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DOCUMENTATION AND DESCRIPTION
OF THE BENT
IONOSPHERIC MODEL

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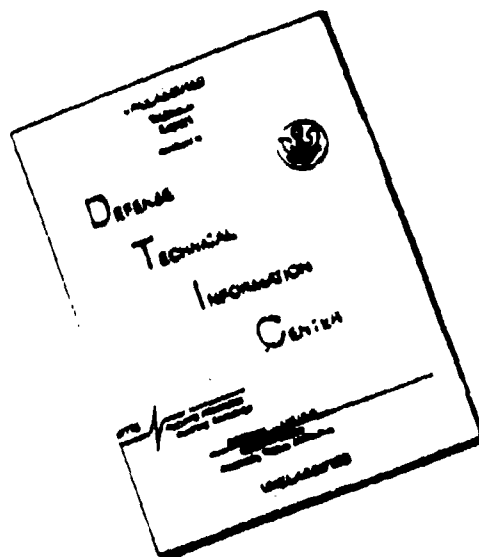
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<p>This report documents the computer programs of the Bent Ionospheric Model and briefly describes the development of the model. The FORTRAN Program is designed for general use and can generate ionospheric data on a world-wide basis for any past or future date. For a given condition consisting of station, satellite and time information, the electron density versus height profile is computed from which range, range rate, and angular refraction corrections as well as vertical and angular total electron content are obtained. The model has the additional capability of improving its predictions by updating with actual ionospheric observations. Considerable tests in the past have proved this empirical model highly successful. Also included in the documentation is an alternate version of the ionospheric program to be used when stringent space and time requirements are imposed by the operating system. However, several options of the standard program are not incorporated and the accuracy of the results is somewhat reduced.</p>			

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This document was prepared by Atlantic Science Corporation of Indialantic, Florida, for the Air Force Space & Missile Systems Organization (SAMSO), System 821B under Contract F04701-73-C-0207. This contract was jointly sponsored by funds from SAMSO and The Air Force Cambridge Research Laboratories. The document is assigned the USAF Report No. SAMSO TR-73-252.

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The majority of the development of the model was funded by NASA/Coddard Space Flight Center and monitored by Mr. P. Schmid, Code 591. The remaining portion of the model development was funded by the Air Force Space & Missile Systems Organization (SAMSO), System 821B under Contract F04701-72-C-0380 and monitored by Capt. L.J. Plotkin and Major R.H. Jesson.

The principal investigations in this work as well as the earlier development were performed by Rodney B. Bent and Sigrid K. Llewellyn. Mrs. Llewellyn was totally responsible for the software development and implementation.

Publication of this report does not constitute approval of the reports findings or conclusions. It is published only for the exchange and stimulation of ideas.

B.W. Parkinson, Colonel, USAF

Deputy for Defense Navigation Satellite Systems

ABSTRACT

This report documents the computer programs used in the Bent Ionospheric Model and briefly describes the development of the model. The FORTRAN Program is designed for general use and can generate ionospheric data on a world-wide basis for any past or future date. For a given condition consisting of station, satellite and time information, the electron density versus height profile is computed from which range, range rate, and angular refraction corrections as well as vertical and angular total electron content are obtained. The model has the additional capability of improving its predictions by updating with actual ionospheric observations. Considerable tests in the past have proved this empirical model highly successful. Also included in the documentation is an alternate version of the ionospheric program to be used when stringent space and time requirements are imposed by the operating system. However, several options of the standard program are not incorporated and the accuracy of the results is somewhat reduced.

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GLOSSARY

A	Azimuth angle of measured ray path
E	Elevation angle of measured ray path
ΔE	Error in E due to refraction
\dot{E}	$\frac{dE}{dt}$, time derivative of the elevation angle
f_oF2	Critical frequency of the F2 layer
f	Wave frequency
$\left. \begin{array}{l} h_p \\ h_p F2 \end{array} \right\}$	Height of maximum electron density of f_oF2 above surface of the earth
h_s	Height of satellite
\dot{h}	$\frac{dh_s}{dt}$, time derivative of satellite height
k_1, k_2, k_3	Decay constants of the lower, middle and upper topside exponential layer of the profile
$\left. \begin{array}{l} \text{M factor} \\ M(3000)F2 \end{array} \right\}$	$MUF(3000)F2/f_oF2$
$MUF(3000)F2$	The maximum useable frequency to propagate (by reflection from F2) over 3000 km
N	Electron density at height h
N_m	Maximum electron density
N_T	The total electron content in a vertical direction
R_e	Mean radius of earth
ΔR	One way range correction
$\dot{\Delta R}$	One way range rate correction
y_b	Half thickness of bottomside bi-parabolic layer
y_t	Half thickness of topside parabolic layer
ϕ, λ	Latitude and longitude of the ionospheric point, where the wave passes through the densest part of the ionosphere
ϕ_s, λ_s	Station latitude and longitude

1.0 Scope

This specification establishes the requirements for complete identification of Items #0001 and 0002, "Documentation and Description of the Bent Ionospheric Model," to be formally accepted by the procuring activity.

The Bent Ionospheric Model is an empirical world-wide computerized algorithm capable of predicting the ionospheric electron density profile and the associated delay and directional changes of a wave due to refraction. The following documentation of this model is formatted in accordance with Paragraph 60.5, computer program product specifications, MIL-STD-483, "Configuration Management Practices for Systems, Equipment, Munitions, and Computer Programs."

Sections 3.1 and 3.4 outline the overall program structure, Section 3.2 gives a detailed description of each program component, Sections 3.3 and 4.1 incorporate the program operation description, Section 6.1 and 6.2 outline the ionospheric model development and present its accuracy and limitations, and Appendix I contains the program listings.

2.0 Applicable Documents

The documents of exact issue shown, form a part of this specification to the extent specified herein. In case a conflict occurs between the referenced reports and the detailed content of sections 3, 4, 5, and 10, the detailed content shall be considered a superseding requirement for this CPCI.

References

1. E. V. Appleton & W. J. G. Beynon, Proc. Phys. Soc. 52, Pt. 1, 518 (1940); Proc. Phys. Soc. 59, Pt. II, 58 (1947)
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9. F. G. Stewart, M. Leftin, "Relationship Between 10.7 cm Ottawa Solar Radio Noise Flux and Zurich Sunspot Numbers," ESSA Technical Report (Oct. 1970)

3.0 Requirements - Technical Description

In the area of satellite communications the refraction incurred by a wave propagating through the ionosphere is most important. The Bent Ionospheric Model is an empirical world-wide algorithm capable of accurately estimating the electron density profile and the associated delay and directional changes of a wave due to refraction. The model computes the electron density versus height profile from which the range, range rate, and the angular refraction corrections for the wave are obtained as well as the vertical and angular total electron content. Although the model is presented for ground to satellite communications, it is readily adaptable for ground to ground, or satellite to satellite communications.

The only required inputs to the model are satellite and station position and time information and a limited amount of solar data. For the model's additional capability of improving the ionospheric predictions by use of actual ionospheric observations, measured values of electron content or the critical frequency of the F2 layer, foF2, can be incorporated along with the observation station and time information. This update option uses a weighted mean technique that can accept, for the update, several measurements from different stations separated in time and space from the time and location at which the ionosphere is to be evaluated.

The updating process is generally used for predicting ionospheric conditions or refraction corrections after the fact, when observations are generally available. However, the model's prediction accuracy without update accounts for approximately 75 to 80 percent of the ionosphere which can improve with update to approximately 90 percent. The model, therefore, may be applied for future predictions or after the fact calculations. Since the model has been developed on a world-wide basis, predictions are not limited to any particular land mass or segment of the world. The updating technique does, however, require that ionospheric observations be from stations within 2000 km radius of the evaluation site. The model is applicable for determining

wave refraction and ionospheric characteristics up to 2000 km in height and for all radio wave frequencies as long as the vertical component is slightly higher than critical frequency.

Built into the model are the combined influences of geographical and geomagnetic effects, solar activity, local time, and seasonal variations. These combined effects are the results of an extensive investigation of a vast ionospheric data base that included over 50,000 topside soundings, 6,000 satellite measurements of electron density and related foF2, and over 400,000 bottomside soundings. The data base, which formed the basis of the model, extended over the period of 1962 to 1969, covering the minimum to maximum of a solar cycle. For further information regarding the development and evaluation of the Bent Ionospheric Model, see Reference 2 and Section 6.0.

3.1 Functional Allocation Description

The ionospheric PROGRAM ION is written in FORTRAN IV code and has a simple load structure with no overlay requirements. The following program/subroutines comprise the CPCI, and the attached diagram identifies the calling routines and the subprograms called for each computer program component;

CPCs : PROGRAM ION, and SUBROUTINES REFRAC, PLOTNH, PROFL1, PROFL2, BETA, SICOJT, DKSICO, MAGFIN, GK, DKGK.

The following library subprograms are required :

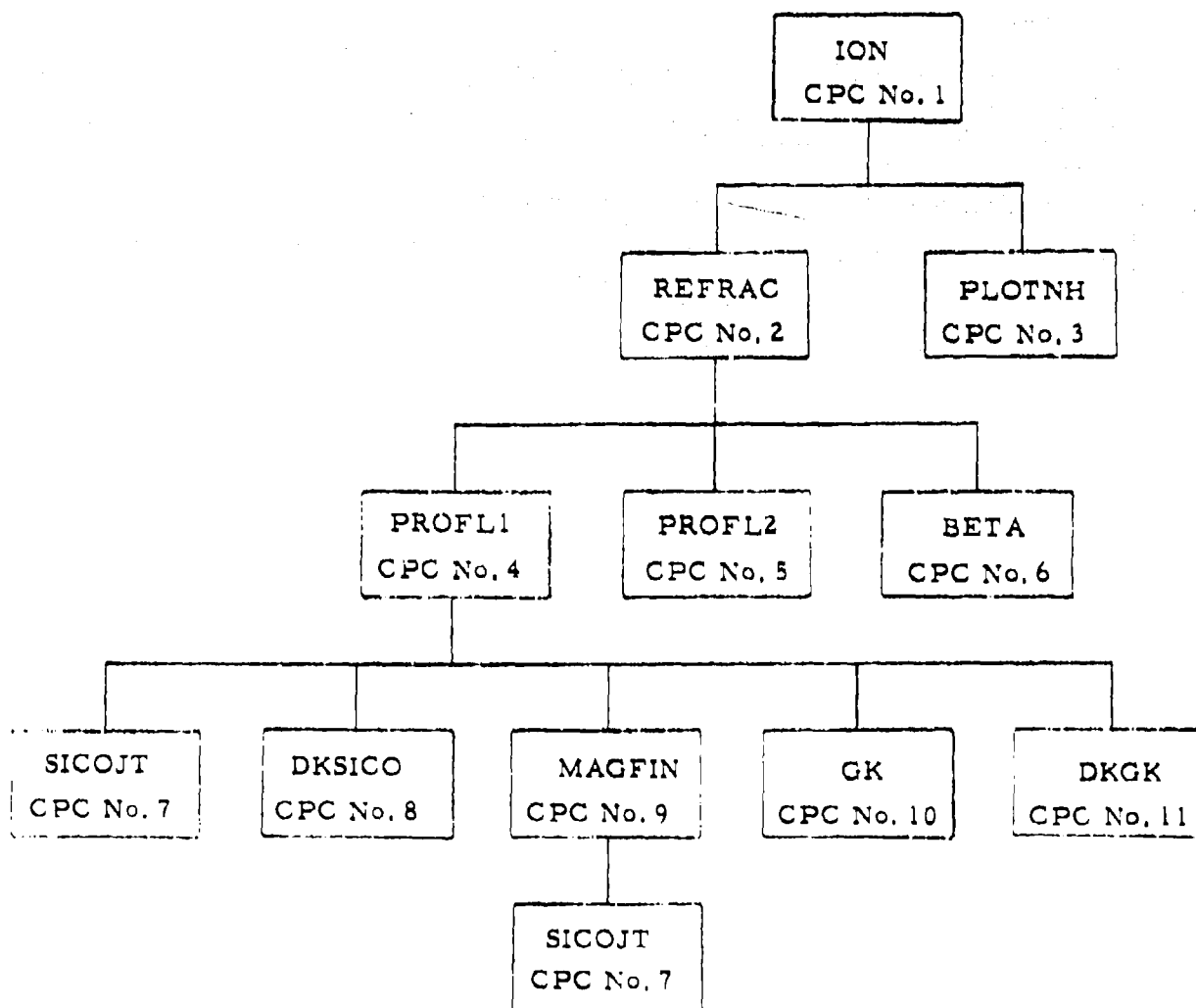
ABS, AMOD, ATAN, COS, EXP, LOG10, SIGN, SIN, SQRT.

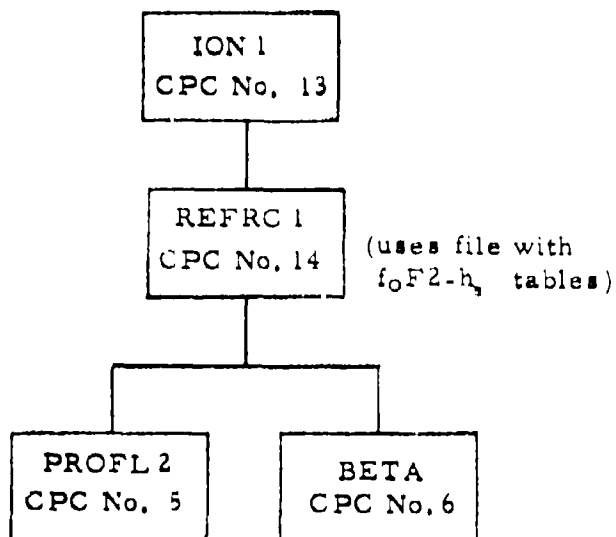
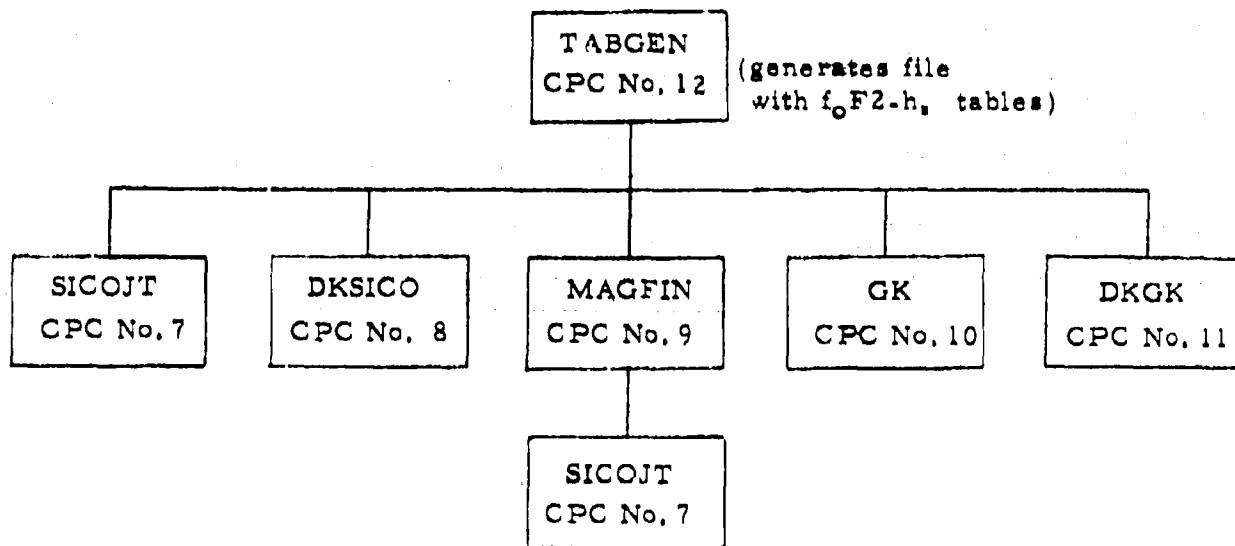
All internal data transfer between the individual CPCs occurs through labeled common blocks and through the calling sequences, which are both described under Section 3.2.1.3 for each CPC. The external data transfer consists of input coming from the data card deck into PROGRAM ION and from the ionospheric coefficient data tape into SUBROUTINE REFRAC, and of output of the results from PROGRAM ION and SUBROUTINE PLOTNH to the line printer; these files are described in detail in Section 3.3.1. The functions performed by the program are described in Section 3.4 and referenced to the CPCs to which they are assigned.

An alternate version of the ionospheric program is included in this documentation, consisting of a preprocessor TABGEN and a reduction program ION1. Both programs are written in FORTRAN IV code, have a simple load structure with no overlay requirements, are run as separate entities, and are only linked by the data file (disc or tape) produced by the preprocessor and utilized in ION1. PROGRAM TABGEN requires the following SUBROUTINES SICOJT, DKSICO, MAGFIN, GK, DKGK, and the library functions AMOD, ATAN, COS, SIN, SQRT. All internal data transfer occurs through the calling sequences; the external data transfer consists of input coming from the data card deck and the ionospheric coefficient tape and of output of f_oF2-h_p tables to disc or tape, all in PROGRAM TABGEN. PROGRAM ION1 requires the

following SUBROUTINES REFRCL, PROFL2, BETA and the library functions ABS, AMOD, ATAN, COS, FLOAT, SIN, SQRT. All internal data transfer occurs through the labeled common blocks and through the calling sequences. The external data transfer consists of input coming from the data card deck into ION1, from the preprocessed disc or tape file with f_oF2-h_x tables into SUBROUTINE REFRCL, and of output of the results from PROGRAM ION1 to the line printer. The second attached diagram shows the program structures, the data files are described in Section 3.3.1, and the functions performed by the preprocessor and reduction program are outlined in Section 3.4.

Whenever ionospheric predictions are desired, PROGRAM ION should have preference over the program set TABGEN-ION1. ION will yield more accurate results than ION1 where approximations are introduced through interpolating the f_oF2-h_x tables and through bypassing the iteration on the height estimate of the ionosphere. ION also has the additional features not included in ION1 of computing range rate corrections for range differencing, of plotting the ionospheric profile, and of updating the predictions with actual ionospheric observations. For many applications ION will be suited even for real-time processing. The program set TABGEN-ION1 should only be used when stringent core space and/or run time requirements are imposed that cannot be met by PROGRAM ION, or when program modifications for special applications are attempted. Running PROGRAM TABGEN in a preprocessing mode results in the significant core space and run time reduction of PROGRAM ION1.





3.2 Functional Description

This paragraph contains the detailed technical descriptions of the computer program components identified in Paragraph 3.1 of this specification. The instruction listings contained in Appendix I specify the exact configuration of the Bent Ionospheric Program ION and the alternate version TABGEN - ION1.

Following are specifically the descriptions for:

CPC No. 1	-	PROGRAM ION
CPC No. 2	-	SUBROUTINE REFRAC
CPC No. 3	-	SUBROUTINE PLOTNH
CPC No. 4	-	SUBROUTINE PROFL1
CPC No. 5	-	SUBROUTINE PROFL2
CPC No. 6	-	SUBROUTINE BETA
CPC No. 7	-	SUBROUTINE SICOJT
CPC No. 8	-	SUBROUTINE DKSICO
CPC No. 9	-	SUBROUTINE MAGFIN
CPC No. 10	-	SUBROUTINE GK
CPC No. 11	-	SUBROUTINE DKGK

Particular to all subroutines is the fact that none of the input variables transferred through common or the calling sequences are modified during execution of the program code. The units internal to all subroutines are kept in meters for distances, radians for angles and times, meters/second for linear velocities, radians/second for angular rates, MHz for frequencies and Gauss for magnetic field strength.

Included are also the descriptions of the routines that are required in addition to the ones listed above for the alternate version of the ionospheric program, consisting of separate preprocessor and reduction programs:

CPC No. 12	-	PROGRAM TABGEN
CPC No. 13	-	PROGRAM ION1
CPC No. 14	-	SUBROUTINE REFR1

3.2.1 Computer Program Component 1

CPC No. 1, main PROGRAM ION, is written in FORTRAN code. It handles the card input and the printing of the results for the entire program, except for the list and plot of the profile which is done by SUBROUTINE PLOTNH upon call from ION. ION transfers the input conditions through commons/EVAL/ and/UPDT/ and by calling SUBROUTINE REFRAC receives the computed profile parameters and refraction corrections through common/CORR/.

3.2.1.1 CPC No. 1 Description

ION reads the selections for the output and update options from cards, it reads the station, satellite and time information for the condition to be evaluated, and as needed, reads the solar data from cards. If the option for updating the predictions with measured ionospheric data was chosen, the number of observations to be used for the update and the corresponding observation along with station and time information are read from cards. Up to eight measurements can be used simultaneously for updating any one evaluation condition. All input data is listed for reference in the print out.

The input data is converted to the internal units of meters for distances and radians for angles and times. The variables specifying the evaluation condition are transferred through common/EVAL/, the update conditions through common/UPDT/ to SUBROUTINE REFRAC. Through REFRAC and other routines called by REFRAC ionospheric profile parameters, vertical and angular electron content, refraction corrections to elevation angle, range, and instantaneous range rate are computed as desired and returned to ION through common/CORR/. ION prints the results as requested and calls SUBROUTINE PLOTNH for an electron density profile plot and list, when this type of output is specified.

If the refraction correction to range rate, obtained by range differencing over a finite time during which the ionosphere can undergo changes, is requested, the input for the evaluation condition above relates to the first range observation, and additional satellite and time information that is read from card relates to the last range observation used in the differencing technique. Upon return the

second range correction from REFRAC, ION computes the requested correction by differencing the two range corrections and dividing by the interval; the result is printed.

Any number of evaluation conditions can be processed by supplying additional input data and repeating the program steps outlined above. For more details about the input data and output options refer to the input data description under 3.3.1.

3.2.1.2 CPC No. 1 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 1 Interfaces

- a) Library subprograms required: none
- b) Other subprograms called: SUBROUTINES REFRAC, PLOTNH
- c) Calling program: none
- d) Calling sequence: PROGRAM ION
- e) Common blocks: EVAL, UPDT, CORR

Variables in common:

See description for EVAL, UPDT, CORR under SUBROUTINE REFRAC, CPC No. 2.

- f) File requirements: card reader, line printer

The requirements for the input data card file are specified under 3.3.1.

3.2.1.4 CPC No. 1 Data Organization

Variables defined in data statements:

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
LYRMO	1	= 0, initialization constant for (year+100+month)
IDRD	1	= 0, default condition; range rate correction for observation over finite time is not desired
IOPT	1	= 1, default condition; computation of critical frequency and corresponding height is desired

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
MEAS	5 x 3	Array containing hollerith data for print out

Other constants defined in data statement:

QO=0, Q1000=1000, Q3600=3600; DR=1°, HR=1 hour, PI2=360° converted to radians,

Important variables are described under 3.2.1.3 a) of SUBROUTINE REFRAC,

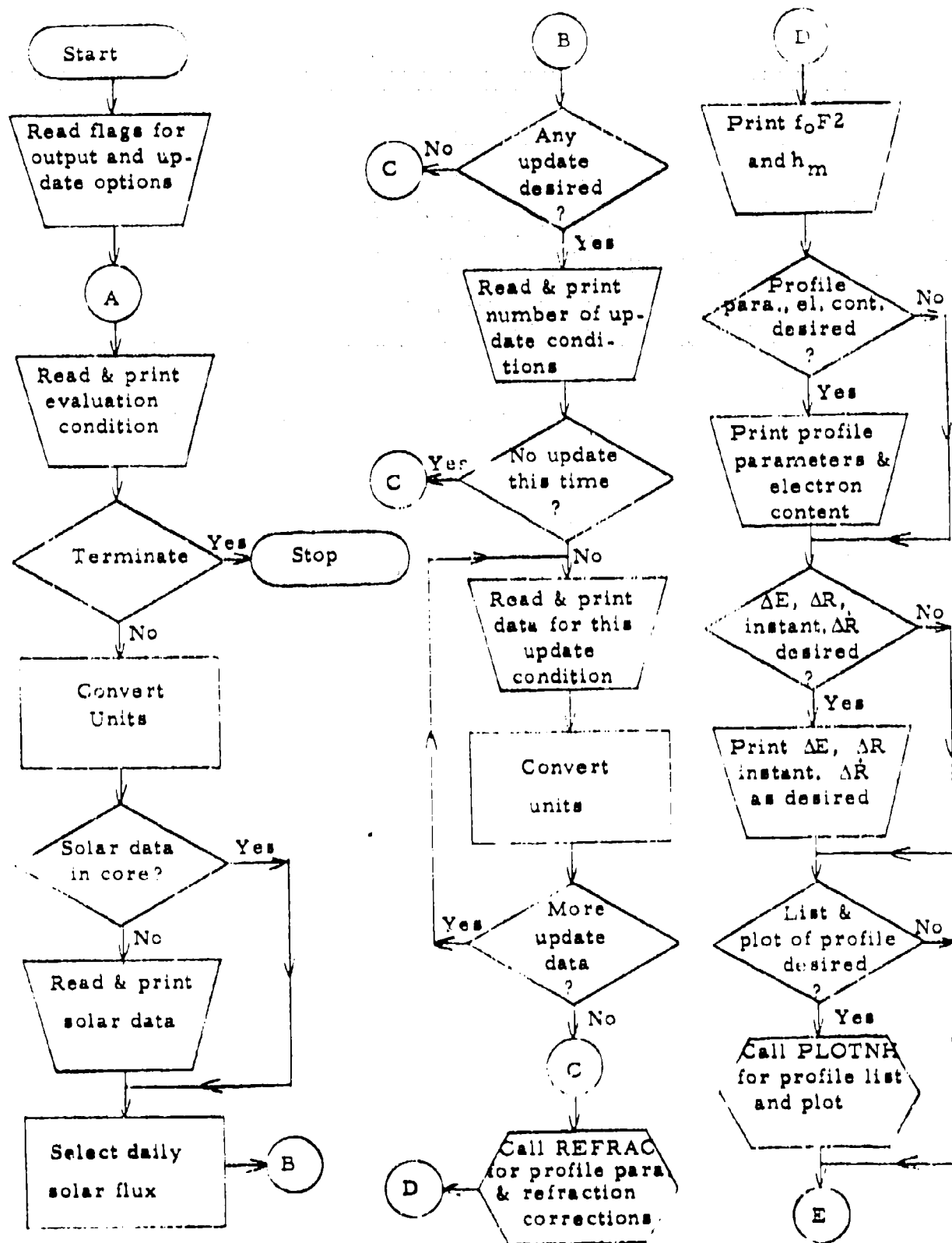
CPC No. 2.

3.2.1.5 CPC No. 1 Limitations

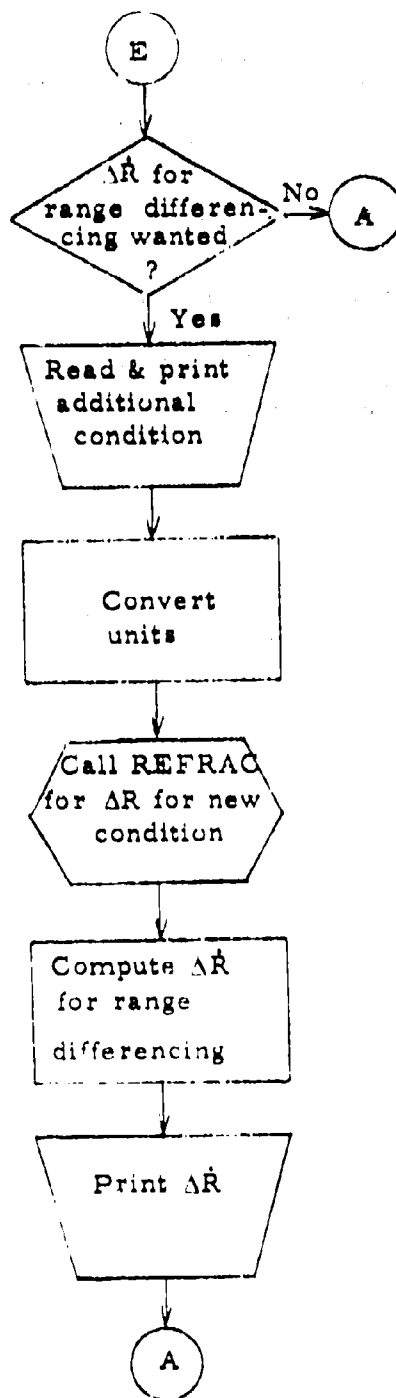
Up to eight measurement entries can be used simultaneously for updating the predictions for any one evaluation condition. If update with more than eight conditions is requested, the program uses the first eight entries, ignores any additional input data and prints a message to that effect.

Error tests on the sequence, units and formats of the input data are not performed, except on the dates of the solar data cards. However, mistakes in the set up of the card deck are revealed in the printout of the input data that is listed along with the results.

CPC No. 1 Flowchart, PROGRAM ION



PROGRAM ION (continued)



3.2.1 Computer Program Component 2

CPC No. 2, SUBROUTINE REFRAC, is written in FORTRAN code and is called from the main PROGRAM ION. REFRAC prepares the coefficient and solar input data, it obtains the ionospheric profile parameters via PROF1.1 and PROF2.2, it performs an optional update using up to eight observation entries, it computes the ionospheric refraction corrections ΔR for range, $\Delta \dot{R}$ for instantaneous range rate and obtains the refraction correction ΔE for the elevation angle via LETA.

3.2.1.1 CPC No. 2 Description

REFRAC prepares the coefficients to be used in SUBROUTINE DKSICO for the computation of the time dependent coefficients which in turn are required for the computation of critical frequency f_oF2 and $M(3000)F2$. At first it is checked if the coefficients are already available for the desired date, and if not available, the proper coefficients are read from tape. These general coefficients are valid for any condition and do not have to be updated or replaced, but can be adjusted for any time in the past or future.

The general f_oF2 coefficients were derived using the work of Jones and Obitts (Reference 6); they provide annual continuity and are valid for approximate 10 day periods, for the spans from day 1 to 10, day 11 to 20, and day 21 to 30 (or 28, 29, 31) of each month. There are coefficients for 36 periods to cover the whole year. The general f_oF2 coefficients $W_{i,j,k}$ represent the coefficients to a second order polynomial in the 12-month running average of solar flux F_{12} (observed Ottawa 10.7 cm solar flux). They are evaluated for the specific F_{12} of the evaluation date to yield the specific f_oF2 coefficient set $U_{i,j,k}$ (stored in array U) used in SUBROUTINE DKSICO;

$$U_{i,j,k} = W_{1,i,j,k} + W_{2,i,j,k} \times F_{12} + W_{3,i,j,k} \times F_{12}^2, \text{ for } i=0,1,\dots,12 \text{ and } k=0,1,\dots,75.$$

The general M(3000)F2 coefficients available from NOAA, Boulder, are valid for monthly periods. There are coefficients for 12 periods to cover the whole year, and for each period there are two sets $V_{1,k}(0)$ and $V_{1,k}(100)$, one for a 12-month running average of sunspot number $S_{12} = 0$ and the other for $S_{12} = 100$. The coefficients are adjusted by interpolating or extrapolating the two sets to the specific S_{12} of the evaluation date yielding the specific M(3000)F2 coefficient set $U_{1,k}$ (stored in array UM) used in SUBROUTINE DKSICO;

$$U_{1,k} = V_{1,k}(0) + \left[V_{1,k}(100) - V_{1,k}(0) \right] \times \frac{S_{12}}{100}, \text{ for } i=0, 1, \dots, 8 \text{ and } k=0, 1, \dots, 48.$$

The 10.7 cm Ottawa solar flux data is prepared for use in SUBROUTINES PROFL1 and PROFL2. The difference ΔF between the daily value F and the 12-month running average of the solar flux is formed, $\Delta F = F - F_{12}$. If the daily solar flux is not available, F_{12} is substituted. If the daily solar flux is greater than 130, 130 is substituted which is a limit imposed by the data base on which development of the model was founded.

The first parameters for the ionospheric profile, the critical frequency f_0F2 and the corresponding height h_s are obtained via SUBROUTINE PROFL1.

On option REFRAC updates the predicted f_0F2 with observations of f_0F2 or with vertical or angular electron content reduced from Faraday rotation measurements from other stations. Up to eight update observations of either type separated by different amounts in time and space from the evaluation time and station can be accepted. To obtain the best possible update, the observation times and stations should be the closest to the evaluation condition available, in any case, the update station should be within 2000 km of the evaluation site.

If the observation is angular electron content N_{rA} , it is reduced to total vertical electron content N_r by,

$$N_r = N_{rA} \sqrt{1 - \left(\frac{R_s \cos E}{R_s + h_s} \right)^2},$$

E being the elevation angle of the observation, and R_e the mean earth radius. For each update observation the predicted f_oF2 is obtained by calling SUBROUTINE PROFLL1, and the update ratio r is formed for f_oF2 observations,

$$r = \frac{f_oF2 \text{ obs.}}{f_oF2 \text{ pred.}}$$

If the observation is electron content, the additional profile parameter N_f/N_e is obtained via SUBROUTINE PROFLL2, and the following ratio is formed,

$$r = \sqrt{\frac{N_f \text{ obs.}}{1.24 \times 10^{10} f_oF2^2 \text{ pred.} \left(\frac{N_f}{N_e} \right)_{\text{pred.}}}}, \text{ where } f_oF2 \text{ is in MHz}$$

and since the maximum electron density is $N_e = 1.24 \times 10^{10} f_oF2^2$, and N_f is approximately proportional to f_oF2^2 , the electron content information is reduced to a f_oF2 ratio,

$$r = \sqrt{\frac{N_f \text{ obs.}}{N_f \text{ pred.}}} = \frac{f_oF2 \text{ obs.}}{f_oF2 \text{ pred.}}$$

If there is only one update condition, the ratio r is used for the final ratio R to update f_oF2 . If several n conditions are used for the update, a weighted mean technique combines all n ratios r_i to the final ratio R having as weights w_i the time differences Δt_i between observation and evaluation times and/or the earth central angles α_i between the ionospheric points at which the rays from the observation and evaluation stations pass through the ionosphere,

$$R = \frac{\sum_{i=1}^n \frac{r_i}{w_i}}{\sum_{i=1}^n \frac{1}{w_i}},$$

$w_i = \Delta t_i$, if observations are from one station at different times,

$w_i = \alpha_i$, if observations are from several stations at the same time,

$w_i = \Delta t_i \alpha_i$, if observations are from several stations at different times.

$$\Delta t = |t - t_0| \quad \text{and}$$

$$\cos \alpha = \sin \phi \sin \phi_0 + \cos \phi \cos \phi_0 \cos (\lambda - \lambda_0),$$

where t, ϕ, λ and t_0, ϕ_0, λ_0 are the time, latitude and longitude of the ionospheric points for evaluation and observation condition respectively. The final ratio R updates the critical frequency by the same overall percentage by which the predictions deviate from the ionospheric observations,

$$f_o F2 \text{ upd.} = f_o F2 \text{ pred.} \times R.$$

By calling SUBROUTINE PROF2 the remaining profile parameters are obtained: y_p the half thickness of the bottomside bi-parabolic layer, y_t the half thickness of the topside parabolic layer, k_1, k_2, k_3 the decay constants for the lower, middle, and upper section of the topside exponential layer, N_T/N_m the ratio of the total integrated electron content to the maximum electron density, m the multiplier of the \dot{h} , rate of change in height, term in the range rate equation.

The one-way ionospheric refraction correction ΔE to the elevation angle E is calculated via SUBROUTINE BETA. The total integrated electron content N_T along a vertical path through the ionosphere and the angular content along the line of sight N_{T_A} are computed as:

$$N_T = 1.24 \times 10^{10} f_o F2^2 \left(\frac{N_T}{N_m} \right), \quad N_{T_A} = \frac{N_T}{\sqrt{1 - \left(\frac{R_e \cos E}{R_e + h_p} \right)^2}}$$

The one-way ionospheric refraction correction to range ΔR is given by the equation:

$$\Delta R = \frac{40.3 \times 10^{-12} N_T}{f^2 \sqrt{1 - \left(\frac{R_e \cos E}{R_e + h_p} \right)^2}} = \frac{40.3 \times 1.24 \times 10^{-2}}{\sqrt{1 - \left(\frac{R_e \cos E}{R_e + h_p} \right)^2}} \left(\frac{f_o F2}{f} \right)^2 \frac{N_T}{N_m}$$

where f is the transmission frequency, $\frac{1}{f^2} = \frac{1}{2} \left(\frac{1}{f_u^2} + \frac{1}{f_d^2} \right)$ f_u and f_d are uplink and downlink frequencies.

The one-way ionospheric refraction correction to range rate $\dot{\Delta R}$ consists of two terms, one multiplied by the altitude rate \dot{h} , the other by the elevation rate \dot{E} ;

$$\Delta \dot{R} = - \frac{40.3 \times 1.24 \times 10^{-4}}{\sqrt{1 - \left(\frac{R_e \cos E}{R_e + h_s} \right)^2}} \left(\frac{f_0 F_2}{f} \right)^2 m \dot{h} + \frac{\Delta R \left(\frac{R_e}{R_e + h_s} \right)^2 \sin E \cos E}{1 - \left(\frac{R_e \cos E}{R_e + h_s} \right)^2} \dot{E}$$

This range rate correction formulation applies only to instantaneous range rate measurements, since it assumes that the only variation in the total electron content over the time of the observation is due to the positional change of the satellite and that the ionosphere between station and satellite remains constant for the duration of the measurement. Corrections to range differencing are discussed under 3.2.1.5.

The signs of the refraction corrections are set for the corrections to be subtracted from their respective observations. The units in all equations above are kept in meters, meters/second, radians, radians/second and MHz.

3.2.1.2 CPC No. 2 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 2 Interfaces

- a) Library subprograms required: ABS, ATAN, COS, SIN, SQRT
- b) Other subprograms called: SUBROUTINES PROFL1, PROFL2, BETA
- c) Calling programs: PROGRAM ION
- d) Calling sequence: SUBROUTINE REFRAC
- e) Common blocks: EVAL, UPDT, CORR

Variables in common:

<u>Common Name</u>	<u>Variable Name</u>	<u>Dimension</u>	<u>I/O</u>	<u>Description</u>
EVAL	FS	1	I	Transmission frequency (MHz)
EVAL	FLAT	1	I	Latitude of station (radians)
EVAL	FLON	1	I	Longitude of station (radians)
EVAL	ELEV	1	I	Elevation to satellite (radians)

<u>Common Name</u>	<u>Variable Name</u>	<u>Dimension</u>	<u>I/O</u>	<u>Description</u>
EVAL	AZ	1	I	Azimuth to satellite (radians)
EVAL	HS	1	I	Height of satellite (m)
EVAL	EDOT	1	I	Elevation rate (radians/sec)
EVAL	HDOT	1	I	Altitude rate (m/sec)
EVAL	TIME	1	I	Universal time (radians)
EVAL	FLXD	1	I	Daily solar flux
EVAL	SIS	1	I	12-month running average of sun- spot number
EVAL	SIF	1	I	12-month running average of solar flux
EVAL	IYR	1	I	Year (last 2 digits)
EVAL	MON	1	I	Month (=1 through 12)
EVAL	IDAY	1	I	Day (=1 through 31)
EVAL	IOPT	1	I	Control constant for optional computa- tions: =1 to compute f_oF2 and h_p , =2 to also compute remaining profile parameters and electron content, =3 to compute MUF in addition, =4 to also compute ΔR
EVAL	IDEL	1	I	Control constant to compute ΔE be- sides profile parameters and electron content, =0 compute, =1 not
EVAL	IDRD	1	I	Flag to eliminate unnecessary computa- tions during calculation of the second range correction used in the differenc- ing for the range rate correction. =0 for first, =1 for second calculation
EVAL	IUPDT	1	I	Update flag, =0 no update, =1 update
EVAL	ITP	1	I	Unit assignment of general iono- spheric coefficient tape
UPDT	ULAT	8	I	Latitudes of update stations (radians)
UPDT	ULON	8	I	Longitudes of update stations (radians)
UPDT	ULEV	8	I	Elevation angles of observations (radians)

Common Name	Variable Name	Dimension	I/O	Description
UPDT	UZIM	8	I	Azimuth angles of observations (radians)
UPDT	UT	8	I	Universal time of observations (radians)
UPDT	OBS	8	I	Observation of f_oF2 , vertical or angular electron content (MHz or electrons/m ²)
UPDT	ITYP	8	I	Observation type, =1 for f_oF2 , =2 for vertical, =3 for angular electron content
UPDT	NUPDT	1	I	Number of update conditions
CORR	DRANG	1	O	Range correction (m)
CORR	DRATE	1	O	Range rate correction (m/sec)
CORR	DELEV	1	O	Elevation angle correction (radians)
CORR	F0F2	1	O	Critical frequency (MHz)
CORR	HM	1	O	Height at maximum electron density (meters)
CORR	YM	1	O	Half thickness of the bottomside bi-parabolic layer (meters)
CORR	YT	1	O	Half thickness of the topside parabolic layer (meters)
CORR	XK	3	O	Decay constants of lower, middle and upper section of the exponential topside layer (1/meter)
CORR	TOTN	1	O	Total vertical electron content (e/m ² column)
CORR	TOTNA	1	O	Total angular electron content (e/m ² column)

f) File requirements: general coefficient input tape, line printer

The format of the general coefficient tape is described under 3.3.1.

3.2.1.4 CPC No. 2 Data Organization

Variables defined in data statements:

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
R	1	Mean earth radius (meters)
STRS	1	Approximate height of stationary satellite used when updating with observed electron content (meters)
TOL	1	Tolerance for differences in positions or observation times of multiple update stations below which they are assumed to be identical (radians)
MONDY	1	Initialization constants for last and first (month * 100 + day) for which coefficients are in core
MOND	1	
LYRMO	1	Initialization constant for (year * 100 + month)

Other constants defined in data statements:

QO=0, Q1=1, Q100=100, Q130=130, QP1=.1, QNM= 1.24×10^{-6} , RN3=.49972;
PI=180°, PI2=360° converted to radians.

Other important variables are described under 3.2.1.3 e).

3.2.1.5 CPC No. 2 Limitations

The daily value of solar flux transferred to SUBROUTINE PROF2 for the computation of the decay constants for the topside exponential profile is truncated at a maximum value of 130. This is the boundary that was imposed by the data base during the model development and is thus a limit to the model since the extension of solar flux beyond 130 could result in invalid profiles.

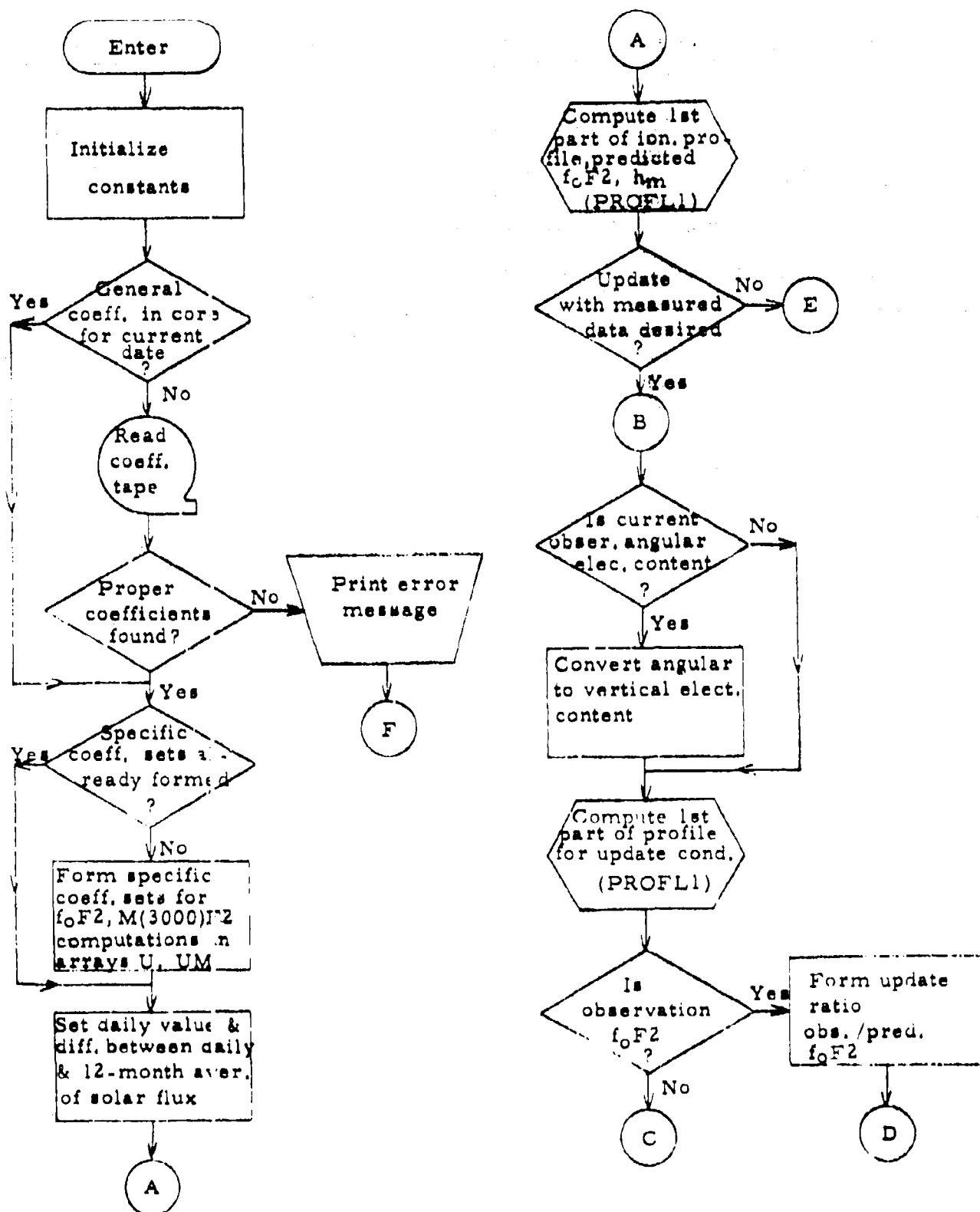
The dimensions of several arrays restrict the update procedure to be applied to the predictions of any one evaluation condition, to not include more than eight observation entries.

The range rate correction formula in this routine applies only to instantaneous range rate measurements, since it is assumed that the only

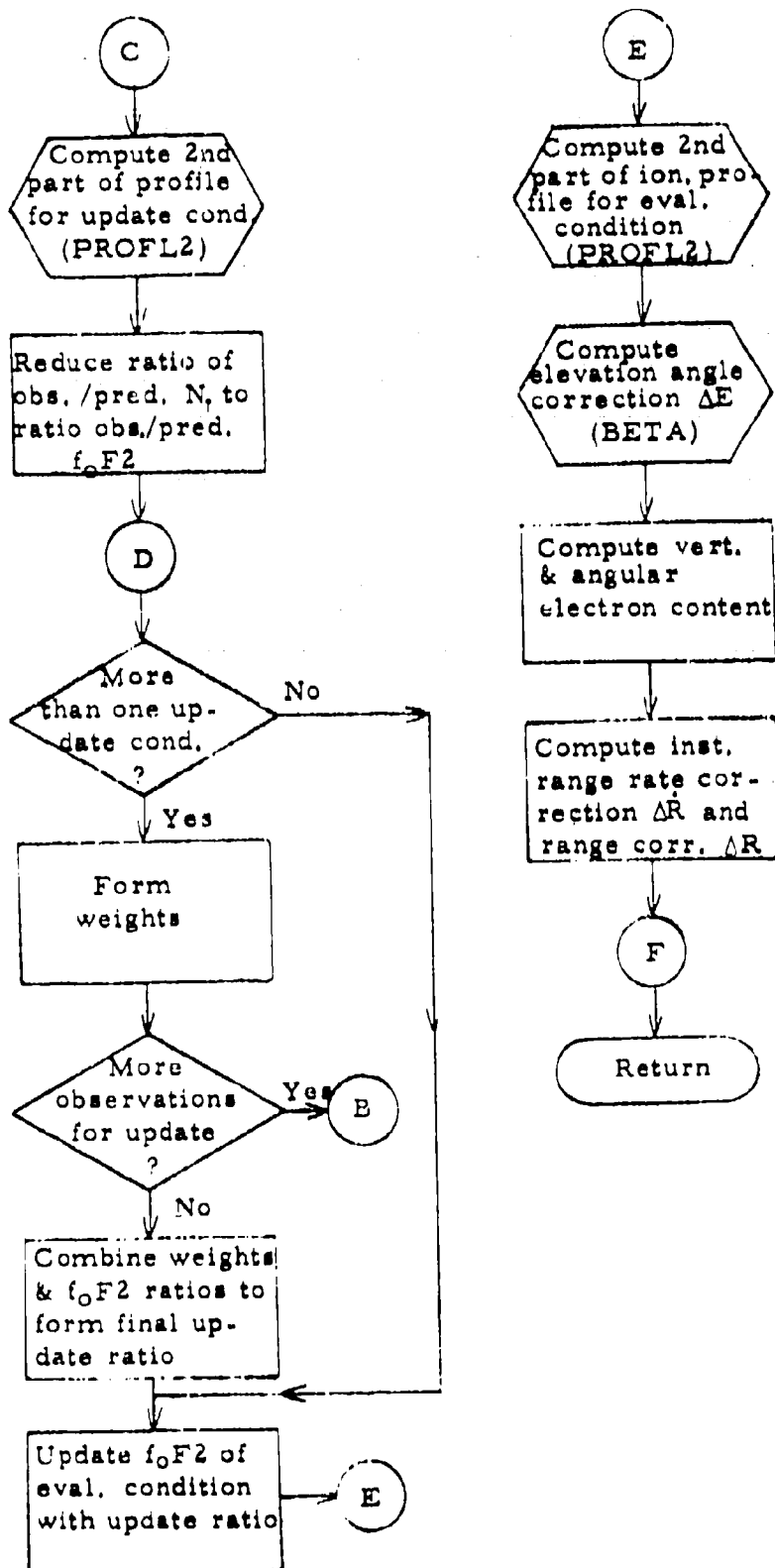
variation in electron content over the time of the observation is due to the positional change of the satellite and that the ionosphere between station and satellite remains constant. If the range rate corrections are desired for observations obtained by range differencing over a finite time interval during which the ionosphere can undergo significant changes, a range correction differencing technique should be used over the same time interval. This type of correction can optionally be requested, it requires additional satellite and time information and is handled directly in PROGRAM ION, CPC No. 1.

If the ionospheric coefficients are not found on the tape for the evaluation date, an error condition has occurred, a message is printed out, and control is transferred to PROGRAM ION to proceed with the next data case.

CPC No. 2 Flowchart, SUBROUTINE REFRAC



SUBROUTINE REFRAC (continued)



3.2.1 Computer Program Component 3

CPC No.3, SUBROUTINE PLOTNH, is written in FORTRAN code. It is called from the main PROGRAM ION and lists and plots the electron density versus height profile.

3.2.1.1 CPC No. 3 Description

PLOTNH plots a graph of electron density N versus height h at 25 km height increments from 25 km to 1000 km and it prints a list of electron densities for corresponding height values from 25 km to 2000 km at 25 km increments

The electron density is modeled differently in five height layers (see Figure 2 in Section 6.1). k_1, k_2, k_3 denote the decay constants for the lower, middle and upper section of the exponential topside profile, and y_1, y_2 are the values of half thickness for the topside parabolic layer and for the bottomside bi-parabolic layer respectively. The height limits for each layer are first determined and the value of electron density at the start point of the various layers N_s, N_0, N_1, N_2 . The height increments measured from the start point of the various layers are denoted as variables b_1, b_2, a_1, a_2, a_3 . The electron density equations are;

$$N = N_s \left(1 - \frac{b_s^2}{y_s^2} \right)^2 \quad \text{for} \quad h_s - y_s \leq h < h_s$$

$$N = N_s \left(1 - \frac{b_s^2}{y_s^2} \right) \quad \text{for} \quad h_s \leq h < h_0 = h_s + d$$

$$N = N_0 e^{-k_1 a_1} \quad \text{for} \quad h_0 \leq h < h_1 = h_0 + (1012 \text{ km} - h_0) / 3$$

$$N = N_1 e^{-k_2 a_2} \quad \text{for} \quad h_1 \leq h < h_2 = h_1 + (1012 \text{ km} - h_0) / 3$$

$$N = N_2 e^{-k_3 a_3} \quad \text{for} \quad h_2 \leq h \leq 2000 \text{ km}$$

where h_c is the height at the maximum electron density, d is the distance above h_c at which the lower exponential layer starts, and the electron densities at the start points of the various layers,

$$N_c = 1.24 \times 10^{10} f_o F^2$$

$$N_o = N_c \left(1 - \frac{d^2}{y_c^2} \right)$$

$$N_1 = N_o e^{-k_1 (h_1 - h_o)}$$

$$N_2 = N_1 e^{-k_2 (h_2 - h_1)}$$

3.2.1.2 CPC No. 3 Flowchart

The flowchart as shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 3 Interfaces

- a) Library subprograms required: EXP, LOG10, SQRT
- b) Other subprograms called: none
- c) Calling program: SUBROUTINE REFRAC
- d) Calling sequence: CALL PLOTNH (F0F2, HM, YM, YT, XK)

Variables in calling sequence:

<u>Name</u>	<u>Dimension</u>	<u>I/O</u>	<u>Description</u>
F0F2	1	I	Critical frequency (MHz)
HM	1	I	Height at the critical frequency (meters)
YM	1	I	Half thickness of the bottom bi-parabolic layer (meters)
YT	1	I	Half thickness of the topside parabolic layer (meters)
XK	3	I	Decay constants for lower, middle, and upper section of the topside exponential layer (1/meter)

- e) Common blocks: none
- f) File requirements: line printer

3.2.1.4 CPC No. 3 Data Organization

Variables defined in data statement:

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
IBLANK	1	Hollerith "blank" symbol used for plotting
MARK	1	Hollerith " * " symbol used for plotting

Other constants listed in data statement:

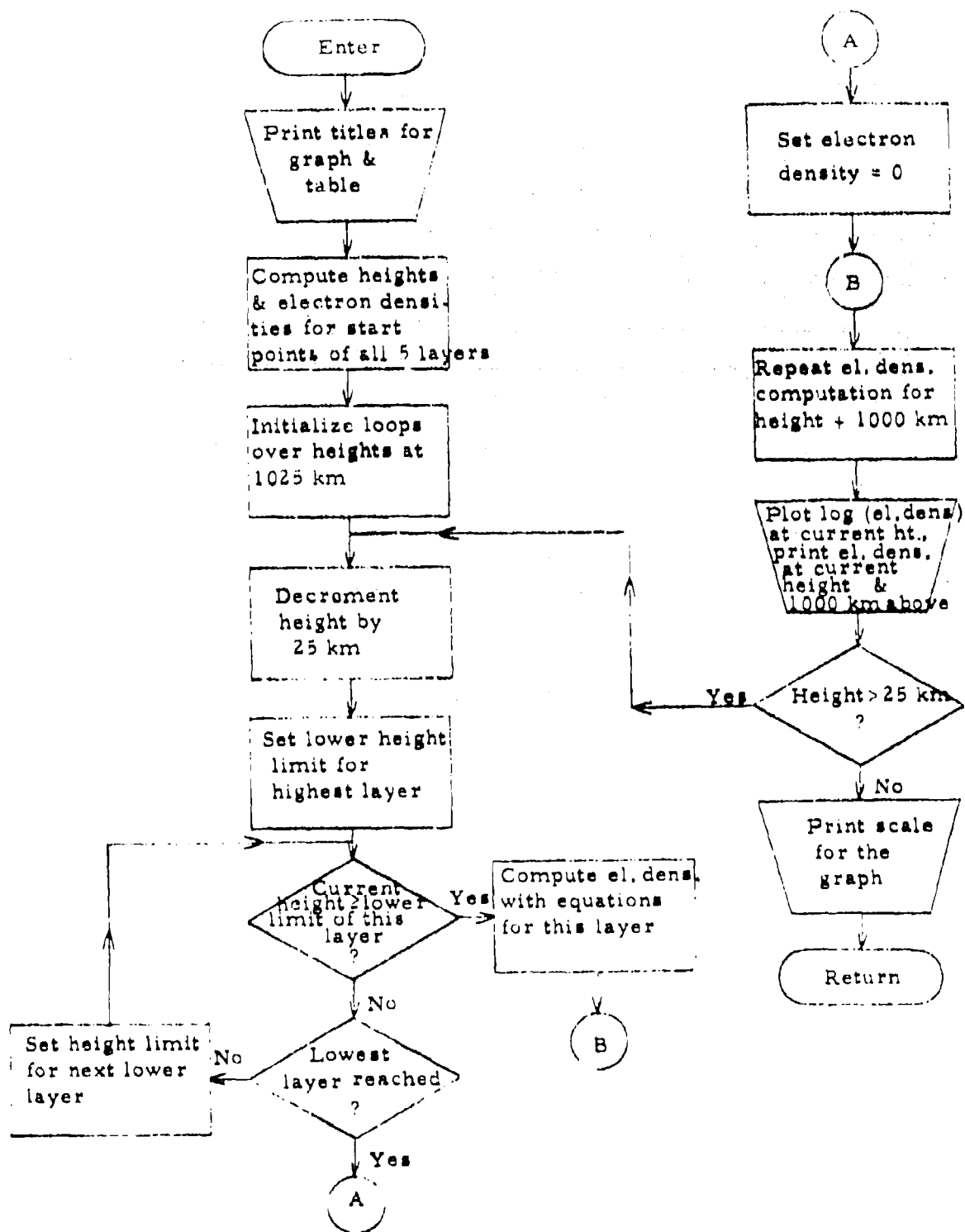
Q0=0, Q1=1, Q3=3, Q124E=1.24 × 10¹⁰, Q1012E=1012000, Q1025E=1025000,
Q25E=25000, Q10=10, Q27=27, Q2025E=2025000.

Other important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 3 Limitations

If electron density values are computed smaller than 10¹⁰ or larger than 5 × 10¹² (electrons/meter³), they exceed the limits of the graph and automatically are not plotted. Since these cases do not normally involve error conditions, a message is not required and the values are printed as computed in the electron density versus height list.

CPC No. 5 Flowchart, SUBROUTINE PLOTNH



3.2.1 Computer Program Component 4

CPC No. 4, SUBROUTINE PROFL1, is written in FORTRAN code. It is called from SUBROUTINE REFRAC and computes the ionospheric profile parameters critical frequency f_oF2 and the corresponding height h_p at the location where the wave passes through the ionosphere.

3.2.1.1 CPC No. 4 Description

PROFL1 computes the ionospheric characteristics f_oF2 and $M(3000)F2$ following the analysis of Jones, Graham and Leftin (Reference 5). First the trigonometric functions of the multiples of the Greenwich hour angle t , $-180^\circ \leq t \leq 180^\circ$, $t=0$ at Greenwich noon, are computed via SUBROUTINE SICOJT for use in DKSICO. The time dependent coefficients are computed via SUBROUTINE DKSICO based on the coefficient sets $U_{i,k}$ prepared in REFRAC. Utilizing the f_oF2 and $M(3000)F2$ coefficient sets (in arrays U and UM) the time dependent coefficients respectively for the f_oF2 and $M(3000)F2$ evaluation are prepared.

Defined by the latitude ϕ and longitude λ at which the ray from station to satellite passes through the ionosphere is the ionospheric point. It is calculated as a function of the station latitude ϕ_s , longitude λ_s , and the elevation angle E and azimuth angle A to the satellite;

$$\phi = \arcsin (\sin \phi_s \cos \alpha + \cos \phi_s \sin \alpha \cos A)$$
$$\lambda = \lambda_s + \arcsin \left(\frac{\sin A \sin \alpha}{\cos \phi} \right),$$

where α is the earth central angle between the station and the ionospheric point,

$$\alpha = \frac{\pi}{2} - E - \arcsin \left(\frac{R_e \cos E}{R_e + h_p} \right),$$

R_e is the mean earth radius, and h_p is the height of the ionosphere at the maximum electron density above the surface of the earth. Since h_p is to

be determined later on in this subroutine, a first estimate of h_p is required and assumed as $h_p = 300$ km. After computing the actual h_p prediction, the new value is compared with the estimate and if it deviates by more than 1 km, all computations starting with the determination of the ionospheric point are repeated using the new h_p .

The position dependent functions required for the f_oF2 and $M(3000)F2$ computations are all evaluated at the ionospheric point which can differ by up to 21° from the station position. First the earth's magnetic field components X-north, Y-east and Z-vertical up are computed at the ionospheric point via SUBROUTINE MAGFIN, and they form in turn the modified magnetic dip x as a function of the magnetic dip I :

$$x = \arcsin \frac{I}{\sqrt{I^2 + \cos^2 \phi}} \quad , \quad I = \arctan \frac{-Z}{\sqrt{X^2 + Y^2}} \quad .$$

Based on the following coordinates, ionospheric latitude, longitude and modified magnetic dip, SUBROUTINE GK evaluates the geographic coordinate functions for the f_oF2 computation. Extracted from these functions is the subset which forms the geographic coordinate functions needed for the $M(3000)F2$ computation.

SUBROUTINE DKGK multiplies and sums the proper sets of time dependent coefficients and position dependent functions and forms $M(3000)F2$. With the Appleton-Beynon equations (Reference 1), a second order polynomial in $M(3000)F2$, the height of the maximum electron density is obtained in meters;

$$h_p = \{ 1346.92 - 526.40 \times M(3000)F2 + 59.825 [M(3000)F2]^2 \} \times 10^3$$

h_p is compared with its estimate and if the difference is greater than 1 km, the computations above starting with the ionospheric point determination are iterated on using the new value for h_p .

Using the proper time dependent coefficients and position dependent functions, SUBROUTINE DKGK computes the 10 day mean of the critical frequency which then is adjusted for day to day changes in the ionosphere and for additional magnetic latitude variations, following the model description in Section 6.1. The magnetic latitude of the ionospheric point is determined as,

$$\phi_m = \arcsin [\sin\phi \sin\phi_p + \cos\phi \cos\phi_p \cos(\lambda - \lambda_p)],$$

where ϕ_p , λ_p are the latitude and longitude of the magnetic north pole and interpolating the model constants (array CENT) to ϕ_m results in c_2 . The daily variation from the mean value is dependent on ΔF , the difference between the daily value and the 12-month running average of the solar flux and on the model constant c_1 (variable PER). The f_oF2 computed by DKGK is multiplied by the adjustment factor $(c_1 \Delta F + c_2)$ to yield the final predicted f_oF2 .

The units in the above equations are kept in meters, radians and MHz.

3.2.1.2 CPC No. 4 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 4 Interfaces

- a) Library subprograms required: ABS, ATAN, COS, SIN, SQRT
- b) Other subprograms called: SUBROUTINES SICOJT, DKSICO, GK, MAGFIN, DKGK
- c) Calling program: SUBROUTINE REFRAC
- d) Calling sequence: CALL PROF1(FLAT, FLON, ELEV, AZ, TIME, DFLUX, U, UM, OLAT, OLON, FOF2, HM, HLAT)

Variables in calling sequence:

<u>Name</u>	<u>Dimension</u>	<u>I/O</u>	<u>Description</u>
FLAT	1	I	Station latitude (radians)
FLON	1	I	Station longitude (radians)
ELEV	1	I	Elevation angle to satellite (radians)
AZ	1	I	Azimuth angle to satellite (radians)
TIME	1	I	Universal time (radians)
DFLUX	1	I	Difference between the daily value and the 12-month running average of the solar flux
U	13 x 76	I	Array containing coefficients used for the f_oF2 computation
UM	9 x 49	I	Array containing coefficients used for the $M(3000)F2$ computation
OLAT	1	O	Latitude of the ionospheric point (radians)
OLON	1	O	Longitude of the ionospheric point (radians)
F0F2	1	O	Critical frequency f_oF2 (MHz)
HM	1	O	Height at the maximum electron density h_p (meters)
HLAT	1	O	Magnetic latitude of the ionospheric point (radians)

e) Common blocks: none

f) File requirements: none

3.2.1.4 CPC No. 4 Data Organization

Variables defined in data statements:

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
K	10	Interger indices and index arrays used for the computation of f_oF2 and $M(3000)F2$ in SUBROUTINES DKSICO, GK and DKGK
KN	10	
KM10	1	
NFF	1	
NMF	1	
R	1	Mean earth radius (meters)
SPLAT	1	Sine function of the geographic latitude of the magnetic north pole

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
CPLAT	1	Cosine of the geographic latitude of the magnetic north pole
PLON	1	Geographic longitude of the magnetic north pole (radians)
H1	1	Coefficients used in the formula expressing h_p as a second order polynomial of $M(3000)F_2$
H2	1	
H3	1	
PER	1	Model constants used for adjusting f_oF_2 for daily variation, dependent on the daily value and the 12-month running average of solar flux and magnetic latitude
CENT	3	

Other constants listed in data statements:

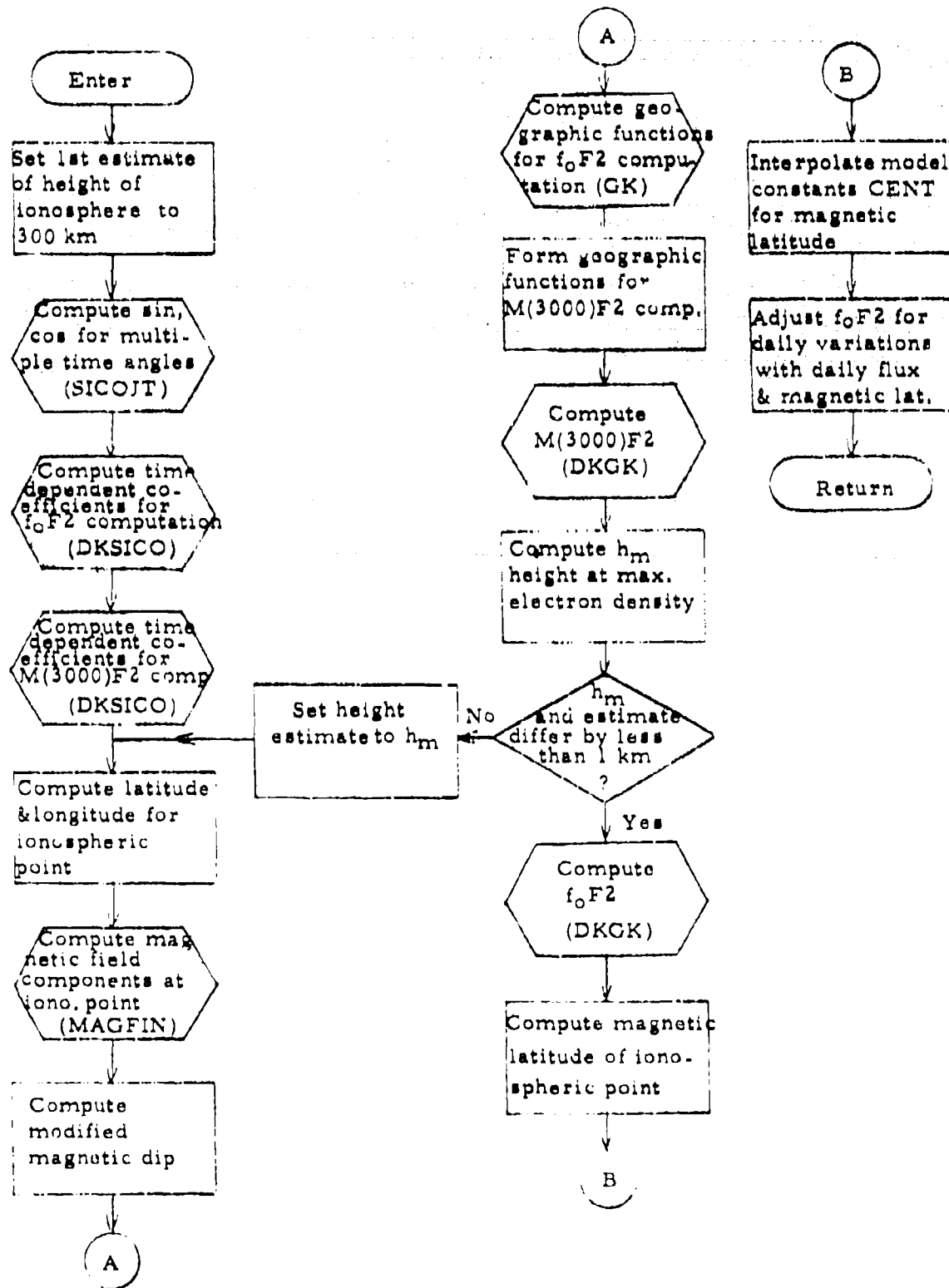
$Q1=1$, $Q1000=1000$, $Q1P9999=1.999999$, $Q3T6=3 \times 10^6$, $D180=180^\circ$,

$DG(1)=59^\circ$, $DG(2)=28^\circ$, $DG(3)=-33^\circ$ converted to radians.

Other important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 4 Limitations

There are no program restrictions connected with this subroutine, and the limitations to the accuracy of the results obtained from the formulas are discussed in Section 6.2.



3.2.1 Computer Program Component 5

CPC No. 5, SUBROUTINE PROFL2, is written in FORTRAN code. It is called from SUBROUTINE REFRAC and computes the following ionospheric profile parameters: the values of half thickness y_b , y_t for the bottomside bi-parabola and the topside parabola respectively, the decay values k_1 , k_2 , k_3 for the topside exponential layers, the ratio N_t/N_b of the total content to the maximum electron density, and the multiplier m for use in the range rate computation.

3.2.1.1 CPC No. 5 Description

PROFL2 evaluates the ionospheric profile based on the model constants presented in graphic form in Section 6.1. The local time is computed from the universal time t and the longitude λ of the ionospheric point,

$$t_{loc} = t + \lambda.$$

The half thickness y_b of the bottomside bi-parabola varies with critical frequency f_oF2 and local time. Values of the half thickness are tabulated in array YMTAB at 1 MHz increments for $f_oF2=2, 3, \dots, 10$ MHz and at 2 hour intervals for $t_{loc}=0, 2, \dots, 22$ hours. To obtain y_b for the given conditions, the tables are interpolated in two dimensions between the fixed values; local time interpolation is carried continuously across the 0/24 hour mark, and the boundary values are assumed whenever f_oF2 is outside the limits 2 and 10 MHz.

For seasonal adjustments computation of the parameter $\Delta\chi$ (variable DSZA) is required. $\Delta\chi$ is the deviation of the daily value χ from the yearly average $\bar{\chi}$ of the noontime solar zenith angle. First the solar declination δ is evaluated for the given day,

$$\delta = \delta_{max} \sin \left[\frac{2\pi}{365} (JDAY-80) \right],$$

$\delta_{max}=23.4444^\circ$ is the maximum solar declination, JDAY is the day of the year. For stations in the northern hemisphere and outside the tropics,

with latitudes $\geq 23.4444^\circ$, $\Delta\chi=\delta$; for stations in the southern hemisphere and outside the tropics, $\Delta\chi=-\delta$. In the tropics the yearly average of the noontime solar zenith angle is computed as,

$$\bar{\chi} = \frac{2}{\pi} \left(\sqrt{\delta_{\max}^2 - \phi^2} + \phi \arcsin \frac{\phi}{\delta_{\max}} \right),$$

ϕ being the latitude of the ionospheric point. The daily noontime solar zenith angle is $\chi = |\phi - \delta|$, and the difference $\Delta\delta = \bar{\chi} - \chi$.

The half thickness of the bottomside parabola y_0 is multiplied by a seasonal adjustment factor that varies with $\Delta\chi$, local time and magnetic latitude ϕ_m . Adjustment factors are tabulated in array YRAT at 8° increments for $\Delta\chi = 24, 16, 8, 0, -8, -16, -24$ degrees, at 6 hour intervals for $t_{100} = 5.5, 11.5, 17.5, 24.5$ hours where the absolute value of the magnetic latitude is greater or equal 15° , and at 12 hour intervals $t_{100} = 3, 15$ hours where $|\phi_m| \leq 5^\circ$. The seasonal adjustment factor for the given conditions is obtained by three dimensional interpolation; the local time interpolation is carried continuously across the 0/24 hour mark and the magnetic latitude interpolation is only performed between 5 and 15 degrees.

The decay constants k_1, k_2, k_3 for the lower, middle and upper layer of the exponential topside are related to the daily solar flux F through the first order polynomial,

$$k_i = S_i \times F + C_i, \quad i = 1, 2, 3.$$

The slopes S_i , stored in array SLOP, and the intercepts C_i in array CEPT of this straight line relationship vary with magnetic latitude ϕ_m and with f_oF2 . For each of the three topside layers, S_i and C_i are tabulated at 30° intervals for $|\phi_m| = 15, 45, 75$ degrees, and at 3 MHz increments for $f_oF2 = 2, 5, 8, 11$ MHz. To obtain the decay constants for the given conditions, the tables for S_i and C_i are interpolated in two dimension between the fixed values, and whenever f_oF2 is outside the limits 2 and 11 MHz or $|\phi_m|$ is outside 15 and 75 degrees, the boundary values are used.

Seasonal effects are imposed on the topside by multiplying the decay constants by season adjustment factors that vary with the deviation $\Delta\chi$ in the solar zenith angle and with local time. The adjustment factors are tabulated in array RATAK for each of the three topside layers at 8° increments for $\Delta\chi = 24, 16, 8, 0, -8, -16, -24$ degrees, and at 6 hour intervals for $t_{100} = 2, 8, 14, 20$ hours. They are interpolated for each k_i , $i=1, 2, 3$ in two dimensions to the given conditions; the local time interpolation is carried continuously across the 0/24 hour mark.

The half thickness of the topside parabola, extending from the point of maximum electron density to the lower exponential layer, is dependent on y_1 and f_oF2 through the relationship,

$$y_1 = \begin{cases} y_1 & , \text{ for } f_oF2 \leq 10.5 \\ y_1 [1 + 0.133333 (f_oF2 - 10.5)] & , \text{ for } f_oF2 > 10.5 \end{cases}$$

The distance d above the height at maximum electron density h_p where the slopes of the parabola and the lower exponential layer are the same is,

$$d = \frac{1}{k_1} \left(\sqrt{1 + k_1^2 y_1^2} - 1 \right)$$

The total vertical electron content N_T is obtained by integrating the electron density profile from zero to the height of the satellite h_s . The program computes the ratio of total electron content to the maximum electron density N_T/N_p (variable XNTNM) by one of the following six equations depending on the upper integration limit. At the same time, the multiplier m (variable RRM) required for the instantaneous range rate computation is evaluated and its formulation also varies depending on the height of the satellite. 1 for a satellite below the bi-parabolic layer of the ionosphere;

$$N_T/N_p = 0$$

$$m = 0$$

For a satellite in the bottomside bi-parabolic layer with half thickness y_2 :

$$N_T = N_s \left\{ -\frac{8}{15} y_2 - (h_2 - h_1) + \frac{2}{3} \frac{(h_2 - h_1)^3}{y_2^3} - \frac{1}{5} \frac{(h_2 - h_1)^5}{y_2^5} \right\} .$$

$$m = \left[1 - \left(\frac{h_2 - h_1}{y_2} \right)^2 \right]^2 .$$

For a satellite in the topside parabolic layer with half thickness y_1 :

$$N_T = N_s \left\{ \frac{8}{15} y_1 - (h_2 - h_1) + \frac{1}{3} \frac{(h_2 - h_1)^3}{y_1^3} \right\} .$$

$$m = 1 - \left(\frac{h_2 - h_1}{y_1} \right)^2 .$$

For a satellite in the lower exponential layer of the topside with decay constant k_1 :

$$N_T = N_s \left(1 - \frac{d^2}{y_1^2} \right) \left\{ \frac{1}{k_1} \left(1 - e^{-k_1 (h_2 - h_0)} \right) \right\} + N_s ,$$

and the height of the bottom of the lower exponential layer is $h_0 = h_1 + d$, and

$$N_s = N_s \left\{ \frac{8}{15} y_1 - (h_2 - h_0) + \frac{1}{3} \frac{(h_2 - h_0)^3}{y_1^3} \right\} .$$

$$m = \left(1 - \frac{d^2}{y_1^2} \right) e^{-k_1 (h_2 - h_0)}$$

For a satellite in the middle exponential layer of the topside with decay constant k_2 :

$$N_T = N_s \left(1 - \frac{d^2}{y_1^2} \right) \left\{ \frac{1}{k_1} + e^{-k_1 (h_1 - h_0)} \left[-\frac{1}{k_1} + \frac{1}{k_2} \left(1 - e^{-k_2 (h_2 - h_1)} \right) \right] \right\} + N_s ,$$

and the height of the bottom of the middle exponential layer is:

$$h_1 = h_0 + \frac{1}{3} (1.012 \times 10^6 - h_0),$$

$$m = \left(1 - \frac{d^2}{y_1^2}\right) e^{-k_1(h_1 - h_0)} e^{-k_2(h_1 - h_1)}.$$

For a satellite in the upper exponential layer of the topside with decay constant k_3 :

$$N_T = N_1 \left(1 - \frac{d^2}{y_1^2}\right) \left\{ \frac{1}{k_1} + e^{-k_1(h_1 - h_0)} \left[-\frac{1}{k_1} + \frac{1}{k_2} + e^{-k_2(h_2 - h_1)} \right. \right. \\ \left. \left. \left(-\frac{1}{k_2} + \frac{1}{k_3} - \frac{1}{k_3} e^{-k_3(h_3 - h_2)} \right) \right] \right\} + N_2,$$

and the height of the bottom of the upper exponential layer is,

$$h_2 = h_0 + \frac{2}{3} (1.012 \times 10^6 - h_0).$$

$$m = \left(1 - \frac{d^2}{y_1^2}\right) e^{-k_1(h_1 - h_0)} e^{-k_2(h_2 - h_1)} e^{-k_3(h_3 - h_2)}.$$

3.2.1.2 CPC No. 5 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 5 Interfaces

- a) Library subprogram required: ABS, AMOD, ATAN, EXP, SIN, SQRT
- b) Other subprograms called: none
- c) Calling program: SUBROUTINE REFRAC
- d) Calling sequence: CALL PROFL2 (OLAT, OLON, HS, TIME, IDAY, MON, FLUX, FOF2, HM, HLAT, YM, YT, XK, RRM, XNTNM)

Variables in calling sequence:

<u>Name</u>	<u>Dimension</u>	<u>I/O</u>	<u>Description</u>
OLAT	1	I	Latitude of ionospheric point (radians)
OLON	1	I	Longitude of ionospheric point (radians)
HS	1	I	Height of satellite above earth's surface (meters)
TIME	1	I	Universal time (radians)
IDAY	1	I	Day (=1 through 31)
MON	1	I	Month (=1 through 12)
FLUX	1	I	Daily solar flux value
FOF2	1	I	Critical frequency (MHz)
HM	1	I	Height at maximum electron density (meters)
HLAT	1	I	Magnetic latitude of ionospheric point (radians)
YM	1	O	Half thickness of the bottom bi-parabolic layer (meters)
YT	1	O	Half thickness of the topside parabolic layer (meters)
XX	3	O	Decay constants for lower, middle and upper section of the topside exponential layer (1/meter)
RRM	1	O	Multiplier of the h' term in the range rate formula (dimensionless)
XNTNM	1	O	Ratio of total vertical electron content to the electron density (meters)

e) Common blocks: none

f) File requirements: none

3.2.1.4 CPC No. 5 Data Organization

Variables defined in data statements:

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
SO1	1	Maximum solar declination (radians)
SO2	1	Multiplier to convert 365 days to 2π radians (radians/day)

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
RN4	1	Average frequency to which topside sounders measured the ionospheric profiles is $RN4 \times f_oF2$
H1012	1	Average height to which topside exponential layer was modeled (meters)
CEPT	4x3x3	Model constants used for computing the decay constants for the lower, middle and upper section of the topside exponential layer, dependent on daily solar flux, critical frequency and magnetic latitude
SLOP	4x3x3	
RATK	4x4x3	Model constants used for adjusting the computed decay constants for the lower, middle and upper exponential topsides for seasonal effects, dependent on the difference between the yearly average and the daily value of the noontime solar zenith angle and on local time
YMTAB	12x9	Model constants used for computing the half thickness of the bottomside bi-parabola, dependent on local time and critical frequency
YRAT	7x6	Model constants used for adjusting the computed half thickness of the bottomside bi-parabola for seasonal effects, dependent on the difference between the yearly average and the daily value of the noontime solar zenith angle, on local time and magnetic latitude

Other constants listed in data statements for convenience:

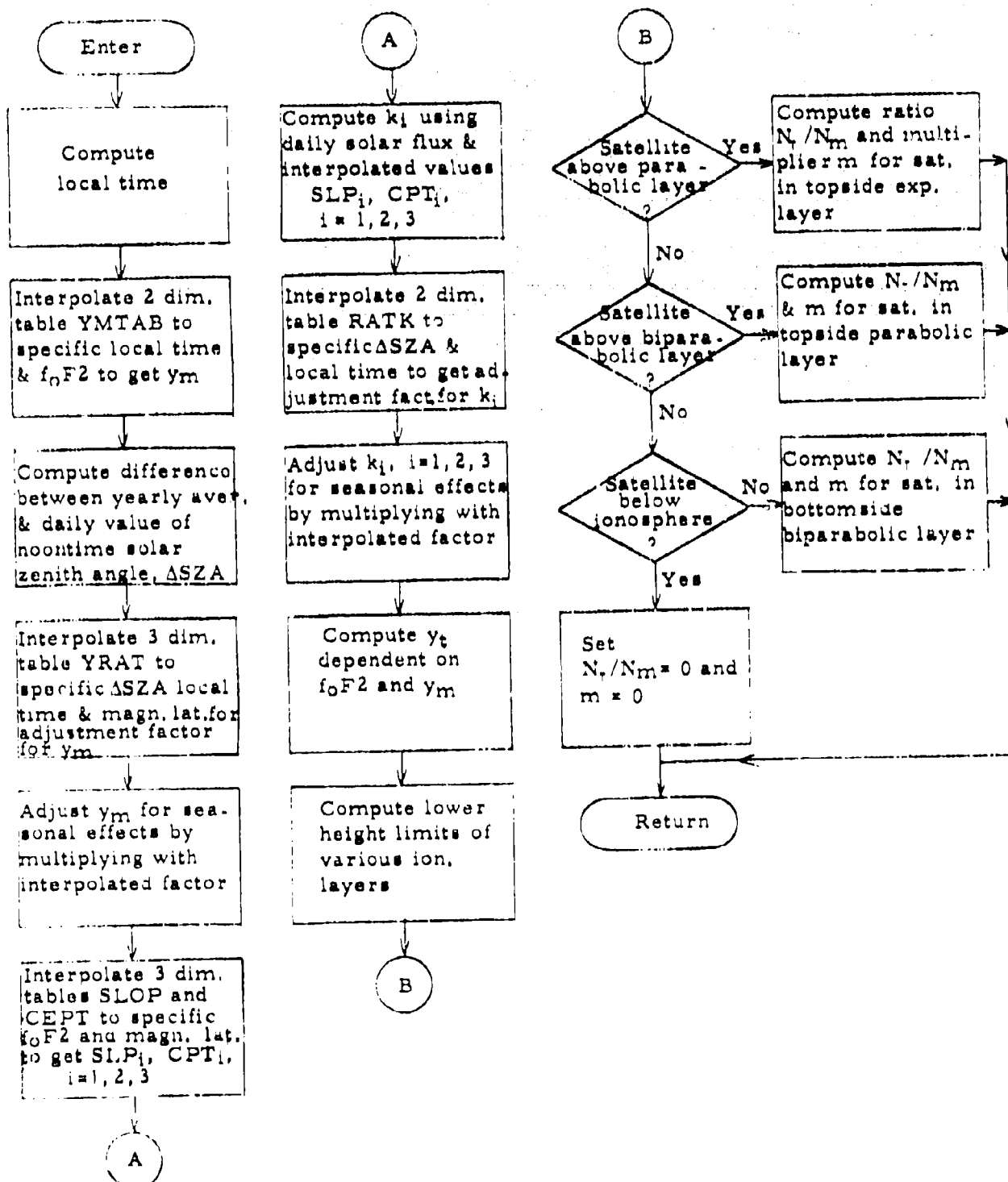
QO=0, Q1=1, Q2=2, Q3=3, Q4=4, Q5=5, Q6=6, Q8=8, Q24=24, Q37=37,
 Q1000=1000, QP05=.05, QP1333=.133333, QP95=.95, Q2P5=2.5,
 Q10P5=10.5, Q8Q15=.533333333;
 D5=5°, D7P5=7.5°, D8=8°, D10=10°, D16=16°, D30=30°, D135=135°,
 D180=180°, PIH=90°, PI2=360°, DEG(1)=75°, DEG(2)=45°, DEG(3)=15°
 converted to radians.

Other important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 5 Limitations

There are no programming restrictions connected with this subroutine, and the limitations to the accuracy of the results obtained from the formulas are discussed in Section 6.2.

CPC No. 5 Flowchart, SUBROUTINE PROFL2



3.2.1 Computer Program Component 6

CPC No. 6, SUBROUTINE BETA, is written in FORTRAN code. It is called from SUBROUTINE REFRAC and computes the ionospheric refraction correction for the elevation angle.

3.2.1.1 CPC No. 6 Description

BETA computes the angular refraction correction to the elevation angle. Using the results of Maliphant's work (Reference 8), the deviation angle α is expressed as the angle between the true ray path above the ionosphere and the apparent ray path.

$$\alpha = \frac{1}{2} \left(\frac{f_0 F2}{f} \right)^2 \xi \frac{\tan \varphi_0 \sec^2 \varphi_0}{r_0} \frac{N_T}{N_s} ,$$

where f is the transmission frequency, $f_0 F2$ the critical frequency, N_T the total electron content, N_s the maximum electron density;

$$r_0 = R_e + h_s + 0.5333 y_s ,$$

and R_e is the earth radius, h_s the height of the maximum electron density, and y_s the half thickness of the bottom layer of the ionosphere;

$$\varphi_0 = \arcsin \left(\frac{R_e}{r_0} \cos E \right) , \quad E \text{ being the elevation angle,}$$

and ξ is a function of the squared deviation factor $(\sec \varphi_s \times f_0 F2 / f)^2$ and is interpolated from tabulated values ξ^{-1} ; $\varphi_s = \arcsin \left(\frac{R_e}{R_e + h_s} \cos E \right)$.

After determining α the following two auxiliary equations are evaluated,

$$X_1 = \left[(R_e + h_s)^2 - R_e^2 \cos^2 E \right]^{\frac{1}{2}} + R_e \cos E \tan \frac{\alpha}{2}$$

$$X_2 = R_e \sin E - R_e \cos E \tan \frac{\alpha}{2} .$$

The elevation angle correction ΔE is then given by,

$$\Delta E = \arccos \frac{X_1 \cos \alpha - X_2}{(X_1^2 + X_2^2 - 2X_1 X_2 \cos \alpha)^{1/2}}$$

3.2.1.2 CPC No. 6 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 6 Interfaces

- a) Library subprograms required: ABS, ATAN, COS, SIN, SQRT
- b) Other subprograms called: none
- c) Calling program: SUBROUTINE REFRAC
- d) Calling sequence: CALL BETA (FRAT, XNTNM, HS, HM, YM, SE, CE, DELEV)

Variables in calling sequence:

<u>Name</u>	<u>Dimension</u>	<u>I/O</u>	<u>Description</u>
FRAT	1	I	Square ratio of critical frequency to the transmission frequency
XNTNM	1	I	Ratio of total electron content to the electron density (meter)
HS	1	I	Height of the satellite above the earth's surface (meters)
HM	1	I	Height of the maximum electron density (meters)
YM	1	I	Half thickness of the bottom layer of the ionosphere (meters)
SE	1	I	Sine function of the elevation angle
CE	1	I	Cosine of the elevation angle
DELEV	1	O	Ionospheric refraction correction to the elevation angle (radians)

- e) Common blocks: none
- f) File requirements: line printer

3.2.1.4 CPC No. 6 Data Organization

Variables defined in data statements:

<u>Name</u>	<u>Dimensions</u>	<u>Description</u>
XAX	5	Values of the squared deviation factor $(\sec \phi_e \times f_o F2/f)^2$ for which the function ξ^{-1} is tabulated
YAX	5	Tabulation of the function ξ^{-1} as given in Reference 8
R	1	Mean earth radius (meters)

Other constants listed in data statements:

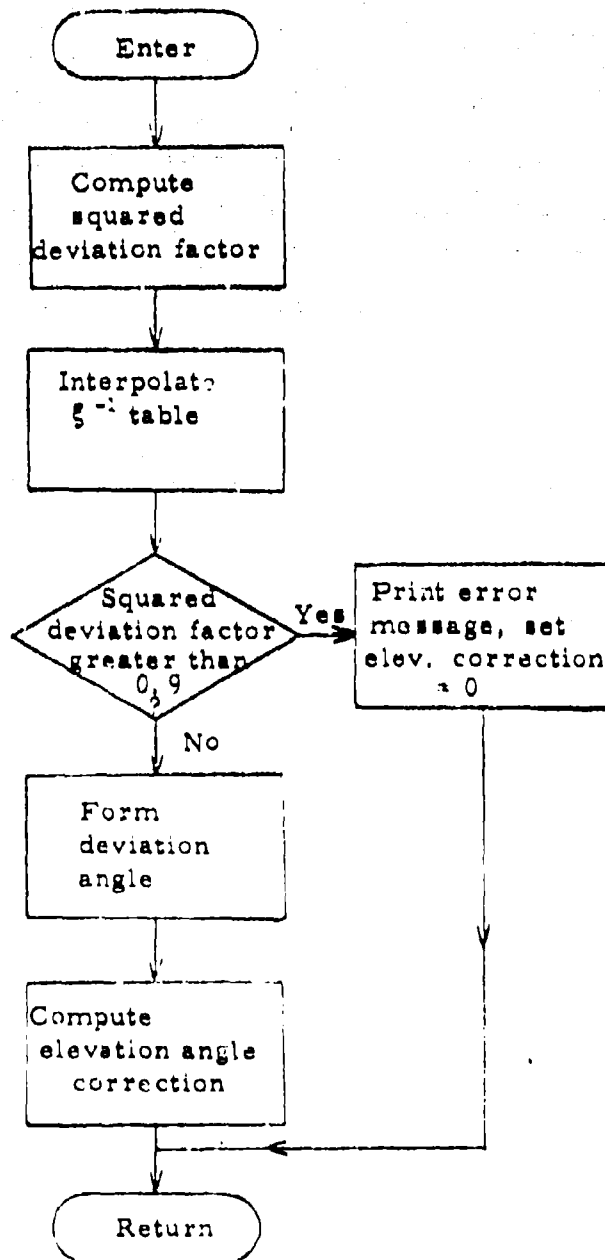
Q0=0, Q1=1, Q2=2, Q5333=.5333

Other important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 6 Limitations

The equations for the deviation angle α which are coded into SUB-ROUTINE BETA are accurate everywhere except right about reflection conditions. Whenever the deviation factor $(\sec \phi_e \times f_o F2/f)$ is less than 0.9, all equations are valid; this means the results are correct whenever the component of the wave frequency vertical to the ionosphere is slightly larger than the critical frequency $(1.1 \times f_o F2)$. But the more the deviation factor exceeds 0.9, the larger the errors might be in the computation for α and therefore ΔE . An error check, programmed into the routine, tests if the deviation factor is greater than 0.9 in which event a zero elevation angle correction is returned and an error message is printed.

CPC No. 6 Flowchart, SUBROUTINE BETA



3.2.1 Computer Program Component 7

CPC No. 7, SUBROUTINE SICOJT, is coded in FORTRAN code. It is called from SUBROUTINES PROFL1 and MAGFIN and performs auxiliary computations by expressing the multiple angle trigonometric functions.

3.2.1.1 CPC No. 7 Description

SICOJT computes the trigonometric functions for multiples of the angle. It forms $\sin(jT)$, $\cos(jT)$ for $j=1, \dots, L$ by computing $\sin T$, $\cos T$ for the single angle T , and by using for multiple angles the recursive equations:

$$\begin{aligned}\sin [(j+1) T] &= \sin T \cos (j T)+\cos T \sin (j T) \\ \cos [(j+1) T] &= \cos T \cos (j T)-\sin T \sin (j T).\end{aligned}$$

3.2.1.2 CPC No. 7 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 7 Interfaces

- a) Library subprograms required: COS, SIN
- b) Other subprograms called: none
- c) Calling programs: SUBROUTINES PROFL1 and MAGFIN
- d) Calling sequence: CALL SICOJT (L, C, S, T)

Variables in calling sequence:

<u>Name</u>	<u>Dimension</u>	<u>I/O</u>	<u>Description</u>
L	1	I	The largest integer by which T is to be multiplied
C	L	O	Array containing values $\cos(jT)$, $j=1, \dots, L$
S	L	O	Array containing values $\sin(jT)$, $j=1, \dots, L$
T	1	I	The angle (radians)

- e) Common blocks; none
- f) File requirements; none

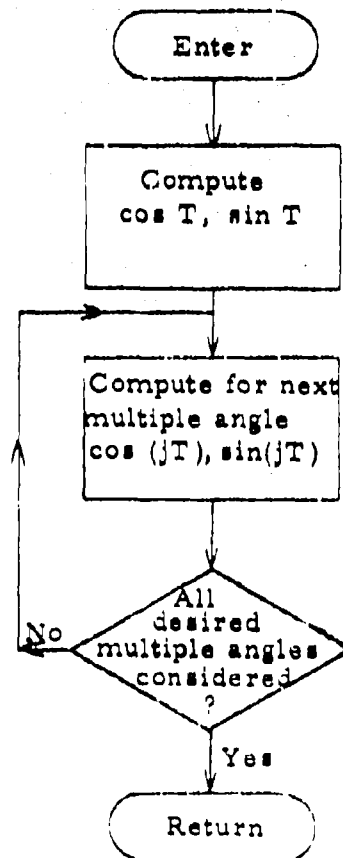
3.2.1.4 CPC No. 7 Data Organization

Important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 7 Limitations

None.

CPC No. 7 Flowchart, SUBROUTINE SICOJT



3.2.1 Computer Program Component 8

CPC No. 8, SUBROUTINE DKSICO, is written in FORTRAN code. It is called from SUBROUTINE PROF1 and calculates the time dependent coefficients which are required for the computation of critical frequency and associated height.

3.2.1.1 CPC No. 8 Description

DKSICO forms the orthonormal coefficients D_k for a fixed time T represented by the Fourier series representation,

$$D_k(T) = U_{0,k} + \sum_{j=1}^H \left[U_{2j,k} \cos(jT) + U_{2j-1,k} \sin(jT) \right], k=1, \dots, K.$$

These coefficients are to be used for the computation of the ionospheric characteristics in DKGK. The number of harmonics retained in the series is H , higher harmonics are not considered since they are produced more by noise than by real physical variation. For the f_oF2 computation $H=6$ and for the $M(3000)F2$ computation $H=4$ are sufficient. The coefficients $U_{i,k}$ are either a monthly predicted coefficient set for $M(3000)F2$ or a ten day predicted coefficient set for f_oF2 , which are both specific subsets derived from the generalized f_oF2 and $M(3000)F2$ coefficients in SUBROUTINE REFRAC. The D_k coefficients are computed for each term in a series with cutoff point K , $K=75$ for the series expressing f_oF2 and $K=48$ for the series representing $M(3000)F2$.

3.2.1.2 CPC No. 8 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 8 Interfaces

a) Library subprograms required: none

- b) Other subprograms called: none
- c) Calling program: SUBROUTINE PROF1
- d) Calling sequence: CALL DKSICO (MX, LH, D, SITIME, COTIME, DK)

Variables in calling sequence:

<u>Name</u>	<u>Dimension</u>	<u>I/O</u>	<u>Description</u>
MX	1	I	Cutoff index = cutoff point of series +1
LH	1	I	Number of harmonics retained in Fourier series representation of D_k
D	$(LH+2+1) \times MX$	I	Predicted coefficient array $U_{1,k}$ for $f_0 F2$ or for $M(3000)F2$
SITIME	LH	I	Array of values $\sin(jT)$
COTIME	LH	I	Array of values $\cos(jT)$
DK	MX	O	Array of coefficients D_k at fixed time T , $k=0, \dots, K$

- e) Common blocks: none
- f) File requirements: none

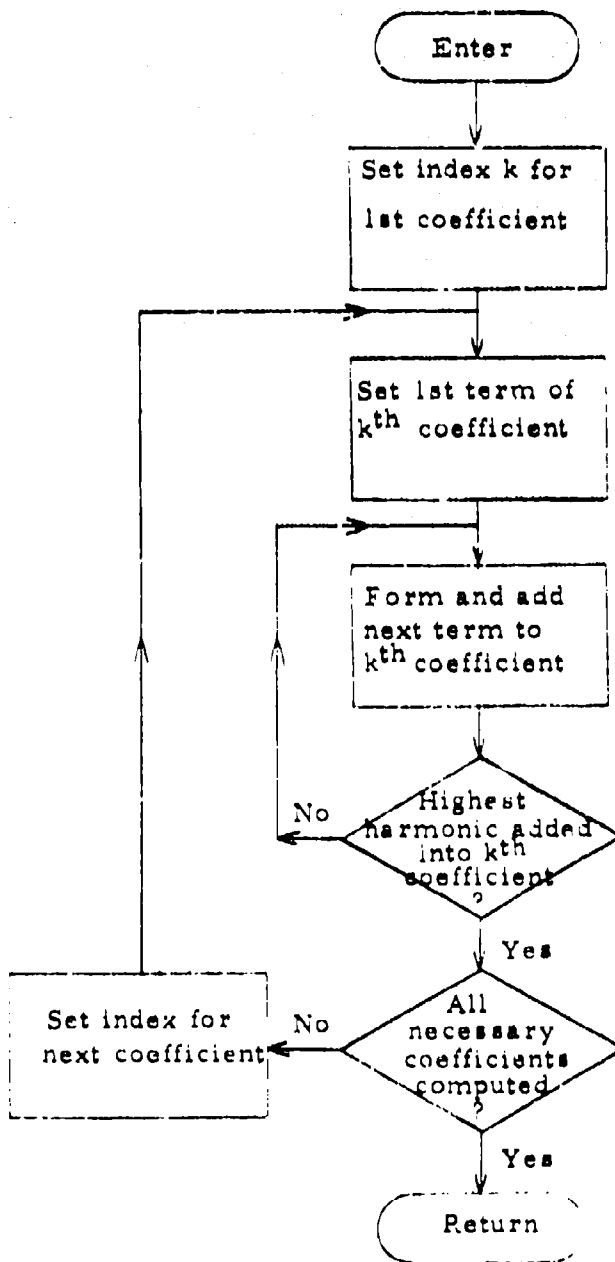
3.2.1.4 CPC No. 8 Data Organization

Important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 8 Limitations

None.

CPC No. 8 Flowchart, SUBROUTINE DKSICO



3.2.1 Computer Program Component 9

CPC No. 9, SUBROUTINE MAGFIN, is written in FORTRAN code. It is called from SUBROUTINE PROF1 and evaluates the magnetic field components at the point where the wave penetrates the ionosphere. The field components are required for the computation of the critical frequency and the associated height.

3.2.1.1 CPC No. 9 Description

MAGFIN computes the earth's magnetic field components at a desired location following the spherical harmonic analysis of the magnetic field by Chapman and Bartels (Reference 3) and using the coefficients g_n^a , h_n^a given by Jensen and Cain (Reference 4) for Epoch 1960. The X-north, Y-east, and Z-vertical (up) components of the magnetic field are used for the computation of the modified magnetic dip in SUBROUTINE PROF1.

Using the specified point (ϕ, λ, h_p) , the colatitude is introduced $\varpi = 90^\circ - \phi$, and the ratio $R = R_e / (R_e + h_p)$, where R_e is the radius of the earth and $h_p = 300$ km is the F2 layer height on which the coefficient analysis was based. The trigonometric functions $\sin(m\lambda)$, $\cos(m\lambda)$ for the multiple longitude angle λ are computed via SUBROUTINE SICOJT. The magnetic field components are defined in the following equations and are obtained by first expressing the multiple of the associated Legendre function and its derivative, then accumulating the terms of the inner sums and finally forming the outer sums.

$$\begin{aligned} X &= \sum_{n=1}^6 \left\{ R^{n+2} \sum_{m=0}^n \frac{d}{d\varpi} P_{n,m}(\cos\varpi) \left[g_n^a \cos(m\lambda) + h_n^a \sin(m\lambda) \right] \right\} \\ Y &= \frac{1}{\sin\varpi} \sum_{n=1}^6 \left\{ R^{n+2} \sum_{m=0}^n m P_{n,m}(\cos\varpi) \left[g_n^a \sin(m\lambda) - h_n^a \cos(m\lambda) \right] \right\} \\ Z &= \sum_{n=1}^6 \left\{ (n+1) R^{n+2} \sum_{m=0}^n P_{n,m}(\cos\varpi) \left[g_n^a \cos(m\lambda) + h_n^a \sin(m\lambda) \right] \right\} \end{aligned}$$

The multiple of the associated Legendre function is given by,

$$P_{n,m}(\cos\varphi) = \sin^m\varphi \left[\cos^{n-m}\varphi - \frac{(n-m)(n-m-1)}{2(2n-1)} \cos^{n-m-2}\varphi \right. \\ \left. + \frac{(n-m)(n-m-1)(n-m-2)(n-m-3)}{(2)(4)(2n-1)(2n-3)} \cos^{n-m-4}\varphi - \dots \right]$$

3.2.1.2 CPC No. 9 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 9 Interfaces

- a) Library subprograms required: ABS, SIGN, SIN, SQRT
- b) Other subprograms called: SUBROUTINE SICOJT
- c) Calling program: SUBROUTINE PROF1
- d) Calling sequence: CALL MAGFIN (POS, UNE)

Variables in calling sequence:

<u>Name</u>	<u>Dimension</u>	<u>I/O</u>	<u>Description</u>
POS	3	I	Array containing latitude, longitude and height (radians and meters)
UNE	3	O	Array with Z (vertical up), X(north), and Y(east) components of magnetic field (gauss) at the location specified by POS

- e) Common blocks: none
- f) File requirements: none

3.2.1.4 CPC No. 9 Data Organization

Variables defined in data statements:

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
CT	7x7	Array containing coefficients for the computation of the associated Legendre function
G	7x7	Array of g_n^m coefficients given in Reference 4 for the earth magnetic field for Epoch 1960
H	7x7	Array of h_n^m coefficients given in Reference 4 for the earth magnetic field for Epoch 1960

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
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RE	1	Mean earth radius (meters)
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Other constants listed in data statements;

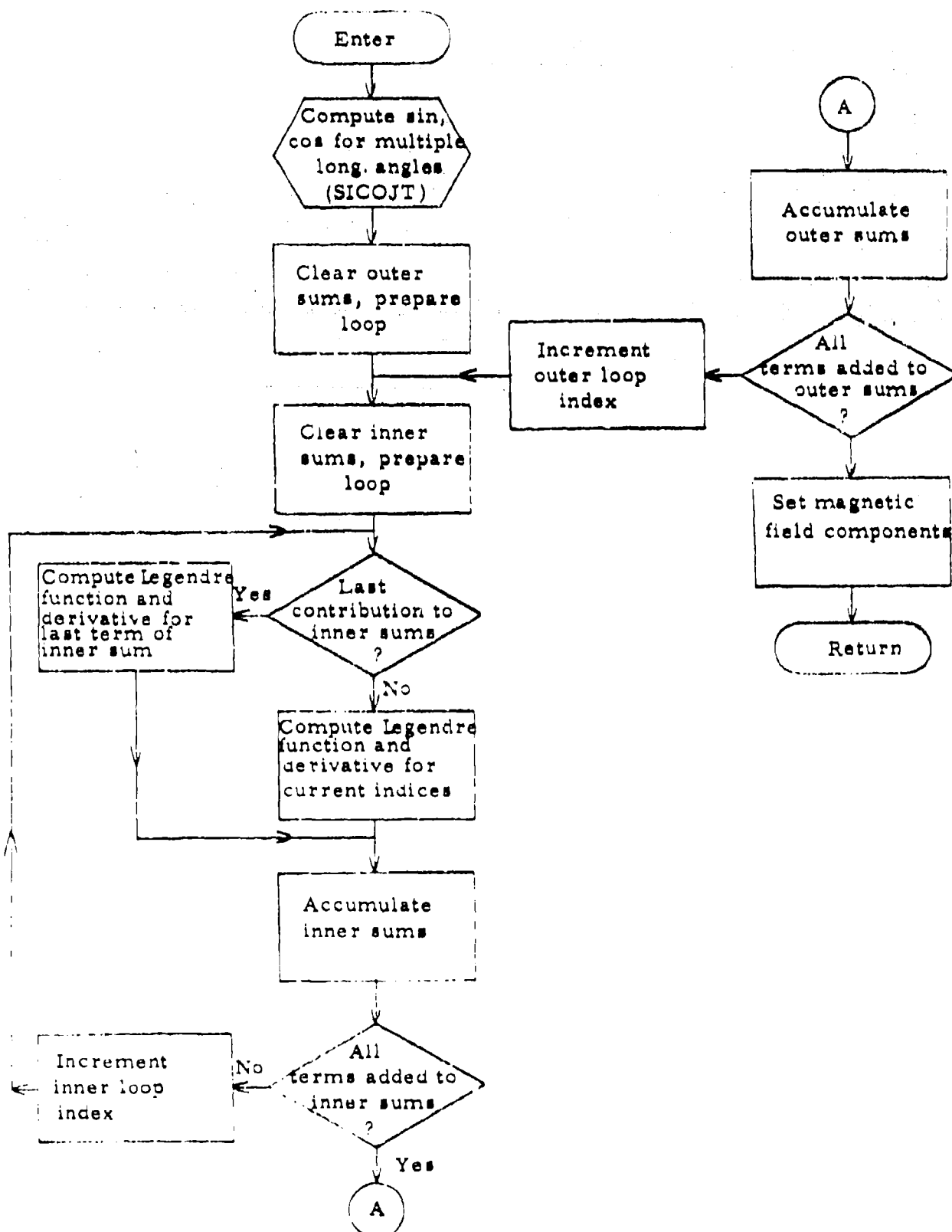
P(1,1)=1, DP(1,1)=0, SP(1)=0, CP(1)=1, Q0=0; R899=89.9°
converted to radians

Other important variables are described under 3.2.1.3 d).

3.2.1.5 CFC No. 9 Limitations

None.

CPC No. 9 Flowchart, SUBROUTINE MAGFIN



3.2.1 Computer Program Component 10

CPC No. 10, SUBROUTINE GK, is written in FORTRAN code. It is called from SUBROUTINE PROF1 and calculates the geographic coordinate functions which are required for the computation of critical frequency and associated height.

3.2.1.1 CPC No. 10 Description

GK computes the geographic coordinate functions G_k as a function of latitude ϕ , longitude λ , and modified magnetic dip $x=x(\phi, \lambda)$, which itself is dependent on the geographic position. These coordinate functions are to be used for the computation of the ionospheric characteristic f_oF_2 in subroutine DKGK. The functions G_k represent the main latitudinal variation and the first order through 8th order longitudinal variation terms. The main latitudinal variation is expressed as,

$$G_k = \sin^k x \quad \text{for } k=0, 1, \dots, 11,$$

and the j th order longitude terms are computed as,

$$G_k = \begin{cases} (\sin x)^{(k-2j)/2} \cos^2 \phi \cos(j\lambda) & , \text{ for } k \text{ even} \\ (\sin x)^{(k-2j-1)/2} \cos^2 \phi \sin(j\lambda) & , \text{ for } k \text{ odd} \end{cases} \quad k=m_j, (m_j+1), \dots, (m_{j+1}-1).$$

The longitude orders are $j=1, 2, \dots, 8$ while $k=12, 13, \dots, 75$, and the indexing is defined by: $m_1=12$, $m_2=36$, $m_3=54$, $m_4=64$, $m_5=68$, $m_6=70$, $m_7=72$, $m_8=74$.

3.2.1.2 CPC No. 10 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 10 Interfaces

- a) Library subprograms required: COS, SIN
- b) Other subprograms called: none
- c) Calling program: SUBROUTINE PROF1
- d) Calling sequence: CALL GK (K,C,G)

Variables in calling sequence:

<u>Name</u>	<u>Dimension</u>	<u>I/O</u>	<u>Description</u>
K	10	I	Integer index array containing $(m_j - 1)$
C	3	I	Array containing modified magnetic dip, geographic latitude and longitude (radians)
G	76	O	Array with geographic functions G_k , $k=0, \dots, 75$

- e) Common blocks: none
- f) File requirements: none

3.2.1.4 CPC No. 10 Data Organization

Constants defined in data statements:

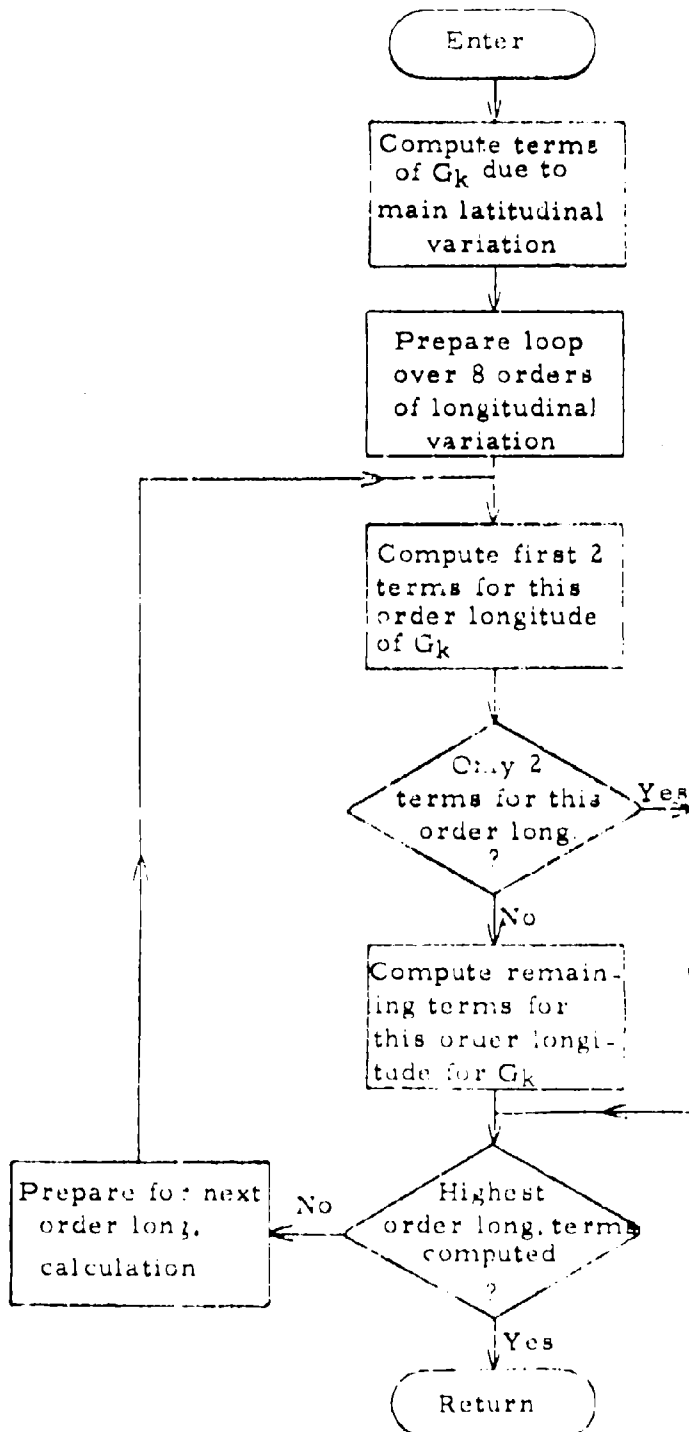
$Q1=1$, $N=8$ = Highest order of longitude included in G_k computation.

Important variables are described under 3.2.1.3 d).

3.2.1.5 CPC No. 10 Limitations

None.

CPC No. 10 Flowchart, SUBROUTINE GK



3.2.1 Computer Program Component 11

CPC No. 11, SUBROUTINE DKGK, is written in FORTRAN code. It is called from SUBROUTINE PROF11 and computes the critical frequency or the associated height depending on the input.

3.2.1.1 CPC No. 11 Description

DKGK computes the ionospheric characteristic Ω , by forming a series of products of time dependent coefficients D_k and position dependent geographic functions G_k ,

$$\Omega(\phi, \lambda, T) = \sum_{k=0}^K D_k(T) G_k(\phi, \lambda).$$

The coefficients D_k are precomputed for a fixed time T , and the geographic functions G_k are for a fixed latitude ϕ and longitude λ . K is the cutoff point for the approximate series representation of Ω . For the determination of the ionospheric characteristic $\Omega=f_oF2$ the cutoff point $K=75$ is used and for the calculation of $\Omega=M(3000)F2$ the cutoff point is $K=48$. The inputs D_k and G_k are specifically set for either the f_oF2 or the $M(3000)F2$ computation.

3.2.1.2 CPC No. 11 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 11 Interfaces

- a) Library subprograms required: none
- b) Other subprograms called: none
- c) Calling program: SUBROUTINE PROF11
- d) Calling sequence: CALL DKGK (MX, G, DKSTAR, OMEGA)

Variables in calling sequence:

<u>Name</u>	<u>Dimension</u>	<u>I/O</u>	<u>Description</u>
MX	1	I	Cutoff index=cutoff point K of series +1
G	MX	1	Array of geographic functions G_k , $k=0, \dots, K$
DKSTAR	MX	1	Array of coefficients D_k , $k=0, \dots, K$
OMEGA	1	O	Ionospheric characteristic f_oF2 (MHz) or $M(3000)F2$ (dimensionless)

e) Common blocks: none

f) File requirements: none

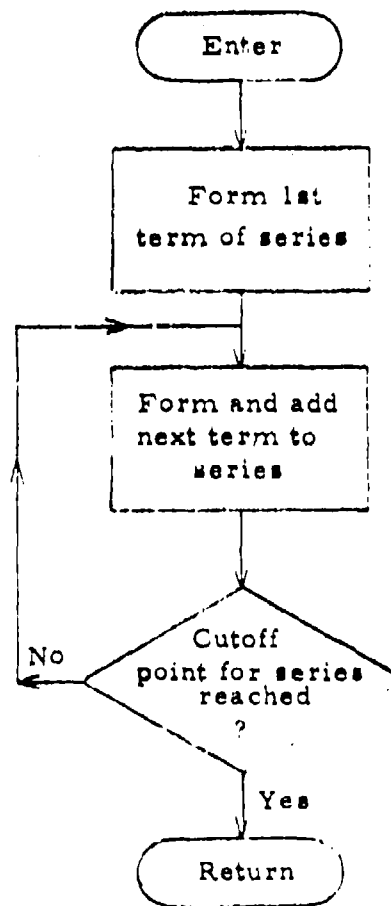
3.2.1.4 CPC No. 11 Data Organization

Important variables are described under 3.2.1.3 d).

3.2.1.5 CFC No. 11 Limitations

None.

CPC No. 11 Flowchart, SUBROUTINE DKGK



3.2.1 Computer Program Component 12

CPC No. 12, main PROGRAM TABGEN, is written in FORTRAN code. For any specified date and station preprocessor TABGEN computes values of critical frequency and corresponding height for 14 time intervals at each of 25 locations around the station covering the visible ionosphere. The resulting f_oF2-h_p tables are written onto file for use in the ionospheric reduction program ION1.

3.2.1.1 CPC No. 12 Description

TABGEN reads the date, station, and solar flux information from card for which f_oF2-h_p tables are to be generated. It lists the input data for reference in the print out and converts the units of the angles to radians. The general coefficients are read from tape if not already available and the specific coefficient sets required for the f_oF2 and $M(3000)F2$ computation are prepared as well as the solar data. The applicable procedures are already described in the first four paragraphs of Section 3.2.1.1, CPC No. 2.

A pattern of 25 points is generated around the station as shown in Figure 1; the point distribution covers the visible ionosphere in fairly even density. The earth central angle α between station and ionospheric point varies in 7° increments, while the azimuth A is 0° for $\alpha=0^\circ$, and rotates in 90° steps for $\alpha=7^\circ$, in 45° steps for $\alpha=14^\circ$, and in 30° steps for $\alpha=21^\circ$ out of the northern position. For each ionospheric point the geographic latitude ϕ and longitude λ and the magnetic latitude ϕ_m are reduced from the station position ϕ_s, λ_s , the position of the magnetic north pole ϕ_p, λ_p , and α and A ;

$$\phi = \arcsin (\sin \phi_s \cos \alpha + \cos \phi_s \sin \alpha \cos A)$$

$$\lambda = \lambda_s + \arcsin \left(\frac{\sin A \sin \alpha}{\cos \phi} \right)$$

$$\phi_m = \arcsin \left[\sin \phi \sin \phi_p + \cos \phi \cos \phi_p \cos(\lambda - \lambda_p) \right].$$

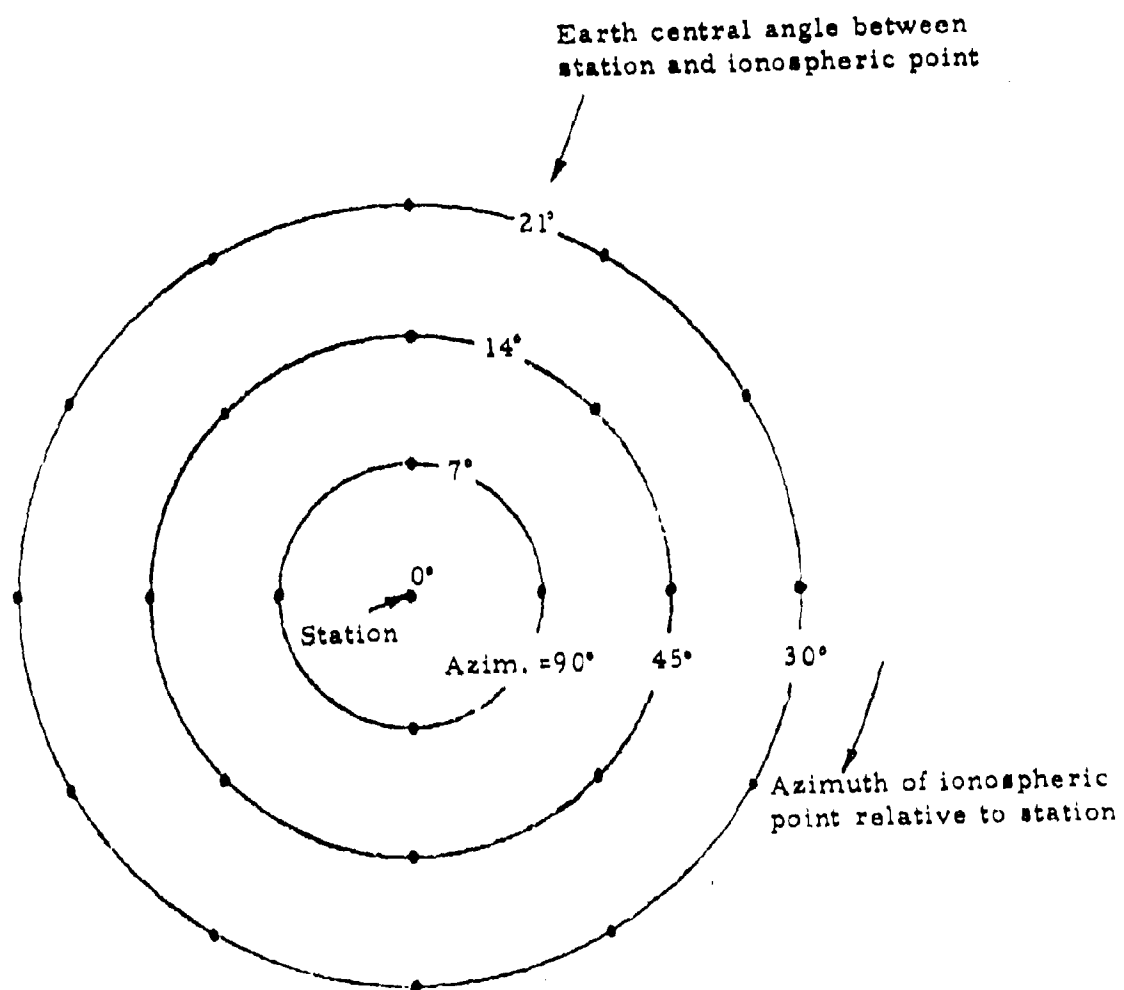


Figure 1. 25 Point Pattern of Ionospheric Points around Station

The position dependent functions required for the f_oF2 and $M(3000)F2$ computation are evaluated using SUBROUTINE MAGFIN and GK as described in the third paragraph of Section 3.2.1.1, CPC No. 4.

The diurnal variation at each of the 25 points is produced by evaluating the critical frequency and corresponding height at 14 different time intervals at 0, 2, 4, 5, 6, 7, 8, 10, 12, 14, 16, 18, 20, 22 hours of local time. The time pattern is densified around sunrise to properly represent the rapid change in the ionosphere during that time. f_oF2 and $M(3000)F2$ are computed by preparing the time dependent coefficients via SUBROUTINES SICOJT and DKSICC and combining the time dependent coefficients and position dependent functions by calling SUBROUTINE DKGK. The height of the maximum electron density h_p is computed with the Appleton-Beynon equation (Reference 1) in units of km;

$$h_p = 1346.92 - 526.40 \times M(3000)F2 + 59.825 [M(3000)F2]^2$$

The critical frequency is adjusted for day to day variations as a function of ΔF , the difference between the daily value and the 12-month running average of the solar flux. Using the model constants c_1 (variable PER) and c_2 obtained by interpolating the constant table (array CENT) to the magnetic latitude of the ionospheric point, f_oF2 is multiplied by the adjustment factor $(c_1 \Delta F + c_2)$.

For each point and time f_oF2 and h_p are coded into one 8 digit integer, the first four digits defining h_p in units of $\frac{1}{10}$ km the last 4 digits specifying f_oF2 in units of $\frac{1}{100}$ MHz. The f_oF2 - h_p table is accumulated for all 14 time intervals and all 25 points, and is written to tape or disc file along with the date, station, and solar flux information. The process can be repeated for any number of date and station conditions desired, by specifying additional input data and repeating the steps outlined in this section.

3.2.1.2 CPC No. 12 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 12 Interfaces

- a) Library subprograms required: AMOD, ATAN, COS, SIN, SQRT
- b) Other subprograms called: SUBROUTINES MAGFIN, GK, SICOJT, DKSICO, DKGK
- c) Calling programs: none
- d) Calling sequence: PROGRAM TABGEN
- e) Common blocks: none
- f) File requirements: general coefficient input tape, output disc or tape file with f_oF2-h_p tables, card reader, line printer

The formats of the general coefficient input tape of the f_oF2-h_p table output file and the requirements for the input data card file are specified under 3.3.1.

3.2.1.4 CPC No. 12 Data Organization

Variables defined in data statements:

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
JAZ	4	Index array specifying number of azimuth angle divisions for each earth central angle used in 25 point pattern
ITP	1	Unit assignment of general ionospheric coefficient tape
JTP	1	Unit assignment of file with f_oF2-h_p tables
MONDY	1	Initialization constants for last and first (month \times 100 + day) for which coefficients are in core
MOND	1	
LYRMO	1	Initialization constant for (year \times 100 + month)
K	10	Integer indices and index arrays used for the computation of f_oF2 and $M(3000)F2$ in SUBROUTINES DKSICO, GK, and DKGK
KN	10	
KM10	1	
NFF	1	
NMF	1	

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
PER	1	Model constants used for adjusting f_oF2 for daily variation, dependent on the daily value of the 12-month running average of solar flux and magnetic latitude
CENT	3	
SPLAT	1	Sine function of the geographic latitude of the magnetic north pole
CPLAT	1	Cosine of the geographic latitude of the magnetic north pole
PLON	1	Geographic longitude of the magnetic north pole (radians)
H1	1	Coefficients used in the formula expressing h_p as a second order polynomial of $M(3000)F2$
H2	1	
H3	1	

Other constants listed in data statements:

$Q1=1$, $Q10=10$, $Q100=100$, $Q130=130$, $Q3T5=3 \times 10^5$, $QP1=.1$, $QP5=.5$;

$DR=1^\circ$, $PI2=160^\circ$, $D7=7^\circ$, $DHR1=1^h$, $DHR2=2^h$, $D180=180^\circ$,

$DG(1)=59^\circ$, $DG(2)=28^\circ$, $DG(3)=-33^\circ$ converted to radians.

3.2.1.5 CPC No. 12 Limitations

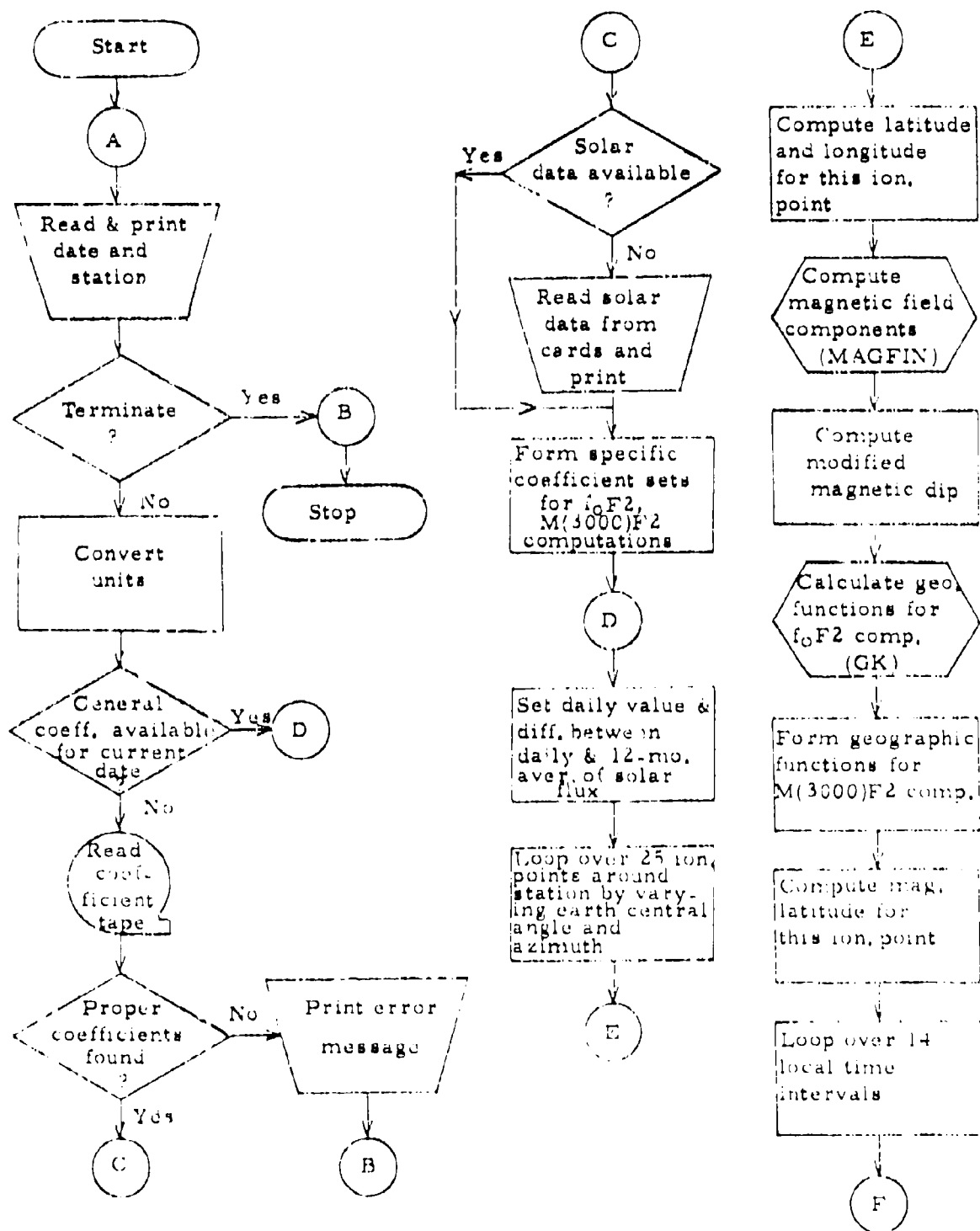
The daily value of solar flux transferred through the data file to the ionospheric reduction program for computation of the decay constants for the topside exponential profile is truncated at a maximum value of 130. This is the boundary that was imposed by the data base during model development and extension of solar flux beyond 130 could result in invalid profiles.

Approximations are introduced through bypassing the iteration on the height estimate of the ionosphere. In this case the latitude and longitude of the ionospheric points are not effected, only the height itself at which the magnetic field components are evaluated. Error estimates for these approximations are not yet available.

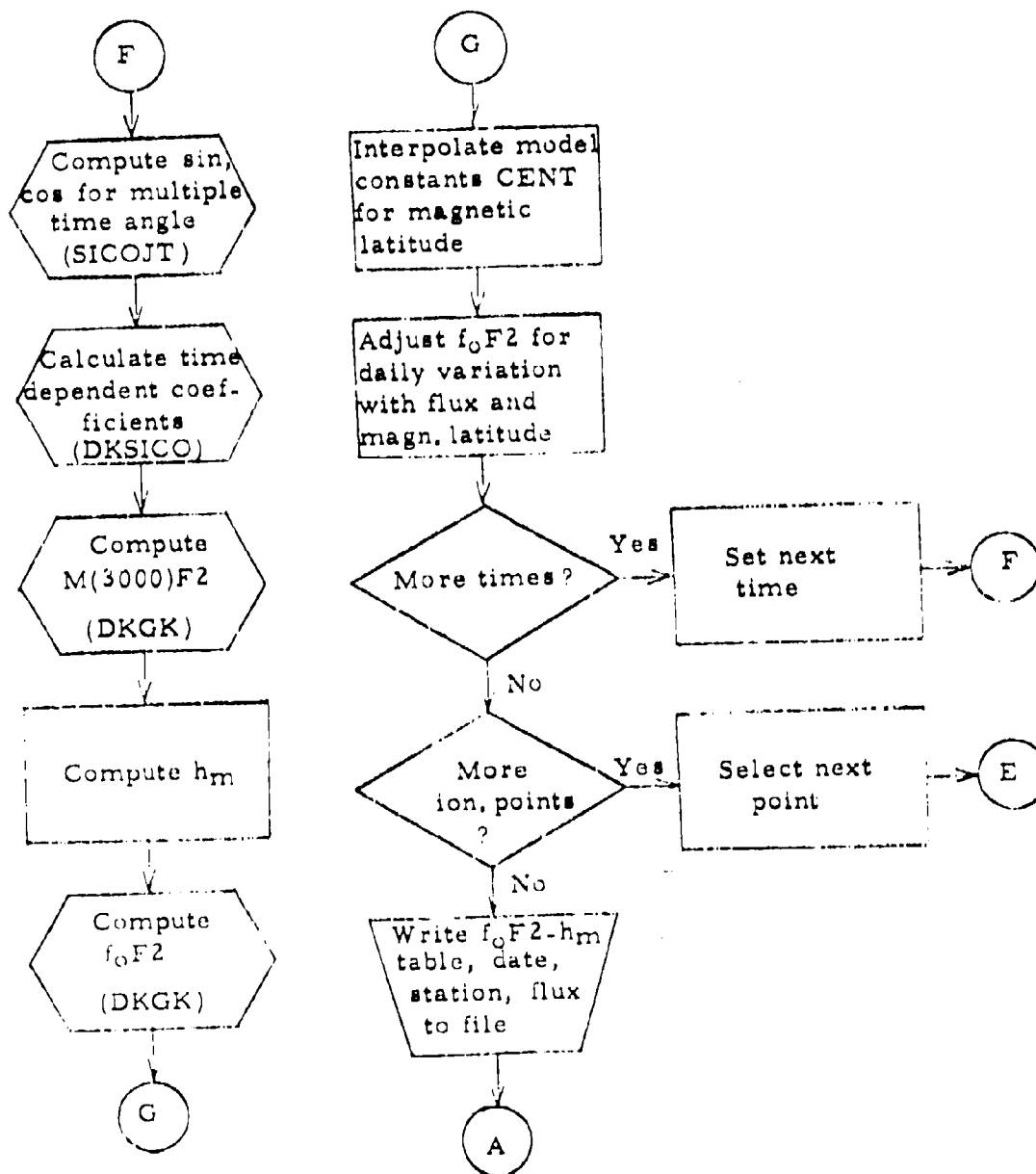
If the ionospheric coefficients are not found on the tape for the specified date, an error condition has occurred, a message is printed out, and the program is terminated.

The solar input data cards are checked for consistency of the date and if disagreement is found, a message is printed and the program is terminated.

CPC No. 12 Flowchart, PROGRAM IAEGEN



PROGRAM TABGEN (continued)



3.2.1 Computer Program Component 13

CPC No. 13, main PROGRAM ION1, is written in FORTRAN code. It handles the card input and the printing of the results for the entire program. ION1 transfers the input conditions through common/EVAL1/, and by calling SUBROUTINE REFRCL receives the computed profile parameters and refraction corrections through common/CORR1/.

3.2.1.1 CPC No. 13 Description

ION1 reads the station, satellite, and time information for the condition to be evaluated from cards. The input data is converted to the internal units of meters for distances and radians for angles and times. The variables specifying the evaluation condition are transferred through common/EVAL1/ to SUBROUTINE REFRCL. Through REFRCL and other routines called by REFRCL, ionospheric profile parameters, vertical and angular electron content, refraction corrections to elevation angle, range, and instantaneous range rate are computed. They are returned to ION1 through common/CORR1/ and are printed.

Any number of evaluation conditions can be processed by supplying additional input data and repeating the program steps outlined above. For more details about the input and output data refer to the file descriptions under 3.3.1.

3.2.1.2 CPC No. 13 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 13 Interface

- a) Library subprograms required: none
- b) Other subprograms called: SUBROUTINE REFRCL
- c) Calling programs: none

- d) Calling sequence: PROGRAM ION1
- e) Common blocks: EVAL1, CORR1

Variables in Common:

See description for EVAL1, CORR1 under SUBROUTINE REFRC1,
CPC No. 14

- f) File requirements: card reader, line printer

The requirements for the input data card file are specified under 3.3.1.

3.2.1. - CPC No. 13 Data Organization

Constants defined in data statement:

Q0=0, Q1000=1000, Q3600=3600; DR=1°, HR=1^h converted to radians.

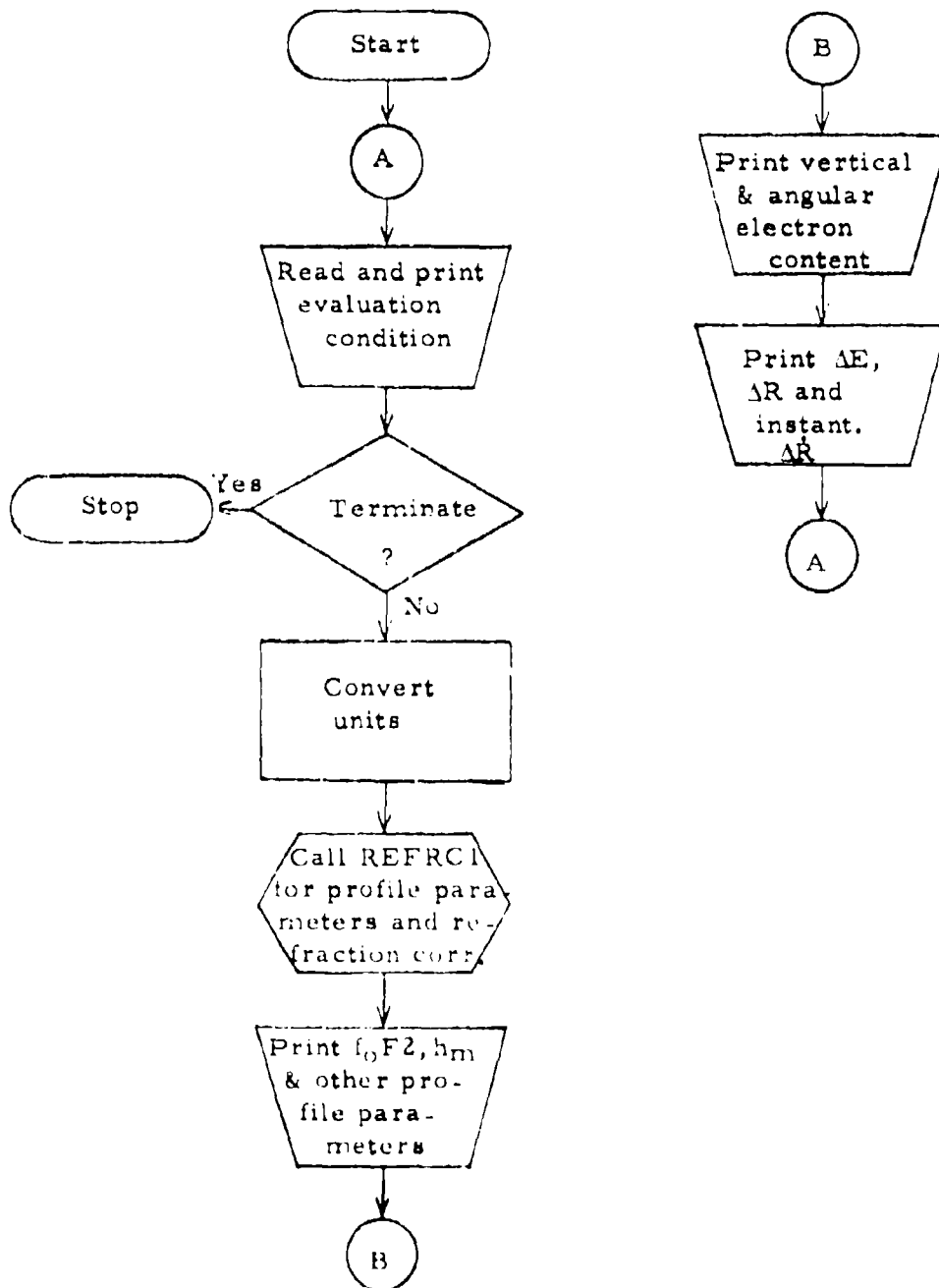
Important variables are described under 3.2.1.3 e) of SUBROUTINE
REFRC1, CPC No. 14.

3.2.1.5 CPC No. 13 Limitations

Error tests on the sequence, units, and formats of the input data are not performed. However, mistakes in the set up of the card deck are revealed in the printout of the input data that is listed along with the results.

ION1 is a program for special applications and limited use compared to the general purpose PROGRAM ION. Not included in ION1 are the additional features of ION of plotting the ionospheric profile, of updating the predictions with actual ionospheric observations, and of computing range rate corrections for range differencing. For the purpose of saving space only four digits are carried for f_oF2 and h_p in the f_oF2-h_p tables which eliminates the option of differencing range corrections where the 5th and 6th digit of f_oF2 are significant to the result. Because of approximations in TABGEN and REFRC1, ION1 also yields less accurate results than ION.

CPC No. 13 Flowchart, PROGRAM ION1



3.2.1 Computer Program Component 14

CPC No. 14, SUBROUTINE REFRCL, is written in FORTRAN code and is called from main PROGRAM ION1. REFRCL extracts the f_oF2-h_p tables from tape or disc file and interpolates the values in the tables to the specified position and time. The remaining profile parameters are obtained via SUBROUTINE PROFL2, the ionospheric refraction corrections to range ΔR , to instantaneous range rate $\dot{\Delta R}$ are computed and SUBROUTINE BETA provides the elevation angle correction ΔE .

3.2.1.1 CPC No. 14 Description

REFRCL retrieves the f_oF2-h_p tables from the tape or disc file that was prepared by the preprocessor TABGEN, if the tables for the given evaluation condition are not already available. Data for up to four station and date combinations can be kept in core simultaneously which greatly reduces the IO requirements for data reductions where a few stations are observing intermittently. In addition, if new data is requested, it automatically replaces of the four tables the one having been in core for the longest time.

The earth central angle between station and ionospheric point, the geographic latitude and longitude, and the magnetic latitude of the ionospheric point are computed using the equations shown in Section 3.2.1.1, CPC No. 4. Local time t_{loc} is computed from the universal time t and the longitude λ ,

$$t_{loc} = t + \lambda$$

Critical frequency and corresponding height are extracted from the f_oF2-h_p table containing data for 14 time intervals during the specified day at each of 25 locations covering the visible ionosphere around the given station. A linear interpolation process is used in three dimensions, in azimuth, earth central angle, and local time. First it is arranged for indexing purposes that azimuth lies between 0 and 360 degrees, central angle between 0 and 90 degrees, and local time between 0 and 24 hours. The indices

and increments for the interpolation are computed for all three variables. Continuous interpolation is insured between 22 and 0 hours of local time and between the highest value and 0 degrees of azimuth for each central angle. The limiting values at 21 degrees are used if due to some rare occasion or an error condition, the earth central angle should exceed 21 degrees; this value was arrived at for the extreme condition of an observer looking horizontally at a 453 km high ionosphere.

By calling SUBROUTINES PROFL2 and BETA the remaining profile parameters and the refraction correction to the elevation angle are evaluated respectively. Vertical and angular total electron content as well as the refraction corrections to range and instantaneous range rate, are computed following the description in the last five paragraphs of Section 3.2.1.1, CPC No. 2.

3.2.1.2 CPC No. 14 Flowchart

The flowchart is shown on the page following 3.2.1.5.

3.2.1.3 CPC No. 14 Interfaces

- a) Library subprograms required: ABS, AMOD, ATAN, COS, FLOAT, SIN, SQRT
- b) Other subprograms called: SUBROUTINES PROFL2, BETA
- c) Calling program: PROGRAM ION1
- d) Calling sequence: SUBROUTINE REFRCL
- e) Common blocks: EVAL1, CORR1

Variables in common:

Common Name	Variable Name	Dimension	I/O	Description
EVAL1	FS	1	I	Transmission frequency (MHz)
EVAL1	FLAT	1	I	Latitude of station (radians)
EVAL1	FLON	1	I	Longitude of station (radians)

Common Name	Variable Name	Dimension	I/O	Description
EVAL1	ELEV	1	I	Elevation to satellite (radians)
EVAL1	AZ	1	I	Azimuth to satellite (radians)
EVAL1	HS	1	I	Height of satellite (m)
EVAL1	EDOT	1	I	Elevation rate (radians/sec)
EVAL1	HDOT	1	I	Altitude rate (m/sec)
EVAL1	TIME	1	I	Universal time (radians)
EVAL1	IYR	1	I	Year (last 2 digits)
EVAL1	MON	1	I	Month (=1 through 12)
EVAL1	IDAY	1	I	Day (=1 through 31)
EVAL1	JTP	1	I	Unit assignment of ionospheric file with f_oF2-h_p tables
CORR1	DRANG	1	O	Range correction (m)
CORR1	DRATE	1	O	Range rate correction (m/sec)
CORR1	DELEV	1	O	Elevation angle correction (radians)
CORR1	F0F2	1	O	Critical frequency (MHz)
CORR1	HM	1	O	Height at maximum electron density (meters)
CORR1	YM	1	O	Half thickness of the bottomside bi-parabolic layer (meters)
CORR1	YT	1	O	Half thickness of the topside parabolic layer (meters)
CORR1	XK	3	O	Decay constants of lower, middle, and upper section of the exponential topside layer (1/meter)
CORR1	TOIN	1	O	Total vertical electron content (e/m^2 column)
CORR1	TOTNA	1	O	Total angular electron content (e/m^2 column)

f) File requirements: ionospheric input tape or disc file with f_oF2-h_p tables. The format of the file containing the f_oF2-h_p tables is described under 3.3.1.

3.2.1.4 CPC No. 14 Data Organization

Variables defined in data statements:

<u>Name</u>	<u>Dimension</u>	<u>Description</u>
JAZ	4	Index arrays used in defining the 25 point pattern around the station
KAZ	4	
NO	1	Initialization constants for storage condition of f_oF2-h_p tables
NR	1	
R	1	Mean earth radius (meters)
SPLAT	1	Sine function of the geographic latitude of the magnetic north pole
CPLAT	1	Cosine of the geographic latitude of the magnetic north pole
PLON	1	Geographic longitude of the magnetic north pole (radians)
RM	1	Estimate for radial distance of ionosphere from earth center (meters)
TOL	1	Tolerance allowed in identifying station latitude and longitude (radians)

Other constants listed in data statements:

$Q0=0$, $Q1=1$, $Q2=2$, $Q7=7$, $Q100=100$, $Q3P5=3.5$, $Q4P5=4.5$, $QNM=1.24 \times 10^{30}$,
 $RN3=.49972$; $PI2=360^\circ$, $DR=1^\circ$, $HR=1^\circ$ converted to radians.

Other important variables are described under 3.2.1.3 e).

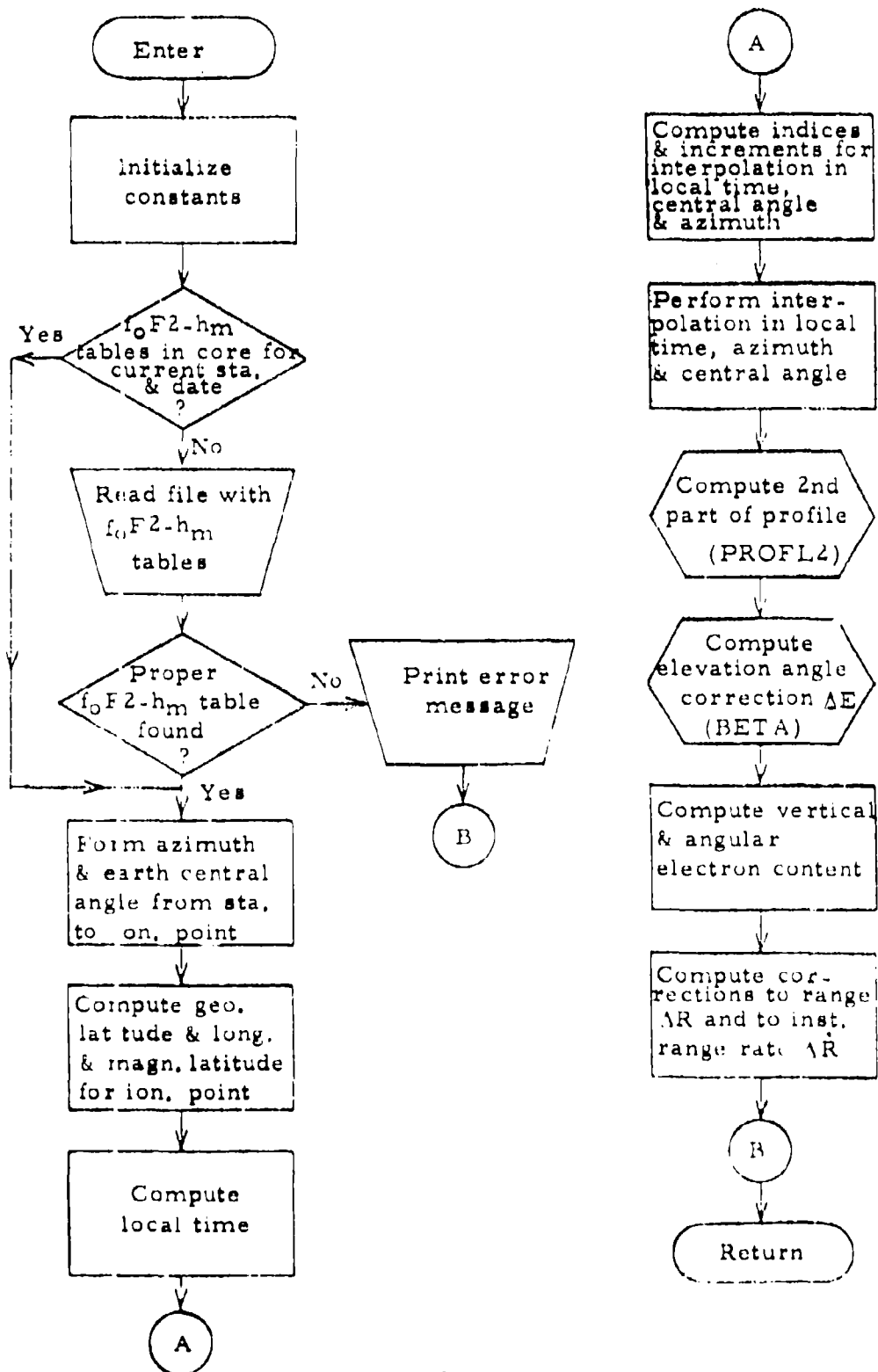
3.2.1.5 CPC No. 14 Limitations

Approximations are introduced into the computation of the critical frequency and the height of the maximum electron density by two facts; through the linear interpolation in space and time of the precomputed f_oF2-h_p tables, and through bypassing the iteration on the height estimate of the ionosphere. Thus caution should be used and further tests of accuracy requirements might be desired when using this program version. An estimate of the expected errors is given in Section 6.2.

The range rate correction formula in this routine applies only to instantaneous range rate measurements since it is assumed that the only variation in electron content over the time of observation is due to the positional change of the satellite and that the ionosphere between station and satellite remains constant. Range rate corrections to observations obtained by range differencing over a finite time interval during which the ionosphere can undergo distinct changes, cannot be computed by this routine because the f_oF2-h_p tables do not carry enough significant digits. For this purpose PROGRAM ION should be used.

If the f_oF2-h_p table for the specified date and station is not found in the data file, an error message is printed out and control is transferred to PROGRAM ION1 to proceed with the next data case.

CPC No. 14 Flowchart, SUBROUTINE REFRCL



3.3 Storage Allocation

The size requirements and storage allocations of the total program and the individual components were extracted from computer runs of the programs on the CDC 6600 computer system. In the load maps that are shown on the following pages the starting addresses of the program and system functions in the detailed breakdown are listed in octal words.

The total core space requirements are:

37604 octal = 16260 decimal words for the Bent Ionospheric PROGRAM ION;
24232 octal = 10394 decimal words for the preprocessor PROGRAM TABGEN,
6524 octal = 3412 decimal words for the reduction PROGRAM ION1
of the alternate version of the ionospheric program.

Following are the size requirements for the individual components:

Component	Size in decimal words
COMMON /EVAL/	20
COMMON /UPDT/	57
COMMON /CORR/	12
PROGRAM ION	3841
SUBROUTINE REFRAC	5426
SUBROUTINE PLOTNH	366
SUBROUTINE PROFL1	624
SUBROUTINE PROFL2	1085
SUBROUTINE BETA	180
SUBROUTINE SICOJT	64
SUBROUTINE DKSICO	72
SUBROUTINE MAGFIN	520
SUBROUTINE GK	147
SUBROUTINE DKGK	39
COMMON /EVAL1/	13
COMMON /CORR1/	12
PROGRAM TABGEN	10394
PROGRAM ION1	3412
SUBROUTINE REFRAC1	1988

Load Map for PROGRAM ION:

-PROGRAM---ADDRESS-
ION 000231

REFRAC 007632

PLOTNH 022314
PROFL1 023072
PROFL2 024252
BETA 026347
SICOUT 026633
OKSICC 026733
MAGFIN 027043
GK 030053
DKGK 030276
ACGOER\$ 030345
ABSS 030360
AMOD\$ 030363
SIGN\$ 030370
ALNLOGE 030374
ALOG10\$ 030433
ATANE 030465
EYP\$ 030505
EXPE 030547
SINCCSE 030615
SQRT\$ 030672
SORTE 030716
GETBA 030740
SIC\$ 030757
CCSS 032372
SIN\$ 032424
ATANE 032456
SYSTEM\$ 032537
IFENDF\$ 033547
INPUTF\$ 033626
INPUTC\$ 034107
KODEP\$ 034236
KRAKE\$ 035652
OUTPTC\$ 037436
REWIM\$ 037532

--LAELED---COMMON--

EVAL	000100
UPDT	000124
CORR	000215
EVAL	000100
UPDT	000124
CORR	000215

Load map for PROGRAM TABGEN:

-PROGRAM----	ADDRESS-	--LABELED---	COMMON--
TABGEN	020100		
SICOUT	024332		
OKSICC	024432		
MAGFIN	024542		
GK	025552		
DKGK	025775		
ABS	026044		
AMODS	026047		
SIGNS	026054		
ATANS	026060		
SINCCSS	026100		
SCRTS	026155		
SCRTS	026201		
GETBA	026223		
SIOS	026242		
COSS	027655		
SINS	027707		
ATANE	027741		
SYSTEMS	030022		
ENDFILS	031032		
IFENGFS	031103		
INFUTS	031162		
INPUTCS	031443		
KODERS	031572		
KRAKERS	033206		
OUTPTS	034772		
OUTPTCS	035251		
REWINMS	035345		

Load map for PROGRAM ION1;

-PROGRAM----	ADDRESS-	--LABELED---	COMMON--
ION1	000131	EVAL1	000100
		CORR1	000115
REFRG1	006655	EVAL1	000100
		CORR1	000115
PROFL2	012561		
BETA	014656		
ABSE	015142		
AMODS	015145		
FLOATS	015152		
ATANS	015155		
EXPS	015176		
EXPE	015237		
SINCCSE	015305		
SQRTS	015362		
SORTE	015406		
GETBA	015430		
SLOS	015442		
COSS	017062		
SINS	017114		
ATANE	017146		
SYSTEMS	017227		
IFENDFS	020237		
INPUTES	020316		
INFUTCS	020577		
KODERE	020726		
KRAKERS	022342		
OUTPTCS	024126		
REWINS	024222		

3.3.1 Data Base Characteristic - File Description

External data transfer in and out of the ionospheric model ION is handled through three files; the input data card deck read in PROGRAM ION, the input ionospheric coefficient tape read in SUBROUTINE REFRAC, and the output to the line printer is written in PROGRAM ION and SUBROUTINE PLOTNH.

Program	File Type	Mode	I/O	Fortran Unit No.	Description	Details Under
ION	Tape	BIN	I	1	Ionospheric coeff. tape	3.3.1.1
ION	Line printer	BCD	O	6	Output listing from ION	3.3.1.2
ION	Card reader	BCD	I	5	Input data deck to ION	3.3.1.3

The alternate version of the ionospheric program consists of two separate entities, the preprocessor TABGEN and the reduction program ION1. External data transfer in and out of TABGEN is handled through four files: an input data card deck, data output to line printer, the input ionospheric coefficient tape, and the output disc or tape file with f_0F2-h_p tables. External data transfer in and out of ION1 is handled through the following 3 data files: an input data card deck, the input data file with f_0F2-h_p tables, and output to the line printer.

Program	File Type	Mode	I/O	Fortran Unit No.	Description	Details Under
TABGEN	Tape	BIN	I	1	Ion. coeff. tape	3.3.1.1
TABGEN	Disc or tape	BIN	O	2	File with f_0F2-h_p tables	3.3.1.4
TABGEN	Line printer	BCD	O	6	Output listing from TABGEN	3.3.1.5
TABGEN	Card reader	BCD	I	5	Input data deck to TABGEN	3.3.1.6
ION1	Disc or tape	BIN	I	2	File with f_0F2-h_p tables	3.3.1.4
ION1	Card reader	BCD	I	5	Input data deck to ION1	3.3.1.8
ION1	Line printer	BCD	O	6	Output listing from ION1	3.3.1.7

3.3.1.1 Ionospheric Coefficient Tape

There are 36 fixed length records on the tape followed by a double end-of-file. Each record contains, in 3848 words, the generalized 10-day f_oF2 and 30-day $M(3000)F2$ coefficients to be used for one third of one month. The 36 records are in time sequence and valid for the periods January 1-10, January 11-20, January 21-31, February 1-10, February 11-20, February 21-28 or 29, . . . , December 21-31.

<u>Word</u>	<u>Mode</u>	<u>Fortran Name</u>	<u>Description</u>
1	Integer	LOND	=(month*100+day), first date for which coefficients are valid
2	Integer	LONDY	=(month*100+day), last date for which coefficients are valid
3-2966	Real	WCOEF	Array of dimension 3*13*76 of generalized f_oF2 coefficients valid for the time interval specified by words 1 and 2
2967-3407	Real	UM	Array of dimension 9*49 of $M(3000)F2$ coefficients valid for a 12-month running average of the sunspot number = 0, and to be used for the time interval specified by words 1 and 2
3408-3848	Real	UM1	Array of dimension 9*49 of $M(3000)F2$ coefficients valid for a 12-month running average of the sunspot number = 100, and to be used for the time interval specified by words 1 and 2

The formation of the specific coefficient sets for f_oF2 and $M(3000)F2$ from the general coefficients is discussed under 3.2.1.1, CPC No. 2.

3.3.1.2 Line Printer Output Listing from ION

The typical output format of the results from ION is shown for some test cases under 4.1. In addition, the following error messages may occur:

Printed in PROGRAM ION, "Error in solar input data for year . . and month = . ." where upon the computer run is terminated.

Printed in PROGRAM ION, "Remaining update data not used"; if more than eight update conditions are supplied, the first eight are used, the remaining cards are skipped over.

Printed in SUBROUTINE REFRAC, "Coefficients not found on tape for year, month, day =", where upon control is transferred to PROGRAM ION to proceed with the next data case.

Printed in SUBROUTINE BETA, "Ray is reflected at ionosphere or near reflection condition, elevation angle correction is not computed," where upon control is transferred to SUBROUTINE REFRAC to proceed normal with the remaining computations.

3.3.1.3 Input Data Card Deck to ION

The input card deck to ION specifies the output and update options and it defines the evaluation and update conditions and the required solar data. The set up procedure for the card deck is described below followed by a description of the solar data and by the detailed card type and format information.

a) Procedure to Set Up Card Deck for ION

**** Specify options ****

Card type 1 : ISEL(1) - ISEL(5), output options for ionospheric profile and refraction corrections. =0 wanted, =1 not wanted.

Card type 2 : IUPDT, IDRDAV, update option and output option for correction to range differencing. =0 not wanted, =1 wanted. If =1, additional input data is required, cards 9 and 10 and/or card 11.

**** Specify evaluation condition ****

Card type 3 : FS, FLAT, FLON, station information: wave frequency, latitude and longitude. If refraction corrections are not desired, FS is not used and should be left blank or set =0 or positive.

Card type 4 : ELEV, AZ, HS, EDOT, HDOT, satellite information: elevation angle, azimuth, height, elevation rate, altitude rate. If the instantaneous range rate correction is not desired, EDOT and HDOT are not used and should be left blank or set to any value.

Card type 5 : IYR, MON, IDAY, TIME, time information: year, month, day, time.

**** Specify solar data ****

**** If the year and month of this condition are the same as the year and month of the previous condition, skip cards 6, 7, 8.**

Card type 6 : IYR, MON, FLX(1)-FLX(16), date and daily values of observed, solar flux for the first 16 days of the month. If future predictions are to be evaluated, leave array FLX blank.

Card type 7 : IYR, MON, FLX(17)-FLX(31), date and daily values of observed solar flux for the latter part of the month. If there are less than 31 days to the month, the additional spaces are normally left blank.

Card type 8 : IYR, MON, SIS, SIF, date and 12-month running average of sunspot number and solar flux.

Preparation of solar data is discussed under b).

**** Specify update data ****

**** If update is not desired, IUPDT=0 on card 2, skip cards 9 and 10.**

Card type 9 : NUPDT, number of observation conditions to be used for updating the predictions for the evaluation condition.
Maximum = 8.

**** If update is not desired for this particular evaluation condition, NUPDT=0, skip card 10.**

Card type 10 : ULAT, ULON, ULEV, UZIM, UT, OBS, ITYPE, update data: latitude, longitude of observation station, elevation and azimuth of observation, observation time, value of measurement and type. When the observation is critical frequency set elevation to 90° and azimuth to 0°. For vertical and angular content use the appropriate angles.

**** Repeat card 10 until all NUPDT conditions are defined.**

**** Specify additional data for range differencing ****

**** If corrections to range rate by differencing technique are not desired, IDRDAV = 0, skip card 11.**

Card type 11 : ELEV, AZ, HS, TIME, satellite information, elevation, azimuth, and height and time information for the second observation used for the range differencing.

**** Repeat cards 3 through 11 for any number of conditions desired.**

**** Terminate with card 3 containing a negative value for the wave frequency FS.**

b) Preparation of Solar Data

The solar data can be extracted from the "Solar-Geophysical Data" monthly publications, issued by NOAA, Boulder, Colorado.

The daily values of solar flux are to be copied from the table "Daily Solar Indices" (normally page 7) under the column "Observed Flux Ottawa 2800" MHz (corresponds to 10.7 cm wavelength). If future predictions are to be evaluated and therefore no measurements available, the daily flux values required on card with the appropriate year and month are to be left blank. The program automatically checks for this condition and inserts the best estimate for the daily flux values which is the 12-month running average of the solar flux.

The 12-month running average $I_{12,j}$ for month j of a solar index I with a mean value \bar{I}_k for month k is defined as,

$$I_{12,j} = \frac{1}{12} \left(\frac{\bar{I}_{j-6} + \bar{I}_{j+6}}{2} + \sum_{i=-5}^{+5} \bar{I}_{j+i} \right)$$

The monthly means of the index for the month under consideration, for 1 through 5 month past and prior and half the value of the monthly mean for 6 months past and prior are added and divided by 12, yielding an average over 12 months centered around the specified month. The 12-month running average (=smoothed) of the sunspot numbers $S_{12,j}$ for month j are listed in the "Solar Geophysical Data" publication (normally page 9) in table "Smoothed Observed and Predicted Sunspot Numbers" and are to be used for past as well as future evaluations.

The 12-month running average of the solar flux is computed from the accumulated monthly means using the formula above. The monthly means are listed along with the daily values of solar flux. If not enough advance data is available to form the 12-month running average, that value can be approximated with a 11.5, 10.5 or 9.5-month running average;

$$\text{approx. } F_{12,j} = F_{12.5-k,j} = \frac{1}{12.5-k} \left(\frac{\bar{F}_{j-6}}{2} + \sum_{i=-5}^{6-k} \bar{F}_{j+i} \right), \quad k = 1, 2, \text{ or } 3.$$

If not even enough data is available to form a 9.5-month running average, an estimate of the 12-month running average of the solar flux can be derived from the 12-month running average of the sunspot number for which tabulated predictions are available. The relationship between solar flux and sunspot number was arrived at by Stewart and Leftin, Reference 9.

$$\text{approx. } F_{12,j} = 63.75 + 0.728 \times S_{12,j} + 0.00089 \times S_{12,j}^2.$$

The attached tables contain the final 12-month running averages for sunspot number and solar flux from 1960 on and the monthly means for solar flux from 1970 on.

Table 1. 12-Month Running Average of the Zurich Relative Sunspot Number

	<u>1960</u>	<u>1961</u>	<u>1962</u>	<u>1963</u>	<u>1964</u>	<u>1965</u>	<u>1966</u>	<u>1967</u>	<u>1968</u>	<u>1969</u>
Jan.	128.9	80.2	45.2	29.4	19.5	11.7	27.7	75.0	102.6	110.0
Feb.	125.0	74.8	41.8	29.8	17.8	12.0	31.3	78.8	102.9	109.6
Mar.	121.6	68.8	39.8	29.7	15.4	12.5	34.5	82.2	104.7	108.0
Apr.	119.6	64.3	39.4	29.0	12.7	13.6	37.4	84.6	107.2	106.4
May	117.0	60.1	39.2	28.7	10.8	14.6	40.7	87.5	107.6	106.2
June	113.9	55.8	38.3	28.2	10.2	15.0	44.7	91.3	106.6	106.1
July	108.6	53.1	36.8	27.7	10.3	15.5	50.3	94.1	105.2	105.8
Aug.	102.4	52.5	34.9	27.2	10.2	16.4	56.6	95.3	104.8	106.4
Sept.	97.9	52.3	32.7	26.9	9.9	17.4	63.1	95.3	107.0	105.4
Oct.	93.3	51.4	30.8	26.0	9.6	19.7	67.6	95.0	109.9	104.1
Nov.	87.9	50.5	30.0	23.8	10.1	22.3	70.2	97.1	110.6	104.6
Dec.	83.7	48.7	29.8	21.3	11.0	24.5	72.7	100.6	110.1	104.9

	<u>1970</u>	<u>1971</u>	<u>1972</u>
Jan.	105.6	80.4	70.8
Feb.	106.0	77.8	71.2
Mar.	106.2	74.4	72.4
Apr.	106.1	70.9	73.4
May	105.8	68.1	72.9
June	105.3	66.7	70.5
July	103.8	65.5	68.1
Aug.	101.0	65.0	65.4
Sept.	97.2	66.4	62.0
Oct.	93.9	67.1	60.3
Nov.	89.4	67.6	58.5
Dec.	84.1	69.9	54.8

Table 2. 12-Month Running Average of the Solar Flux at 10.7 cm Wavelength (Ottawa)

	<u>1960</u>	<u>1961</u>	<u>1962</u>	<u>1963</u>	<u>1964</u>	<u>1965</u>	<u>1966</u>	<u>1967</u>	<u>1968</u>	<u>1969</u>
Jan.	178.7	128.9	97.9	81.8	76.4	73.8	85.7	128.1	150.0	150.2
Feb.	174.6	124.1	95.2	81.8	75.5	74.4	88.4	131.5	149.4	150.2
Mar.	170.8	119.1	93.1	81.8	74.4	74.9	91.2	134.3	149.3	150.1
Apr.	168.6	115.1	91.7	81.5	73.3	75.4	93.8	136.3	150.4	150.0
May	166.2	110.8	91.1	81.2	72.5	75.8	96.5	138.8	150.8	150.8
June	162.9	106.6	90.4	81.0	72.2	76.0	100.1	141.7	149.9	151.4
July	157.8	103.7	89.2	80.6	72.3	76.4	104.6	145.0	147.8	151.4
Aug.	151.8	102.4	87.7	80.3	72.4	77.2	109.7	147.8	145.5	152.5
Sept.	147.4	102.0	85.8	80.1	72.2	78.3	115.3	148.2	146.0	152.8
Oct.	143.1	101.5	84.2	79.8	72.1	80.0	119.6	147.4	148.3	152.5
Nov.	137.9	101.1	83.1	78.7	72.5	81.9	122.8	147.9	149.0	153.7
Dec.	133.1	100.2	82.3	77.3	73.2	83.6	125.7	149.3	149.4	154.4
	<u>1970</u>	<u>1971</u>	<u>1972</u>							
Jan.	154.7	135.0	120.5							
Feb.	155.1	132.5	121.2							
Mar.	155.2	129.9	122.1							
Apr.	155.2	126.6	123.1							
May	155.2	122.8	123.2							
June	155.8	119.7	121.7							
July	156.3	116.5	120.3							
Aug.	155.0	114.7	118.0							
Sept.	151.4	115.5	115.0							
Oct.	147.6	116.1	113.5							
Nov.	143.3	116.7	111.8							
Dec.	138.6	118.9	108.6							

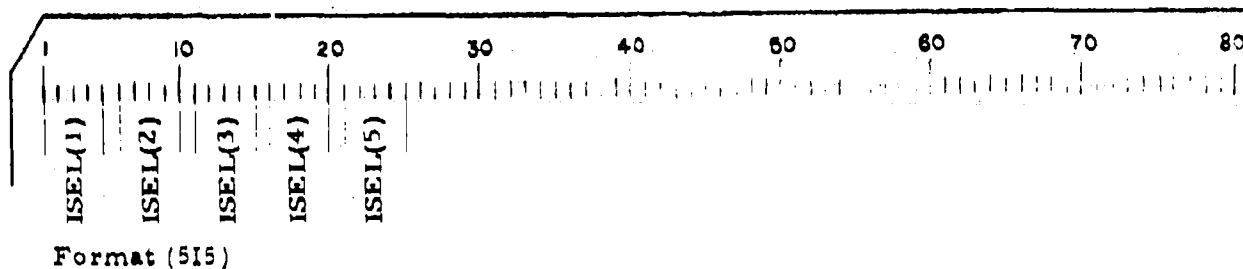
Table 3. Monthly Mean of the Solar Flux

	<u>1970</u>	<u>1971</u>	<u>1972</u>	<u>1973</u>
January	158.3	162.6	114.8	102.2
February	175.4	137.8	141.8	98.7
March	158.4	111.9	128.5	100.4
April	162.0	116.7	112.9	105.0
May	168.4	109.9	129.6	97.0
June	154.9	101.7	135.4	91.2
July	152.0	117.4	122.0	
August	138.2	114.1	125.7	
September	143.2	104.0	113.7	
October	148.3	107.2	121.1	
November	162.0	114.0	101.6	
December	152.8	124.5	102.9	

c) Card Type and Format Information

Card Type 1

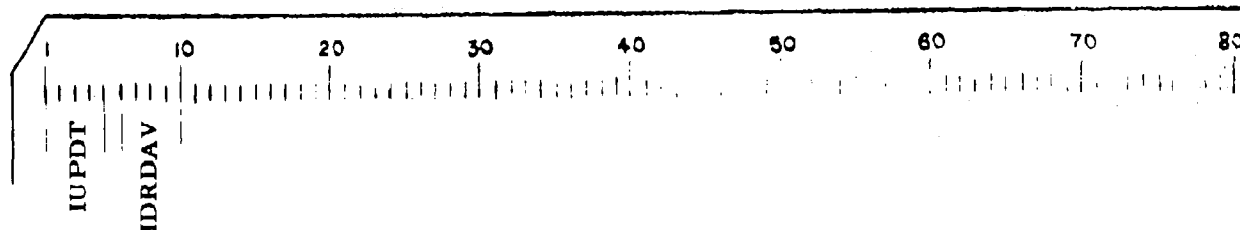
Output options for ionospheric profile and refraction corrections



Word No.	Program Variable	Units	Format	Column	Description
1	ISEL(1)	--	15	1-5	= 0 profile parameters and total content desired, =1 not desired
2	ISEL(2)	--	15	6-10	= 0 profile plot desired, =1 not desired
3	ISEL(3)	--	15	11-15	= 0 elevation angle correction desired, = 1 not desired
4	ISEL(4)	--	15	16-20	= 0 range correction desired, = 1 not desired
5	ISEL(5)	--	15	21-25	= 0 instantaneous range rate correction desired, = 1 not desired
					If words 1-5 above are all =1, only the critical frequency and corresponding height will be completed.

Card Type 2

Update option and output option for correction to range differencing



Format (215)

Word No.	Program Variable	Units	Format	Column	Description
1	IUPDT	--	I 5	1-5	Update flag: = 0 no update for any of following evaluation conditions, = 1 update in some or all of the following evaluation conditions
2	IDRDAV	--	I 5	6-10	Output option: = 0 correction to range rate obtained by differencing technique is not requested, = 1 desired

Card Type 3

Station data for evaluation condition

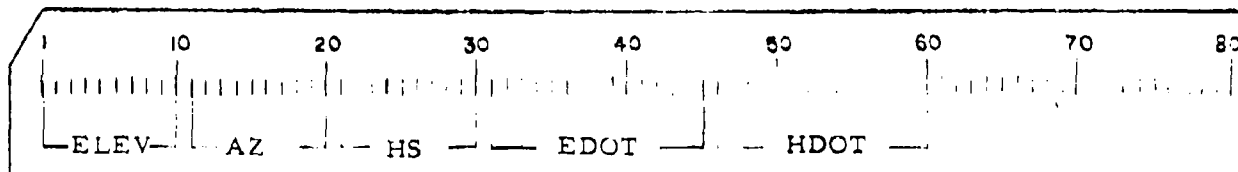
	10	20	30	40	50	60	70	80
FS	FLAT		FLON					

Format (F 10.4, 2F 10.5)

Word No.	Program Variable	Units	Format	Column	Description
1	FS	MHz	F10.4	1-10	Transmission frequency
2	FLAT	degrees	F10.5	11-20	Station latitude
3	FLON	degrees	F10.5	21-30	Station longitude (positive east, 0-360 degrees)

Card Type 4

Satellite data for evaluation condition

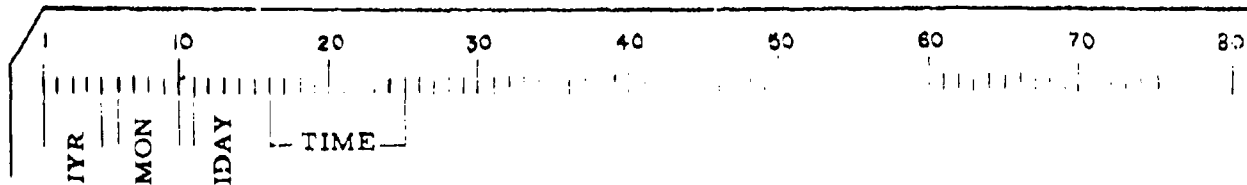


Format (2 F10.6, F10.0, 2D15.8)

Word No.	Program Variable	Units	Format	Column	Description
1	ELEV	degrees	F10.6	1-10	Elevation angle to satellite
2	AZ	degrees	F10.6	11-20	Azimuth angle
3	HS	km	F10.0	21-30	Height of satellite above surface of earth
4	EDOT	rad/sec	D15.8	31-45	Elevation rate
5	HDOT	m/sec	D15.8	46-60	Altitude rate

Card Type 5

Time data for evaluation condition

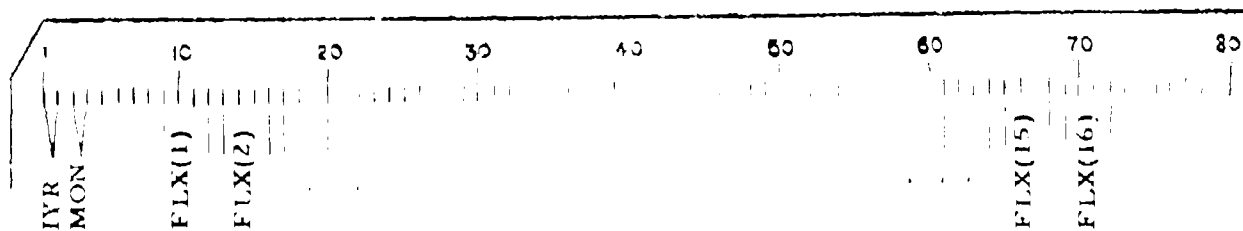


Format (315, F10.7)

Word No.	Program Variable	Units	Format	Column	Description
1	IYR	--	I 5	1-5	Year (last 2 digits)
2	MON	--	I 5	6-10	Month (=1 through 12)
3	IDAY	--	I 5	11-15	Day (=1 through 31)
4	TIME	hours	F10.7	16-25	Universal time

Card Type 6

Daily solar flux data for first part of month

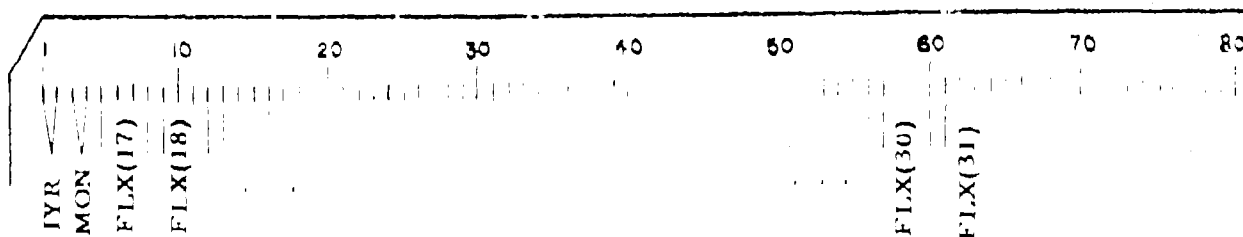


Format (2I2, 4x, 16I4)

Word No.	Program Variable	Units	Format	Column	Description
1	IYR	--	1 2	1-2	Year (last 2 digits)
2	MON	--	1 2	3-4	Month (=1 through 12)
3	FLX(1)	-	1 4	9-12	Daily solar flux x10 for day 1 of month
4	FLX(2)	--	1 4	13-16	Daily solar flux x10 for day 2 of month
.
.
.
18	FLX(16)	--	1 4	69-72	Daily solar flux x10 for day 16 of the month

Card Type 7

Daily solar flux data for second part of month

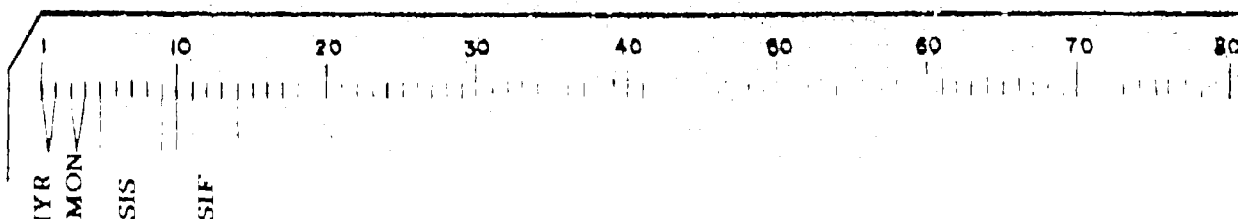


Format (2I2, 15I4)

Word No.	Program Variable	Units	Format	Column	Description
1	IYR	--	I 2	1-2	Year (last 2 digits)
2	MON	--	I 2	3-4	Month (= 1 through 12)
3	FLX(17)	--	I 4	5-8	Daily solar flux x 10 for day 17 of month
4	FLX(18)	--	I 4	9-12	Daily solar flux x 10 for day 18 of month
...
17	FLX(31)	-	I 4	61-64	Daily solar flux x 10 for day 31 of month; if the month has less than 31 days, the spare locations are left blank

Card Type 8

Final or predicted 12-month running averages of sunspot number and solar flux

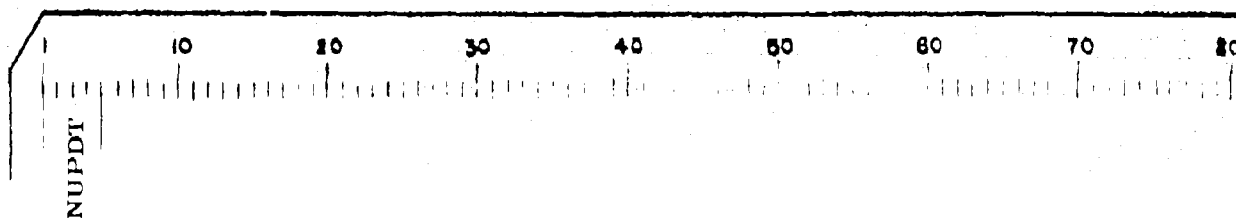


Format (212, 215)

Word No.	Program Variable	Units	Format	Column	Description
1	IYR	--	1 2	1-2	Year (last two digits)
2	MON	--	1 2	3-4	Month (= 1 through 12)
3	SIS	--	1 5	5-9	12-month running average of sunspot number x 10
4	SIF	--	1 5	10-14	12-month running average of solar flux x 10

Card Type 9

Update control constant

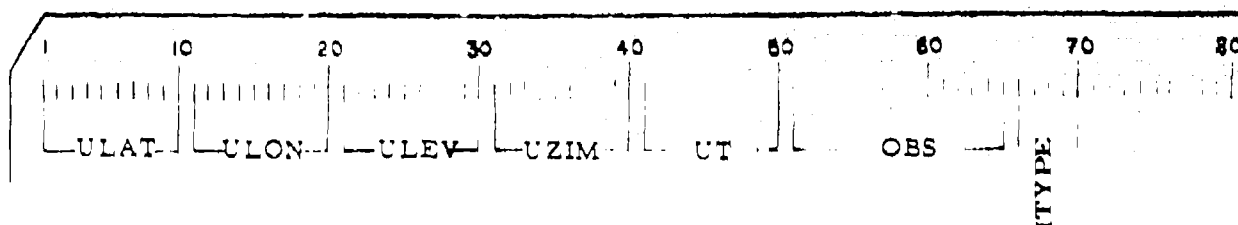


Format (1 5)

Word No.	Program Variable	Units	Format	Column	Description
1	NUPDT	-	1 5	1-5	Number of update conditions, maximum = 8

Card Type 10

Update data condition



Format (2F10.5, 2F10.6, F10.7, D15.8, I 5)

Word No.	Program Variable	Units	Format	Column	Description
1	ULAT	degrees	F10.5	1-10	Latitude of update station
2	ULON	degrees	F10.5	11-20	Longitude of update station (positive east, 0-360 degrees)
3	ULEV	degrees	F10.6	21-30	Elevation angle of observation (=90 for f_oF2 data, = elevation to satellite for vertical and angular electron content)
4	UZIM	degrees	F10.6	31-40	Azimuth angle of observation
5	UT	hours	F10.7	41-50	Universal time of observation
6	OBS	MHz or e/m^2	D15.8	51-65	Observation to be used for update
7	ITYPE	--	I 5	66-70	Observation flag, = 1 for f_oF2 , = 2 for vertical electron content, = 3 angular electron content

Card Type 11

Satellite and time information for second observation used for range differencing

1	10	20	30	40	50	60	70	80
ELEV		AZ	HS	TIME				

Format (2F10.6, F10.0, F10.7)

Word No.	Program Variable	Units	Format	Column	Description
1	ELEV	degrees	F10.6	1-10	Elevation angle to satellite
2	AZ	degrees	F10.6	11-20	Azimuth angle
3	HS	km	F10.0	21-30	Height of satellite above surface of earth
4	TIME	hours	F10.7	31-40	Universal time

3.3.1.4 Ionospheric Data File with f_oF2 - h_p Tables

The file with f_oF2 - h_p tables is generated in PROGRAM TABGEN for use in the alternate ionospheric version PROGRAM ION1. It consists of fixed length records, as many as were generated in PROGRAM TABGEN, terminated by a single end-of-file. Each record contains, in 354 words, the date, the station position, the daily solar flux and values of critical frequency f_oF2 and corresponding height h_p . The values for f_oF2 and h_p are tabulated for the given date for 14 different times at each location of a 25 point pattern around the station which covers the ionosphere visible from that station.

<u>Word</u>	<u>Mode</u>	<u>Fortran Name</u>	<u>Description</u>
1	Integer	IYMD	Date: year $\times 10000 + \text{month} \times 100 + \text{day}$
2	Real	FLAT	Latitude of station in radians
3	Real	FLON	Longitude of station in radians
4	Real	FLUX	Value of daily solar flux (if the daily flux is greater than 130, the limit value of 130 is substituted)
5-354	Integer	IFH	Array of dimension 14×25 containing packed integer tabulated values for f_oF2 and h_p for 14 local time hours at each location of the 25 point pattern around the station. Each integer has 8 digits, the first 4 digits define h_p in units of $\frac{1}{10}$ km, the last 4 digits give f_oF2 in units of $\frac{1}{100}$ MHz.

3.3.1.5 Output Listing from TABGEN

The only line printer output from TABGEN is the printout of the input data conditions. In addition, the following error messages may occur:

Printed in PROGRAM TABGEN, "Error in solar input data for year = . . and month = . .", where upon the computer run is terminated.

Printed in PROGRAM TABGEN, "Coefficients not found on tape for year, month, day =", where upon the computer run is terminated.

3.3.1.6 Input Data Deck to TABGEN

The input to TABGEN consists of card type 12, shown on the next page containing date and station information and of card types 6, 7, 8 as described under 3.3.1.3 c) specifying the solar data.

Card type 12 : IYR, MON, IDAY, FLAT, FLON, year, month, day, latitude and longitude.

** If the year and month of this condition are the same as the year and month of the previous condition, skip cards 6, 7, 8.

Card type 6 : IYR, MON, FLX(1)-FLX(16), date and daily values of observed solar flux for the first 16 days of the month. If future predictions are to be evaluated, leave array FLX blank.

Card type 7 : IYR, MON, FLX(17)-FLX(31), date and daily values of observed solar flux for the latter part of the month. If there are less than 31 days to the month, the additional spaces are normally left blank.

Card type 8 : IYR, MON, SIS, SIF, date and 12-month running average of sunspot number and solar flux.

Preparation of the solar data is discussed under 3.3.1.3 b).

** Repeat cards 12, 6, 7, 8 for any number of conditions desired.

** Terminate with card 12 containing a zero or negative value for the year IYR.

3.3.1.7 Output Listing from ION1

The typical output format of the results from ION1 is shown for some test cases under Section 4.1. In addition, the following error messages may occur:

Card Type 12

Date and station evaluation condition

1	10	20	30	40	50	60	70	80
IYR	MON	IDAY	FLAT	FLON				

Format (3I5, 2F10.5)

Word No.	Program Variable	Units	Format	Column	Description
1	IYR	--	1 5	1-5	Year (last 2 digits)
2	MON	--	1 5	6-10	Month (=1 through 12)
3	IDAY	--	1 5	11-15	Day (=1 through 31)
4	FLAT	degrees	F10.5	16-25	Station latitude
5	FLON	degrees	F10.5	26-35	Station longitude (positive east, 0-360 degrees)

Printed in SUBROUTINE REFRCL, "foF2-h, tables for this station and date not found in file," where upon control is transferred to PROGRAM ION1 to proceed with the next data case.

Printed in SUBROUTINE BETA, "Ray is reflected at ionosphere or near reflection condition, elevation angle correction is not computed," where upon control is transferred to SUBROUTINE REFRCL to proceed normal with the remaining computations.

3.3.1.8 Input Data Deck to ION1

The input data to ION1 involves only card types 3, 4, and 5 as they are described under 3.3.1.3 c) to specify the evaluation condition.

Card type 3 : FS, FLAT, FLON, station information: wave frequency, latitude and longitude. Set FS=0 or positive, if refraction corrections are not requested.

Card type 4 : ELEV, AZ, HS, EDOT, HDOT, satellite information: elevation angle, azimuth, height, elevation rate, altitude rate. If the instantaneous range rate correction is not desired, EDOT and HDOT are not used and can be left blank or set to any value.

Card type 5 : IYR, MON, IDAY, TIME, time information: year, month, day, time.

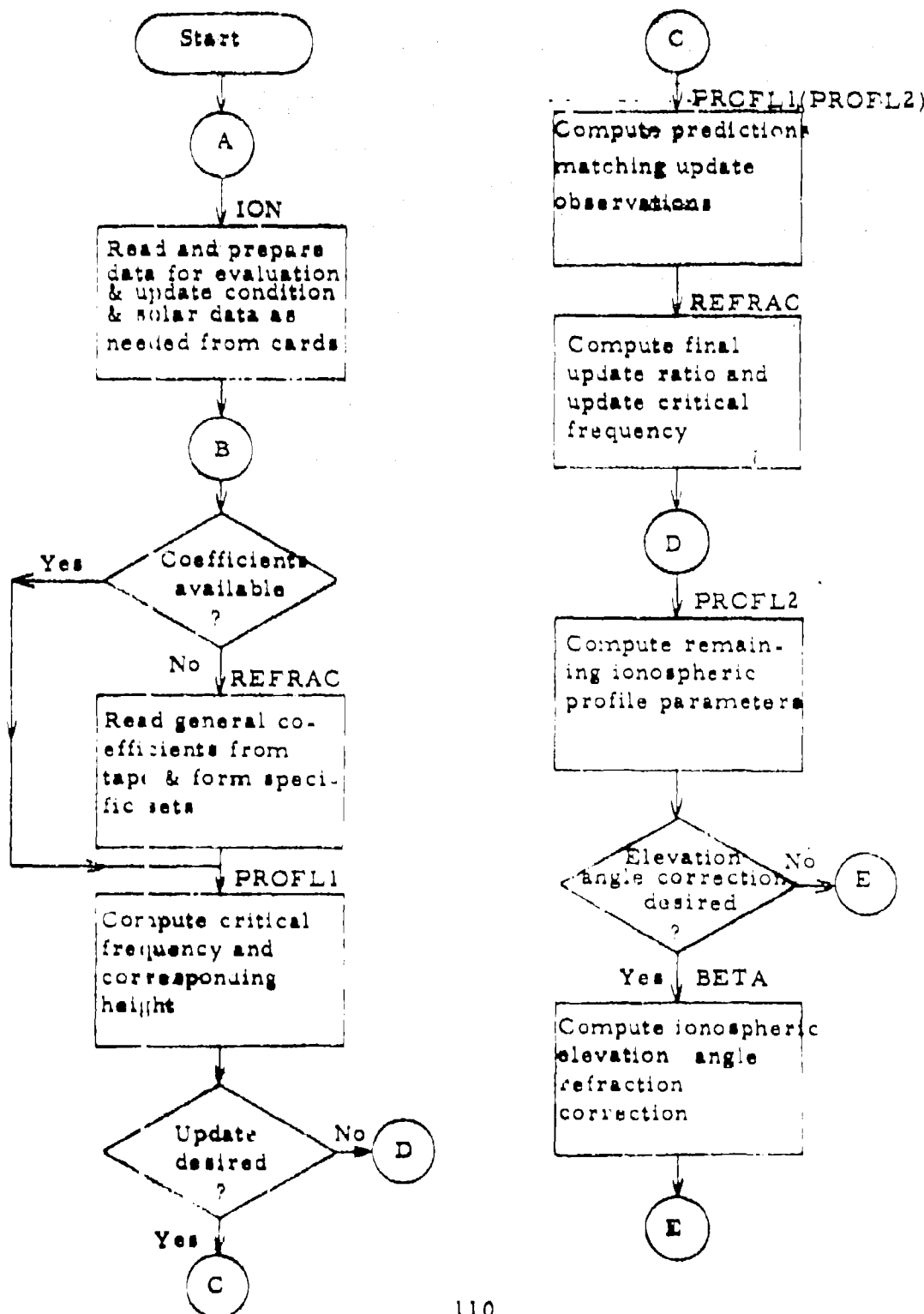
** Repeat cards 3 through 5 for any number of conditions desired.

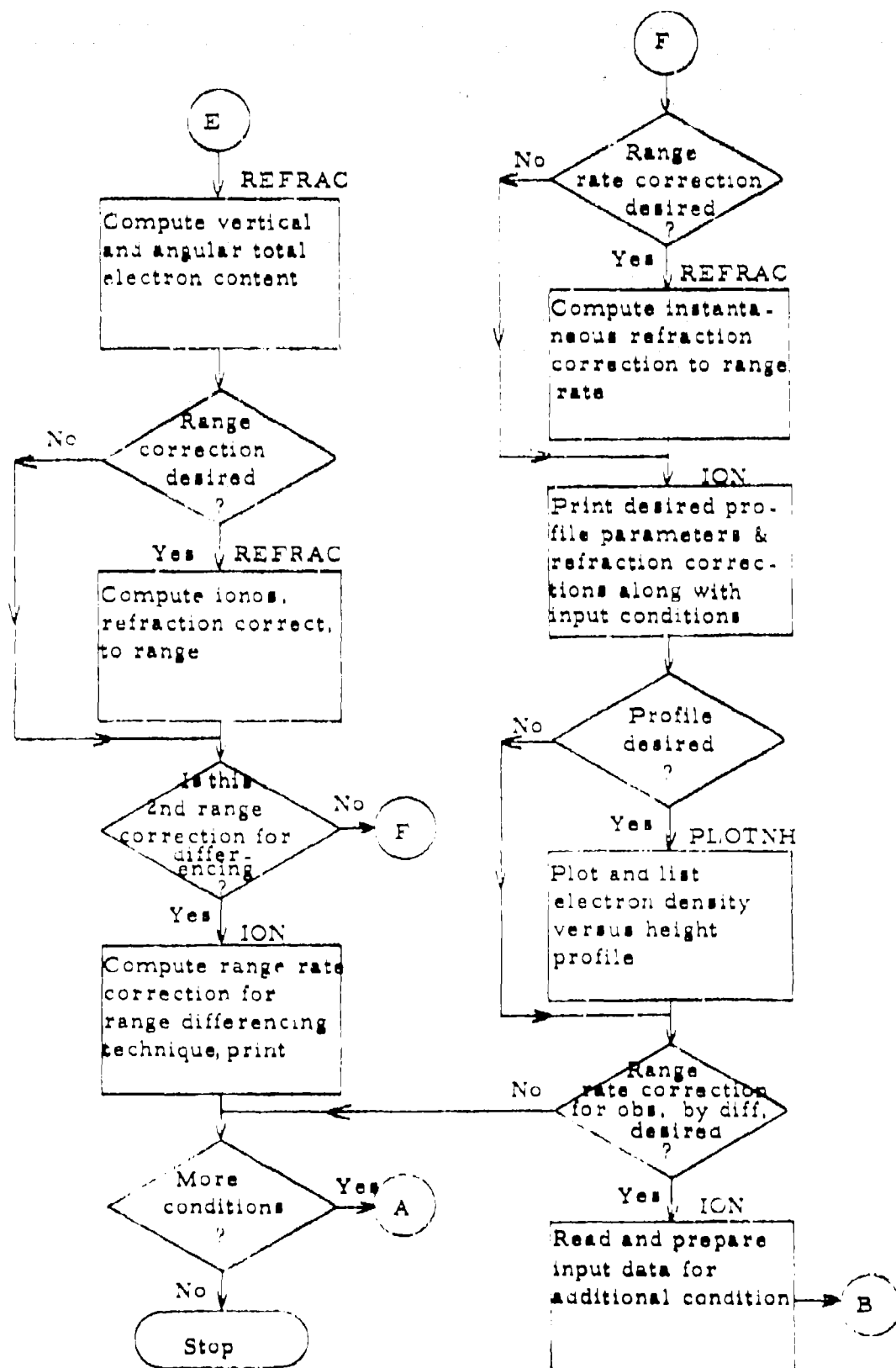
** Terminate with card 3 containing a negative value for the wave frequency FS.

3.4 Computer Program Functional Flow Diagram

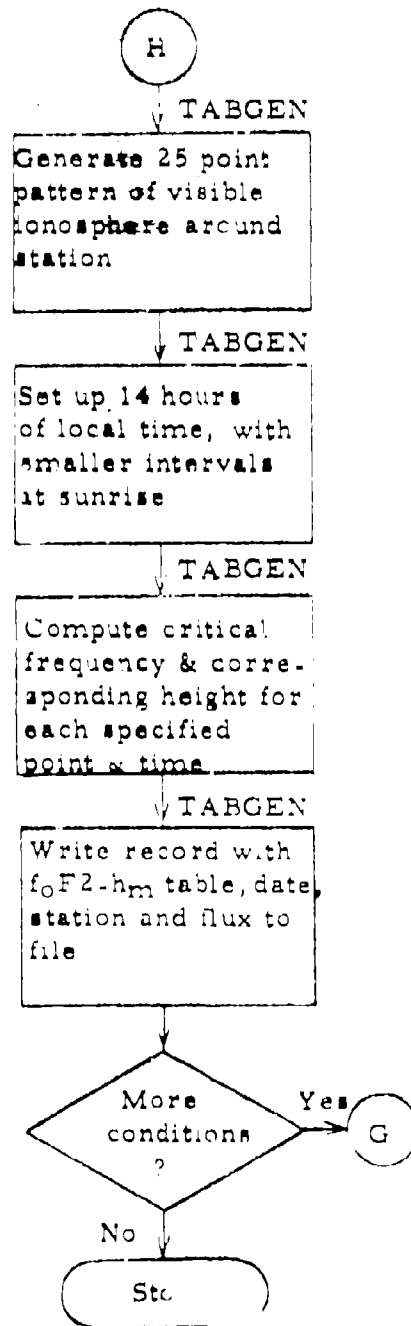
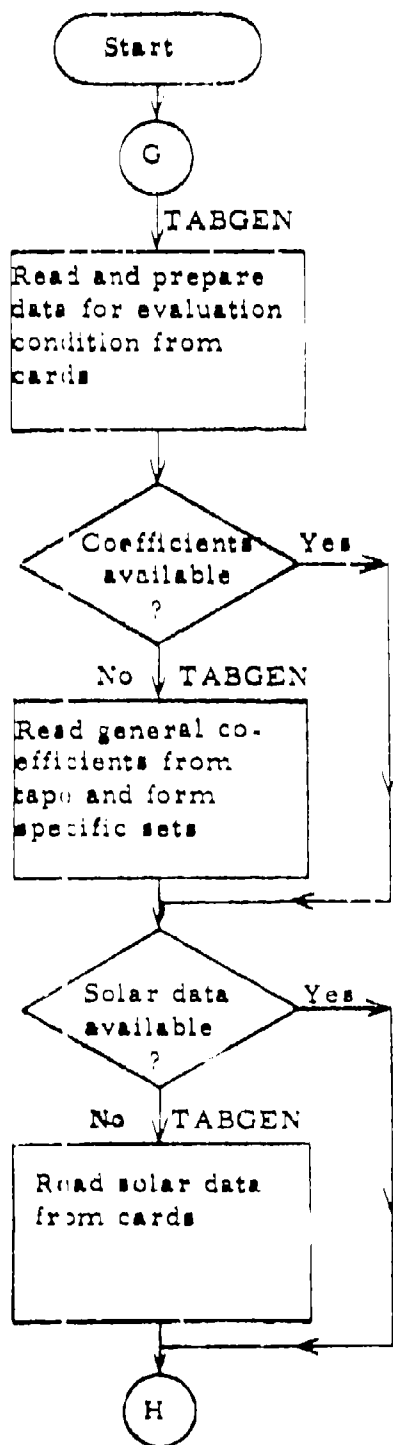
The functional flow diagram of the Bent Ionospheric Program ION is presented as well as the diagrams for the alternate version TABGEN-ION1. The labels to the right top of each block specify the program/subroutines that perform the function described in the block. Lower level flowcharts disclosing more details are listed under the individual computer program component descriptions in Section 3.2.1.2.

Functional Flow Diagram for ION

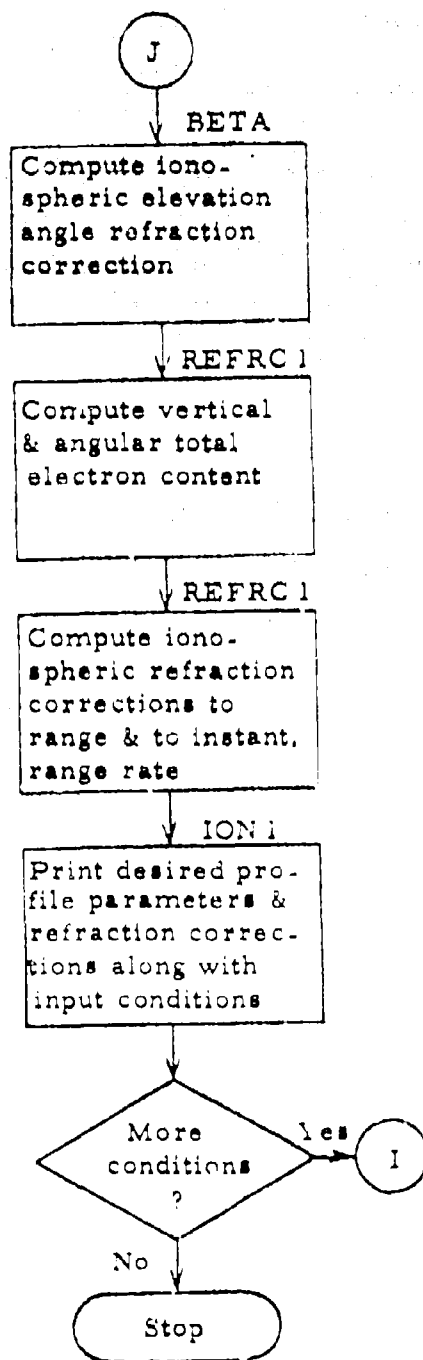
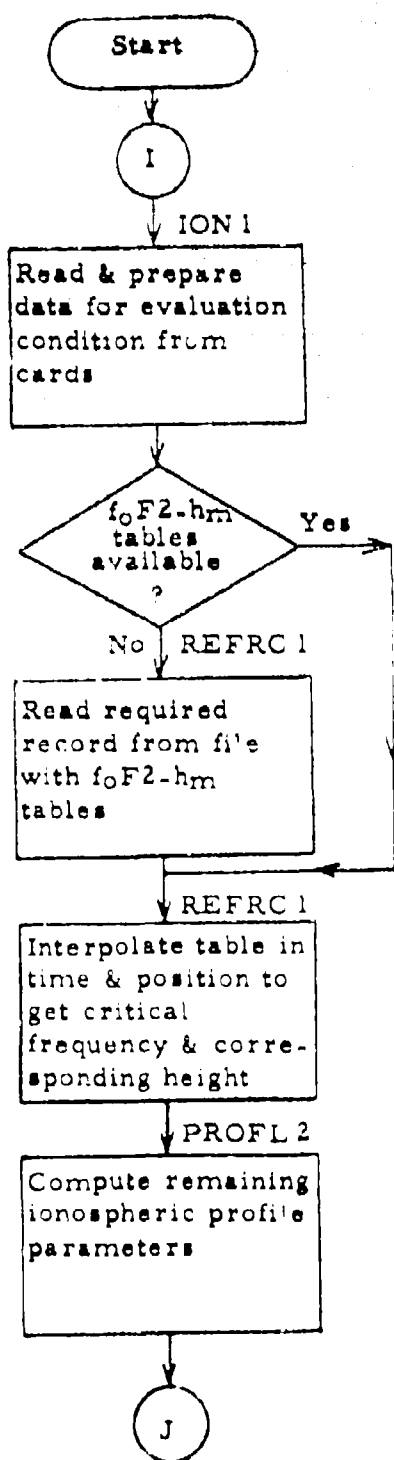




Functional Flow Diagram for TABGEN



Functional Flow Diagram for ION1



4.0 Quality Assurance

All aspects of the ionospheric model were tested thoroughly during and after the development phase and some of the results are shown in Section 6.2. The shape of the electron density versus height profile was compared with actual composite profiles compiled at NASA/GSFC and they were always in close agreement. The integrated electron content was compared extensively with the vertical electron content derived from Faraday rotation measurements. The results of this work performed for SAMSO, are described in Reference 2. The predictions alone accounted for 70 to 80% of the actual electron content and after updating with ionospheric observations, up to 90% of the ionosphere was estimated. The ionospheric refraction corrections were tested in orbit determination work performed at NASA/GSFC. The iterative least square reduction programs were run with and without ionospheric corrections and the final RMS values of the measurement residuals were greatly reduced by 30 to 75% upon use of ionospheric corrections.

After modifying the ionospheric program to its current form, a number of test cases were run and the results including all possible outputs were compared with results from previous runs before modifications. The same test cases listed under 4.1 should be checked out whenever the program is duplicated and transferred to another computer system to insure that all parts of the program are in working order.

4.1 Test Plan/Procedure

The following pages show a list of the input card deck and the corresponding printed output results for test cases 1 through 5 and a cross reference list in Table 4 of the various conditions tested. The five test cases evaluate the functions of the ionospheric program for various possibilities in latitude, longitude, local time, season, and solar activity effecting the ionospheric profile and therefore also electron content and refraction corrections. Each of the five test cases computes all possible output results; critical frequency

and corresponding height, the values of half thickness and the decay constants for the shape of the profile, the profile plot and list, vertical and angular electron content and refraction corrections to elevation angle, to range, to instantaneous range rate and to range differencing.

For the standard ionospheric PROGRAM ION the input is listed in Table 5 for all five test cases, and the output in Table 6. For the alternate version of the ionospheric program, the input and output of the preprocessor PROGRAM TABGEN are shown in Table 7 and the input and output of the reduction PROGRAM ION1 are given in Tables 8 and 9 respectively. Only test cases 1, 2, and 5 are presented for the alternate program since the update capability tested in cases 3 and 4 is not included in this version.

4.2 Other Quality Assurance Provisions

Whenever the program is reproduced for use on another system, the program card decks should be duplicated and verified. If the program is transferred to a system with compatible binary coding, the binary magnetic tape containing the ionospheric coefficients should be copied and verified. If the program is to be used on a computer with different binary word or record structure, the binary tape should be copied to a BCD tape and at the new location, transferred back onto a binary tape. Care should be taken that during the binary to BCD tape copy process no loss of significance will occur, which means the format (E17.11) is required for the general f_oF_2 coefficients and the format (E14.8) is required for the general $M(3000)F_2$ coefficients. The binary tape format is described under 3.3.1. When tape and card decks are available on the new system, the test runs described in 4.1 should be performed and the results compared with the output results in the tables for agreement.

Table 4. Cross Reference List of Conditions Examined in 5 Test Cases

Condition Tested	Case 1	Case 2	Case 3	Case 4	Case 5
Read coefficient data	yes	no	yes	no	yes
Read solar data	yes	no	yes	no	yes
Update with observations	no	no	single update	multiple update	no
Evaluate ionosphere for:					
Station latitude	low (-17°)	low (0°)	medium (35°)	medium (35°)	high (75°)
Station longitude	218°	355°	277°	277°	90°
Local time	evening (20 ^h)	morning (6 ^h)	noon (13 ^h)	noon (13 ^h)	night (1 ^h)
Season	summer (Aug)	summer (Aug)	autumn (Nov)	autumn (Nov)	winter (Feb)
Solar activity	high (Flux=181)	high (Flux=181)	medium (Flux=103)	medium (Flux=103)	low (Flux=79)
Elevation	low (5°)	med. high (60°)	med. low (31°)	med. low (31°)	high (90°)
Azimuth	180°	90°	298°	208°	350°
Height of satellite	med. (1000km)	low (500km)	high (200,000km)	high (200,000km)	med. (2000km)

Table 5. Input Card Deck to PROGRAM ION, for 5 Test Cases

[illegible]

Table 62. Output Results from PROGRAM ION for 5 Test Cases - Case 1

-- INPUT --

FREQUENCY= 140-0000 MHz, LATITUDE= -16-67000 DEG, LONGITUDE OF STATION= 218-00300 DEG
ELEVATION= 5-000000 DEG, AZIMUTH=140-000000 DEG, HEIGHT OF SATELLITE= 1000-0 KM, ELEVATION RATE= -.12870530E-02 RAD/SEC
YEAR=68, MONTH= 8, DAY=15, U-TIME= 6-00000000 HRS, ALTITUDE RATE= .00000000E 00 M/SEC
DAILY FLUX= 181-0, 12-MONTH RUNNING AVERAGE OF SOLAR FLUX= 145-5, OF SUNSPOT NUMBER= 104-8

-- OUTPUT --

HEIGHT AT MAXIMUM ELECTRON DENSITY Hm= 301-241 KM, CRITICAL FREQUENCY FOF2= 5-753 MHz
TOTAL INTERMEDIATE ELECTRON DENSITY VERTICAL Nm= .007057E 22 C/CM-2, ANGULAR MTA= .281039E 18 L/(MCM COLUMN)
HALF THICKNESS OF IONOSPHERIC SPHERICAL Ym= 100-480 KM, OF IONOSPHERIC PARABOLA Yp= 100-480 KM
DECAY CONSTANTS FOR IONOSPHERIC EXPONENTIAL LAYERS, LOWER K1= .075054E-05, MIDDLE K2= .53508E-05, UPPER K3= .34474E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE= .168130E 03 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE = .577850E 03 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE = -.661804E 00 M/SEC

Table 6b. Output Results from PROGRAM ION for 5 Test Cases - Case 1 (continued)

HEIGHT (KM)	VERSUS ELECTRON DENSITY (E/M ³)	HEIGHT VS. I.L. DENSITY
1000 +	-.5000 10	2000 ---
975 +	-.1040 11	1975 ---
950 +	-.1130 11	1950 ---
925 +	-.1240 11	1925 ---
900 +	-.1350 11	1900 ---
875 +	-.1470 11	1875 ---
850 +	-.1600 11	1850 ---
825 +	-.1750 11	1825 ---
800 +	-.1900 11	1800 ---
775 +	-.2120 11	1775 ---
750 +	-.2360 11	1750 ---
725 +	-.2780 11	1725 ---
700 +	-.3170 11	1700 ---
675 +	-.3630 11	1675 ---
650 +	-.4150 11	1650 ---
625 +	-.4740 11	1625 ---
600 +	-.5420 11	1600 ---
575 +	-.6190 11	1575 ---
550 +	-.7050 11	1550 ---
525 +	-.8140 11	1525 ---
500 +	-.1050 12	1500 ---
475 +	-.1270 12	1475 ---
450 +	-.1530 12	1450 ---
425 +	-.1850 12	1425 ---
400 +	-.2230 12	1400 ---
375 +	-.2680 12	1375 ---
350 +	-.3200 12	1350 ---
325 +	-.3780 12	1325 ---
300 +	-.4400 12	1300 ---
275 +	-.5060 12	1275 ---
250 +	-.5770 12	1250 ---
225 +	-.6530 11	1225 ---
200 +	-.7350 11	1200 ---
175 +	-.8230 00	1175 ---
150 +	-.9170 00	1150 ---
125 +	-.1010 00	1125 ---
100 +	-.1000 00	1100 ---
75 +	-.1000 00	1075 ---
50 +	-.1000 00	1050 ---
25 +	-.1000 00	1025 ---

1-E10 1-E11 1-E12
LOG SCALE - ELECTRON DENSITY (E/M³)

.. INPUT .. SECOND SATELLITE POSITION USED FOR RANGE DIFFERENCING
ELEVATION= 6.926255 DEG. AZIMUTH=180.000000 DEG. HEIGHT= 1000.0 KM UT TIME= 6.0002778 HRS
.. OUTPUT .. RANGE RATE CORRECTION FOR RANGE DIFFERENCING OVER 1.0001 SECONDS = .239271E 01 M/SEC

Table 6c. Output Results from PROGRAM ION for 5 Test Cases - Case 2

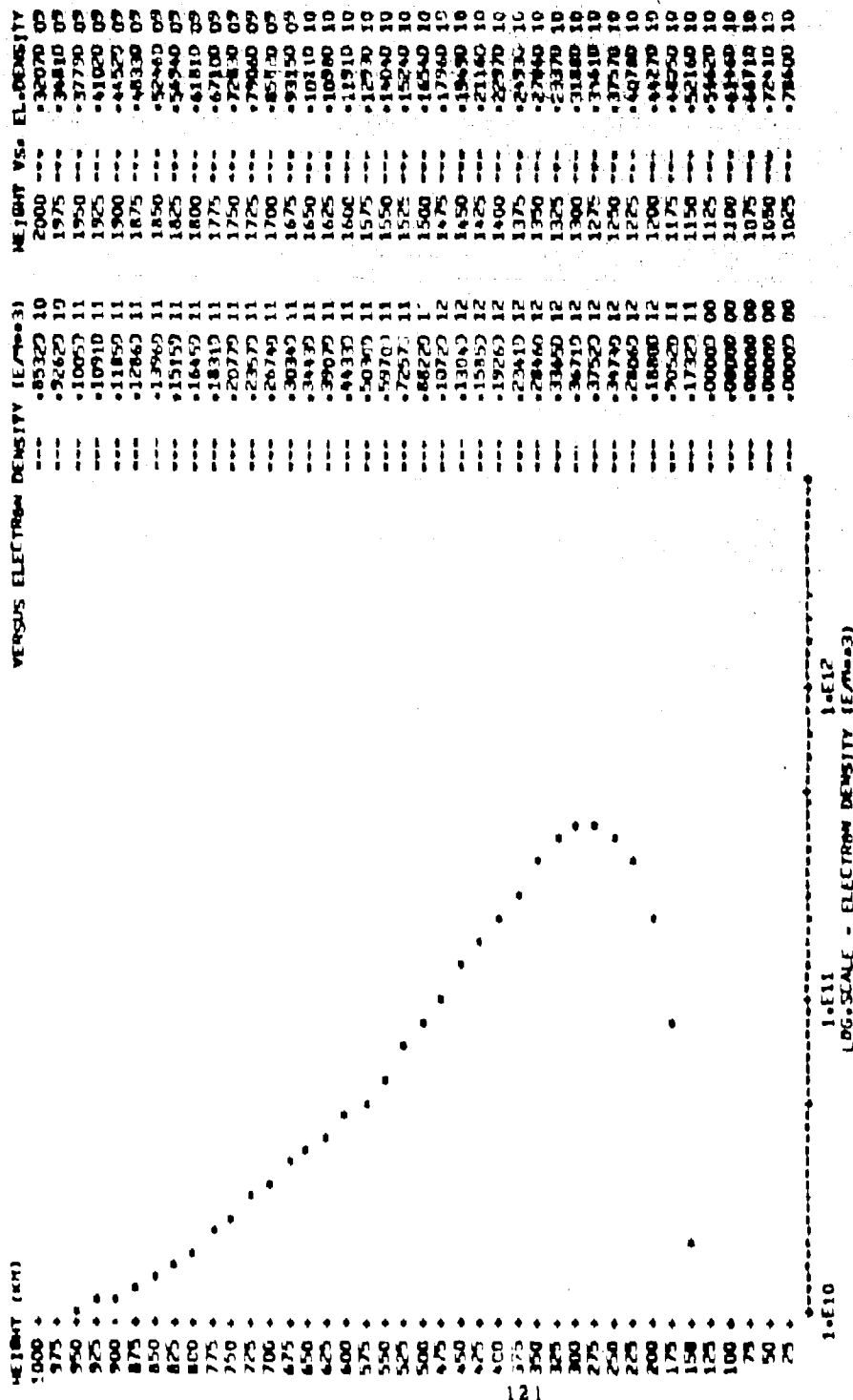
.. INPUT ..

FREQUENCY= 140.0000 MHz, LATITUDE= .00000 DEG, LONGITUDE OF STATION= 355.00000 DEG
ELEVATION= 60.00000 DEG, AZIMUTH= 90.00000 DEG, HEIGHT OF SATELLITE= 500.0 KM, ELEVATION RATE= .011740290E-01 RAD/SEC
YEAR=68, MONTH= 9, DAY=15, U-TIME= 6.0000000 HRS, ALTITUDE RATE= .00000000E 03 M/SEC
DAILY FLUX= 131.0, 12-MONTH RUNNING AVERAGE OF SOLAR FLUX= 105.5, SF SUNSPOT NUMBER= 104.8

.. OUTPUT ..

HEIGHT AT MAXIMUM ELECTRON DENSITY 140= 278.308 KM, CRITICAL FREQUENCY FOR 24 5=503.742
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL 140= .788791F 17 E/(MHz), ANGULAR WTA= .898624E 17 E/(MHz COLUMN)
WAVELENGTHS OF BOTTOMSIDE SIPARABOLA 140= 144.796 CM, SF TOPSIDE PARABOLA VT= 144.794 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1= .78084E-05, MIDDLE K2= .50534E-05, UPPER K3= .32812E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE= .348309E 02 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE 140= .139769E 03 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE 140= .0150375E 01 M/SEC

Table 6d. Output Results from PROGRAM ION for 5 Test Cases - Case 2 (continued)



.. INPUT .. SECOND SATELLITE POSITION USED FOR RANGE DIFFERENCING
 ELEVATION= 59.326185 DEG, AZIMUTH= 90.000000 DEG, HEIGHT= 500.4 KM, U-TIME= 6.0002778 HRS
 .. OUTPUT .. RANGE RATE CORRECTION FOR RANGE DIFFERENCING OVER 1.0001 SECONDS = -0.166296E 01 M/SEC

Table 6c. Output Results from PROGRAM ION for 5 Test Cases - Case 3

== INPUT ==

FREQUENCY= 140.0000 MHz, LATITUDE= 35.19887 DEG, LONGITUDE OF STATION= 277.12620 DEG
ELEVATION= 31.000000 DEG, AZIMUTH=208.000000 DEG, HEIGHT OF SATELLITE= 200000.0 KM, ELEVATION RATE= .14544410E-02 RAD/SEC
YEAR=71, MONTH=11, DAY= 8, UTIME=18.3000000 MRS, ALTITUDE RATE= .10000000E 03 M/SEC
DAILY FLUX= 102.7, 12-MONTH RUNNING AVERAGE OF SOLAR FLUX= 116.7, OF SUNSPOT NUMBERS= 67.6

UPDATE DATA

FLATE= 39.70200, LONG= 20.00000, ELEV= 3700.00000, ALT= 200000.00000 MRS, MAGNETIC FOF2= .58000000E 01 MHz

== OUTPUT ==

HEIGHT AT MAXIMUM ELECTRON DENSITY Hm= 270.152 KM, CRITICAL FREQUENCY FOF2= 3.896 MHz
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL Hm= 276187E 18 E/100M, ANGULAR VTA= .51937E 18 E/100M COLUMBI
HALF THICKNESS OF BOTTOMSIDE IONOSPHERE Ym= 143.516 KM, OF TOPSIDE PARABOLA Yt= 143.516 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1= .45656E-04 MIDDLE K2= .52204E-05, UPPER K3= .27230E-03 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE= .783457E 02 DEG OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE ° .104895E 04 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE ° .194324E 01 M/SEC

Table 6f. Output Results from PROGRAM ION for 5 Test Cases - Case 2 (continued)

WEIGHT (GM)	VERSUS ELECTRON DENSITY (E/CM ³)	WEIGHT VS. EL. DENSITY
1000	0.2333 11	2000 ---
975	0.2510 11	1975 ---
950	0.2701 11	1950 ---
925	0.2906 11	1925 ---
900	0.3127 11	1900 ---
875	0.3365 11	1875 ---
850	0.3621 11	1850 ---
825	0.3896 11	1825 ---
800	0.4182 11	1800 ---
775	0.4480 11	1775 ---
750	0.4790 11	1750 ---
725	0.5112 11	1725 ---
700	0.5446 11	1700 ---
675	0.5792 11	1675 ---
650	0.6150 11	1650 ---
625	0.6520 11	1625 ---
600	0.6902 12	1600 ---
575	0.7296 12	1575 ---
550	0.7702 12	1550 ---
525	0.8120 12	1525 ---
500	0.8550 12	1500 ---
475	0.8992 12	1475 ---
450	0.9446 12	1450 ---
425	0.9912 12	1425 ---
400	1.0390 12	1400 ---
375	1.0880 12	1375 ---
350	1.1382 12	1350 ---
325	1.1896 13	1325 ---
300	1.2422 13	1300 ---
275	1.2960 13	1275 ---
250	1.3510 13	1250 ---
225	1.4072 13	1225 ---
200	1.4646 12	1200 ---
175	1.5232 12	1175 ---
150	1.5830 11	1150 ---
125	1.6440 00	1125 ---
100	1.7062 00	1100 ---
75	1.7696 00	1075 ---
50	1.8342 01	1050 ---
25	1.9000 00	1025 ---

1.E10 1.E11 1.E12
LOG SCALE - ELECTRON DENSITY (E/CM³)

INPUT ** SECOND SATELLITE POSITION USED FOR RANGE DIFFERENCING
ELEVATION= 33.499473 DEG, AZIMUTH=208.000000 DEG, WEIGHT= 200083.0 KG, UTIME=18.308333 HRS
OUTPUT ** RANGE RATE CORRECTION FOR RANGE DIFFERENCING CYR 29.9999 SECONDS = 184114E 01 M/SEC

Table 6g. Output Results from PROGRAM ION for 5 Test Cases - Case 4

-- INPUT --

FREQUENCY= 140.0000 MHZ, LATITUDE= 35.19687 DEG, LONGITUDE OF STATION= 277.12420 DEG
ELEVATION= 31.000000 DEG, AZIMUTH=208.000000 DEG, WEIGHT OF SATELLITE= 200000.0 KG, ELEVATION RATE= .1654441DE-02 RAD/SEC
YEAR=72, MONTH=11, DAY= 8, UTIME=18.3000000 MRS, ALTITUDE RATE= .10000000E 03 "/SEC
DAILY FLUX= 102.7, 12-MONTH RUNNING AVERAGE OF SOLAR FLUX= 116.7, OF SUNSPOT NUMBER= 67.6

IONOSPHERIC DATA

11LAT= 37.90000, LONG= 285.50000, ELEV= 90.000000, AZIM= .000000 DEG, UT=19.000000 MRS, OBSERVED EFF= .10000000E 02 MHZ
21LAT= 40.00000, LONG= 270.00000, ELEV= 60.000000, AZIM=140.000000 DEG, UT=18.5000000 MRS, OBS-VERT-CONTENT= .30000000E 18 E/M2
31LAT= 40.00000, LONG= 270.00000, ELEV= 60.000000, AZIM=140.000000 DEG, UT=19.0000000 MRS, OBS-ANGEL-CONTENT= .65000000E 18 E/M2

-- OUTPUT --

HEIGHT AT MAXIMUM ELECTRON DENSITY KM= 274.152 KM, CRITICAL FREQUENCY FOF2= 10.217 MHZ
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL M30= .31217E 18 E/CM2, ANGULAR NTAP= .54789E 18 E/CM2 COLUMN
HALF THICKNESS OF BOTTOMSIDE BIPARABOLA YH= 142.298 KM, OF TOPSIDE PARABOLA YP= 142.298 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1= .84823E-05, MIDDLE K2= .52597E-05, UPPER K3= .29129E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE= .82449E 02 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE = .11265E 04 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE = .20881E 01 M/SEC

Table 6h. Output Results from PROGRAM ION for 5 Test Cases Case 4 (continued)

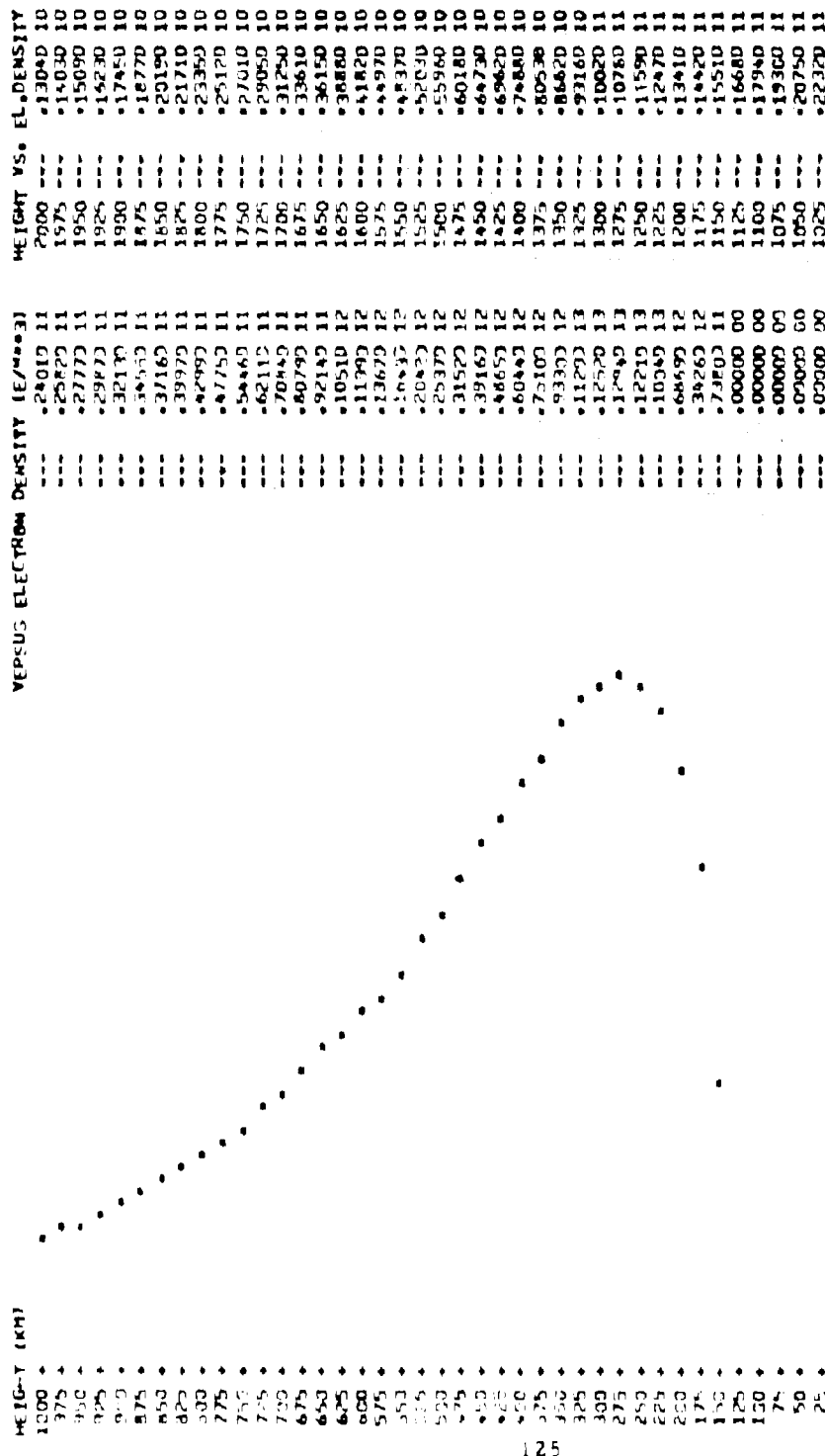


Table 61. Output Results from PROGRAM ION for 5 Test Cases - Case 5

.. INPUT ..

FREQ/SEC= 140.0000 MHZ, LATITUDE= 75.00000 DEG, LONGITUDE OF STATION= 90.00000 DEG
 ELEVATION= 90.00000 DEG, AZIMUTH=30.00000 DEG, HEIGHT OF SATELLITE= 2000.0 KM, ELEVATION RATE= .00000000E 00 RAD/SEC
 YEAR=65, MONTH=7, DAY=21, J-TIME=19.00000000 HRS, ALTITUDE RATE= .20000000E 03 M/SEC
 DAILY FLUX= 75.5, 12-CENTM RUNNING AVERAGE OF SOLAR FLUX= 75.5, OF SUNSPOT NUMBER= 17.8

.. OUTPUT ..

HEIGHT AT MAXIMUM ELECTRON DENSITY 170 310.608 KM, CRITICAL FREQUENCY FOF2= 2.743 MHZ
 TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL 170 .159534E 17 E/PCU, ANGULAR 170 .159534E 17 E/(M-1 COLUMN)
 HALF THICKNESS OF BOTTOMSIDE IONOSPHERE 170 87.237 KM, OF TOPSIDE PARABOLA 170 87.237 KM
 DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1= .79515E-05, UPPER K2= .86440E-05, UPPER K3= .23454E-05 1/M
 IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE= .434671E-02 SEC OF ARC
 IONOSPHERIC REFRACTION CORRECTION TO RANGE = .317741E 02 M
 IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE = -.106845E-03 M/SEC

Table 6j. Output Results from PROGRAM ION for S T Cases - Case 5 (continued)

HEIGHT (KM)	VERSUS ELECTRON DENSITY (E/M ³)	HEIGHT VS. EL. DENSITY
1000 +	--- 27130 10	2000 --- 25900 09
975 +	--- 28760 10	1975 --- 27250 09
950 +	--- 30500 10	1950 --- 28220 09
925 +	--- 32340 10	1925 --- 30980 09
900 +	--- 34300 10	1900 --- 32850 09
875 +	--- 36370 10	1875 --- 34830 09
850 +	--- 38560 10	1850 --- 36940 09
825 +	--- 40890 10	1825 --- 39170 09
800 +	--- 43360 10	1800 --- 41540 09
775 +	--- 45970 10	1775 --- 44040 09
750 +	--- 48720 10	1750 --- 46700 09
725 +	--- 51610 10	1725 --- 49520 09
700 +	--- 54640 10	1700 --- 52520 09
675 +	--- 57810 10	1675 --- 55690 09
650 +	--- 61120 10	1650 --- 59050 09
625 +	--- 64570 10	1625 --- 62620 09
600 +	--- 68160 10	1600 --- 66400 09
575 +	--- 71890 10	1575 --- 70410 09
550 +	--- 75760 10	1550 --- 74660 09
525 +	--- 79770 10	1525 --- 79170 09
500 +	--- 83920 10	1500 --- 83950 09
475 +	--- 88210 10	1475 --- 89020 09
450 +	--- 92640 10	1450 --- 94400 09
425 +	--- 97210 10	1425 --- 10010 10
400 +	--- 101920 10	1400 --- 10610 10
375 +	--- 106870 10	1375 --- 11260 10
350 +	--- 111960 10	1350 --- 11940 10
325 +	--- 117190 10	1325 --- 12640 10
300 +	--- 122560 10	1300 --- 13360 10
275 +	--- 128070 10	1275 --- 14120 10
250 +	--- 133720 10	1250 --- 14900 10
225 +	--- 139510 10	1225 --- 15700 10
200 +	--- 145440 10	1200 --- 16540 10
175 +	--- 151510 10	1175 --- 17420 10
150 +	--- 157720 10	1150 --- 18340 10
125 +	--- 164070 10	1125 --- 19300 10
100 +	--- 170560 10	1100 --- 20320 10
75 +	--- 177190 10	1075 --- 21400 10
50 +	--- 183960 10	1050 --- 22540 10
25 +	--- 190870 10	1025 --- 23840 10

.. INPUT .. SECOND SATELLITE POSITION USED FOR RANGE DIFFERENCING
 ELEVATION= 85.000000 DEG, AZIMUTH= 31.000000 DEG, HEIGHT= 2002.0 KM, U-TIME= 19.002778 HRS
 .. OUTPUT .. RANGE RATE CORRECTION FOR RANGE DIFFERENCING OVER 10.0001 SECONDS = -293044E-01 M/SEC

Table 8. Input Card Deck to PROGRAM IONI for 3 Test Cases

Test Case#		Card Type									
1	3	140-0000	-16.4700	214.00000	1000-	1.2870000E-03	0.0000000E 00				
	4	5-000000	180.000000	1000-	1.2870000E-03	0.0000000E 00					
	5	68	15 6.								
2	3	140-0000	0.00000	355.00000	500-	-0.1176000E 00	0.0000000E 02				
	4	60-000000	90.000000	500-							
	5	68	15 6.								
5	3	140-0000	75.00000	90.00000	2000-	0.0000000E 00	0.2000000E 03				
	4	90-000000	350.000000	2000-							
	5	64	2119.000000								
Termination	3	-1.									

Table 9. Output Results from PROGRAM ION1 for 3 Test Cases

Case 1

```

.. INPUT ..
FREQUENCY= 140.0000 MHz, LATITUDE= -16.67000 DEG, LONGITUDE OF STATION= 218.00000 DEG
ELEVATION= 5.000000 DEG, ALTITUDE= 140.000000 DEG, HEIGHT OF SATELLITE= 1000.0 KM,
YEAR=89, MONTH= 2, DAY=15, JTIME= 6.000000000 HRS,
ELEVATION RATE= -.12870530E-02 RAD/SEC
ALTITUDE RATE= .00000000E 00 M/SEC

.. OUTPUT ..
HEIGHT AT MAXIMUM ELECTRON DENSITY KM= 301.205 KM, CRITICAL FREQUENCY F0F2= 5.923 MHz
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL VT= .91550E 17 E/PMU, ANGULAR VIA= .296724E 18 E/PMU (COLUMN)
WAVE THICKNESS OF IONOSPHERE PARABOLA VM= 100.359 KM, OF TOPSIDE PARABOLA VT= 100.359 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER KL= .75429E-05, TIDOLE K2= .54027E-05, UPPER K3= .34452E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE= .177607E 03 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE = .610100E 03 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE = -.652977E 00 M/SEC

```

Case 2

```

.. INPUT ..
FREQUENCY= 140.0000 MHz, LATITUDE= .00000 DEG, LONGITUDE OF STATION= 345.00000 DEG
ELEVATION= 60.000000 DEG, ALTITUDE= 90.000000 DEG, HEIGHT OF SATELLITE= 500.0 KM,
YEAR=89, MONTH= 2, DAY=15, JTIME= 6.000000000 HRS,
ELEVATION RATE= -.11760250E-01 RAD/SEC
ALTITUDE RATE= .00000000E 03 M/SEC

.. OUTPUT ..
HEIGHT AT MAXIMUM ELECTRON DENSITY KM= 274.564 KM, CRITICAL FREQUENCY F0F2= 5.645 MHz
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL VT= .825688E 17 E/PMU, ANGULAR VIA= .940844E 17 E/PMU (COLUMN)
WAVE THICKNESS OF IONOSPHERE PARABOLA VM= 143.564 KM, OF TOPSIDE PARABOLA VT= 143.564 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER KL= .75010E-05, TIDOLE K2= .51073E-05, UPPER K3= .32647E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE= .385616E 02 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE = .193409E 03 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE = -.126402E 01 M/SEC

```

Case 5

```

.. INPUT ..
FREQUENCY= 140.0000 MHz, LATITUDE= 75.00000 DEG, LONGITUDE OF STATION= 90.00000 DEG
ELEVATION= 90.000000 DEG, ALTITUDE= 340.000000 DEG, HEIGHT OF SATELLITE= 2000.0 KM,
YEAR=89, MONTH= 2, DAY=15, JTIME= 10.000000000 HRS,
ELEVATION RATE= .00000000E 00 RAD/SEC
ALTITUDE RATE= .20000000E 03 M/SEC

.. OUTPUT ..
HEIGHT AT MAXIMUM ELECTRON DENSITY KM= 310.200 KM, CRITICAL FREQUENCY F0F2= 2.355 MHz
TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL VT= .156177E 17 E/PMU, ANGULAR VIA= .156177E 17 E/PMU (COLUMN)
WAVE THICKNESS OF IONOSPHERE PARABOLA VM= 87.363 KM, OF TOPSIDE PARABOLA VT= 87.363 KM
DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER KL= .70521E-05, TIDOLE K2= .46437E-05, UPPER K3= .23461E-05 1/M
IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE= .434671E 02 SEC OF ARC
IONOSPHERIC REFRACTION CORRECTION TO RANGE = .321120E 02 M
IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE = -.107691E-03 M/SEC

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5.0 Preparation for Delivery

The completed CPCI (Computer Product Configuration Item) for the Bent Ionospheric Model consists of three parts which are packed and shipped separately: a magnetic tape, card decks, and a documentation manual. The tape is mailed first class or airmail and is marked with "Special Handling-Electro Magnetic Item." The card decks and manuals can be shipped third class. For storage of the magnetic tape and the card decks, a cool and dry place should be selected to insure that the good condition of the items is preserved. The following list described the delivered items in detail:

- a) Magnetic tape containing the general ionospheric coefficients in either BCD or Binary code depending on the compatibility of the computers between which the transfer occurs.
- b) Card decks:
 - 1) Fortran card deck to copy the BCD tape with ionospheric coefficients to a Binary tape of the proper form. This deck is not needed if the required Binary tape is supplied in place of the BCD tape.
 - 2) Fortran card deck for PROGRAM ION, standard version of the ionospheric program.
 - 3) Data cards for testrun of PROGRAM ION.
 - 4) Fortran card deck for PROGRAM TABGEN, preprocessor for the alternate version of the ionospheric program.
 - 5) Data cards for testrun of PROGRAM TABGEN.
 - 6) Fortran card deck for PROGRAM ION1, reduction program for the alternate version of the ionospheric program.
 - 7) Data cards for testrun of PROGRAM ION1.
 - 8) Additional data cards of solar input data from 1962 to 1973.
- c) Manual: "Documentation and Description of the Bent Ionospheric Model." For the setup and checkout of the programs, Section 3.3.1 File Description and Section 4.1 Test Plan should be consulted.

6.0 Notes

Section 6.1 describes the development of the ionospheric model, the data base on which the analysis was founded and the justifications for the derivation of each step in the development. In Section 6.2 the accuracy and the limitations of the model are outlined; justifications of approximations used in the model are given along with estimates of the resulting errors.

6.1 Ionospheric Model Development

For several years scientists have investigated many different approaches to modeling the ionospheric profile on a theoretical basis. The names and types of these methods are well known and will not be discussed here, but it is obvious after all the years that a good theoretical ionospheric profile still does not exist.

The object of our past investigations was to come up with an ionospheric profile that could give much improved results for refraction corrections in satellite communications to ground or to another satellite than had been obtained with the Chapman and many other theoretical profiles. It would have been pointless for us to sit down and investigate another theoretical approach when so many more competent scientists are working on this problem. For this reason we decided that in this present time of computers, an empirical model taken from a vast data base may provide us with the profile we were looking for.

It was our intention to acquire ionospheric data of any kind that helped us build up a data base covering minimum to maximum of a solar cycle and providing information up to 1000km. The lower layers of the ionosphere were neglected in terms of their irregularities although their electron content was added into the larger F layer; this was done to simplify the approach and as the prime objective was to obtain refraction corrections through the ionosphere, or at least to a point above 150 km, such an elimination would not be very detrimental.

Data from bottomside ionospheric sounders was obtained over the year 1962 through 1969 covering 14 stations approximately along the American longitudes having geographic latitudes 76 degrees to -12 degrees or magnetic latitudes 85 degrees to 0 degrees. This data was in the form of hourly profiles of the ionosphere up to the f_oF2 peak. Topside soundings were acquired for the years 1962 to 1966 covering the magnetic latitude range 85 degrees to -75 degrees and providing electron density profiles from about 1,000 km down to a height just above maximum electron density. As the topside data was

not available near the solar maximum, electron density probe data was obtained from the Ariel 3 satellite over the period May 1967 to April 1968 from 70 degrees north to 70 degrees south geographic latitude and linked in real time to f_oF2 values obtained from 13 stations on the ground.

6.1.1 Ionospheric Profile

In order to analyse the vast amount of data that was obtained a number of assumptions had to be made. In the first case the topside sounding data did not geographically cover the entire globe and the bottomside data was only available for land masses and not over the oceans; however, as a local time effect is far more significant than a longitude effect, the data was analysed as a function of latitude and local time. Geographic longitude was, however, taken into account for the determination of maximum electron density by using the ITU coefficients for f_oF2 which are a function of latitude, longitude, time and solar activity. Secondly a theoretical profile was determined to which the data would fit. This profile which is used in the evaluation discussed later, is shown in Figure 2 and is the result of earlier work by Kazantsev (Reference 7), and unpublished work of Bent (1967) while at the Radio and Space Research Station in England and requires the knowledge of the parameters k_1 , k_2 , k_3 , y_1 , y_2 , f_oF2 , and h_p . The equation of the upper topside is exponential, namely,

$$N = N_o e^{-x/a},$$

the lower ionosphere is a bi-parabola,

$$N = N_b \left(1 - \frac{b_1^2}{y_1^2} \right)^2,$$

and the top and bottomside are fit together with a parabola,

$$N = N_b \left(1 - \frac{b_1^2}{y_1^2} \right),$$

where,

- N is the electron density
- N_m is the maximum value of electron density
- N_o is the maximum electron density for each exponential layer
- a and b are vertical distances
- y_1 is the half thickness of the lower layer
- y_2 is the half thickness of the upper parabolic layer
- k is the decay constant for an exponential profile.

The upper parabola extends from the height of the maximum electron density up to the point where the slope of the parabola matches the slope of the exponential layer. The data investigated included over 50,000 topside soundings, 6,000 satellite electron density and related f_oF2 measurements, and over 400,000 bottomside soundings.

6.1.2 Topside Ionosphere

The initial approach was to take the topside soundings and break them down into zones 5 degrees of latitude by 40 minutes of local time eliminating data in the same zones that have similar times and profiles, and therefore are duplicated. This resulted in over 1,200 different areas in the northern and southern hemisphere with a reasonably constant density of data in each area. By these means it was possible to investigate the decay constant k in the exponential topside profile as a function of local time, latitude, solar flux, sunspot number and season. One of the major concerns was whether the decay constant k would be uniform for each sounding over the range 1,000 km to the minimum height, and investigations showed that such an exponential profile does not exist. The layer was, therefore, divided into three equal height sections from 1,000 km to the minimum recorded height and the exponent k computed for the center point in each section. Figure 2 shows such a division where the values under investigation are the decay constants k_1 , k_2 , k_3 . In most cases the topside soundings do not reach the height

of maximum electron density and therefore the gradient at this lower point was mathematically equated to the point where the gradient of the 'nose' parabola was the same. Extensive analysis of the acquired data showed these gradients to be similar, on average, at a height $y_p/4$ above the maximum electron density. At this point the value of $f_k F2$, which defines the lowest point of the topside sounding, is $0.43 f_o F2$. (N_o in Figure 2 is the equivalent electron density to the frequency $f_k F2$).

For an initial test the decay constants k for each of the three layers, upper, middle, and lower topside were plotted as a function of magnetic latitude and $f_k F2$. Values from the northern and southern hemispheres were treated independently at first, but the analysis showed that there was excellent correlation between the two. Figure 3 shows the relationship between the three decay constants k and magnetic latitude for all local times, solar activity, and season. The equatorial anomaly and a 40 degree trough show in the lower topside layer. The 65 degree trough is not as evident as it is when the same analysis is done for various local times which suggests the physical variances of these anomalies should be investigated in more detail.

It was found that correlations in k for specific $f_k F2$ did not bear any further local time correlation, but bore a significant variation with solar activity and magnetic latitude. However, the correlation with solar flux was considerably better than that with sunspot number, even allowing for the delay in the effect reaching the ionosphere, so all further correlations were with the Ottawa 10.7 cm solar flux. All these correlations were then plotted in graphical form to enable final interpolation.

Unfortunately the Alouette data did not cover the period at the peak of the solar cycle, but the Director of the U.K. Radio & Space Research Station made available electron density data from the Ariel 3 satellite to cover this period. The data had already been reduced thoroughly and the satellite electron density at about 550 km was provided with the sub-satellite $f_o F2$ value obtained from 13 stations around the world. If the satellite was not directly over an

ionosonde at the time of observation, the f_oF2 values from two or three transmitters in the general area had been interpolated in time and position to give the sub-satellite value. These interpolations had been carried out taking care to modify the values for uneven ionospheric gradients. Data that was in doubt was eliminated. While these values did not give the three exponential decay constants at each point, it was found that for similar conditions of solar flux and position, the Ariel 3 data fit very closely to the profiles deduced from Alouette 1. The profile equations developed for the lower solar activity period related to the topside sounders could, therefore, be extended to the larger solar flux values and still be in good agreement with the Ariel 3 data. Typical results from this analysis are shown in the graphs of Figure 4. The original data curves were less regular, and since the variations were mainly caused by the relatively low data density in each group after division of the large data base, the data was smoothed by the fitting of straight lines. In order to interpret these graphs and obtain a profile, we need the value of f_oF2 , and the magnetic latitude position. These values will indicate which graph relates the 10.7 cm flux to the decay constants k for the upper, middle, and lower portions of the topside ionosphere. Figure 4, therefore, shows the basis of obtaining the 3 independent slopes of the topside ionosphere as a function of f_oF2 , latitude, and solar flux.

A further correlation to investigate the seasonal effects on k was carried out with some 15,000 totally different Alouette soundings and fluctuations in the k values of $\pm 15\%$ were noted from the average spring and autumn values. The seasonal variation is monitored by observing the change in the daily maximum solar zenith angle from the equinoctial mid-day value. Figure 5 shows the seasonal fluctuation in k for each of the three layers in the topside profile. There is considerable evidence that this seasonal relationship has an added local time factor and this point will shortly be under investigation.

Examination of the upper part of the 'nose' of the N-h profile is difficult because topside sounding information rarely gives any values in this region.

Evidence from many leading scientists also implies that the topside profiles have about a +4% error in the effective distance from the sounding satellite indicating the obtained topside profiles are too low near the peak. This evidence is based on comparisons with two-frequency data, backscatter results, Faraday rotation and overlap tests, etc. Preliminary results in this empirical model showed that a parabola in this region gave the better comparison with integrated total electron content when compared with two-frequency and Faraday rotation data. A simple parabola having a half thickness y_1 was fitted between the bi-parabola and the exponential layer. Upon initial test y_1 was set equal to the half thickness of the bi-parabola y_1 for f_oF2 values below 10.5 MHz, and y_1 increases with f_oF2 values rising above 10.5 MHz. Further investigations of this problem are planned in future work.

The final step in predicting the shape of the ionosphere is arranging for the gradient in the upper parabolic layer to be the same as the gradient in the lowest part of the topside exponential layer. This is the case at a distance $d = 1/k [(1+y_1^2 k^2)^{1/2} - 1]$ above the height of the maximum electron density.

6.1.3 Bottomside Ionosphere

Modeling the bottomside ionospheric profile was a somewhat easier task because for each profile the value of f_oF2 was known and the electron density versus height profile from h_{min} to h_{max} was also known. Once more the geographic effect of longitude was eliminated and replaced with the more simple local time correlation. From Figure 2 we see that the equation of the lower layer is a parabola squared or a bi-parabola. This was found in general to fit the real profile somewhat better than a simple parabola. The unknown in this equation is the half thickness of the layer y_2 and in the reduction of the data the y_2 value was treated in a similar way to a topside k value.

The irregularities in the ionosonde data due to the lower layers of the ionosphere were smoothed out because the prime objective of the work was to simplify the model, but keep the total content as accurate as possible. The

sounding data was therefore integrated up to the peak electron density (N_p) and forced to fit the bi-parabolic equation along with the value of N_p obtained from the sounding. In each instance the value of y_p was computed ready for further correlation.

A number of real profiles from various stations at different local times were compared with the computed profile and excellent agreement found. A further 12,000 soundings from all 14 stations were analyzed and the computed value of y_p compared to the actual measured value. These results are shown in Figure 6 along with the RMS errors. The two tests indicate that the bi-parabolic profile is, on average, in close agreement to the real profile. Investigations, similar to those carried out for the topside decay constants, correlated y_p with solar flux f_oF2 , local time and season. Surprisingly, no direct correlation was found between y_p and solar flux, but a definite correlation existed in local time and also in the solar zenith angle at local noon which represents the season.

Figure 7 indicates how y_p can be determined from local time and f_oF2 , and Figure 8 shows the seasonal update as a function of local time for the sunrise, sunset, night and daytime period. In the cases where f_oF2 was larger than 10 MHz the local time curve fluctuated very little from the 10 MHz curve. All of the curves displayed have not been hand smoothed; due to the large data base the average of all values taken every hour fit precisely on the lines shown.

The remaining unknowns which are needed to compute the profile are f_oF2 and the height of that value; by far the most important of these being the value of f_oF2 .

6.1.4 Predicting f_oF2

Severe horizontal gradients in f_oF2 exist within the ionosphere as can be seen by examining Figure 9. In fact even if the value of f_oF2 is known directly above a station, it can change considerably over the whole visible ionosphere from that site. Figure 9 is a predicted status of f_oF2 over the world at 6.0 am during August 1968 and two types of severe gradients are immediately noticeable, one due to sunrise causes rapid changes in f_oF2 in an east to west direction and the other situated around the equatorial anomaly occurs primarily during the afternoon and early evening and causes severe gradients in the north to south direction. Two hypothetical stations, A and B, are marked on Figure 9 along with the ionosphere 'visible' from those sites. In case A the value of f_oF2 changes from 11.5 MHz directly overhead to 5 MHz on the southern horizon. This change must be squared when converting to electron content hence a difference of a factor of over 5 in the vertical content arises before correcting for elevation angle effects. Similar gradients exist over half the earth's surface at some time of the day and it is therefore imperative to model these gradients in any ionospheric model.

For many years NOAA (formerly CRPL and ITSA) have been engaged in the development of numerical methods and computer programs for mapping and predicting characteristics of the ionosphere used in telecommunications. The most advanced method for producing an f_oF2 model undoubtedly comes from their work. Jones, Graham & Leftin (Reference 5) describe their techniques on how a monthly median of the F2 layer critical frequency (f_oF2) was developed from an extremely large worldwide data base. In fact the gradient map shown in Figure 9 is a result of this work. We have already shown that it is important to include the horizontal gradients of f_oF2 in any analysis and the work by Jones et al is undoubtedly the only satisfactory approach to this problem.

The document by Jones et al describing this work includes a Fortran program which, with monthly coefficients obtainable from NOAA, enables the monthly median value of f_oF2 to be computed above any point in the world at

any time. This program was primarily written to accept monthly coefficient, using an average sunspot number, but more recent work by Jones & Obitts (Reference 6) has described a more generalized set of coefficients which provides annual continuity and uses more extensive analysis. These generalized coefficients can be obtained from the Ionospheric Prediction Service, NOAA, Boulder, for a sunspot number or a solar flux approach. The value of a monthly median f_oF2 can be computed on a worldwide basis centralized around the specific day in question rather than the 15th of the month; it can also be based on a 12-month running average of solar flux or sunspot number. Private communication with Mrs. Leftin at NOAA indicates that the solar flux approach is likely to provide more accurate values of f_oF2 than the use of the sunspot number.

For the ionospheric profile under discussion, it was decided to use the generalized f_oF2 coefficients from NOAA incorporating solar flux thereby eliminating any need to purchase monthly data from them. The program was made self-contained and enabled a monthly median f_oF2 to be produced above any surface position for any time of day or season and any twelve month running average of solar flux.

The question now arises as to how good these monthly median values are and how much error is introduced by day to day fluctuations. Many daily soundings were analyzed and the monthly median value computed; these were compared with the monthly median predicted values and the actual day to day fluctuations. Some typical results are shown in Figure 10. It is seen that the monthly median predicted values are indeed very close to the actual measured value, but the day to day fluctuations can be as large as $\pm 75\%$. A technique therefore had to be derived to bring the computed monthly median value closer to the actual value.

It would be pointless to use the daily value of solar flux in the generalized coefficient set which had been built up using a twelve month running average, but it was thought possible that there may be a relation between the difference in f_oF2 from monthly median to daily value and the difference in the 12-month running average of solar flux to the daily value.

Approximately 6,000 real values of f_oF2 from 13 stations widely spread in latitude, longitude, and solar cycle were compared with the predicted values using the NOAA solar flux method. A very surprising result emerged and can be explained by referring to Figure 11. Eliminating the data from stations close to the magnetic poles which did not quite follow the trend of the other stations a comparison between the difference in daily and 12-month flux value and the percentage difference of computed and measured f_oF2 showed all stations having a very similar bias. Figure 11 shows this comparison where the stations having similar latitude were averaged quoting their mean magnetic latitude. The fact that the lines did not pass through the zero points in the graph undoubtedly indicates an erroneous bias in the NOAA predictions, but results help one to update substantially the monthly median f_oF2 value on a daily basis. Further comparisons were carried out with two years of hourly f_oF2 values obtained near solar maximum from H wall and the results fit perfectly in the latitude position expected in Figure 11. By these means it is possible to come somewhat nearer the actual daily value of f_oF2 . Further accuracy can be derived by update from stations within the general area if this is available and the investigation of this approach will now be explained.

In order to investigate the size of an area from which ionospheric values would show similar deviations from normal, many comparisons of three or more stations were investigated for random dates. It is well known that magnetic disturbances can effect the ionosphere above one station in one direction and a nearby station in an opposite direction. For this reason investigations of disturbances were not carried out near to the magnetic poles. Over 100 groups of stations from various continents and having similar longitudes were compared in similar ways. Figure 12 is a typical result of such a test and shows f_oF2 disturbances being recorded simultaneously at sites 1,000km apart. The percentage error in the predicted f_oF2 value when compared to the real value was noted to be similar in 90% of the cases where stations were within 2,000km of one another in a longitudinal direction and investigations over the 'quiet' North American continent show improvement

in 9 out of 10 cases when f_oF2 was updated with information from across the continent; or 3,000 to 4,000km. However, in general, the update procedure is restricted to information from within 2,000km of the evaluating station.

6.1.5 Predicting the Height of the Maximum Layer

In order to predict the real height of f_oF2 the $M(3000)F2$ predictions from NOAA were used. To explain the terminology:

$$M(3000)F2 = M \text{ FACTOR} = MUF(3000)F2 / f_oF2,$$

where $MUF(3000)F2$ is the maximum usable frequency to propagate by reflection from the F2 layer a distance of 3,000km. The $M(3000)F2$ predictions can be calculated on a monthly basis from a generalized set issued by NOAA and provide the monthly median value as a function of sunspot number.

Knowledge of this factor along with the f_oF2 value enables the height of the layer to be calculated using the equations of Appleton & Beynon (Reference 1). If M is the $M(3000)F2$ factor and one assumes that y_e divided by the height of the bottom edge of the lower layer is greater than 0.4, then it is possible to derive the following polynomial,

$$h_p = 1346.92 - 526.40M + 59.825M^2,$$

where h_p is the required height.

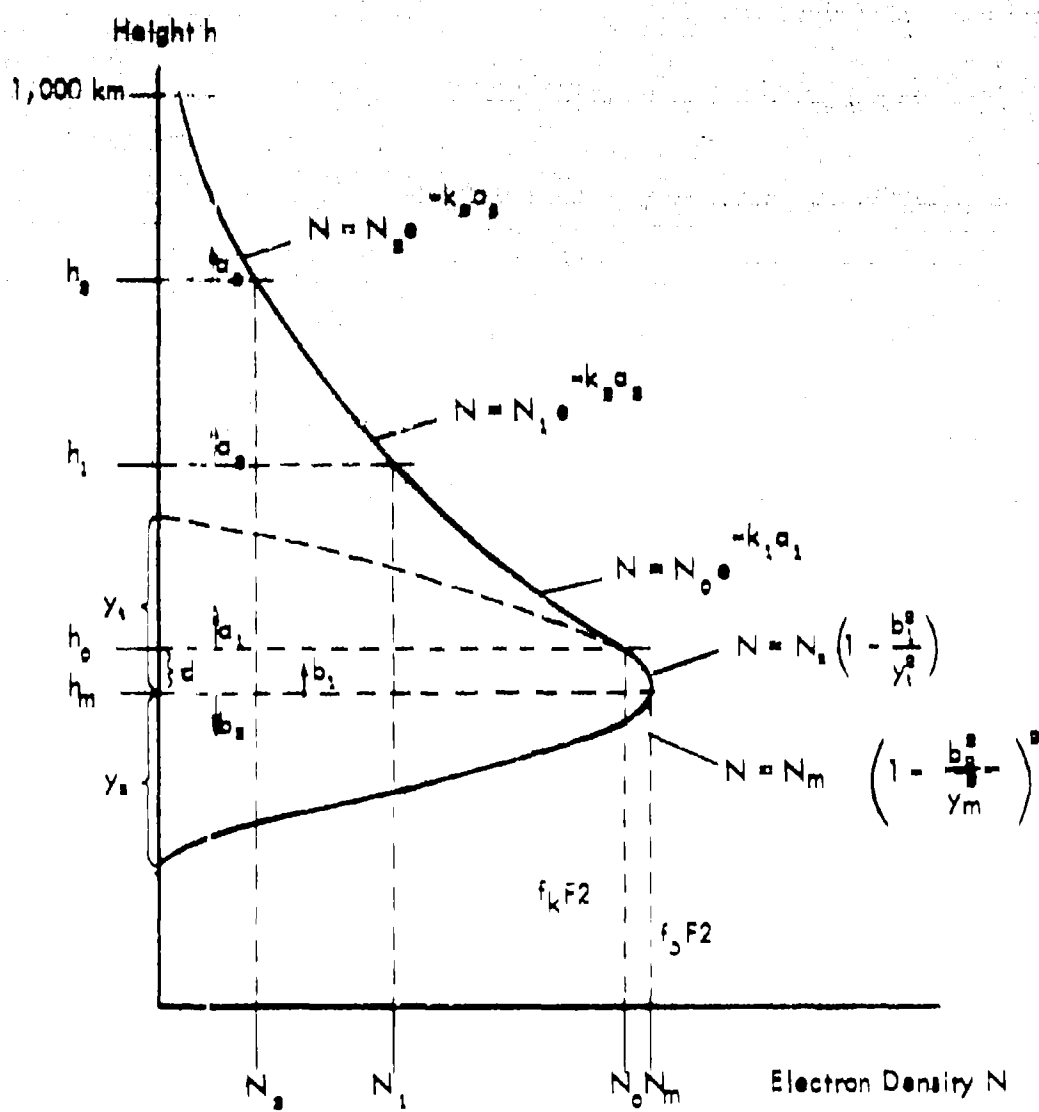


FIG. 2 The Exponential Parabolic & Bi-parabolic Profile

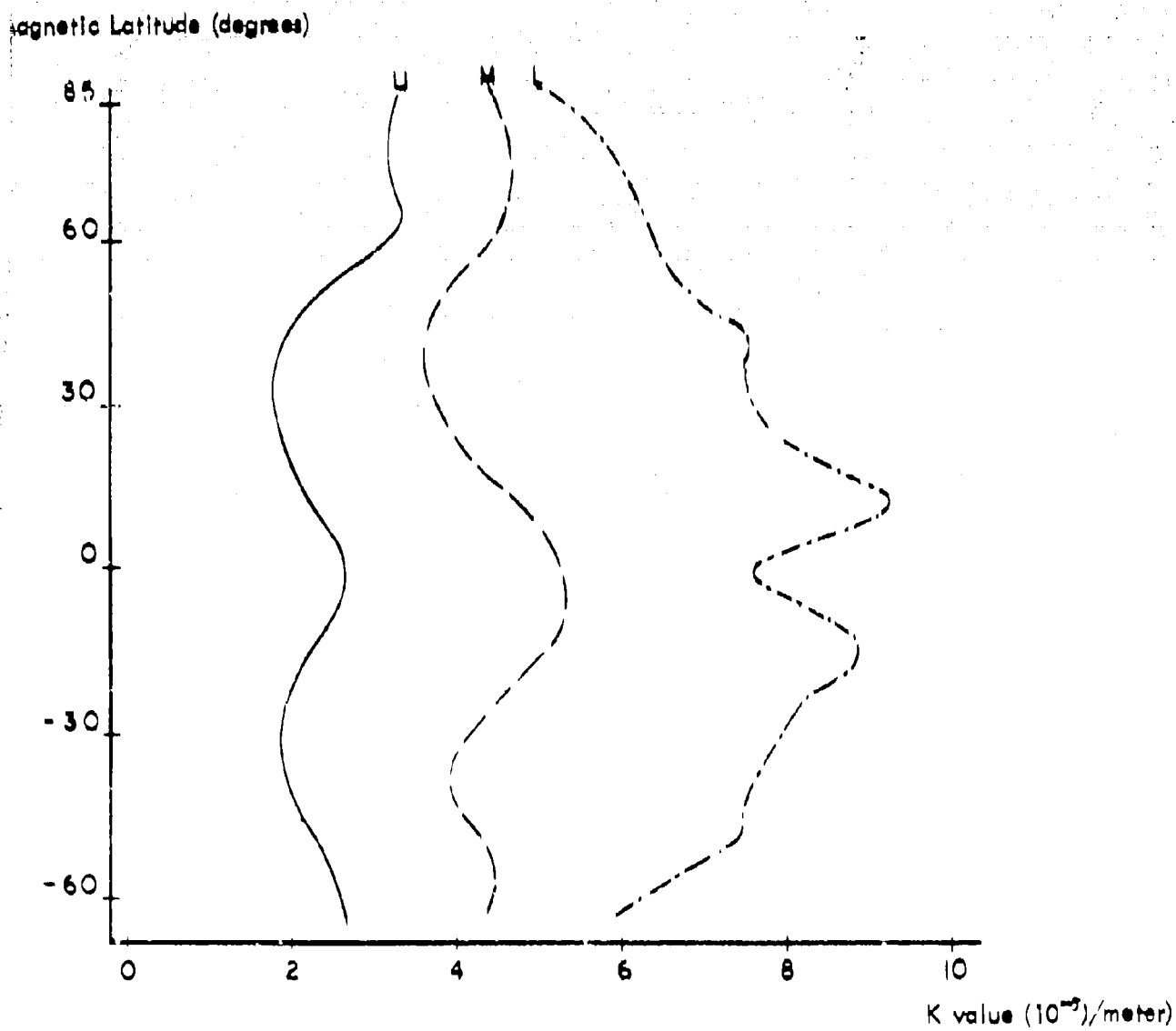


Fig. 3 The mean fluctuation of the decay constant k with magnetic latitude for the upper (U), middle (M) and lower (L) portions of the topside ionosphere.

(10.7 cm)
DAILY
SOLAR
FLUX

$f_oF2 = 1.8 \text{ MHz}$

$f_oF2 = 4.5 \text{ MHz}$

$f_oF2 = 7.4 \text{ MHz}$

$f_oF2 = 10.2 \text{ MHz}$

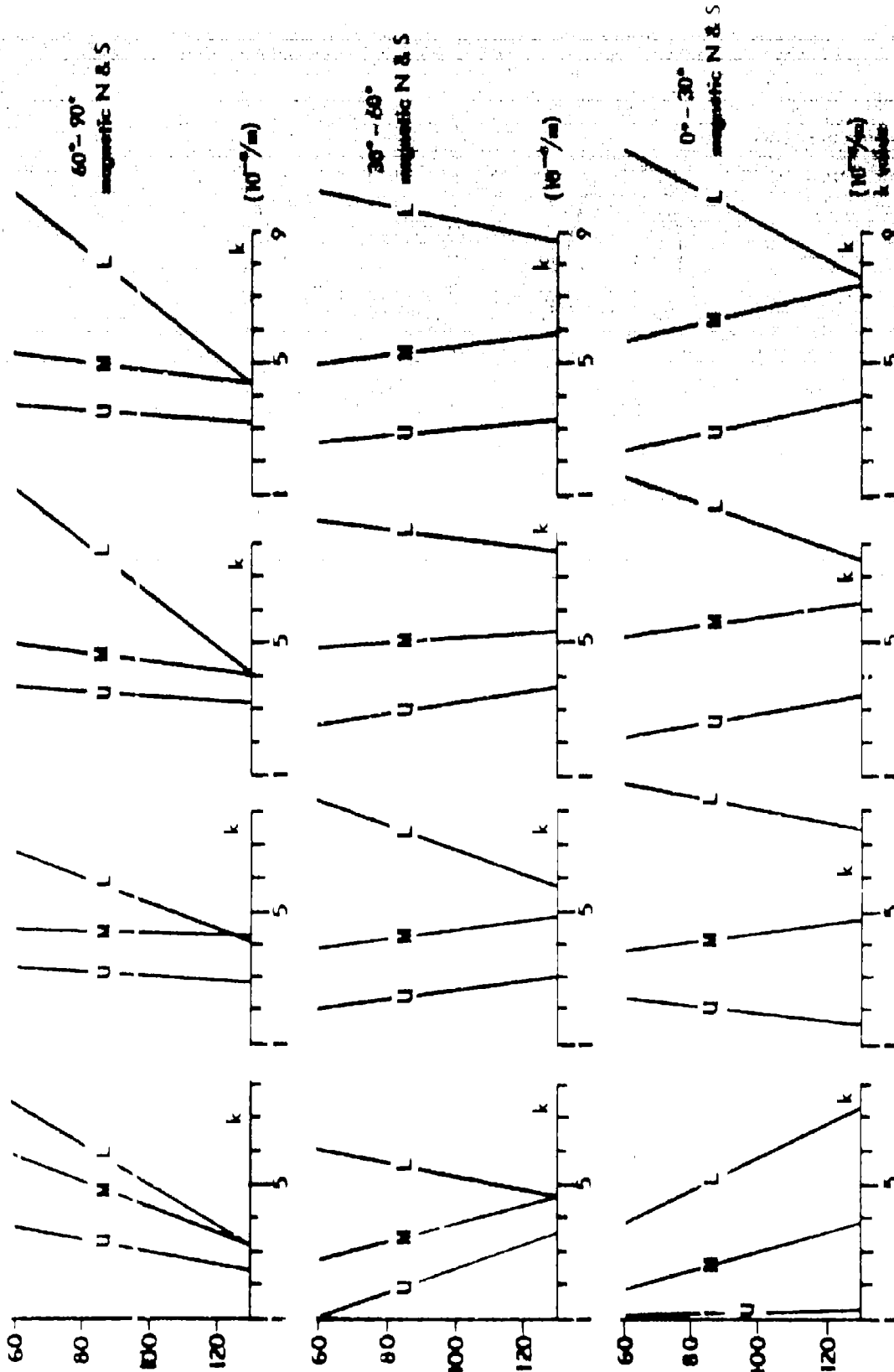


Fig. 4 Variation of k for the upper (U), middle (M) and lower (L) topside profile due to solar flux, f_oF2 and magnetic latitude.

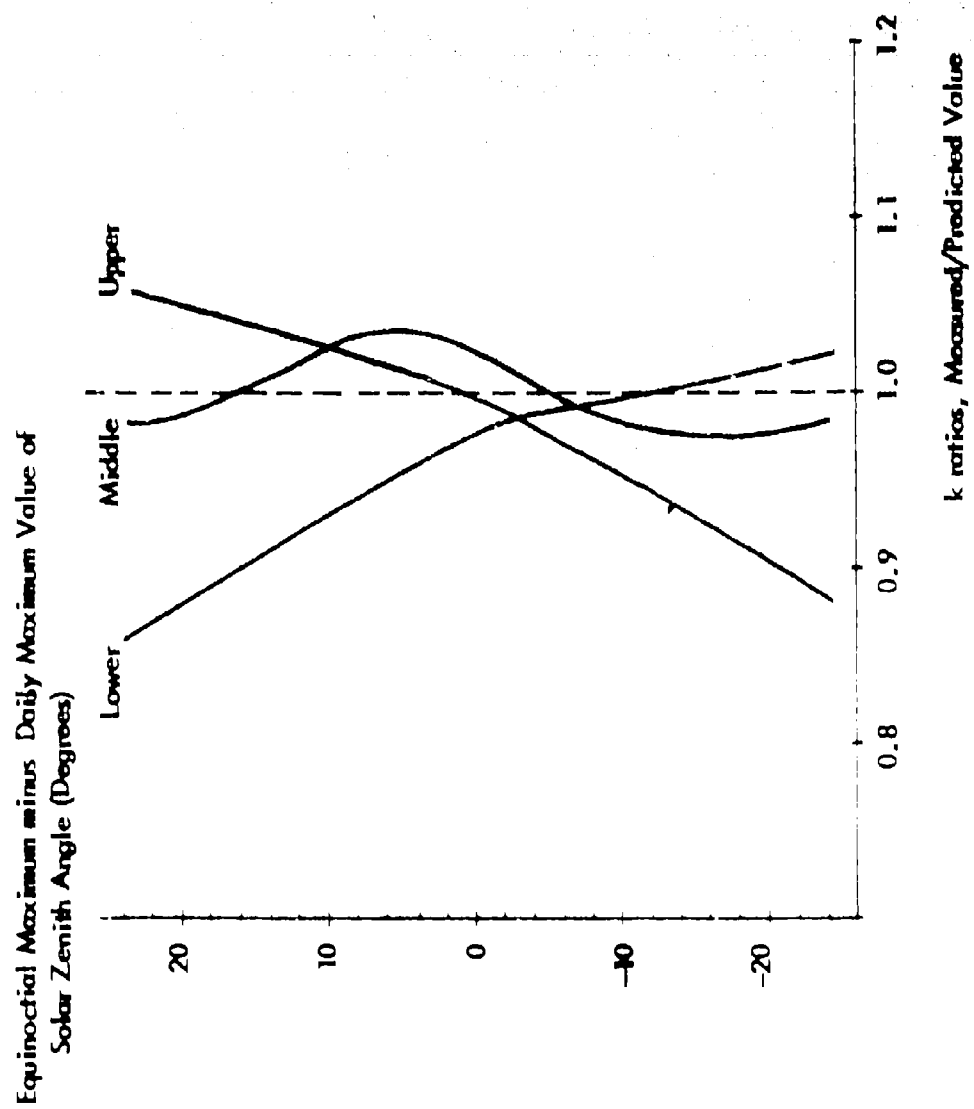


Fig. 5 The seasonal variation in the predicted k values

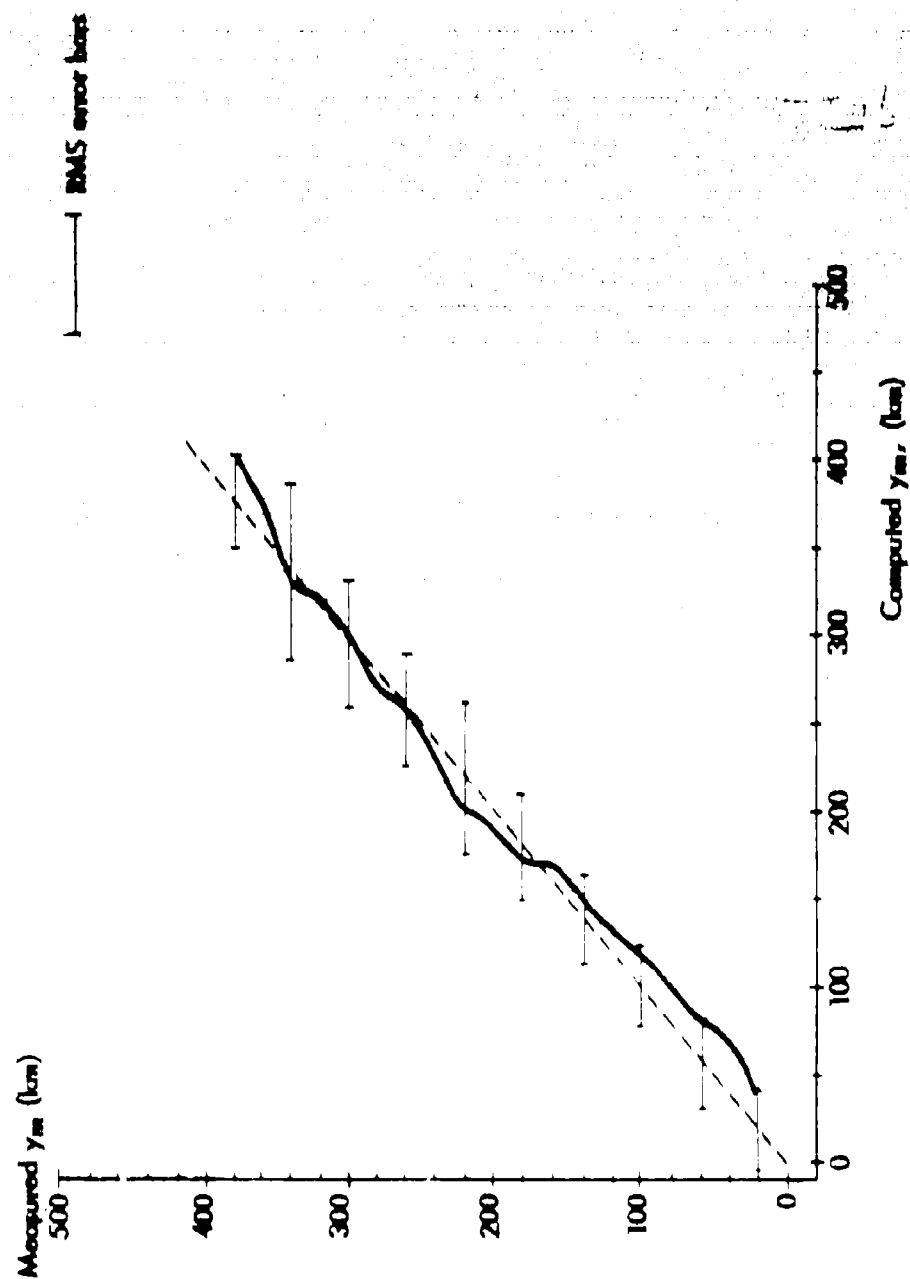


Fig. 6 The comparison of measured and predicted y_m for 12,000 profiles showing RMS error bars.

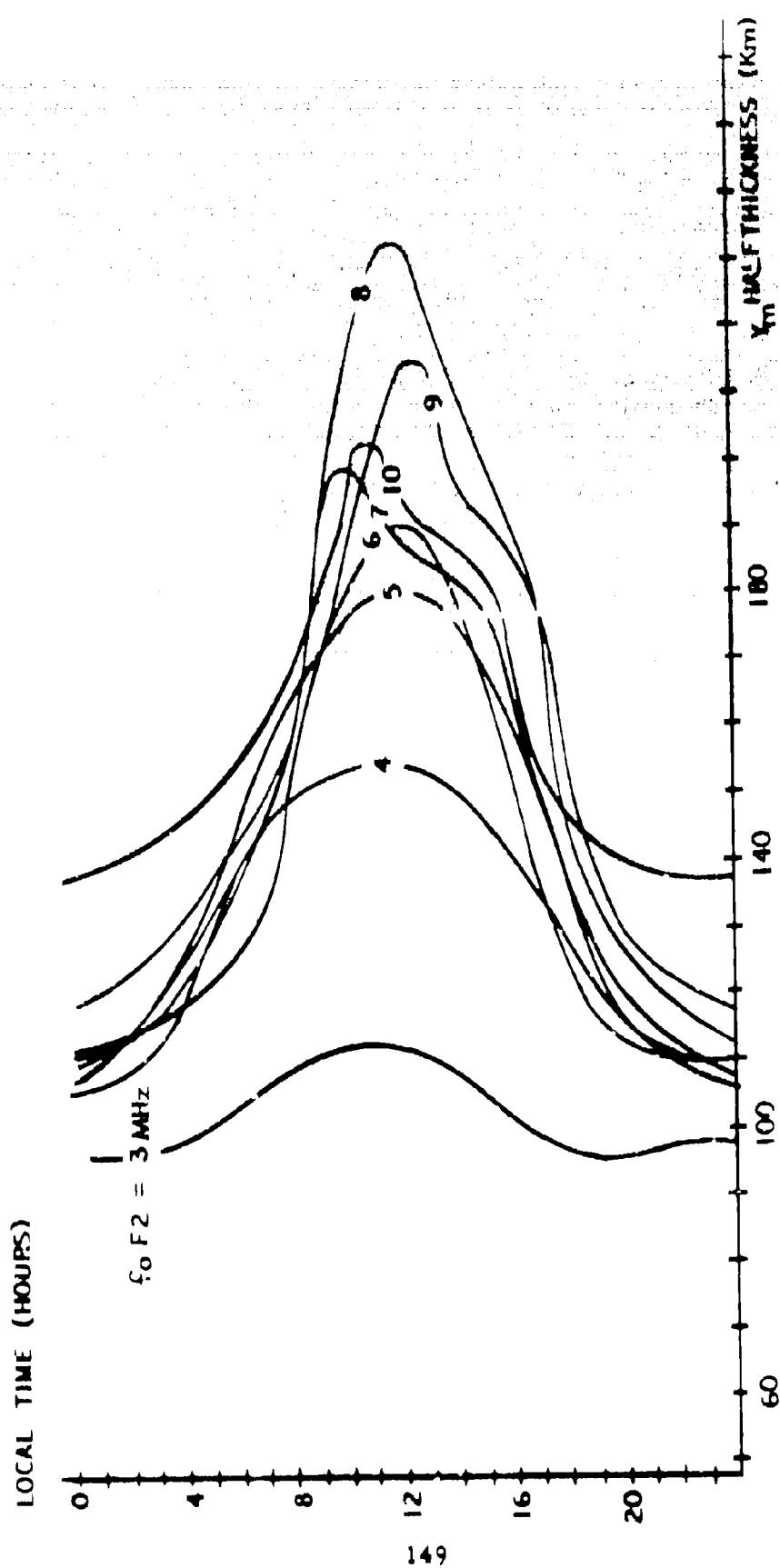


Fig. 7 Variation of y_m as a function of $f_o F2$ and local time.

Average minus Daily Value of
Solar Zenith Angle (Degrees)

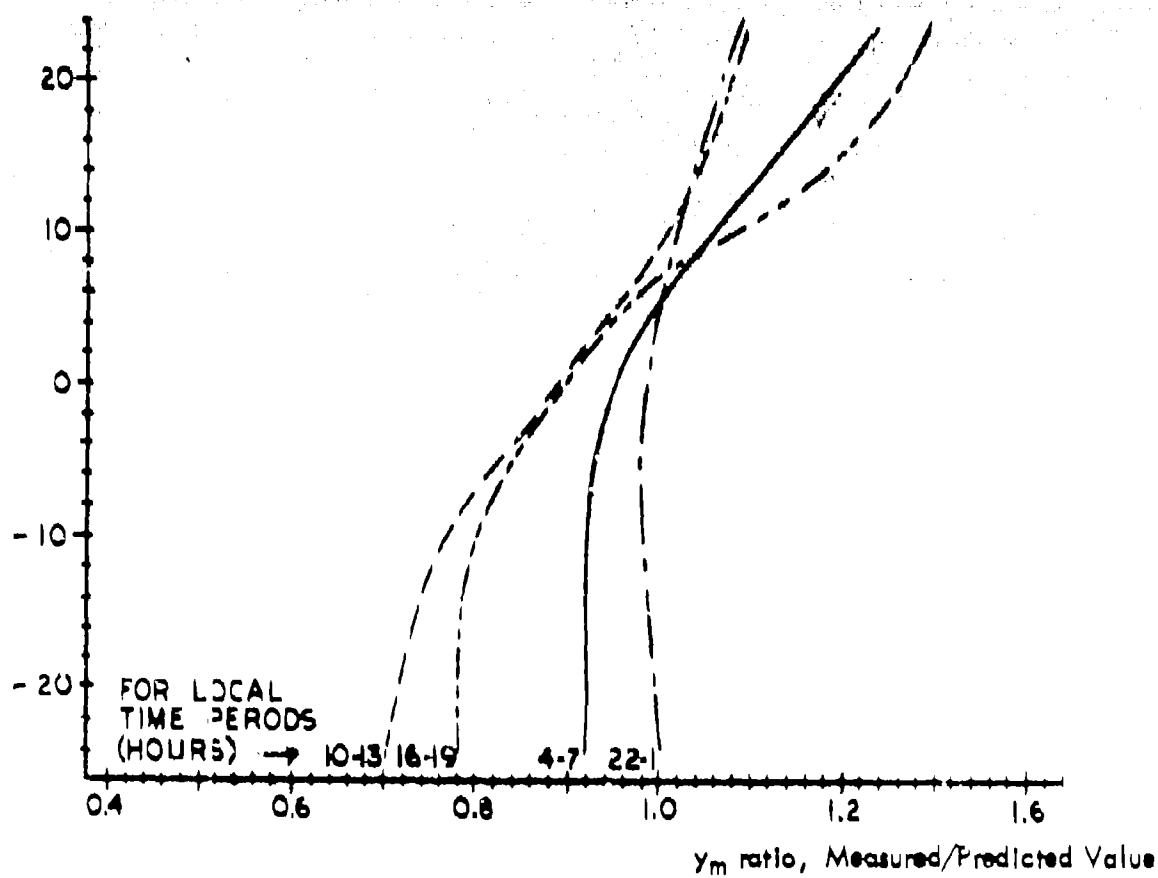


Fig. 8 The seasonal variation of predicted y_m as a function of local time.

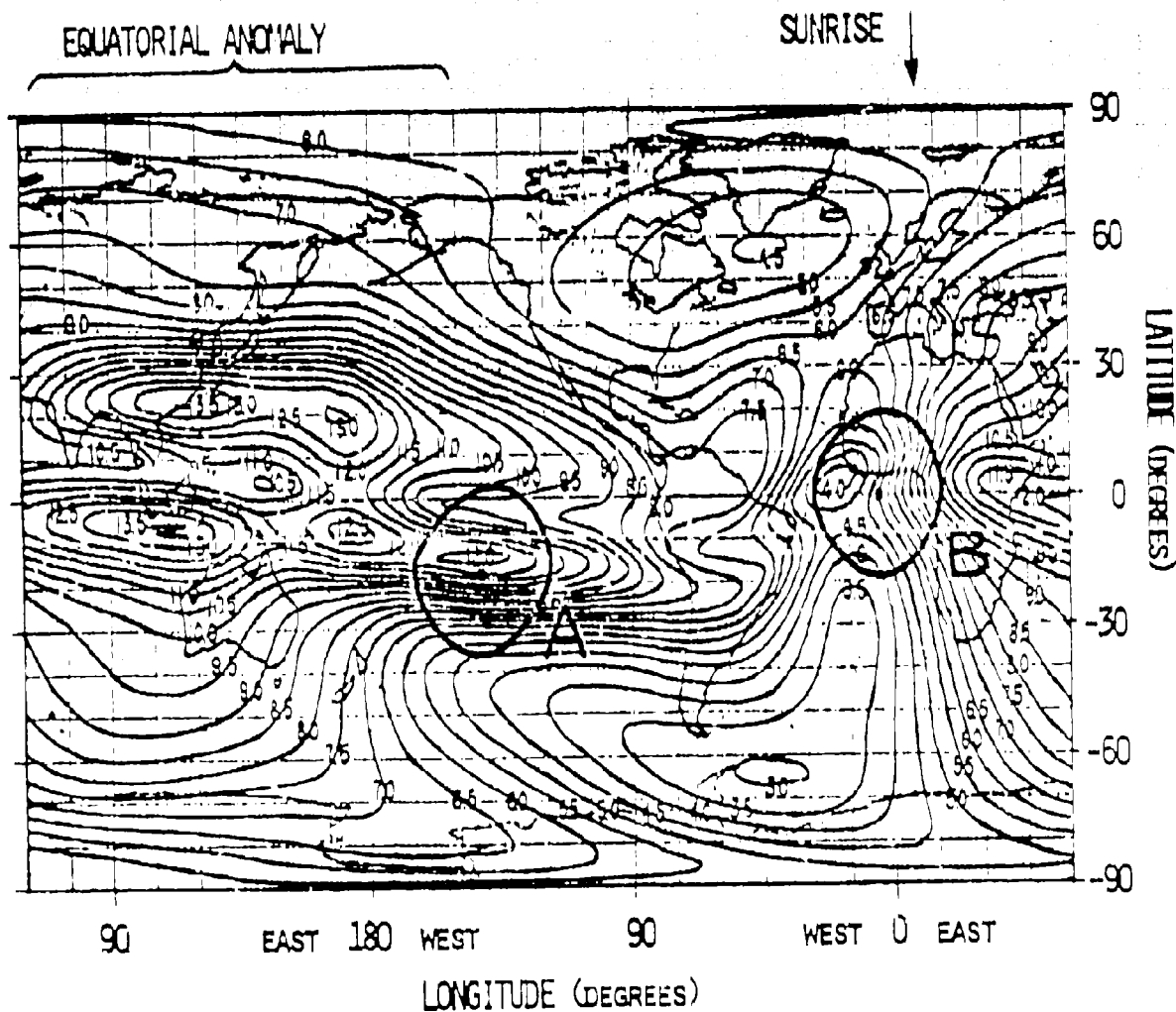


Fig. 9 The predicted global status of a monthly median f_xF_2 at 6.0 a.m. UT August 1968 showing areas of visibility for two hypothetical ground stations.

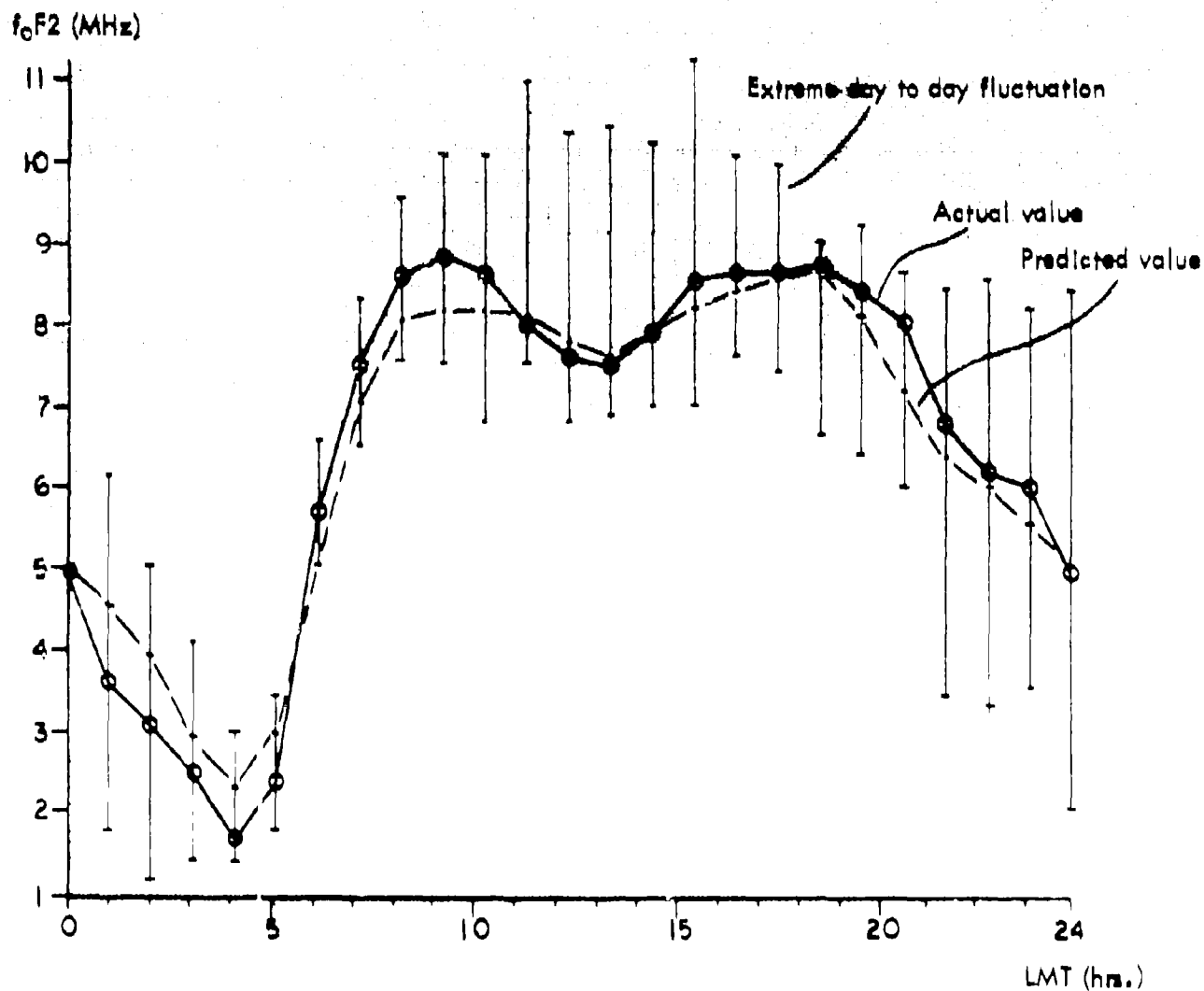


Fig. 10 The predicted and actual monthly median values of f_oF2 for Ibadan June 1962 showing the extreme day to day fluctuations.

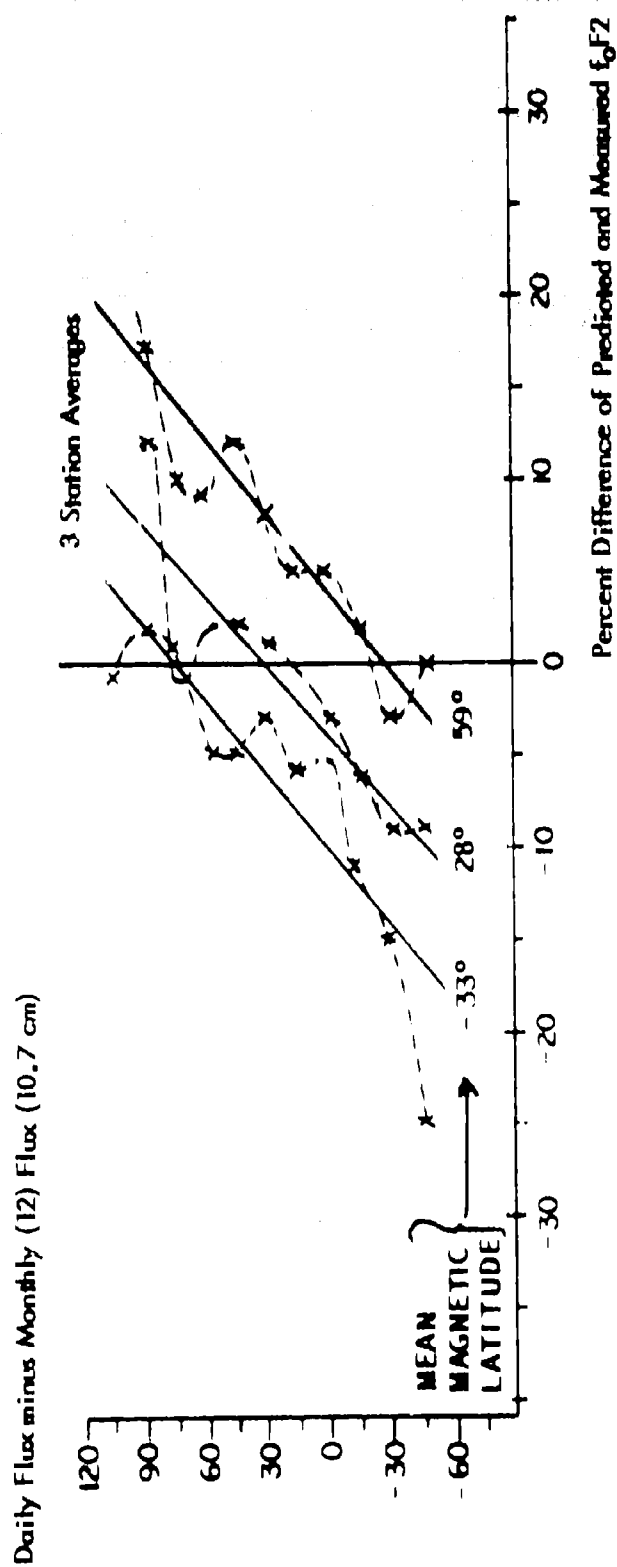


Fig. 11 An error in the NOAA f_oF2 predictions as a function of magnetic latitude and daily solar flux minus the 12 month running average.

Percent Error in
Predicted f_oF_2

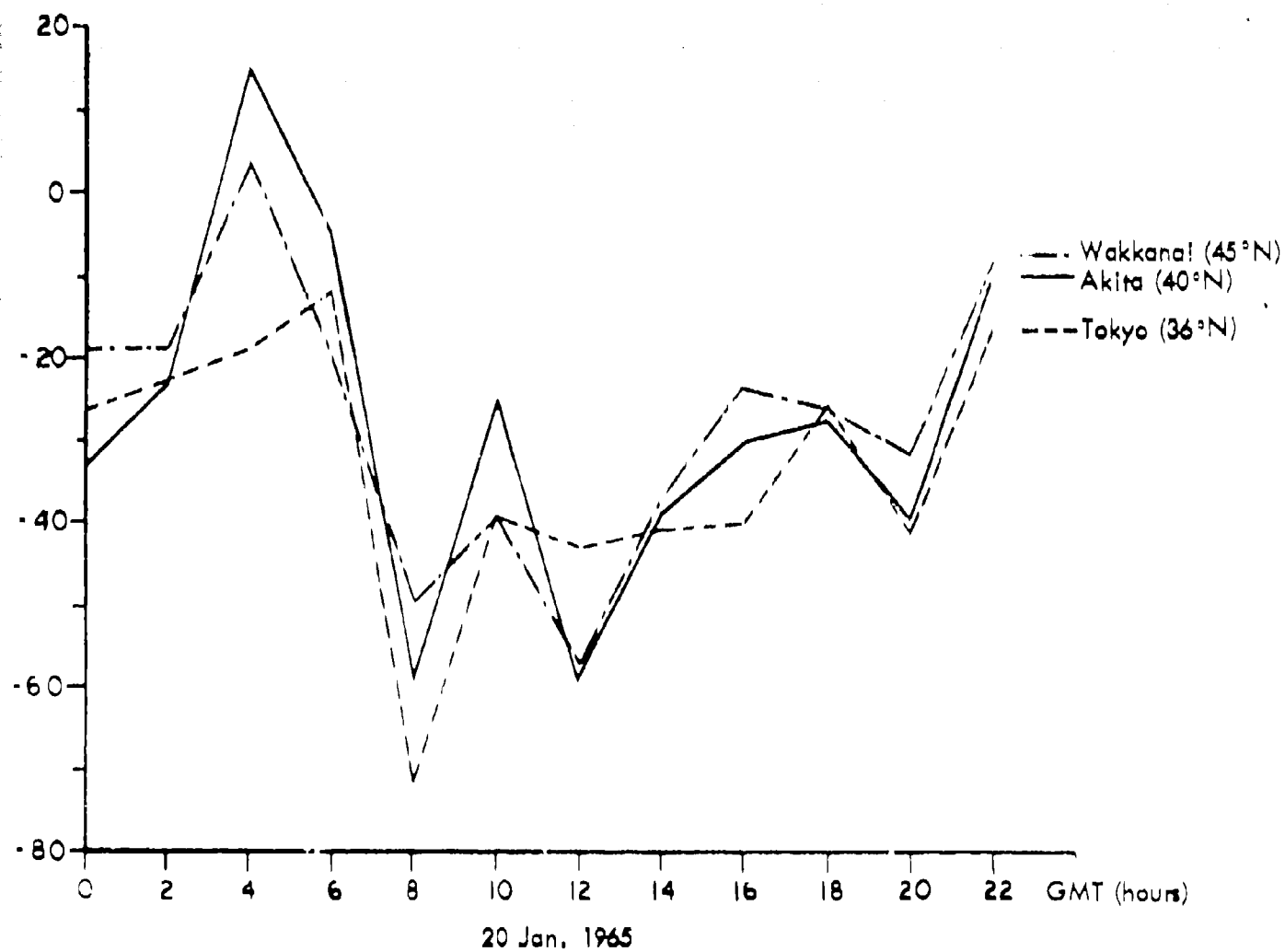


Fig. 12 Deviations in f_oF_2 evident over a distance of 1,000 km

6.2 Model Accuracy and Limitations

As a means of testing the accuracy of the model, an intense comparison with Faraday rotation data has been performed as well as tests with two frequency data, actual ionospheric profiles, and use in orbit determination programs.

Remarkable improvements have been noticed in precise orbit determination systems and the model has reduced the number of iterations needed for the program to converge as well as the size of the residuals by upto a factor of four. Excellent results have been noted with orbit programs using elevation angle, range, and range rate systems.

The most extensive tests were carried out by comparing Faraday rotation data for seven stations from Hawaii to Puerto Rico to Alaska looking at the ATSI, ATS3, and SYNCOM3 satellites. In all, over 100 station months of continuous data were used during the years 1965 and 1967-1969 with data taken every hour. The integrated model data was compared with these actual results; unusual situations were also investigated. The results are shown in Figure 13 where the percentage of the ionosphere removed with the model is shown. In general, between 75 and 90% of the ionospheric effects are removed and these circumstances are for solar maximum conditions.

6.2.1 Basic Misconceptions in Ionospheric Modeling

During the course of developing this ionospheric model thorough investigations were carried out on a number of other ionospheric models as a means to finding their basic inaccuracies. The limitations and inaccuracies were then considered in the final development of the Bent Ionospheric Model.

Among the basic simplifications in the models leading to inaccuracies, were formulae related to a flat earth and ionosphere as well as little consideration for the height of the ionosphere. Each of these approaches causes f_oF2 to be evaluated at an incorrect position, consequently produces an error in f_oF2 which propagates into electron content and the refraction corrections, and in addition large errors in elevation angle correction can result from the incorrect geometric conditions.

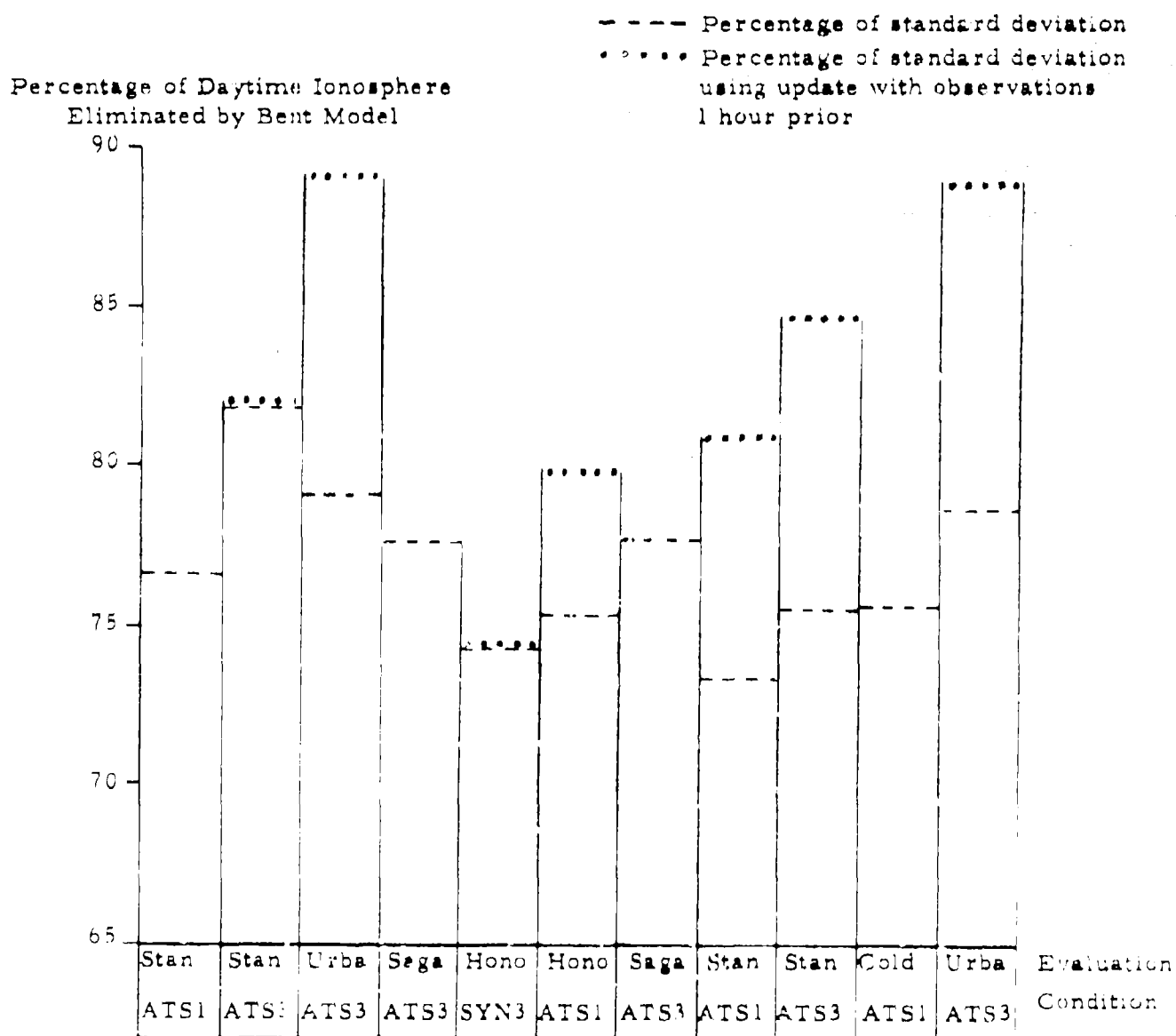


Figure 13 Percentage of Daytime Ionosphere Eliminated for Different Evaluation Conditions

The bad effect of a flat ionosphere on low elevation angle satellites is obvious, and serious problems also exist for satellites at large distances. Elevation angle corrections cannot be obtained for satellites at infinity, and errors of a factor of 2 in elevation angle still occur with satellites at 5000 km altitude. The height $h_p F2$ quite commonly changes by over 175 km during the course of a day at low latitudes. Ignoring the importance of the $h_p F2$ computation can give rise to an error of a factor of 2 in elevation angle correction, and at low elevations also to a difference of 3 degrees in earth central angle between the observer and the ionospheric point, which in turn can produce a change in $(f_o F2)^2$ of 20%.

6.2.2 Errors in Range Rate Computations

A problem can occur in computing range rate corrections through the ionosphere to a satellite. Many Doppler satellite tracking systems integrate cycle counts over a few seconds of time. The ionospheric corrections for such a technique are best obtained by range differencing the ionospheric corrections and dividing by the integration period; hence time, elevation and azimuth changes are incorporated. A typical ionospheric range rate correction can be significantly changed by the sixth digit in the ionospheric range correction; precautions have therefore to be taken to ensure that no irregularities occur in computing the two adjacent range corrections. Furthermore, the ionospheric height at the ray intersection point must be computed to 1km convergence in order to obtain a precise ionospheric latitude and longitude for $f_o F2$ computations. An error of over 1km in $h_p F2$ will cause the $f_o F2$ value to be very slightly different and from this a change in the 5th or 6th digit in range can easily arise leading to very large errors in range rate. It is not claimed that $h_p F2$ has to be accurate to 1km as this is an impossible prediction, but the values of $h_p F2$ should be consistent in their calculation to 1km convergence.

The theoretical approach to range rate correction either by differentiating range or using the deviation angle of arrival at the satellite is in no way accurate.

The differentiating technique yields a correction to an instantaneous measurement which can vary greatly from the correction to Doppler range rate measured over a finite time interval, from a fraction of a second up to over a minute's time. In addition, the range rate correction is not only influenced by the change in the satellite position, but also by the changing ionosphere below the moving satellite, which has mostly been neglected in either approach. To explain this fact, consider the range correction ΔR as given by

$$\Delta R = \frac{KN_i}{\sin E} \quad \text{where } K = \frac{40.3}{f^2},$$

N_i is the integrated vertical content and E is the local elevation angle in the ionosphere. Differentiating ΔR while considering the case where the satellite passes directly overhead where no azimuth change is observed:

$$\dot{\Delta R} = -KN_i \frac{\cos E}{\sin^2 E} \dot{E} + \frac{K}{\sin E} \left(\frac{\partial N_i}{\partial E} \right) \dot{E} + \frac{K}{\sin E} \left(\frac{\partial N_i}{\partial t} \right) \quad \begin{matrix} t = \text{constant} & E = \text{constant} \end{matrix}$$

In this equation the first term is in many cases the only one used, but it applies only to the instantaneous change in the satellite position. The other two terms are, however, often dominant. The second term is due to the positional change in the ionosphere and the last term represents the time variation of the ionosphere. For instance, with a high satellite moving east-west across the north-south ionospheric gradients at sunrise, the time variation is dominant as these gradients move towards the west with time. For a satellite moving north-south across the east-west ionospheric gradients near the equator, the time variation in the ionosphere is very small because the gradients change little in position while the ionosphere rotates with time. The second term which indicates positional change in the ionosphere is dominant for lower satellites where the ray path to the observer moves faster through the ionosphere. In cases where the satellite does not pass overhead the azimuth change must also be considered.

The Bent Ionospheric Model was developed for general use even at frequencies close to critical frequency and therefore all these basic misconceptions were eliminated as much as possible. The limitations still present in the system are now discussed in more detail.

6.2.3 Electron Density above 1000 km

The topside sounding data used to derive the data base for this model was taken from satellites at altitudes of about 1000 km and analysis showed that the ionosphere above $h_p F2$ is not truly exponential; in fact at times, large deviations from a perfect exponential layer exist. In the use of this model it is recommended that the decay constant from the uppermost exponential layer is the value that should be taken for all analysis between 1000 and 2000 km. At times, however, this value will be too large thereby giving a lower electron density than actually exists.

Some scientists have reported that 10 to 20% of the ionosphere lies above 1000 km, but there is not conclusive evidence to support this. Further studies are now underway using satellite topside sounding data at 3000 to 4000 km altitudes and the model will be improved accordingly.

6.2.4 The Uncertainty in the Profile just above $h_p F2$

An uncertainty existed in defining a profile for the area just above $h_p F2$. Topside sounding data provided a profile to a short distance above $h_p F2$ and bottomside data provided accurate values to the height of $h_p F2$. In order to investigate this unknown region both parabolic and bi-parabolic profiles were incorporated into that part of the model and extensive tests carried out with total electron content data provided from Faraday rotation experiments. The model was used to predict total content to 2000 km where Faraday rotation probably ceases. The mean value of the residuals between Faraday computed electron content and model integrated electron content indicated the accuracy of the profile just above the peak. This region was found to have diurnal and seasonal dependency, but these characteristics have not yet been well enough defined to incorporate into the model. It was found, however, that a parabolic layer with half thickness a function of $f_o F2$ gave significantly improved results, but further work will be needed to define this region more accurately as a function of time and season.

6.2.5 Profile Inaccuracies in the Lower Layers

The model was developed primarily for use near to or above the height of the F2 layer of the ionosphere. For this reason, it was not necessary to model the E and F1 layers into the profile, but their density values were included in the total electron content below $h_p F2$. This total content was then used in the derivation of the lower layer bi-parabola. Care must be taken, therefore, in using the model if a profile of these lower layers is required, but if the requirements only involve total electron content or refraction corrections for values close to or above $f_o F2$, the model is quite accurate.

6.2.6 Maximum Limit on Solar Flux in the Derivation of the Topside Profile

It can be seen from Figure 4 that the topside exponential decay constants are a function of the 10.7 cm solar flux. The graphs shown in this figure indicate values only when the flux is below 130. This is primarily due to a lack of large amounts of data in the original data base for conditions of higher solar activity. It is not recommended to extrapolate the exponential decay constants beyond this value of flux as it is possible they may become negative giving an erroneous increase of electron density with height. It is suggested that the value of flux be kept at 130 even when measured values are larger.

6.2.7 Limitations in the Computation of $h_p F2$

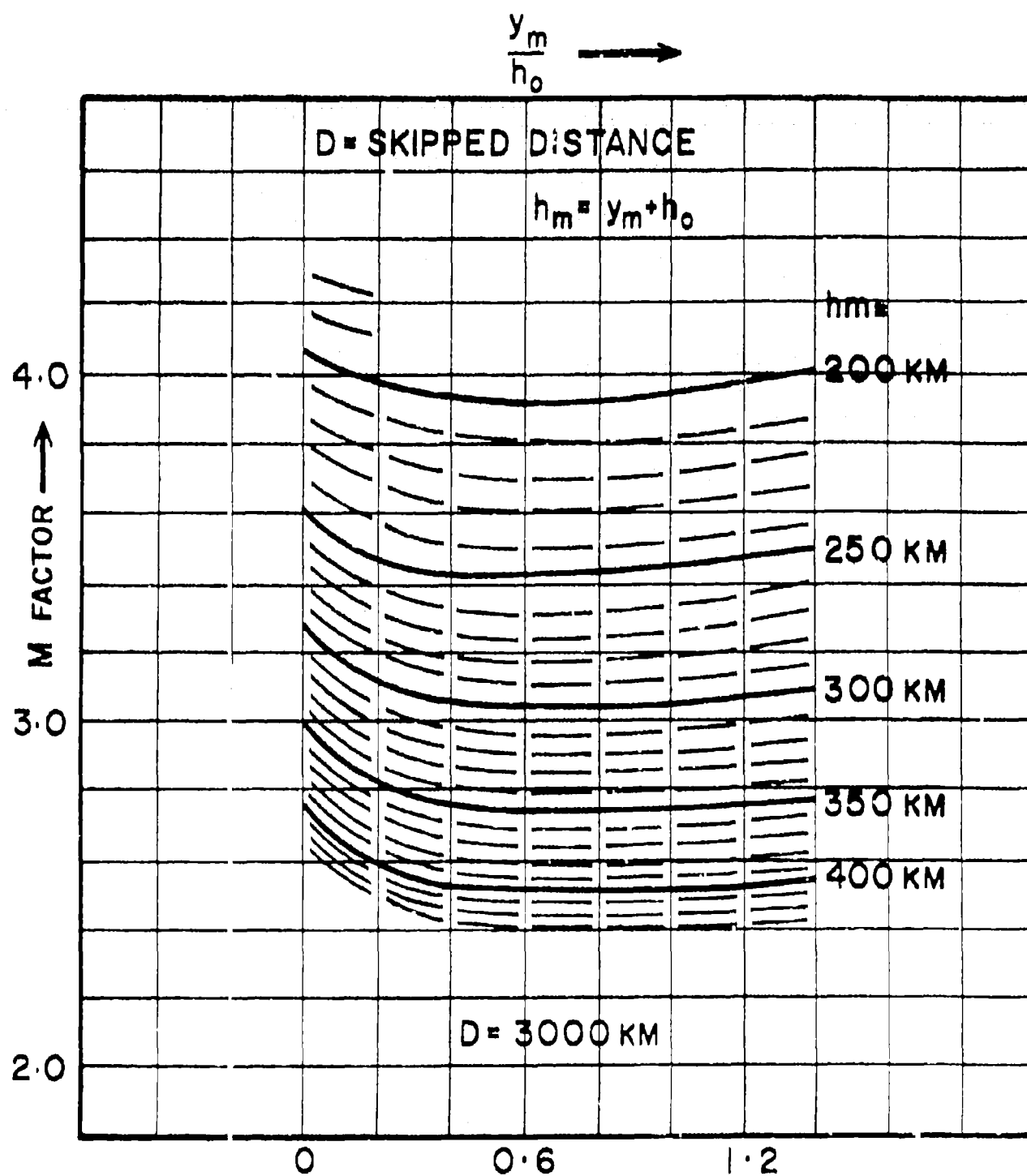
The calculation of the height of the F2 layer is achieved by knowledge of $M(3000)F2$ and the use of the Appleton-Beynon equations (Reference 1). Basically a parabolic model is fit to the nose of the F2 layer and knowing the half thickness y_p , the lower limit h_o of the bottom layer and the value of $M(3000)F2$, the simplified equations permit the calculation of h_p . The equations of Appleton and Beynon permit the construction of a family of curves

showing the variation of the M factor $MUF(3000)F2/f_oF2$ with distance for a range of values to the height of maximum electron density $h_p (=h_o + y_p)$ and for different values of the ratio y_p/h_o . Such a family of curves is shown in Figure 14. The equation used in this model for computing $h_p F2$ (see Section 6.1.5) is derived from these curves where, for a particular h_p , the M factor is constant over a wide range of y_p/h_o . This condition holds for $y_p/h_o \geq 0.4$. Examination of the curves shown in Figure 14 indicates that in general for accurate values of $M(3000)F2$, h_p will be accurate to ± 10 km. If this M factor is in error by $\pm 5\%$, we can have errors in h_p as large as ± 20 km. These errors will increase in the uncommon situations where y_p/h_o is smaller than 0.4.

6.2.8 Limitations in the Application of the Daily Solar Flux Update

Figure 11 shows the results of analyzing thousands of actual values of critical frequency against the predicted values, taking into consideration the daily and monthly solar flux. These values are typical for the following thirteen observing stations from which the data was reduced: Godhavn, Churchill, Boulder, White Sands, Hawaii, El Cerillo, Kenora, Paramaribo, Cocos Island, Buenos Aires, Hobart, Port Stanley, and Argentine Island. The only stations listed that are not on the North and South American chain are Hawaii, Cocos Island, and Hobart, but the results from these stations closely resemble the pattern set up by the American stations.

In using this update procedure outside the American chain one must, therefore, bear in mind that the pattern displayed in Figure 11 is not necessarily a worldwide pattern. However, the results from Hawaii, Cocos Island, and Hobart indicate that this update procedure can be used elsewhere with caution.



$$\text{M FACTOR} = \frac{M_{3000F2}}{f_o F2}$$

y_m = half thickness of layer

Figure 14. Family of Curves from the Appleton-Beynon Equation.

6.2.9 The Errors due to Neglecting Angular Refraction in the Computation of ΔR and $\Delta R'$

The computation of total electron content for determining the ionospheric range and range rate correction assumes the ray passes through the ionosphere undeviated. This assumption was made because the majority of the work for which the model was being developed was for VHF and S band frequencies. Should the actual path length of the ray be much different from the undeviated ray, as will be the case at lower frequencies, Maliphant (Reference 8) gives the following equation for true path length d and apparent path length d' ,

$$d = d' + \alpha R_e \cos E$$

where α is the angular separation of the true ray path above and below the ionosphere, R_e is the radius of the earth and E is the observed elevation angle at the earth's surface. Maliphant (Reference 8) also gives a formula for computing d in wavelengths.

6.2.10 Limitations in the Computation of Angular Refraction

In the computation of ionospheric elevation angle correction, we have used the technique of Maliphant (Reference 8). Anyone wishing to use this technique at frequencies close to critical frequency should read the above reference, in particular where the deviation factor $\left(\frac{foF2}{f} \sec \phi_i\right)$ is larger than 0.9. ϕ_i is the angle of incidence of the apparent direction of propagation measured from the vertical at the height of maximum electron density.

In the Maliphant formula the exact equation for ray deviation has been simplified by separating the functions that are sensitive to distribution changes, and then approximating these functions for a typical electron distribution. The resulting functions vary by only small amounts with changes in electron distribution of the earth's ionosphere so that the equation may be used for most of the values of the deviation factor. However, when the deviation factor is larger than 0.9, the deviation angle thus obtained should be used with

caution as the error may be quite large.

Ray trace comparison at VHF with the model described in this report have shown possible errors in elevation angle correction of only a few percent, and these occur only close to the horizon.

6.2.11 Additional Limitations to the Alternate Version of the Ionospheric Program due to Interpolation of the Preprocessed f_oF2 - h_p Tables

Section 3 2.1.1 CPC No. 12 describes how the tables with values of f_oF2 and h_p are computed and stored for specific times at one hour intervals around sunrise and two hour intervals otherwise, and for the locations around the station defined by the 25 point grid pattern shown in Figure 1 of that section. f_oF2 and h_p for any specific condition are later extracted from the tables by interpolating in time and space. Interpolation over stable ionospheric zones such as North America provides quite accurate results, but problems can arise at sunrise and at places with lower magnetic latitudes.

A number of simulations were performed for situations where the ionospheric gradients were changing rapidly in time around sunrise and in position around the equatorial anomaly. The following errors were detected when comparing the results from the time and space interpolation with the actual model values. In general h_p was interpolated to only two percent error or better than 10 km. The interpolation in f_oF2 , however, provided larger errors. At sunrise, the grid was computed at one hour intervals and the largest possible time interpolation over half an hour provided on the average an RMS error in $(f_oF2)^2$ of 8% with a maximum excursion to 16% for all values of f_oF2 larger than 6 MHz. But for critical frequencies smaller than 6 MHz, the percentage values can be quite a bit larger. Around the equatorial anomaly where the ionosphere changes faster with position than with time, the grid was computed every two hours, allowing for the largest time interpolation over one hour; again an RMS error of 8% in $(f_oF2)^2$ was noted and the maximum excursion was 19%.

10.0 Appendix I

The instruction listings in this section specify the exact configuration of the Bent Ionospheric Program ION and the alternate version TABGEN-ION1. The main programs and subroutines are listed in order of their CPC Numbers.

Requirements for version ION;

PROGRAM	ION,	CPC No. 1
SUBROUTINE	REFRAC,	CPC No. 2
SUBROUTINE	PLOTNH,	CPC No. 3
SUBROUTINE	PROFL1,	CPC No. 4
SUBROUTINE	PROFL2,	CPC No. 5
SUBROUTINE	BETA,	CPC No. 6
SUBROUTINE	SICOJT,	CPC No. 7
SUBROUTINE	DKSICO,	CPC No. 8
SUBROUTINE	MAGFIN,	CPC No. 9
SUBROUTINE	GK,	CPC No. 10
SUBROUTINE	DKGK,	CPC No. 11

Requirements for version TABGEN-ION1;

PROGRAM	TABGEN,	CPC No. 12 (subroutines of the above list required are SICOJT, DKSICO, MAGFIN, GK, DKGK)
PROGRAM	ION1,	CPC No. 13
SUBROUTINE	REFRC1,	CPC No. 14 (subroutines of the above list required are PROFL2, BETA)

ION, CPC, No. 1

```

C
C PROGRAM ION (INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT, TAPE1)
C COMPUTES IONOSPHERIC PROFILE PARAMETERS AND REFRACTION CORRECTIONS
C
C CONTENT OF COMMON BLOCKS EXPLAINED IN SUBROUTINE REFRAC
C COMMON /EVAL/ FS, FLAT, FLBN, FLEV, AZ, HS, EDOT, HDOT, TIME, FLXD, SIG, SIF,
C *IYR, MON, IDAY, IAPT, IDEL, IDRS, IUPDT, ITP
C COMMON /UPDT/ ULAT, ULBN, ULEV, UZIM, UT, UBS, IUTP, IUPDT
C COMMON /CORR/ DRANG, DRATE, DELEV, FOF2, HM, YM, YT, XK, TATN, TATNA

C
C DIMENSION XK(3), ISEL(5)
C DIMENSION MEAS(5,3), ULAT(8), ULBN(8), ULEV(8), UZIM(8), UBS(8), UT(8),
C *ITYP(8), FLX(31)
C DATA GO, C1000, C3600, DR, HR, P12/0., 1000., 3600., .C174532925,
C *.2617993875, .6, .2531850072 /
C DATA LYRHS, IDRS, IAPT/0, 0, 1/
C DATA MEAS/4, 3, 4-HSER, 4-HVED, 4-HSEP, 4-HHZ, 4-HBS, 4-HVERT, 4-HCON,
C *4-HTENT, 4-HE/4, 4-HBS, 4-HANG, 4-HCON, 4-HTENT, 4-HE/4/
C ITP=1

C
C SET UPDATE FLAG AND OUTPUT SELECTIONS
C READ(5,1) ISEL
C READ(5,1) IUPDT, IORDAY
C 1 FORMAT(5I5)
C DO 16 I=1,5
C IF (ISEL(I).EQ.0) IAPT=2
C 16 CONTINUE
C IF (ISEL(4).EQ.0) IAPT=3
C IF (ISEL(5).EQ.0) IAPT=4
C IF (IAPT.LT.3.AND. IORDAY.EQ.1) IAPT=3
C IDEL=ISEL(3)
C IF (IUPDT.EQ.0) WRITE(6,2)
C 2 FORMAT(14H *** NO UPDATE *** )
C 10 CONTINUE

C
C READ AND PRINT EVALUATION CONDITIONS
C READ(5,3) FS, FLAT, FLBN
C 3 FORMAT(F10.4, 2F10.5)
C IF (FS.LT.0.) GO TO 100
C READ(5,4) FLEV, AZ, HS, EDOT, HDOT
C 4 FORMAT(2F10.6, F10.0, 2E15.8)
C READ(5,5) IYR, MON, IDAY, TIME
C 5 FORMAT(3I5, F10.7)
C WRITE(6,1) FS, FLAT, FLBN, FLEV, AZ, HS, EDOT, IYR, MON, IDAY, TIME, HDOT
C 6 FORMAT(14H11H** INPUT **//
C * 11H FREQUENCY, F10.4, 15H MHZ, LATITUDE, F10.5,
C *27H DEG, LONGITUDE OF STATION, F10.5, 4H DEG/11H ELEVATION, F10.6,
C *15H DEG, AZIMUTH, F10.6, 27H DEG, HEIGHT OF SATELLITE, F11.1,
C *21H KM, ELEVATION RATE, E15.8, 4H RAD/SEC/6H YEAR, I2, 4H MONTH,
C *12, 6H DAY, I2, 10H, 0, TIME, F10.7, 5H KRS, 39X, 15H ALTITUDE RATE,
C *E15.8, 6H M/SEC)

```

ION,CPC No. 1

```

C      CONVERT UNITS
      FLAT=FLAT*DR
      FLBN=FLBN*DR
      ELEV=ELEV*DR
      AZ=AZ*DR
      HS=HS*Q1000
      TIME=TIME*HR
      IYRMB=IYR*100+MBN

C
C      READ AND SELECT SOLAR DATA
      IF(IYRMB.EQ.IYRMB) GO TO 30
      READ(8,7) IYM1,(FLX(1),I=1,16),IYM2,(FLX(1),I=17,31),IYM3,SIS,SIF
7  FORMAT(14,4X,16F4.1/14,16F4.1/14,2F5.1)
      IF(IYM1.EQ.IYM2.AND.IYM2.EQ.IYM3.AND.IYM3.EQ.IYRMB) GO TO 20
      WRITE(6,8) IYR,MBN
8  FORMAT(7,3H ***ERROR IN SOLAR INPUT DATA FOR YEAR=,12,11H AND MBN
      *TH=,12)
      GO TO 100
20  IYRMB=IYRMB
30  FLXD=FLX(10AY)
      WRITE(6,15) FLXD,SIF,SIS
15  FORMAT(12H DAILY FLUX=,F6.1,41H, 12-MONTH RUNNING AVERAGE OF SOLAR
      * FLUX=,F6.1,20H, OF SUNSPOT NUMBER=,F6.1)

C
C      READ AND PRINT UPDATE DATA
      IF(1UPDT.EQ.0) GO TO 50
      READ(5,1) NUPDT
      IF(NUPDT.EQ.0) GO TO 50
      MUPDT=NUPDT*8
      IF(MUPDT.GT.0) NUPDT=8
      WRITE(6,9)
9  FORMAT(7,13H UPDATE DATA=)
      DO 40 I=1,NUPDT
      READ(5,11) ULAT(1),ULBN(1),ULEV(1),UZIM(1),UT(1),SEBS(1),ITYPE
11  FORMAT(2F10.5,2F10.6,2F10.7,2F15.8,1F5)
      WRITE(6,12) ULAT(1),ULBN(1),ULEV(1),UZIM(1),UT(1),(MEAS(L,ITYPE),
      * L=1,4),SEBS(1),MEAS(5,ITYPE)
12  FORMAT(1X,11,5H) LAT=,F10.5,7H, LONG=,F10.5,7H, ELEV=,F10.6,7H, AZI
      * M=,F10.6,9H DEG, UT=,F10.7,6H HRS, 14A4,1H=E15.8,1X,A4)

C
C      CONVERT UNITS OF UPDATE DATA
      ULAT(1)=ULAT(1)*DR
      ULBN(1)=ULBN(1)*DR
      ULEV(1)=ULEV(1)*DR
      UZIM(1)=UZIM(1)*DR
      UT(1)=UT(1)*HR
40  ITP(1)=ITYPE
      IF(MUPDT.LE.0) GO TO 43
      DO 41 I=1,MUPDT
41  READ(5,11) SKIP
      WRITE(6,42)
42  FORMAT(31H REMAINING UPDATE DATA NOT USED)
43  CONTINUE

```

ION, CPC No. 1

```

C
C  COMPUTE AND PRINT IONOSPHERIC DATA
50 CALL REFRAC
   IF(IYR*LT*0) GO TO 10
   XMM=HM/01000
   WRITE(6,21) XMM,FOF2
21  FORMAT(7/13H ** OUTPUT ** 7/35H HEIGHT AT MAXIMUM ELECTRON DENSITY,
   *10X,3HH*,F8.3,30H KM, CRITICAL FREQUENCY FOF2*,F7.3,4H MHZ)
   IF(ISEL(1) *NE*0) GO TO 17
   XMM=YM/01000
   XYT=YT/01000
   WRITE(6,22) TSTN,TSTNA,XMM,XYT,XK
22  FORMAT(40H TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL NT*,E13.6,
   *25H E/(M*H), ANGULAR STA*,E13.6,15H E/(M*H CBLUMN)/
   *58H HALF THICKNESS OF BOTTOMSIDE BIPARABOLA YM*,F8.3,
   *30H KM, OF TOPSIDE PARABOLA YT*,F8.3,3H KM/
   *58H DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1*,
   *E12.5,12H, MIDDLE K2*,E12.5,11H, UPPER K3*,F12.5,4H 1/M)
17  IF(ISEL(3) *NE*0) GO TO 18
   TELEV=ELEV*GRACC /DR
   WRITE(6,23) TELEV
23  FORMAT(54H IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE*,
   *E13.6,11H SEC OF ARC)
18  IF(ISEL(4) *EQ*0) WRITE(6,24) ORANG
24  FORMAT(63H IONOSPHERIC REFRACTION CORRECTION TO RANGE,10X,1H*,
   *E13.6,2H M)
   IF(ISEL(5) *EQ*0) WRITE(6,25) ORATE
25  FORMAT(54H IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE
   *E13.6,2H 1/SEC)
   IF(ISEL(2) *EQ*0) CALL PLTAL(FOF2,XM,YM,YT,XK)
   IF(IORDAY*E*1) GO TO 10

```

```

C
C  COMPUTE RANGE RATE CORR. FOR OBSERVATION OVER FINITE TIME
C  TIME
   READ(5,13) ELEV,AZ,HS,TIME
13  FORMAT(2F10.6,F10.0,F10.7)
   WRITE(6,14) ELEV,AZ,HS,TIME
14  FORMAT(7/37H ** INPUT ** SECOND SATELLITE POSITION USED FOR RANGE
   * DIFFERENCING/13X,11H ELEVATION*,F10.6,15H DEG, AZIMUTH*,F10.6,
   *14H DEG, HEIGHT*,F11.0,13H KM, LTIME*,F10.7,4H HRS)
   ELEV=ELEV*DR
   AZ=AZ*DR
   HS=HS*01000
   TIME=TIME*HR
   DT=TIME-OT
   IF(DT*01.10) DT=H12*DT
   OT=OT*036107*HR
   ORANGS=ORANG
   IORD=1
   CALL REFRAC
   IORD=0
   ORDAY=((ORANG-ORANGS)/DT
   WRITE(6,25) DT,ORDAY

```

ION, CPC No. 1

```
26 FORMAT(13H ** OUTPUT **/13X,51H RANGE RATE CORRECTION FOR RANGE DI  
  *FREQUENCY OVER ,F10.4,10H SECONDS *,E14.6,6H M/SEC)  
  GO TO 10  
100 CONTINUE  
  STOP  
  END
```

REFRAC, CPC No. 2

```

C
C      IONOSPHERIC REFRACTION MODEL
C      SUBROUTINE REFRAC
C
C      INPUT: COMMON /EVAL/, COMMON /UPDT/
C      OUTPUT: COMMON /OBSR/
C
C      COMMON /EVAL/ FS, FLAT, FLON, ELEV, AZ, HS, EDBT, HDBT, TIME, FLXD, SIS, SIF,
C      *IYR, MON, IDAY, IPRT, IDEL, IDRD, IUPDT, ITP
C
C      FS   ■ TRANSMISSION FREQUENCY IN MHZ
C      FLAT ■ STATION LATITUDE IN RADIANS OF ARC
C      FLON ■ STATION LONGITUDE IN RADIANS OF ARC (POSITIVE EAST, 0 TO 360 D)
C      ELEV ■ ELEVATION OF SATELLITE IN RADIANS OF ARC
C      AZ   ■ AZIMUTH OF SATELLITE IN RADIANS OF ARC
C      HS   ■ HEIGHT OF SATELLITE IN METERS
C      EDBT ■ ELEVATION RATE IN RADIANS OF ARC/SECOND
C      HDBT ■ RATE OF CHANGE IN HEIGHT OF SATELLITE IN METERS/SECOND
C      TIME ■ UNIVERSAL TIME IN RADIANS OF ARC
C      FLXD ■ DAILY SOLAR FLUX
C      SIS  ■ 12 MONTH RUNNING AVERAGE OF SUNSPOT NUMBER
C      SIF  ■ 12 MONTH RUNNING AVERAGE OF SOLAR FLUX
C      IYR  ■ YEAR (LAST 2 DIGITS ONLY)
C      MON  ■ MONTH (1-12)
C      IDAY ■ DAY (1-31)
C      IPRT ■ OUTPUT SELECTION FLAG, #1 COMPUTE FOF2, HM,
C      *#2 ALSO COMPUTE PROFILE PARAMETERS, ELECTRON CONTENT
C      *#3 ALSO COMPUTE RANGE CORRECTION
C      *#4 ALSO COMPUTE RANGE RATE CORRECTION
C      IDEL ■ SELECTION FLAG TO ELEVATION CORRECTION, #0 COMPUTE, #1 NOT
C      IDRD ■ FLAG FOR CORRECTION TO RANGE DIFFERENCING, #1 FOR RANGE
C      *CORRECTION TO 2 POINTS, #0 OTHERWISE
C      IUPDT ■ UPDATE FLAG, #0 NO UPDATE, #1 UPDATE
C      ITP  ■ UNIT ASSIGNMENT OF IONOSPHERIC COEFFICIENT TABLE
C
C      COMMON /UPDT/ LAT, LON, ELEV, AZ, UT, HBS, ITYP, NUPDT
C
C      LAT ■ ARRAY WITH LATITUDES OF UPDATE STATIONS (RADIANS)
C      LON ■ ARRAY WITH LONGITUDES OF UPDATE STATIONS (RADIANS)
C      ELEV ■ ARRAY WITH ELEVATIONS TO SATELLITE (RADIANS)
C      AZIM ■ ARRAY WITH AZIMUTHS TO SATELLITE (RADIANS)
C      UT   ■ ARRAY WITH UNIVERSAL TIMES OF OBSERVATIONS (RADIANS)
C      HBS  ■ ARRAY WITH IONOSPHERIC OBSERVATIONS (MHZ OR E/M**2)
C      ITYP ■ ARRAY WITH OBSERVATION TYPES, #1 FOF2, #2 VERT.E.C., #3 ANGLE.E.C.
C      NUPDT ■ NUMBER OF UPDATE CONDITIONS
C
C      COMMON /OBSR/ DRANG, DRATE, DELEV, FOF2, HM, YM, YT, XK, TBTN, TBTNA
C
C      DRANG ■ RANGE CORRECTION IN METERS
C      DRATE ■ RANGE RATE CORRECTION IN METERS/SECOND
C      DELEV ■ ELEVATION ANGLE CORRECTION IN RADIANS OF ARC
C      *RANGE, RANGE RATE, AND ELEVATION ANGLE CORRECTIONS ARE TO BE
C      *SUBTRACTED FROM THEIR RESPECTIVE OBSERVATIONS
C      FOF2 ■ CRITICAL FREQUENCY (MHZ)
C      HM   ■ HEIGHT AT MAXIMUM ELECTRON DENSITY (M)

```

REFRAC, CPC No. 2

```

C  YN  = HALF THICKNESS OF THE BOTTOMSIDE BIPARABOLA (M)
C  YT  = HALF THICKNESS OF THE TOPSIDE PARABOLA (M)
C  XK  = ARRAY CONTAINING DECAY CONSTANTS FOR THE LOWER, MIDDLE AND
C        UPPER SECTION OF THE TOPSIDE EXPONENTIAL LAYER (1/M)
C  TOTN = VERTICAL ELECTRON CONTENT (E/M**2)
C  TOTNA= ANGULAR ELECTRON CONTENT (E/M**2)
C
C        DIMENSION ULAT(8),ULBN(8),ULEV(8),UZIM(8),ITYP(8),BBS(8)
C        DIMENSION UT(8),FACF2(8),W(8,3),WT(8),XK(3),DB(3)
C        DIMENSION WCOEF(3,13,76),L(13,76),UM(9,49),UM1(9,49)
C        DATA MBNDY,MBND,LYRMB/0,10000,0/
C        DATA R,STRS,TBL/6371.253,36.E6,1.E-6/
C        DATA Q0,Q1,Q100,Q130,QF1,QNM,RN3,PI,PI2/0.,1.,100.,130.,
C        *.1,1.24E10,.49972,3.1415926536,16.2831853072 /
C
C        INITIALIZE CONSTANTS
C        DELEV=Q0
C        DRANG=Q0
C        DRATE=Q0
C        TOTN =Q0
C        TOTNA=Q0
C        IFLAG=0
C        ISKIP=0
C        IYRMB=IYR+100+MBN
C        IMBNDY=MBN+100+IDAY
C
C        READ COEFFICIENT TAPE AND FORM COEFFICIENT ARRAYS
C
10  IF (IMBNDY.LE.MBNDY.AND.(IMBNDY.GE.MBND)) GO TO 29
20  READ(IIP) LBND,LENDY,WCOEF,UM,UM1
    IF (EOP,IIP) 23,22
22  ISKIP=1
    MBND=LBND
    MBNDY=LENDY
    GO TO 10
23  REWIND IIP
    IFLAG=IFLAG+1
    IF (IFLAG.LE.1) GO TO 20
    WRITE(6,25) IYR,MBN,IDAY
25  FORMAT(54H ***COEFFICIENTS NOT FOUND ON TAPE FOR YEAR,MONTH,DAY=,
    *3I3)
    IYR=-1
    GO TO 140
29  IF (ISKIP.EQ.0.AND.(IYRMB.EQ.LYRMB)) GO TO 80
    LYRMB=IYRMB
    DO 62 J=1,49
    DO 62 I=1,9
    UM(I,J)=UM(I,J)+(UM1(I,J)-UM(I,J))*SIS/Q100
62  CONTINUE
    DO 70 J=1,76
    DO 70 I=1,13
    U(I,J)=WCOEF(1,I,J)+(WCOEF(2,I,J)+WCOEF(3,I,J)*SIF)*SIF
70  U(I,J)=WCOEF(1,I,J)+(WCOEF(2,I,J)+WCOEF(3,I,J)*SIF)*SIF
80  CONTINUE

```

REFRAC, CPC No. 2

```

C
C     PREPARE SOLAR DATA
C     FLUX=FLX0
C     IF (FLUX.LT.0P1)   FLUX=51F
C     DFLUX=FLUX*51F
C     IF (FLUX.GT.0130)  FLUX=0130
C
C     COMPUTE FIRST PART OF PROFILE
C     CALL PRPF1(FLAT,FLBN,ELEV,AZ,TIME,DFLUX,UM,
C     *          BLAT,BLON,FOF2,HM,PLAT)
C     IF (NUPDT.EQ.0) GO TO 115
C     IF (NUPDT.EQ.0) GO TO 115
C
C     UPDATE COMPUTED FOF2 WITH ANY OF FOLLOWING 10% OBSERVATIONS,
C     *TYP(1)=1 FOF2, *2 VERT.ELECTRON CONTENT, *3 ANGL.CONTENT
C     *UP TO 8 MEASURED ENTRIES CAN BE USED FOR THE UPDATE PROCESS
C     DO 100 I=1,NUPDT
C     BBSERV=BBS(I)
C     IF (TYP(1).LE.2) GO TO 85
C     BBSERV=BBSERV+ SQRT(Q1*(R+ CBS(ULEV(I))/(R+HM))*2)
85 CALL PRPF1(ULAT(I),ULEN(I),ULEV(I),OZIM(I),UT(I),DFLUX,UM,
C     *          TLAY,TLBN,STF2,STHM,STHLAT)
C     IF (TYP(1).GT.1) CALL PRPF2(TLAT,TLBN,STRS,UT(I),IDAY,MBN,FLUX,
C     *STF2,STHM,STHLAT, D1,D2,D3,D4,SLAB)
C     FAF2(I)=BBSERV/STF2
C     IF (TYP(1).GE.2) FAF2(I)= SQRT(FAF2(I)/(GM*STF2*SLAB))
C     IF (NUPDT.EQ.1) GO TO 110
C
C     FORM WEIGHTS FOR MULTIPLE UPDATE STATIONS
C     W(1,1)= ABS(TIME-UT(I))
C     IF (W(1,1).GT.P1) W(1,1)=P12-W(1,1)
C     CANG= SIN(TLAT)* SIN(BLAT)+ COS(TLAT)* CBS(BLAT)* COS(TLBN-B_LBN)
C     SANG= SQRT(Q1-CANG**2)
C     W(1,2)= ABS( ATAN(SANG/CANG))
90 W(1,3)=W(1,1)*W(1,2)
C
C     DETERMINE WEIGHTS TO BE USED
C     M1=0
C     M2=0
C     DO 95 I=2,NUPDT
C     IF (ABS(W(1,1)-W(I,1)).GT.TOL) M1=1
C     IF (ABS(W(1,2)-W(I,2)).GT.TOL) M2=2
95 CONTINUE
C     MARK=M1+M2
C     IF (MARK.EQ.0) GO TO 110
C
C     COMBINE WEIGHTS AND APPLY 1% UPDATE RATIO
C     DO 100 J=1,NUPDT
C     WT(I)=Q1
C     DO 100 U=1,NUPDT
C     IF (I.EQ.U) GO TO 100
C     WT(I)=WT(I)*W(U,MARK)
100 CONTINUE

```

REFRAC, CPC No. 2

```

CBEF=Q0
FUNC=Q0
DO 105 I=1,NUPDT
CBEF=CBEF+AT(I)
105 FUNC=FUNC+AT(I)*FACF2(I)
   FACF2(I)=FUNC/CBEF
C
C      UPDATE FCF2 RE EVALUATION CONDITION
110 FCF2=FCF2+FACF2(I)
115 CONTINUE
   IF(IOPRT.EQ.1) GO TO 140
C
C      COMPUTE SECOND PART OF PROFILE
CALL PRFPL2(BLAT,PLEN,HS,TIME,IDAY,MN,FLUX,FCF2,HM,HLAT,
*          YM,MT,XK,RNM,XATNM)
   IF(XATNM.LE.Q0) GO TO 140
C
C      COMPUTE ELEVATION ANGLE CORRECTION DELEV
FRAT=(FCF2/FS)**2
SE= SIN(ELEV)
CE= COS(ELEV)
IF(IDEL.NE.Q0.OR.IDRD.EQ.1) GO TO 120
CALL BETAFRAT,XATNM,HS,HM,YM,SE,CE,DELEV)
C
C      COMPUTE VERTICAL AND ANGULAR ELECTRON CONTENT TBTN,TATNA
C      COMPUTE RANGE CORRECTION DRANG
120 CONTINUE
RAT=(R/(1+HM))**2
DEN2=Q1-RAT*CE**2
DEN= SQRT(DEN2)
TBTN=XATNM*NM*FCF2**2
TATNA=TBTN/DEN
   IF(IOPRT.LE.3) GO TO 140
DRANG=FRAT*RN3*XATNM/DEN
C
C      COMPUTE RANGE RATE CORRECTION DRATE
   IF(IOPRT.LE.4.OR.IDRD.EQ.1) GO TO 140
DRATE=DRANG*EDRT*RAT*SE*CE/DEN2
DRATE=DRATE-FRAT*RN3*HDPT*ERM/DEN
140 CONTINUE
RETURN
END

```

PLOTNH, CPC No. 3

```

C
C
C      PLOT AND PRINT ELECTRON DENSITY VERSUS HEIGHT PROFILE
C      INPUT FOF2 IN MHZ,  HM,YM,YT  IN METER,  XK IN 1/METER
C
      SUBROUTINE PLOTNH (FOF2, HM, YM, YT, XK)
      DIMENSION XK(3),U(73),H(2),IH(2),XN(2),HT(5),ED(5)
      DATA G0,G1,IBLANK,MARK/0.,1.,1H,1H*/
      DATA G3,110,227,G124E,G1012E,G1025E,22025E,225E/3.,10.,27.,
      *1.2+E10,1012+E3,1025+E3,2025+E3,25+E3/
      WRITE(6,1)

C
C      COMPUTE PROFILE CONSTANTS
C
      Q = -(G1- SQRT(G1+(XK(1)+YT)**2))/XK(1)
      HT(5) = HM+YM
      HT(4) = HM
      HT(3) = HM+Q
      DELH = (G1012E-HT(3))/G3
      HT(2) = HT(3)+DELH
      HT(1) = HT(2)+DELH
      ED(5) = G124E *FOF2**2
      ED(4) = ED(5)
      ED(3) = ED(4) + (G1-(1/YT)**2)
      ED(2) = ED(3) + EXP(XK(1)*(HT(3)-HT(2)))
      ED(1) = ED(2) + EXP(XK(2)*(HT(2)-HT(1)))

C
C      INITIALIZE LOOP FOR PLOT
C
      H(1) = G1025E
      H(2) = G2025E
      IH(1) = 1025
      IH(2) = 2025
      DO 130 I=1,40
      DO 90 K=1,2
      H(K) = H(K) - 125E
      IH(K) = IH(K) - 25

C
C      COMPUTE ELECTRON DENSITY AT HEIGHT H
C
      DO 10 L=1,5
      IF (H(K).GE.HT(L)) GO TO 20
10  CONTINUE
      ZN=60
      GO TO 40
20  DH=H(K)-HT(L)
      GO TO (30,40,50,60,70),L
30  ZN = EXP(-XK(3)*DH)
      GO TO 40
40  ZN = EXP(-XK(2)*DH)
      GO TO 50
50  ZN = EXP(-XK(1)*DH)
      GO TO 60
60  ZN=G1-(DH/YT)**2
      GO TO 40
70  ZN=(G1-(G1-DH/YM)**2)**2

```

PLOTNH, CPC No. 3

```

80 XN(K)=ED(L)*ZN
90 CONTINUE

C
C      PLST AND PRINT
      XNL=90
      IF(XN(1).LE.90) GO TO 100
      XNL=LOG10(XN(1))
100 CONTINUE
      DB=110 L=1.73
110 J(L)=IMLANK
      NB=(XNL-610)*327+21
      IF(NB.LT.1.HR.NB.GT.73) GO TO 120
      J(NB)=MARK
120 WRITE(6,2) IH(1),J,XN(1),IH(2),XN(2)
130 CONTINUE
      WRITE(6,3)
1  FORMAT (1H1,11HHEIGHT (MM),51X,57HVERSUS ELECTRON DENSITY (E/M**3
  * ) HEIGHT (G. LL.DENSITY)
2  FORMAT(1X,14,2H +,73A1.4H--- ,D11.4,5X,14,5H --- ,D11.4)
3  FORMAT(7X,2(1H+,17(1H-),1H+,8(1H-)),1H+,17(1H-),1H+/
  *5X,5H1.E10,22X,5H1.E11,22X,5H1.E12/
  *30X,37HLOG SCALE = ELECTRON DENSITY (E/M**3))
      RETURN
      END

```

PROFL1, CPC No. 4

```

C      COMPUTE FIRST PART OF PROFILE: CRITICAL FREQUENCY FOF2 AND
C      CORRESPONDING HEIGHT HM
C      SUBROUTINE PRBF1(FLAT,FLBN,ELEV,AZ,TIME,DFLUX,UM,UM)
C      *      FLAT,BLBN,FOF2,HM,FLAT)
C      DIMENSION K(10),U(13,76),KM(10),UM(9,49),CBT(6),SIT(6),P(3),CBM(3)
C      *C(3),G(76),DF(76),GM(49),DM(49)
C      DIMENSION    CG(3)    ,CENT(3)
C      DATA K/11,36,53,63,67,69,71,73,75,67, KM10/4/
C      DATA KM/1,7,13,28,37,48,55,60,65,72//,NFF,NMF/76,49/
C      DATA G1,1000,3375/1, ,1000, ,300000, /
C      DATA D180,73/3,1415926536 ,1.02974426 ,.48869219 ,.07595865 /
C      DATA R,SLAT,CLAT,PLBN/6371.023,1.9799246,1.993684,5.078908/
C      DATA H1,H2,H3/1346.92 ,526.4 ,59.825 /
C      DATA PB,CENT/100133 ,1.035 ,.957 ,.9 /
C
C      P(3)=CBT5
C      SLAT= SIN(FLAT)
C      CLAT= COS(FLAT)
C      SEL= SIN(ELEV)
C      CEL= COS(ELEV)
C      SAZ= SIN(AZ)
C      CAZ= COS(AZ)
C
C      COMPUTE TIME DEPENDENT FUNCTIONS FOR FOF2 AND M3000
C      T=TIME-D130
C      CALL SIGDET(6,CBT,SIT,T)
C      CALL DKSIDE(NFF,K(10),,SIT,CBT,DF)
C      CALL DKSIDE(NMF,KM10,UM,SIT,CBT,DM)
C
C      COMPUTE LATITUDE, LONGITUDE OF REF IONOSPHERIC POINT PLAT,BLBN
23 CONTINUE
C      SF=R*CEL/(1+P(3))
C      CF= SQRT(1-SF*SF)
C      SA = CEL * CF * SEL * SF
C      CA = SEL * CF * CEL * SF
C      SCLAT=SLAT*CA+CLAT*SA*CAZ
C      CCLAT= SQRT(1-SCLAT*SCLAT)
C      BLAT= ATAN(SCLAT/CCLAT)
C      SOLBN=SAZ*SA/CCLAT
C      COLBN= SQRT(1-SOLBN*SOLBN)
C      BLBN=FLBN+ ATAN(SOLBN/COLBN)
C
C      COMPUTE POSITION DEPENDENT FUNCTIONS FOR FOF2 AND M3000
C      P(1)=BLAT
C      P(2)=BLBN
C      CALL MAGFIN(P,CBM)
C      TMP=CBM(2)*CM(2)+CBM(3)*CBM(3)
C      C(2)=P(2)
C      C(3)=P(1)
C      C(1)=ATAN(ATAN(CBM(1)/ SQRT(TMP))/ SQRT(CCLAT))
C      CALL GR(P,C)

```

PROFL1, CPC No. 4

```

KK = 0
DO 15 II=1,10,P
  I1=KN(II)
  I2=KN(II+1)
  DO 15 J=11,1P
    KK = KK + 1
15  GM(KK)=G(J)

C
C      COMPUTE H3000 AND HEIGHT OF MAX. ELECTRON DENSITY HM
CALL DKCK(IMEF,GM,DM,H3000)
HM = (H1+2+H3000+H2+H3000+3000)*01000
IF(ABS(F(3)-HM).LT.01000) GO TO 24
F(3)=HM
GO TO 23

C
C      COMPUTE FOF2 AND ADJUST FOF2 FOR DAILY VARIATION WITH FLUX
2- CONTINUE
CALL DKCK(IMEF,GJ,GF,FOF2)
SML = SMLAT + SPLAT + CNLAT + CPLAT + CRS(PLAN-PLAN)
CML = SQRT(G1=SML*SML)
HLAT = ATAN(SML/CML)
LAT1 = 1
LAT2 = 1
IF(HLAT.GE.DG(LAT2)) GO TO 21
LAT2 = 2
IF(HLAT.GT.DG(LAT2)) GO TO 21
LAT1 = 2
IF(HLAT.EQ.DG(LAT2)) GO TO 21
LAT2 = 3
IF(HLAT.GT.DG(LAT2)) GO TO 21
LAT1 = 3
21 CNT = CENT(LAT1)
IF(LAT1.EQ.LAT2) GO TO 22
CNT = CNT + (CENT(LAT2)-CENT(LAT1)) * (DG(LAT1)-HLAT)
* / (DG(LAT1)-DG(LAT2))
22 FOF2 = FOF2 + (PER*DFLUX + CNT)
RETURN
END

```

CCC

CCC

PROFL2, CPC No. 5

C
C

```

      COMPUTE HALF THICKNESS YM
      T12=TL0C/D30
      LT1=T12
      T1=LT1
      LT2=LT1+1
      IF(LT1.EQ.12) LT2=LT1
      IF(LT1.GE.1) GO TO 55
      LT1=12
55    T1=T12+T1
      IF1=FOF2-QP95
      IF2=FOF2-QP05
      IF(IF1.LT.1) IF1=1
      IF(IF1.GT.9) IF1=9
      IF(IF2.LT.1) IF2=1
      IF(IF2.GT.9) IF2=9
      Y1=(YMTAB(LT1,IF1)+(YMTAB(LT2,IF1)-YMTAB(LT1,IF1))*T1)*Q1000
      IF(IF1.EQ.12) GO TO 60
      Y2=(YMTAB(LT1,IF2)+(YMTAB(LT2,IF2)-YMTAB(LT1,IF2))*T1)*Q1000
      F1=IF1
      Y1=Y1+(Y2-Y1)*(FOF2-F1-Q1)
60    CONTINUE

```

C
C

```

      COMPUTE DIFFERENCE BETWEEN AVER. AND DAILY SOLAR ZENITH ANGLE DSZA
      DAY=(MON-1)*30+IDAY-80
      DSZA=S01* SIN(S02*DAY)
      IF(ABS(OLAT).LT.S01) GO TO 61
      IF(OLAT.LT.Q0) DSZA=-DSZA
      GO TO 62
61    SANG=OLAT/S01
      CANG= SQRT(Q1-ABS(SANG*SANG))
      DANG= ATAN(SANG/CANG)
      ASZA=S01*(CANG+SANG*DANG)/PIH
      DSZA=ASZA-ABS(OLAT-DSZA)

```

C
C

```

      APPLY SEASONAL EFFECT OF DSZA TO HALF THICKNESS YM
62    S12=Q4*DSZA/D8
      IF1=S12
      S1=IF1
      S1=S12-S1
      IF2=IF1+1
      RAT=Q0
      IF(HLAT.LE.D5) GO TO 63
      T12=(TL0C+D7P5)/PIH
      LT1=T12
      T1=LT1
      LT2=LT1+1
      IF(LT2.GT.4) LT2=1
      IF(LT1.LT.1) LT1=4
      RAT1=YRAT(IF1,LT1)+(YRAT(IF2,LT1)-YRAT(IF1,LT1))*S1
      RAT2=YRAT(IF1,LT2)+(YRAT(IF2,LT2)-YRAT(IF1,LT2))*S1
      RAT=RAT1+(RAT2-RAT1)*(T12-T1)
      IF(HLAT.GE.DEG(3)) GO TO 64

```

PROFL2, CPC No. 5

```

63 T12=(TLOC+D135)/D180*Q1
   IF(T12*GT*Q1) T12=Q2+T12
   IF(T12*LT*Q0) T12=T12
   RAT1=YRAT(IF1,5)+(YRAT(IF2,5)-YRAT(IF1,5))*S1
   RAT2=YRAT(IF1,6)+(YRAT(IF2,6)-YRAT(IF1,6))*S1
   RATH=RAT1+(RAT2-RAT1)*T12
   RAT=RATH+(RAT-RATH)*(HLAT-D5)/D10
   IF(HLAT*LE*D5) RAT=RATH
64 YR=YR*RAT

```

C
C

```

      COMPUTE K-PARAMETERS XK
      FGF2 = RN4 + FGF2
      I1=2
      I2=2
      IF(HLAT*DEG(2))28,30,29
28 I1=3
   IF(HLAT*LE*DEG(3))I2=3
   GO TO 30
29 I2=1
   IF(HLAT*GE*DEG(1))I1=1
30 J = (FGF2 + Q1)/Q3
   XF=QC
   IF(J*GE*1) GO TO 35
   J=1
   GO TO 45
35 IF(J*LT*4) GO TO 40
   J=4
   GO TO 45
40 F1=J
   XF = (FGF2 + Q1)/Q3 * F1
45 DO 51 M=1,3
   SLP=(SLP(J+1,I1,M)-SLP(J,I1,M))*XF+SLP(J,I1,M)
   CPT=(CPT(J+1,I1,M)-CPT(J,I1,M))*XF+CPT(J,I1,M)
   IF(I1*EQ*12) GO TO 50
   DEL=(HLAT-DEG(I1))/(DEG(12)-DEG(I1))
   SLP=SLP+((SLP(J+1,I2,M)-SLP(J,I2,M))*XF+SLP(J,I2,M)-SLP)*DEL
   CPT=CPT+((CPT(J+1,I2,M)-CPT(J,I2,M))*XF+CPT(J,I2,M)-CPT)*DEL
50 XK(M) = SLP * FLUX + CPT
51 CONTINUE

```

C
C

```

      APPLY SEASONAL EFFECT OF DSZA TO DECAY CONSTANTS XK
      T12=TLOC/DEG(3)+Q8
      IF(T12*LT*Q0) T12=T12+Q2+
      T12=T12/Q6+Q1
      LT1=T12
      T1=LT1
      LT2=LT1+1
      IF(LT2*GT*4) LT2=1
      S12=Q2P5-DSZA/D16
      IF1=S12
      S1=IF1
      S1=S12-S1
      IF2=IF1+1

```

PROFL2, CPC No. 5

```

DO 52 M=1,3
RAT1=RATK(IF1,LT1,M)*(RATK(IF2,LT1,M)-RATK(IF1,LT1,M))*81
RAT2=RATK(IF1,LT2,M)*(RATK(IF2,LT2,M)-RATK(IF1,LT2,M))*81
RAT = RAT1 + (RAT2-RAT1) * (T12-T1)
52 XK(M)=XK(M)*RAT

C
C      COMPUTE HALF THICKNESS OF TOPSIDE PARABOLA YT
CONV=Q1
IF(FOF2.LE.Q10P5) GO TO 71
CONV=Q1333*(FOF2-Q10P5)+Q1
71 CONTINUE
YT=CONV*YM

C
C      COMPUTE HDBT MULTIPLIER FOR RANGE RATE COMPUTATION RRM
C      COMPUTE TOTAL ELECTRON CONTENT / ELECTRON DENSITY XNTNM
XNTNM=Q0
RRM=Q0
DO=(Q1-SQRT(Q1+(XK(1)*YT)**2))/XK(1)
H(1)=HM+D
IF(HS.LE.H(1)) GO TO 80
RRM=Q1
DELH = (-1012 - H(1))/Q3
H(2) = H(1) + DELH
H(3)=H(2)+DELH
H(4)=HS
M=3
65 IF(HS.GT.H(M)) GO TO 70
H(M)=H(M+1)
MM=M+1
IF(M.GT.1) GO TO 65
70 DH(M)=H(M+1)-H(M)
RK=Q1/XK(M)
EX=Q0
ARG=XK(M)*DH(M)
IF(ARG.LT.Q37) EX= EXP(-ARG)
RRM=RRM*EX
XNTNM=RK+EX*(XNTNM-RK)
M=M+1
IF(M.GT.4) GO TO 70
TEMP=Q8815*YM+Q-Q**3/(Q3*YT*YT)
TEMP1=Q1-(Q/YT)**2
RRM=RRM*TEMP1
XNTNM=TEMP1*XNTNM+TEMP
GO TO 110
80 IF(HS.LE.(HM+YM)) GO TO 110
DIST= HM-HS
IF(HS.LT. HM) GO TO 90
XNTNM=Q8815*YM-DIST+DIST**3/(Q3*YT*YT)
RRM=Q1-((HM-HS)/YT)**2
GO TO 110
90 CONTINUE
XNTNM=Q8815*YM-DIST+Q2*DIST**3/(Q3*YM**2)-DIST**5/(Q5*YM**4)
RRM=(Q1-((HM-HS)/YM)**2)**2

```

PROFL2, CPC No. 5

110 CONTINUE
RETURN
END

BETA, CPC No. 6

```

C
SUBROUTINE BETA(FRAT,XNTNM,HS,HH,YM,BE,CE,DELEV)
C
C   BETA COMPUTES IONOSPHERIC ELEVATION ANGLE CORRECTION TO BE
C   SUBTRACTED FROM MEASURED ELEVATION ANGLE
C   DIMENSION XAX(5),YAX(5)
C   DATA R/Q0, .01,05333,Q2/6371.2E3,0. , 1.E0,.5333E0,2.E0/
C   DATA XAX/0.E0, .2E0, .4E0, .6E0, .81E0/
C   DATA YAX/1.E0,.924E0,.824E0,.7E0,.553E0/
C   R2=R*R
C   RS=HS+R
C
C   COMPUTE SQUARED DEVIATION FACTOR XCBM
C   R0M=R+ HM
C   SF10=R*CE/R0M
C   CF10= SQRT(Q1-SF10**2)
C   XCBM=FRAT/CF10**2
C
C   INTERPOLATE TABULATED VALUES YAX TO GET YCBM
C   DO 30 I=1,5
C   IF(XCBM-XAX(I))20,10,30
10 YCBM=YAX(I)
   GB TO 40
20 YCBM=YAX(I)+(YAX(I+1)-YAX(I))*(XCBM-XAX(I))/(XAX(I+1)-XAX(I))
   GB TO 40
30 CONTINUE
   GB TO 50
40 YCBM=Q1/YCBM
C
C   COMPUTE DEVIATION ANGLE ALPHA
C   R00=R0M+Q5333*YM
C   SF10=R*CE/R00
C   CF10= SQRT(Q1-SF10**2)
C   ALPHA=FRAT*YCBM*XNTNM*SF10/(Q2*R00*CF10**3)
C
C   COMPUTE ELEVATION ANGLE CORRECTION
C   CA= COS(ALPHA)
C   SA= SIN(ALPHA)
C   X3=R*CE*SA/(Q1+CA)
C   X2=R*SE*X3
C   X1= SQRT(RS**2-R2*CE**2)+X3
C   CTE=(X1+CA*X2)/ SQRT(X1**2+X2**2+Q2*X1*X2*CA)
C   STE= SQRT( ABS(Q1-CTE**2))
C   DELEV= ATAN(STE/CTE)
C   RETURN
50 WRITE(6,1)
1 FORMAT( 112H *** RAY IS REFLECTED AT IONOSPHERE OR NEAR REFLECTIO
  N CONDITION, ELEVATION ANGLE CORRECTION IS NOT COMPUTED ***)
C   DELEV=Q0
C   RETURN
C   END

```

SICOJT, CPC No. 7

```

C
C
C
C
SUBROUTINE SICOJT(L,C,S,T)
  COMPUTE SIN(JT),COS(JT),J=1,...,L FOR ANGLE A
  DIMENSION S(1),C(1)
  C(1)= COS(T)
  S(1)= SIN(T)
  DO 10 I=2,L
    C(I)=C(1)*C(I-1)-S(1)*S(I-1)
    S(I)=C(1)*S(I-1)+S(1)*C(I-1)
  10 RETURN
  END

```

DKSICO, CPC No. 8

0
0
0
0

```

SUBROUTINE DKSICO (MX,LH,D,SITIME,COTIME,DK)
  COMPUTE D SUB K, COEFFICIENTS FOR A FIXED TIME
  DIMENSION D(1),COTIME(1),SITIME(1),DK(1)
  LMAX=LH*2+1
  LK=1+LMAX
  DO 5 K=1,MX
    LK=LK+LMAX
    DK(K)=D(LK)
    DO 5 L=1,LH
      NK=LK+L*2
      DK(K)=DK(K)+D(NK-1)*SITIME(L)+D(NK)*COTIME(L)
    RETURN
  END

```

```

C
C
C
SUBROUTINE MAGFIN(PBS,UNE)
C
C
C
  COMPUTE NASA MAGNETIC FIELD COMPONENTS
C
  DIMENSION P(7,7),DP(7,7),CP(7),AGR(7),SP(7),PBS(3),UNE(3),CT(7,7),
    G(7,7),H(7,7)
  DATA CT/2*0.,.33333333,.26166667,.25714286,.25396825,.25252525,
    3*0.,.20000000,.22857142,.23809523,.24242424,
    4*0.,.14285714,.19047619,.21212121,
    5*0.,.11111111,.16161616,
    6*0.,.09090909,
    7*0.,7*0./
  DATA G/ 0.,.304112,.024035,-.031518,-.041794,.016256,-.019523,
    0.,.021474,-.051293,.062130,-.045298,-.034407,-.004853,
    2*0.,-.013381,-.024838,-.021795,-.019447,.003212,
    3*0.,-.006496,.007008,-.000608,.021413,
    4*0.,-.002044,.002775,.001051,
    5*0.,.000697,.000227,
    6*0.,.001115/
  DATA H/7*0.,
    0.,-.057989,.033124,.014870,-.011825,-.000796,-.005758,
    2*0.,-.001579,-.004075,.010006,-.002000,-.008735,
    3*0.,.000210,.000430,.004597,-.003406,
    4*0.,.001385,.002421,-.000118,
    5*0.,-.001218,-.001116,
    6*0.,-.000325/
  DATA P(1,1),DP(1,1),SP(1),CP(1)/1.,0.,0.,1./
  DATA RE,RO,R899/6371200.,EO,C*EO/1.56205059E0/
  P2=PBS(2)
  P1=PBS(1)
  IF(ABS(P1).LE.R899) GO TO 4
  P1=SIGN(R899,P1)
  P2=EO
  CONTINUE
  AR=RE/(RE+300.E3)
  C= SIN(P1)
  S= SQRT(CP(1)-C*C)
  AGR(1)=AR*AR
C
C
C
  COMPUTE SIN,COS FOR MULTIPLE LONGITUDE ANGLE
  CALL SICEUT(6,CP(2),SP(2),P2)
  DO 5 M=2,7
    AGR(M)=AR*AGR(M-1)
C
C
C
  CLEAR OUTER SUMS AND SET UP LOOP
  RV=EO
  RN=EO
  BP=1=EO
  DO 6 M=2,7
    RN=N

```

MAGFIN, CPC No. 9

```

C      CLEAR INNER SUMS AND SET UP LOOP
      SUMR=00
      SUMT=00
      SUMP=00
      DO 7 M=1,N

C      COMPUTE FUNCTIONS AND DERIVATIVES OF MULT.ASS.LEGENDRE FUNCTION
C      IS THIS LAST CONTRIBUTION TO INNER SUM
      IF(M.NE.N) GO TO 8
      P(N,N)=9*P(N-1,N-1)
      DP(N,N)=8*DP(N-1,N-1)+C*P(N-1,N-1)
      GO TO 10
      8      P(N,M)=C*P(N-1,M)+CT(N,M)*P(N-2,M)
      DP(N,M)=C*DP(N-1,M)+8*P(N-1,M)+CT(N,M)*DP(N-2,M)
      10     FM=M-1
      TS=G(N,M)*CP(M)+H(N,M)*BP(M)

C      SUM INTO INNER SUMS FOR Z,X,Y
      SUMR=SUMR+P(N,M)*TS
      SUMT=SUMT+DP(N,M)*TS
      7      SUMP=SUMP+FM*P(N,M)*(-G(N,M)*BP(M)+H(N,M)*CP(M))

C      SUM INTO OUTER SUMS FOR Z,X,Y
      BV=BV+ABR(N)*FN*SUMR
      BN=BN+ABR(N)*SUMT
      6      BPHI=BPHI+ABR(N)*SUMP

C      SET MAGNETIC FIELD COMPONENTS Z=VERTICAL UP,X=NORTH,Y=EAST
      UNE(1)=-BV
      UNE(2)=BN
      UNE(3)=-BPHI/S
      RETURN
      END

```

```

C
SUBROUTINE GK (K,C,G)
C
C   COMPUTE COORDINATE FUNCTIONS, G(I), I=1,...,K+1
C   C(1)=MODIFIED LATITUDE, C(2), C(3)=GEOG. LONGITUDE, LATITUDE
C   G IS THE ARRAY FOR GEOGRAPHIC FUNCTIONS
C
  DIMENSION K(1), C(1), G(1)
  DATA G1/1. /, N/8/
  X=C(1)
  Y=C(2)
  Z=C(3)
  KO=K(1)
  SX= SIN(X)
C
C   SET TERMS DUE TO MAIN LATITUDINAL VARIATION
  G(2)=8X
  G(1)=G1
  DO 10 I=2, KO
    G(I+1)=SX*G(I)
  KDIF=K(2)-KO
  J=1
  CX1= COS(Z)
  CX=CX1
  T=Y
  18 KC=K(J)+4
C
C   COMPUTE FIRST 2 TERMS OF J-TH ORDER LONGITUDINAL VARIATION
  G(KC-2)=CX* COS(T)
  G(KC-1)=CX* SIN(T)
C
C   ARE ONLY 2 TERMS TO BE COMPUTED FOR THIS ORDER LONGITUDE
  IF (KDIF.EQ.2) GO TO 28
  KN=K(J+1)
C
C   COMPUTE REMAINING TERMS OF J-TH ORDER LONGITUDE
  DO 22 I=KC, KN, 2
    G(I)=SX*G(I-2)
    G(I+1)=SX*G(I-1)
  22
C
C   ARE TERMS FOR MAXIMUM ORDER LONGITUDE COMPUTED
  28 IF (J.EQ.N) GO TO 80
C
C   PREPARE FOR NEXT ORDER LONGITUDE COMPUTATIONS
  KDIF=K(J+2)-K(J+1)
  IF (KDIF.EQ.0) GO TO KC
  CX=CX*CX1
  J=J+1
  FU=J
  T=FU*Y
  GO TO 18
  80 RETURN
  END

```

DKGK, CPC No. 11

```
C
C
C
C
SUBROUTINE DKGK(MX,G,DKSTAR,OMEGA)
COMPUTE OMEGA, SUMMING THE GEOGRAPHIC SERIES
DIMENSION G(1),DKSTAR(1)
OMEGA=G(1)*DKSTAR(1)
DO 5 K=2,MX
5 OMEGA=OMEGA+DKSTAR(K)*G(K)
RETURN
END
```

TABGEN, CPC No. 12

```

C      PROGRAM TABGEN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1,TAPE2)
C      PREPROCESSOR GENERATING FOF2-MM TABLES ON TAPE TO BE USED
C      WITH PROGRAM ION1
C      ITP=UNIT ASSIGNMENT OF INPUT TAPE WITH IONOSPHERIC COEFFICIENTS
C      JTP=UNIT ASSIGNMENT OF OUTPUT TAPE WITH ION. FOF2-MM TABLES
      DIMENSION JAZ(4),IFM(14,25),FLX(31)
      DIMENSION K(10),KN(10),COT(6),SIT(6),P(3),CBM(3)
      *,C(3),G(76),DF(76),GM(49),DM(49)
      DIMENSION DB(3),CENT(3)
      DIMENSION WCOEF(3,13,76),U(13,76),UM(9,49),UM1(9,49)
      DATA JAZ/1,4,8,12// ITP,JTP/1,2/
      DATA MONDY,MONDY,LYRMO/0,10000,0/
      DATA K/11,35,53,63,67,69,71,73,75,6// KM10/4/
      DATA KN/1,7,13,28,37,48,55,60,65,72//NMF,NMF/76,49/
      DATA DB/01,010,0100,0130,0375,0P1,0P5/ 1. ,10. ,100. ,130.
      *,300000. ,.1 ,.5 /
      DATA DR,PI2,D7,DHR1,DHR2/.0174532925 ,6.283185308 ,.1221730476
      *,.2617993878 ,.5235987756 /
      DATA D180,D3/3.1415926536 ,1.02974426 ,.48869219 ,-.57595865 /
      DATA PER,CENT/.00133 ,1.035 ,.957 ,.9 /
      DATA SPLAT,CPLAT,PLON/ ,.9799246,.1993684,.5078908/
      DATA H1,H2,H3/1346.92 ,586.4 ,59.825 /
      P(3)=4375

C      LOOP OVER CONDITIONS
C      100 CONTINUE
C
C      READ DATE AND STATION POSITION FROM CARD
      READ(5,1) IYR,MON,IDAY,FLAT,FLON
      1 FORMAT(3I5,2F10.5)
      IF(IYR.LE.0) GO TO 400
      WRITE(6,2) IYR,MON,IDAY,FLAT,FLON
      2 FORMAT(//75H GENERATE RECORD ON OUTPUT TAPE CONTAINING IONOSPHERIC
      * FOF2-MM TABLES FOR /6H YEAR=,I2,6H, MONTH=,I2,6H, DAY=,I2,11H, L
      * ATITUDE=,F10.5,27H DEG, LONGITUDE OF STATION=,F10.5,4H DEG)
      PLAT=FLAT*DR
      PLON=FLON*DR
      IFLAG=0
      ISKIP=0
      IYRMO=IYR*100+MON
      IMODY=MON*100+IDAY
C
C      READ COEFFICIENT TAPE
      10 IF(IMODY.LE.MONDY.AND.IMODY.GE.MOND) GO TO 29
      20 READ(ITP) LOND,LONDY,WCOEF,UM,UM1
      IF(EOF,ITP) 23,28
      22 ISKIP=1

```

TABGEN, CPC No. 12

```

4END=L9ND
4ENDY=L9NDY
55 TO 10
23 REWIND 1TP
   IFLAG=IFLAG+1
   IF(IFLAG.LE.1) GO TO 20
   WRITE(6,25) IYR,M9N,1DAY
25 FORMAT(54H ***COEFFICIENTS NOT FOUND ON TAPE FOR YEAR,MONTH,DAY=,
   *3I3)
   55 TO 400
29 IF(ISKIP.EQ.0.AND.IYRM9.EQ.LYRM9) GO TO 80
C
C   READ SOLAR DATA
   IF(IYRM9.EQ.LYRM9) GO TO 55
   READ(5,7) IYM1,(FLX(I),I=1,16), IYM2,(FLX(I),I=17,31), IYM3,SIS,SIF
7  FORMAT(14,4X,16F4.1/14,15F4.1/14,2F5.1)
   IF(IYM1.EQ.IYM2.AND.IYM2.EQ.IYM3.AND.IYM3.EQ.IYRM9) GO TO 50
   WRITE(6,8) IYR,M9N
8  FORMAT(17/39H ***ERROR IN SOLAR INPUT DATA FOR YEAR=,12,11H AND M9N
   *TH=,12)
   55 TO 400
50 LYRM9=IYRM9
C
C   PREPARE SPECIFIC COEFFICIENT SETS
55 55 62 J=1,49
   55 62 I=1,9
   UM(1,J)=UM(1,J)+(UM1(1,J)-JM(1,J))*SIS/0100
62 CONTINUE
   55 70 J=1,76
   55 70 I=1,13
70 U(1,J)=WCDEF(1,1,J)+(WCDEF(2,1,J)+WCDEF(3,1,J)*SIF)*SIF
C
C   PREPARE SOLAR DATA
80 FLXD=FLX(1DAY)
   WRITE(6,15) FLXD,SIF,SIS
15 FORMAT(12H DAILY FLUX=,F6.1,41H, 12-MONTH RUNNING AVERAGE OF SOLAR
   * FLUX=,F6.1,20H, OF SUNSPOT NUMBER=,F6.1)
   FLUX=FLXD
   IF(FLUX.LT.0P1) FLUX=SIF
   DFLUX=FLUX-SIF
   IF(FLUX.GT.0130) FLUX=0130
C
C   GENERATE 25 POINT PATTERN AROUND STATION
   L99P OVER EARTH CENTRAL ANGLES
ECA=07
4=0
55 300 ICA=1,4
   ECA=ECA+07
   SA= SIN(ECA)
   CA= COS(ECA)
   NAZ=JAZ(ICA)
   DAZ=NAZ
   DAZ=PI2/DAZ

```

AZ=DAZ

C
C

LOOP OVER AZIMUTH
DO 300 IAZ=1,NAZ
MBM+1
AZ=AZ+DAZ
SXZ= SIN(AZ)
CAZ= COS(AZ)

C
C

COMPUTE LATITUDE, LONGITUDE OF IONOSPHERIC POINT BLAT,BLON
SNLAT= SIN(FLAT)*CA+ COS(FLAT)*SA*CAZ
CNLAT= SQRT(21-SNLAT*SNLAT)
BLAT= ATAN(SNLAT/CNLAT)
BDLON=SAZ*SA/CNLAT
CDLON= SQRT(21-BDLON*BDLON)
BLON=FLON+ ATAN(BDLON/CDLON)

C
C

COMPUTE POSITION DEPENDENT FUNCTIONS FOR FOF2 AND M3000
P(1)=BLAT
P(2)=BLON
CALL MAGFIN(P,COM)
TMP=COM(2)*COM(2)+COM(3)*COM(3)
C(2)=P(2)
C(3)=P(1)
C(1)= ATAN(ATAN(-COM(1)/ SQRT(TMP))/ SQRT(CNLAT))
CALL GK(X,C,3)
KK= 0
DO 85 II=1,10,2
II=KN(II)
I2=KN(II+1)
DO 85 J=I1,12
KK= KK + 1
85 GK(KK)=3(J)

C
C

COMPUTE MAGNETIC LATITUDE OF IONOSPHERIC POINT
SML= SNLAT * SPLAT + CNLAT * CPLAT + COS(BLON-PLON)
CML= SQRT(21-SML*SML)
MLAT= ATAN(SML/CML)

C
C

LOOP OVER 14 LOCAL HOURS
TLOC=DHR2
DO 200 IH=1,14
DHR=DHR2
IF(IH*GE.4.AND.IH*LE.7) DHR=DHR1
TLOC=TLOC+DHR
TIME=TLOC*BLN+P12
TIME=AMBD(TIME,P12)

C
C

COMPUTE TIME DEPENDENT FUNCTIONS FOR FOF2 AND M3000
TBTIME=D180
CALL SICOUT(6,COT,BIT,T)
CALL OKSICH(NFF,K(10),U,BIT,COT,DF)
CALL OKOICH(NMF,KM10 ,UM,BIT,COT,DM)

TABGEN, CPC No. 12

```

C
C      COMPUTE H3000 AND HEIGHT OF MAX. ELECTRON DENSITY HM
CALL DK3K(NMF,3M,DM,H3000)
HM = H1-H2+H3000+H3+H3000+H3000

C
C      COMPUTE FOF2 AND ADJUST FOF2 FOR DAILY VARIATION WITH FLUX
CALL DK3K(NFF,3,DF,FQF2)
LAT1 = 1
LAT2 = 1
IF(HLAT,GE,D3(LAT2)) GO TO 91
LAT2 = 2
IF(HLAT,GT,D3(LAT2)) GO TO 91
LAT1 = 2
IF(HLAT,EQ,D3(LAT2)) GO TO 91
LAT2 = 3
IF(HLAT,GT,D3(LAT2)) GO TO 91
LAT1 = 3
91 CNT = CENT(LAT1)
IF(LAT1,EQ,LAT2) GO TO 92
CNT = CNT + (CENT(LAT2)-CENT(LAT1)) * (D3(LAT1)-HLAT)
* / (D3(LAT1)-D3(LAT2))
92 FOF2 = FOF2 + (PER*DFLUX + CNT)
IFH(IH,M) = HM*310+QPS
IF2=FOF2*3100+QPS
IFH(IH,M) = IFH(IH,M)*10000+IF2
200 CONTINUE
300 CONTINUE

C
C      WRITE OUTPUT RECORD OF IONOSPHERIC FOF2-HM TABLES
IYMD = IYR*10000+MBN*100+IDAY
WRITE(JTP) IYMD,FLAT,FLBN,FLUX,IFH
GO TO 100
400 CONTINUE
END FILE JTP
REWIND JTP
STOP
END

```

```

C
C PROGRAM ION1 (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE2)
C COMPUTES IONOSPHERIC PROFILE PARAMETERS AND REFRACTION CORRECTIONS
C UTILIZING PRECOMPUTED FOF2-HM TABLES
C ***** TO BE USED ONLY FOR STRINGENT CORE SPACE AND/OR RUN TIME
C ***** REQUIREMENTS, SINCE INTERPOLATIONS OF THE PRECOMPUTED FOF2-HM
C ***** TABLES CREATE LESS ACCURATE RESULTS THAN THOSE OBTAINED
C ***** FROM PROGRAM ION
C
C CONTENT OF COMMON BLOCKS EXPLAINED IN SUBROUTINE REFRC1
C COMMON /EVAL1/ FS,FLAT,FLON,ELEV,AZ,HS,EDOT,HDOT,TIME,
C *IYR,MON,IDAY,JTP
C COMMON /CORR1/ DRANG,DRATE,DELEV,FOF2,HM,YM,YT,XK,TOTN,TOTNA
C
C DIMENSION XK(3)
C DATA Q0,Q1000,Q3600,DR,HR /0. ,1000. ,3600. ,.0174532925 ,
C *.2617993875 /
C JTP=2
C NUN=0
C WRITE(6,26)
26 FORMAT(1H1)
10 CONTINUE
C
C READ AND PRINT EVALUATION CONDITION
C READ(5,3)FS,FLAT,FLON
3 FORMAT(F10.4,2F10.5)
C IF(FS.LT.Q0 ) GO TO 100
C READ(5,4)ELEV,AZ,HS,EDOT,HDOT
4 FORMAT(2F10.6,F10.0,2E15.8)
C READ(5,5)IYR,MON,IDAY,TIME
5 FORMAT(3I5,F10.7)
C WRITE(6,6)FS,FLAT,FLON,ELEV,AZ,HS,EDOT,IYR,MON,IDAY,TIME,HDOT
6 FORMAT( 12H ** INPUT **//
C * 11H FREQUENCY=,F10.4,15H MHZ, LATITUDE=,F10.5,
C *.27H DEG, LONGITUDE OF STATION=,F10.5,4H DEG/11H ELEVATION=,F10.6,
C *.15H DEG, AZIMUTH=,F10.6,27H DEG, HEIGHT OF SATELLITE=,F11.1,
C *.21H KM, ELEVATION RATE=,E15.8,8H RAD/SEC/6H YEAR=,12,8H, MONTH=,
C *.12,6H, DAY=,12,10H, U.TIME=,F10.7,5H HRS,,39X,15H ALTITUDE RATE=,
C *.E15.8,6H M/SEC)
C
C CONVERT UNITS
C FLAT=FLAT*DR
C FLON=FLON*DR
C ELEV=ELEV*DR
C AZ=AZ*DR
C HS=HS*Q1000
C TIME=TIME*HR
C
C COMPUTE AND PRINT IONOSPHERIC DATA
C CALL REFRC1
C IF(IYR.LT.0) GO TO 10
C XHM=HM/Q1000
C WRITE(6,21) XHM,FOF2

```

ION1, CPC No. 13

```

21 FORMAT( /13H ** OUTPUT **//35H HEIGHT AT MAXIMUM ELECTRON DENSITY,
  *10X,3HHH=F8.3,30H KM, CRITICAL FREQUENCY F0F2=F7.3,4H MHZ,
  XYH=YM/01000
  XYT=YT/01000
  WRITE(6,22)TOTN,TOTNA,XYH,XYT,XK
22 FORMAT(42H TOTAL INTEGRATED ELECTRON CONTENT, VERTICAL NT=E13.6,
  *25H E/(M*H), ANGULAR NTA=E13.6,15H E/(M*H COLUMN)/
  *48H HALF THICKNESS OF BOTTOMSIDE BIPARABOLA YM=F8.3,
  *30H KM, OF TOPSIDE PARABOLA YT=F8.3,3H KM/
  *58H DECAY CONSTANTS FOR TOPSIDE EXPONENTIAL LAYERS, LOWER K1,
  *E12.5,12H, MIDDLE K2=E12.5,11H, UPPER K3=E12.5,4H 1/M)
  TELEV=DELEV*03600 /DR
  WRITE(6,23)TELEV
23 FORMAT(54H IONOSPHERIC REFRACTION CORRECTION TO ELEVATION ANGLE=,
  *E13.6,11H SEC OF ARC)
  WRITE(6,24) DRANG
24 FORMAT(43H IONOSPHERIC REFRACTION CORRECTION TO RANGE,10X,1H,
  *E13.6,2H M)
  WRITE(6,25) DRATE
25 FORMAT(54H IONOSPHERIC REFRACTION CORRECTION TO RANGE RATE =,
  *E13.6,6H M/SEC)
  NUM=NUM+1
  IF(NUM*LT.3) GO TO 22
  WRITE(6,26)
  NUM=0
  GO TO 10
27 WRITE(6,28)
28 FORMAT(/)
  GO TO 10
100 CONTINUE
  STOP
  END

```

```

C
C      IONOSPHERIC REFRACTION MODEL UTILIZING PRECOMPUTED FOF2-HM
C      TABLES FOR INTERPOLATION
C      ***** TO BE USED ONLY FOR STRINGENT CORE SPACE AND/OR RUN TIME
C      ***** REQUIREMENTS
C      SUBROUTINE REFRC1
C
C      INPUT: COMMON /EVAL1/
C      OUTPUT: COMMON /CORR1/
C
C      COMMON /EVAL1/ FS,FLAT,FLON,ELEV,AZ,HS,EDOT,HDOT,TIME,
C      *IYR,MON,IDAY,JTP
C      FS = TRANSMISSION FREQUENCY IN MHZ
C      FLAT = STATION LATITUDE IN RADIANS OF ARC
C      FLON = STATION LONGITUDE IN RADIANS OF ARC (POSITIVE EAST, 0 TO 360 D)
C      ELEV = ELEVATION OF SATELLITE IN RADIANS OF ARC
C      AZ = AZIMUTH OF SATELLITE IN RADIANS OF ARC
C      HS = HEIGHT OF SATELLITE IN METERS
C      EDOT = ELEVATION RATE IN RADIANS OF ARC/SECOND
C      HDOT = RATE OF CHANGE IN HEIGHT OF SATELLITE IN METERS/SECOND
C      TIME = UNIVERSAL TIME IN RADIANS OF ARC
C      IYR = YEAR (LAST 2 DIGITS ONLY)
C      MON = MONTH (=1 THROUGH 12)
C      IDAY = DAY (=1 THROUGH 31)
C      JTP = UNIT ASSIGNMENT OF IONOSPHERIC TAPE WITH FOF2-HM TABLES
C
C      COMMON /CORR1/ DRANG,DRATE,DELEV,FOF2,HM,YM,YT,XK,TOTN,TOTNA
C      DRANG = RANGE CORRECTION IN METERS
C      DRATE = RANGE RATE CORRECTION IN METERS/SECOND
C      DELEV = ELEVATION ANGLE CORRECTION IN RADIANS OF ARC
C      RANGE, RANGE RATE, AND ELEVATION ANGLE CORRECTIONS ARE TO BE
C      SUBTRACTED FROM THEIR RESPECTIVE OBSERVATIONS
C      FOF2 = CRITICAL FREQUENCY (MHZ)
C      HM = HEIGHT AT MAXIMUM ELECTRON DENSITY (M)
C      YM = HALF THICKNESS OF THE BOTTOMSIDE BIPARABOLA (M)
C      YT = HALF THICKNESS OF THE TOPSIDE PARABOLA (M)
C      XK = ARRAY CONTAINING DECAY CONSTANTS FOR THE LOWER, MIDDLE AND
C      UPPER SECTION OF THE TOPSIDE EXPONENTIAL LAYER (1/M)
C      TOTN = VERTICAL ELECTRON CONTENT (E/M**2)
C      TOTNA = ANGULAR ELECTRON CONTENT (E/M**2)
C
C      DIMENSION XK(3),LYMD(4),ALAT(4),ALON(4),FLXD(4),IFH(14,25,4)
C      DIMENSION LT(2),MP(2),PT(2),HT(2),FI(2),HI(2),FA(2),HA(2),JAZ(4),
C      *KAZ(4)
C      DATA JAZ/1,4,8,12/, KAZ/1,2,6,14/, LYMD/0,0,0,0/, NB,NR/4,0/
C      DATA R,SPLAT,CPLAT,FLON/6371.2E3,.9799246,.1993684,5.078908/
C      DATA RH,TBL/6671200, .0087264463 /
C      DATA Q0,Q1,Q2,Q3,Q100,Q3P5,Q4P5,QNM,QN3,P12,DR,HR/0, .1, .2,
C      .7, .100, .3.5, .4.5, .1.24E10,.49972, .4.2831853072,
C      .0174532925, .2417993878 /
C      EQUIVALENCE (LT(1),LT1),(LT(2),LT2),(MP(1),MP1),(MP(2),MP2)

```

C INITIALIZE CONSTANTS

DELEV=00
 DRANG=00
 DRATE=00
 TSTN=00
 TSTNA=00
 IFLAG=0
 NYMD=IYR*10000+MBN*100+IDAY

C
 C

READ FOR2-HM INTERPOLATION TABLES FROM FILE, SELECT PROPER SET

1 DO 2 1=1,NB
 IF(NYMD.NE.LYMD(1)) GO TO 2
 IF(ABS(ALAT(1)-FLAT).GT.TBL) GO TO 2
 IF(ABS(ALON(1)-FLON).GT.TBL) GO TO 2
 GO TO 6
 2 CONTINUE
 NR=NR+1
 IF(NR.GT.NB) NR=1
 3 READ(JTP) LYMD(NR),ALAT(NR),ALON(NR),FLXD(NR),((IPH(L,LL,NR)
 *,L=1,14),LL=1,25)
 IF(EOF,JTP) 4,1
 4 REWIND JTP
 IFLAG=IFLAG+1
 IF(IFLAG.LE.1) GO TO 3
 WRITE(6,5)
 5 FORMAT(63H *** FOR2-HM TABLES FOR THIS STATION AND DATE NOT FOUND
 * IN FILE)
 IYR = -1
 RETURN
 6 FLUX=FLXD(1)

C
 C
 C

FORM AZIMUTH AZ, EARTH CENTRAL ANGLE STATION TO SAT, ECA,
 IONOSPHERIC LAT., LHN, BLAT, PLON, MAGNETIC LAT. OF ION. PRINT
 HEAT, AND LOCAL TIME TLOC

IF(AZ.LT.00) AZ=AZ+PI2
 SLAT= SIN(FLAT)
 CLAT= COS(FLAT)
 SEL= SIN(FLEV)
 CEL= COS(FLEV)
 SAZ= SIN(AZ)
 CAZ= COS(AZ)
 SF=R*CEL/R4
 CF= SQRT(01-SF*SF)
 SA= CEL * CF * SEL * SF
 CA= SEL * CF * CEL * SF
 ECA= ATAN(SA/CA)/DR
 SNLAT=SLAT*CA+CLAT*SA*CAZ
 CNLAT= SQRT(01-SNLAT*SNLAT)
 BLAT= ATAN(SNLAT/CNLAT)
 SDLON=SAZ*SA/CNLAT
 CDLON= SQRT(01-SDLON*SDLON)
 PLON=FLON+ ATAN(SDLON/CDLON)
 SML= SNLAT * SNLAT * CNLAT * CPLAT * COS(PLON-PLON)
 CML= SQRT(01-SML*SML)
 MLAT= ATAN(SML/CML)
 TLOC=TIME+0_LON+PI2

```

TLBC=AMSD(TLBC,PI2)
TEBCAL=TLBC/HR

```

```

      INTERPOLATE FORB-HM TABLES

```

```

      COMPUTE INDICES LT1,LT2, INCREMENT DLT FOR LOCAL TIME INTERPOL.

```

```

XLT=TLBCAL/Q2+31

```

```

LT1=XLT

```

```

DLT=LT1

```

```

DLT=XLT-DLT

```

```

IF(XLT-GE+23P5) LT1=LT1+1

```

```

IF(XLT-GE+24P5) LT1=LT1+1

```

```

IF(LT1-LT+3.0R-LT1-QT+6) GO TO 10

```

```

DLT=DLT+Q2

```

```

IF(DLT-GE+31) DLT=DLT-31

```

```

10 IF(LT1-QT+14) LT1=1

```

```

LT2=LT1+1

```

```

IF(LT2-QT+14) LT2=1

```

```

      COMPUTE EARTH CENTRAL ANGLE INDEX IALF, INCREMENT DALF

```

```

ALF=ECA/Q7+31

```

```

IALF=ALF

```

```

IF(IALF-QT+4) IALF=4

```

```

DALF=ALF-FL0AT(IALF)

```

```

KI=1

```

```

      COMPUTE AZIMUTH INDICES MP1,MP2, INCREMENT DELAZ

```

```

20 NAZ=JAZ(IALF)

```

```

MP1=KAZ(IALF)

```

```

IF(MP1-QT+1) GO TO 30

```

```

DELAZ=Q0

```

```

MP2=1

```

```

GO TO 60

```

```

30 DAZIM=PI2/FL0AT(NAZ)

```

```

AZIM=Q0

```

```

DO 40 LOOP=1,NAZ

```

```

MP2=MP1

```

```

MP1=MP1+1

```

```

IF(LOOP-EQ,NAZ) MP1=MP1-NAZ

```

```

AZIM=AZIM+DAZIM

```

```

IF(AZIM-GE+AZ) GO TO 50

```

```

40 CONTINUE

```

```

50 DELAZ=(AZIM-AZ)/DAZIM

```

```

60 CONTINUE

```

```

      INTERPOLATE IN TIME FOR PROPER POINTS MP1,MP2 TO GET FI,HI

```

```

DO 80 IPT=1,2

```

```

MPT=MP(IPT)

```

```

DO 70 L=1,P

```

```

LTM=LT(L)

```

```

IH1=IFH(LTM,MPT,1)/10000

```

```

HT(L)=FL0AT(IH1)*0100

```

```

IF1=IFH(LTM,MPT,1)-IH1*10000

```

```

70 FT(L)=FL0AT(IF1)/0100

```

REFRC1, CPC No. 14

```

      FI(IPT)=FT(1)+(FT(2)-FT(1))*DLT
80  HI(IPT)=HT(1)+(HT(2)-HT(1))*DLT
C
C      INTERPOLATE IN AZIMUTH TO GET FA,HA
      FK(1)=FI(1)+(FI(2)-FI(1))*DELTAZ
      HK(1)=HI(1)+(HI(2)-HI(1))*DELTAZ
      IF(K1.EQ.2) GO TO 100
      K2=2
      IALF=IALF+1
      IF(IALF.GT.4) GO TO 90
      GO TO 20
90  FK(2)=FA(1)
      HK(2)=HA(1)
C
C      INTERPOLATE IN EARTH CENTRAL ANGLE TO GET FOF2,HM
100 FOF2=FA(1)+(FA(2)-FA(1))*DALF
      HM=HA(1)+(HA(2)-HA(1))*DALF
C
C      COMPUTE SECOND PART OF PROFILE
      CALL PROF2(OLAT,OLONG,HB,TIME,TDAY,MON,FLUX,FOF2,HM,HLAT,
      *          YM,YT,XK,RRM,XNTNM)
      IF(XNTNM.LE.30) GO TO 140
C
C      COMPUTE ELEVATION ANGLE CORRECTION DELEV
      FRAT=(FOF2/FH)**2
      CALL BETA(FRAT,XNTNM,HB,HM,YM,BEL,CEL,DELEV)
C
C      COMPUTE VERTICAL AND ANGULAR ELECTRON CONTENT TOTN,TOTNA
C      COMPUTE RANGE CORRECTION DRANG
      RAT=(R/(R+HM))**2
      DEN2=D1-RAT*CEL*CEL
      DEN=SQRT(DEN2)
      TOTN=XNTNM*QNH*FOF2**2
      TOTNA=TOTN/DEN
      DRANG=FRAT*RN3*XNTNM/DEN
C
C      COMPUTE RANGE RATE CORRECTION DRATE
      DRATE=DRANG*EDOT*RAT*BEL*CEL/DEN2
      DRATE=DRATE*FRAT*RN3*HDOT*RRM/DEN
140 CONTINUE
      RETURN
      END

```