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Boulder Laboratories

MEAN ELECTRON DENSITY VARIATIONS OF THE QUIET IONOSPHERE

NO. 13, SUMMARY OF ONE YEAR OF DATA MAY 1959 - APRIL 1960

BY J. W. WRIGHT

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS

Technical Note

40-13

April 15, 1962

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ABSTRACT

The CRPL has initiated a program for large-scale computation of electron density profiles from ionospheric vertical soundings. Scaling is performed at field stations, permitting computation of hourly profiles at the Central Laboratory. These profiles are combined to form hourly mean quiet profiles for each station and month. This report is the last of a series which has illustrated the electron density variations in the mean quiet ionosphere between latitudes 15°N and 50°N along the 75°W meridian. It contains a summary of phenomena evident in the individual reports of the series, and a summary presentation of the year's data.

(This study performed under contract NTF-84 with the National Aeronautics and Space Administration.)

Table of Contents

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1. INTRODUCTION

By the end of the IGY, the number of ionospheric soundings reduced to electron density profiles was comparatively small, measured in terms of the very large vertical soundings program then underway. The orginial difficulties stemmed from the considerable labor necessary for manual computation of single profiles, but by the time of the IGY, the availability of electronic computers had largely eliminated this. The remaining limitation was the rather formidable amount of scaled data necessary for each computation. The IGY electron density profile surveys conducted by Schmerling [1957] and Thomas and Vickers [Thomas, 1959] for selected stations on International Quiet or Regular World Days were limited in their scope by the large amount of data preparation necessary.

When the National Bureau of Standards embarked upon a similar program early in the IGC (1959), part of the effort was devoted to developing techniques by which the valuable manpower resources of the network of U. S. and associated vertical soundings stations -- already the mainstay of the conventional ionospheric soundings data published by NBS -- could be applied to numerical reduction of their ionograms for N(h) analyses. Simple methods were developed for this purpose, permitting the station scientist to derive and tabulate data for subsequent N(h) analysis by the central laboratory's computer. These methods, applied to the hourly ionograms of a day's observations, require about the same effort as the preparation of a quarter-hourly f-plot.

Since May 1959, the NBS has conducted an hourly electron density profile survey, using data provided by the ionospheric stations, from a current total of 11 stations. These stations, their affiliation, and their initial date of participation in the grogram are given in table I.

Table I

Station	Affiliation	Latitude	Longitude	Mag. Dip	Began N(h)
Puerto Rico	NBS	18°30'N	67°12'W	51.5°N	Jan. 1959
Grand Bahama Is.	USA SigC.	26°40'N	78°22'W	59.5°N	Feb. 1959
Fort Monmouth	USA SigC.	40°15'N	74°01'W	51.7°N	Feb. 1959
White Sands, N. M	USA SigC.	32°24'N	106°52'W	60° N	Mar. 1959
St. Johns, Newf.	DRTE	47°33'N	52°40'W	72° N	June 1959
Adak, Alaska	USA SigC.	51°54'N	176°39'W	63° N	June 1959
Okinawa, Ryukus	USA SigC.	26°30'N	128° W	36.5°N	June 1959
Thule, Greenland	USA SigC.	76°31'N	68°50'W	86.2°N	July 1959
Huancayo, Peru	NBS	12°03'S	75°20'W	0.5°N	Jan. 1960
Talara, Peru	NBS	4°34'S	81°15'W	13° N	Jan. 1960
Baguio, Philippines	NBS	16°25'N	120°36'E	17° N	Feb. 1960

Our first objective in the study of these data has been to classify and describe the mean quiet geographical, temporal, and height structure of the northern mid-latitude ionosphere. For this purpose, five of these stations (Newfoundland, Ft. Monmouth, White Sands, Grand Bahama Island and Puerto Rico) are close enough together geographically to permit the delineation of the structure of the mean quiet ionosphere between geographic latitudes of 15° to 50°N, and geomagnetic latitudes of 30°N to 59°N, with some confidence. The results from these stations for one year of data (March 1959 - April 1960) are issued by the NBS in a series of Technical Notes [Wright et al., 1959-1961]. It is the purpose of this summary report to review this considerable volume of data, to portray it in a different summary form, and to discuss certain other results which assist in the interpretation of the shole.

2. CALCULATION OF THE ELECTRON DENSITY DATA

For the data discussed here, the well known matrix method of Budden [1955] has been used to derive the electron density profiles. It is unnecessary to review the details of the primary virtual height-to-true height conversion, since in most respects the procedure has corresponded exactly to Budden's. However, it should be observed that this method has several shortcoming which lead to errors in the N(h) data. The shortcomings are nearly as well known as the method itself and do not need detailed discussion here; it suffices to itemize them: (a) The electron density is assumed to be a monotonic function of height; if a valley exists there will be a height error which diminishes from a value equal to the valley width just above the valley, to smaller values at greater frequencies. (b) The shape of the profile is somewhat inaccurately determined in regions of strong curvature, because of a convenient but inappropriate assumption made about the variation of electron density within small intervals [Paul, 1960]. (c) Because the ionogram observations themselves do not ordinarily contain information about electron densities below about $10^4/cm^3$, there is usually an error at night due to neglect of retardation in this ionization.

While one or more of these may be serious for individual profiles, and while their resultant may give mean profile parameters which contain net errors of perhaps 10%, these errors are small compared with the total variations discussed here.

The result of the primary matrix multiplication is a table of true heights at particular plasma frequencies. It is more convenient to derive from these data certain other quantities amenable to convenient physical interpretation. Our primary true height data has therefore been put through a secondary calculation process in which the following parameters are derived:

(1) Electron density at fixed heights: The plasma frequencies (f_N) are converted to electron densities by the relation N(electrons/cm^3) = 12,400 $f_N^2 (Mc/s)^2$. A linear interpolation among the corresponding true heights then provides the electron density at 10 km height intervals throughout the observable portion of the profile.

(2) Height and characteristic thickness at the F2 peak: Ionograms contain no direct information from a layer peak itself, since the virtual height of a radio frequency penetrating just to this level is immeasurable. Nevertheless, this level is of unique interest, and it is essential to devise means for its description. A practical method is to fit the portion of the true height profile near the peak with a suitable curve, and to determine the parameters of the peak from this curve. The parabola is the simplest curve for this purpose, and has the additional merit of closely approximating the peak of a "Chapman" distribution.

The parabola is given by

$$N = Nmax \left\{ 1 - \left(\frac{hmax - h}{Ym} \right)^2 \right\}, \qquad (1)$$

Where hmax is the height of the layer peak, Nmax the peak electron density corresponding to the critical frequency, and Ym is a parameter characteristic of the thickness of the layer. This curve has been fit to the highest portion of our true height curves, using the measured critical frequency and two true heights: the highest and the fourth from highest. The accuracy with which the parabola may be fit to these data depends slightly upon the spacing of the two heights and rather critically upon the accuracy of determination of Nmax. In the data described here, various checks have been applied to eliminate extreme errors due to the latter cause. The frequency spacing of the two true heights used for fitting the parabola is a compromise between a narrow spacing (sensitive to small relative errors in the data) and a wide spacing (sensitive to real departures from the parabola). In practice, these points are separated by about 0.8 Mc/s.

In addition to the height of the peak, the quantity Ym/2, which we call "Scat" is determined. This is the quarter-thickness of the parabola, and is taken as a measure of the scale height of the atomic species at the level hmaxF2, in what follows. The reasons for this interpretation are included in the following section.

(3) Extrapolation of profiles above hmaxF2: For sunspot maximum conditions it was previously shown [Wright, 1960] that an electron distribution above the F2 peak of the form

$$N = N\max \exp \frac{1}{2} \left\{ 1 - \frac{h\max - h}{H} - \exp\left(- \frac{h\max - h}{H} \right) \right\} \qquad (2)$$

agreed fairly well with available rocket and other data, for a neutral particle scale height of H = 100 km. This is, of course, the well-known equation derived by Chapman for the equilibrium distribution due to electron production and recombination-type loss, but it is also the equilibrium form theoretically expected of a layer under the combined influences of diffusion and attachment-like loss, as has been shown by Hirono [1955], among others. Since these latter processes are thought to be effective in determining the F2 peak [Ratcliffe et al., 1956], the use of equation (2) for extrapolation above the F2 peak has some theoretical justification. Since equation (2) approximates to the parabola of equation (1) with Ym = 2H, the interpretation of Scat in terms of the scale height receives a similar degree of theoretical justification. This interpretation is quite important to the following sections of this report.

Each of the hourly profiles used in this study has been extrapolated above hmaxF2 by equation (2), with H = 100 km. The total electron content, which we term Shinf, is given by adding to the subpeak content Shmax (vide infra), the quantity 2.82 HNmax, as may be shown easily by integration of (2) between limits hmax and infinity.

(4) Subpeak electron content: The total number of electrons in a unit column extending from the height of the lowest observable ionization (usually less than Ne = $10^4/cm^3$) to hmax, is termed Shmax. It has been obtained in the course of our secondary calculations by numerical integration of each profile between these two limits.

(5) Mean electron density profile data: The systematic calculation of hourly profiles provides a great quantity of data containing, among other inhomogeneities, various degrees of ionospheric disturbance. Our first objective has been to obtain the mean quiet variations from these data. This has been done by eliminating profiles at those hours for which the magnetic character figure Kp exceeds 4 +; from the remaining data, the monthly mean values of electron density at 10 km height intervals, and similar averages of the other special quantities are obtained for each hour. Generally, data from about 20 profiles comprise such a mean.

At the same time, the standard deviation of the data entering each mean is obtained. For some of the parameters a more useful measure of the variability is the relative standard deviation or percentage variability of the quantity. This is obtained by dividing the standard deviation by the mean. From the program described here, some features of the behavior of σ hmax, (σ Scat)/Scat, (σ Shmax)/ Shmax, and (σ Nmax)/Nmax are discussed in an appendix to this report.

3. TYPICAL EXAMPLES OF TN 40 - SERIES REPRESENTATIONS

The mean values of the quiet-day electron density profiles and their derived parameters, for each month of the year March 1959 - February 1960, are portrayed in a variety of representations in the NBS Technical Note series 40 - 1, 2, 3, ... etc. Typical diagrams from this series will first be illustrated and discussed as an introduction to the parameters and as a brief review of the variety of information available. While comments are offered regarding the significance and interpretation of specific phenomena evident in these diagrams, no attempt is made here to discuss their generality; rather, the aim is to point out several of the special properties of each form of representation. Throughout, it should be borne in mind that our data and conclusions pertain to a period near the maximum of the solar cycle. In the following sections the entire body of data will then be represented in a series of month-by-hour diagrams (for a year, running from May 1959 through April 1960), which summarize the diurnal and seasonal variations in the northern mid-latitude ionosphere.

(1) Vertical cross sections: Figure 1 (from NBS Technical Note 40-6) illustrates a vertical cross section of the ionosphere, nominally above the 75°W meridian between geographic latitudes of 15° and 50°N, for 1700 75°W time, August 1959. Contours of plasma frequency f_N in Mc/s, related to electron density N by $12,400 f_N^2 =$ N electron/cm^3, represent the true heights of reflection vertically incident radio waves. The height of maximum electron density is represented by the dashed line, and electron densities above this level are the result of an extrapolation according to the model discussed in Section 1 (3). Lines of the geomagnetic field would be very nearly vertical within this diagram, and are therefore omitted. Note that the vertical scale is expanded relative to the horizontal by a factor of about 5.5.

Near the level of maximum density a latitudinal gradient of about 0.0015 Mc/s per kilometer or 0.16 Mc/s per degree of latitude may be seen, and this is a fairly typical maximum value at this latitude. It becomes rapidly smaller at heights below the maximum, and not so rapidly smaller at heights above the maximum. It is interesting to note that the latitudinal gradient considerably exceeds the longitudinal sunrise gradient. A typical value of the sunrise gradient is 0.0007 Mc/s per kilometer or 0.07 Mc/s per degree of longitude near the F2 layer maximum.

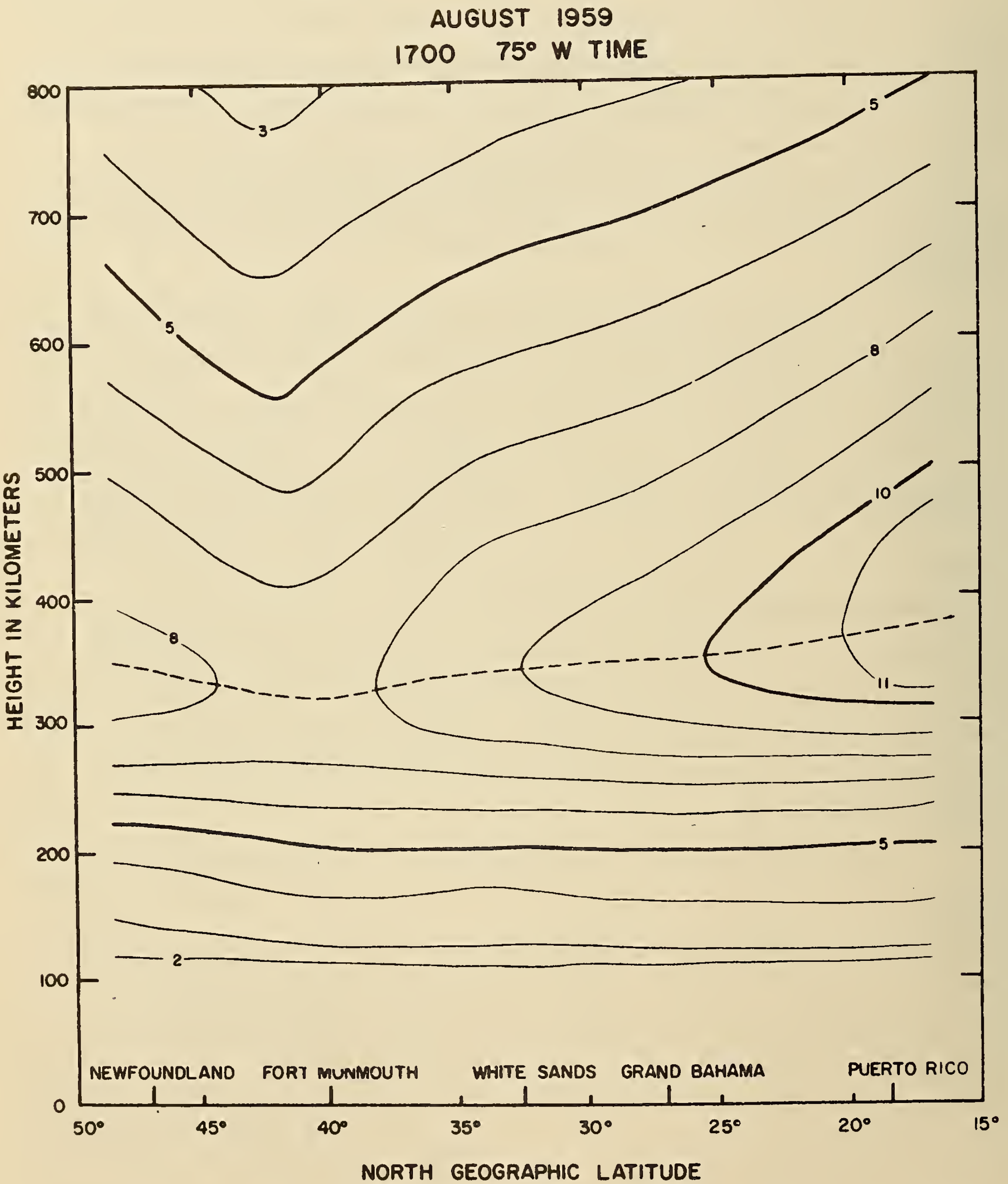


Figure 1 Vertical cross section along 75°W meridian. Contours of plasma frequency in Mc/s. Dashed line represents height of F2 peak. Contours above this level obtained from Chapman model with H = 100 km.

(2) Electron density maps in latitude versus time: Contours of electron density at constant heights of 200 and 300 km are shown in figures 2 and 3, for the months June 1959 and January 1960, respectively. In these diagrams, the contours are given at intervals of 10^5 electrons/cm^3. In addition to illustrating the diurnal variation of electron density at a fixed height versus latitude, these diagrams may also be considered as representing the mean longitudinal variations when it is noon over the 75°W meridian. For this purpose, the latitude scale is expanded by a factor of 10.76 relative to the "longitude" (time) scale.

At 200 km (fig. 2), the almost exclusively solar control of the ionization densities is obvious: the electron densities rise rapidly at sunrise from values less than $10^4/cm^3$ (the minimum detectable with present observing devices) and decrease below this limit a little more slowly at sunset. A small latitudinal gradient may be seen corresponding to the greater solar zenith angles nearer the equator. Note, however, that at this season one of the anomalies of the ionosphere at higher altitudes is reversed at 200 km: the maximum electron density is reached before noon, at least at the higher latitudes. This diurnal asymmetry has been noted by Croom et al [1959].

At 300 km (fig. 3) strong solar control is also evident, but it is clear that other factors are relatively more important than at lower altitudes. The initial increase of electron density at sunrise is nearly the same at all latitudes, although the later midmorning values are considerably greater at low latitudes. There is also a peak above 45°N, which is partially explained by the lower altitude of the entire layer there. The curious irregularity in the midday contours, which appears to "move" to later hours at lower latitudes is explained by the latitude/time variations of the height of maximum density: hmaxF2 is nearly 300 km and varies with time above and below 300 km in the vicinity of this irregularity.

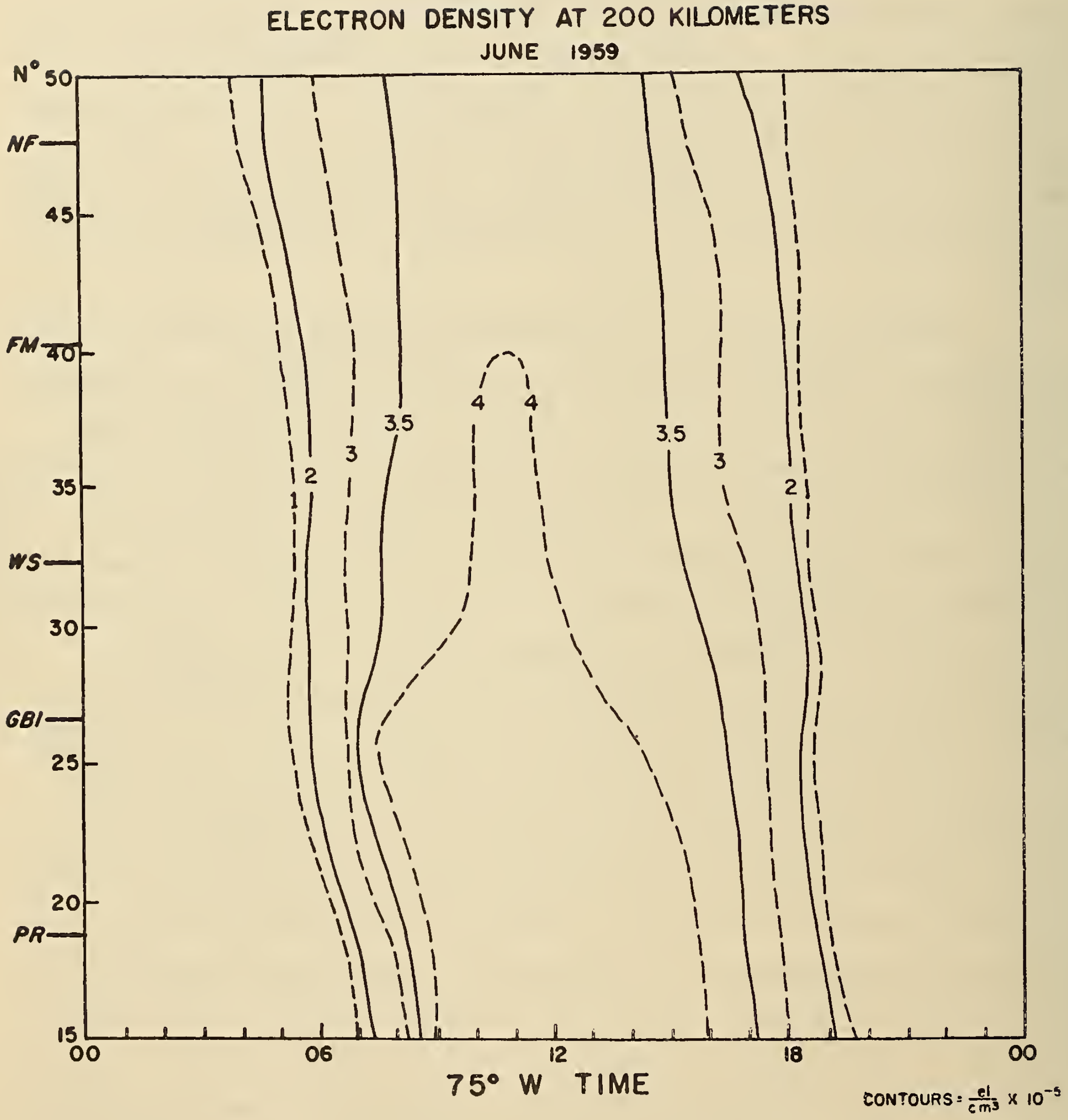


Figure 2 Latitude versus local-time isoionic map at 200 km. Contours in electrons per $cm^3 \times 10^{-5}$.

Figure 3 Latitude versus local-time isoionic map at 300 km. Contours in electrons per $cm^3 \times 10^{-5}$.

(3) Latitude versus time variation of hmaxF2: The height of the F2 peak is illustrated for March 1959, in figure 4. This is one of the simplest of similar diagrams for other months. Its most obvious feature is that the F2 peak falls at sunrise from about 380 km to about 300 km uniformily at all latitudes. The daytime variation is characterized by a gradual rise at all latitudes, but this proceeds more rapidly, and reaches a higher daytime altitude, at the lower latitudes. It continues to increase until sunrise at middle and higher latitudes, but decreases somewhat before midnight at low latitudes.

(4) Latitude versus time variation of F2 layer thickness: The "thickness" of the F region is characterized by our quantity "Scat," the quarter-thickness of a parabola fit to the F2 peak. Its latitudinal and time variations are illustrated in figure 5 for the month of July 1959. This parameter is of special interest since it is probably an approximate measure of the neutral particle scale height -- and hence the temperature -- at the F2 peak. It is at once clear that the thickness is strongly under solar control , increasing at sunrise from a nighttime value of about 50 km to about 70 km during daytime. In a significant departure from solar control, however, the higher latitudes have a thicker daytime F region than the lower latitudes.

(5) Latitude versus time variations of sub-peak electron content: The number of electrons in a unit column below the F2 peak is designated Shmax; its latitudinal versus time variations for May 1959 are illustrated in figure 6. The behavior of the electron content is extremely simple, closely following the solar zenith angle. Nevertheless, certain anomalies are evident. At low latitudes, the maximum value of Shmax follows noon by $1\frac{1}{2}$ - 2 hours, rather in accord with simple theory, while in middle latitudes, the maximum is distinctly at noon. It appears that a higher latitudes the maximum again shifts to post-noon. Also the latitudinal midday gradient in Shmax is very much larger than would be expected from the latitudinal dependence of the midday solar zenith angle.

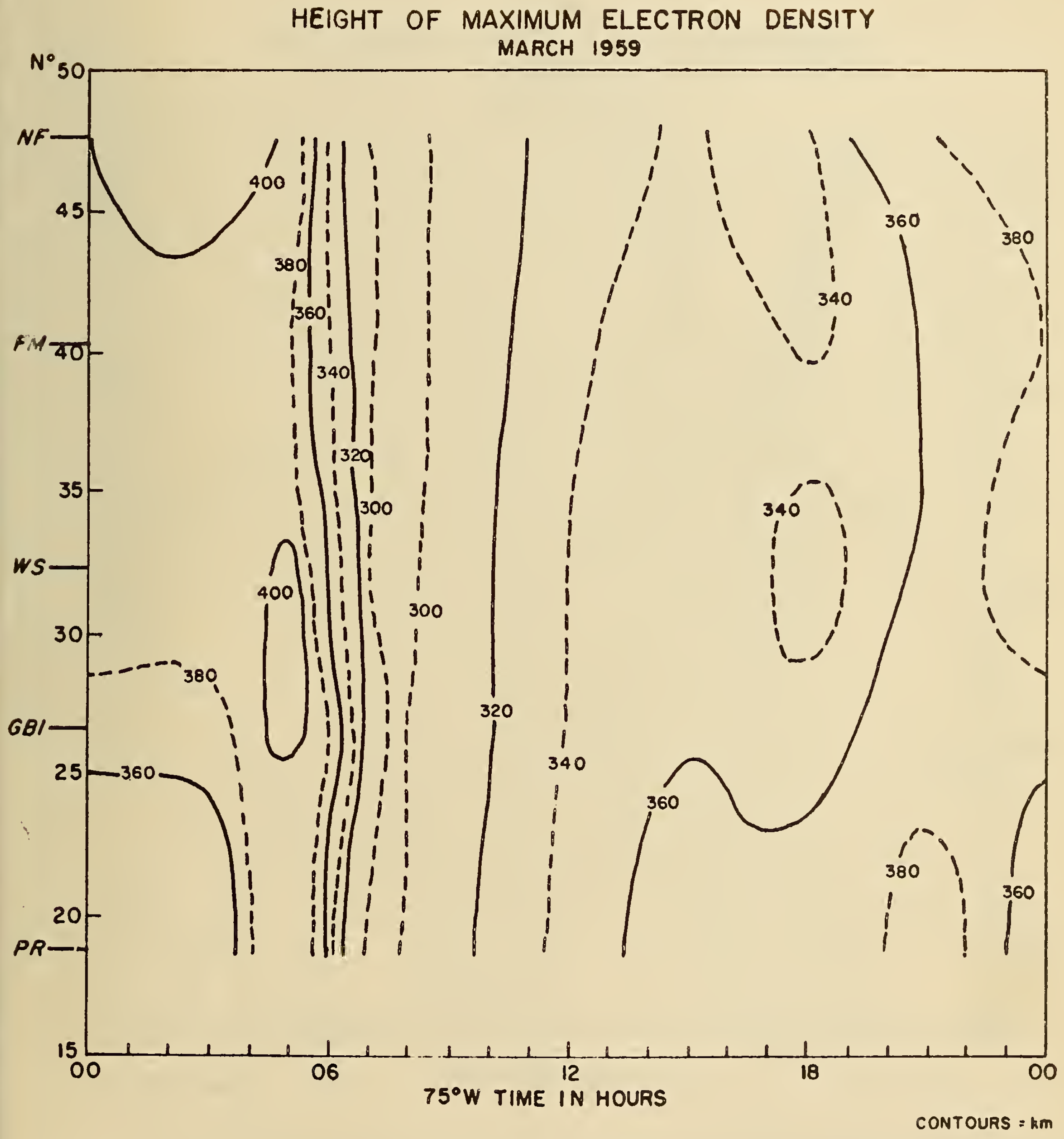


Figure 4 Latitude versus local-time map of the height of the F2 peak. Contours in kilometers.

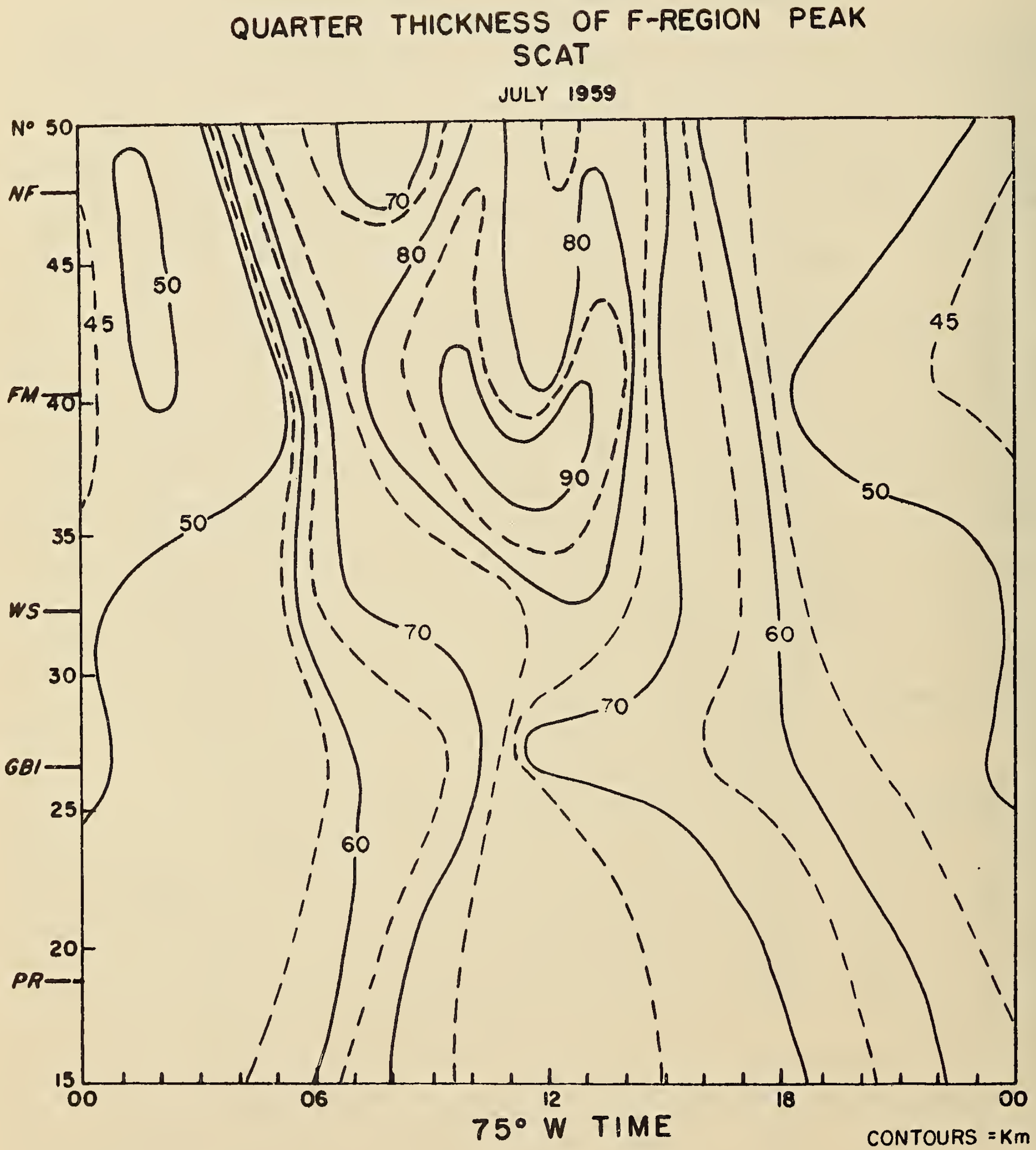


Figure 5 Latitude versus local-time map of the quarter-thickness of the F2 peak. Contours in kilometers.

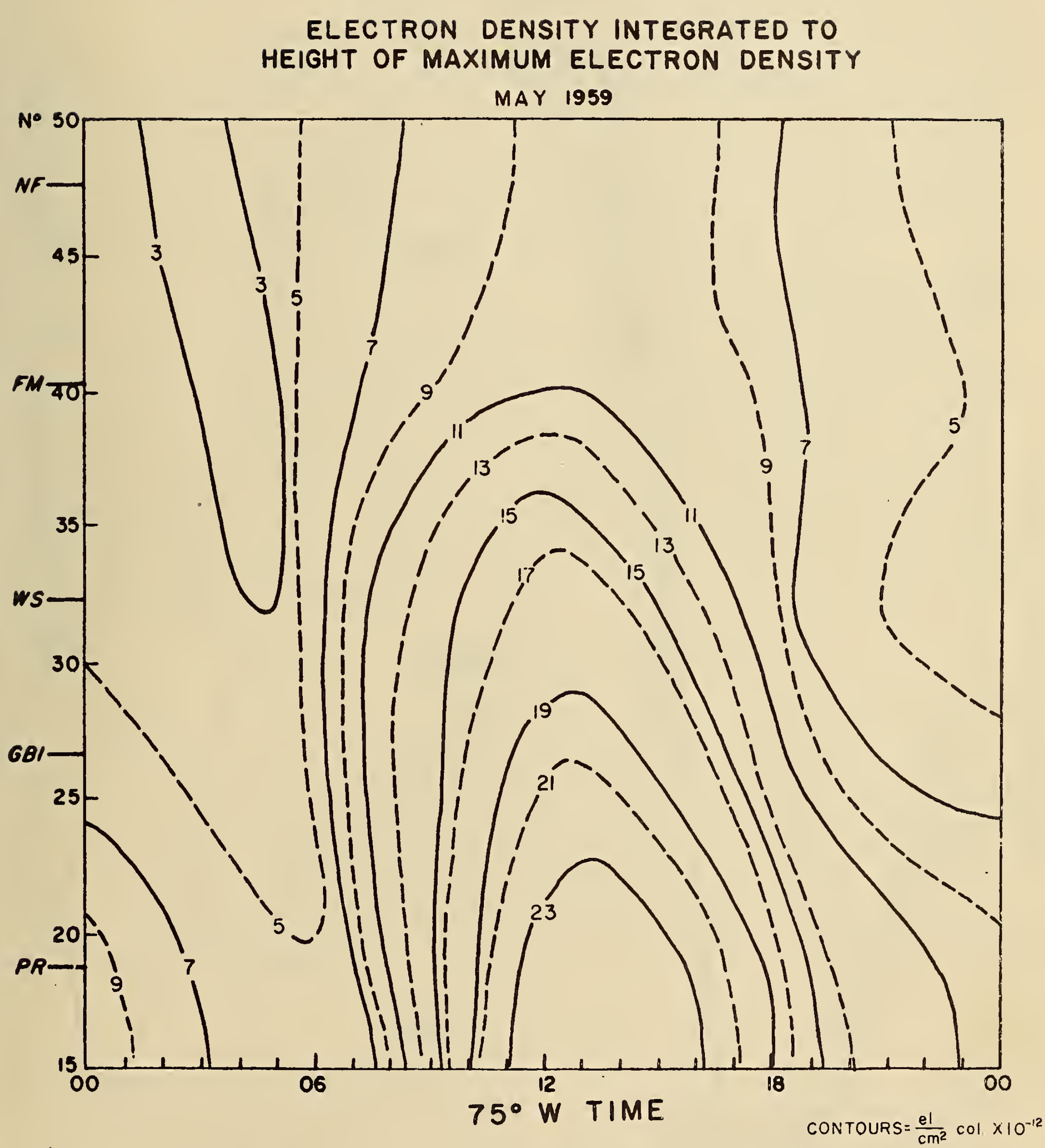
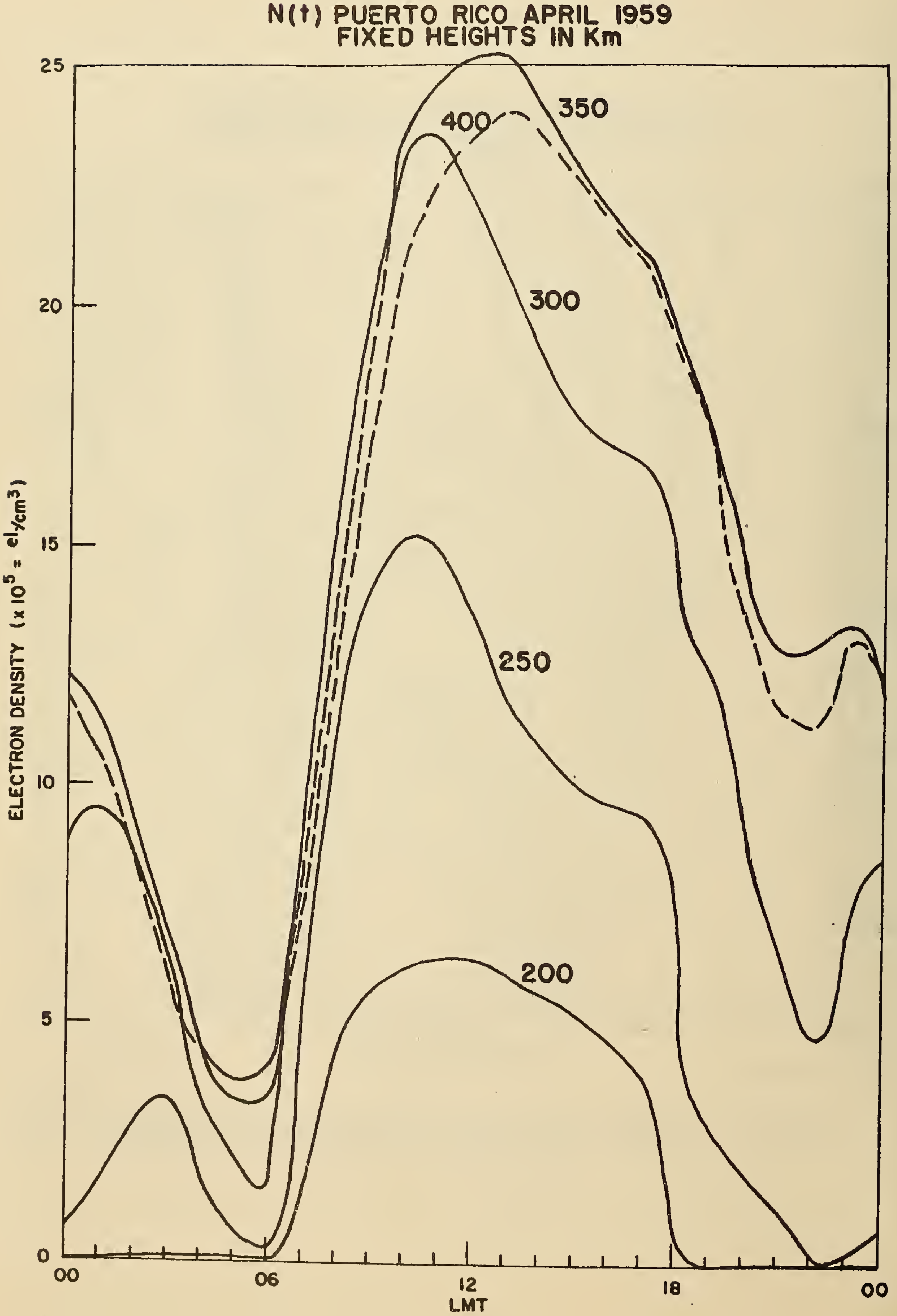


Figure 6 Latitude versus local-time map of the subpeak electron content. Contours in electrons per cm^2 column x 10^{-12} .


N(t) PUERTO RICO APRIL 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x 10^5 = el/cm^3)
25
20
15
10
5
0
400
350
300
250
200
00
06
12
18
00
LMT

(6) Diurnal variation of electron density at fixed heights: The diurnal variation of electron density at a given height is at first sight the most natural representation of ionospheric variations, and is in any case the data necessary for a full numerical analysis of ionospheric variations. An example is shown in figure 7 for Puerto Rico, April 1959. When the height of maximum falls below the fixed heights represented here, the corresponding curves are dashed. Such electron densities are the result of the topside model discussed above. The envelope of these curves corresponds to the maximum density.

It is interesting to note the progressive departure from simple solar control at successively greater altitudes. While the sunrise period (and until 1000) is characterized by a rapid increase of electron density at all heights, there then occurs a general decrease, most marked at heights above 250 km.* That at least part of this behavior might be attributable to movement of the layer, is suggested by the post-sunset increases in electron density which occur at successively later times at lower altitudes.

4. DIURNAL AND SEASONAL VARIATIONS

A great deal of the basic information describing the F region of the ionosphere is contained in the parameters hmaxF, Scat, Nmax, and Shmax, which measure the height, thickness, and electron density at the peak, and the sub-peak electron content, respectively. These parameters have been displayed for separate months in the latitude-local time plane, in the NBS Technical Note Series 40; examples of them have been discussed above.

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* This height cannot be taken as accurately determined; it represents a probable lower limit because of the possibility of a "valley error" as mentioned in Section 2.

With one year of data available, it becomes practical to display this large quantity of information in very compact form. For each of these four parameters, and each of the five stations, we have prepared contour "maps" showing the diurnal vs. seasonal variation of these parameters. Figures 8 through 27 may be referred to in the discussion which follows.

We shall discuss the various parameters individually from a phenomenological point of view, drawing attention to their characteristic diurnal and seasonal features and to the latitude variation evident from the five stations' data.

(1) Height of the F2 peak (hmaxF2, figures 8, 9, 10, 11, 12): Characteristically, hmaxF2 is lowest at the time immediately following sunrise, as low as 250 km in the winter and at higher latitudes. It rises throughout the daylight period and generally continues to rise after sunset and throughout the nighttime period. The total diurnal excursion of hmaxF2 is surprisingly constant (100 km), whatever the season or latitude, except that at mid-latitudes the variation is somewhat less in winter. There is a distinct similarity between the daytime 300 km contours at the station pairs White Sands/Grand Bahama, and Fort Monmouth/Newfoundland. These pairs of stations have nearly the same magnetic dip (60° and 72°, respectively), although their geographic latitudes are rather dissimilar.

The largest values of hmaxF2 occur in the summer nighttime, and are typically 400 km. At all but the lowest latitude studied, these high values are centered on local midnight; at Puerto Rico, they occur before midnight, centered on 2100 local time in the summer months. It is interesting to note that this tendency is entirely absent at Grand Bahama, which is farther north by only 8° (geographic, geomagnetic, or dip). On the other hand, the daytime similarity noted above between stations with similar magnetic dip, is also evident in the diurnal/seasonal patterns of the nighttime 400 km contour.

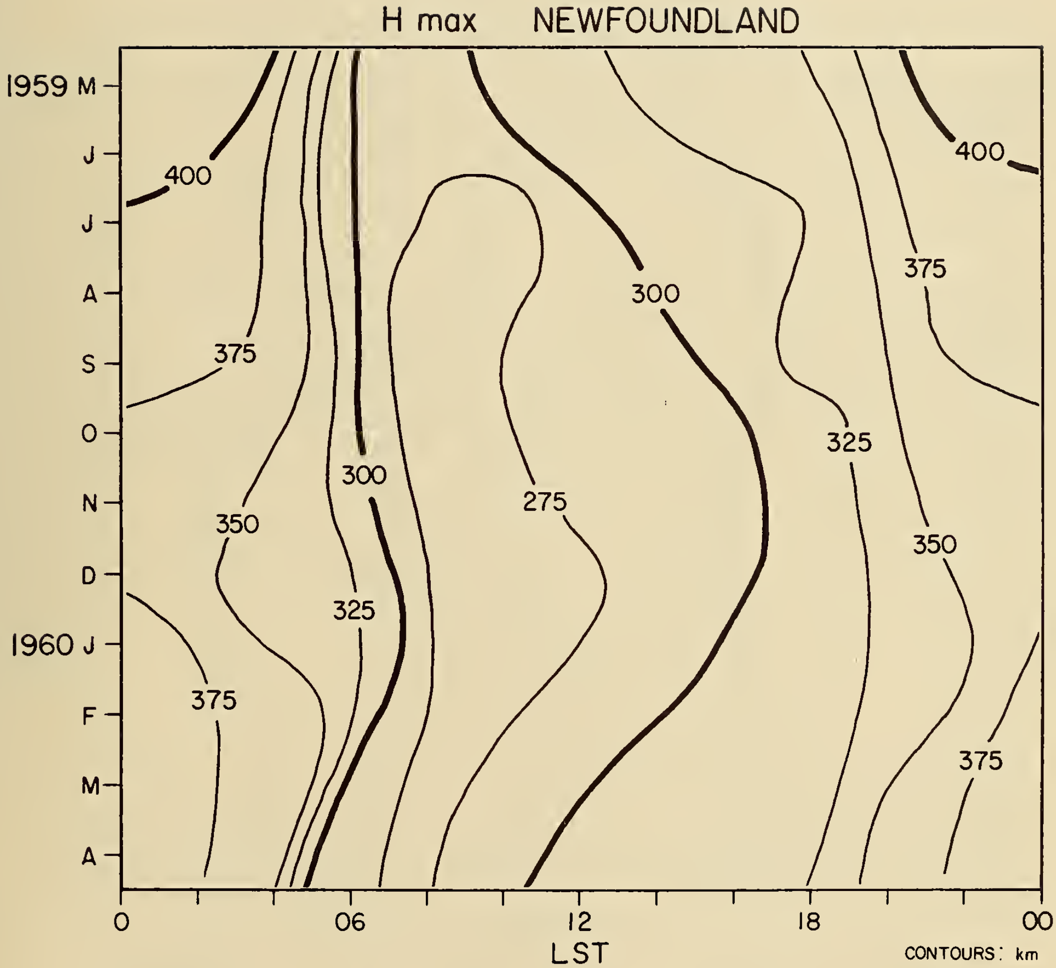

Figure 8 Diurnal and seasonal variations of hmax - Newfoundland. Contours in kilometers.

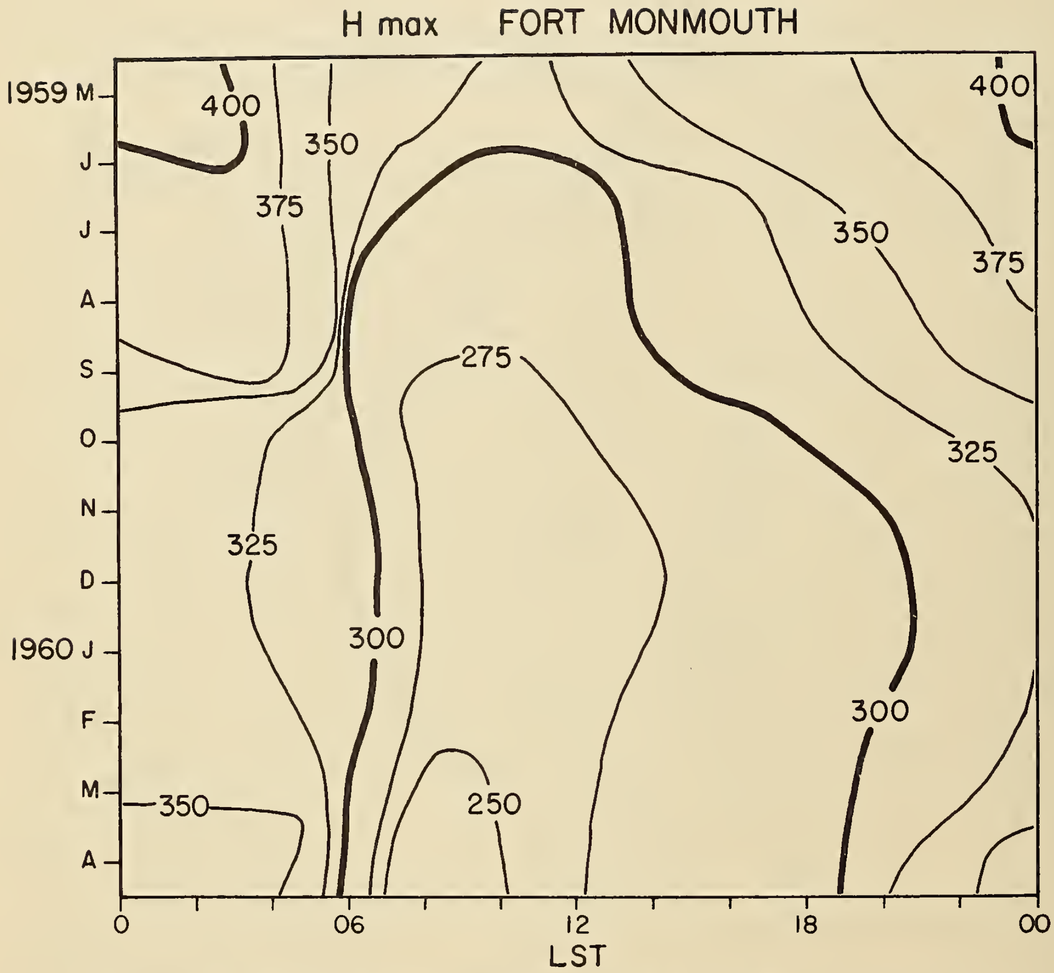

Figure 9 Diurnal and seasonal variations of hmax - Ft. Monmouth. Contours in kilometers.

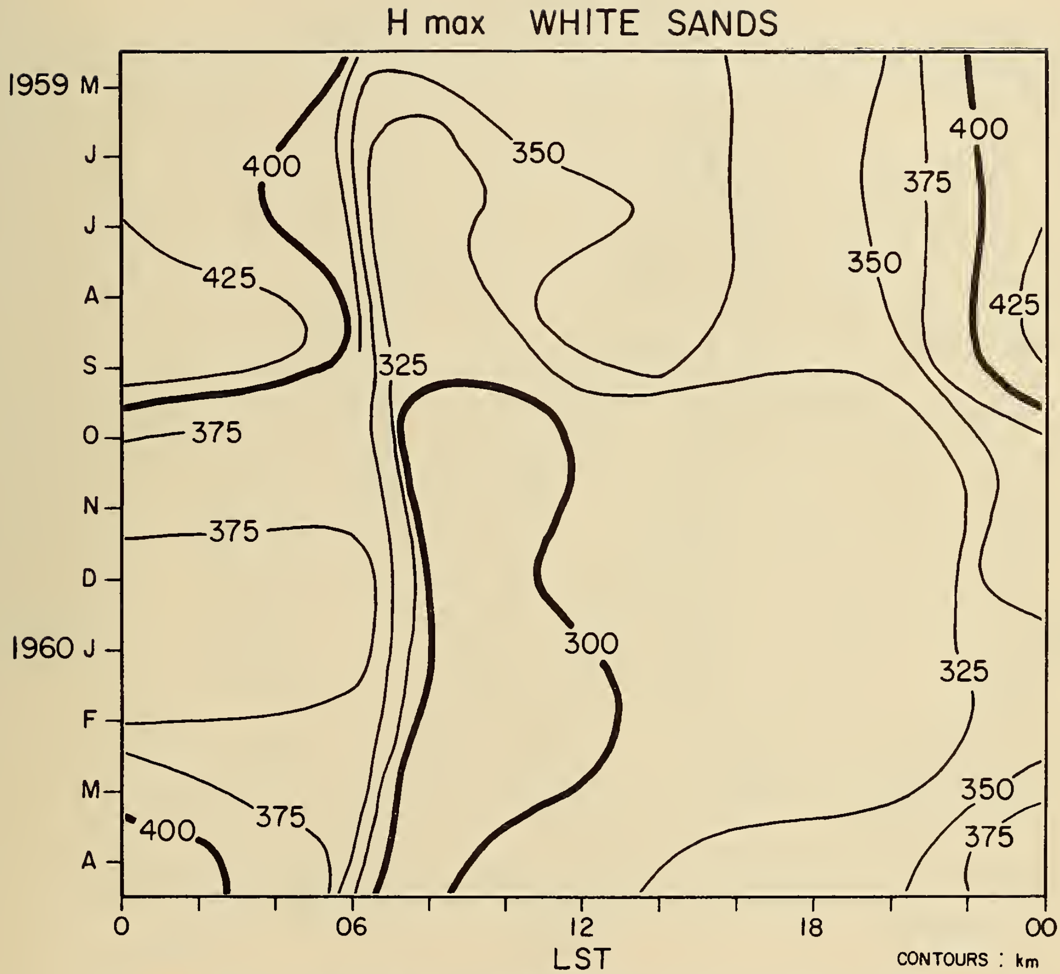

Figure 10 Diurnal and seasonal variations of hmax - White Sands, New Mexico. Contours in kilometers.

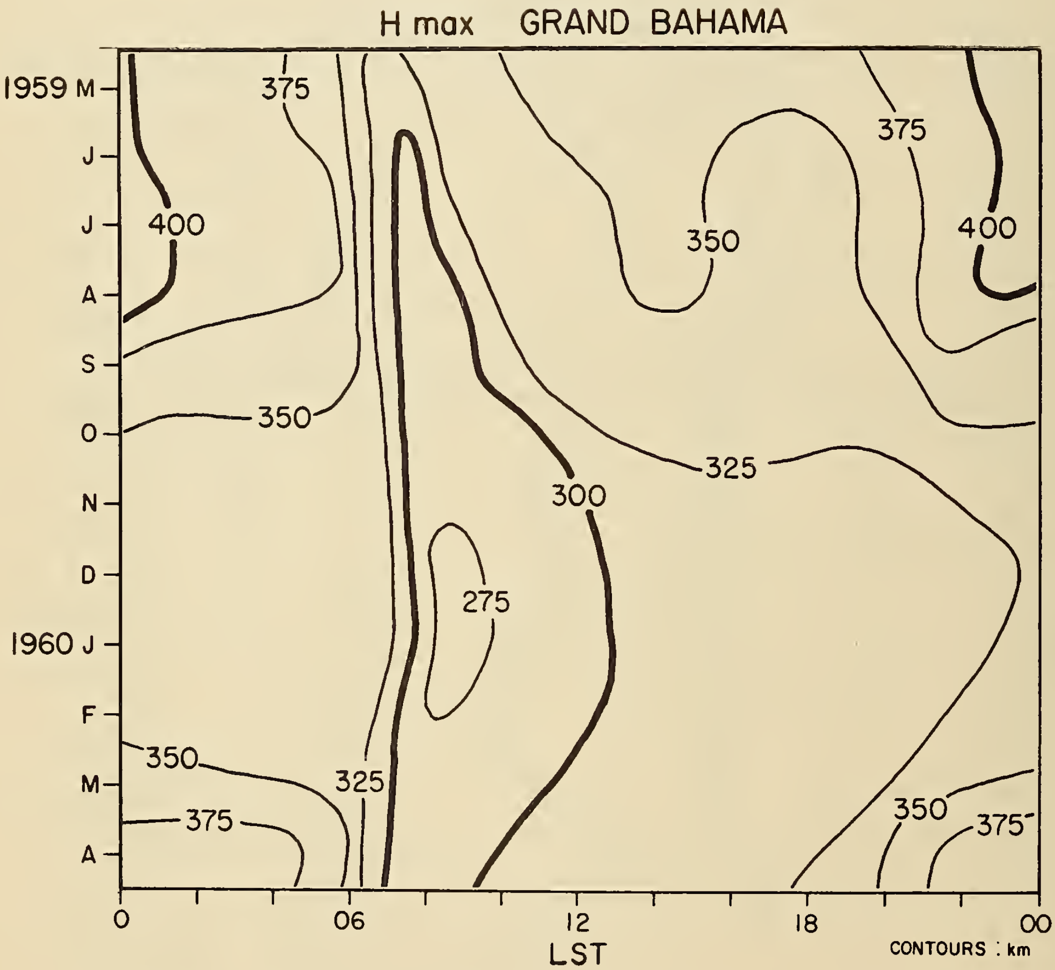

Figure 11 Diurnal and seasonal variations of hmax - Grand Bahama Island. Contours in kilometers.

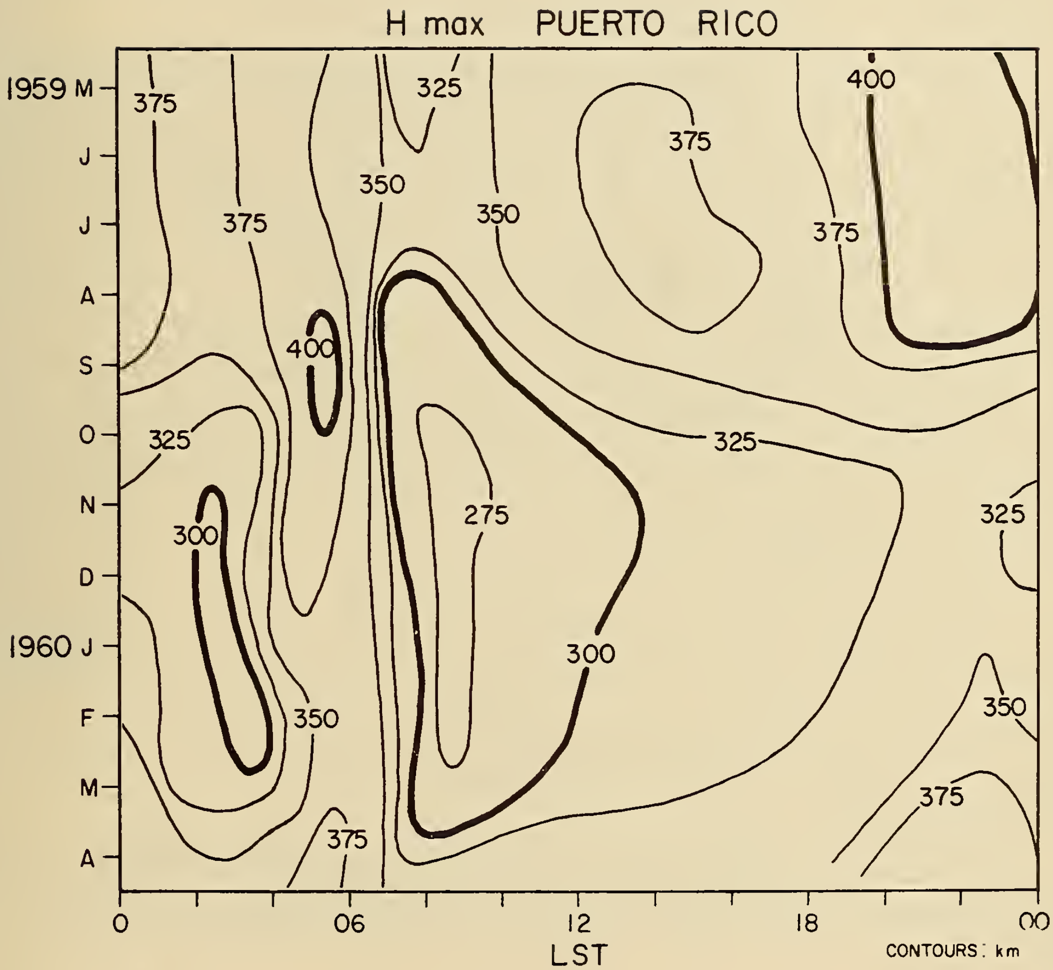

Figure 12 Diurnal and seasonal variations of hmax - Puerto Rico. Contours in kilometers.

(2) Quarter-thickness of the F2 peak (Scat, figures 13 - 17): The possibility of interpreting this quantity in terms of the (neutral particle) scale height at the F2 peak (see Section 2 (3)) suggests that "Scat" may be an important indicator of the temperature in the F region. We shall keep this possibility in mind, as the phenomenology of Scat is discussed.

Scat shows a diurnal variation at all latitudes and seasons, and this is most marked in the high latitude summer. Noon values of Scat approach 100 km in the high latitude summer, but the nighttime values are typically 50 km or less. At Newfoundland, the highest latitude, the sense of the diurnal variation is reversed in the winter: maximum values then occur in the pre-dawn hours, and generally occur earlier in the equinox months than at the winter solstice. At all other latitudes, the daytime values are distinctly larger than at night. As with hmaxF2 there is somewhat more similarity in the total pattern between stations of similar magnetic dip, than among those of similar geographic latitude.

There is only a small seasonal variation at the lowest latitude (Puerto Rico), with minimum values in the winter and maximum in the summer. The total change is less than at high latitudes, but the smallest values (30 km, winter pre-dawn) are as small as the minima elsewhere.

There is a suggestion of a semi-diurnal variation in the mid-latitude winter, with maxima at 0200 and 1400, minima at 0730 and 1930.

(3) F2 maximum electron density (NmaxF2, figures 18 - 22): Although the phenomenology of this parameter is well-known from its direct relationship with foF2, we shall review its phenomenology here in order to complete our picture of variations at the F2 peak. It will also prove interesting to compare NmaxF2 with the F2 subpeak electron content. The very great range of NmaxF2 (through a factor of ten at all latitudes) renders the maxima very prominent, and the minima only slightly less so.

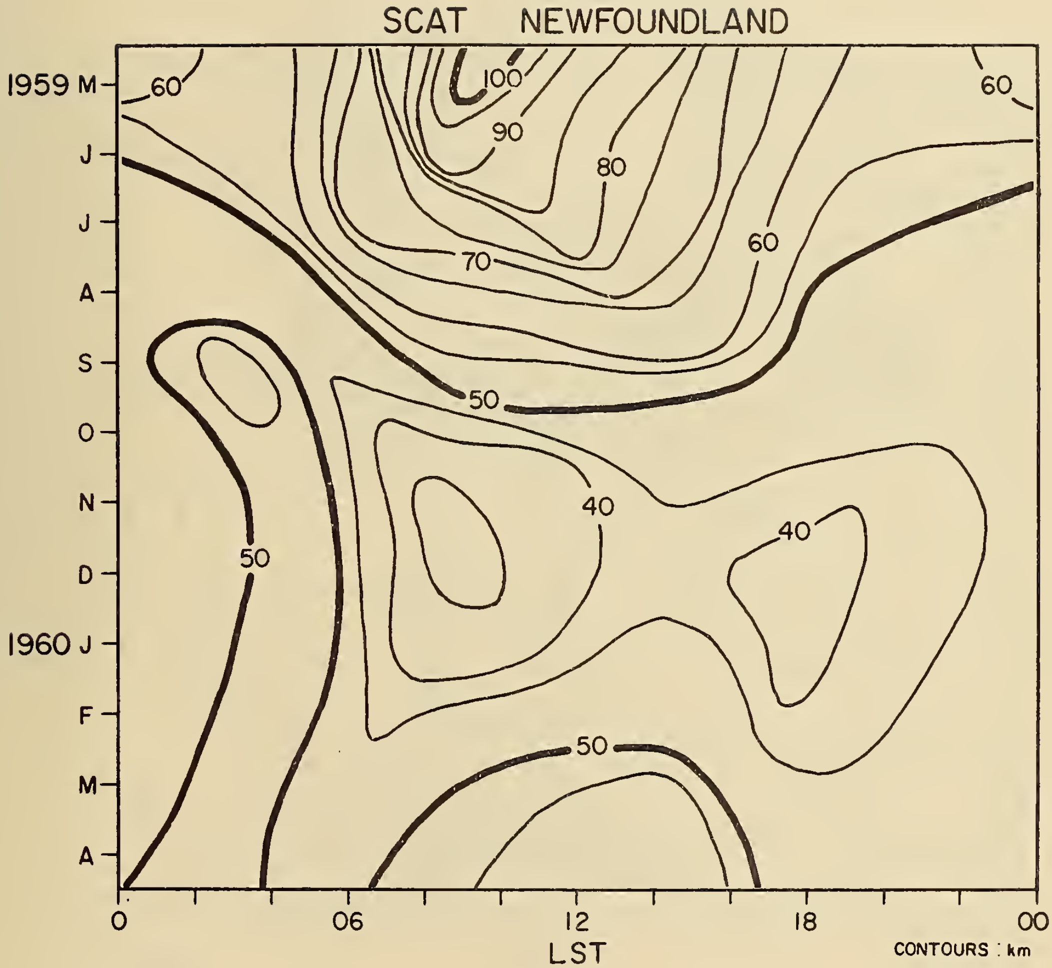

Figure 13 Diurnal and seasonal variations of Scat - Newfoundland. Contours in kilometers.

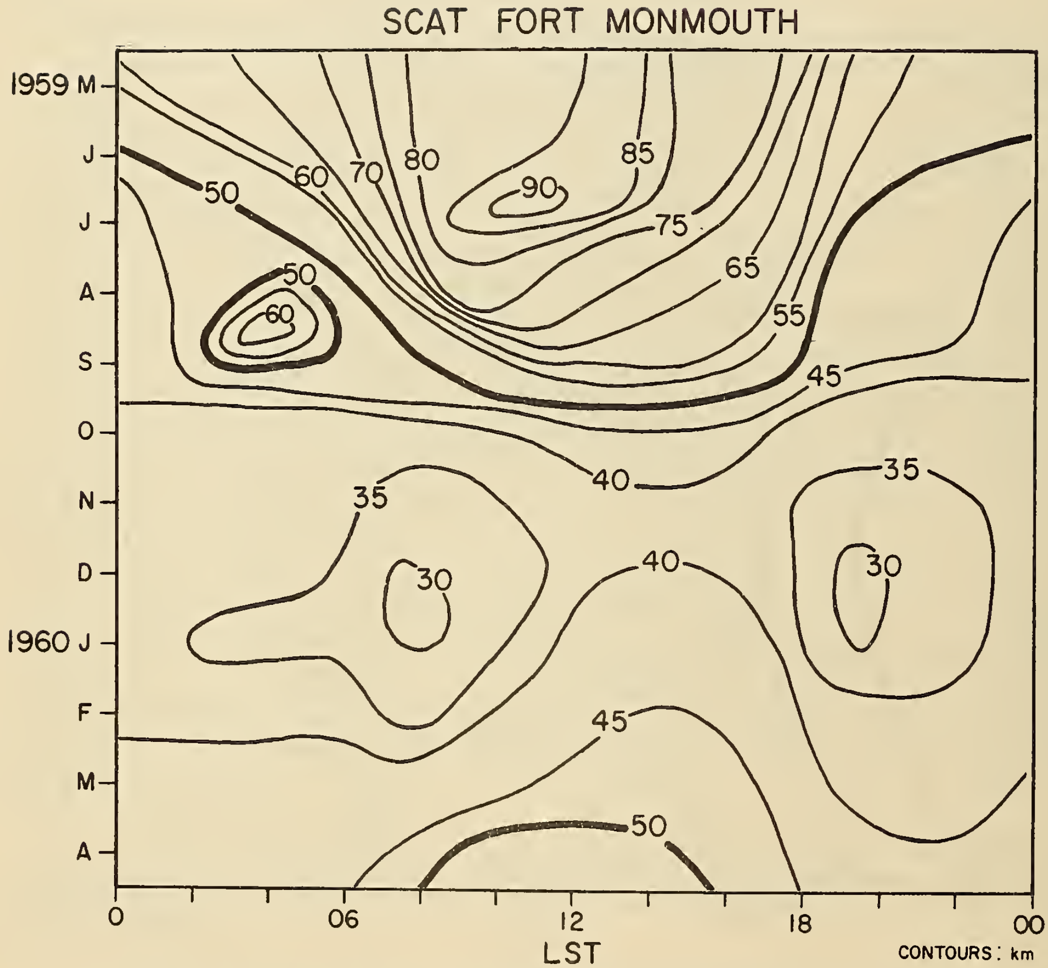

Figure 14 Diurnal and seasonal variations of Scat - Ft. Monmouth. Contours in kilometers.

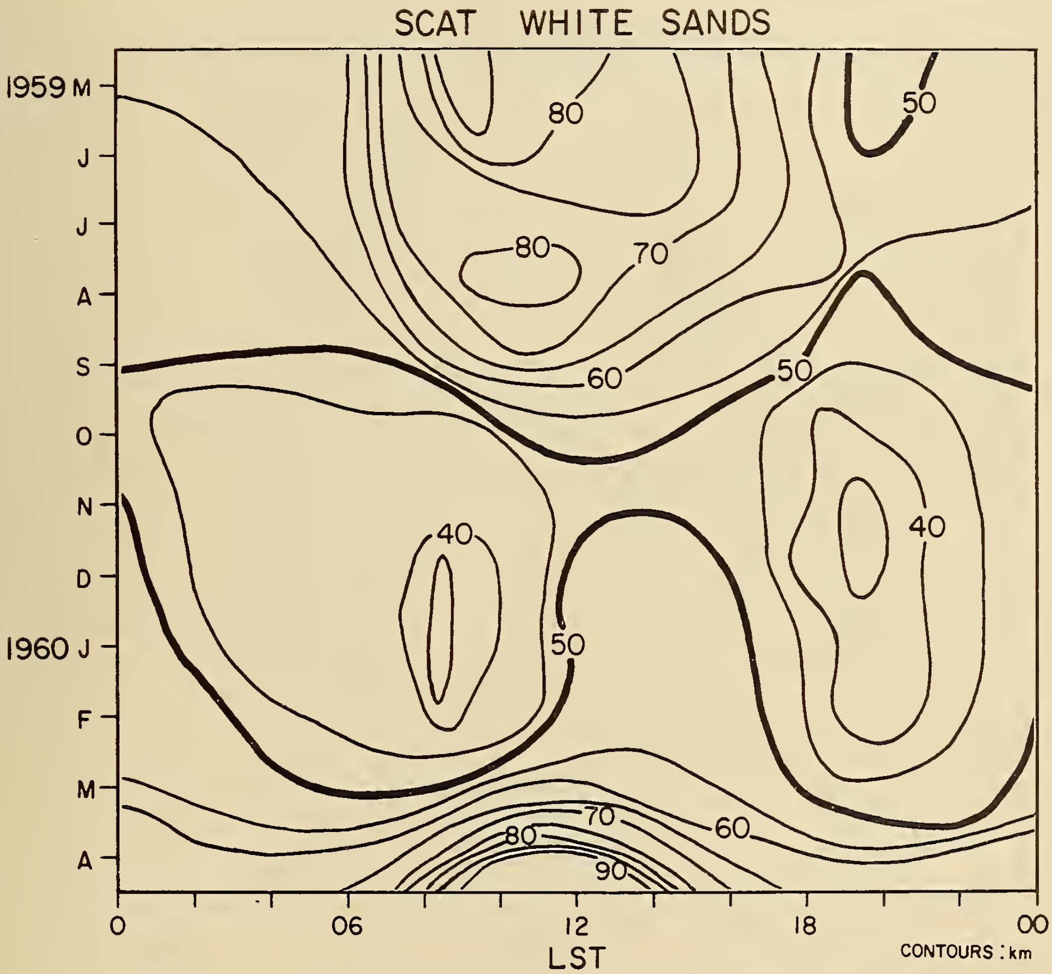

Figure 15 Diurnal and seasonal variations of Scat - White Sands, New Mexico. Contours in kilometers.

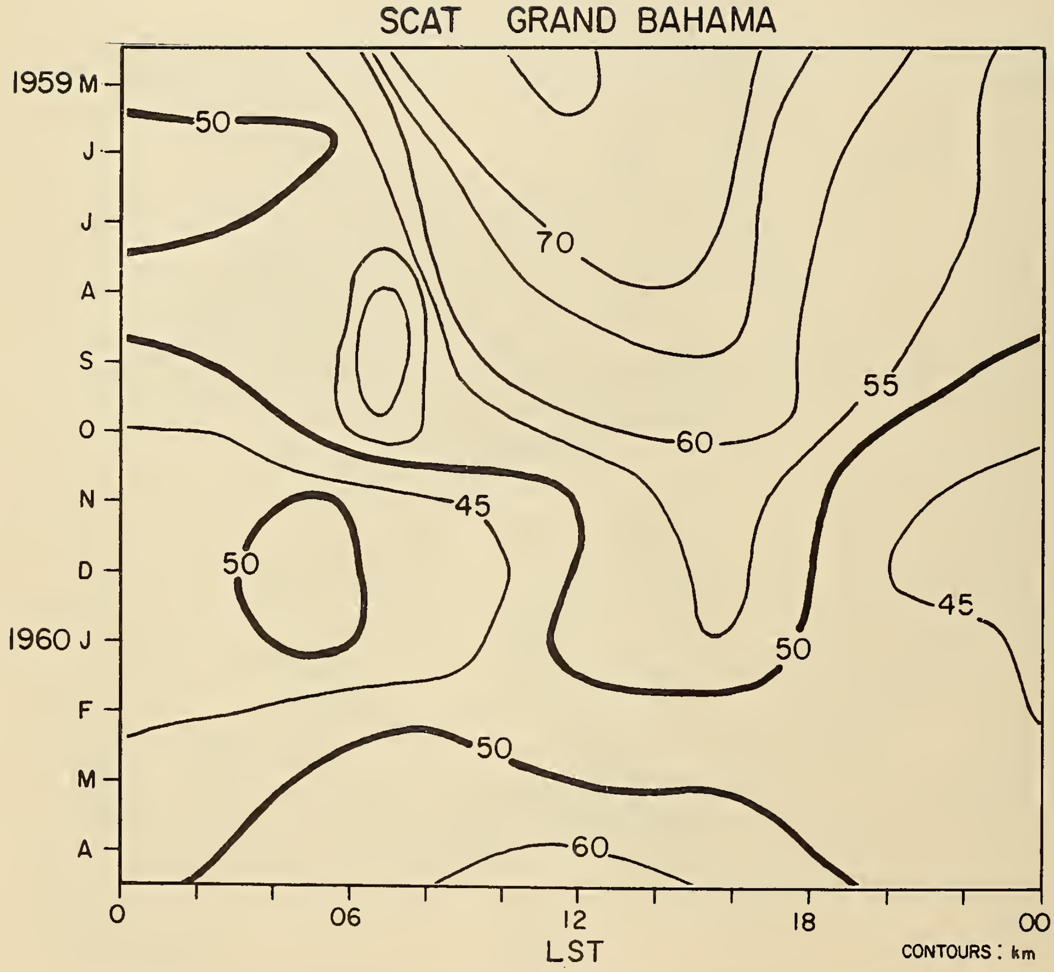

Figure 16 Diurnal and seasonal variations of Scat - Grand Bahama Island. Contours in kilometers.

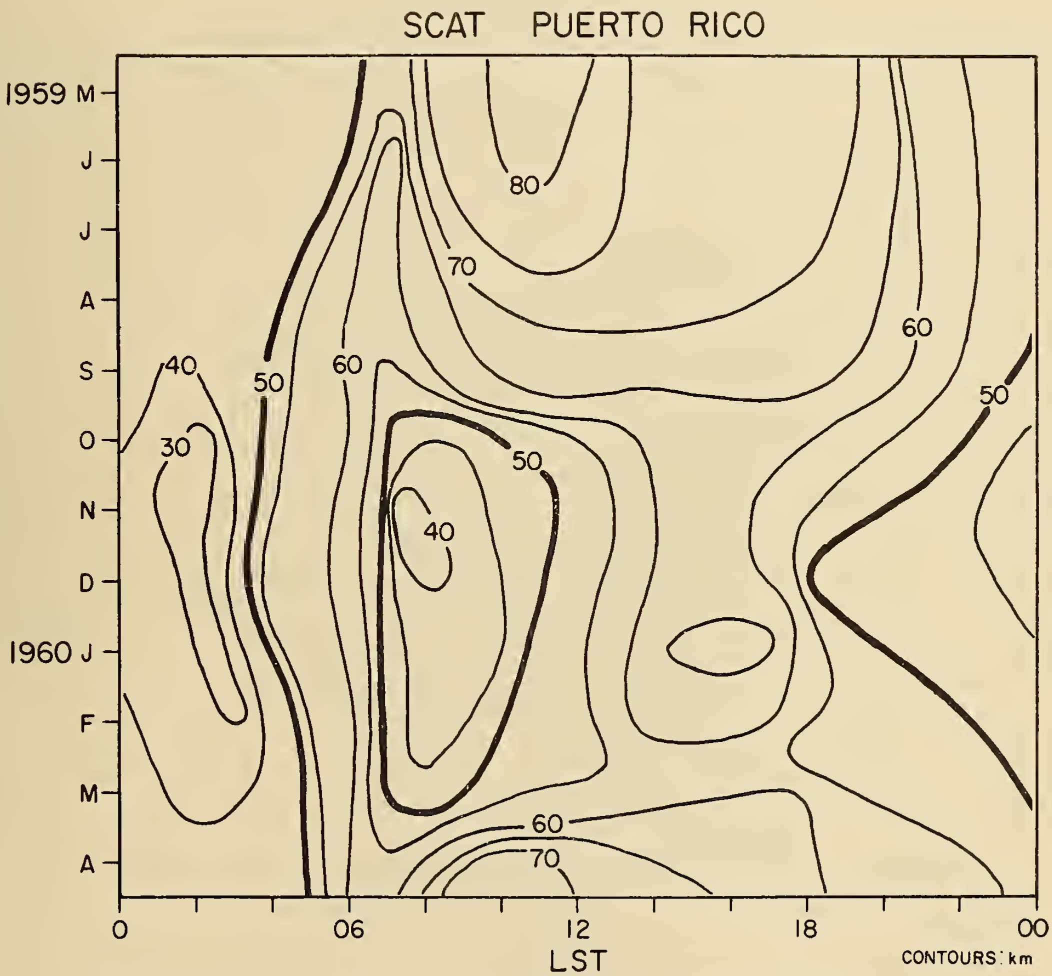

Figure 17 Diurnal and seasonal variations of Scat - Puerto Rico. Contours in kilometers.

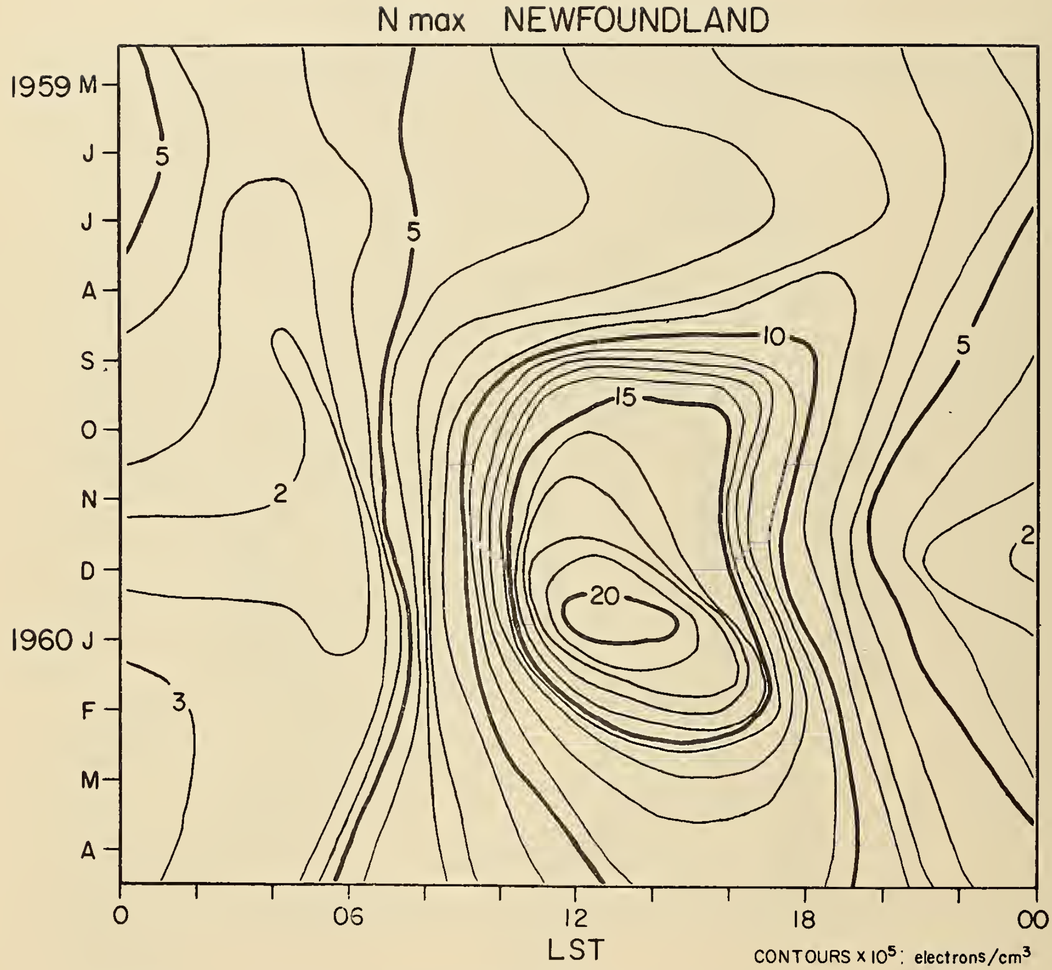

Figure 18 Diurnal and seasonal variations of NmaxF2 - Newfoundland. Contours in (electrons/cm^3) x 10^{-5}.

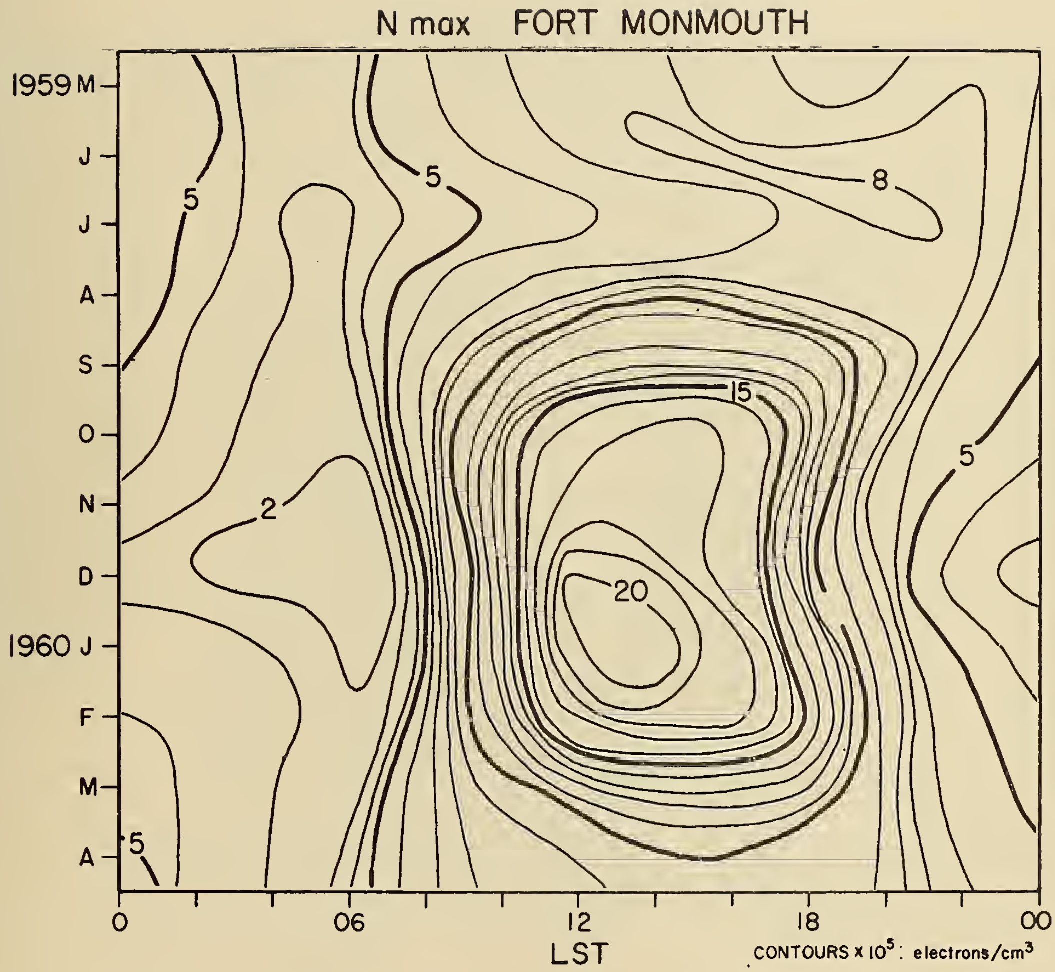

Figure 19 Diurnal and seasonal variations of NmaxF2 - Ft. Monmouth. Contours in (electrons/cm^3) x 10^{-5} .

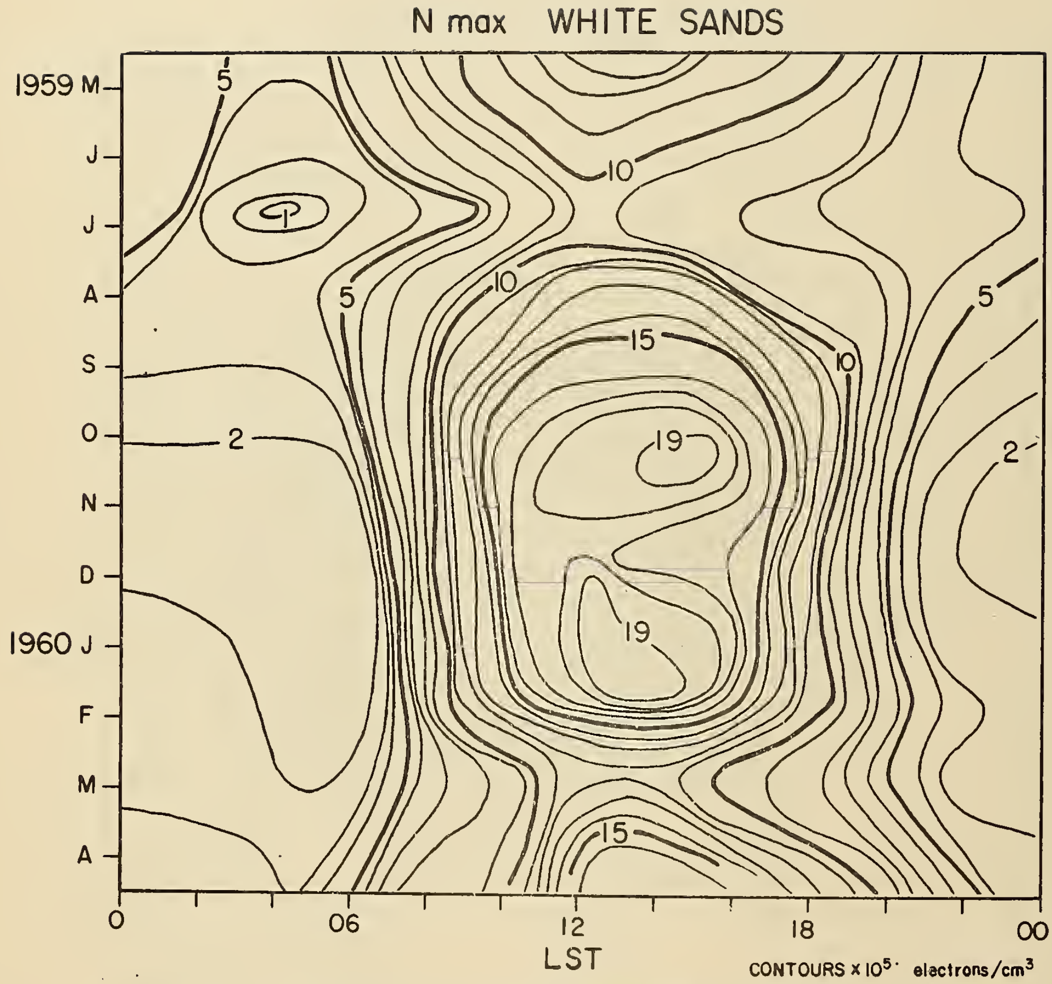

Figure 20 Diurnal and seasonal variations of NmaxF2 - White Sands, New Mexico. Contours in (electrons/cm^3) x 10^{-5} .

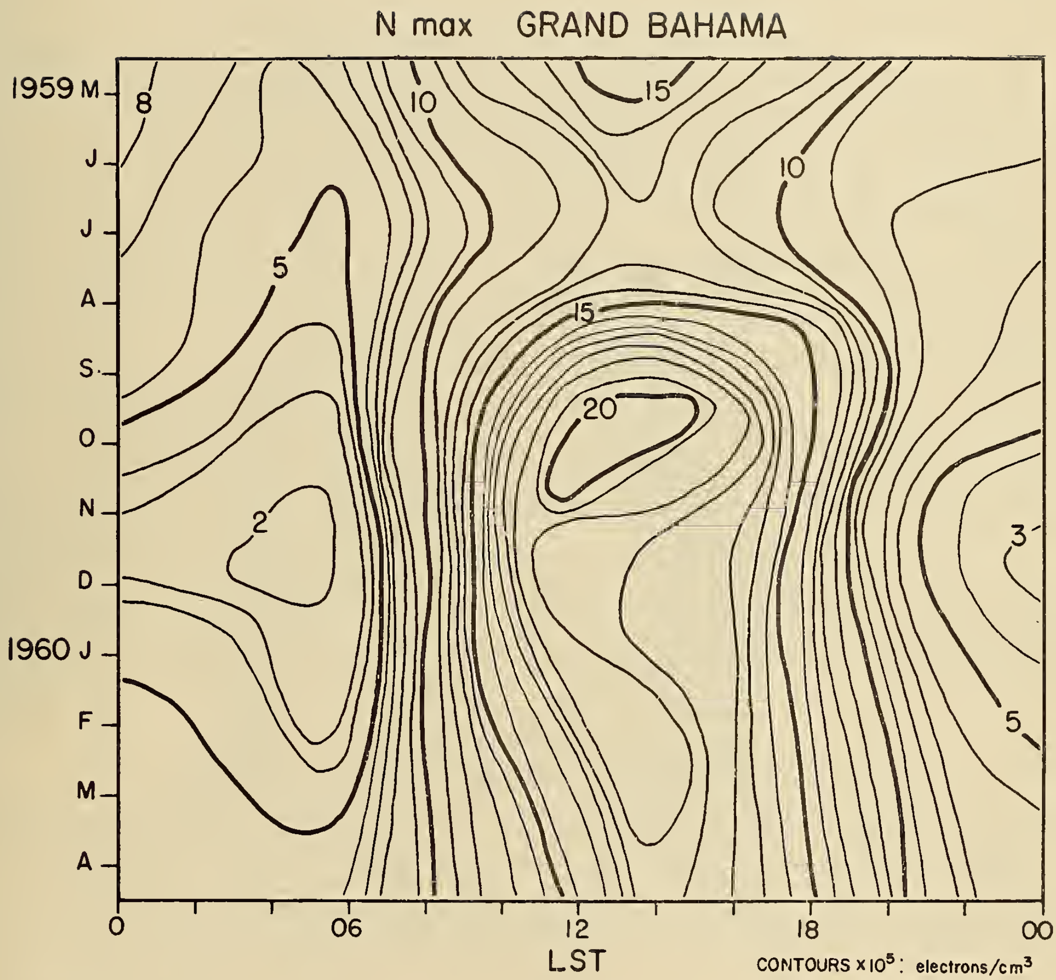

Figure 21 Diurnal and seasonal variations of NmaxF2 - Grand Bahama Island. Contours in (electrons/cm^3) x 10^{-5} .

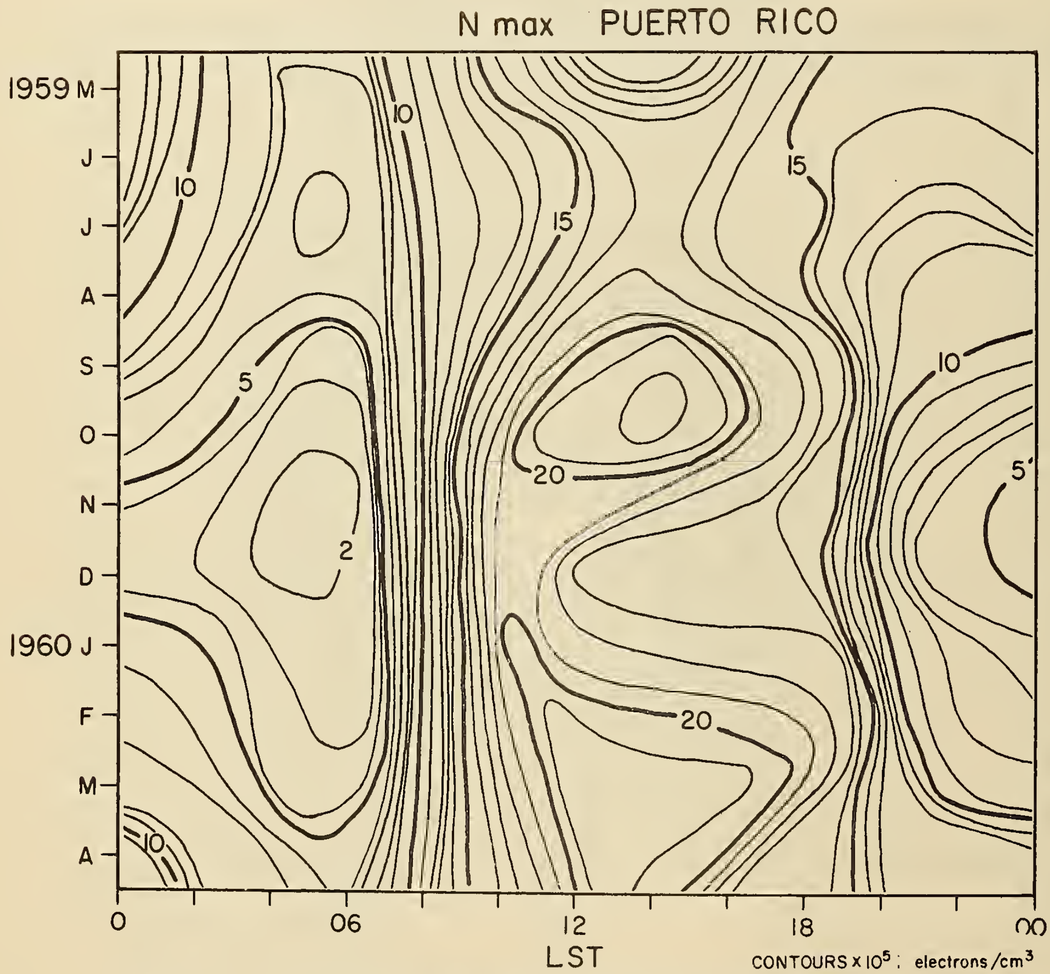

Figure 22 Diurnal and seasonal variations of NmaxF2 - Puerto Rico. Contours in (electrons/cm^3) x 10^{-5} .

In the daytime, high latitudes show a single winter post-noon maximum which shifts wildly to late afternoon in summer, while at lower latitudes the post-noon maximum is between 1300 - 1400, nearly independent of latitude or season. The similarity between the late afternoon summer maxima at Ft. Monmouth and Newfoundland suggests magnetic rather than solar control for this anomaly.

Low latitudes show distinct equinoctial maxima, with minima in the summer and winter. At intermediate latitudes, the daytime seasonal variation is complicated by the transition between these two clear patterns. The equinox noon maxima at low latitude provide the very highest values of Nmax. At higher latitudes, the highest values are nearly independent of latitude, but possess the diurnal and seasonal pattern just mentioned.

At night, the minimum values always occur in winter, and the largest values occur in summer, at all latitudes. The minimum value of Nmax is nearly the same at all latitudes, and occurs in the pre-dawn hours. The period of time occupied by the minimum (seasonally centered on December and diurnally centered on about 0500), becomes larger with increasing latitude.

(4) Subpeak electron content (Shmax, figures 23 - 27): The detailed variations of Shmax show the influence of each of the preceding parameters. Again considering first the daytime periods, it is clear that the pattern of the maxima is the same as for Nmax: high latitudes display a winter maximum which "divides" into two equinoctial maxima at lower latitudes. The Maxima are generally post noon, but not as late as those of Nmax. The pre-noon increase in Shmax is more uniform with season and with latitude than is the case with Nmax. The maximum values of Shmax decrease with increasing latitudes.

At night, the minimum values of Shmax occur in the pre-dawn period, and are lowest in winter. However, there is a tendency, also suggested in the Nmax data, for the lowest values to occur before the winter solstice, rather than at it. The minimum values of Shmax decrease with increasing latitude.

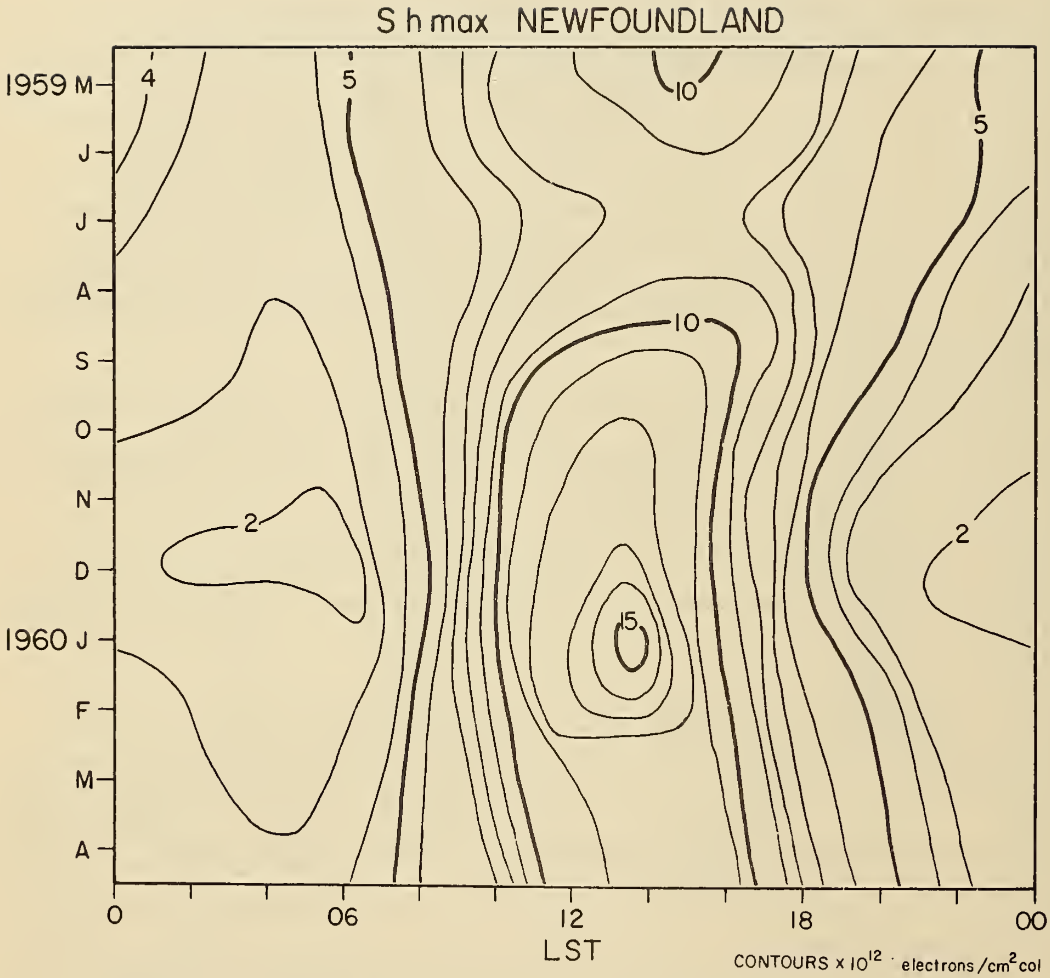

Figure 23 Diurnal and seasonal variations of Shmax - Newfoundland. Contours in (electrons/cm^2col) x 10^{-12} .

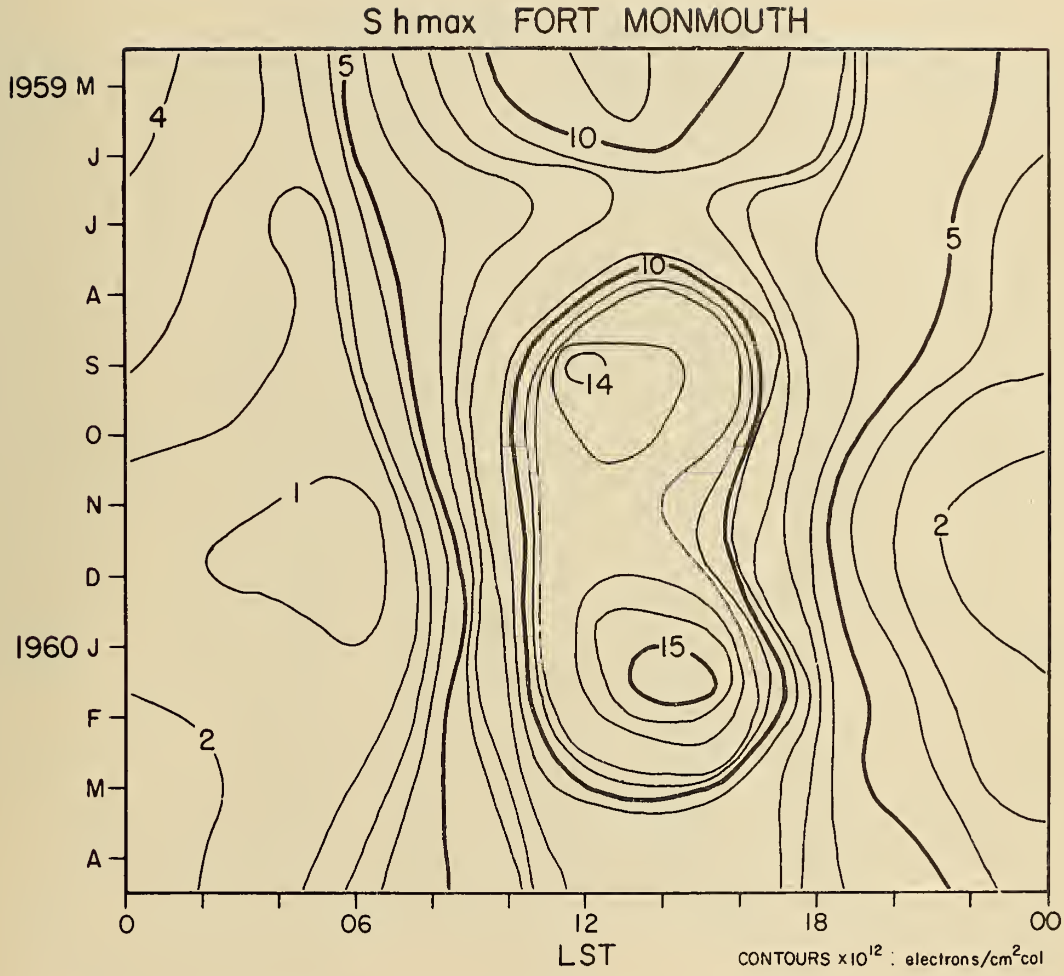

Figure 24 Diurnal and seasonal variations of Shmax - Ft. Monmouth. Contours in (electrons/cm^2col) x 10^{-12} .

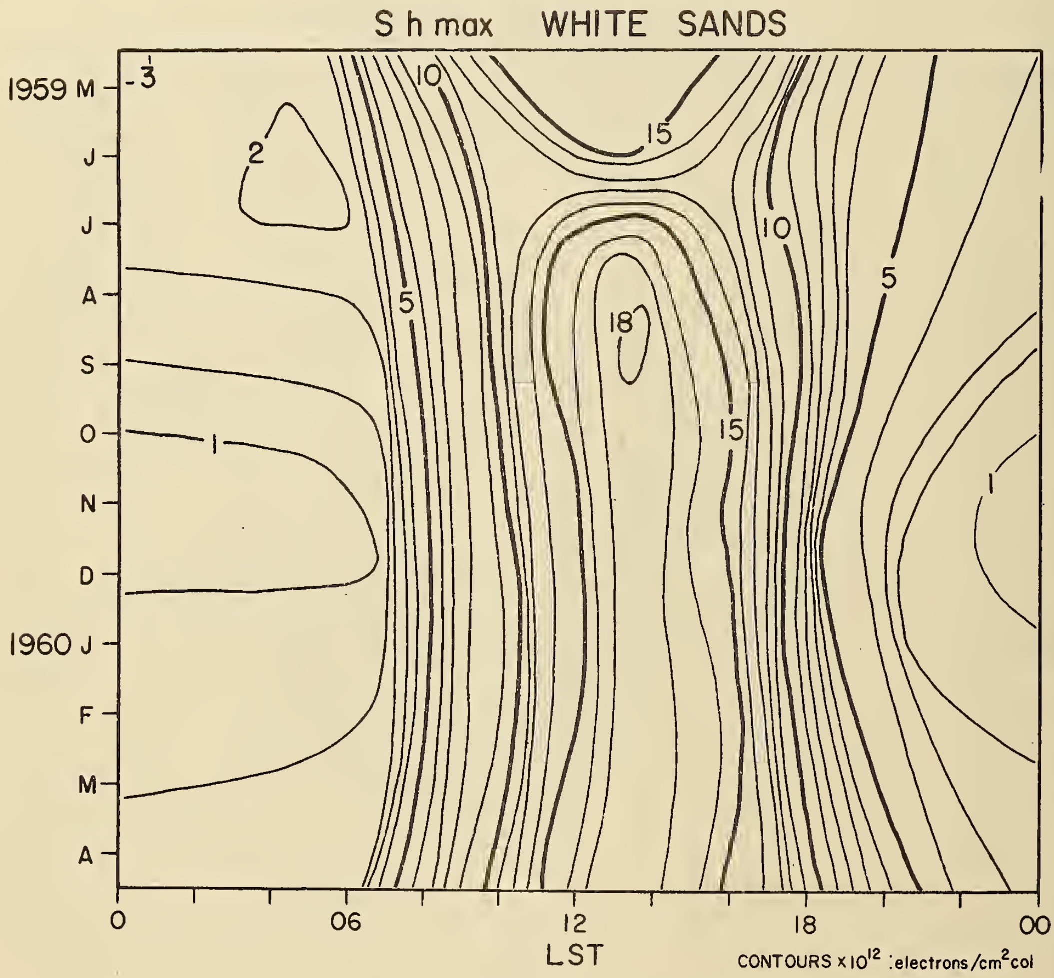

Figure 25 Diurnal and seasonal variations of Shmax - White Sands, New Mexico. Contours in (electrons/cm^{2}col) x 10^{-12} .

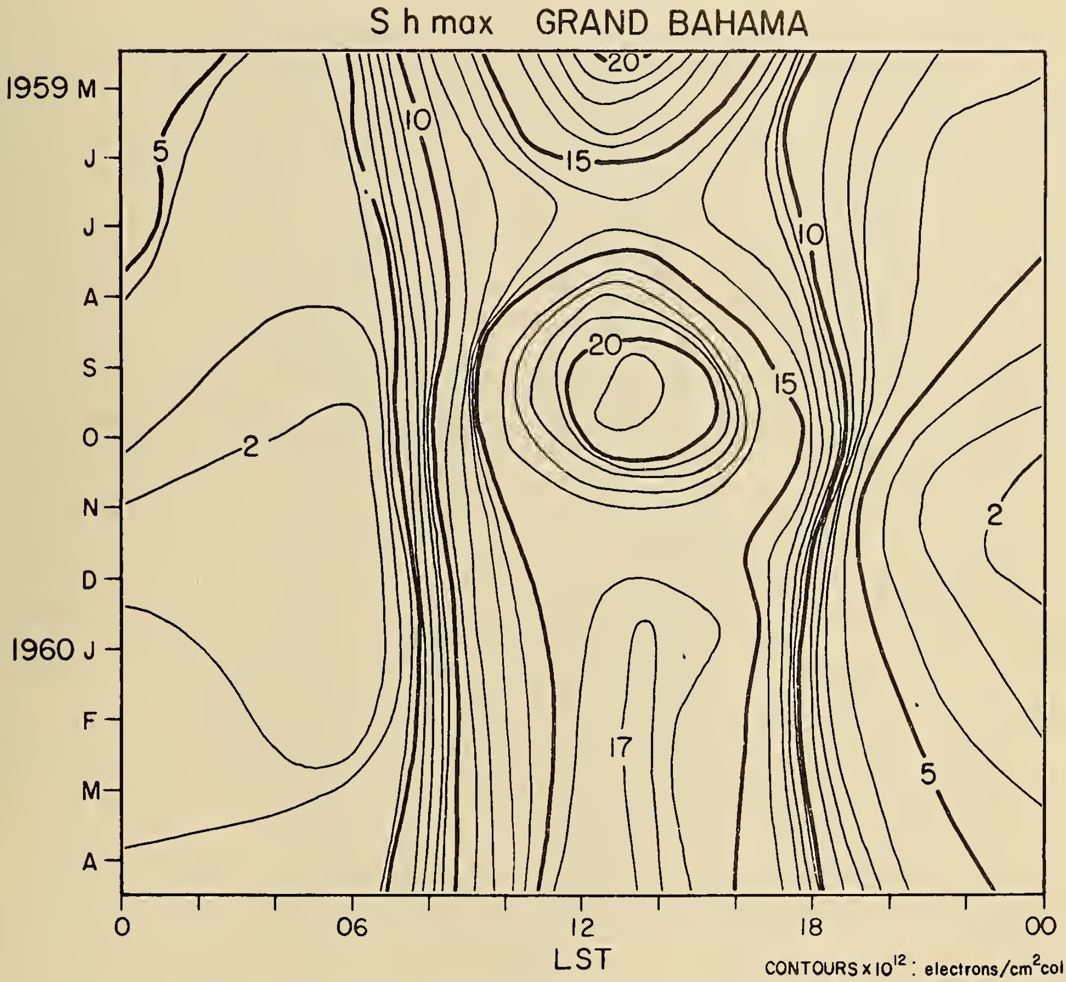

Figure 26 Diurnal and seasonal variations of Shmax - Grand Bahama Island. Contours in (electrons/cm^2col) x 10^{-12}.

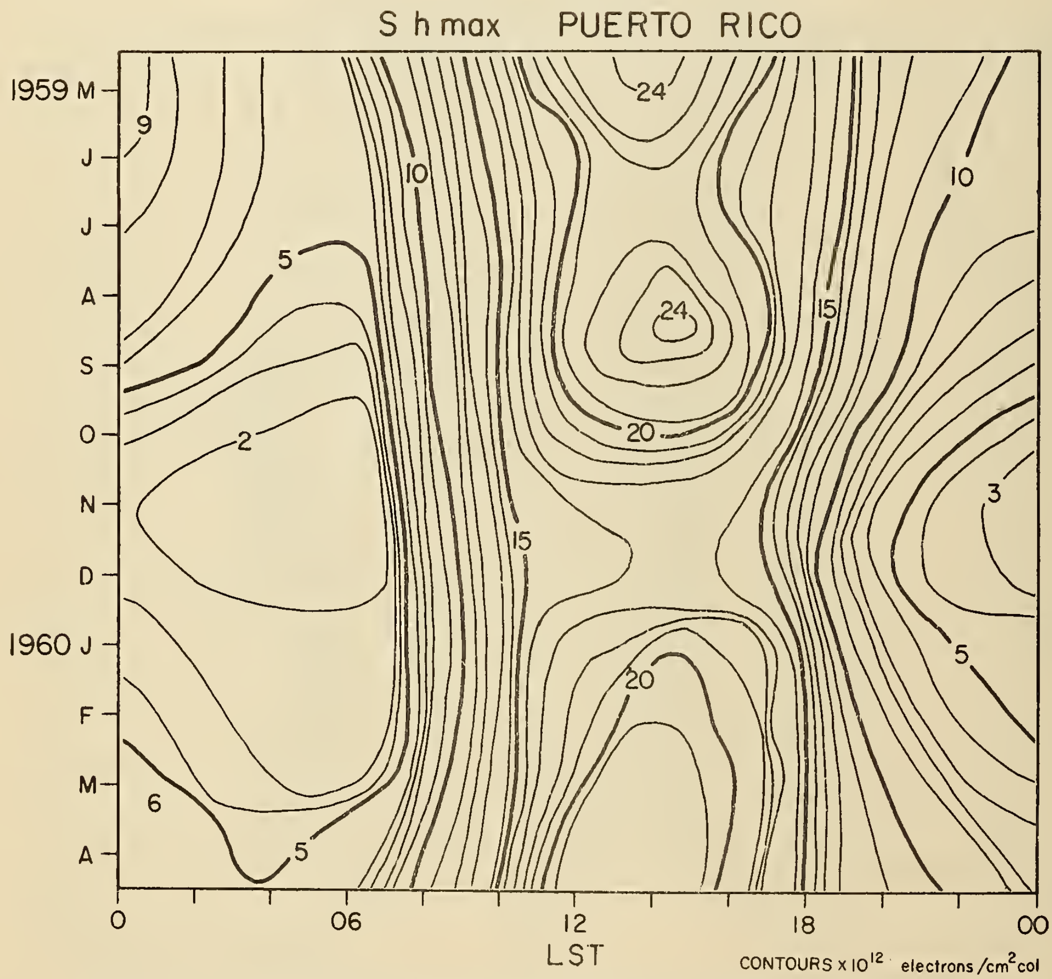

Figure 27 Diurnal and seasonal variations of Shmax - Puerto Rico. Contours in (electrons/cm^2col) x 10^{-12}.

APPENDIX

A Note on the Day-to-Day Variability of the Ionosphere

As was mentioned earlier in the discussion of the averaging process, the standard deviations (σ) and relative standard deviations (σ/mean) of the profile data are also obtained. These parameters give a quantitative measure of the day-to-day variability of the quiet ionosphere, and permit some interesting conclusions regarding the degree to which various external influences control the ionosphere.

The standard deviation of the (roughly 20) values of hmax, Shmax, Scat, and Nmax entering their respective means have been determined hourly for each month of the year May 1959 - April 1960. In the case of the electron density parameters Shmax and Nmax, it is immediately evident that the standard deviations are closely proportional to the mean values themselves, and that a clearer picture of the variability of the quantity is obtained if the standard deviation is expressed in percent of the mean value. This is also meaningful for the quarter-thickness, Scat, but has little meaning for hmax. Accordingly, our figures and remarks will concern the percentage variability of Shmax, Nmax and Scat, but will deal with the true variability of hmax, in kilometers.

From the one-year's data available to this study, it has not proven possible to observe any important seasonal variation in these variability data. There is a slight tendency for winter daytime values to be smaller (especially for Nmax and Hmax) than at other times and seasons, but this has not been explored further.

Because of the relatively minor seasonal dependence of the variability parameters, all months of the year's data have been averaged together for the preparation of the latitude versus local time maps of figures 28, 29, 31, 32. These maps show contours of the true variability of hmax (in km) and the percent variability of Scat, Shmax, and Nmax, respectively, between latitudes of 15°N to 50°N versus 75°W time.

1. Variability of hmax: As shown in figure 28, hmaxF2 has about twice the variability at night as in the daytime, and is generally larger at lower latitudes. The minimum variability is at midday, but the maximum variability is generally post-midnight -- markedly so, at lower latitudes.

2. Relative variability of Scat: The percent variability of the F2 layer quarter-thickness is shown in figure 29. Scat has been interpreted as a measure of the neutral scale height and hence the temperature at the F2 peak. Its variability is generally larger at high latitudes and in the early morning or sunrise periods, ranging from 10% to 30% of its mean value. The greater variability at high latitudes may be related to corpuscular heating at latitudes approaching the auroral zones; it is reasonable that any corpuscular heating of the atmosphere will have more day-to-day variability than the heating due to solar radiation.

We should also recall the remarks made concerning accuracies of these data in the introduction. The determination of Scat depends rather delicately upon the accuracy of Nmax. Almost certainly some of the variability of Scat is attributable to this cause. It is clear, however, that the variability due to errors cannot exceed 10%, the minimum variability observed.

It is of interest to inquire to what extent the variabilities of the height of the F2 peak and its characteristic thickness are related. It might be imagined, for example, that all the variability of hmax might be accounted for by variability in the thickness of the layer. This would be the case if the lower edge of the layer were essentially fixed in position and merely varied in thickness from day to day. Alternatively, it might be imagined that the whole region is located differently from day to day, producing a variation in hmax that is essentially independent of variations in the layer thickness.

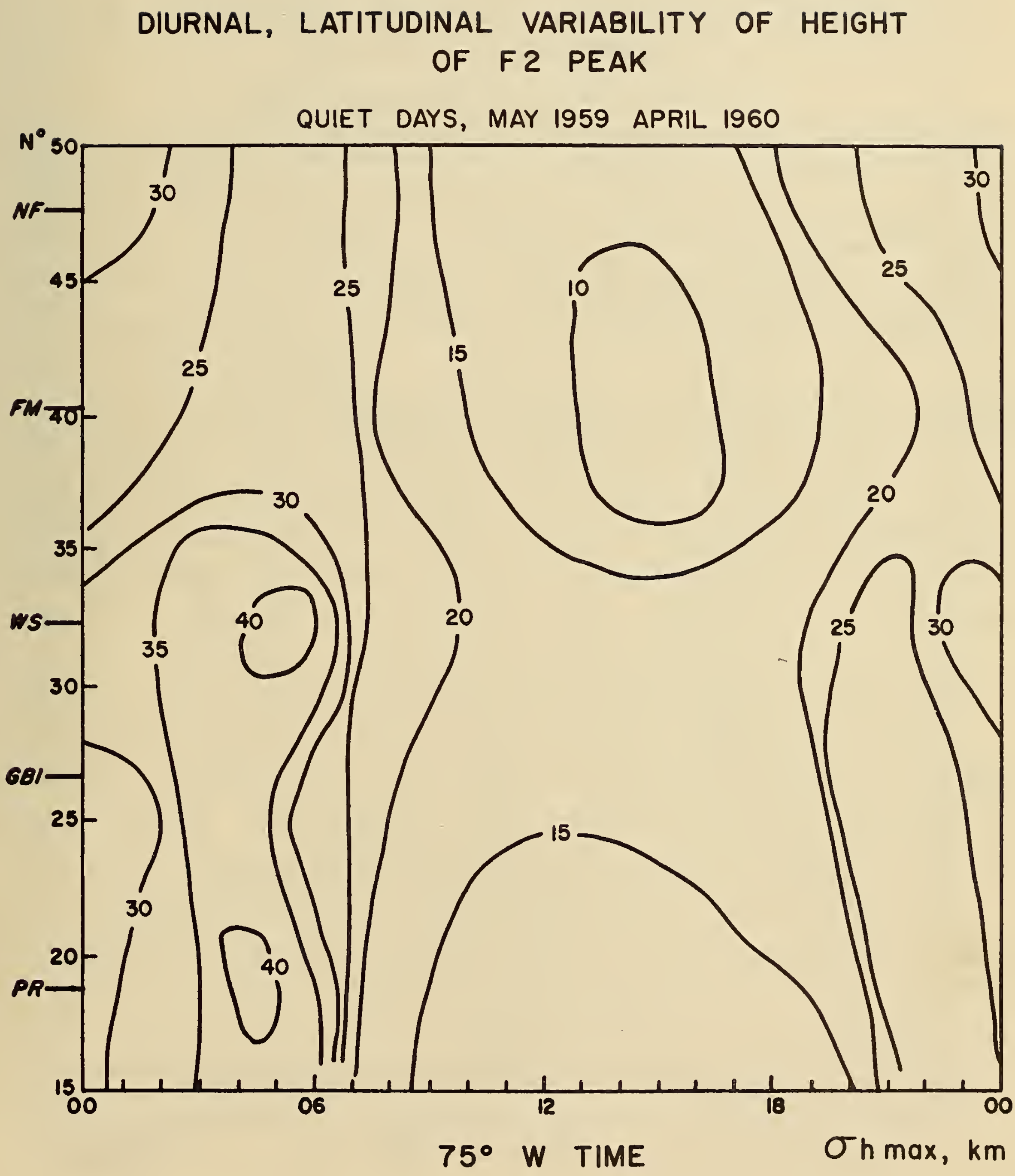

Figure 28 Diurnal, latitudinal variability of hmaxF2; quiet mean values averaged over May 1959 - April 1960. Contours in kilometers.

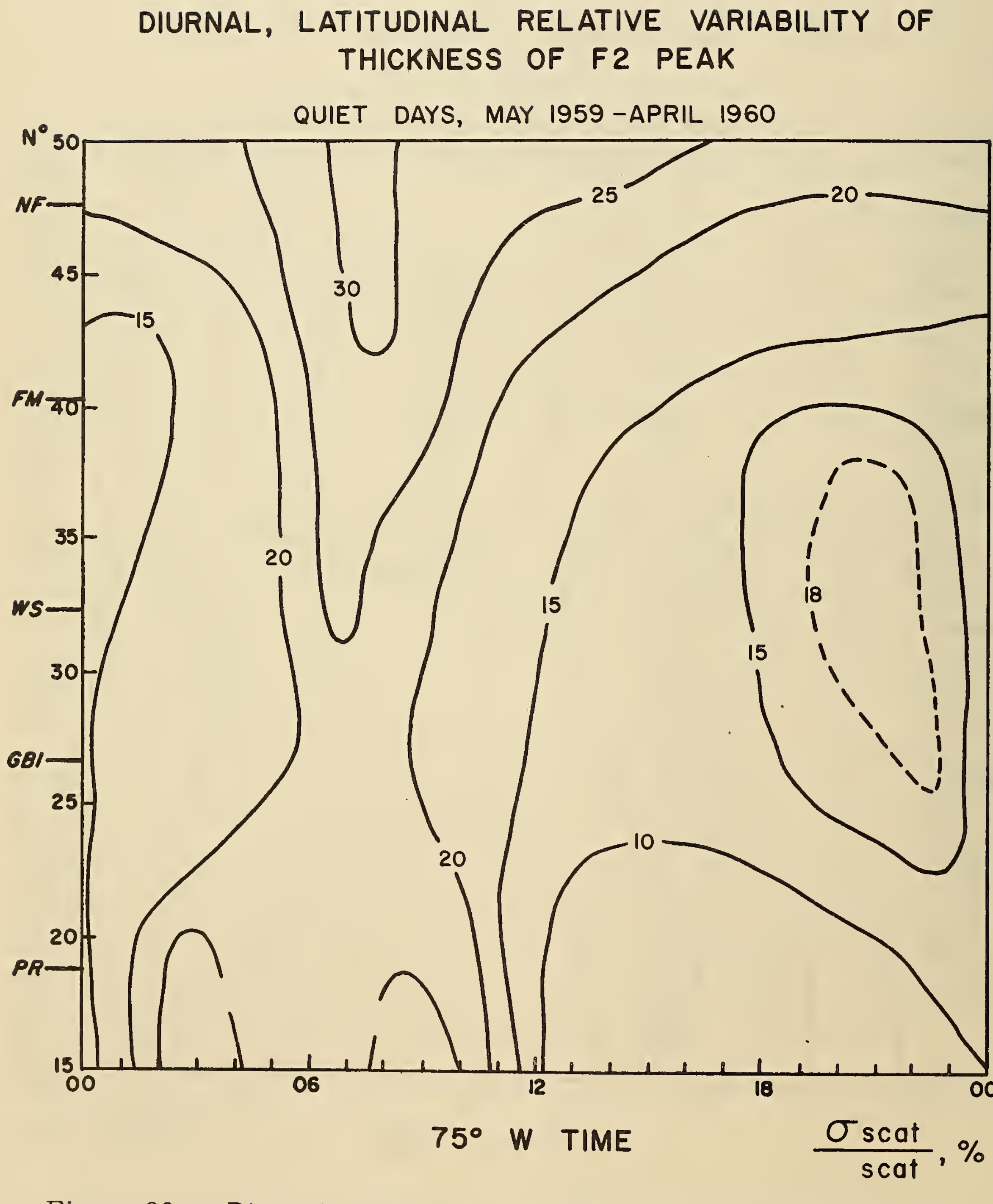

Figure 29 Diurnal, latitudinal relative variability of Scat; quiet mean values averaged over May 1959 - April 1960. Contours in percent.

To examine this point, in figure 30 we have plotted diurnally the standard deviations (in km) of hmaxF2 and Scat averaged over the entire year's data and for the two stations Newfoundland and Puerto Rico. The shaded area shows in each case the part of the variability of hmax which cannot be accounted for directly by the variability in Scat, or vice versa.

First, one notes that generally hmax varies more than Scat, except during high latitude daytime, when the two are essentially the same. There is a great difference between the two at night, indicating that the layer is found at considerably different positions (altitudes) from day to day with comparatively little change in thickness. There is, however, some indication of a correlation between the magnitudes of the two parameters.

3. Relative variability of total electron content: This parameter (fig. 31) has a very regular seasonal and time dependence. It is nearly constant (30%) at night, independent of latitude, and appears to depend very simply upon the solar zenith angle, being smallest during daytime at low latitude. The diurnal minimum value occurs, however, from one to three hours post-noon.

4. Relative variability of maximum electron density: In contrast with the variability of Shmax, the variability of the maximum electron density (fig. 32) suggests a mixture of latitudinal and solar control. The maximum values (40%) occur in the pre-dawn period at high latitudes. The minimum values occur towards lower latitudes in the daytime, and these become equal to the relative variability in sub-peak electron content discussed in paragraph 3. This is consistent with the Chapman-like behavior of the low latitude daytime ionosphere employed in section 1 (3): If the F region possesses a Chapman-like behavior, the electron density at all altitudes varies in proportion to the maximum density, and hence the electron content does also. This behavior is somewhat evident at all latitudes near midday, but is definitely not the case at night -- especially at higher latitudes.

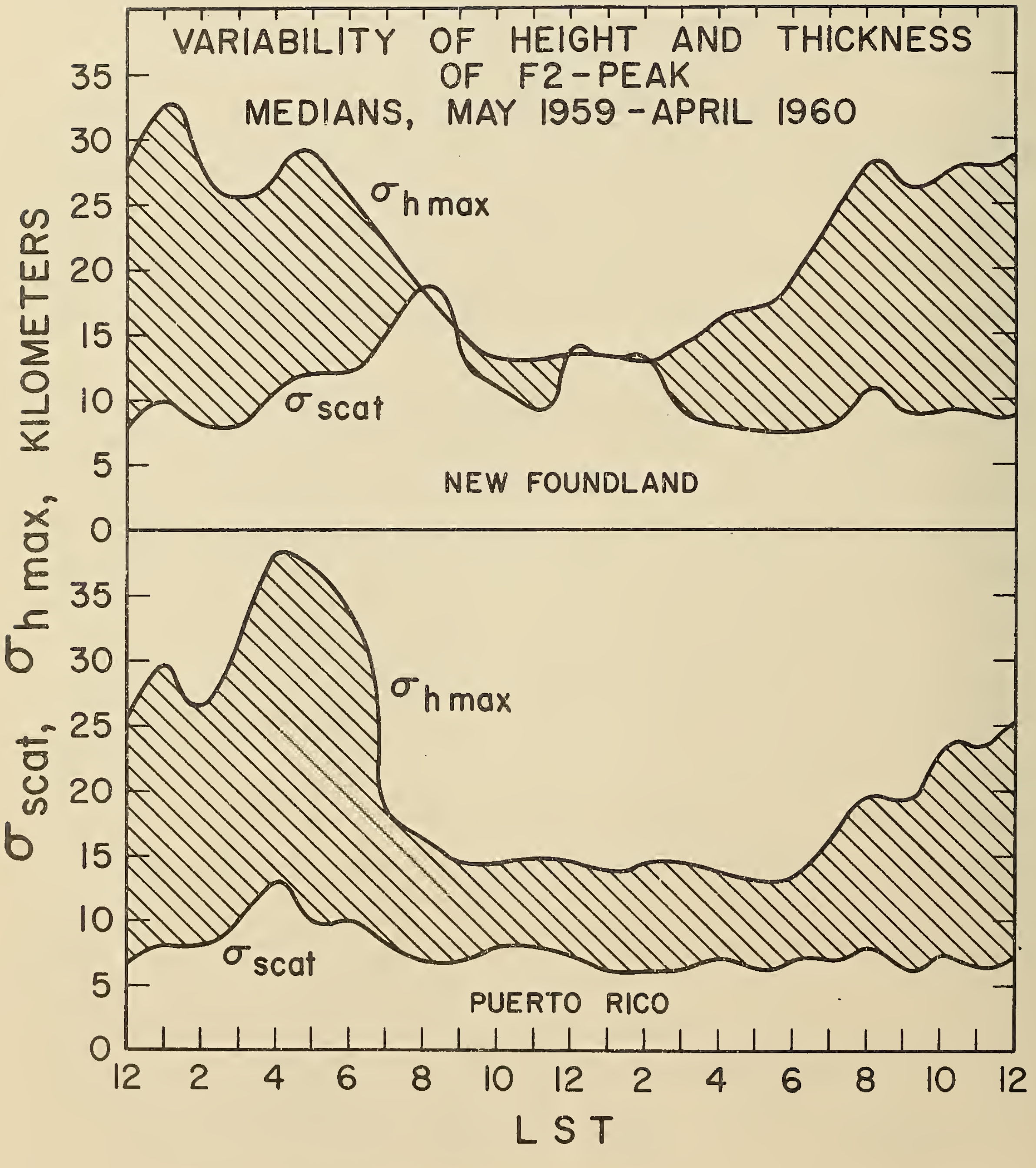

Figure 30 Comparative variability of hmaxF2 and Scat versus time, at Newfoundland and Puerto Rico, averaged over May 1959 - April 1960.

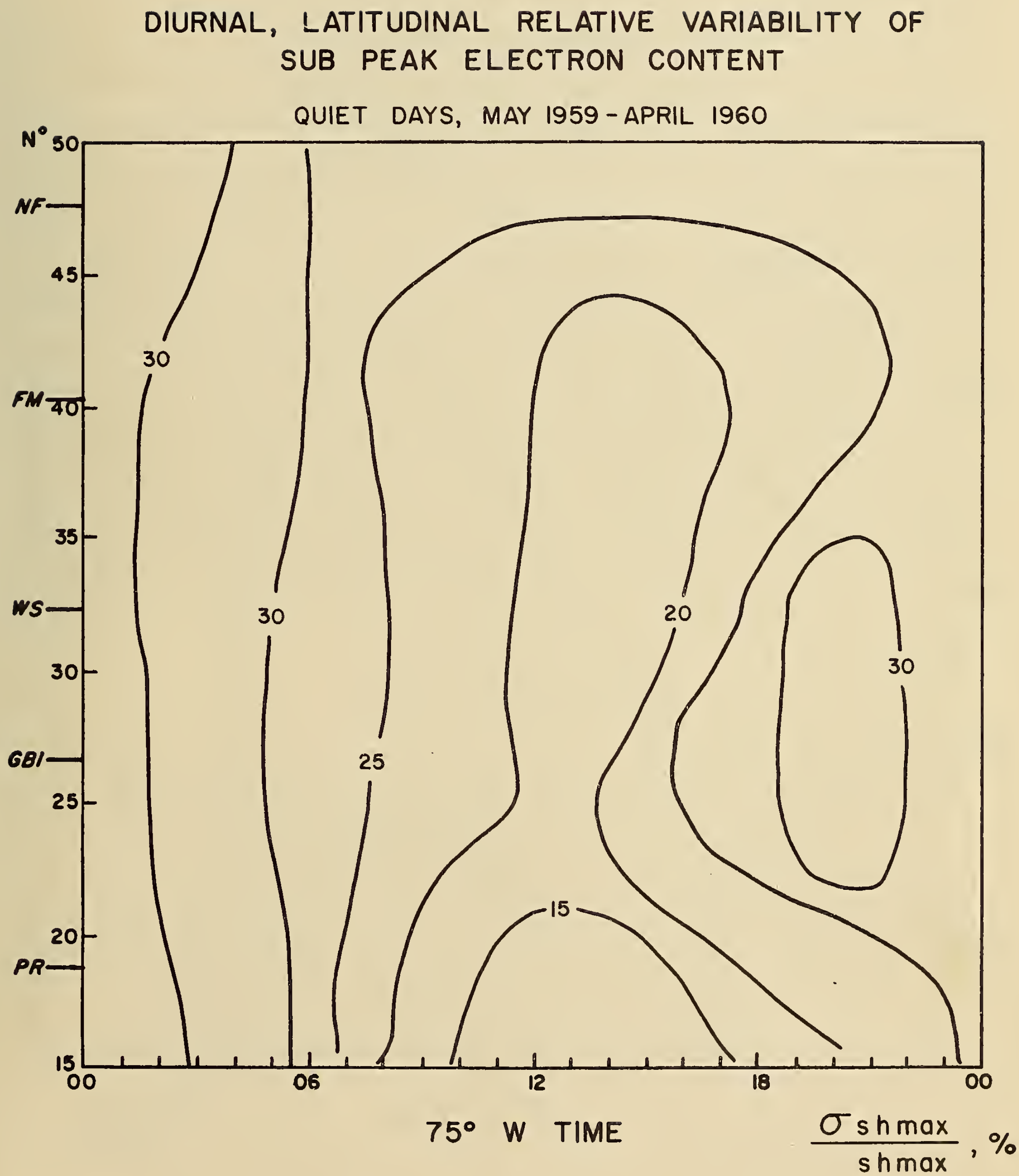

Figure 31 Diurnal, latitudinal relative variability of Shmax; quiet mean values averaged over May 1959 - April 1960. Contours in percent.

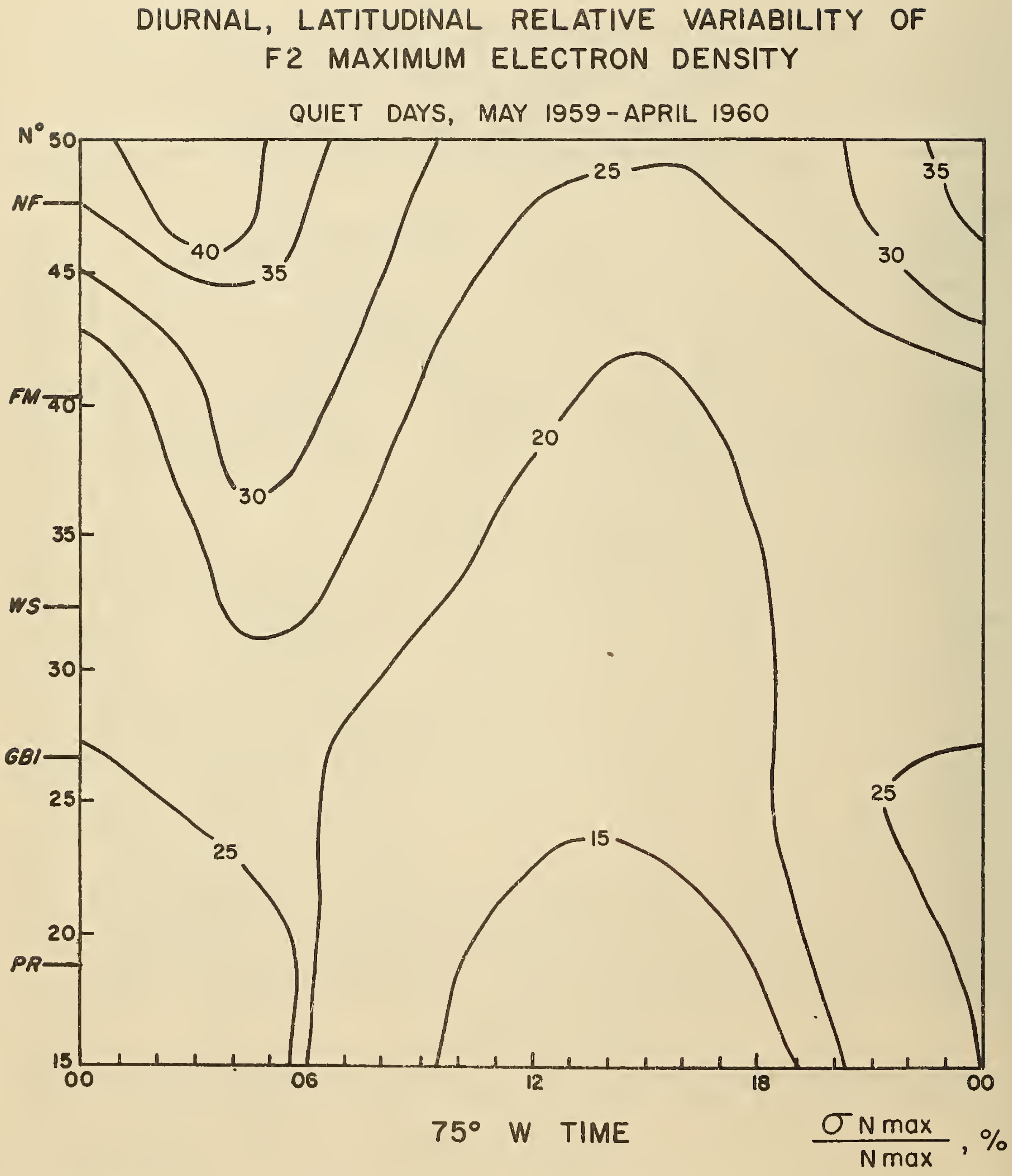

Figure 32 Diurnal, latitudinal relative variability of NmaxF2; quiet mean values averaged over May 1959 - April 1960. Contours in percent.

However, we may note that the high latitude pre-dawn peak variability of Shmax occurs at nearly the same time as the peak variability in layer thickness (vide supra). The behavior of the variabilities of Nmax, Shmax, and Scat at high latitudes during nighttime are again consistent with corpuscular heating of the atmosphere: As the day-to-day changes in temperature modulate the thickness of the nighttime F region, its maximum density varies in inverse fashion without appreciable change in the electron content.

Summary: The day-to-day variability of an ionospheric parameter, expressed as a percentage of the monthly mean, has been shown to be subject to interpretation consistent with the physical processes controlling the layer. The variability of a given parameter shows properties relatable to certain physical influences which may be obscured in the real values of the parameters themselves. In particular, the variability of the high latitude nighttime ionosphere is consistent with a variable corpuscular influence (probably corpuscular heating) not evident at lower latitudes.

ACKNOWLEDGEMENTS

As implied in the introduction, this study has been possible only because of the assistance rendered at the data's primary source, the ionospheric field stations; I wish to express our sincere appreciation for the efforts of the many station scientists involved. The NBS N(h) group led by G. H. Stonehocker, has rendered a service that is second only in chronology. Similarly invaluable has been the programing of the work for NBS' high speed computer by Dr. H. H. Howe.

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