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IONOSPHERIC RESEARCH

F_2 PEAK ELECTRON DENSITIES IN THE MAIN TROUGH REGION OF THE IONOSPHERE

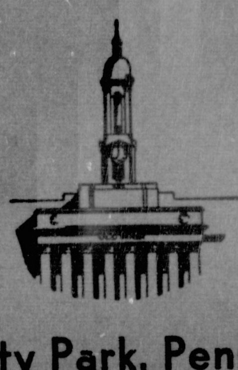
by

Barry W. Halcrow

May 1976

The research reported in this document was partially supported by The National Aeronautical and Space Administration under Contract Grant No. NGL 39-009-003.

IONOSPHERE RESEARCH LABORATORY



University Park, Pennsylvania

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

ABSTRACT

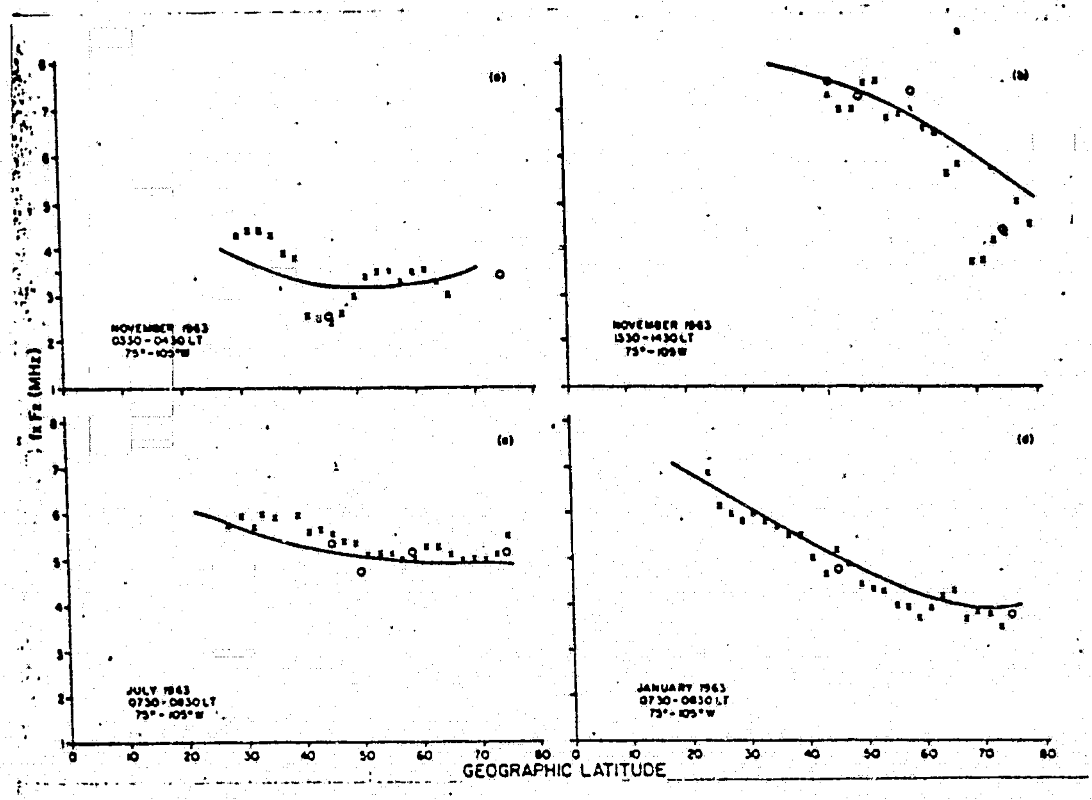
A study of the main trough in the F_2 region has been made using observations from Alouette I and II. Parameters needed to predict the occurrence of the trough were determined from the many observations. These parameters were used to develop a modification factor for use with C. E. I. R. model of predicted NmF_2. This modification factor reduced the C. E. I. R. model predicted NmF_2 to more representative values of NmF_2 in the main trough region.

CHAPTER 1

GENERAL STATEMENT OF THE PROBLEM

Ionospheric models of the peak electron densities of the F_2 layer have many uses such as the prediction of ionospheric propagation conditions of high frequency radio waves. Advances in airborne and satellite observations of the ionosphere have provided many latitudinal cross-sections which clearly indicate a strong dissimilarity between the ionosphere as it is observed in reality and the ionospheric picture obtained from presently available model ionospheres. The smoothing which results from the averaging of the data on which the models are based severely limits the usefulness of the models for the prediction of propagation conditions in the middle and high latitude regions. Compared with the quasi-instantaneous cross-sections, all of the models have one thing in common. The models do not reproduce the large horizontal electron density gradients associated with the main ionospheric trough. This fact is shown in Figure 1 (a) when Peterie and Lockwood (1969) were comparing the C.C.I.R. model (1966) of predicted fxF_2 to topside sounder data. There are several reasons for this:

1. The number of ground ionosonde stations used as the basis for the models is extremely limited, at least as far as the polar ionosphere is concerned. Phenomena, which are relatively small in scale as the trough and variable in location, are seldom sampled and do not show up in the monthly averages used to develop the models.



Predicted values of C.C.I.R. model are shown by solid line. Monthly median values determined from Alouette I shown by crosses. The circles are the corresponding monthly median values of fxF_2 obtained from ground-based ionosonde measurements at Ottawa, Winnipeg, Churchill, and Resolute Bay. Petrie and Lockwood (1969).

Figure 1. fxF_2 of C.C.I.R. Compared to Observed Values of fxF_2

2. The models average the monthly data over all lower Kp values and other known parameters which control the magnitude and location of the trough.

3. The coordinate system of the data for the models is geographic. This makes the location of the trough additionally variable because the phenomenon is oriented to the terrestrial magnetic field and is more easily specified in a magnetic coordinate system.

4. Most models of the peak electron density in the F_2 region are based on spherical harmonies. The size of the trough is such that to represent it adequately would require a much higher number of components than are used at present or can be justified based on the number of ground based ionosonde stations.

What is needed is a modification to existing models that will produce more representative electron densities in the main trough region of the F_2 layer.

CHAPTER 2

PREVIOUS RELATED STUDIES

2.A. The Main Trough

Muldrew (1965), after an investigation of critical frequency data taken from the ionosonde aboard the Alouette I satellite, found an electron density trough, a region of sharply decreased electron densities, to exist regularly on the night side of the earth's ionosphere at roughly 45°N geographic latitude. The name "main trough" was given by Muldrew to distinguish it from temporary "high latitude troughs" of the polar cavity which he also studied.

In the literature, "main trough," "mid-latitude trough," "Ottawa trough," and "high-latitude trough," have all been used to refer to this condition of decreased ionization. In this work, "main trough" or simply "trough" will be used. Trough will also be defined to mean the entire region of depressed electron density, including the trough walls.

The sudden depressions in electron density have been observed from the ground (beneath the trough); however, the latitudinal scan available only from mobile satellite ionosondes are most useful for understanding the development and morphology of the trough.

Since Muldrew's discovery of the trough, there have been several investigations of it. Rycroft and Thomas (1970) established a relationship between the location of the trough and the plasmapause. Tulunay and Sayers (1971) made a statistical survey of deep troughs in both hemispheres. One problem with the trough region is the various definitions of the trough and the large number of other geophysical discontinuities in the general area. One must be careful in comparing statistics of different investigators. All statistics are in agreement on the trough being a nighttime feature which moves equatorward with increasing Kp.

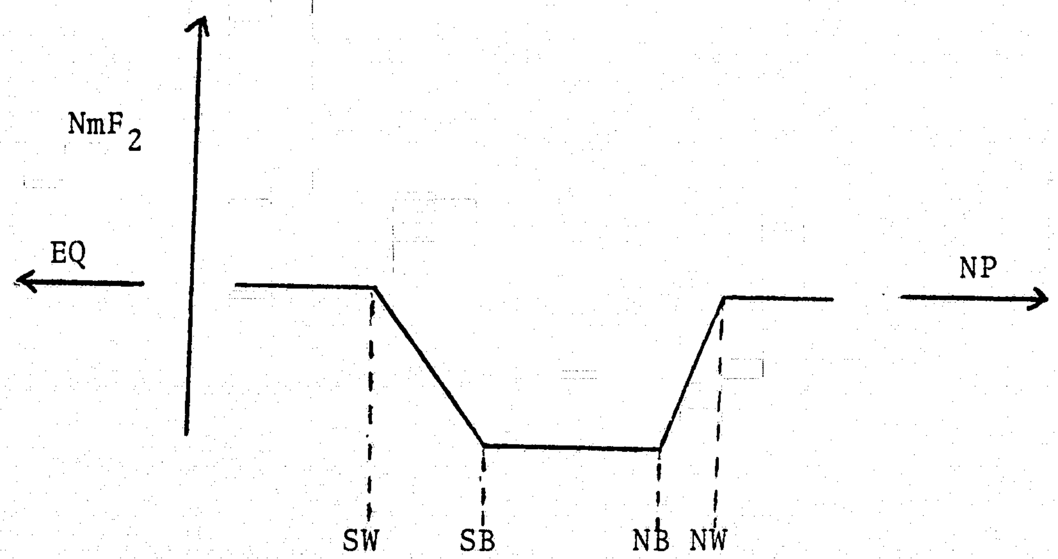
2.B. Other Trough Models

One of the more indepth and detail studies of the trough was done by Feinblum (1973). In attempting to establish criteria for locating the trough, using the data from Alouette I and II, Feinblum chose not to specify any minimum required electron density decrease ratio for a trough. Thus, he sought to identify the trough even when weak or ill defined. Using a magnetic coordinate system of invariant latitude with intersection at 300 Km, Feinblum adopted a model of four latitudes to describe the trough as shown in Figure 2.

Feinblum established three separate criteria, all of which must be met in order to predict the existence of the trough:

1. He determined the trough region boundaries, in terms of SW, SB, NB, and NW, as functions of local time and Kp. (This is the region where the trough could exist normally if the other criteria was fulfilled.)

2. He next used "lagged solar zenith angle," χ_c, to order the location of the trough walls during formation and dissipation; he defined four critical values of this quantity: α, β, γ, δ. α and δ were critical angles for trough walls at dusk and dawn respectively. β and γ were critical angles



SW - Lat. of southern south wall edge of the trough

SB - Lat. of northern edge of the south wall or southern trough bottom

NB - Lat. of southern edge of the north wall or northern trough bottom

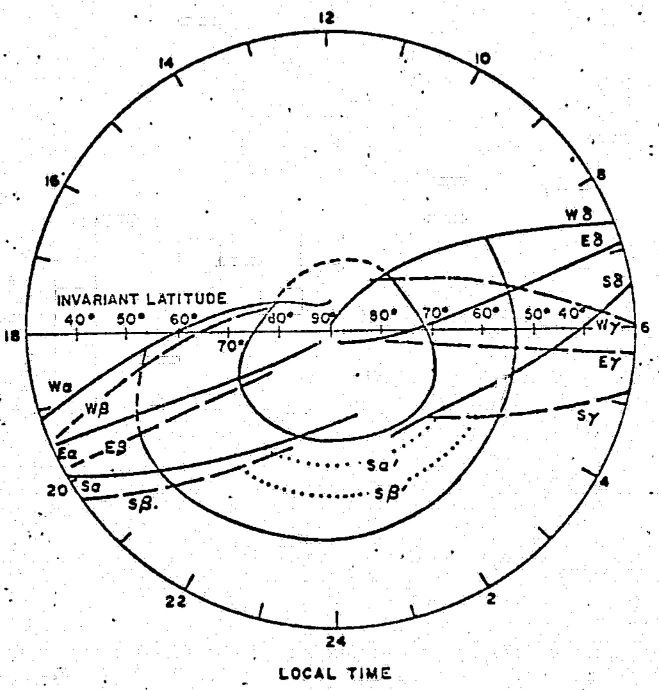
NW - Lat. of northern north wall edge of the trough

Figure 2. Trough Defined

for the trough bottom at dusk and dawn respectively. Since solar zenith angle is a function of local time and season, this criteria established the location of the trough as a function of local time and season. Thus, the second criteria was that $\chi_c \geq \alpha$ before midnight or $\chi_c \geq \gamma$ after midnight.

3. The third criteria was a time limitation on the formation on the trough; $\chi_c \geq \gamma$ (and $\chi_c \geq \beta$) had to occur no later than 22:00 (21:40) local time. This restricts the northward extent of the trough and moves the trough and trough bottom southward to make the trough narrower during the summer when the Arctic becomes "the land of the midnight sun." Figure 3 shows the model developed by Feinblum for 77°W longitude.

The Feinblum model only defined criteria for predicting a trough and if so what part of the trough was present for any given location.



Feinblum Model Prediction of Trough Boundaries for all Seasons at 77°W Longitude.

The curves of SW and NW are plotted. Curves of SB and NB are omitted. The letters W, E, S denote season: W - winter soltice, E - equinox (spring or fall), and S - summer soltice. $\alpha, \beta, \gamma, \delta$ are the solar zenith angle curves. $S\alpha^1$ and $S\beta^1$ denote the effect of the requirement that the trough (bottom) must be formed by 22:00 (21:40) if it is to be formed at all. Feinblum (1973).

Figure 3. Feinblum Model

CHAPTER 3

SPECIFIC STATEMENT OF THE PROBLEM

To develop a model of the ionospheric F_2 layer that will reproduce the peak electron densities and their horizontal gradients including the main trough region as a function of latitude, longitude, time, season, and solar and magnetic activity.

CHAPTER 4

DATA AND ANALYSIS

The data used for this study was supplied by Feinblum and consisted of 29,770 observations of the peak electron densities measured by Alouette I and II in the Northern Hemisphere with the majority of data confined to the Western Hemisphere. These observations were originally from Alouette I (1968a) Alouette II (1970a) 1962 to 1970. The virtual heights measured were reduced to true height profiles. These electron densities were then fitted to a standard profile to obtain the peak F_2 layer electron densities.

The data was sorted into groups:

months - 12

local time - 24

KP - 9; $0\text{-}1^-$, $1\text{-}2^-$, etc.

RZ - 4; 0-50, 51-100, 101-150, and 151-200.

The coordinate system used to organize the data must be based on the physical variables controlling the trough. For this work, local time and invariant latitude (intersection at 300 Km) were employed.

The electron densities of the trough region were investigated by using a function called "phi." Phi is the ratio of the observed peak electron density of the F_2 layer, hereafter abbreviated NmF_2, to the NmF_2 predicted by the C.C.I.R. model (1966). The C.C.I.R. model uses spherical harmonics to predict NmF_2 based on years of ground ionosonde measurements of the time and geographic variations of NmF_2. Figure 1 in the beginning section of this paper demonstrated the C.C.I.R. model provides a reasonably good estimate, except in the trough. For this project, the C.C.I.R. model was adopted to represent the large scale features of the F_2 region so that the phi function generated represents a modification factor to the C.C.I.R. model for the main trough region. Outside the trough region, the C.C.I.R. NmF_2 values are used unmodified, that is, phi equals unity. The convenience of phi was to provide both the location of the trough and the modification factor to be used with the C.C.I.R. model.

CHAPTER 5

TROUGH MODEL

5.A. Trough Region - North to South Extent

Latitudinal cross-sections for each local time and Kp values were examined to determine the trough boundaries. Tables and graphs were made of the location of:

- SW - lat. of southern south wall edge of the trough.
- SB - lat. of northern edge of south wall or southern trough bottom.
- NB - lat. of southern edge of north wall or northern trough bottom.
- NW - lat. of northern north wall edge of the trough.

Location for missing hours and/or Kp values was interpolated using continuity of the observational data and established trough relationships with other geophysical features such as the auroral oval. Equations 1-4 (the next page) give the location of the four invariant latitudes which define the trough region as a function of local time and Kp. These latitudes are to be used for all seasons and have a $\pm$ 3° error.

The Kp study of the movement of the trough region showed the SW to have little sensitivity to Kp values. NW, on the other hand, moved southward on the average of 1.25° per unit increase of Kp. NB and SB moved 1.0° and 0.5° per unit increase of Kp respectively.

1. $$SW = 48° + 5° \left\{ \left[1 + \left(\frac{T^2 - 4}{5.65T + .1} \right)^{22} \right]^{-1/2} + 1 - \left[1 + \left(\frac{T^2 - 8}{12.35T + .1} \right)^{14} \right]^{-1/2} \right\}$$

2. $$SB = 54° + 7° \left\{ \left[1 + \left(\frac{T^2 - 4}{5.8T + .1} \right)^{22} \right]^{-1/2} + 1 - \left[1 + \left(\frac{T^2 - 8}{13.5T + .1} \right)^{16} \right]^{-1/2} \right\} - 0.5° (Kp - 1/3)$$

3. $$NB = 64° + 9° \left[\exp\left(-0.000019T^{5.419}\right) + \exp\left(-0.00215(T-24)^{4.55}\right) \right] - 1.0° (Kp - 1/3)$$

4. $$NW = 67° + 9° \left[\exp\left(-0.000017T^{5.3476}\right) + \exp\left(-0.000466(24-T)^{4.10}\right) \right] - 1.25° (Kp - 1/3)$$

$T = LT + 12$ If $LT < 12$

$T = LT - 12$ If $LT \geq 12$

5.B. Trough Region - West to East Extent

The latitudes between SW-NW were examined at dawn and dusk to determine when a trough existed in this region. During dawn, the actual solar zenith angle at the time of the observation was used with the critical angles denoted as γ and σ. When γ began to exceed $95° \pm 1°$, the trough bottom depth began to decrease. By the time $\sigma = 87° \pm 2°$, the entire trough region became filled in and no depression existed. The values of σ and γ did not register any Kp dependence. The dusk angles were more difficult to evaluate. The actual solar zenith angles at the time of the observations had tremendous scatter. To decrease the scatter, lagged solar zenith angles were used. The 1.0 and 1.5 hour lagged angles were calculated for the critical angles α, the beginning of the trough, and β, the time when the trough bottom depth values were observed. The 1.0 hour lag ordered α best and the 1.5 hour lag ordered β best. Since the same lag time was needed and β determined when the trough minimum value would be reached, the 1.5 hour lagged values where used for α and β. Both α and β registered significant Kp dependence. A decrease of $3° \pm .5°$ was measured with each increase of unit of Kp. The final values used were:

$$\alpha = [87° \pm 3°] - (3° \pm 0.5°)(Kp - 1/3)$$

$$\beta = [91° \pm 3°] - (3° \pm 0.5°)(Kp - 1/3)$$

The critical solar zenith angles are crude measurements of the solar irradiation and other affects over a finite time span. Since the various time derivatives of solar zenith angle vary with season and geographic location, it is clear there is no unique value which can work perfectly.

5.C. Trough Prediction Algorithm

With the criteria now established, a trough prediction for above a location at 300 Km invariant latitude Λ, geographic longitude λ, and geographic local time LT can be made by going through the following series of statements:

I. $SW \leq \Lambda \leq NW$ (equations 1 and 4 page 13)

if true, continue; if not no trough

II. $\chi(\Lambda,\lambda, LT \leq 20{:}30) \geq [87°+3°] - (3° \pm .5°)(Kp-1/3)$

if true, continue; if not no trough

A. Relative Dusk Criterion: $12{:}00 \leq LT \leq 24{:}00$

$\chi(\Lambda,\lambda, LT-1.5\ hr.) \geq [87° \pm 3°] - (3° \pm .5°)(Kp-1/3)$

if true, trough predicted; if not, no trough

B. Relative Dawn Criterion: $00{:}00 \leq LT \leq 12{:}00$

$\chi(\Lambda,\lambda,LT) \geq 87° \pm 2°$

if true, trough predicted; if not, no trough

Similarly, a prediction can be made for the trough bottom for any Λ,λ,LT by using:

I. $SB \leq \Lambda \leq NB$ (equations 2 and 3 page 13)

if true, continue; if not no trough bottom

II. $\chi(\Lambda,\lambda,LT \leq 20{:}30) \geq [91° \pm 3°] - (3° \pm .5°)(Kp-1/3)$

if true, continue; if not no trough bottom

A. Relative Dusk Criterion: $12{:}00 \leq LT \leq 24{:}00$

$\chi(\Lambda,\lambda,LT-1.5\ hr.) \geq [91° \pm 3°] - (3° \pm .5°)(Kp-1/3)$

if true, trough bottom; if not no trough bottom

B. Relative Dawn Criterion: $00{:}00 \leq LT \leq 12{:}00$

$\chi(\Lambda,\lambda,LT) \geq 95° \pm 1°$

if true, trough bottom; if not <u>no trough bottom</u>

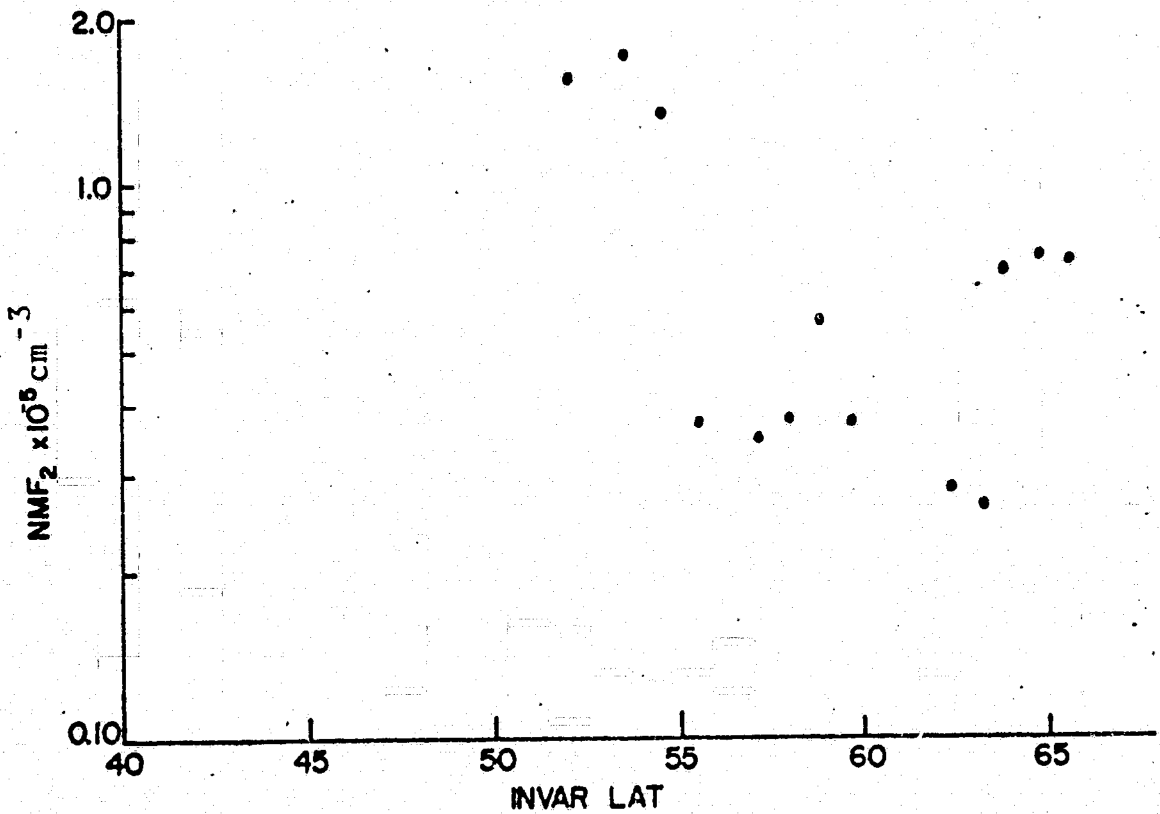
The first argument of statement II is the time restriction on the formation of the trough (and bottom). This makes 20:30 the latest local time the trough (and bottom) can begin forming when the 1.5 hour lag value for α (and β) is used as the critical value for the solar zenith angle.

CHAPTER 6

MODIFICATION FACTOR FOR THE C.C.I.R. MODEL

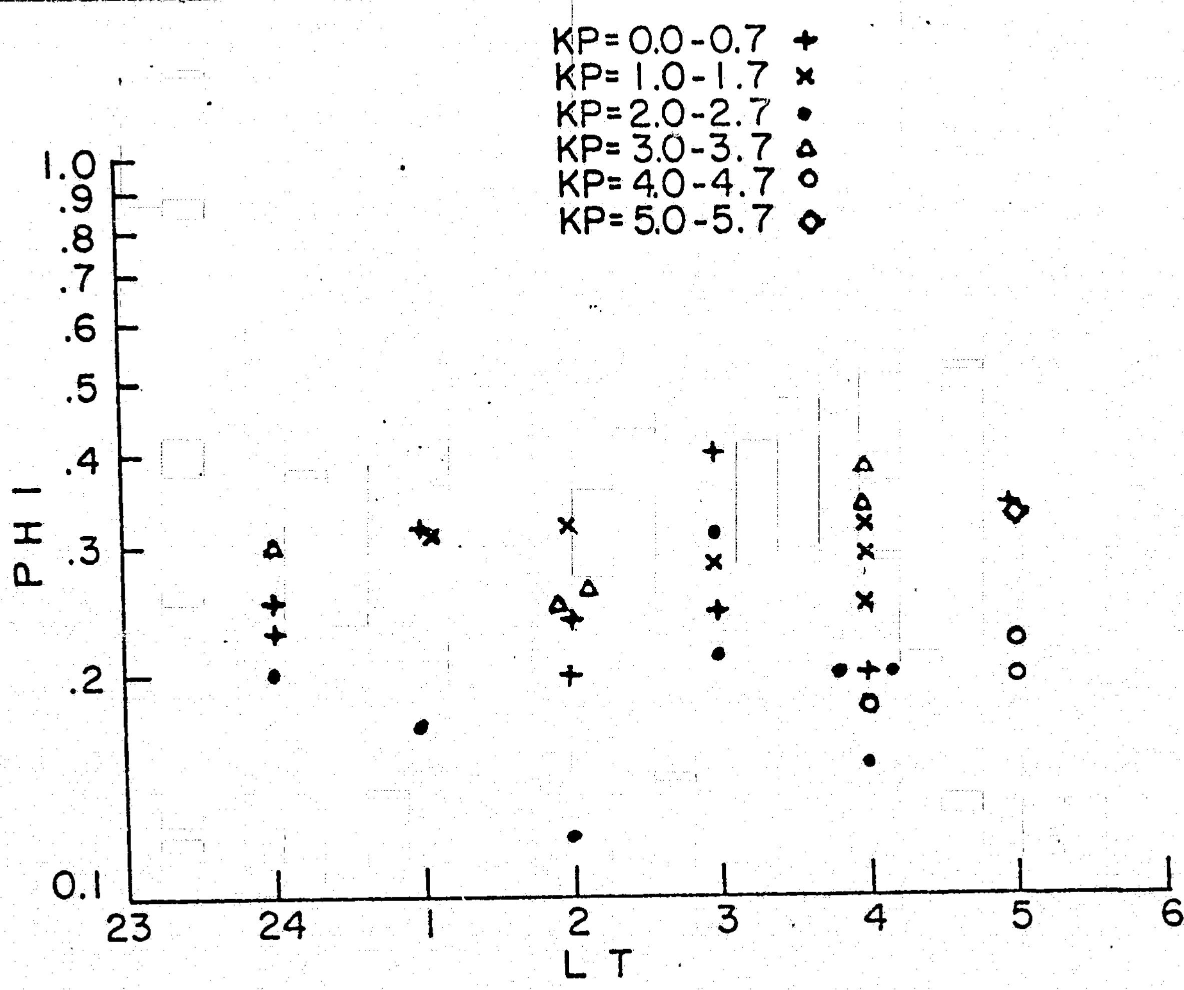
After many cross-sections were examined, it was apparent from such observations as Figure 4 that the walls could be approximated by straight lines. Figure 4 also shows some structure in the trough bottom. There was insufficient data to delimate this very small feature. A simple model consisting of linear gradients of the phi function in the north and south walls with a uniform value in the trough bottom was adopted. Figures 5 and 6 show some of the data used in the analysis of determining the trough bottom value of phi. The bottom values at SB and NB did not indicate any significant variation with season, Kp, Rz, or local time. One fact determined was that the minimum value of the trough bottom does not increase continuously throughout the night. Once the trough is formed, the bottom value remains nearly constant until the filling begins at dawn. The values of phi between 0.20 and 0.30 appeared with the most frequency in the trough bottom. Therefore, the value of 0.25 ± 0.05 was chosen for use in this work.

With the phi value of 1.0 at the trough boundaries of SW and NW and the phi value of 0.25 at SB and NB, phi values could be calculated throughout the trough region as a function of latitude. Making phi a linear function of the solar zenith angles, determined in the previous section, provided the smooth transition of phi from unity to 0.25 and



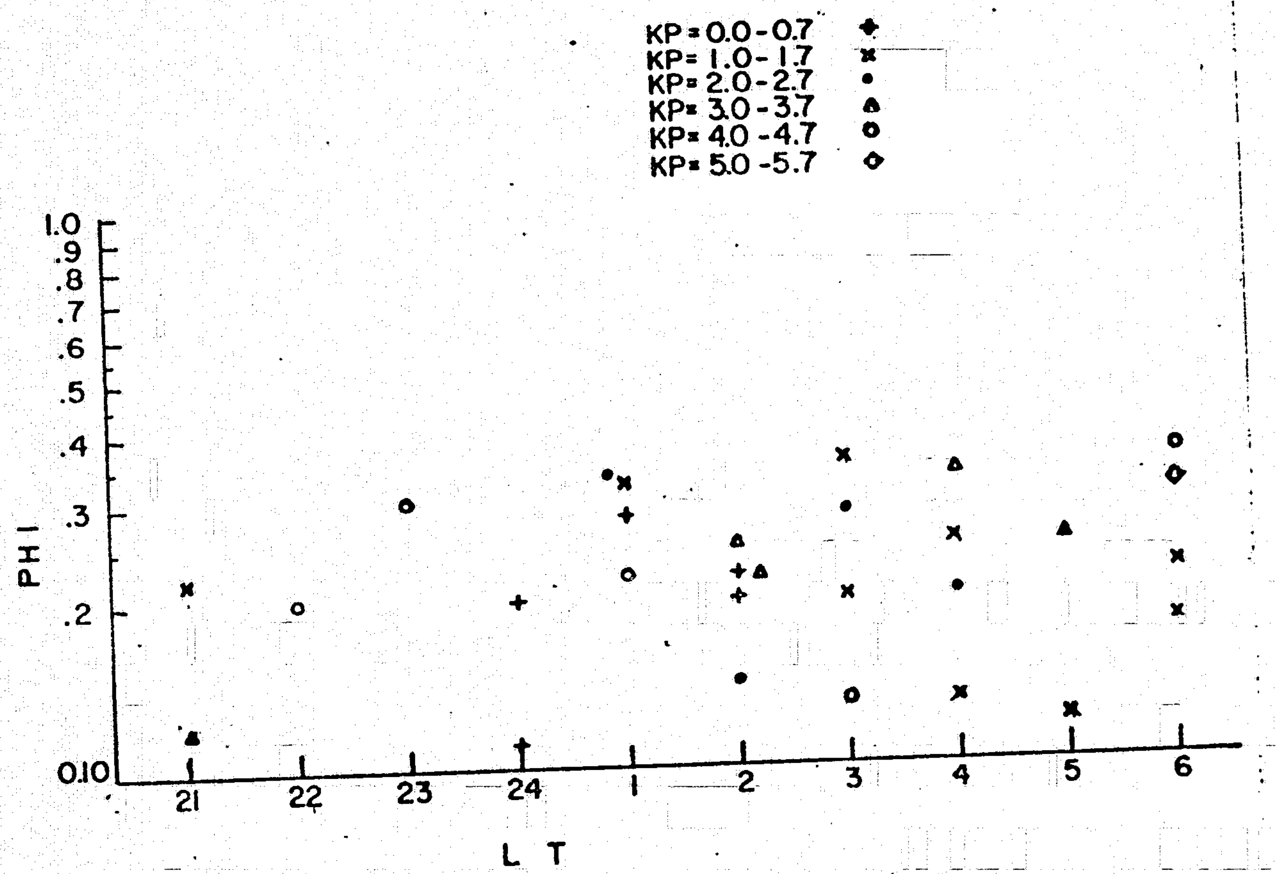
LT = 3
RZ = 37
KP = 0^+
3 Dec 62

Figure 4. Observed NmF_2 from Alouette I



Some average trough bottom values of phi at SB for all seasons, RZ $\leq$ 50.

Figure 5. Phi Values at SB



Some average trough bottom values of phi at NB for all seasons, RZ $\leq$ 50.

Figure 6. Phi Values at NB

back to unity in the trough region at dusk and dawn. Phi as a function of invariant latitude and solar zenith angle gave it the variability needed to be used as a modification factor for the C.C.I.R. model to produce more representative NmF_2 and horizontal electron density gradients in the main trough region.

CHAPTER 7

SUMMARY AND PRESENTATION OF RESULTS

This work contributes to resolving the problem of smoothing over the main trough region of the F_2 layer by major ionospheric models. Parameters needed to predict the occurrence of the trough have been determined from many observations. A modification factor has been developed for the C.C.I.R. model in order to predict more representative values of NmF_2 in the main trough region.

The prediction of the trough and modification factor for the C.C.I.R. model have been incorporated into a computer program designed to predict NmF_2. This program is listed in Appendix A. Tables 1 and 2 are a sample output from the program. By providing location, U.T., day, solar and magnetic activity, one is provided with the corresponding invariant lat., the trough location in invariant lat., solar zenith angles in the trough region, the C.C.I.R. model predicted NmF_2, the phi modification factor, and the modified C.C.I.R. model predicted NmF_2 in the trough region.

Figures 9 - 14 are applications of this model for different seasons, solar and magnetic activity. Figure 7 is a map of NmF_2 as predicted by the C.C.I.R. model. The contour lines do not show any trough region. Figure 8 is a map of the location of the trough and associated phi values at Equinox (spring or fall). The contour value of 1.0 is the predicted location of SW and NW. The contour value of 0.25 is the predicted location of SB and NB. Figure 9 is the

KP= 0.33
RZ= 50.00
DAY#= 80.00
GLONG= 280.00
U.T.= 6.00

LATITUDE	L. TIME	INV. LAT.	S. WALL	S. BOUND	N. BOUND	N. WALL	CHI	GAMMA	SIGMA	CCIR	PHI	PHI*CCIR
30.00	0.67	45.40	49.16	54.50	64.00	67.00	0.00	0.00	0.00	2.00E 05	1.00	2.00E 05
31.00	0.67	46.30	49.16	54.50	64.00	67.00	0.00	0.00	0.00	1.96E 05	1.00	1.96E 05
32.00	0.67	47.21	49.16	54.50	64.00	67.00	0.00	0.00	0.00	1.91E 05	1.00	1.91E 05
33.00	0.67	48.11	49.16	54.50	64.00	67.00	0.00	0.00	0.00	1.86E 05	1.00	1.86E 05
34.00	0.67	49.01	49.16	54.50	64.00	67.00	0.00	0.00	0.00	1.82E 05	1.00	1.82E 05
35.00	0.67	49.91	49.16	54.50	64.00	67.00	145.33	95.00	87.00	1.77E 05	0.89	1.59E 05
36.00	0.67	50.81	49.16	54.50	64.00	67.00	144.37	95.00	87.00	1.73E 05	0.77	1.33E 05
37.00	0.67	51.71	49.16	54.50	64.00	67.00	143.42	95.00	87.00	1.70E 05	0.64	1.09E 05
38.00	0.67	52.61	49.16	54.50	64.00	67.00	142.46	95.00	87.00	1.66E 05	0.52	8.56E 04
39.00	0.67	53.50	49.16	54.50	64.00	67.00	141.50	95.00	87.00	1.62E 05	0.39	6.34E 04
40.00	0.67	54.40	49.16	54.50	64.00	67.00	140.54	95.00	87.00	1.59E 05	0.26	4.21E 04
41.00	0.67	55.29	49.16	54.50	64.00	67.00	139.58	95.00	87.00	1.56E 05	0.25	3.90E 04
42.00	0.67	56.19	49.16	54.50	64.00	67.00	138.61	95.00	87.00	1.53E 05	0.25	3.83E 04
43.00	0.67	57.08	49.16	54.50	64.00	67.00	137.65	95.00	87.00	1.50E 05	0.25	3.76E 04
44.00	0.67	57.98	49.16	54.50	64.00	67.00	136.68	95.00	87.00	1.48E 05	0.25	3.70E 04
45.00	0.67	58.87	49.16	54.50	64.00	67.00	135.71	95.00	87.00	1.46E 05	0.25	3.64E 04
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51.00	0.67	64.23	49.16	54.50	64.00	67.00	129.88	95.00	87.00	1.36E 05	0.31	4.17E 04
52.00	0.67	65.12	49.16	54.50	64.00	67.00	128.91	95.00	87.00	1.35E 05	0.53	7.16E 04
53.00	0.67	66.02	49.16	54.50	64.00	67.00	127.93	95.00	87.00	1.34E 05	0.75	1.01E 05
54.00	0.67	66.91	49.16	54.50	64.00	67.00	126.96	95.00	87.00	1.34E 05	0.98	1.31E 05
55.00	0.67	67.80	49.16	54.50	64.00	67.00	0.00	0.00	0.00	1.34E 05	1.00	1.34E 05
56.00	0.67	68.69	49.16	54.50	64.00	67.00	0.00	0.00	0.00	1.34E 05	1.00	1.34E 05
57.00	0.67	69.58	49.16	54.50	64.00	67.00	0.00	0.00	0.00	1.34E 05	1.00	1.34E 05
58.00	0.67	70.47	49.16	54.50	64.00	67.00	0.00	0.00	0.00	1.34E 05	1.00	1.34E 05
59.00	0.67	71.37	49.16	54.50	64.00	67.00	0.00	0.00	0.00	1.35E 05	1.00	1.35E 05
60.00	0.67	72.26	49.16	54.50	64.00	67.00	0.00	0.00	0.00	1.35E 05	1.00	1.35E 05

Table 1. Sample Computer Output from a Spring Equinox Morning

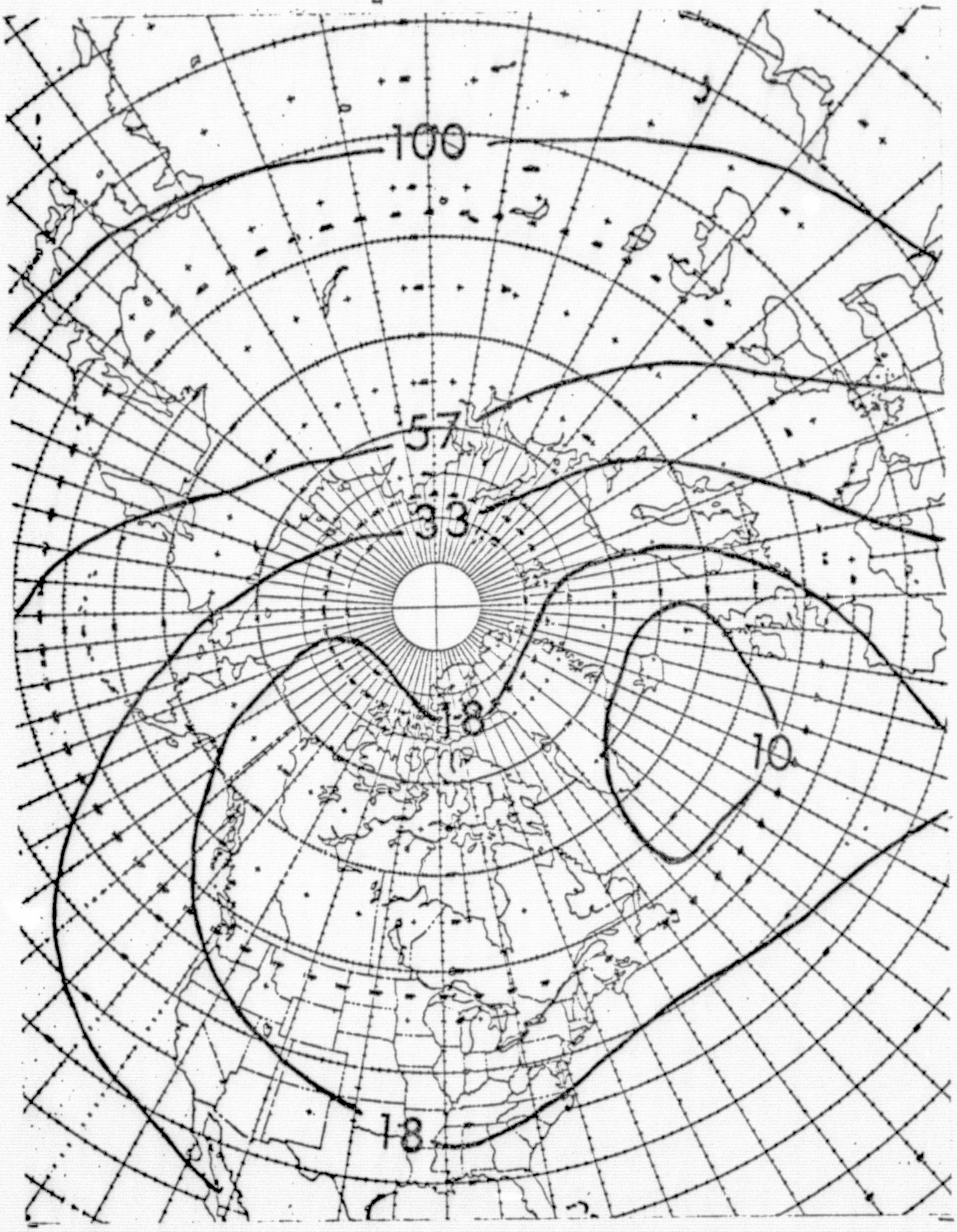
KP= 0.33
RZ= 50.00
DAY#= 80.00
GLONG= 240.00
U.T.= 6.00

LATITUDE	L. TIME	INV. LAT.	S. WALL	S. BOUND	N. BOUND	N. WALL	CHILAG	ALPHA	BETA	CCIR	PHI	PHI*CCIR
35.00	22.00	43.31	48.05	54.09	64.06	67.21	0.00	0.00	0.00	2.41E 05	1.00	2.41E 05
36.00	22.00	44.29	48.05	54.09	64.06	67.21	0.00	0.00	0.00	2.31E 05	1.00	2.31E 05
37.00	22.00	45.27	48.05	54.09	64.06	67.21	0.00	0.00	0.00	2.22E 05	1.00	2.22E 05
38.00	22.00	46.24	48.05	54.09	64.06	67.21	0.00	0.00	0.00	2.14E 05	1.00	2.14E 05
39.00	22.00	47.21	48.05	54.09	64.06	67.21	0.00	0.00	0.00	2.06E 05	1.00	2.06E 05
40.00	22.00	48.18	48.05	54.09	64.06	67.21	118.76	87.01	91.01	1.98E 05	0.98	1.95E 05
41.00	22.00	49.15	48.05	54.09	64.06	67.21	118.33	87.01	91.01	1.91E 05	0.86	1.65E 05
42.00	22.00	50.11	48.05	54.09	64.06	67.21	117.90	87.01	91.01	1.84E 05	0.74	1.37E 05
43.00	22.00	51.07	48.05	54.09	64.06	67.21	117.45	87.01	91.01	1.77E 05	0.63	1.11E 05
44.00	22.00	52.02	48.05	54.09	64.06	67.21	117.00	87.01	91.01	1.71E 05	0.51	8.67E 04
45.00	22.00	52.98	48.05	54.09	64.06	67.21	116.54	87.01	91.01	1.65E 05	0.39	6.41E 04
46.00	22.00	53.93	48.05	54.09	64.06	67.21	116.07	87.01	91.01	1.60E 05	0.27	4.31E 04
47.00	22.00	54.88	48.05	54.09	64.06	67.21	115.60	87.01	91.01	1.55E 05	0.25	3.87E 04
48.00	22.00	55.82	48.05	54.09	64.06	67.21	115.12	87.01	91.01	1.50E 05	0.25	3.76E 04
49.00	22.00	56.76	48.05	54.09	64.06	67.21	114.64	87.01	91.01	1.46E 05	0.25	3.65E 04
50.00	22.00	57.70	48.05	54.09	64.06	67.21	114.14	87.01	91.01	1.42E 05	0.25	3.55E 04
51.00	22.00	58.64	48.05	54.09	64.06	67.21	113.65	87.01	91.01	1.38E 05	0.25	3.46E 04
52.00	22.00	59.57	48.05	54.09	64.06	67.21	113.14	87.01	91.01	1.35E 05	0.25	3.37E 04
53.00	22.00	60.50	48.05	54.09	64.06	67.21	112.64	87.01	91.01	1.32E 05	0.25	3.30E 04
54.00	22.00	61.43	48.05	54.09	64.06	67.21	112.12	87.01	91.01	1.29E 05	0.25	3.23E 04
55.00	22.00	62.36	48.05	54.09	64.06	67.21	111.60	87.01	91.01	1.27E 05	0.25	3.18E 04
56.00	22.00	63.28	48.05	54.09	64.06	67.21	111.08	87.01	91.01	1.25E 05	0.25	3.13E 04
57.00	22.00	64.19	48.05	54.09	64.06	67.21	110.55	87.01	91.01	1.23E 05	0.28	3.46E 04
58.00	22.00	65.11	48.05	54.09	64.06	67.21	110.01	87.01	91.01	1.22E 05	0.50	6.08E 04
59.00	22.00	66.02	48.05	54.09	64.06	67.21	109.48	87.01	91.01	1.21E 05	0.72	8.65E 04
60.00	22.00	66.92	48.05	54.09	64.06	67.21	108.93	87.01	91.01	1.20E 05	0.93	1.12E 05
61.00	22.00	67.82	48.05	54.09	64.06	67.21	0.00	0.00	0.00	1.20E 05	1.00	1.20E 05
62.00	22.00	68.72	48.05	54.09	64.06	67.21	0.00	0.00	0.00	1.20E 05	1.00	1.20E 05
63.00	22.00	69.61	48.05	54.09	64.06	67.21	0.00	0.00	0.00	1.20E 05	1.00	1.20E 05
64.00	22.00	70.50	48.05	54.09	64.06	67.21	0.00	0.00	0.00	1.20E 05	1.00	1.20E 05
65.00	22.00	71.38	48.05	54.09	64.06	67.21	0.00	0.00	0.00	1.21E 05	1.00	1.21E 05

Table 2. Sample Computer Output from a Spring Equinox Evening

result of the product of Figures 7 and 8 to produce a modified C.C.I.R. NmF_2 with increased resolution of the main trough region. Figures 10 and 11 are the resultant maps of modified C.C.I.R. NmF_2 at Equinox but with Rz = 0 and 100 respectively. Again, much improved resolution of the main trough region has been produced by using the modification factor on the C.C.I.R. model. Figure 11 is a map of the modified C.C.I.R. model NmF_2 at Equinox with Kp = 8.0. Increased Kp has made the trough region narrower by moving the northern extent of the trough to the south. The north and south walls now have very large electron density gradients. Figure 13 is a map of modified C.C.I.R. model NmF_2 at winter soltice. The trough is predicted to be a continuous feature around the world at this time of year because the Eastern Hemisphere trough region always has very large solar zenith angles. Figure 14 is a map of modified C.C.I.R. model NmF_2 at summer soltice. Now in contrast to Figure 13, the trough region is at its smallest longitudinal extent. These are just some sample conditions to show the improved resolution of the main trough region by using this work.

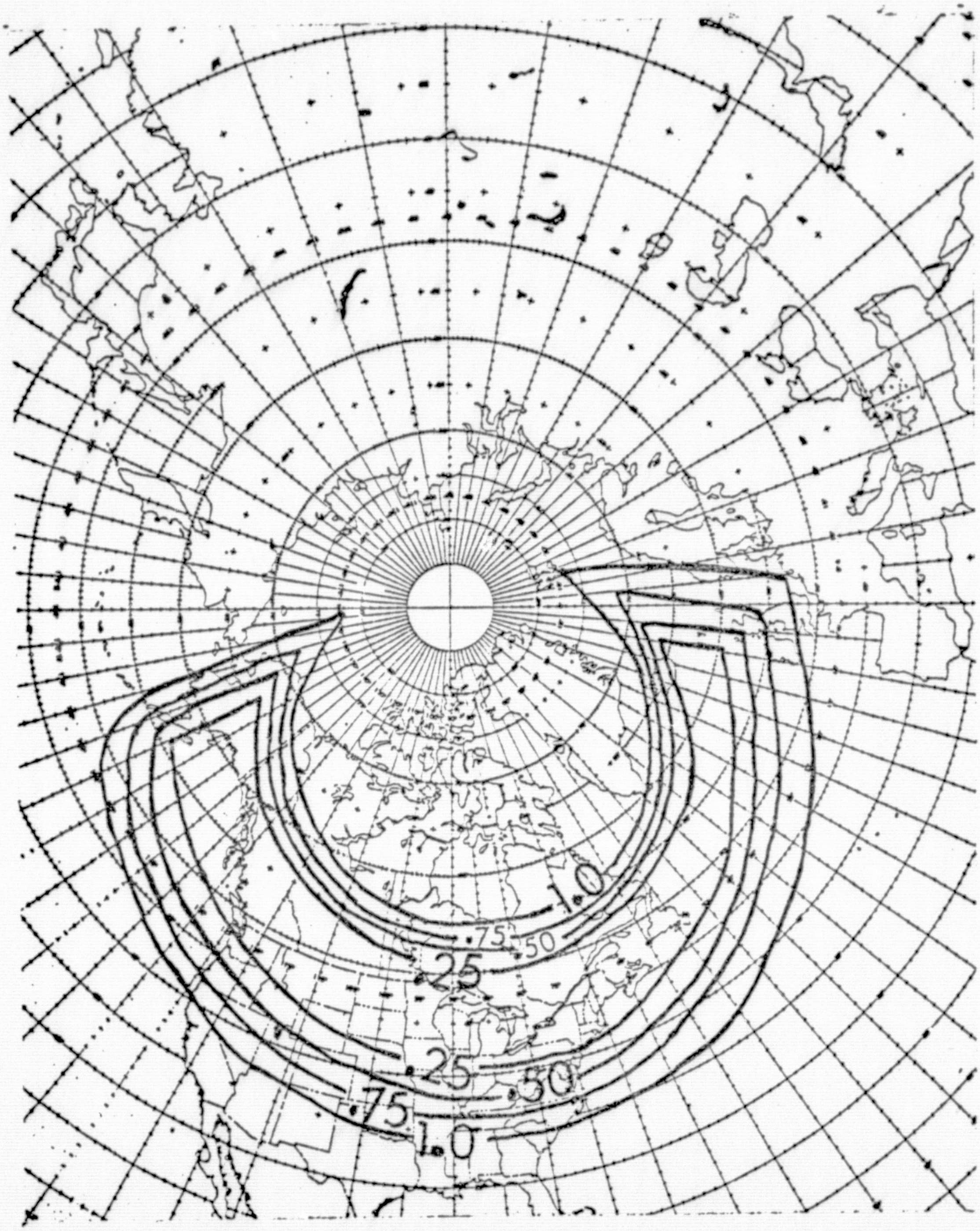
$NmF_2 \times 10^{-10}\ M^{-3}$



Spring Equinox UT = 6.0

RZ = 50 KP = 0^+

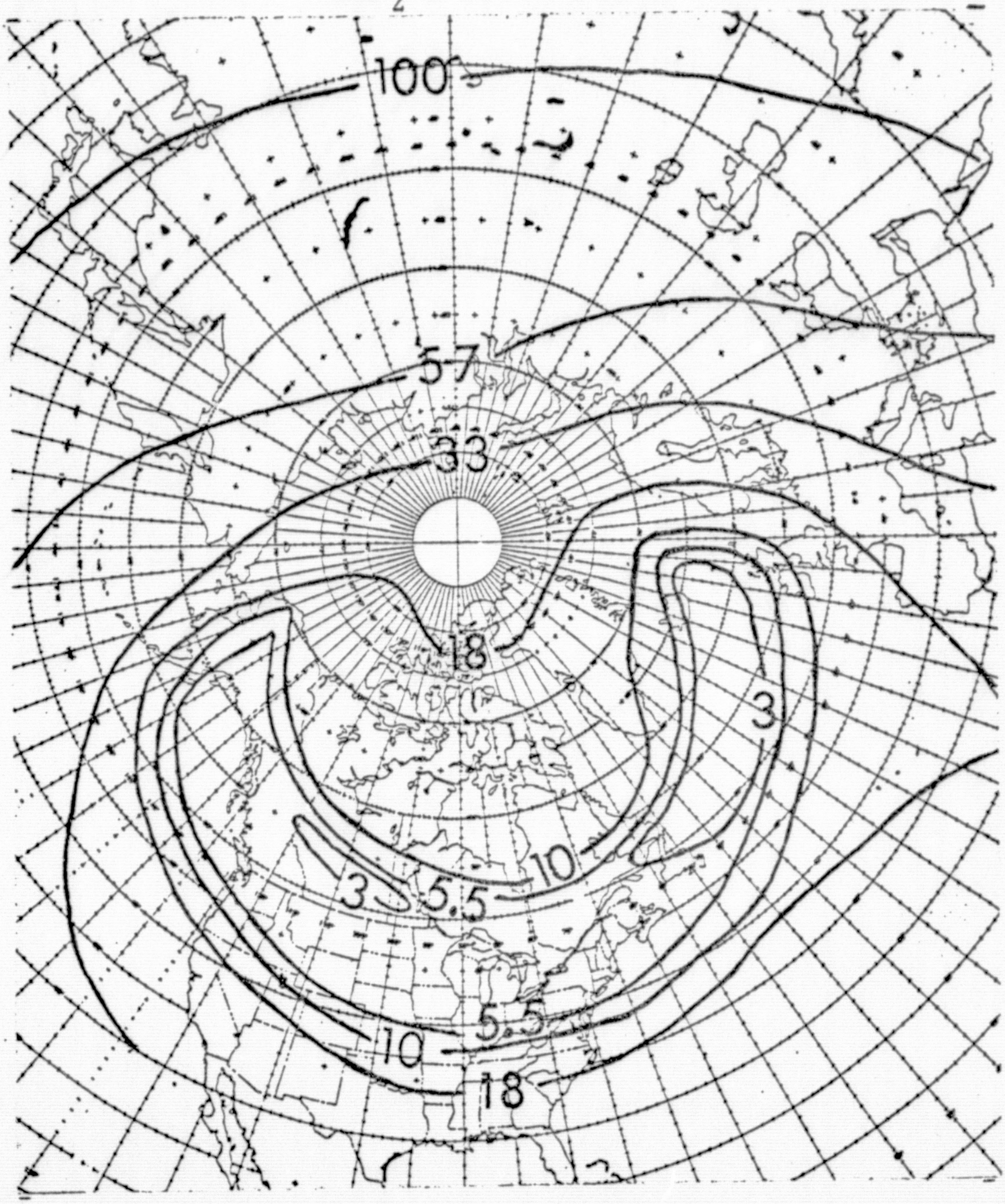
Figure 7. C.C.I.R. Predicted NmF_2



Equinox (Spring or Fall) UT = 6.0
KP = 0^+

Figure 8. Main Trough Location and Associated Phi Values

$NmF_2 \times 10^{-10}\ M^{-3}$

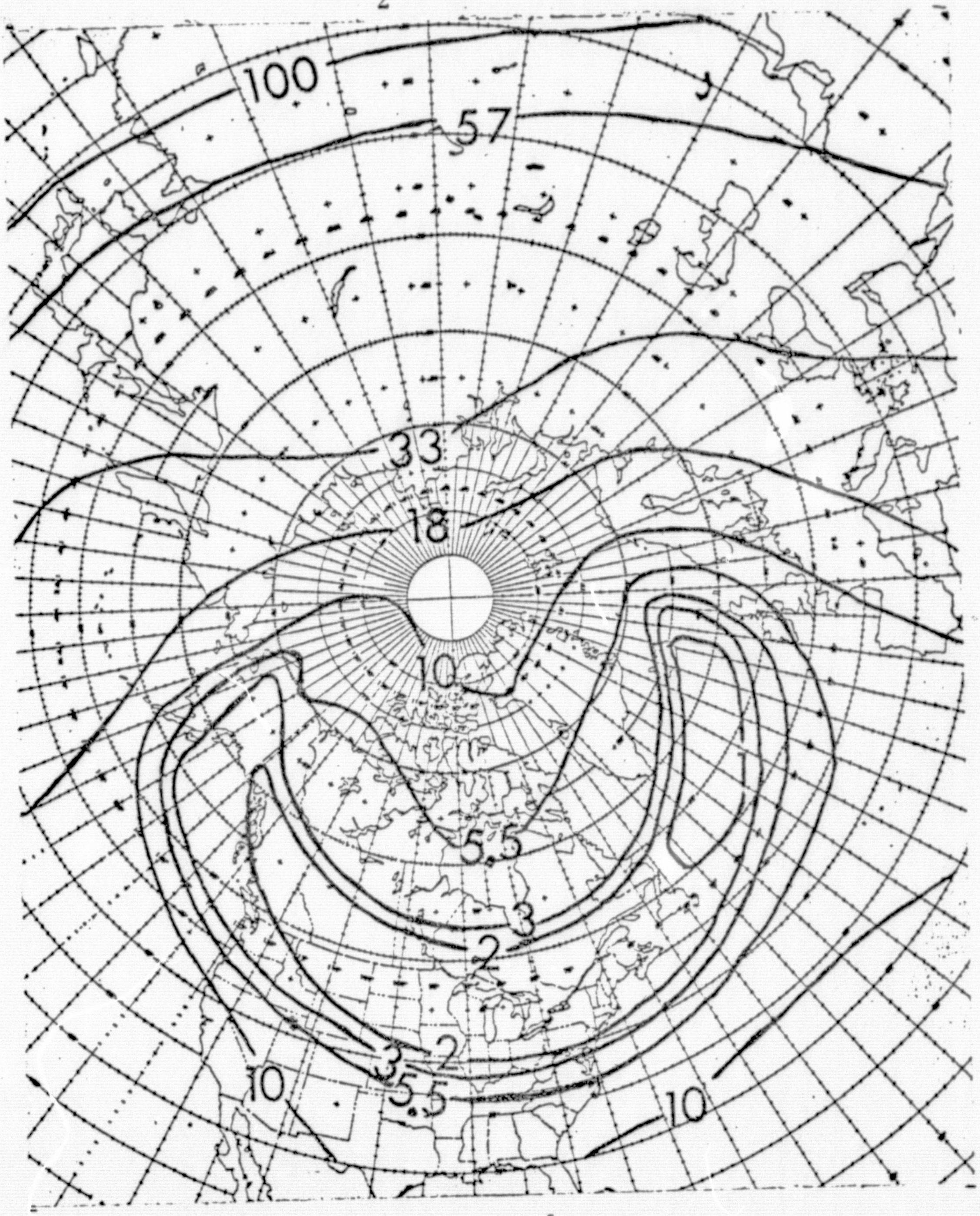


Spring Equinox UT = 6.0

RZ = 50 KP = 0^+

Figure 9. Modified C.C.I.R. Predicted NmF_2

$NmF_2 \times 10^{-10}$ M^{-3}

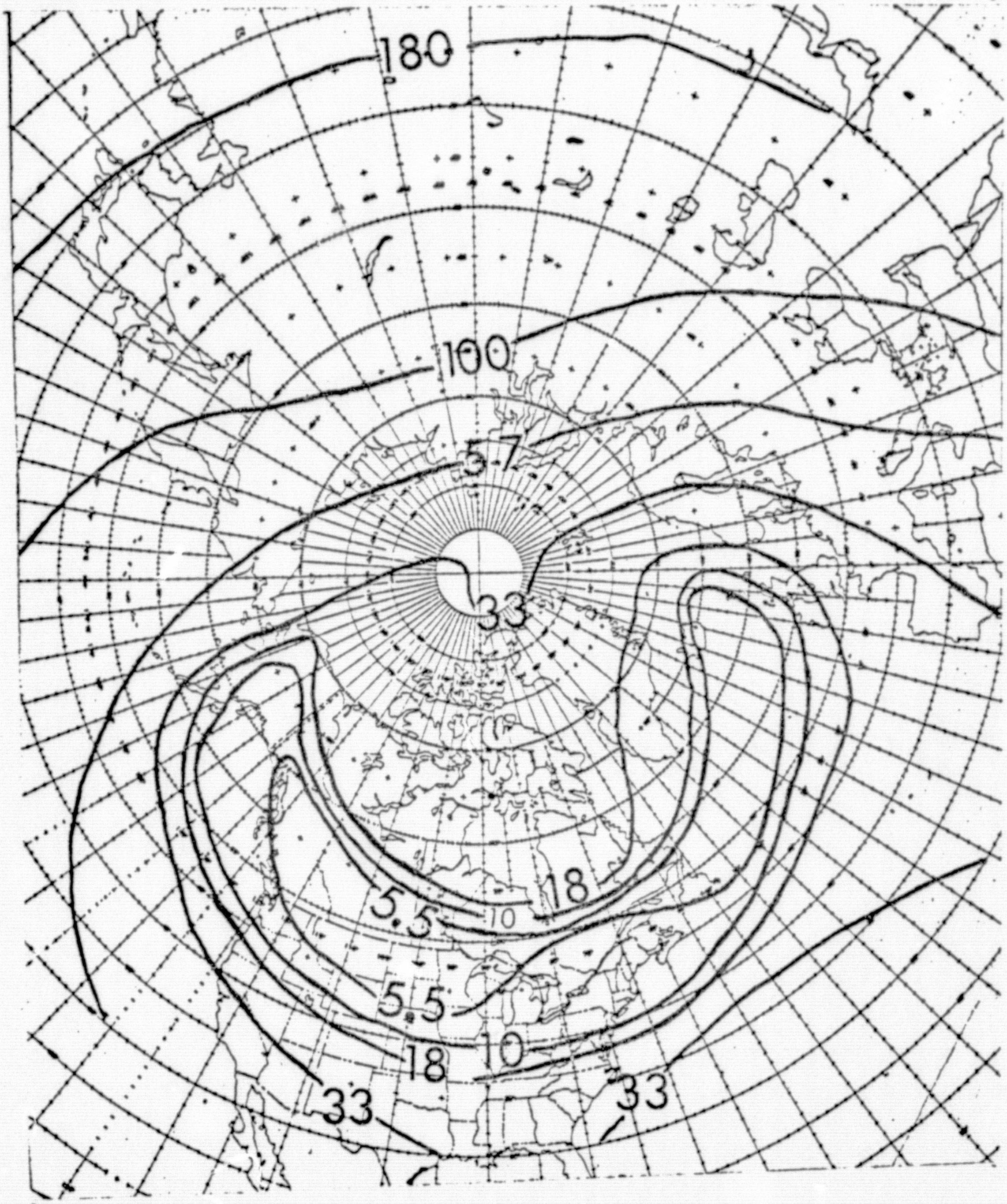


Spring Equinox UT = 6.0

RZ = 0 KP = 0^+

Figure 10. Modified C.C.I.R. Predicted NmF_2

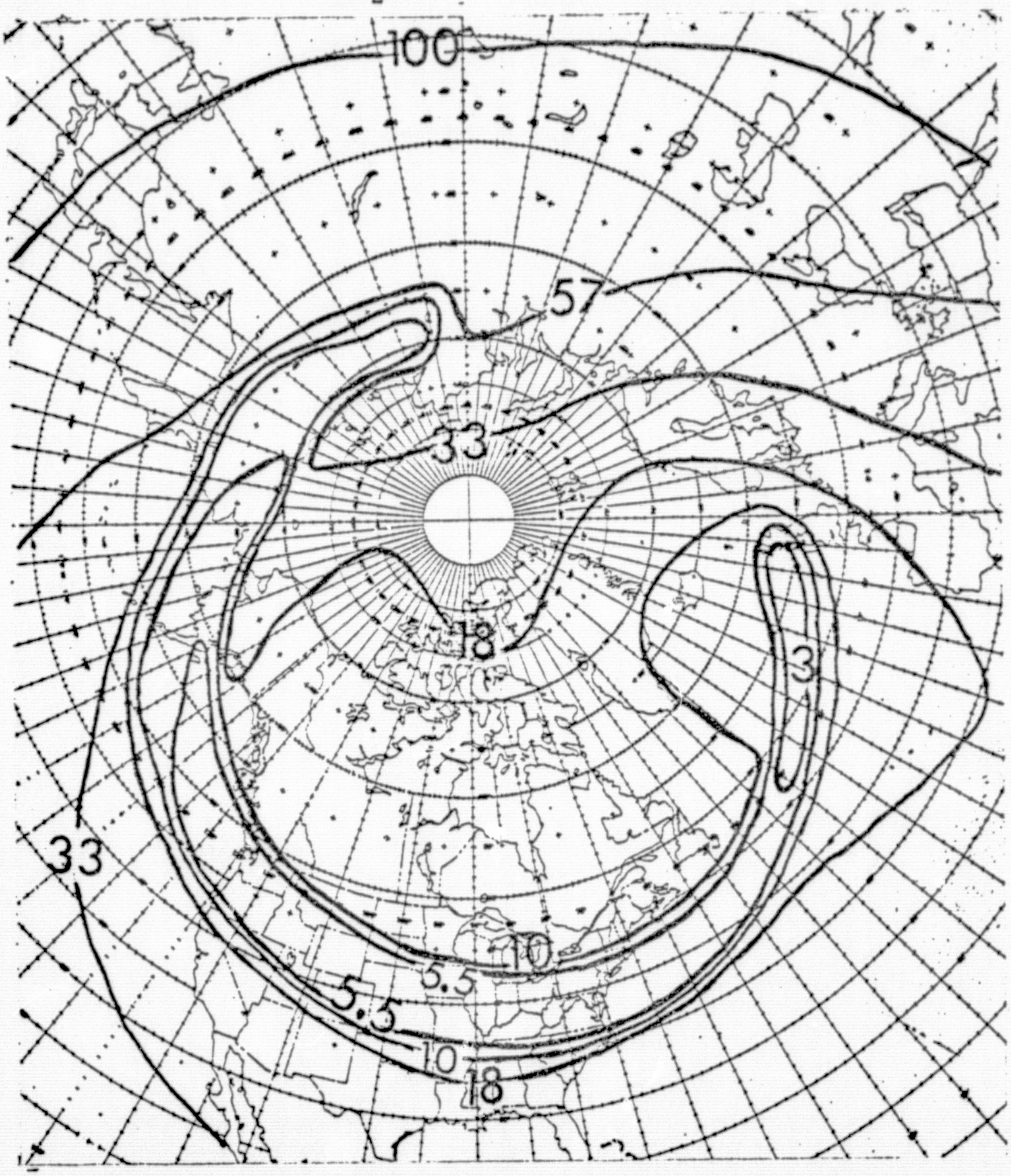
$NmF_2 \times 10^{-10}\ M^{-3}$



Spring Equinox UT = 6.0
RZ = 100 KP = 0^+

Figure 11. Modified C.C.I.R. Predicted NmF_2

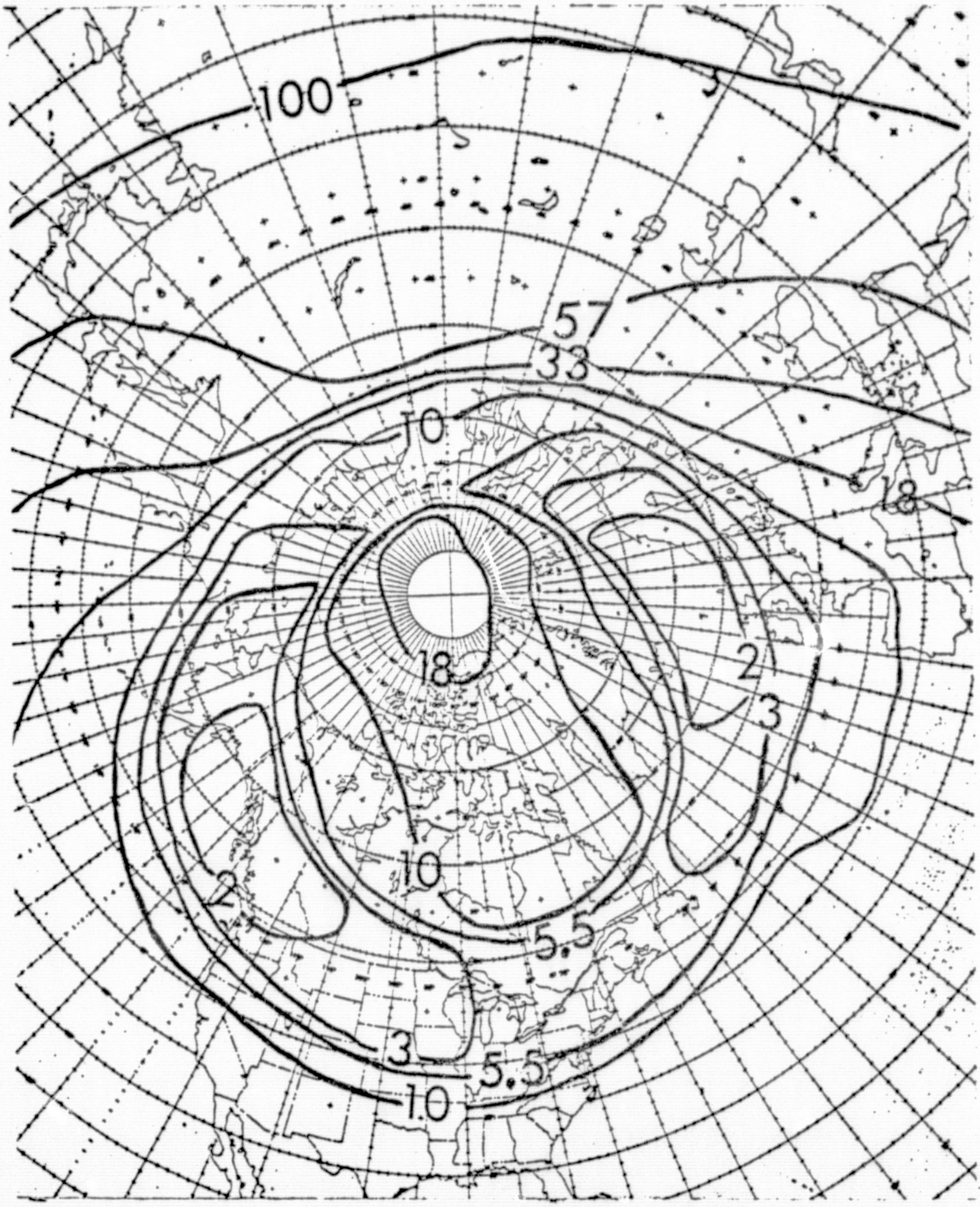
$NmF_2 \times 10^{-10}\ M^{-3}$



Spring Equinox UT = 6.0
RZ = 50 KP = 8.0

Figure 12. Modified C.C.I.R. Predicted NmF_2

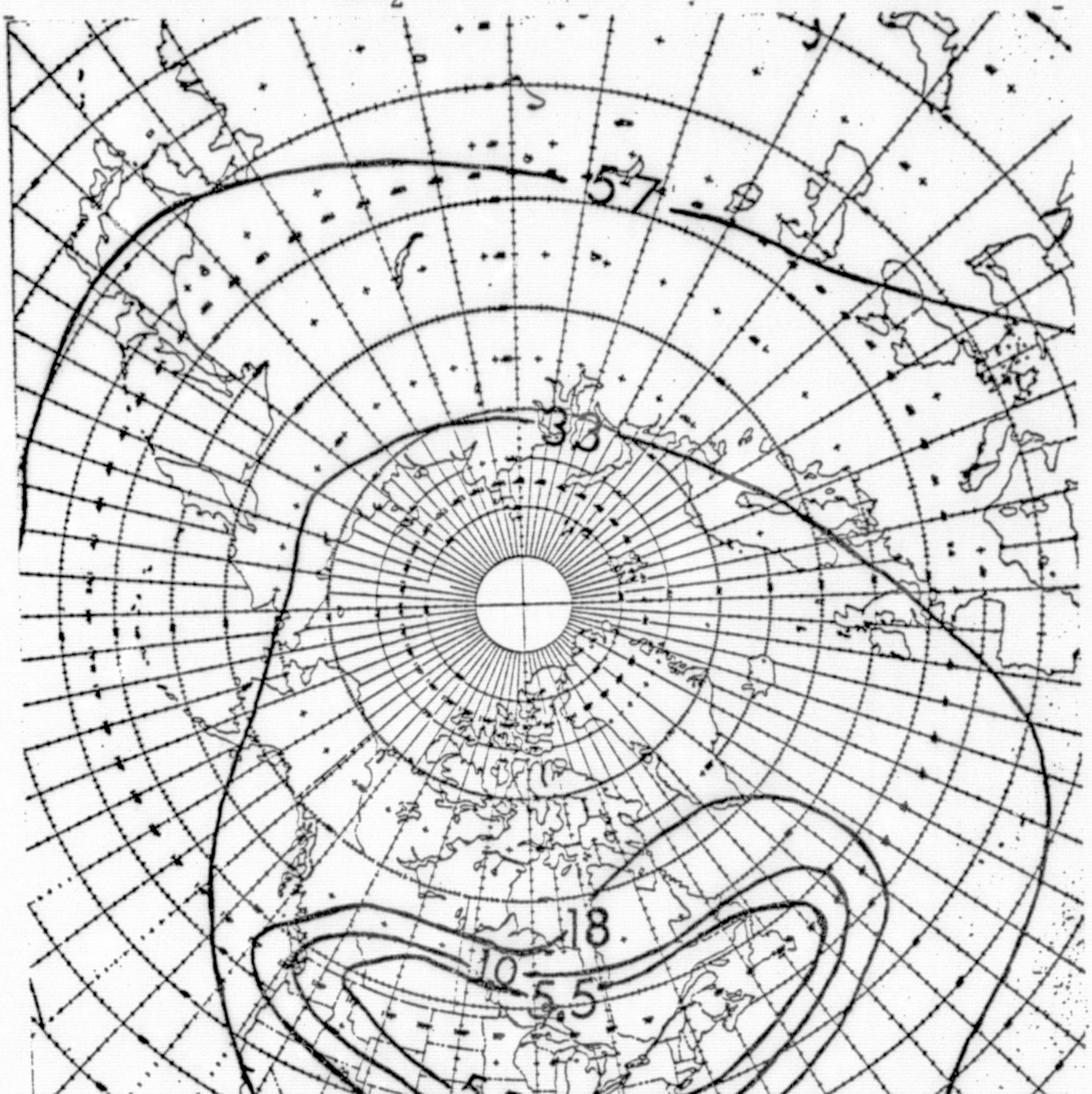
$NmF_2 \times 10^{-10}\ M^{-3}$



Winter Soltice UT = 6.0
RZ = 50 KP = 0^+

Figure 13. Modified C.C.I.R. Predicted NmF_2

$NmF_2 \times 10^{-10}\ M^{-3}$



Summer Soltice UT = 6.0
RZ = 50 KP = 0^+

Figure 14. Modified C.C.I.R. Predicted NmF_2

CHAPTER 8

MODEL LIMITATIONS

The model is designed for use in the Northern Hemisphere and the modification factor was developed for $Rz \leq 100$. There were not enough observations with $Rz > 100$ to determine a separate value of the modification factor.

CHAPTER 9

CONCLUSION AND RECOMMENDATION FOR FUTURE WORK

This work has shown how a modification factor can be developed for use with a global ionospheric model to increase resolution of predicted NmF_2 in relatively small ionospheric feature such as the main trough. Further work needs to be done with observations taken during periods of high solar activity to extend the modification factor to include all possible solar activity levels.

Other investigators of the trough, like myself, believe a better understanding of the relationship of the trough to the plasmapause would provide better parameters than the solar zenith angle for determining formation time of the trough. Theoretical and observational studies to uncover this relationship would be very valuable.

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APPENDIX A

COMPUTER PROGRAM TO OBTAIN: C.C.I.R. MODEL PREDICTED NmF_2, MODIFICATION FACTOR, AND MODIFIED NmF_2 IN THE MAIN TROUGH REGION

```
C-------------------------------------------------------------
     X-------------
C    MAIN PROGRAM TO PRODUCE F2 PEAK MODEL OF TROUGH
C     03/16/76 - - R. DIVANY FOR B. HALCROW
C     VERSION 1.02 - LAST MODIFIED 03/23/76
C-------------------------------------------------------------
     X-------------
C-------------------------------------------------------------
     X-------------
C     THE PROGRAM SWEEPS THROUGH A RANGE OF VALUES FOR GEOG
     XRAPHIC
C     LATITUDE AND LONGITUDE, UNIVERSAL TIME, RZ, KP, AND D
     XAY NUMBER.
C     SUBROUTINE TROUGH IS CALLED TO CALCULATE THE VALUE OF
     XPHI- A
C     PARAMETER WHICH IS USED TO MULTIPLY THE CCIR DERIVED
     XF2 PEAK
C     ELECTRON DENSITIES BY TO INCLUDE THE TROUGH.  FOR TIM
     XES OR
C     LOCATIONS WHERE THERE IS NO TROUGH PHI WILL HAVE A VA
     XLUE OF UNITY.
C     SUBROUTINE TROUGH ALSO CALLS AN ENTRY POINT OF SUBROU
     XTINE ATLAS
C     CALLED POINTS WHICH CALCULATES THE CCIR F2 PEAK ELECT
     XRON DENSITY.
C     THE CCIR MODEL USES SPHERICAL HARMONIC COEFFICIENTS W
     XHICH HAVE
C     BEEN DERIVED FOR CONDITIONS OF R12=0 AND R12=100. THE
     XSPECIFIED
C     RZ VALUE IS CONVERTED TO A 10.7 CM. SOLAR FLUX VALUE
     XAND THE NMF2
C     VALUES ARE CALCULATED FOR BOTH R12=0. AND R12=100. A
     XLINEAR
C     RELATIONSHIP IS THEN USED TO FIND THE NMF2 VALUE FOR
     XTHE GIVEN
C     10.7 CM. FLUX VALUE.THE CCIR MODEL COEFFICIENTS ARE O
     XRGANIZED WITH
C     A SEPARATE SET OF COEFFICIENTS FOR EACH MONTH. THIS P
     XARTICULAR
C     VERSION OF THE PROGRAM CAN ONLY DEAL WITH ONE MONTH A
     XT A TIME.
C     THE SPHERICAL HARMONIC COEFFICIENTS ARE INCLUDED IN T
     XHE MAIN DATA
C     STREAM. THERE ARE NO CHECKS TO INSURE THAT THE DAY NU
     XMBER AGREES.
C     (IS FOR THE PROPER MONTH).
C     IT IS RECOMMENDED THAT USERS CONSIDER MAKING A TAPE W
     XITH ALL
C     TWELVE MONTHS OF COEFFICIENTS ORGANIZED TO ALLOW RUNN
     XING FOR ALL
C     DAY NUMBERS. THIS HAS BEEN IMPLEMENTED IN THE PENN ST
     XATE MARK I
C     IONOSPHERIC MODEL.  SEE SCIENTIFIC REPORT # 355 FROM
     XTHE
```

```
C     PENNSYLVANIA STATE UNIVERSITY IONOSPHERE RESEARCH LAB
     XORATORY (MAY
C     1970).
C-----------------------------------------------------------------
     X-------------
      REAL*4 U(13,76,2),KP,KPLO,KPHI
      INTEGER*4 KK(14,2)
C     ATLAS READS IN THE SPHERICAL HARMONIC COEFFICIENTS AN
     XD CONTROL
C     PARAMETERS.
      CALL ATLAS(KK,U)
C     READ LOWEST, HIGHEST AND INCREMENT VALUES FOR LATITUD
     XE, LONGITUDE,
C     UNIVERSAL TIME, RZ, DAY #, AND KP.
10    READ(5,100,END=99)GLATLO,GLATHI,DELLAT,GLONLO,GLONHI,
     XDELLON,UTLO,
     1UTHI,DELUT,RZLO,RZHI,DELRZ,DAYLO,DAYHI,DELDAY,KPLO,KP
     XHI,DELKP
100   FORMAT (8F10.5)
C     CALCULATE NUMBER OF LATITUDES, LONGITUDES, UNIVERSAL
     XTIMES, RZ
C     VALUES, DAY NUMBERS,AND KP VALUES FOR THE LOOPS.
      NLAT=1+(GLATHI-GLATLO)/DELLAT
      NLON=1+(GLONHI-GLONLO)/DELLON
      NUT=1+(UTHI-UTLO)/DELUT
      NRZ=1+(RZHI-RZLO)/DELRZ
      NDAYS=1+(DAYHI-DAYLO)/DELDAY
      NKP=1+(KPHI-KPLO)/DELKP
C     LOOP FOR KP VALUES.
      DO 20 N=1,NKP
      KP=KPLO+(N-1)*DELKP
      WRITE(6,98)KP
98    FORMAT('1','KP=',1F7.2)
C     LOOP FOR RZ VALUES.
      DO 20 L=1,NRZ
      RZ=RZLO+(L-1)*DELRZ
      WRITE(6,101)RZ
101   FORMAT(' ','RZ=',1F7.2)
C     LOOP FOR DAY NUMBERS.
      DO 20 M=1,NDAYS
      DAY=DAYLO+(M-1)*DELDAY
      WRITE(6,102)DAY
102   FORMAT(' ','DAY#=',1F7.2)
C     LOOP FOR LONGITUDES.
      DO 20 J=1,NLON
      GLONG=GLONLO+(J-1)*DELLON
      WRITE(6,103)GLONG
103   FORMAT(' ','GLONG=',1F7.2)
C     LOOP FOR UNIVERSAL TIMES.
      DO 20 K=1,NUT
      UTIME=UTLO+(K-1)*DELUT
      WRITE(6,104)UTIME
104   FORMAT(' ','U.T.=',1F7.2)
C     LOOP FOR LATITUDE VALUES.
```

```
      DO 20 I=1,NLAT
      GLAT=GLATLO+(I-1)*DELLAT
      CALL TROUGH(GLAT,GLONG,UTIME,RZ,DAY,KP,KK,U,PHI,CCIR)
20    CONTINUE
      GO TO 10
99    STOP 99
      END
      SUBROUTINE TROUGH(GLAT,GLONG,UT,RZ,DAY,KP,KK,U,PHI,CC
     XIR)
C     THIS SUBROUTINE CALCULATES THE CCIR MODEL FOR GIVEN C
     XONDITIONS AND
C     CALCULATES THE VALUE OF PHI WHICH SHOULD BE USED TO M
     XULTIPLY THE
C     VALUE OF NMF2 FROM CCIR MODEL TO INCLUDE THE F-REGION
     XTROUGH.
C     03/16/76 - - R. DIVANY
C     PROGRAM SPECIFICATIONS AND OTHER PERTINENT INFORMATIO
     XN SUPPLIED BY
C     B. HALCROW.
C
      REAL*4 KP,LT,NW,NB,ILAT,ILONG,U(13,76,2)
      INTEGER*4 KK(14,2),LMODE/0/
      PI=ARCOS(-1.0)
      XVLAT=0.
      XVLAT2=0.0
      ALPHA=0.0
      BETA=0.0
      CHILAG=0.0
      CHI=0.0
      SIGMA=0.0
      GAMMA=0.0
      LT=AMOD(UT+24.+GLONG/15.,24.)
      IF(LT .GT. 0.0)GO TO 333
      LT=LT+24.0
333   IF(LT .LT. 12.)GO TO 5
      T=LT-12.
      GO TO 10
5     T=LT+12.
10    MODE=1
      IF(LT .GE. 12.)MODE=2
      IF(MODE .EQ. 1 .AND. MODE .NE. LMODE)WRITE(6,200)
      IF(MODE .EQ. 2 .AND. MODE .NE. LMODE)WRITE(6,201)
      LMODE=MODE
200   FORMAT ('-LATITUDE  L. TIME  INV. LAT.  S. WALL  S. B
     XOUND  N. BOUN
     1D  N. WALL   CHI   GAMMA  SIGMA    CCIR    PHI   PHI*
     XCCIR'/)
201   FORMAT ('-LATITUDE  L. TIME  INV. LAT.  S. WALL  S. B
     XOUND  N. BOUN
     1D  N. WALL CHILAG  ALPHA  BETA     CCIR    PHI   PHI*
     XCCIR'/)
C     CALCULATE THE TROUGH PARAMETERS.
      ARG=-.000017*T**5.3476
      IF(ARG .GT. -180.)GO TO 12
```

```
      TERM1=0.0
      GO TO 13
12    TERM1=EXP(ARG)
13    ARG=-.000466*(24.-T)**4.1
      IF(ARG .GT. -180.)GO TO 14
      TERM2=0.0
      GO TO 15
14    TERM2=EXP(ARG)
15    NW=67.+9.0*(TERM1+TERM2)-1.25*(KP-1./3.)
      ARG=-.000019*T**5.419
      IF(ARG .GT. -180.)GO TO 16
      TERM1=0.0
      GO TO 17
16    TERM1=EXP(ARG)
17    ARG=-.000215*(24.-T)**4.55
      IF(ARG .GT. -180.)GO TO 18
      TERM2=0.0
      GO TO 19
18    TERM2=EXP(ARG)
19    NB=64.+9.0*(TERM1+TERM2)-1.0*(KP-1./3.)
      SB=54.+7.0*((1.0+((T*T-4.0)/(5.8*T+0.1))**18)**(-0.5)
     X+1.0-(1.0+
     1   (((T)**2-8.0)/(13.5*T+0.1))**16)**(-0.5))-0.5*(KP-
     X1./3.)
      SW=48.+5.0*((1.0+((T*T-4.0)/(5.65*T+0.1))**22)**(-0.5
     X)+1.0-(1.0
     1   +(((T)**2-8.0)/(12.35*T+0.10))**14)**(-0.50))
      IF(DAY .LE. 90. .OR . DAY .GE. 260.)GO TO 28
      AB=54.+7.0*((1.0+((T*T-4.0)/(5.8*T+0.1))**18)**(-0.5)
     X+1.0-(1.0+
     1  (((T)**2-8.0)/(13.5*T+0.1))**16)**(-0.50))-0.5*(KP-
     X1./3.)
      XCHI=87.0-3.0*(KP-1./3.)
      TIME=20.5
      CALL WALL(XCHI,TIME,DAY,ALAT3)
      CALL INVAR(ALAT3,GLONG,XVLAT,XVLON)
      NW=AMIN1(NW,XVLAT)
      IF(NW .LE. SW)NW=SW
      XCHI=91.0-3.0*(KP-1./3.)
      TIME=20.5
      CALL WALL(XCHI,TIME,DAY,ALAT3)
      CALL INVAR(ALAT3,GLONG,XVLAT2,XVLON2)
      NB=AMIN1(NB,XVLAT2)
      IF(NB .LT. SB)GO TO 25
      EPSLON=0.25
      GO TO 30
25    NB=(SW+NW)/2.0
      SB=NB
      EPSLON=1.0-(( 1.0-0.25)/(SW-AB))*(SW-SB)
      GO TO 30
28    EPSLON=0.25
30    CALL INVAR(GLAT,GLONG,ILAT,ILONG)
      IF(ILAT .LE. SW .OR . ILAT .GE. NW)GO TO 72
C     CHECK FOR NIGHTTIME CONDITIONS.
```

```
      IF(LT .GE. 12.)GO TO 50
C     CALCULATE CHI
      R4=-0.49015*COS(2.0*PI*(DAY+8.0)/365.25)
      R5=2.0*PI*(LT-12.)/24.
      R6=SIN(GLAT*PI/180.)*SIN(R4)+COS(GLAT*PI/180.)*COS(R4
     X)*COS(R5)
      CHI=180./PI*ARCOS(R6)
      SIGMA=87.0
      GAMMA=95.0
      IF(CHI .LE. 87.)GO TO 72
C     CHECK FOR TROUGH FILLING IN
      IF(CHI .LT. 95.)GO TO 35
      IF(ILAT .GT. SW .AND. ILAT .LT. SB)GO TO 32
      IF(ILAT .GE. SB .AND. ILAT .LE. NB)GO TO 34
      PHI=1.0-((1.0-EPSLON)/(NW-NB))*(NW-ILAT)
      GO TO 87
32    PHI=1.0-((1.0-EPSLON)/(SW-SB))*(SW-ILAT)
      GO TO 87
34    PHI=EPSLON
      GO TO 87
35    Z=1.0-((1.0-EPSLON)/(95.0-87.0))*(CHI-87.0)
      IF(ILAT .GT. SW .AND. ILAT .LT. SB)GO TO 38
      IF(ILAT .GE. SB .AND. ILAT .LE. NB)GO TO 39
      PHI=1.0-((1.0-Z)/(NW-NB))*(NW-ILAT)
      GO TO 87
38    PHI=1.0-((1.0-Z)/(SW-SB))*(SW-ILAT)
      GO TO 87
39    PHI=Z
      GO TO 87
C     CALCULATE LAGGED CHI
50    R4=-0.40915*COS(2.0*PI*(DAY+8.0)/365.25)
      R5=2.0*PI*(LT-(1.5+12.))/24.
      R6=SIN(GLAT*PI/180.)*SIN(R4)+COS(GLAT*PI/180.)*COS(R4
     X)*COS(R5)
      CHILAG=180./PI*ARCOS(R6)
      ALPHA=87.-3.0*(KP-1./3.)
      BETA=91.-3.0*(KP-1./3.)
      IF(CHILAG .LE. ALPHA)GO TO 72
C     CHECK FOR DISCONTINUITY AT NOON
      IF(LT .GE. 12. .AND. LT .LT. 12.75)GO TO 553
      GO TO 554
C     CALCULATE FUGE CHI
 553  R4=-0.40915*COS(2.0*PI*(DAY+8.0)/365.25)
      R5=PI*(11.95-12.)/12
      R6=SIN(GLAT*PI/180.)*SIN(R4)+COS(GLAT*PI/180.)*COS(R4
     X)*COS(R5)
      FUGCHI=180./PI*ARCOS(R6)
      IF(FUGCHI .GT. 87.)GO TO 554
      EPSLON=1.0-((1.0-0.25)/0.75)*(LT-12.)
C     CHECK FOR TROUGH FORMING
554   IF(CHILAG .GT. ALPHA .AND. CHILAG .LT. BETA)GO TO 55
      IF(ILAT .GT. SW .AND. ILAT .LT. SB)GO TO 40
      IF(ILAT .GE. SB .AND. ILAT .LE. NB)GO TO 45
      PHI=1.0-((1.0-EPSLON)/(NW-NB))*(NW-ILAT)
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```
      GO TO 87
40    PHI=1.0-((1.0-EPSLON)/(SW-SB))*(SW-ILAT)
      GO TO 87
45    PHI=EPSLON
      GO TO 87
55    Z=1.0-((1.0-EPSLON)/(BETA-ALPHA))*(CHILAG-ALPHA)
      IF(ILAT .GT. SW .AND. ILAT .LT. SB)GO TO 65
      IF(ILAT .GE. SB .AND. ILAT .LE. NB)GO TO 70
      PHI=1.0-((1.0-Z)/(NW-NB))*(NW-ILAT)
      GO TO 87
65    PHI=1.0-((1.0-Z)/(SW-SB))*(SW-ILAT)
      GO TO 87
70    PHI=Z
      GO TO 87
72    PHI=1.0
C     CALCULATE CCIR  NMF2
87    S107=0.76*RZ+60.
      CALL POINTS(GLAT,GLONG,UT    ,KK,U,S107,CCIR,SINX, SIN
     XSQI,GYRO)
      F2TROF=PHI*CCIR
      IF(MODE .EQ. 1)WRITE(6,203)GLAT,LT,ILAT,SW,SB,NB,NW,C
     XHI,GAMMA,
     1SIGMA,CCIR,PHI,F2TROF
      IF(MODE .EQ. 2)WRITE(6,203)GLAT,LT,ILAT,SW,SB,NB,NW,C
     XHILAG,
     1ALPHA,BETA,CCIR,PHI,F2TROF
203   FORMAT (' ',F7.2,2(F9.2,1X),2F9.2,2(1X,F9.2),F8.2,F7.
     X2,F7.2,1PE10.
     12,0PF6.2,1PE10.2)
      RETURN
      END
      SUBROUTINE WALL(XCHI,TIME,DAY,ALAT3)
      REAL*8 A,D,B,R,S,PID
      PID=DARCOS(-1.0D0)
      A=DSIN(-0.40915D0*DCOS(2.0D0*PID*(DAY+8.0)/365.25))
      D=DSQRT(1.0D0-A*A)
      B=DCOS(PID/180.D0*XCHI)
      C=DCOS(PID*(TIME-12.0D0)/12.0D0)
      R=A*A+D*C*D*C
      S=D*C*DSQRT(R-B*B)
      ALAT1=180.D0/PID*DARSIN((B*A+S)/R)
      ALAT2=180.D0/PID*DARSIN((B*A-S)/R)
      ALAT3=AMAX1(ALAT1,ALAT2)
      RETURN
      END
      SUBROUTINE INVAR(LAT,LONG,ILAT,ILONG)
C     THIS SUBROUTINE CONVERTS GEOGRAPHIC CO-ORDINATES TO I
     XNVARIANT ONES
C     ADAPTED FROM A PL1 PROGRAM SUPPLIED BY B. HALCROW
C     11/05/75 -- R. DIVANY
      REAL LAT,LONG,ILAT,ILONG,COLATO/6.3/,LONGO/-77.5/,A/1
     X.9/,B/.061/
      PI=ARCOS(-1.0)
      DR=PI/180.
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```
      RD=180./PI
      COSCOL=COS(DR*COLATO)
      SINCOL=SIN(DR*COLATO)
      LONG=AMOD(LONG,360.)
      IF(LONG .GT. 180.)LONG=LONG-360.
      FACARG=(LONG+5.)/70.7107
C     CALCULATE DIPOLE COORDINATES
      COSLTG=COS(LAT*DR)
      SINLTG=SIN(LAT*DR)
      DLONG=(LONG-LONGO)*DR
      SINLAT=SINLTG*COSCOL+COSLTG*SINCOL*COS(DLONG)
      COLAT=ARCOS(SINLAT)
      SNCOL=SIN(COLAT)
      SNDLNG=SIN(DLONG)
      SNLONG=COSLTG*SNDLNG/SNCOL
      COLAT=COLAT*RD
      ILONG=ARSIN(SNLONG)
      SNLTCH=COSCOL*SINLAT-SINCOL*SNCOL*COS(ILONG)
      IF(ABS(SINLTG) .LT. 1.0E-7)GO TO 25
      IF(ABS(SNLTCH/SINLTG-1.) .GT. 0.0001)ILONG=PI-ILONG
25    ILONG=ILONG*RD
C     MODIFY THE DIPOLE COORDINATES
      BMPLNG=(0.22+0.004*(COLAT-40.0))*(COLAT-40.0)
      DMLONG=(ILONG-BMPLNG)*DR
      ALONG=(AMOD(ILONG,360.)-165.)/30.
      CMLAT=COLAT*(1.-0.03*EXP(-ALONG**2))
      COSDL=COS(DMLONG)
      COS2DL=COS(2.0*DMLONG)
      FAC=0.30+0.582911*FACARG*EXP(-FACARG**2)
      BETA=(1.0-FAC)*COS2DL+FAC+COSDL
      CLATIN=(CMLAT-A*BETA)/(1.+BETA*B)
      ILAT=AMIN1(90.-CLATIN,90.)
      RETURN
      END
      SUBROUTINE ATLAS (K,U)
C     THIS SUBROUTINE CALCULATES NE AT F2 MAXIMUM USING
C     C.C.I.R. NOTE 340 MODELS
      REAL*4 U(13,76,2),P(3),C(3),COM(3),G(78,2),DF(76,2),A
     XF(9,2)
      REAL*4 BF(9,2),OMEG(24,2),OMEGA(2),                   CO
     XT(8)
      REAL*4 SIT(8),FOF2(2)
      REAL*4 DR/1.745329E-02/,RD/57.29578/
      DATA P(3)/3.0E+05/
      INTEGER*4 NFF(2),K(14,2)
      CALL RT (K,U)
      NFF(1)=K(9,1)+1
      NFF(2)=K(9,2)+1
      RETURN
      ENTRY POINTS (FLAT,FLON,UTIM,K,U,SN,NMAX,SINX,SINSQI,
     XGF)
      REAL*4 NMAX
C     THIS PROGRAM SEGMENT CALCULATES NE AT F2 MAX FOR SEVE
     XRAL STATIONS
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C     AT ONE VALUE OF U.T.
      TIME=UTIM
      T=15.0*TIME-180.0
      I8=8
      CALL SICOJT (I8,COT,SIT,T)
      DO 40  J=1,2
   40 CALL DKSICO (J,NFF(J),K(10,J),U,SIT,COT,DF)
      P(1)=FLAT
      P(2)=FLON
      CALL MAGFIN (P,COM)
      TMP=COM(2)*COM(2)+COM(3)*COM(3)
      C(2)=FLON
      C(3)=P(1)
      C(1)=RD*ATAN(ATAN(-COM(1)/SQRT(TMP))/SQRT(COS(DR*P(1)
     X)))
      SINX=SIN(DR*C(1))
      SINSQI=SIN(ATAN(-COM(1)/SQRT(TMP)))**2
      GF=1.39969*(SQRT(COM(1)*COM(1)+TMP))
      DO 45  J=1,2
      CALL GK (J,K,C,G)
      CALL DKGK (J,NFF(J),G,DF,OMEGA(J))
      OMEGA(J)=1.24E+04*OMEGA(J)*OMEGA(J)
   45 CONTINUE
   50 NMAX=((SN-60.0)*OMEGA(2)+(136.0-SN)*OMEGA(1))/76.0
      RETURN
      END
      SUBROUTINE RT (K,U)
C     SUBROUTINE TO READ FOURIER COEFFICIENTS FROM INPUT ST
     XREAM
      REAL*8 CARD(10,2)
      INTEGER*4 K(14,2)
      REAL*4 U(13,76,2)
    5 READ (05,200) CARD
  200 FORMAT (10A8)
      READ(5,201)K
  201 FORMAT (8I10)
      READ(5,202)U
  202 FORMAT (5E16.7)
      WRITE(6,100)CARD
  100 FORMAT (' HEADER CARDS FOR FOURIER COEFFICIENTS'/(' '
     X,10A8))
      RETURN
      END
      SUBROUTINE MAGFIN (POS,UNE)
C       COMPUTE NASA MAGNETIC FIELD COMPONENTS
      REAL*4 P(7,7),DP(7,7),CP(7),AOR(7),SP(7),POS(3),UNE(3
     X)
      REAL*4 CT(7,7)/0.0,0.0,3.33333E-01,2.66667E-01,2.5714
     X3E-01,2.53968
      1E-01,2.52525E-01,0.0,0.0,0.0,2.00000E-01,2.28571E-01,
     X2.38095E-01,2
      2.42424E-01,0.0,0.0,0.0,0.0,1.42857E-01,1.90476E-01,2.
     X12121E-01,0.0
      3,0.0,0.0,0.0,0.0,1.11111E-01,1.61616E-01,0.0,0.0,0.0,
     X0.0,0.0,0.0,9
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4.09091E-02,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.
X0,0.0,0.0,0.0
5/
 REAL*4 GE(7,7)/0.0,3.04112E-01,2.40350E-02,-3.15180E-
X02,-4.17940E-
102,1.62560E-02,-1.95230E-02,0.0,2.14740E-02,-5.12530E
X-02,6.21300E-
202,-4.52980E-02,-3.44070E-02,-4.85300E-03,0.0,0.0,-1.
X33810E-02,-2.
348980E-02,-2.17950E-02,-1.94470E-02,3.21200E-03,0.0,0
X.0,0.0,-6.496
400E-03,7.00800E-03,-6.08000E-04,2.14130E-02,0.0,0.0,0
X.0,0.0,-2.044
500E-03,2.77500E-03,1.05100E-03,0.0,0.0,0.0,0.0,0.0,6.
X97000E-04,2.2
67000E-03,0.0,0.0,0.0,0.0,0.0,0.0,1.11500E-03/
 REAL*4 H(7,7)/0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,-5.7989
X0E-02,3.31240
1E-02,1.48700E-02,-1.18250E-02,-7.96000E-04,-5.75800E-
X03,0.0,0.0,-1
2.57900E-03,-4.07500E-03,1.00060E-02,-2.00000E-03,-8.7
X3500E-03,0.0,
30.0,0.0,2.10000E-04,4.30000E-04,4.59700E-03,-3.40600E
X-03,0.0,0.0,0
4.0,0.0,1.38500E-03,2.42100E-03,-1.18000E-04,0.0,0.0,0
X.0,0.0,0.0,-1
5.21800E-03,-1.11600E-03,0.0,0.0,0.0,0.0,0.0,0.0,-3.25
X000E-04/
 DATA P(1,1)/1.0/,DP(1,1)/0.0/,HC/6371200.0/,RD/57.295
X780/
 DATA CP(1)/1.0/,SP(1)/0.0/
 P1=POS(1)
 P2=POS(2)
 IF (P1.LT.89.9) GO TO 5
 IF (P1.EQ.89.9) GO TO 10
 P1=89.9
 P2=0.0
 GO TO 10
5 IF (P1+89. .GE.0) GO TO 10
 P1=-89.9
 P2=0.0
10 PHI=P2/RD
 AR=HC/(HC+POS(3))
 C=SIN(P1/RD)
 S=SQRT(CP(1)-C*C)
 SP(2)=SIN(PHI)
 CP(2)=COS(PHI)
 AOR(1)=AR*AR
 AOR(2)=AOR(1)*AR
 DO 15  M=3,7
 SP(M)=SP(2)*CP(M-1)+CP(2)*SP(M-1)
 CP(M)=CP(2)*CP(M-1)-SP(2)*SP(M-1)
15 AOR(M)=AR*AOR(M-1)
 BV=0.0
```

```
      BN=BV
      BPHI=BV
      DO 40  N=2,7
      FN=N
      SUMR=0.0
      SUMT=SUMR
      SUMP=SUMT
      DO 35  M=1,N
      IF (N.EQ.M) GO TO 20
      IF (N.NE.M+1) GO TO 25
      P(N,M)=C*P(N-1,M)
      DP(N,M)=C*DP(N-1,M)-S*P(N-1,M)
      GO TO 30
   20 P(N,N)=S*P(N-1,N-1)
      DP(N,N)=S*DP(N-1,N-1)+C*P(N-1,N-1)
      GO TO 30
   25 P(N,M)=C*P(N-1,M)-CT(N,M)*P(N-2,M)
      DP(N,M)=C*DP(N-1,M)-S*P(N-1,M)-CT(N,M)*DP(N-2,M)
   30 FM=M-1
      TS=GE(N,M)*CP(M)+H(N,M)*SP(M)
      SUMR=SUMR+P(N,M)*TS
      SUMT=SUMT+DP(N,M)*TS
   35 SUMP=SUMP+FM*P(N,M)*(-GE(N,M)*SP(M)+H(N,M)*CP(M))
      BV=BV+AOR(N)*FN*SUMR
      BN=BN-AOR(N)*SUMT
   40 BPHI=BPHI-AOR(N)*SUMP
      UNE(1)=-BV
      UNE(2)=BN
      UNE(3)=-BPHI/S
      RETURN
      END
      SUBROUTINE GK (JR,K,C,G)
C     COMPUTE COORDINATE FUNCTIONS, G(I),I=1,.....K+1
C     C(1)=MODIFIED LATITUDE.C(2),C(3)==GEOG.LAT.,LONGITUDE
     XRESPECTIVELY
      DIMENSION K(14,2),C(1),G(78,2)
      DR=0.017453293
      N=8
      X=DR*C(1)
      Y=C(2)*DR
      Z=DR*C(3)
      K0=K(1,JR)
      SX=SIN(X)
      G(1,JR)=1.0
      G(2,JR)=SX
      IF (K0.EQ.1) GO TO 10
      DO 5  I=2,K0
    5 G(I+1,JR)=SX*G(I,JR)
   10 KDIF=K(2,JR)-K0
      IF (KDIF.EQ.0) GO TO 30
      J=1
      CX1=COS(Z)
      CX=CX1
      T=Y
```

```
   15 KC=K(J,JR)+4
      G(KC-2,JR)=CX*COS(T)
      G(KC-1,JR)=CX*SIN(T)
      IF (KDIF.EQ.2) GO TO 25
      KN=K(J+1,JR)
      DO 20  I=KC,KN,2
      G(I,JR)=SX*G(I-2,JR)
   20 G(I+1,JR)=SX*G(I-1,JR)
   25 IF (J.EQ.N) GO TO 30
      KDIF=K(J+2,JR)-KN
      IF (KDIF.EQ.0) GO TO 30
      CX=CX*CX1
      J=J+1
      FJ=J
      T=FJ*Y
      GO TO 15
   30 RETURN
      END
      SUBROUTINE AJBJ (JR,LH,MX,D,G,ASTAR,BSTAR)
C     PART OF SUBROUTINE TO CALCULATE NMAX F2
C     COMPUTE COEFFICIENTS FOR A FIXED GEOGRAPHIC POINT
      DIMENSION D(13,76,2),G(78,2),ASTAR(9,2),BSTAR(9,2)
      N=LH+1
      DO 5  J=1,N
      ASTAR(J,JR)=0.0
      DO 5  K=1,MX
    5 ASTAR(J,JR)=ASTAR(J,JR)+D(2*J-1,K,JR)*G(K,JR)
      DO 10  J=2,N
      BSTAR(J,JR)=0.0
      DO 10  K=1,MX
   10 BSTAR(J,JR)=BSTAR(J,JR)+D(2*J-2,K,JR)*G(K,JR)
      RETURN
      END
      SUBROUTINE SICOJT (L,C,S,A)
C     PART OF SUBROUTINE TO CALCULATE NMAX F2 TIME SERIES
C     COMPUTE SIN(JT),COS(JT),J=1,....,L FOR ANGLE A
      DIMENSION C(1),S(1)
      T=0.01745329*A
      C(1)=COS(T)
      S(1)=SIN(T)
      DO 5  I=2,L
      C(I)=C(1)*C(I-1)-S(1)*S(I-1)
    5 S(I)=C(1)*S(I-1)+S(1)*C(I-1)
      RETURN
      END
      SUBROUTINE ABSICO (JR,LH,ASTAR,BSTAR,COTIME,SITIME,OM
     XEGA)
C      PART OF SUBROUTINE TO CALCULATE NMAXF2
C     COMPUTE OMEGA, SUMMING THE FOURIER SERIES
      DIMENSION COTIME(1),SITIME(1),ASTAR(9,2),BSTAR(9,2)
      OMEGA=ASTAR(1,JR)
      DO 5  J=1,LH
    5 OMEGA=OMEGA+ASTAR(J+1,JR)*COTIME(J)+BSTAR(J+1,JR)*SIT
     XIME(J)
```

```
      RETURN
      END
      SUBROUTINE DKSICO (JR,MX,LH,D,SITIME,COTIME,DK)
C     PART OF SUBROUTINE TO CALCULATE NMAX F2
0C     COMPUTE D SUB K, COEFFICIENTS FOR A FIXED TIME
      DIMENSION D(13,76,2),COTIME(1),SITIME(1),DK(76,2)
      DO 5  K=1,MX
      DK(K,JR)=D(1,K,JR)
      DO 5  L=1,LH
    5 DK(K,JR)=DK(K,JR)+D(2*L,K,JR)*SITIME(L)+D(2*L+1,K,JR)
     X*COTIME(L)
      RETURN
      END
      SUBROUTINE DKGK (JR,MX,G,DKSTAR,OMEGA)
C     PART OF SUBROUTINE TO CALCULATE NMAX F2
C     COMPUTE OMEGA, SUMMING THE GEOGRAPHIC SERIES
      DIMENSION G(78,2),DKSTAR(76,2)
      OMEGA=G(1,JR)*DKSTAR(1,JR)
      DO 5  K=2,MX
    5 OMEGA=OMEGA+DKSTAR(K,JR)*G(K,JR)
      RETURN
      END
```