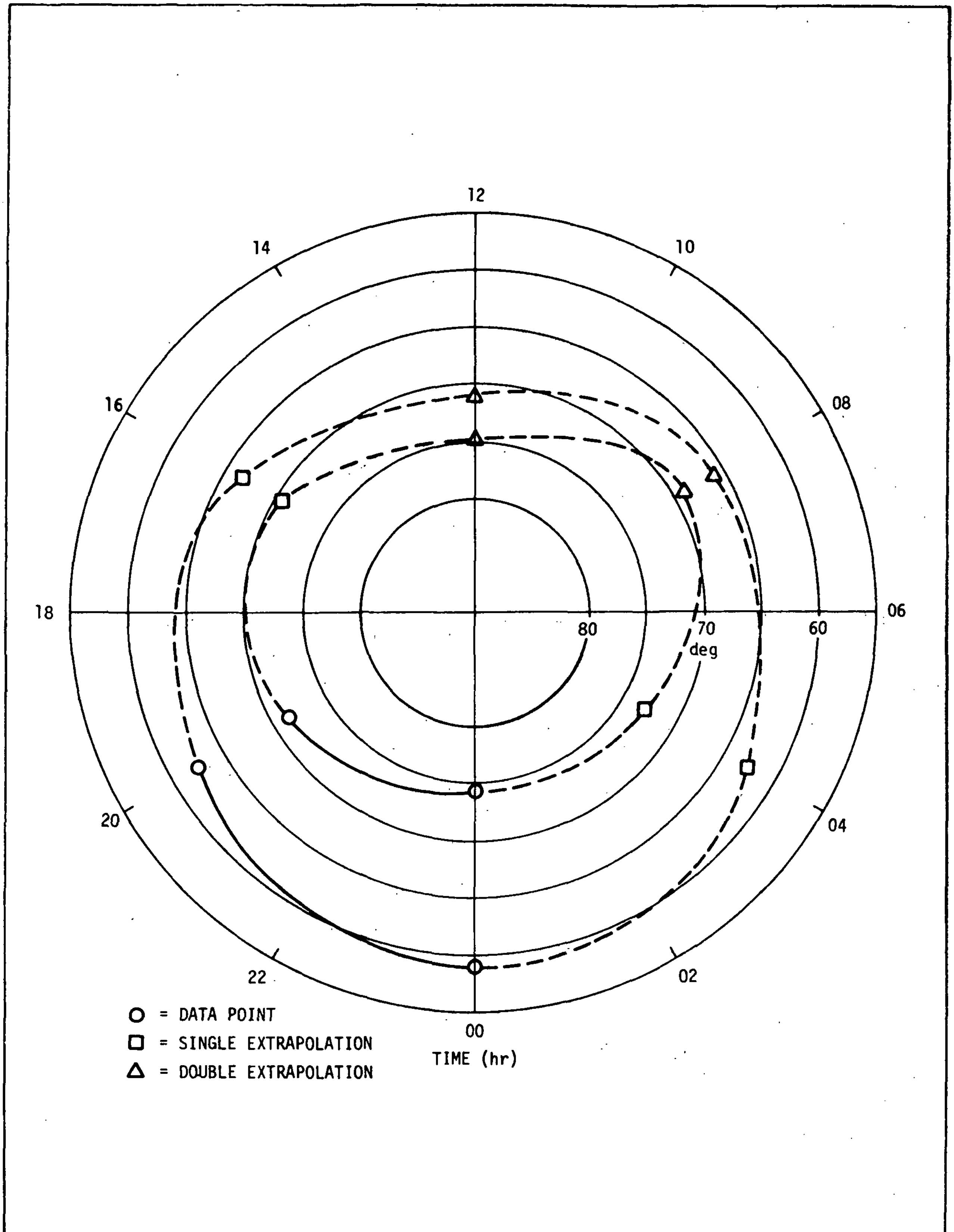

Figure A-9. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL Q = 8. DATA POINTS OBTAINED FROM REFERENCE 5

Appendix B

REFERENCE AURORAL OVALS FOR GEOMAGNETIC ACTIVITY INDEX K_p

NOTE: All graphs are in coordinates of corrected geomagnetic latitude and corrected geomagnetic local time.

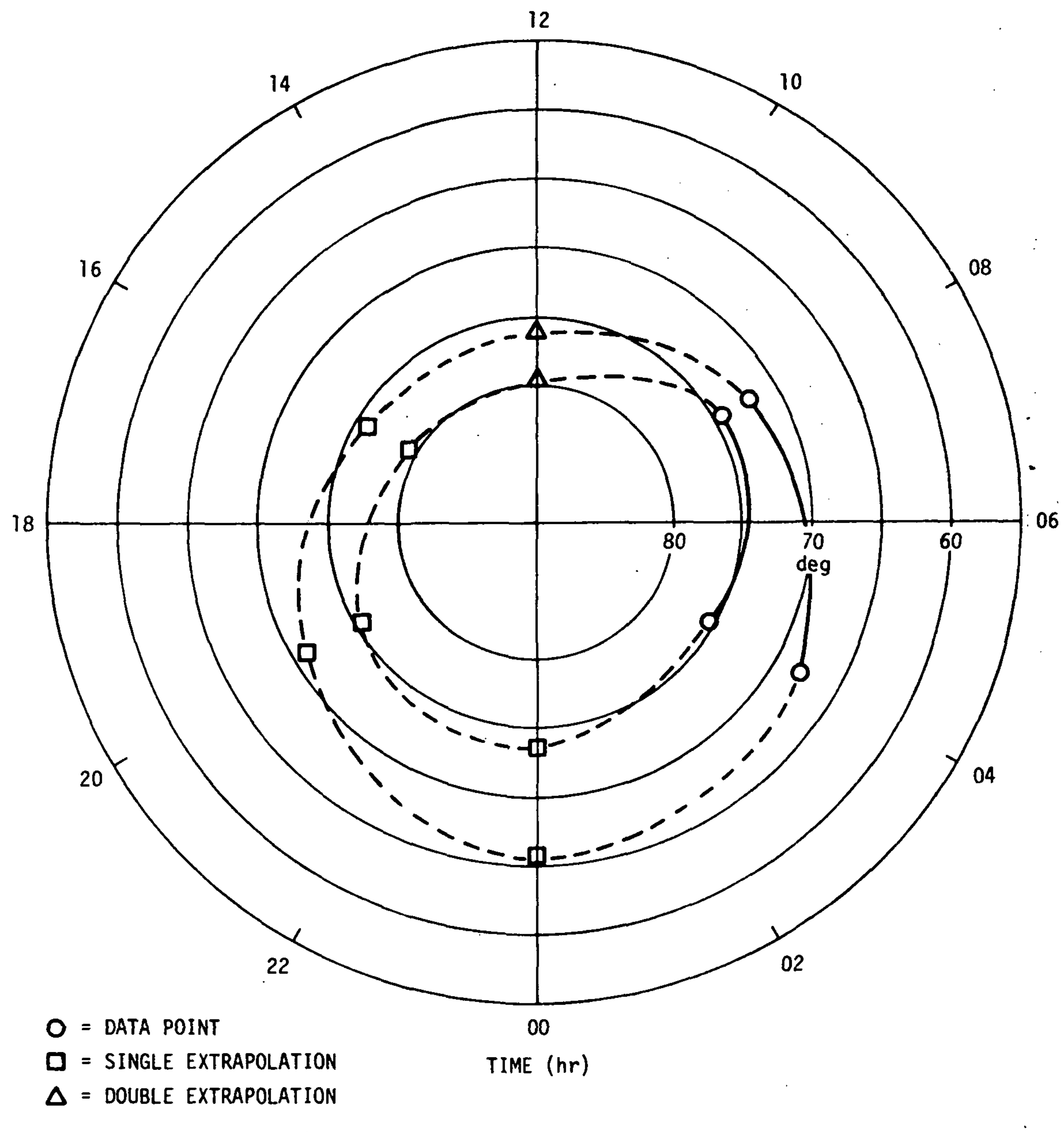

Figure B-1. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL K_p = 0. DATA POINTS OBTAINED FROM REFERENCE 6

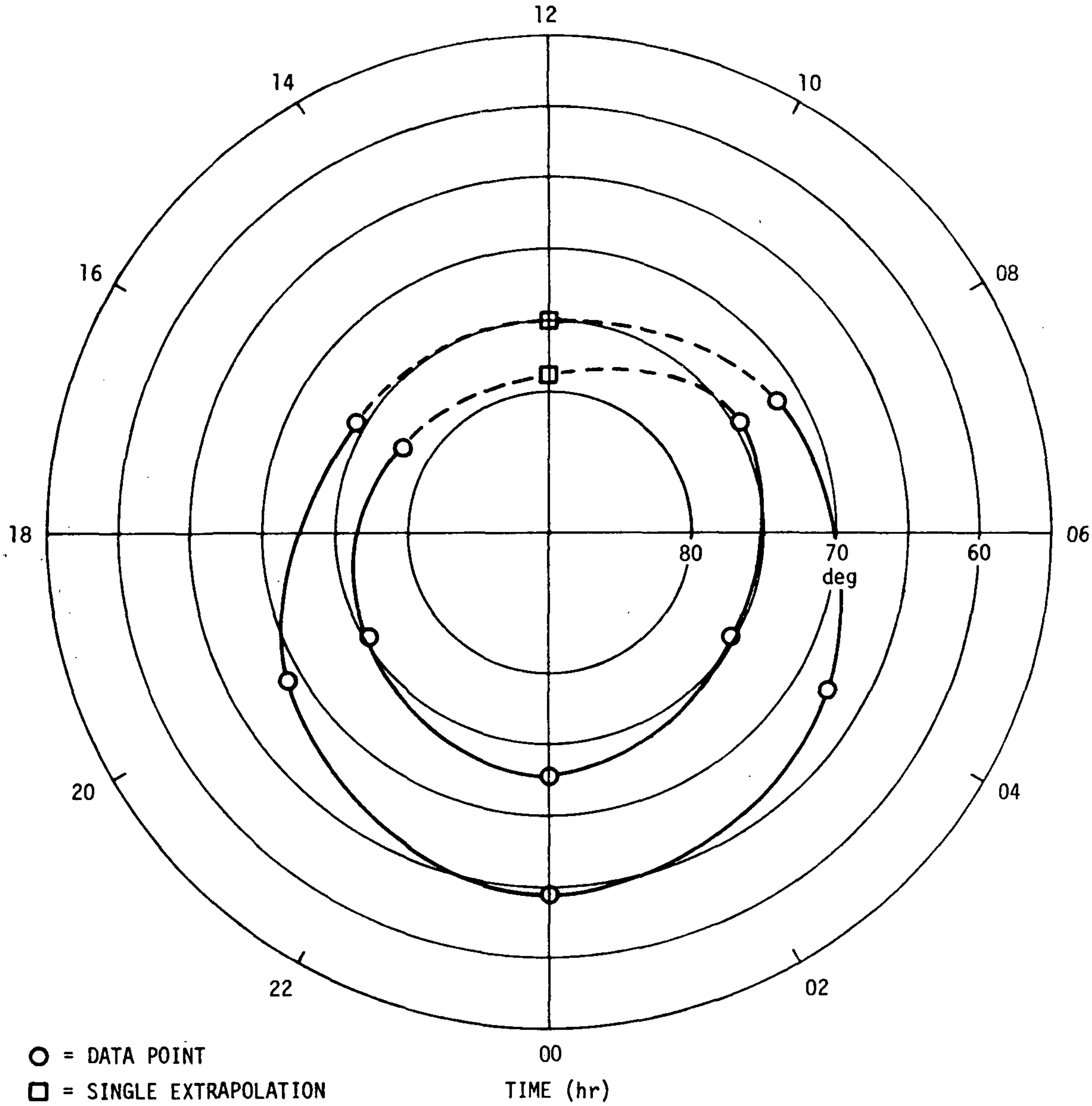

Figure B-2. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL $K_p = 1$. DATA POINTS OBTAINED FROM REFERENCE 6

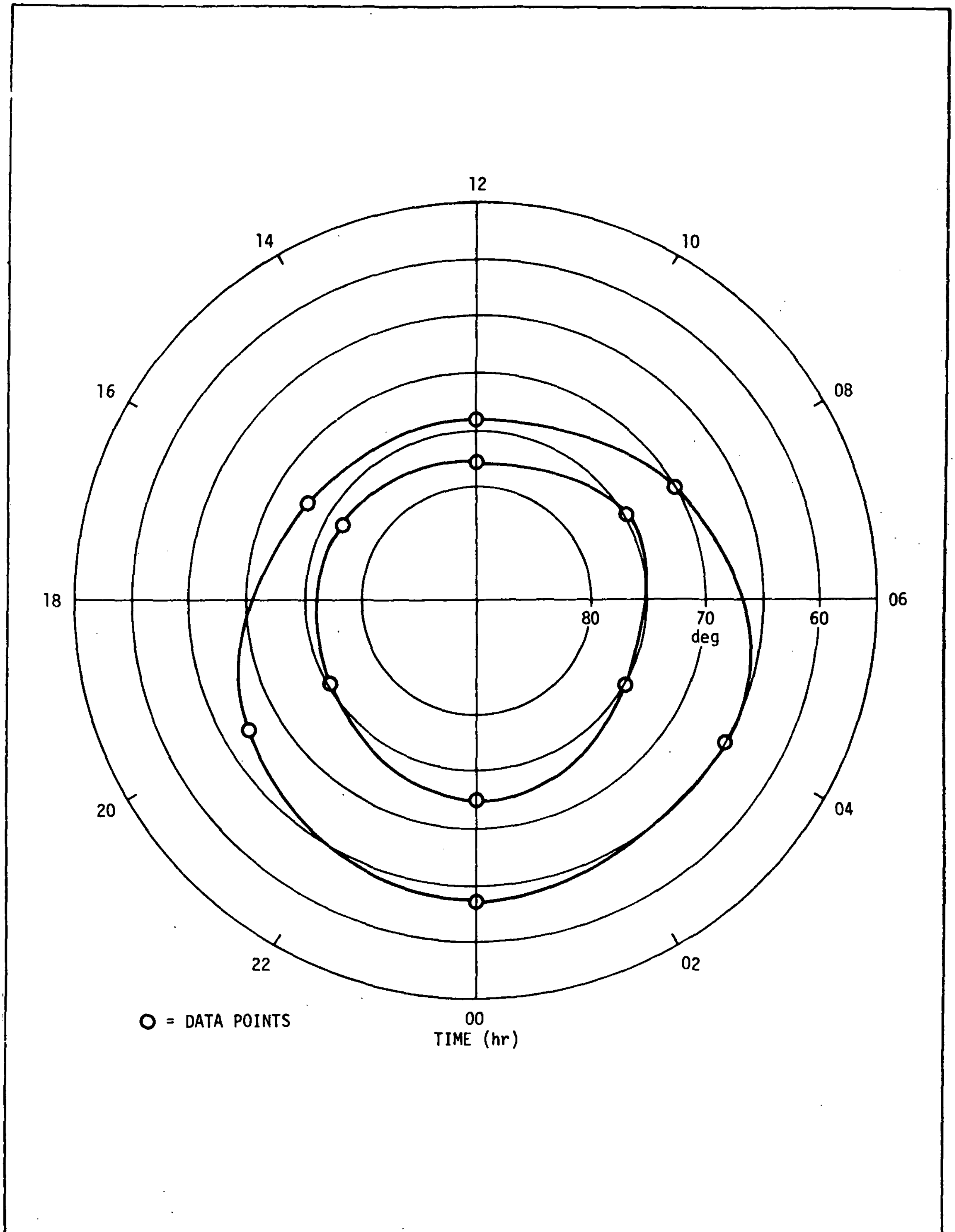

Figure B-3. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL $K_p = 2$. DATA POINTS OBTAINED FROM REFERENCE 6

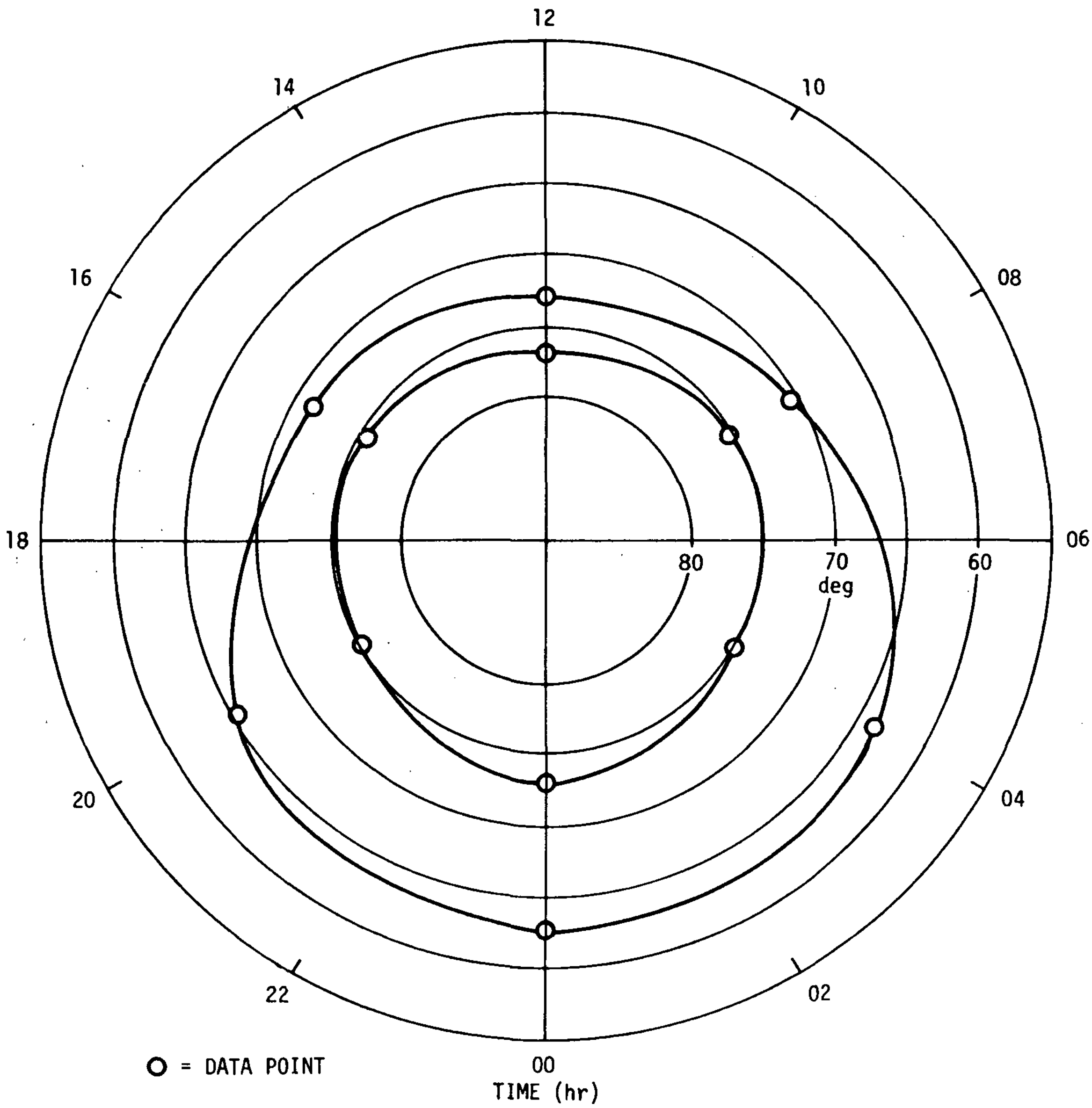

Figure B-4. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL K_p = 3. DATA POINTS OBTAINED FROM REFERENCE 6

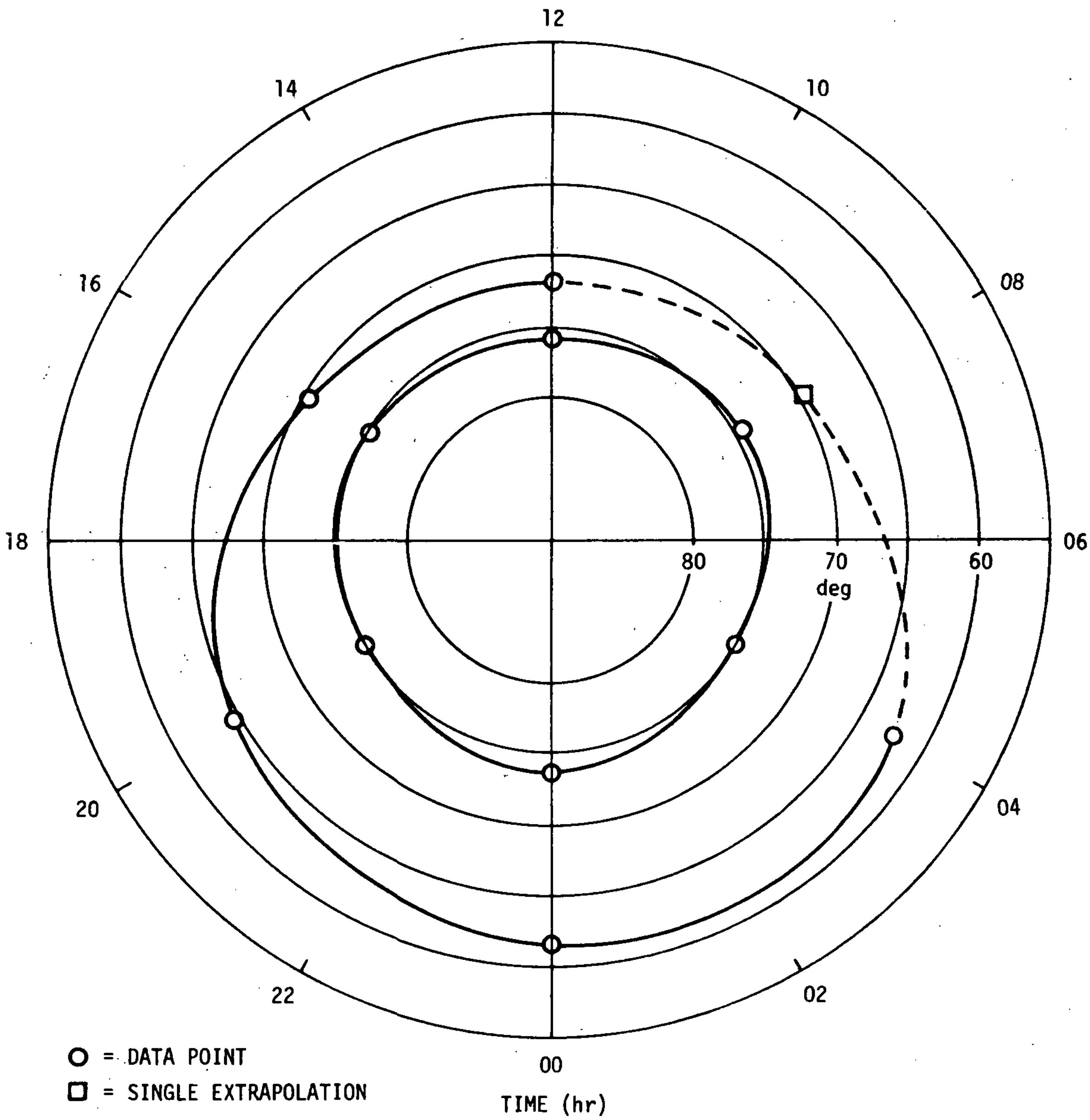

Figure B-5. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL $K_p = 4$. DATA POINTS OBTAINED FROM REFERENCE 6

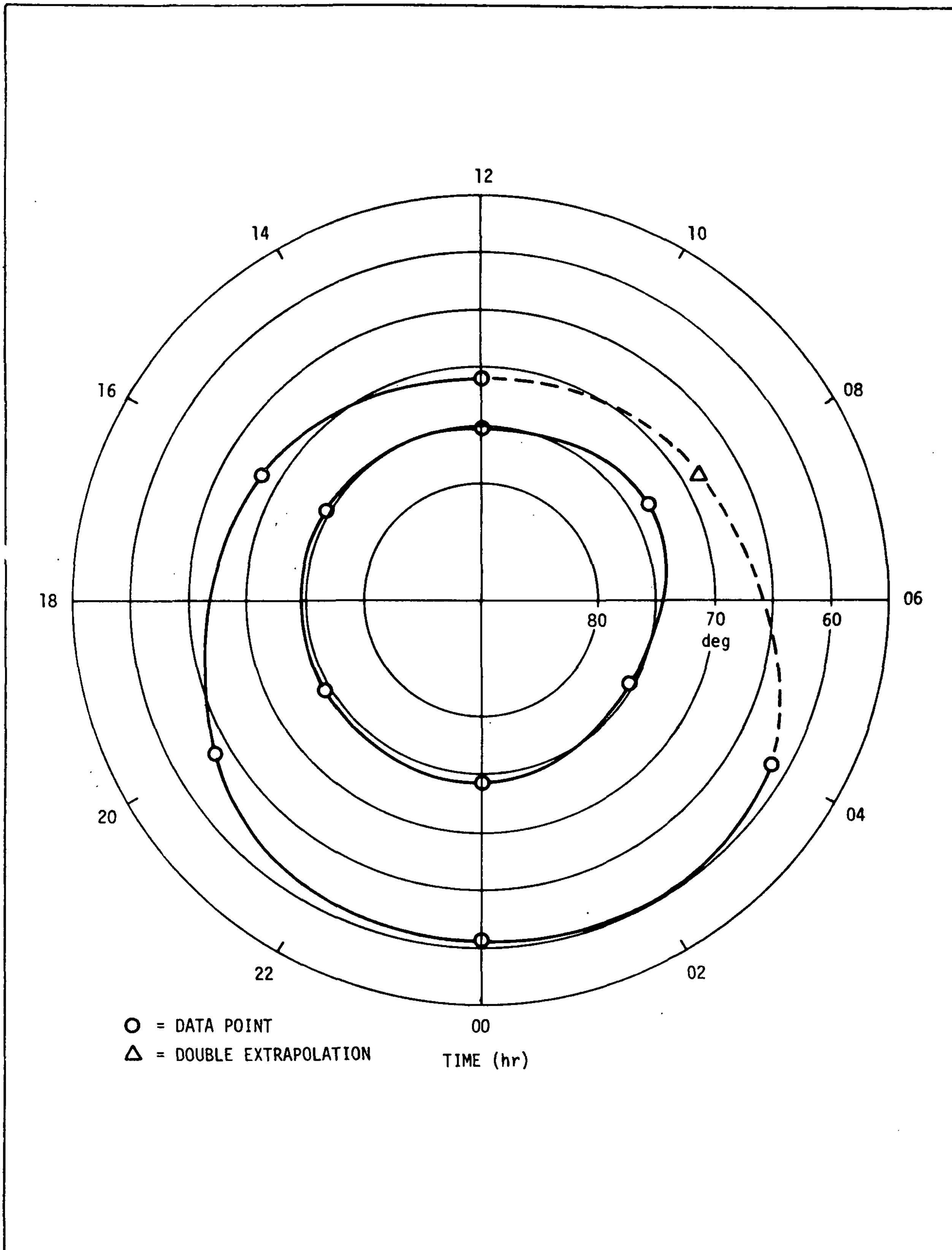

Figure B-6. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL $K_p = 5$. DATA POINTS OBTAINED FROM REFERENCE 6

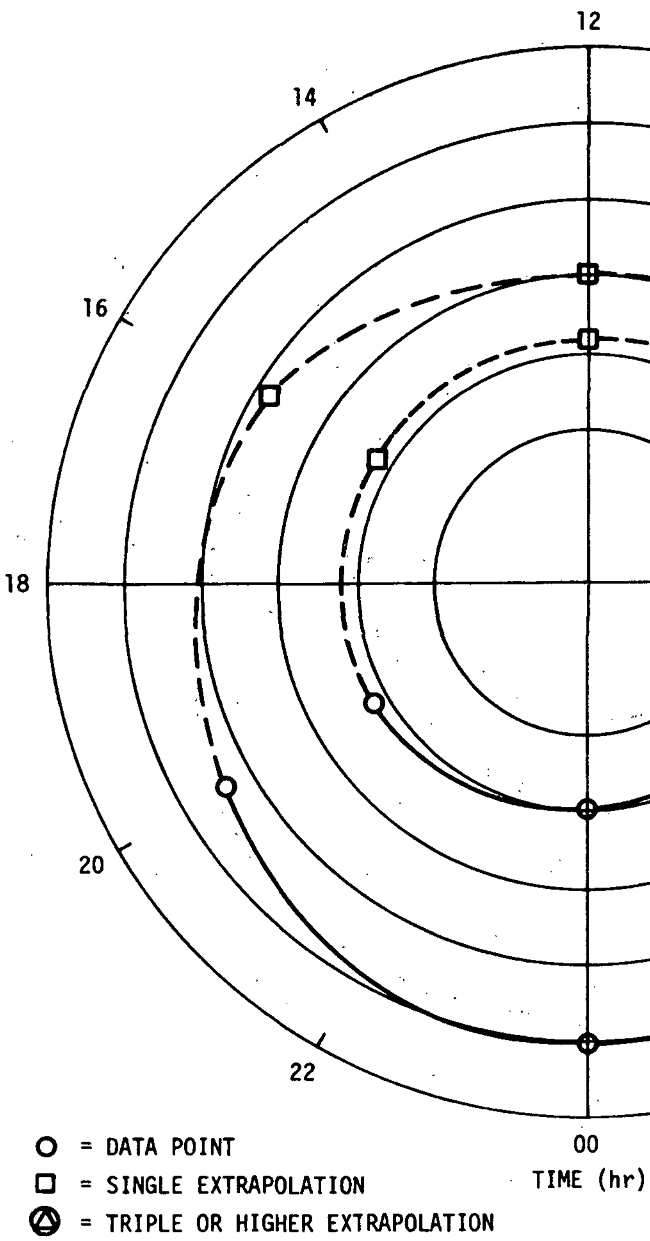

Figure B-7. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL $K_p = 6$. DATA POINTS OBTAINED FROM REFERENCE 6

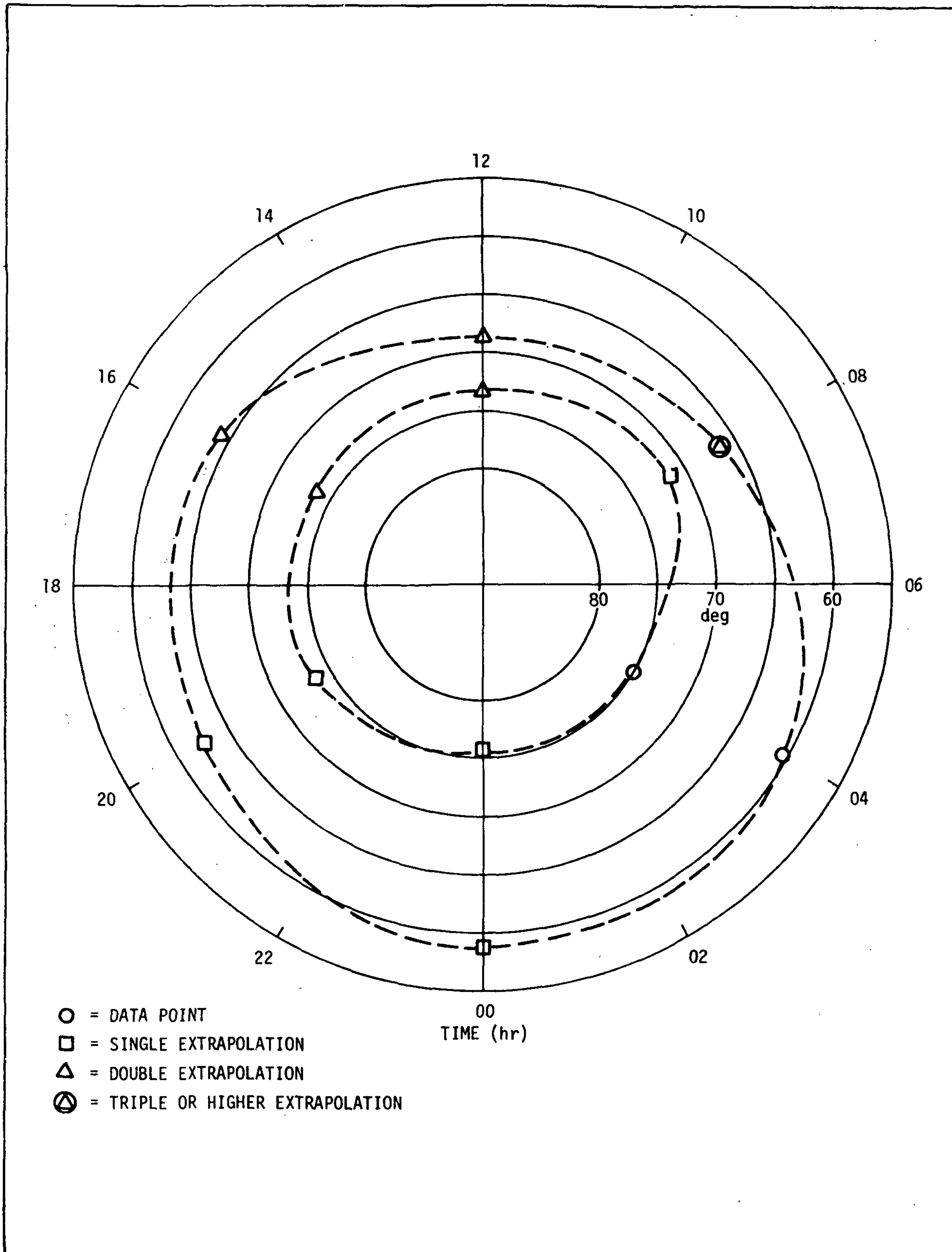

Figure B-8. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL $K_p = 7$. DATA POINTS OBTAINED FROM REFERENCE 6

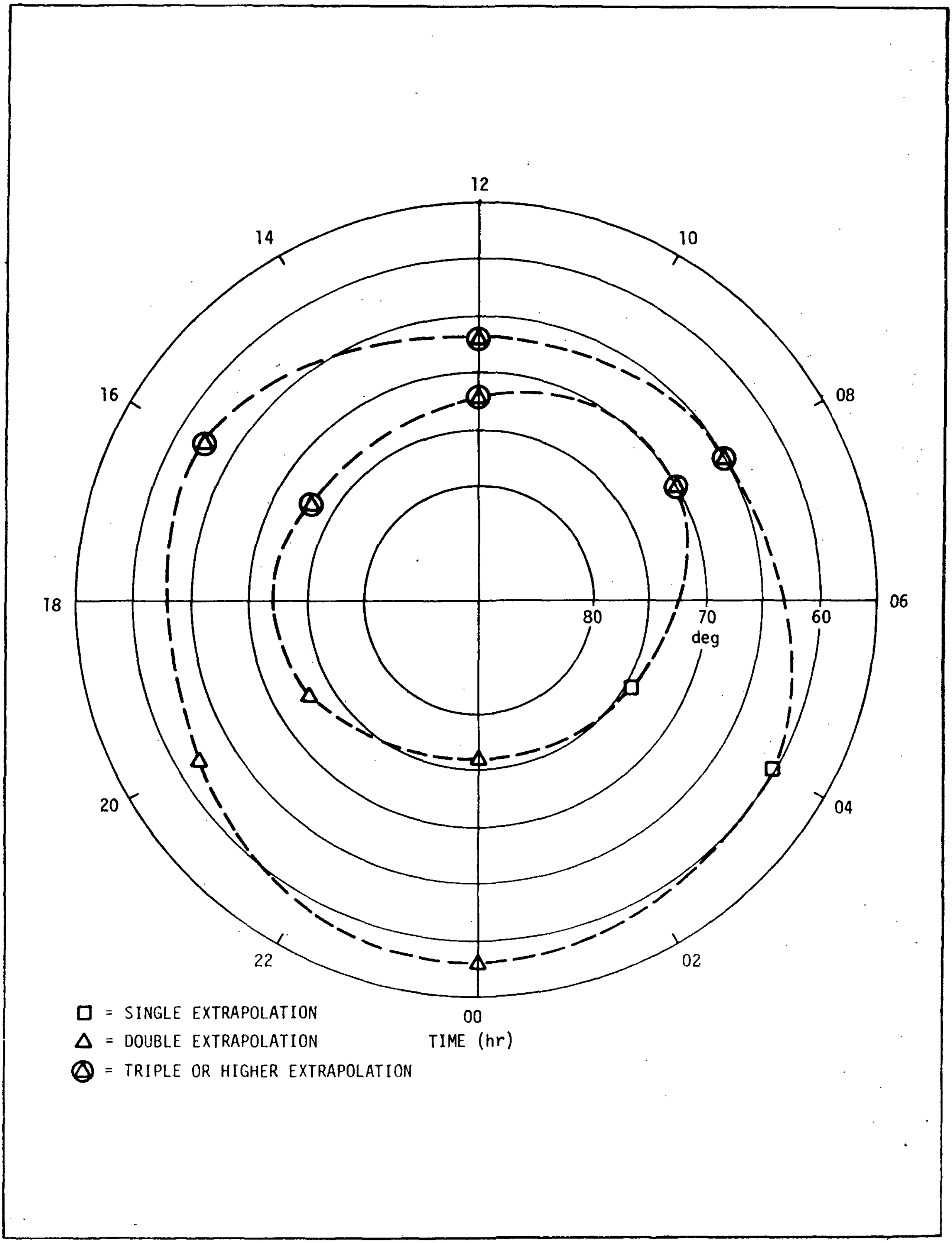

Figure B-9. REFERENCE AURORAL OVAL FOR GEOMAGNETIC ACTIVITY LEVEL K_p = 8. DATA POINTS OBTAINED FROM REFERENCE 6