

NBS

# Technical Note

No. 40-4

Boulder Laboratories

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## MEAN ELECTRON DENSITY VARIATIONS OF THE QUIET IONOSPHERE

4 - JUNE 1959

BY J.W. WRIGHT, L.R. WESCOTT AND D.J. BROWN



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U. S. DEPARTMENT OF COMMERCE  
NATIONAL BUREAU OF STANDARDS

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# NATIONAL BUREAU OF STANDARDS

## *Technical Note*

40-4

May 1961

MEAN ELECTRON DENSITY VARIATIONS  
OF THE QUIET IONOSPHERE 4 - June 1959

by

J. W. Wright, L. R. Wescott and D. J. Brown  
Central Radio Propagation Laboratory

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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. The results of this program for the month of June are illustrated graphically. This report is the fourth of a series illustrating the electron density variations in the mean quiet ionosphere between latitudes  $15^{\circ}\text{N}$  and  $50^{\circ}\text{N}$  along the  $75^{\circ}\text{W}$  meridian.



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I Introduction

Part of the basic responsibility of the Central Radio Propagation Laboratory is to gather ionospheric, solar, or other geophysical data necessary in the pursuit of research leading to improvements in radio communication and knowledge of the earth's upper atmosphere. The existing network of ionospheric vertical sounding stations is an important source of such data. Typically, the radio sounding data directly provide observations of peak electron densities (corresponding to "critical" frequencies  $f_oE$ ,  $f_oF_1$ ,  $f_oF_2$ ), data on Sporadic E, and certain derived propagation data such as maximum usable frequencies or MUF factors (Smith, 1939).

In fact, the vertical sounding is potentially capable of providing the complete electron density profile of the underside of the ionosphere (i.e., below  $h_{max}F_2$ ), and of providing a basis for extrapolation to much greater altitudes. However, because a lengthy and difficult calculation is required, little of this work had been done until quite recently when techniques and computers have become available and the exigencies of the IGY and satellite programs have made it imperative.

In the course of its development of facilities for electron density profile calculations, the CRPL has succeeded in devising means by which basic data for this purpose may be scaled by the individual field stations, thereby decentralizing and simplifying the most onerous part of the work. Through its own station network and those of the U. S. Army Signal Radio Propagation Agency, and through cooperation with closely associated stations in other countries, the CRPL has initiated an extensive systematic data reduction program, from which hourly electron density profiles are being computed for the following stations:

- Puerto Rico (NBS, January 1959)
- Grand Bahama Island (U. S. Army Signal Corps, February 1959)
- Fort Monmouth, New Jersey (U. S. Army Signal Corps, Feb. 1959)
- White Sands, New Mexico (U. S. Army Signal Corps, March 1959)
- St. Johns, Newfoundland (Def. Res. Tel. Establ. Canada, June 1959)
- Adak, Alaska (U. S. Army Signal Corps, June 1959)
- Okinawa, Ryukus (U. S. Army Signal Corps, June 1959)
- Thule, Greenland (U. S. Army Signal Corps, July 1959)
- Bogota, Colombia (January 1960)
- Huancayo, Peru (January 1960)
- Talara, Peru (January 1960)
- Baguio, Philippines (February 1960).

Affiliation and approximate date of initial participation in this program are given in parentheses.

The hourly electron density profiles are extensively used in the research programs of CRPL and are supplied directly to certain other agencies as part of various research and practical activities. However, in this comparatively early stage, broad dissemination of the computed data is a somewhat difficult problem.

In an attempt to make at least a summary of the results of the program widely and rapidly available, the CRPL has initiated the present series of reports. These provide graphical representations of the monthly mean quiet hourly electron densities from certain of the stations in the preceding list, from which a fairly clear picture of the local ionosphere morphology may be obtained.

These reports contain  $N(h)$  data for the stations at Newfoundland, Fort Monmouth, Grand Bahama Island, White Sands, and Puerto Rico. Pertinent facts concerning these stations are given in the following table:

Table 1

Station	Geomag. Coordinates			Geog. Coordinates	
	fH	Lat.	Dip		
St. Johns, Newf.	1.38Mc/s	58.5°N	72°N	47°33'N	52°40'W
Ft. Monmouth, N.J.	1.46	51.7°N	71.5°N	40°15'N	74°01'W
White Sands, N.M.	1.30	41.2°N	60°N	32°24'N	106°52'W
Grand Bahama Island	1.30	37.9°N	59.5°N	26°40'N	78°22'W
Puerto Rico	1.15	30°N	51.5°N	18°30'N	67°12'W

## II Description of Basic Data

True heights of reflection of radio waves are calculated from the observed or "virtual" heights by the method of Budden (1954); this method need not be described here except to point out that full correction for geomagnetic field effects is made and that the usual restrictions to monotonic profiles apply.

Tabulations of the mean electron density data at 10 km intervals and certain related quantities are the bases for the graphs and charts. A sample for the Puerto Rico June data is given on Page 11. The table on the following page identifies the quantities appearing on the tabulation.

TABLE 2

<u>Quantity</u>	<u>Units</u>	<u>Remarks</u>
Average Electron Density (N)	$\times 10^3$ = electron/cm <sup>3</sup> ( $10^{-5}$ on maps)	Body of table; given at each 10 km of height from the lowest hmin to 950 km.
NMAX	$\times 10^3$ = electron/cm <sup>3</sup> ( $10^{-5}$ on maps)	The mean value of Nmax.
COUNT		Count of the number of profiles entering the mean.
HMIN	Kilometers	The average height of zero or very low electron density, obtained by linear extrapolation of the electron density of the individual profiles.
HMAX	Kilometers	The average height of maximum electron density, determined by fitting a parabola to the upper portion of the individual profiles.
SCAT	Kilometers	One half of the half-thickness of the parabola best fitting the upper portion of the F-region profile. Approximates the scale height near the true HMAX.
SHMAX	$\times 10^{10}$ = electrons/cm <sup>2</sup> column ( $10^{-12}$ on maps)	Obtained by averaging the integration of the individual profiles between the limits HMIN and HMAX.
SHINF	$\times 10^{10}$ = electrons/cm <sup>2</sup> column ( $10^{-13}$ on maps)	The average total number of electrons in a column to infinity obtained by extrapolation of observed profiles into the region above HMAX. (See text.)

The following particular features of the tabulated data should be noted:

A. Averaging process. Each hour of each day is identified with its magnetic character figure, Kp. For each hour, those days for which Kp is less than 4+ are included in the "quiet" average. The other days are similarly combined to form a "disturbed" average; however, this rarely has physical significance because the number of disturbed periods is usually small and the behavior of the ionosphere during disturbed hours is not consistent. Thus graphs for these latter averages are not presented here.

B. Determination of hmax. The nature of the "true height" process is such that no direct measure of hmaxF2 is obtained, the virtual height at Nmax being immeasurable. A useful procedure is to fit the portion near hmaxF2 with a suitable curve and to determine hmax from this curve. A parabola is quite satisfactory for this purpose; it is fitted to two of the highest true heights and the measured value of Nmax(foF2).

C. Extrapolation of profiles above hmax. Before averaging, the individual profiles are extrapolated above hmax by a Chapman distribution of 100 km scale height. This assumed model seems to agree well with the few published measurements dealing with the profile of the F region above hmax (Wright, 1960). Extrapolation is necessary in order to calculate homogeneous averages near hmax, and the average profiles are, in fact, given to 950 km.

D. Integrated Electron Densities. The total number of electrons in a unit column of the ionosphere between the effective bottom (hmin) and hmax is called Shmax; it is obtained by numerical integration of the observed profiles between these limits. An estimate of the total electron content to infinity, based upon the Chapman model, is called Shinf. It is obtained by adding to Shmax the quantity  $N_A = 2.82 H N_{\text{max}}$  where H is an (assumed constant) scale height for the region above hmax. Current evidence

(Wright, 1960) indicates  $H = 100$  km, is an acceptable choice.

### III Description of Graphical Representation

The relative smoothness of mean quiet ionosphere data lends itself to various kinds of graphical presentation which offer convenient aids to the visualization of the height, geographic, and temporal variability of the ionosphere. Three such graphical forms are included here, prepared from the tabulations described in Section II.

A. Vertical cross sections of the ionosphere along the  $75^{\circ}\text{W}$  meridian. Pages 12 through 35 give for each hour, a vertical cross section of the mean quiet ionosphere along a meridian section, nominally the  $75^{\circ}\text{W}$  geographic meridian, for the month of June 1959. Contours are parametric in "plasma" frequency ( $f_N$ ) related to electron density  $N$  by

$$12,400 f_N^2 (\text{Mc/s}) = N(\text{electrons/cm}^3).$$

The height of maximum electron density is represented by a dashed line. Note that the vertical scale is expanded about 5.5 times.

With the exception of White Sands, each of these stations is reasonably close to the  $75^{\circ}\text{W}$  meridian (see Table 1). There is the possibility that some of the anomalies imposed by White Sands on these contours are the result of the well-known longitudinal asymmetry of the ionosphere.

B. Local time vs Latitude Maps. Another form of presentation, useful for indicating the two-dimensional geographic variations of the ionosphere, is that illustrated by the maps of pages 36 through 45. Here, for fixed levels in the ionosphere (150, 200, 250, 300, 350, 400 km), contours of electron density are drawn in the latitude vs. local time plane. To the extent to which longitude anomalies are negligible, these maps give also the longitude vs. latitude

distribution of electron densities at the indicated heights when it is noon over the  $75^{\circ}\text{W}$  meridian. Similar maps for the peak density,  $N_{\text{max}}$ ; its height,  $h_{\text{max}}$ ; its characteristic thickness,  $S_{\text{cat}}$ ; the total electron content to  $N_{\text{max}}$ ,  $S_{h_{\text{max}}}$ ; and the estimated total electron content,  $S_{\text{hinf}}$ , are also shown.

C. Electron density vs. time curves ( $N(t)$  curves). The mean quiet diurnal variation of electron density between 150 and 400 km heights above the sounding stations is illustrated by these curves. Dashed lines are used wherever the electron density at any height falls below the peak density (i.e. when the height  $h_{\text{maxF2}}$  falls below the height for the curve in question.) Such electron densities are the result of the extrapolations by the Chapman model discussed in Section II C.

#### IV Discussion and Applications of the Data

Mean quiet electron density data over wide geographic areas are essential for application to numerous problems of both practical and scientific interest. For example, the assessment of the radio refraction errors and Faraday rotation effects in satellite tracking require a knowledge of the electron density profile in the direction of the satellite or an estimate of the electron density at the satellite itself. Alternatively these properties of the ionosphere, or estimates of the total electron content in a column, may be measured by observations from rockets and satellites, or from radar moon-echoes, and compared with ground-based observations of the kind shown here.

Frequently it will be necessary to use instantaneous density data because of the considerable variability of the ionosphere about the quiet mean. In such cases, the mean data are of value as a "reference level" in the design of the experiment; for example, in the choice of radio frequencies, satellite heights, antennas, etc.

Since electron density data represent virtually our only source of continuous, widespread data on the earth's upper atmosphere, such data also are essential to geophysical problems involving the electrical, neutral, and magnetic properties of the atmosphere.

For example, data on the vertical cross sections may be compared with theoretical expectations for the meridional height dependence of the quiet ionosphere. Several workers, (Hirono, 1955), and Martyn (1956), have investigated the equilibrium height (of  $h_{max}$ ) for an ionosphere controlled by diffusion, height-varying electron loss rate, and uniform (or zero) vertical electron drift. The results are qualitatively in agreement with these observations in predicting a rise of  $h_{max}$  towards the equator in daytime and a reversal of this tendency at night.

The  $N(t)$  curves are perhaps the most physically significant representation of electron density data. The strong solar control at all levels and the important perturbations of this solar control in the upper F region may be easily seen.

Acknowledgments

We are indebted to Mr. A. H. Shapley for guidance in the initiation of this work, and to Dr. H. H. Howe for the development of the computer programs upon which the whole system heavily depends. This series of reports results from the combined efforts of the NBS Electron Density Profile Group, including at various times L. R. Wescott, L. Hayden, D. J. Brown, F. J. Burmont, I. Ford, N. Moore, M. Durham, G. Lira, under the direct supervision of G. H. Stonehocker. The cooperation of the U. S. Army Signal Radio Propagation Agency, in particular the assistance of Mr. F. H. Dickson (Chief), is gratefully acknowledged.

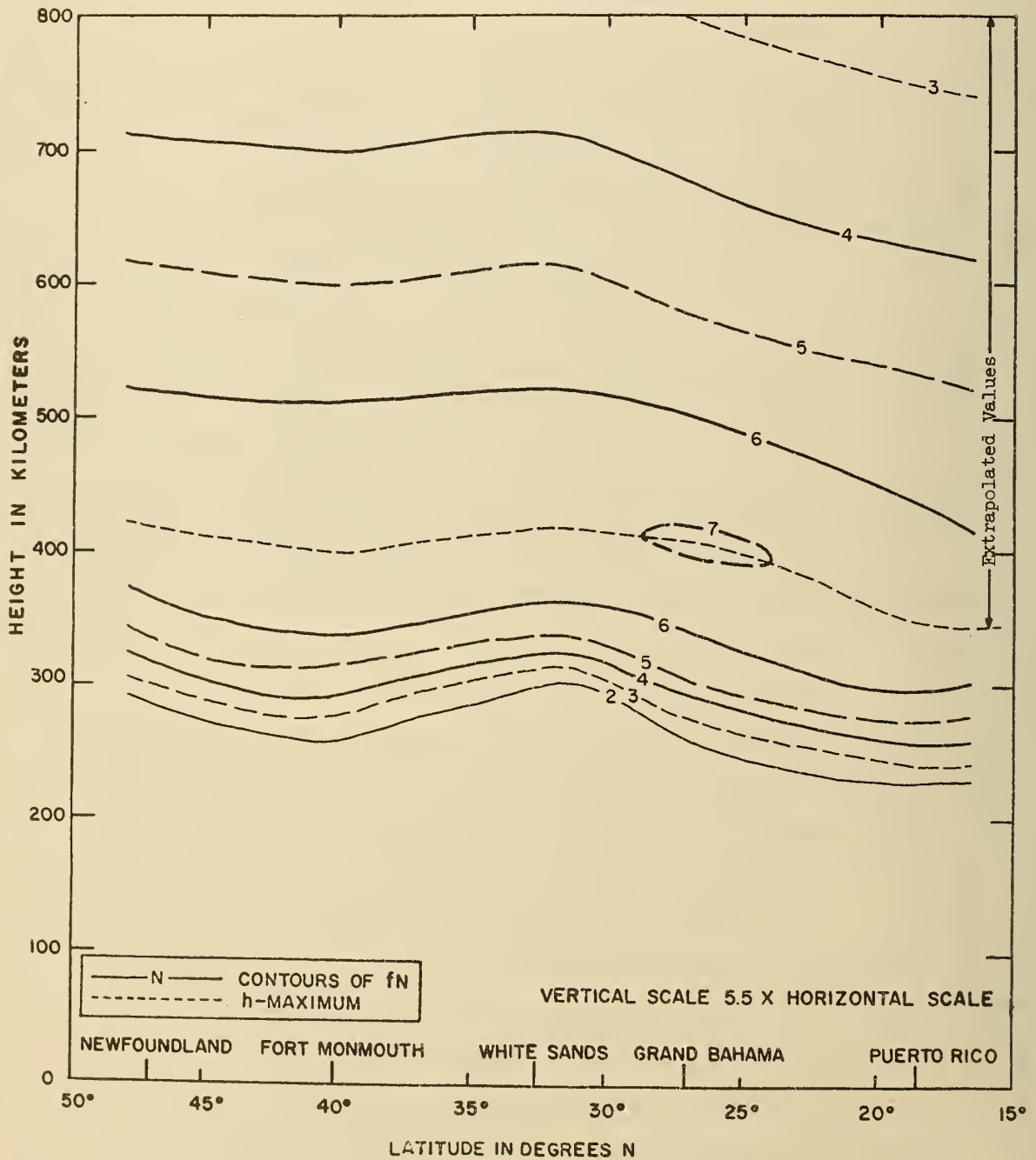
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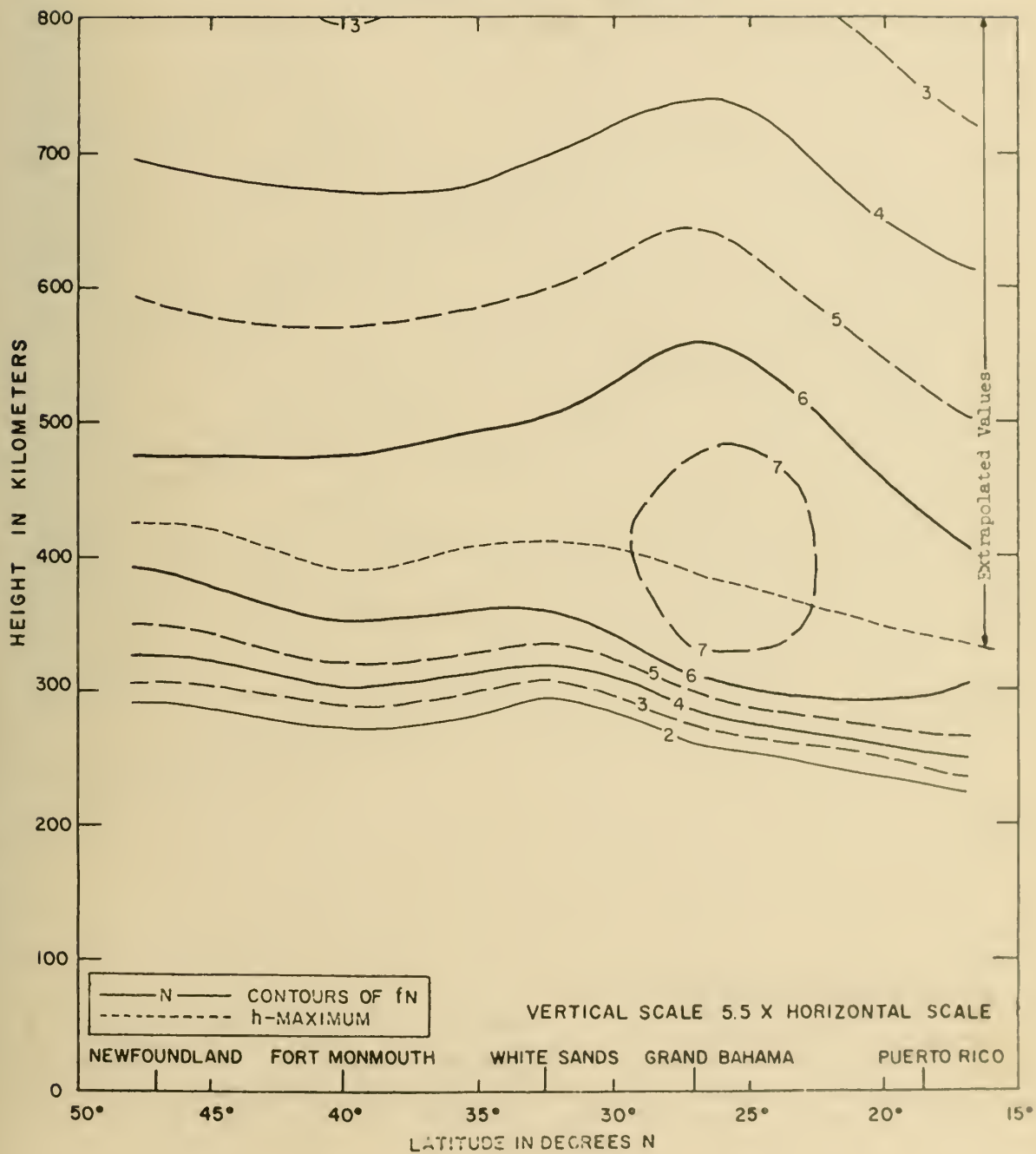
JUNE 1959

0000 75° W TIME



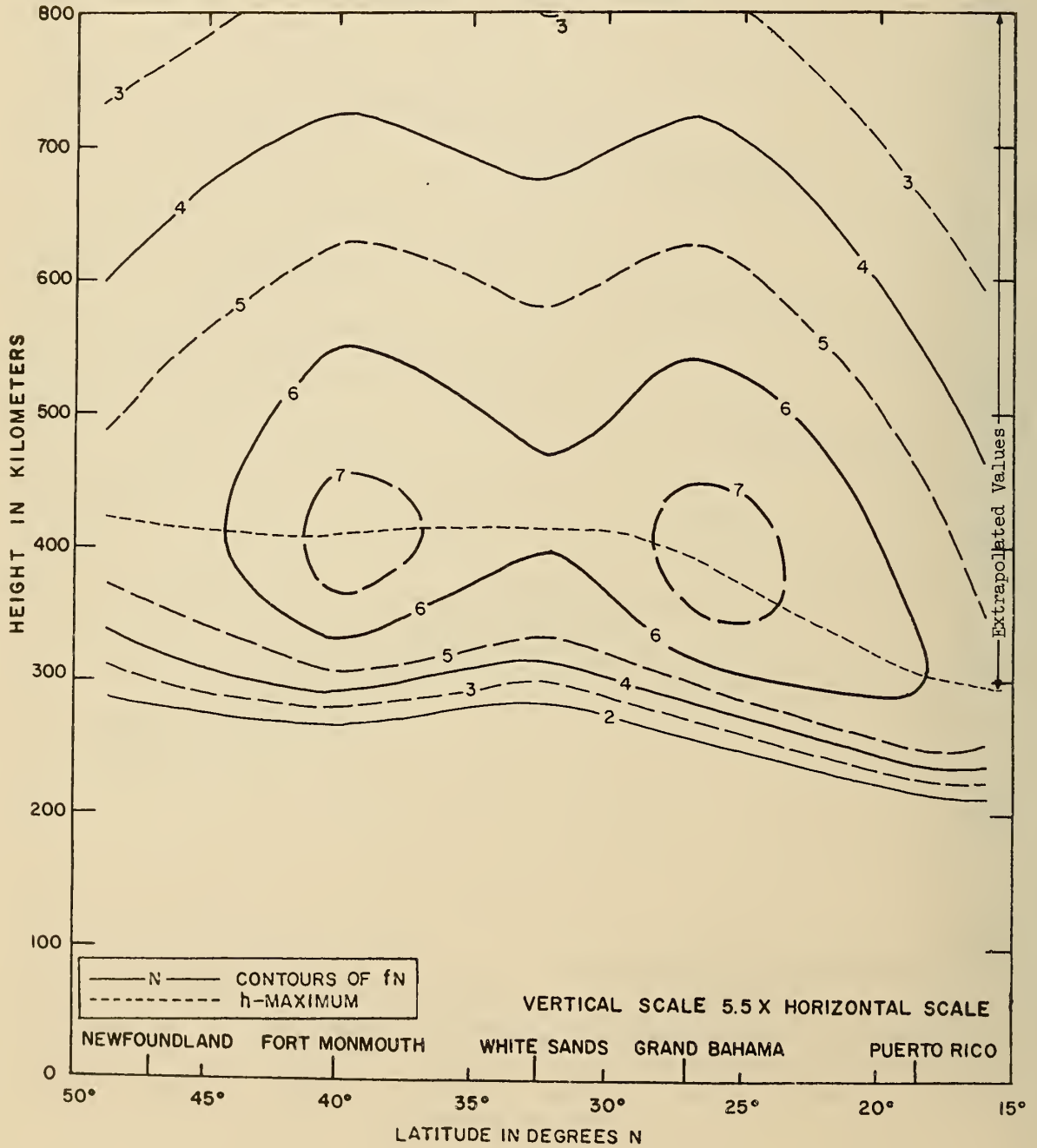
JUNE 1959

0100 75° W TIME



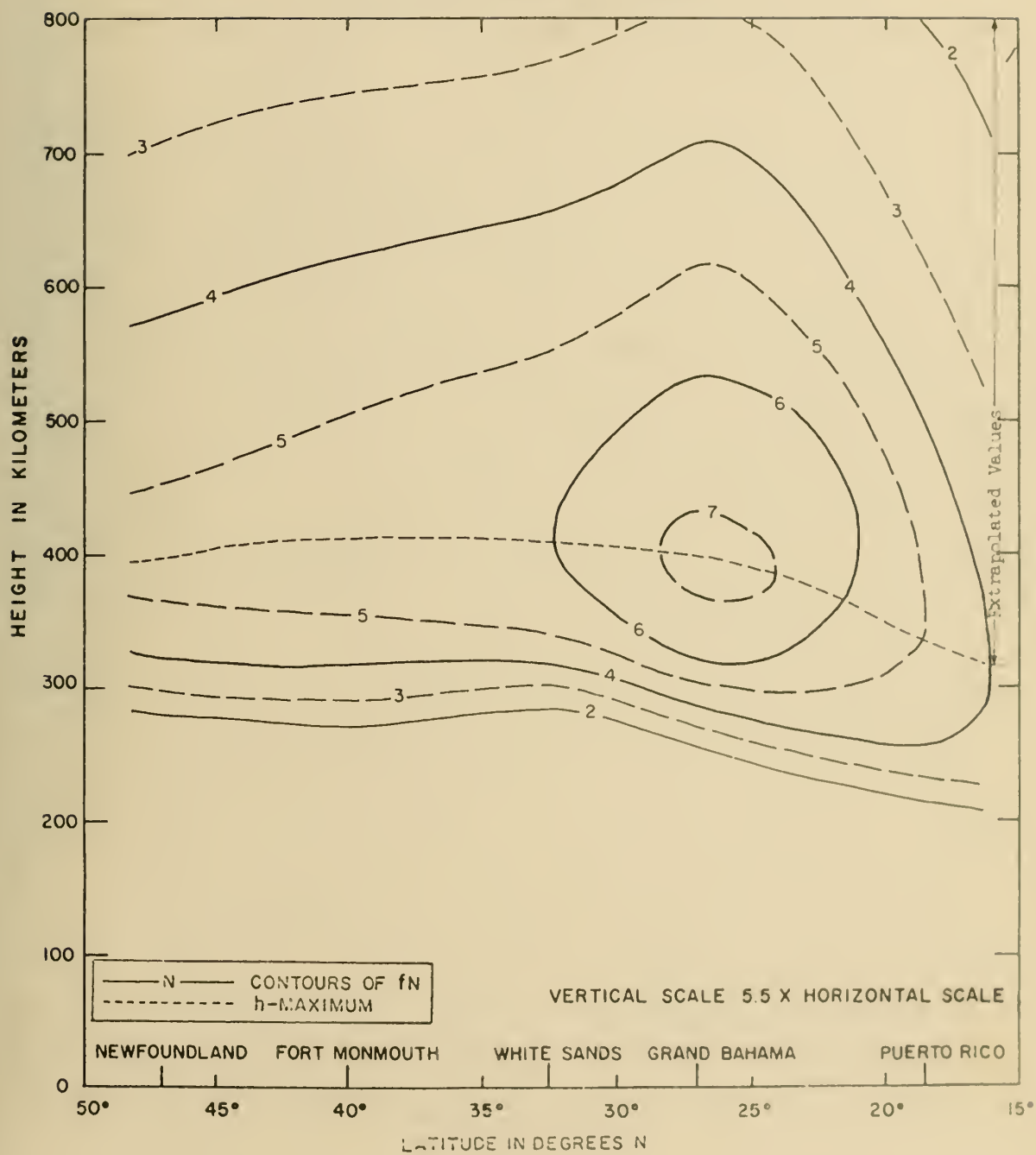
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0200 75° W TIME



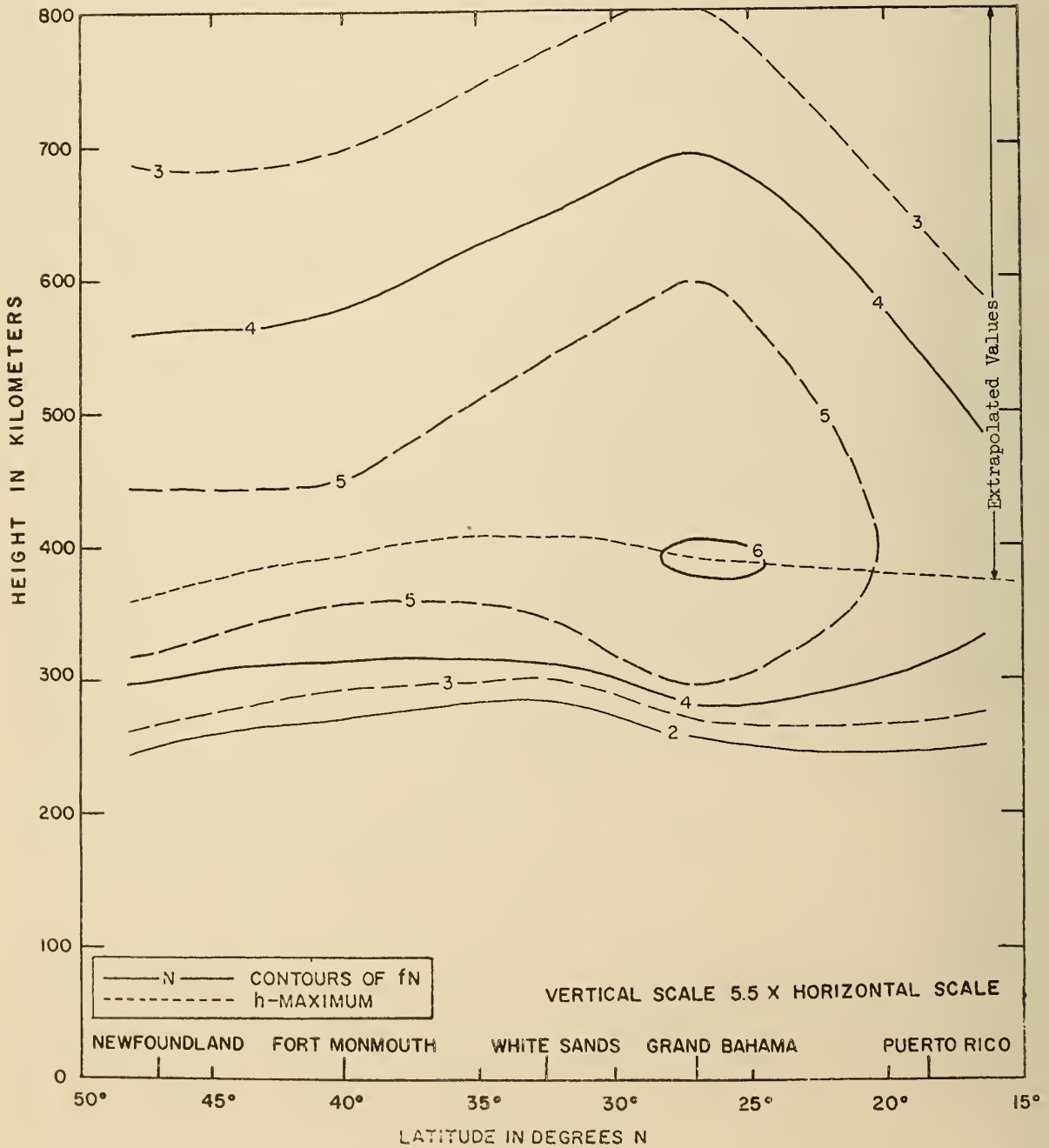
JUNE 1959

0300 75° W TIME



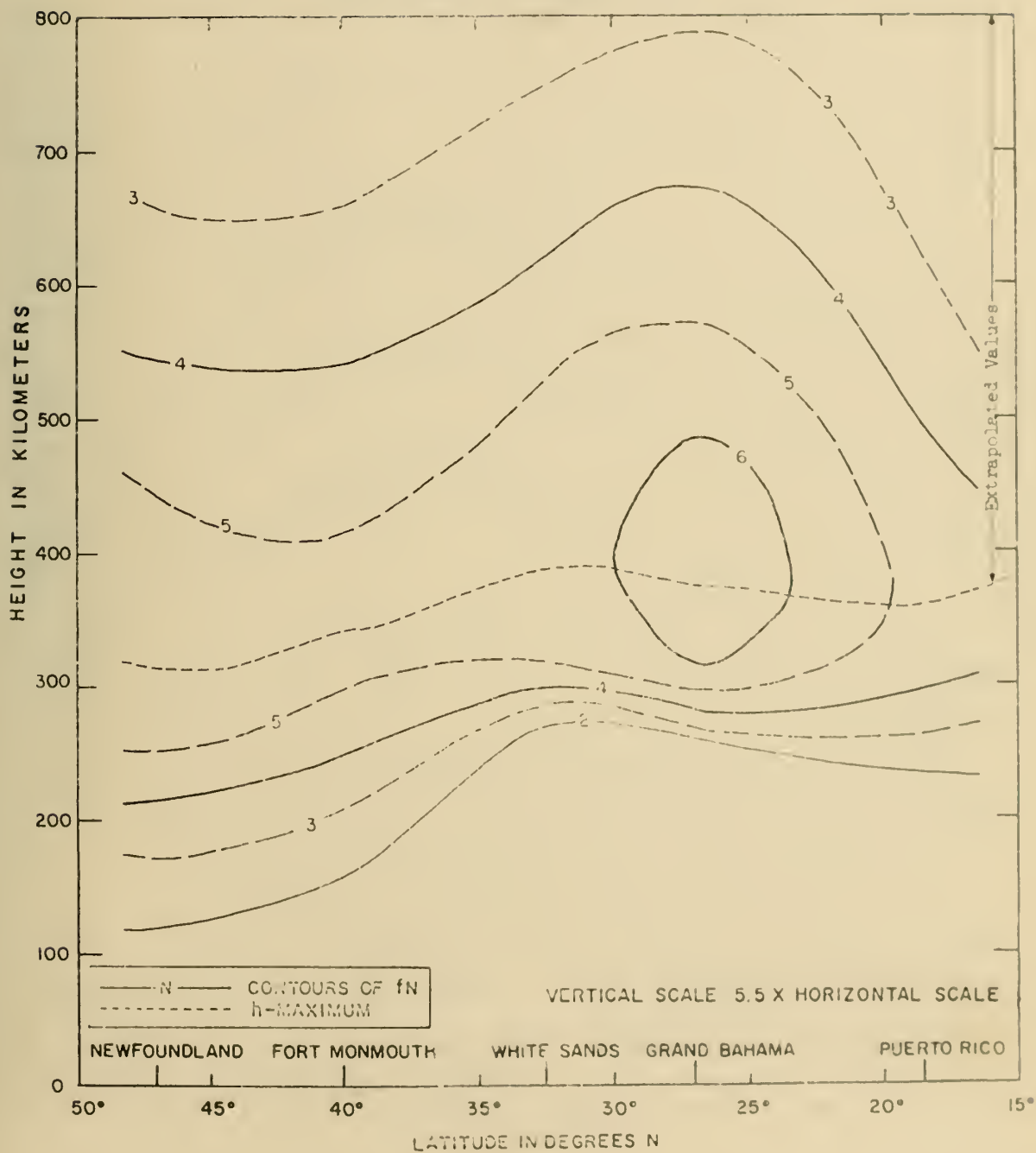
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0400 75° W TIME



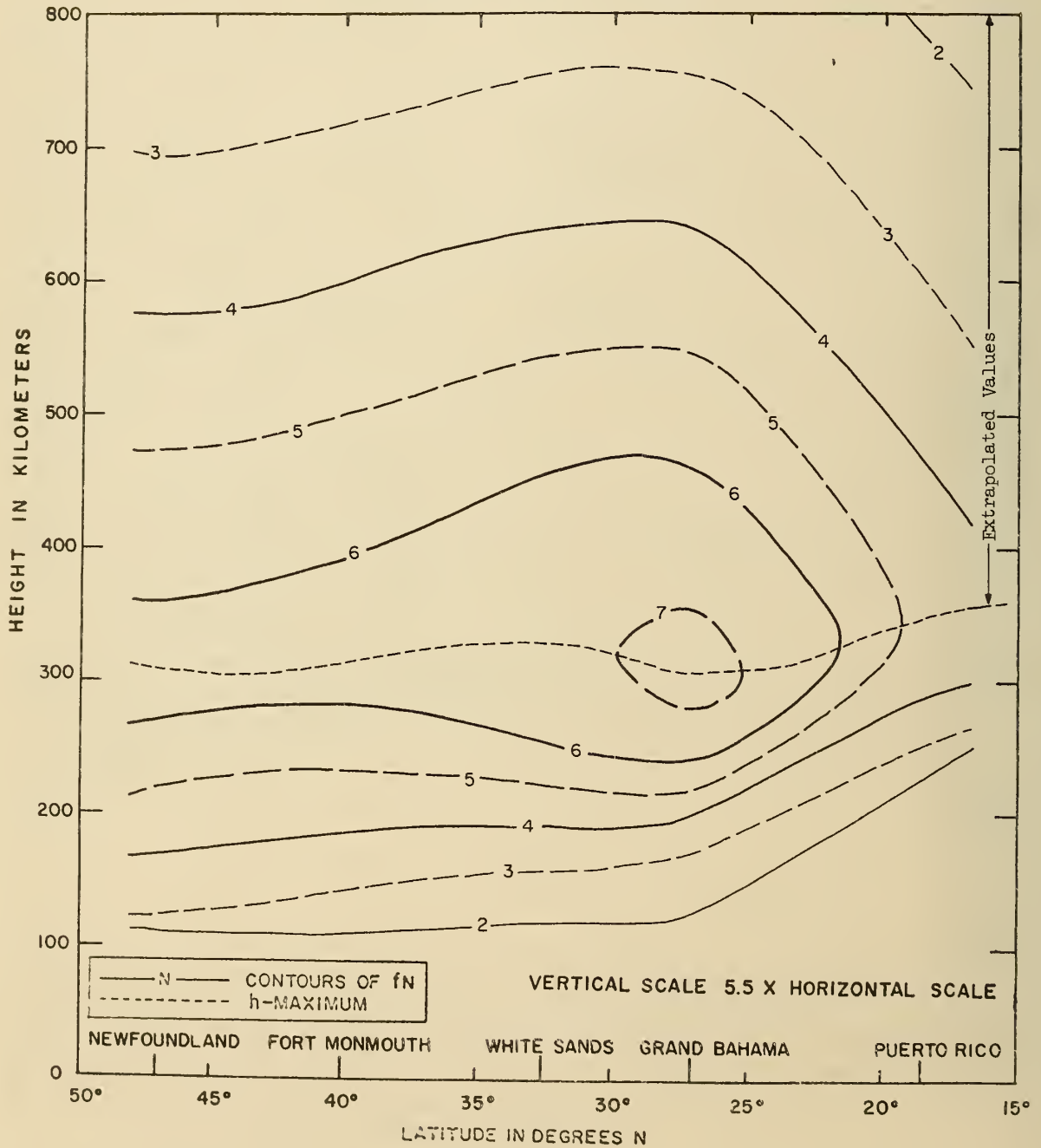
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JUNE 1959

0500 75° W TIME



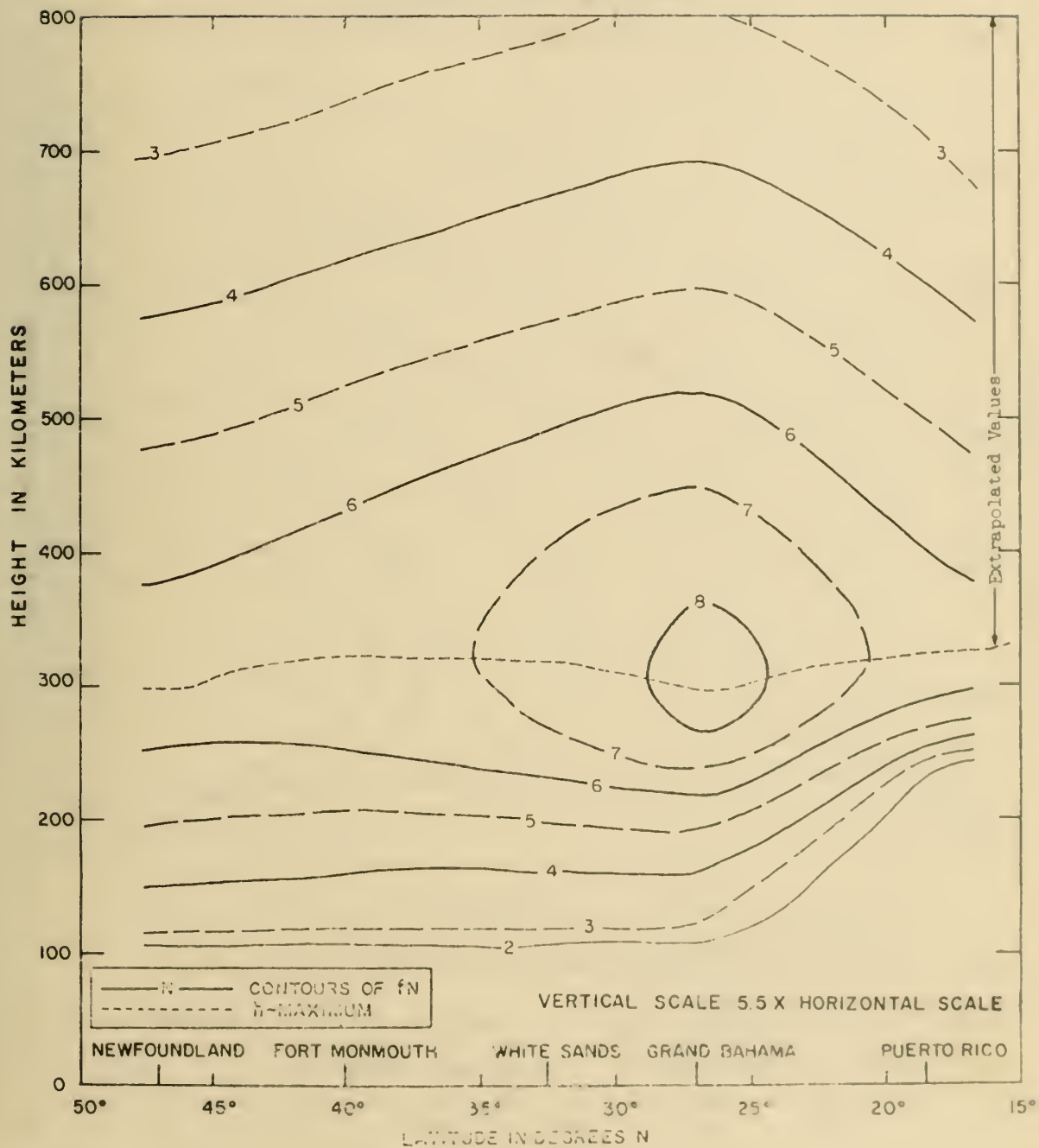
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0600 75° W TIME



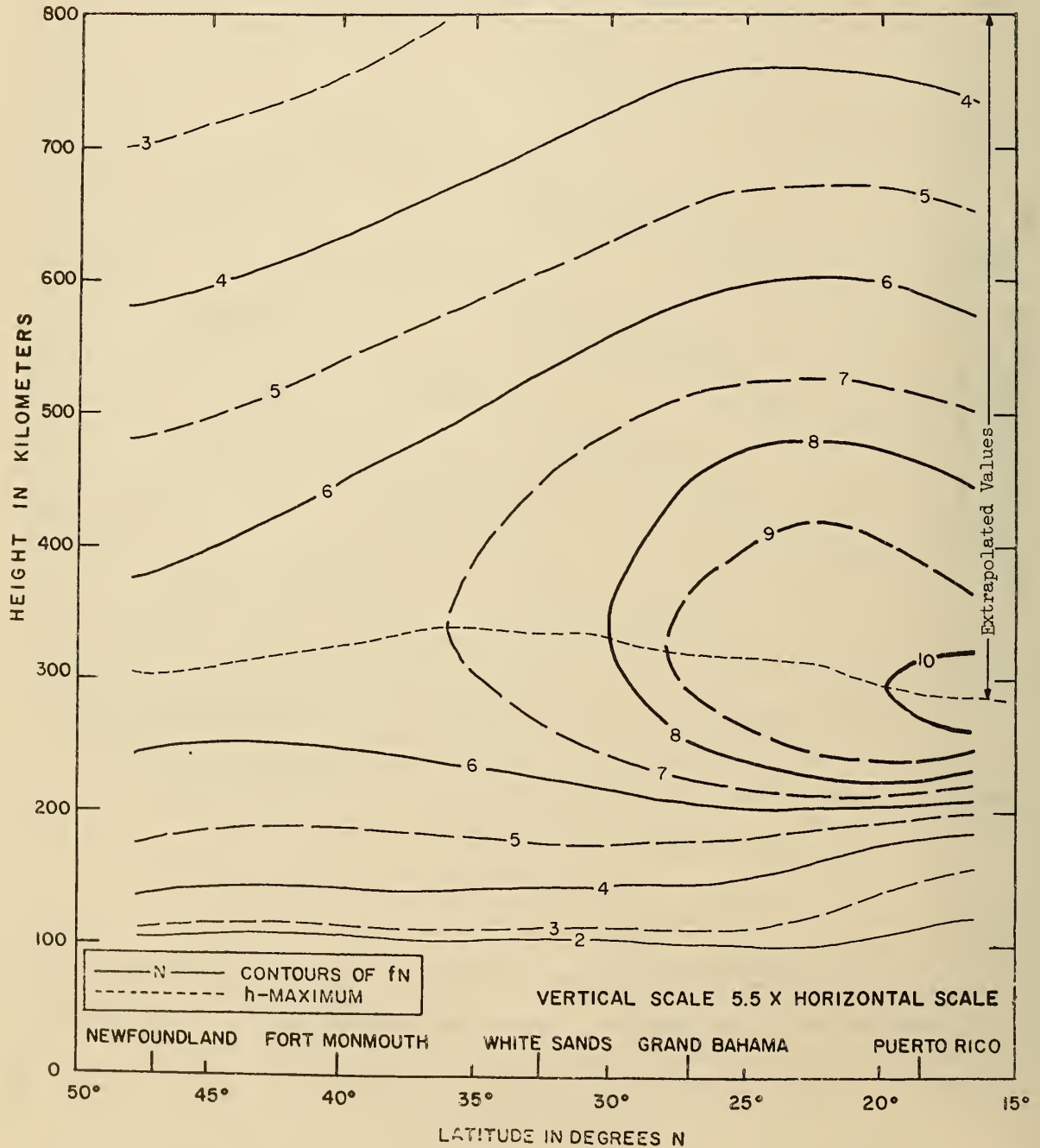
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0700 75° W TIME



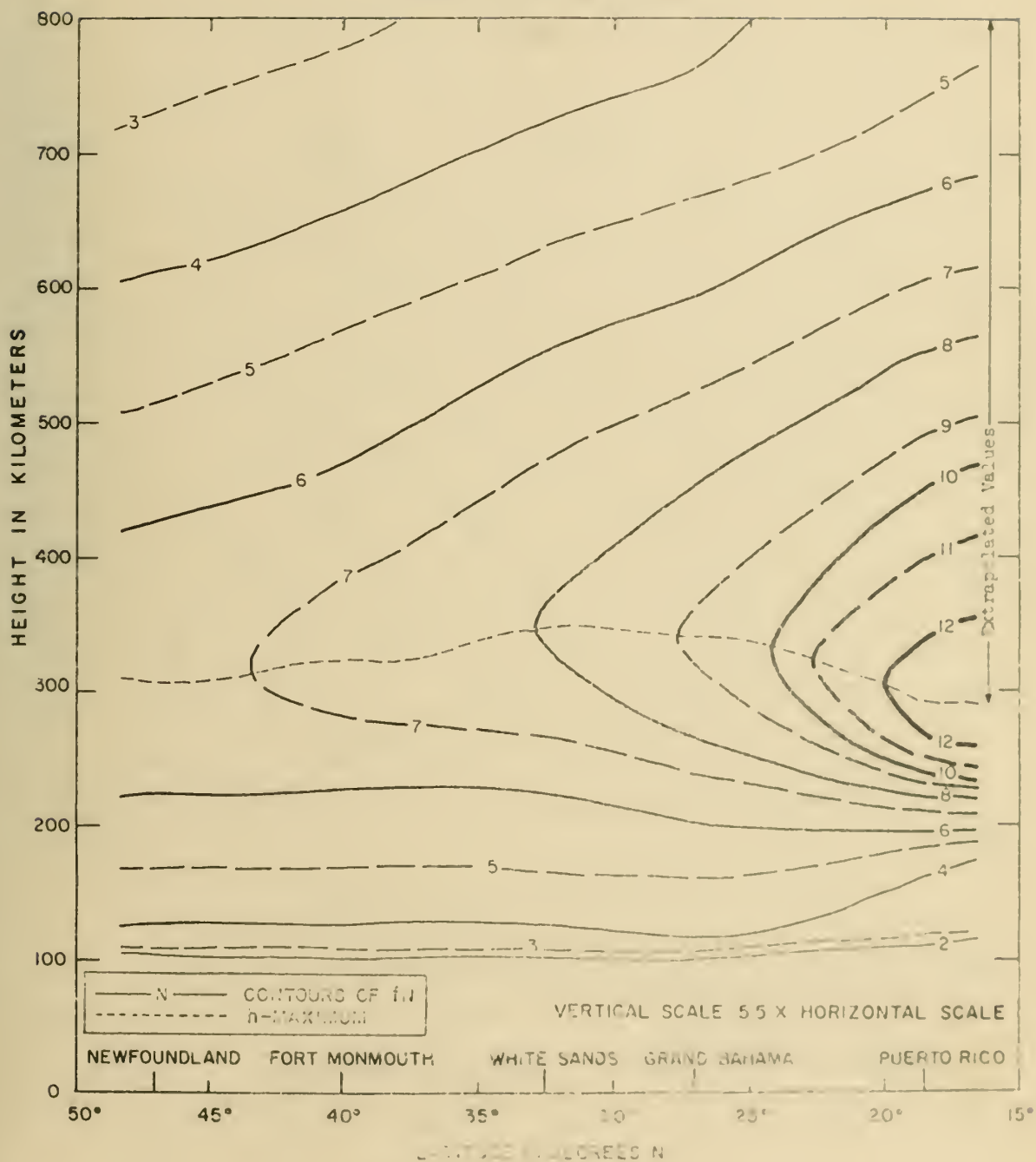
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0800 75° W TIME



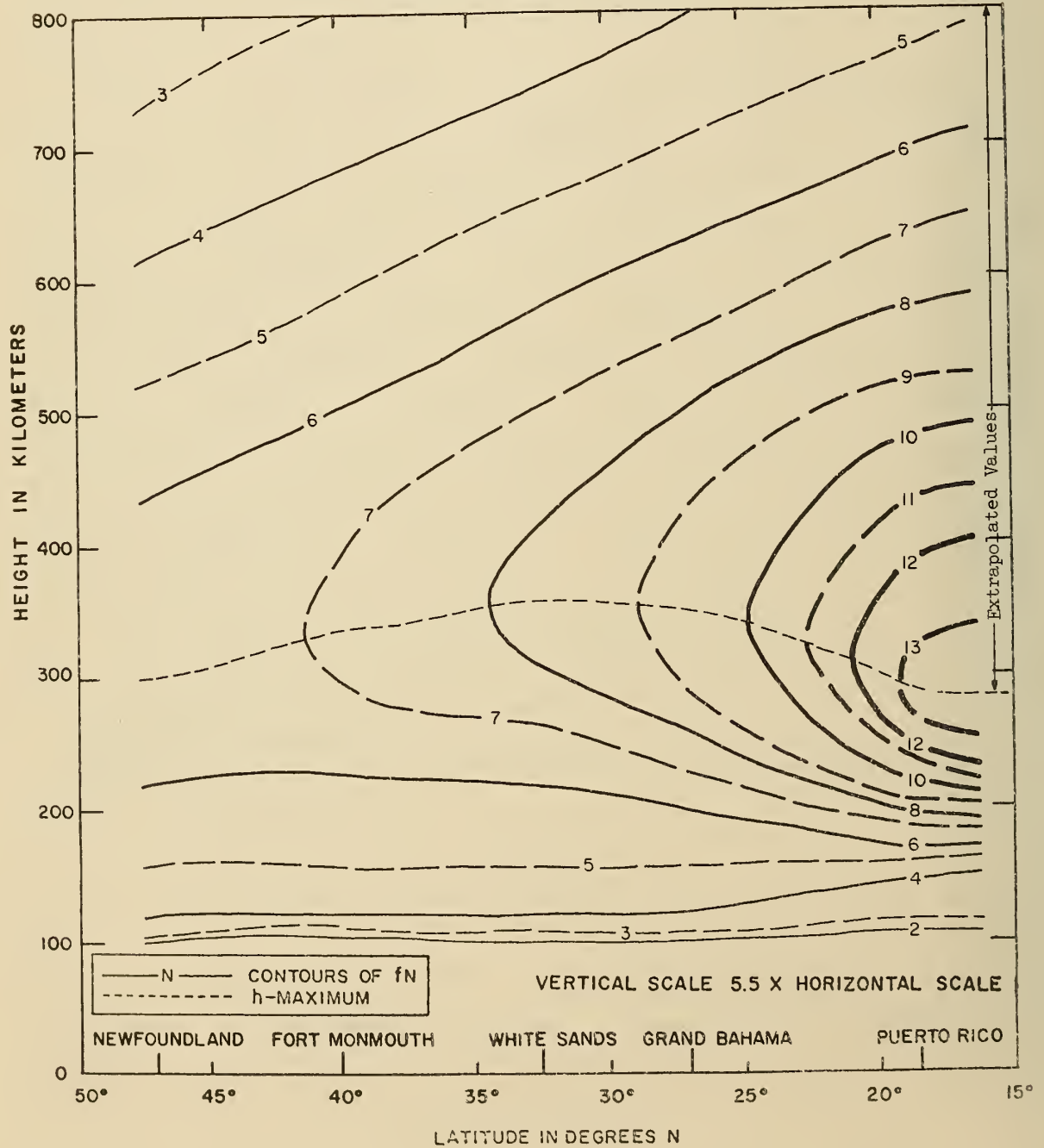
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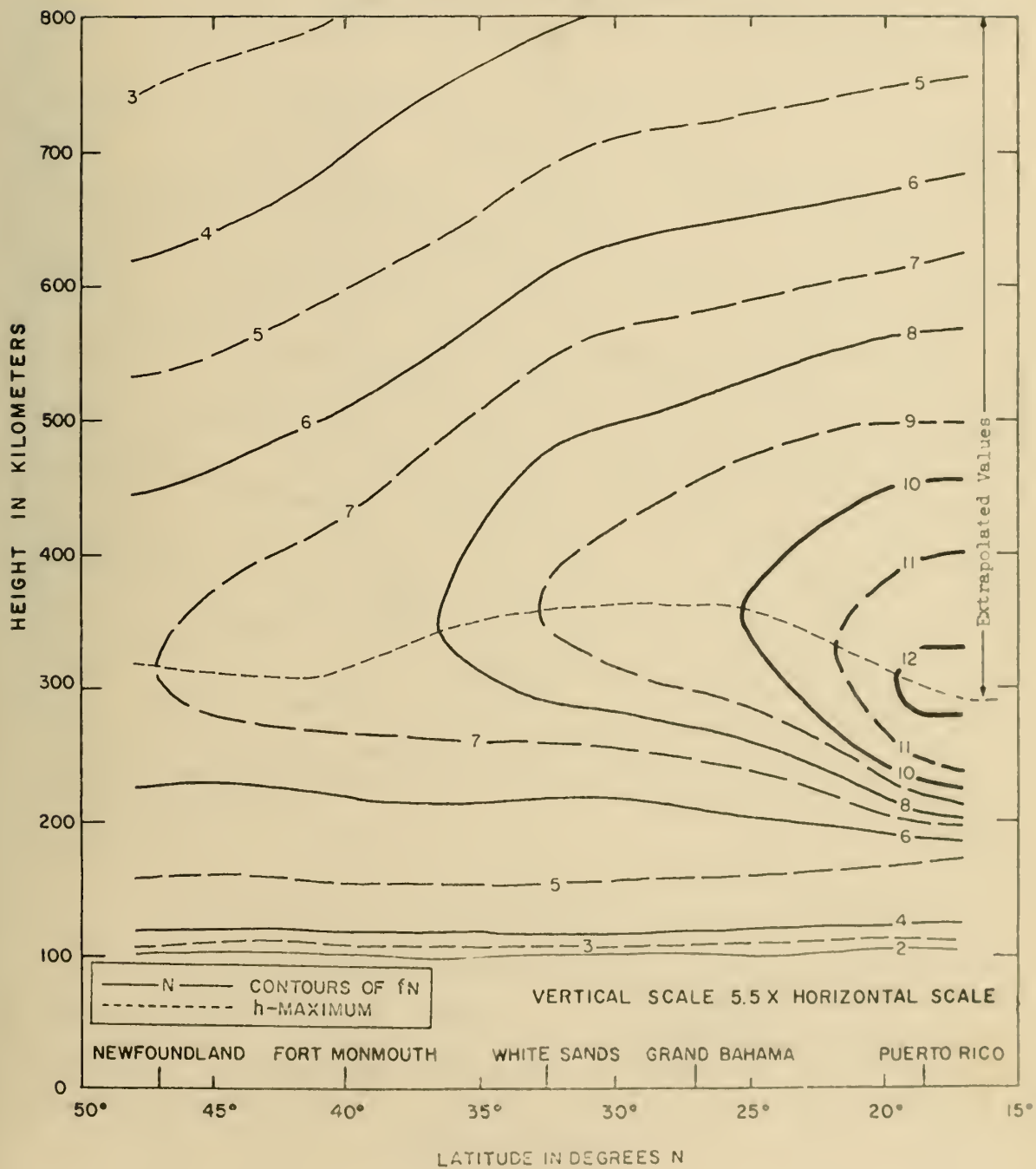
JUNE 1959

1000 75° W TIME



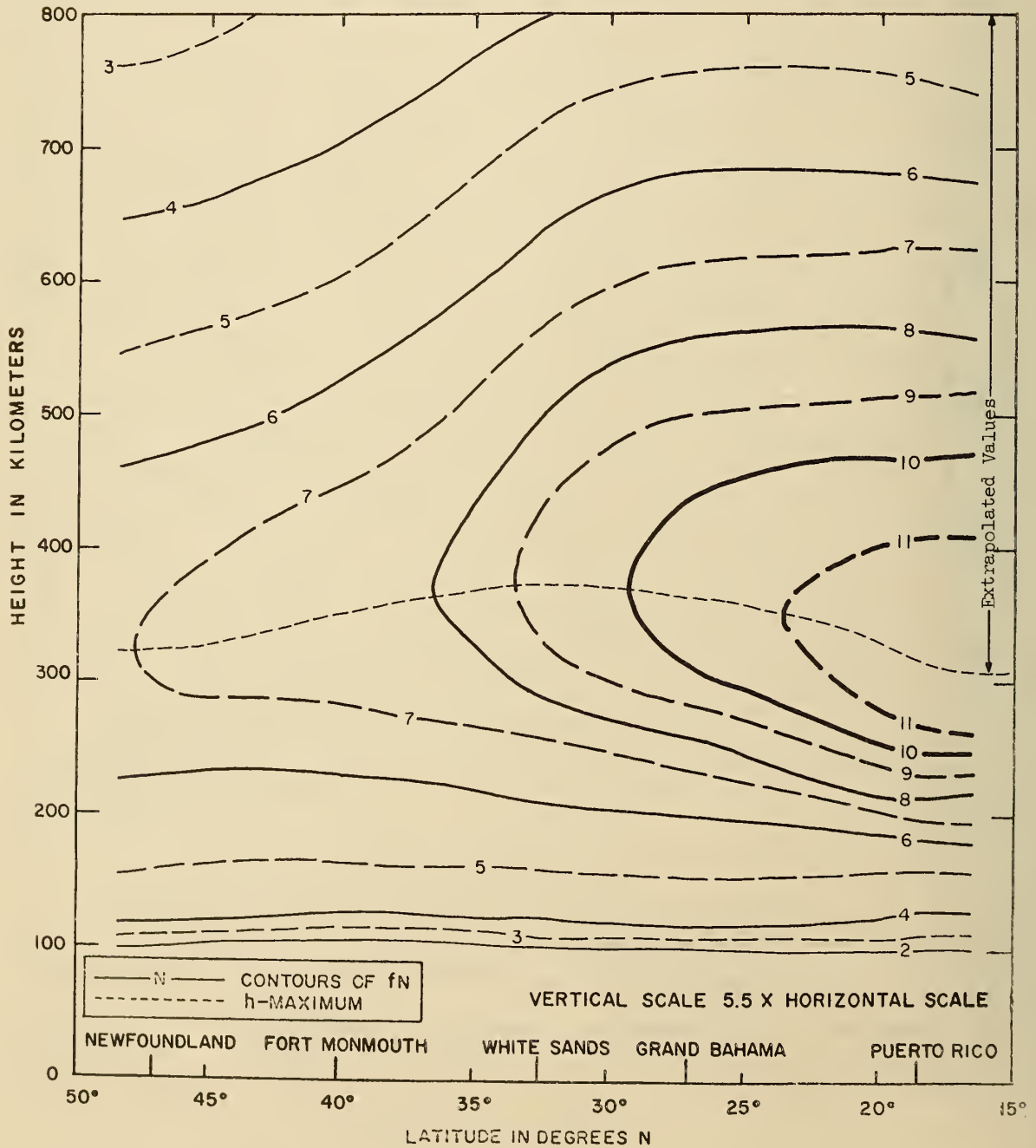
JUNE 1959

1100 75° W TIME



JUNE 1959

1200 75° W TIME



JUNE 1959

1300 75° W TIME

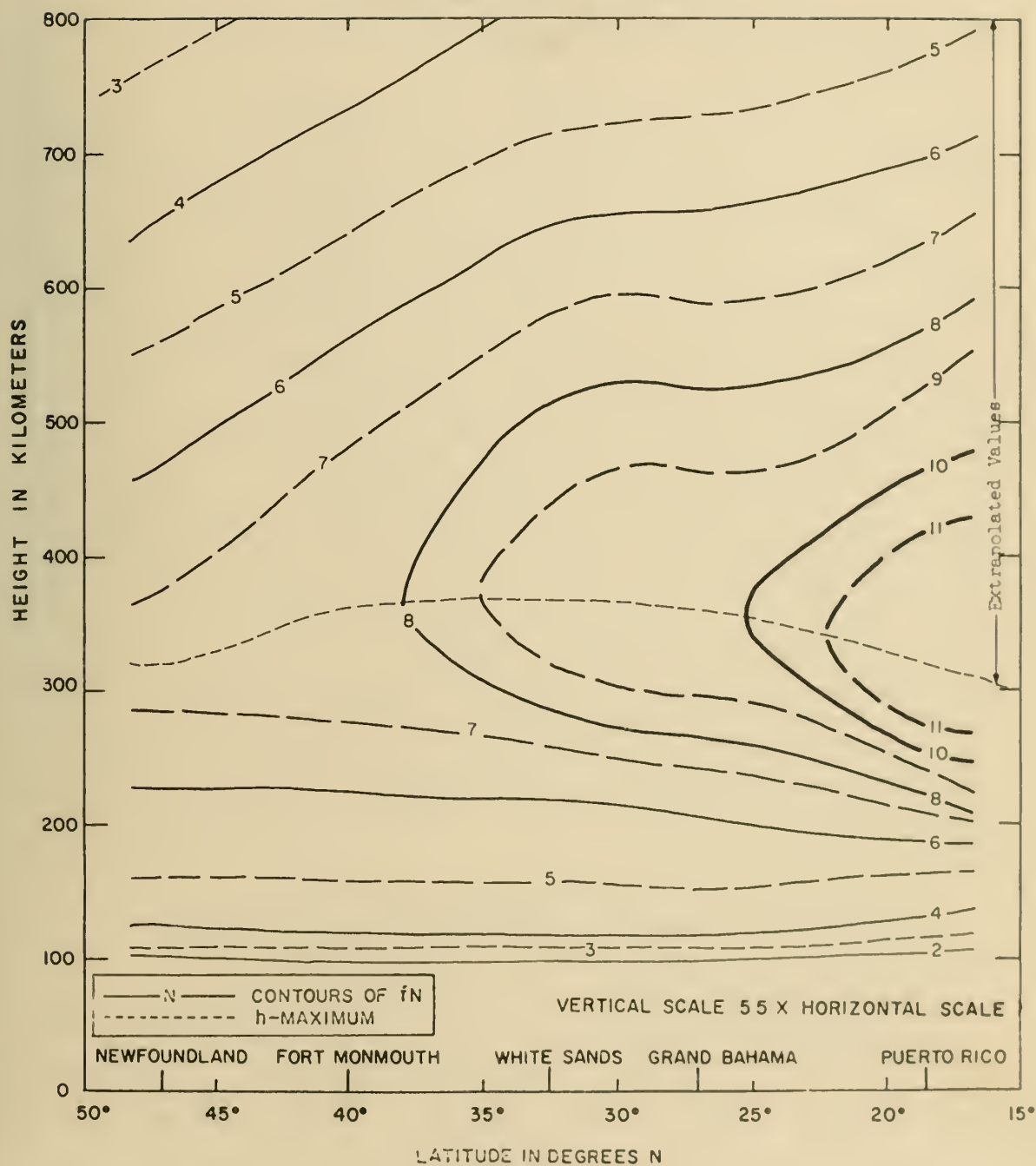
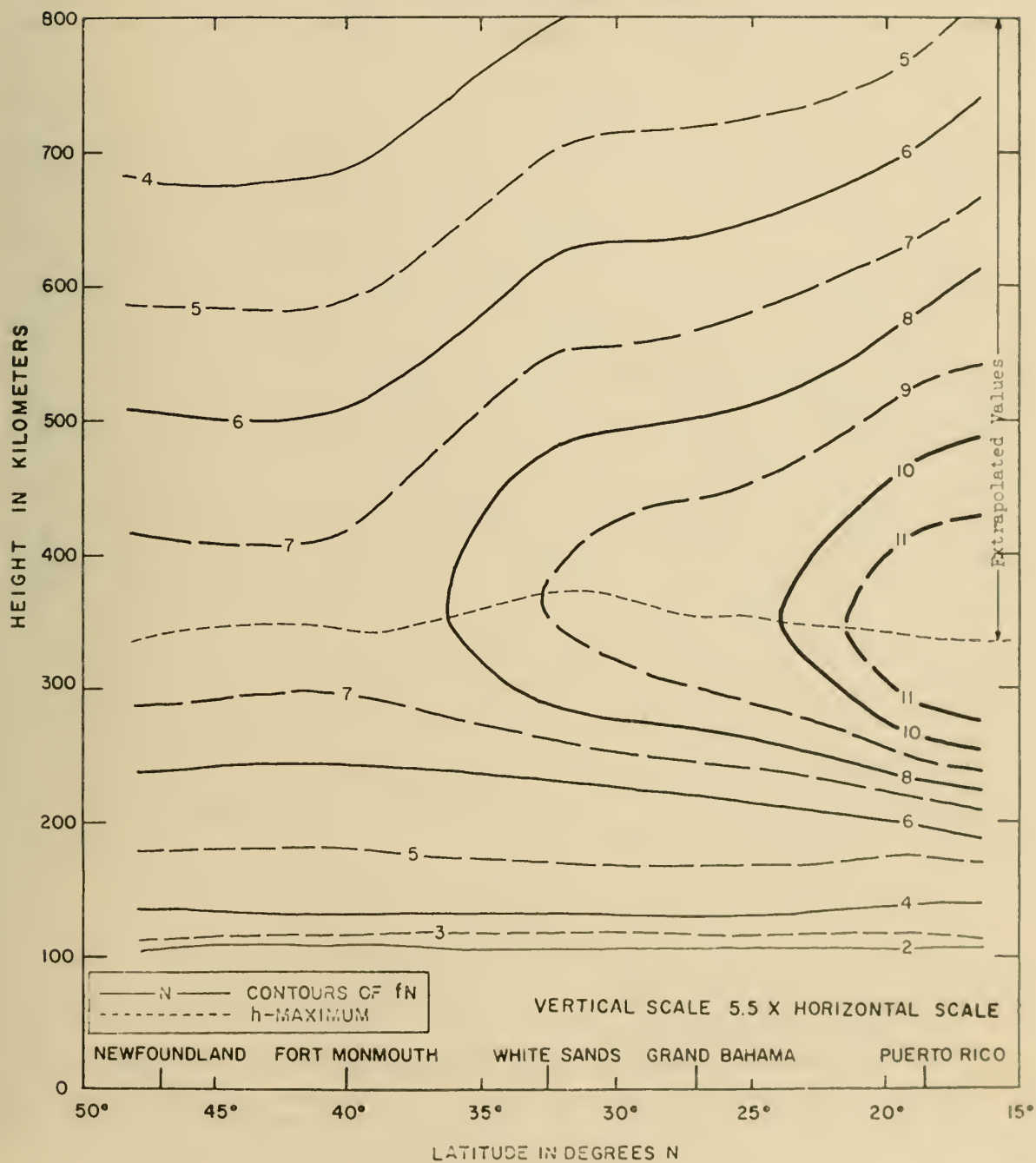


Figure 1 is a contour plot showing the vertical distribution of the maximum height of the F2 layer ( $h'F_2$ ) and the virtual height of the ordinary wave ( $h'foF_2$ ) as a function of latitude. The y-axis represents height in kilometers (0 to 800 km). The x-axis represents latitude in degrees North (50° to 15°). Solid lines represent contours of  $h'foF_2$  (labeled 2 to 11), and dashed lines represent contours of  $h'F_2$  (labeled 3 to 11). The plot shows that  $h'foF_2$  generally increases with altitude and decreases with latitude, while  $h'F_2$  shows a more complex pattern with a minimum around 35°N. A vertical scale bar on the right indicates that the vertical scale is 5.5 times the horizontal scale. A legend at the bottom left identifies the line types. A note at the bottom right states "VERTICAL SCALE 5.5 X HORIZONTAL SCALE". A note at the bottom left indicates "NEWFOUNDLAND FORT MONMOUTH WHITE SANDS GRAND BAHAMA PUERTO RICO".

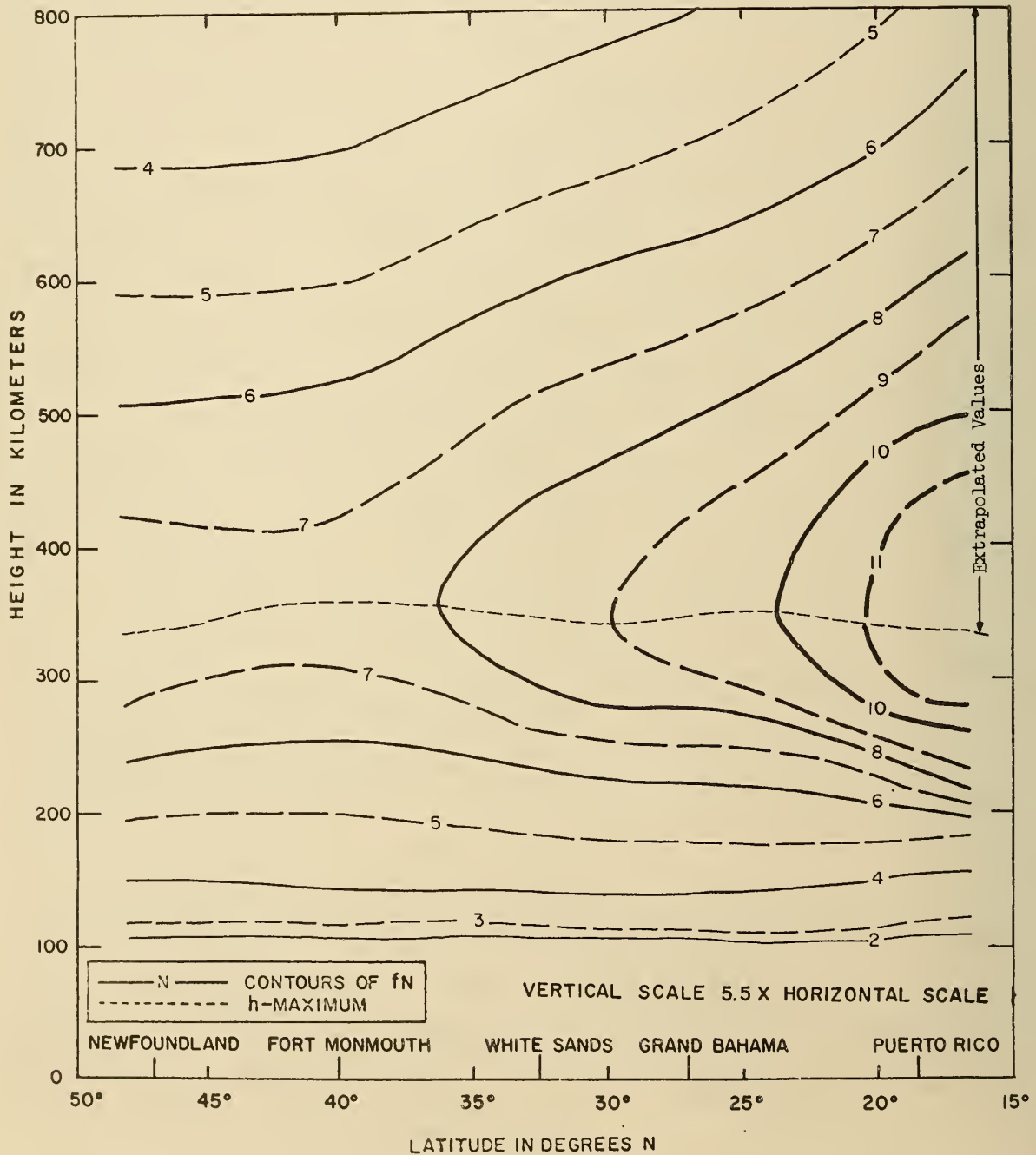
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1500 75° W TIME



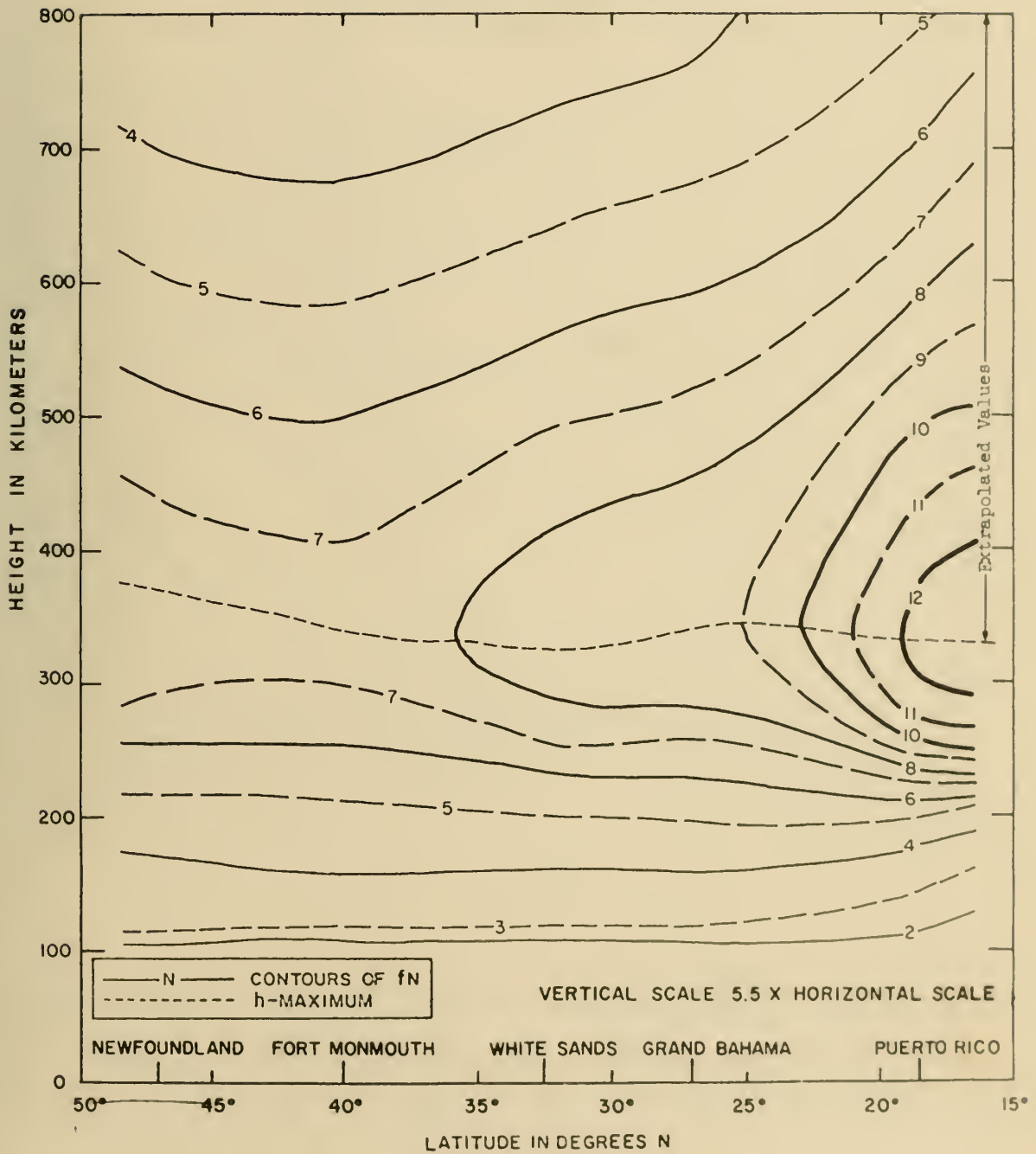
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1600 75° W TIME



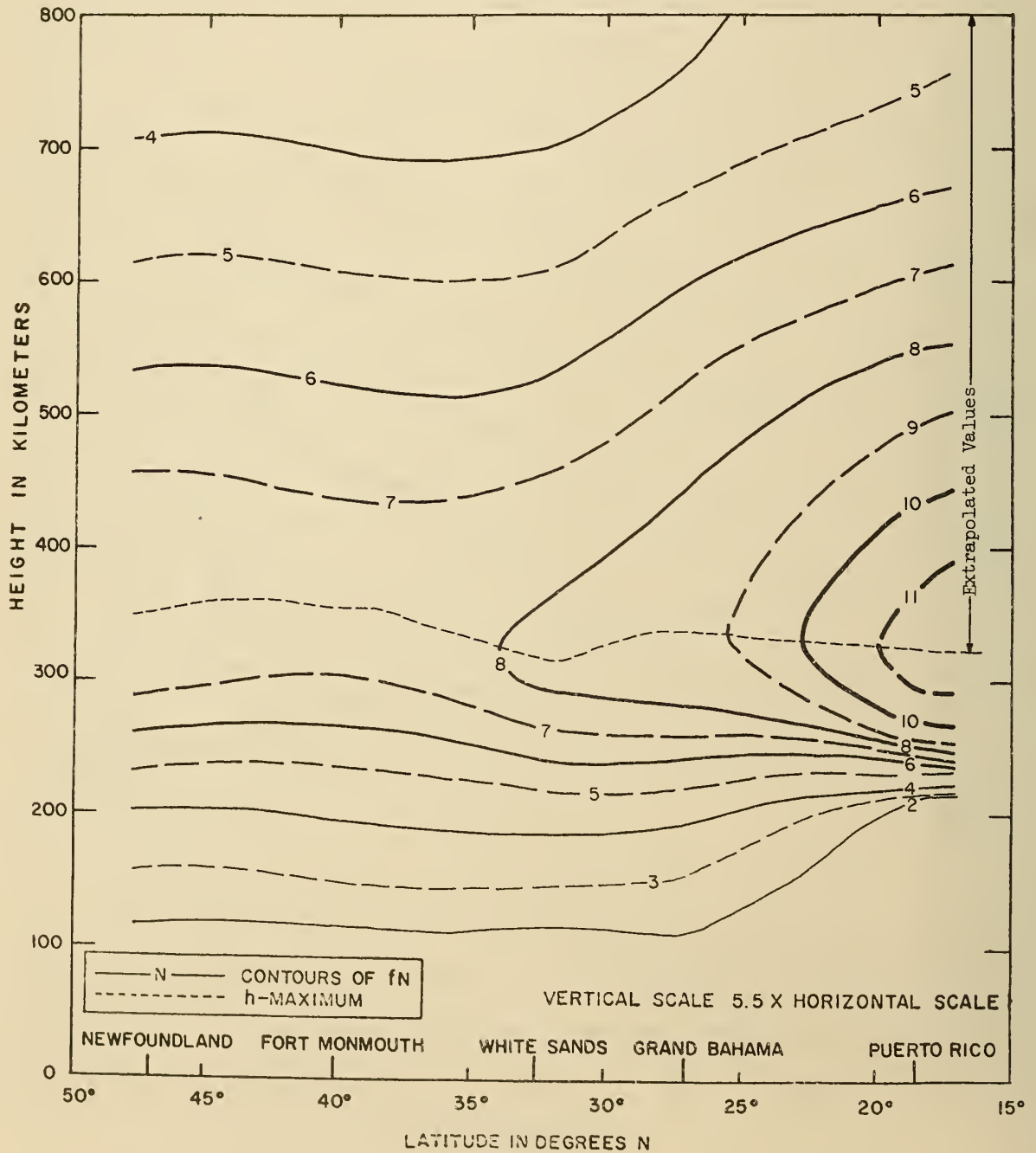
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1700 75° W TIME



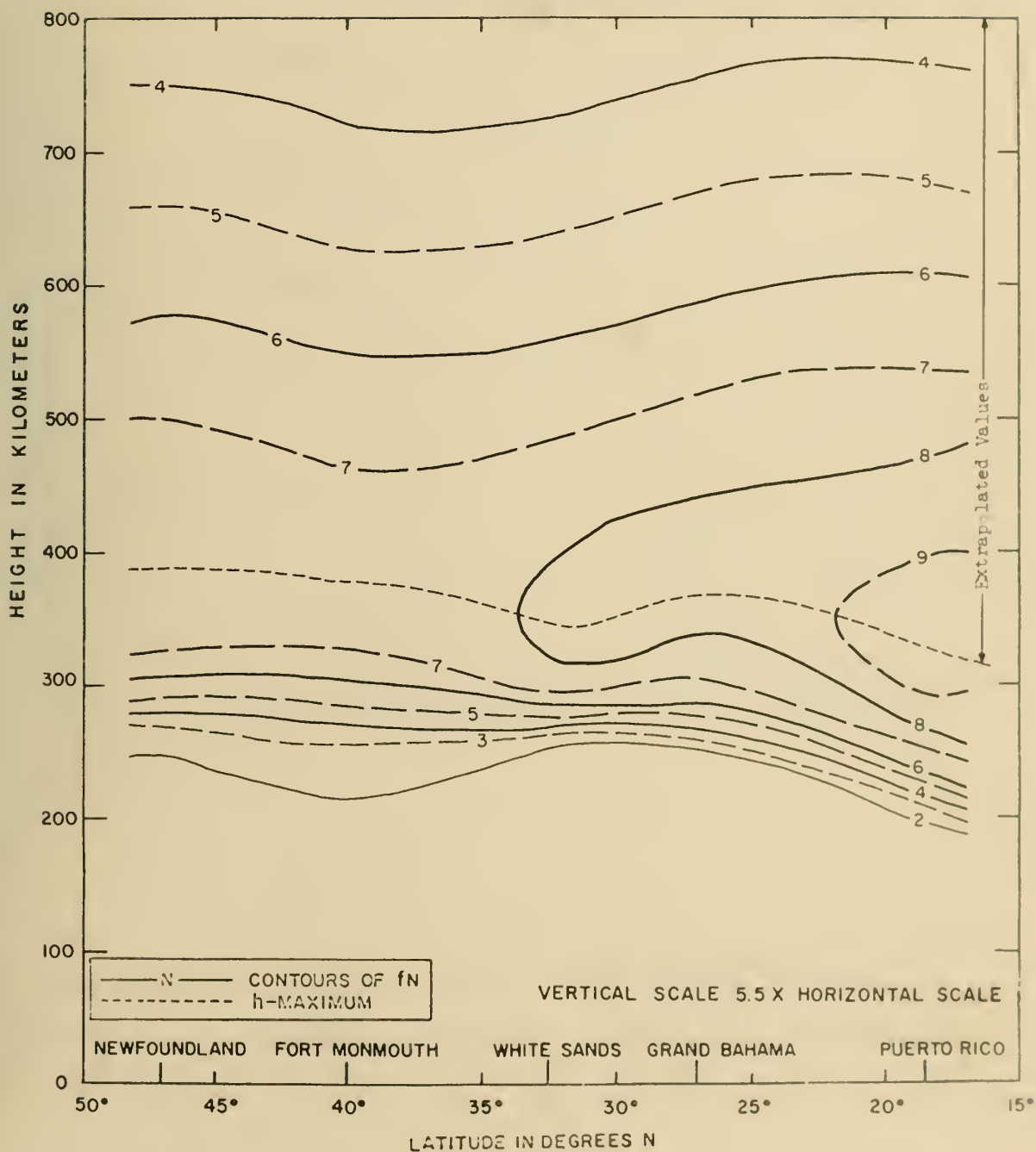
JUNE 1959

1800 75° W TIME

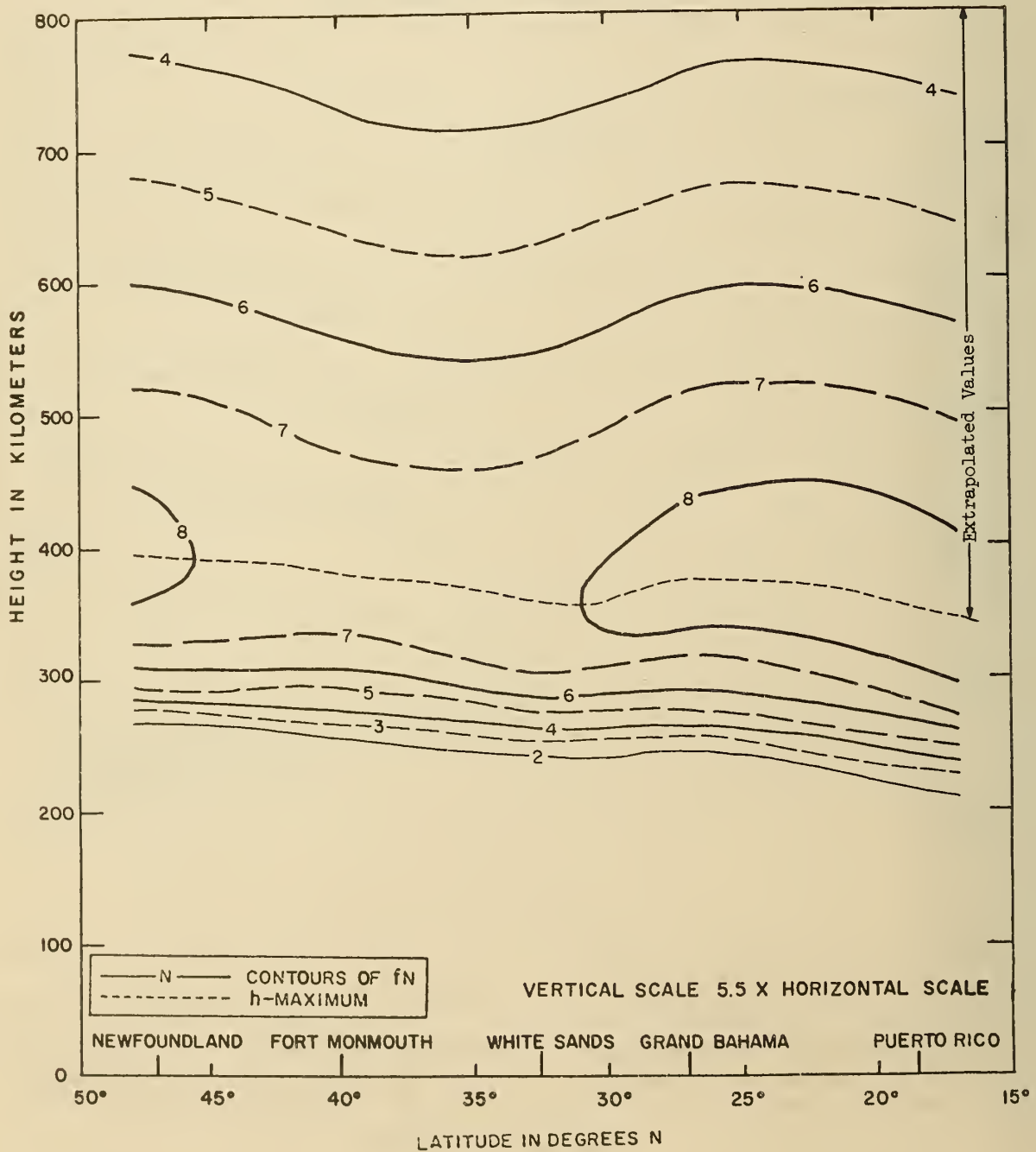


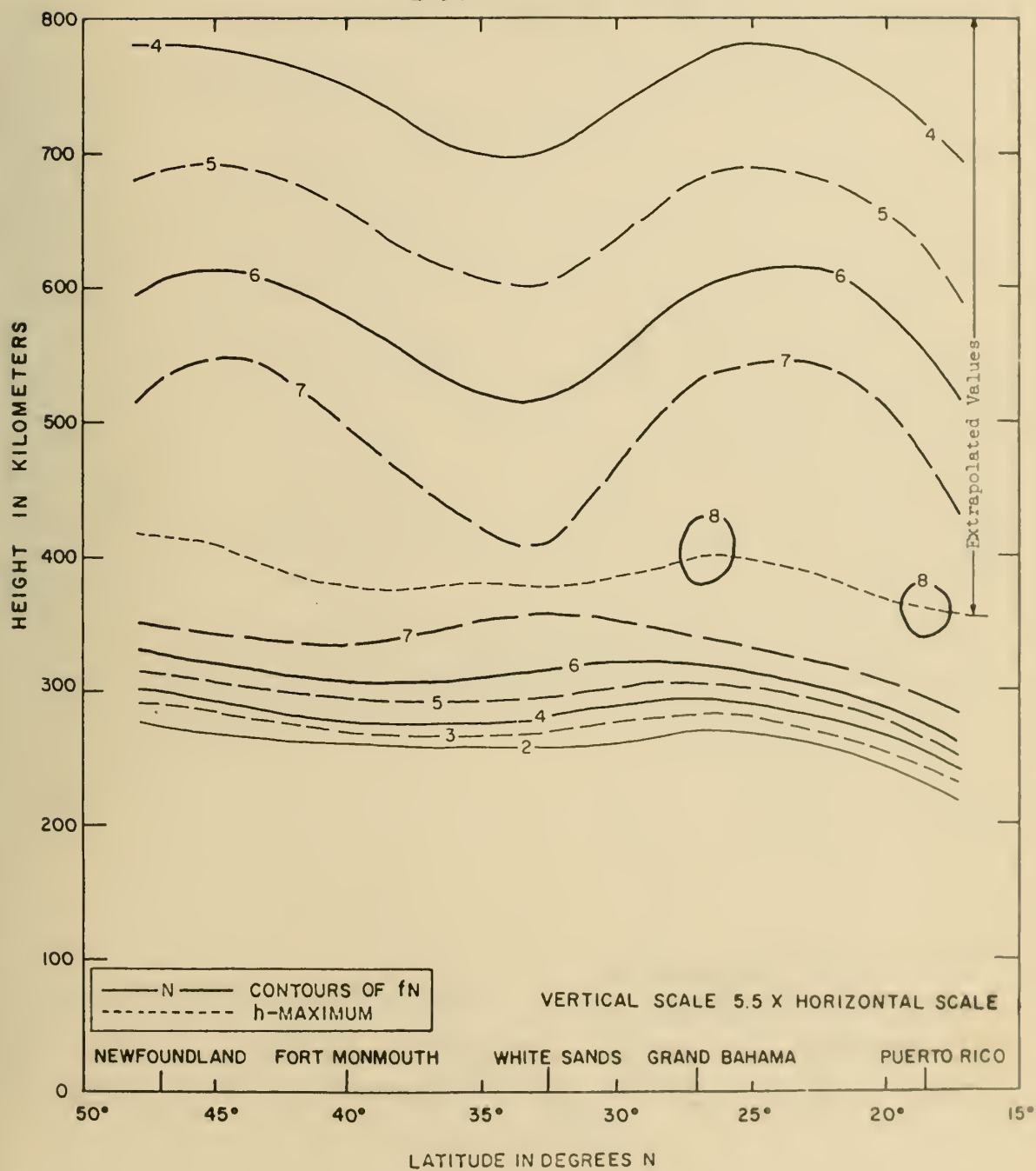
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1900 75° W TIME



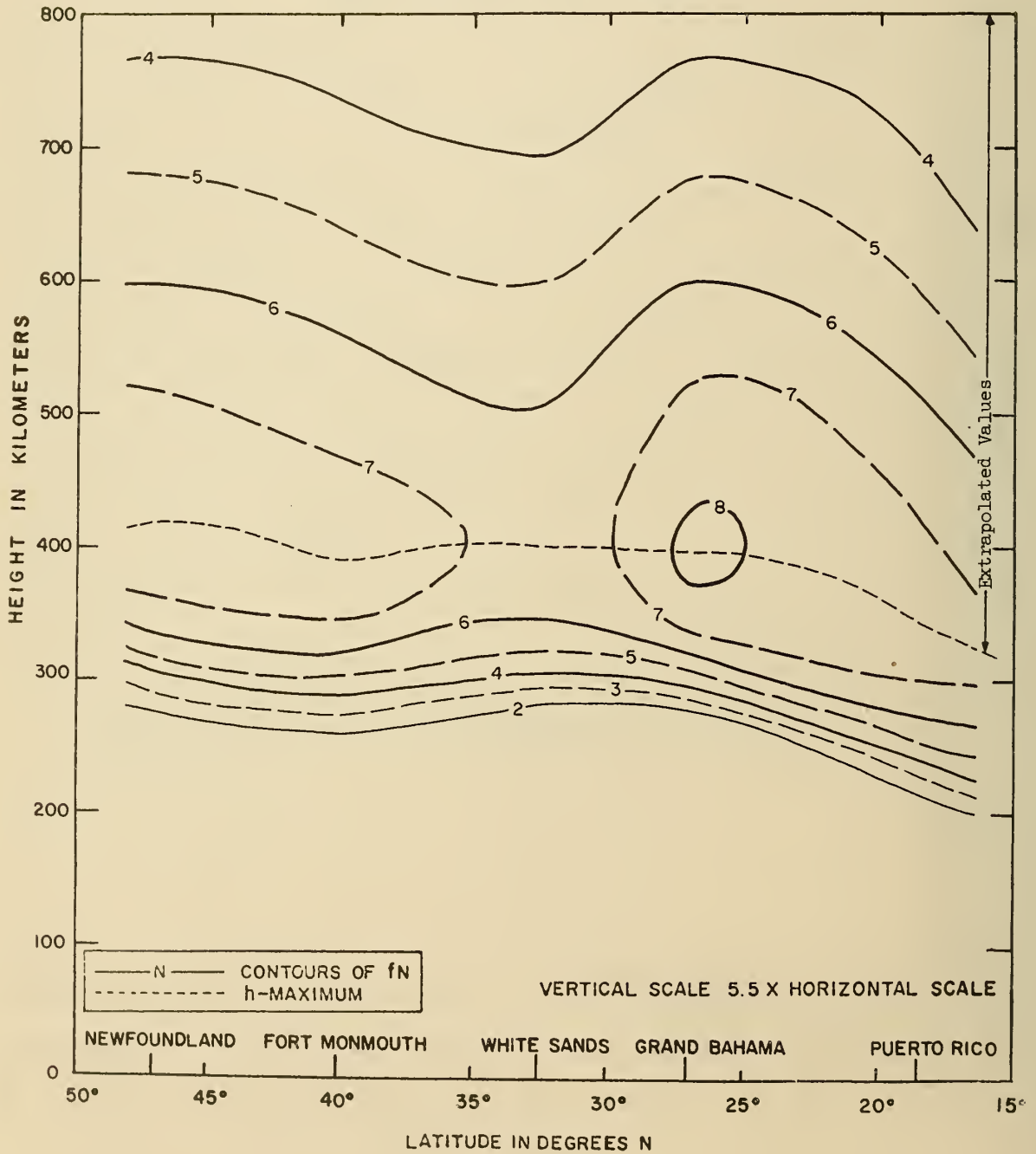
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2000 75° W TIME





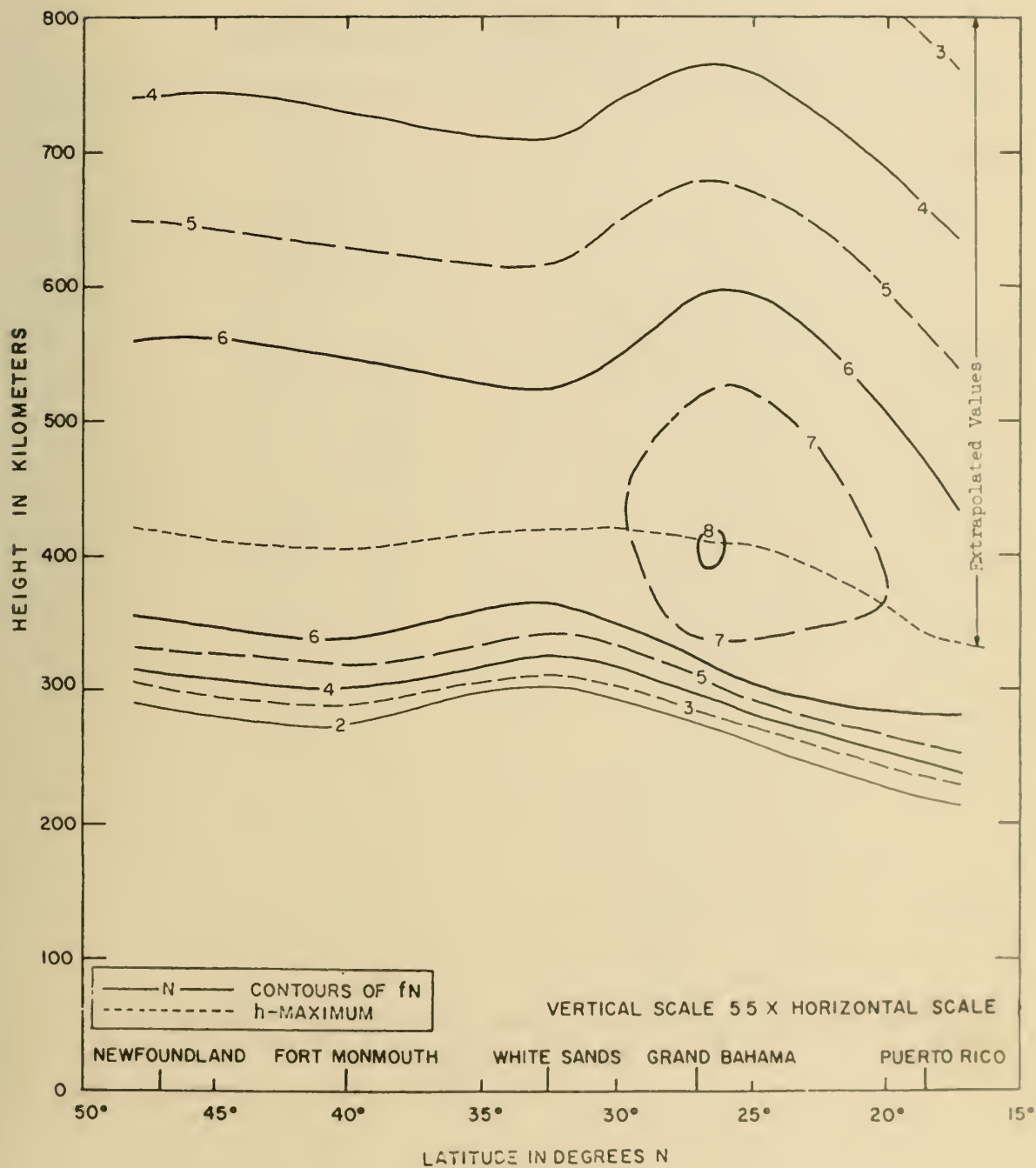
JUNE 1959

2200 75° W TIME



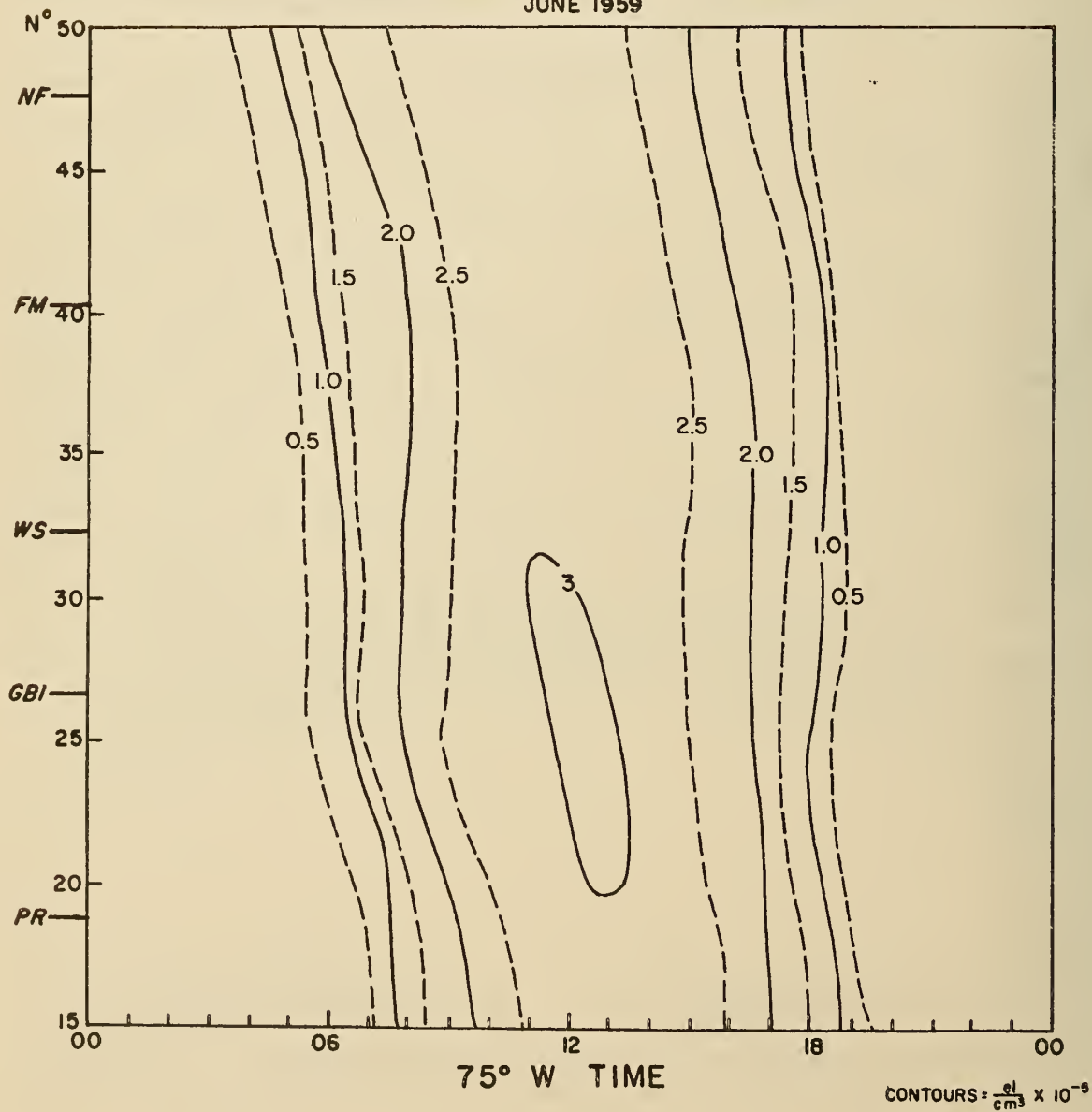
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2300 75° W TIME



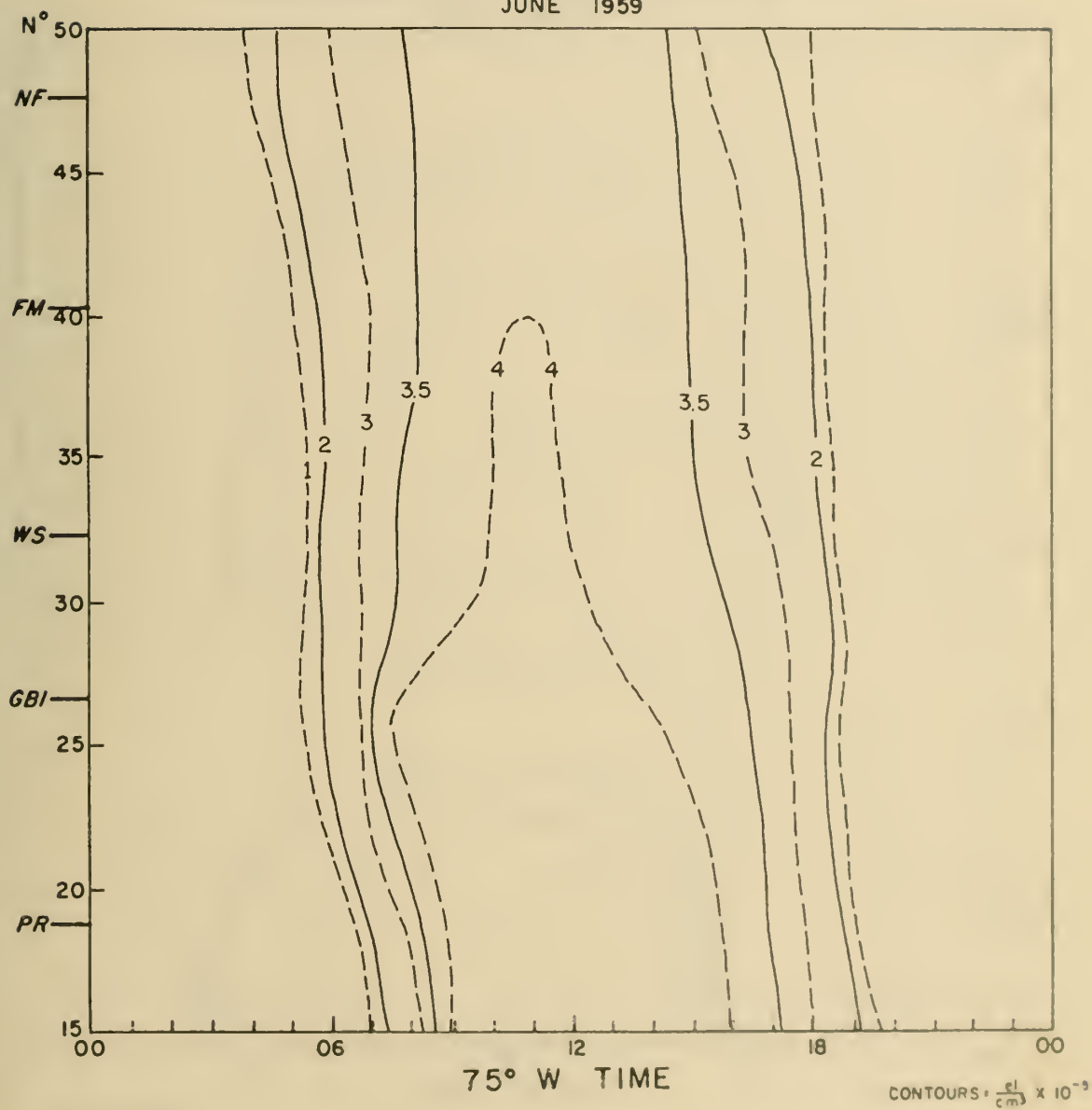
## ELECTRON DENSITY AT 150 KILOMETERS

JUNE 1959



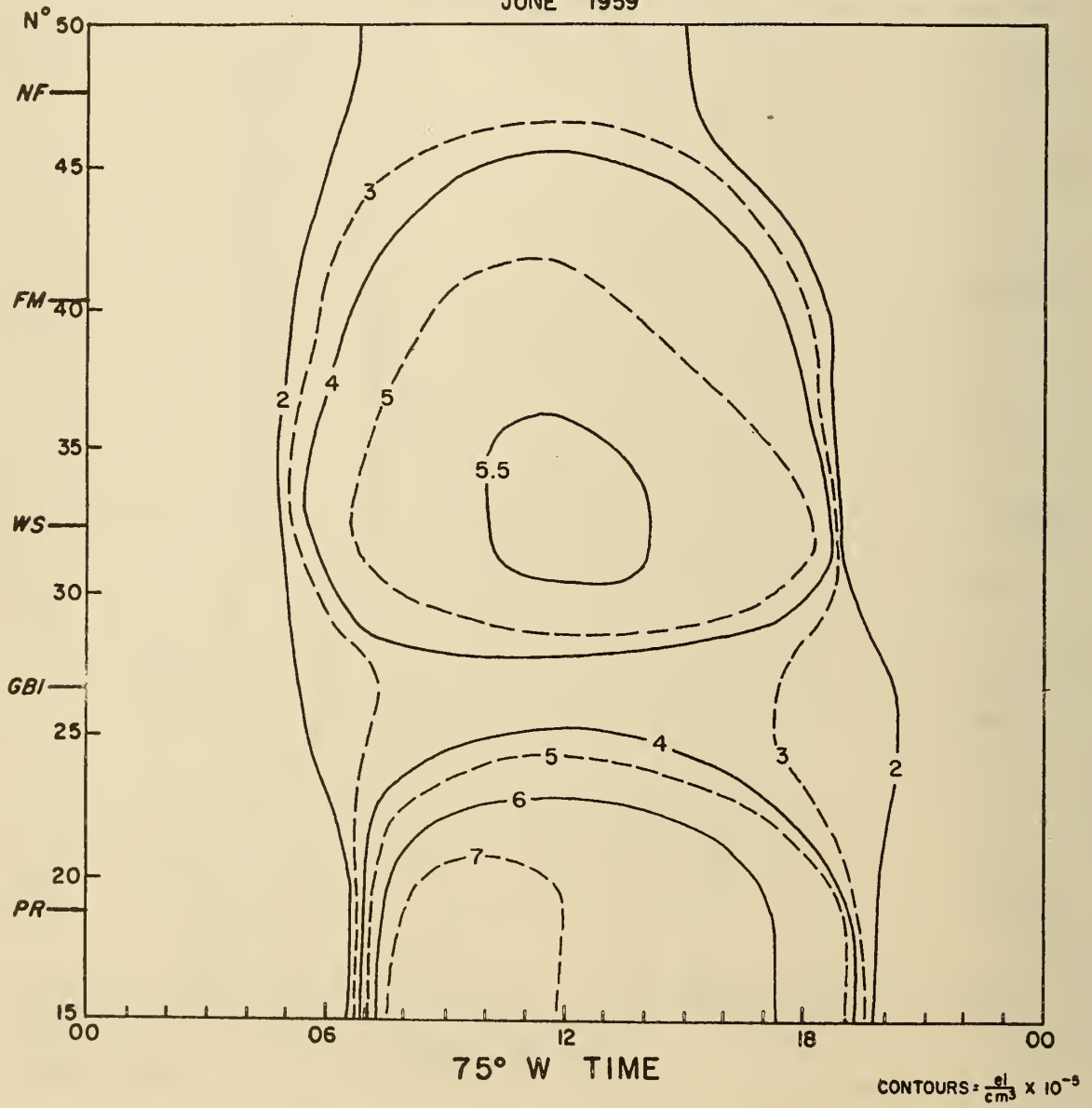
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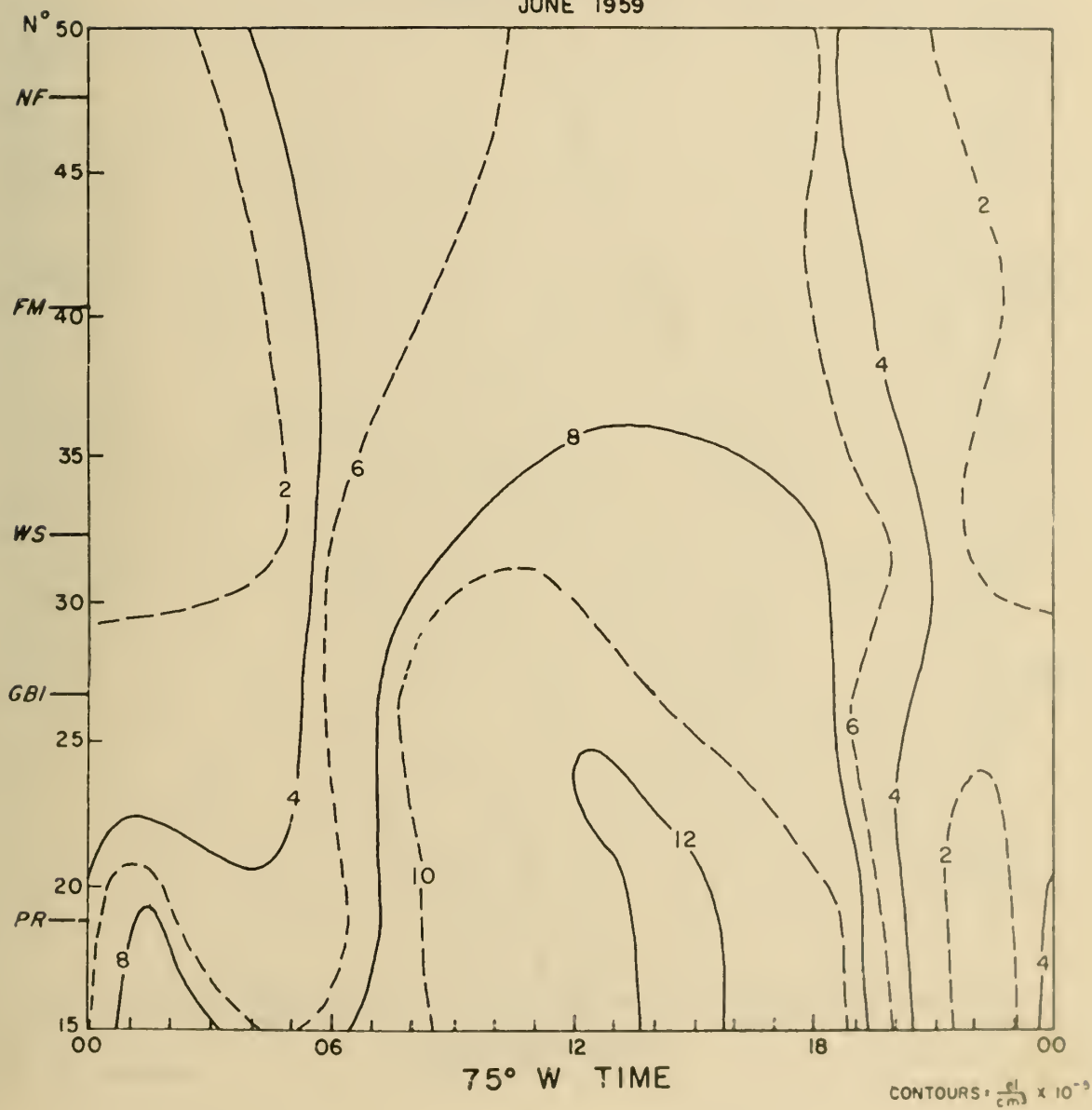
## ELECTRON DENSITY AT 250 KILOMETERS

JUNE 1959



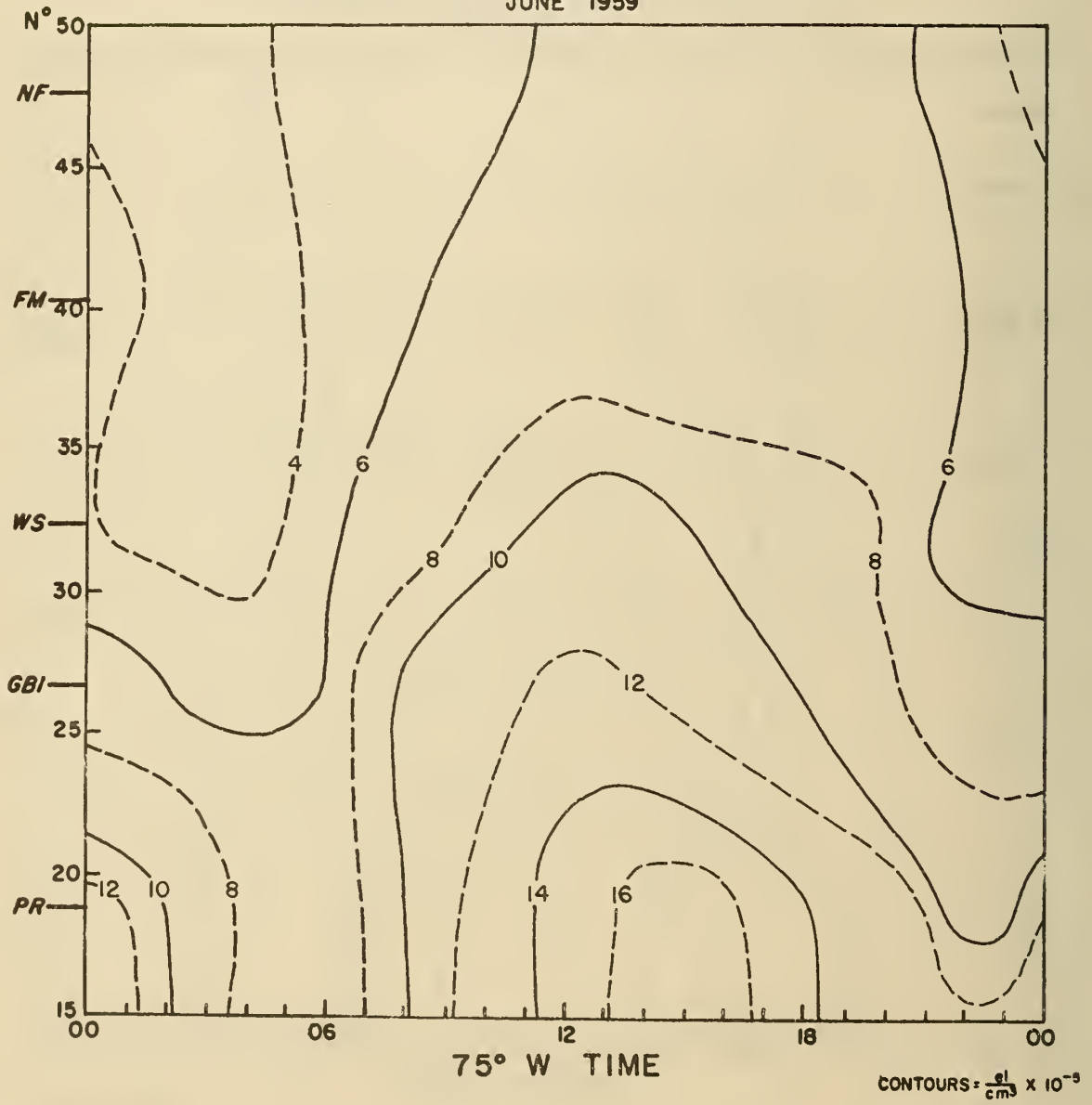
## ELECTRON DENSITY AT 300 KILOMETERS

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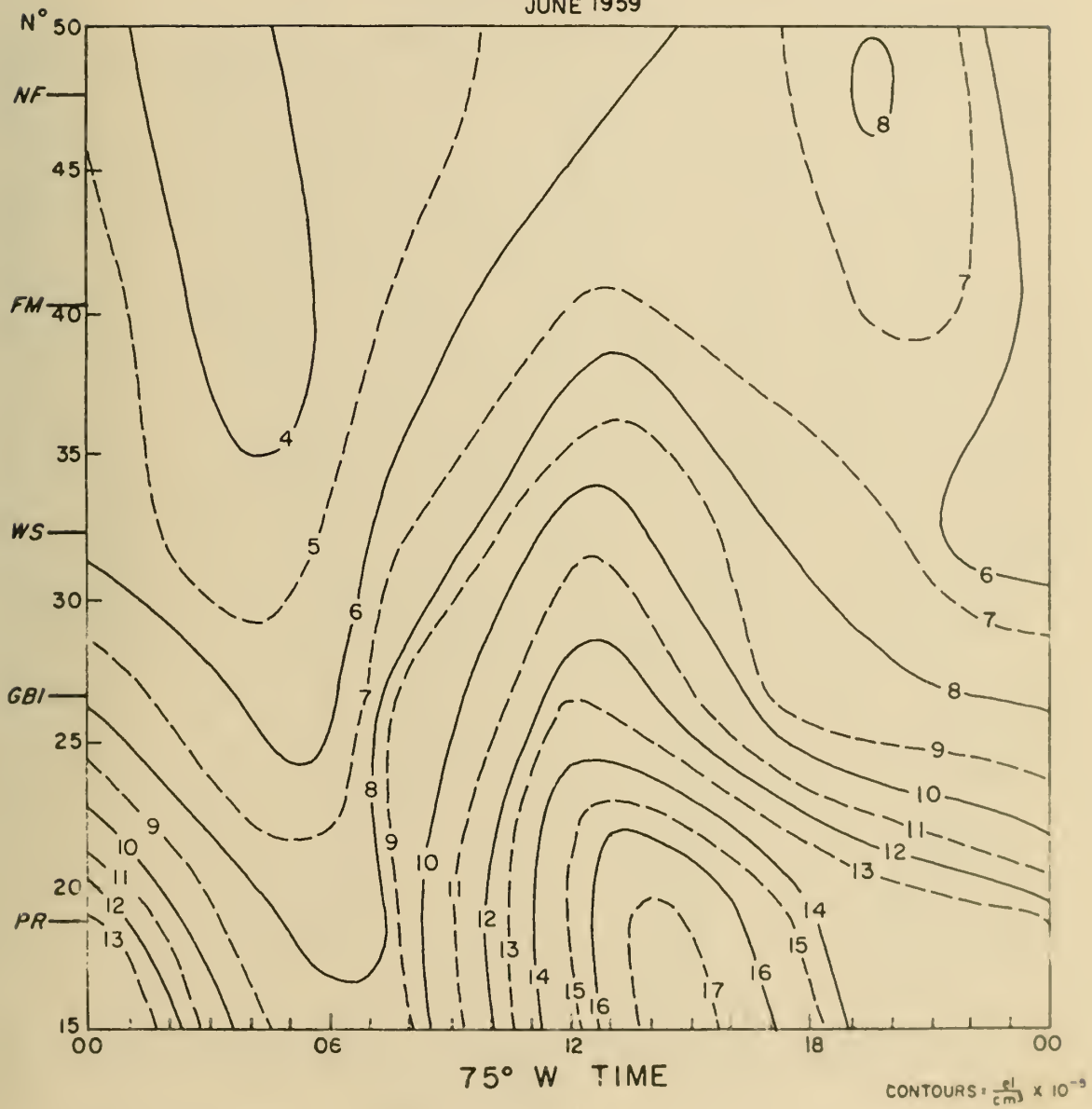
## ELECTRON DENSITY AT 350 KILOMETERS

JUNE 1959



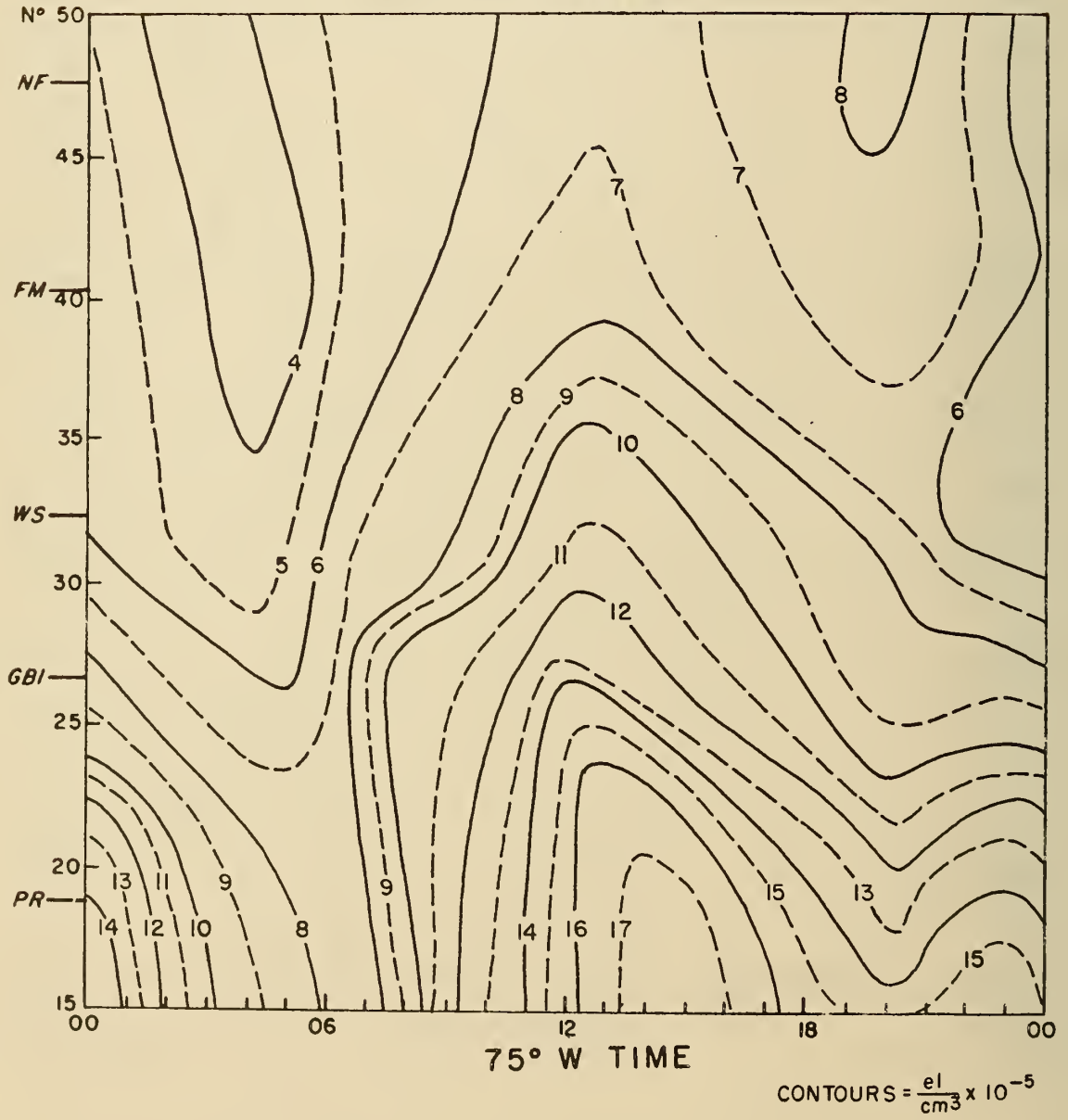
## ELECTRON DENSITY AT 400 KILOMETERS

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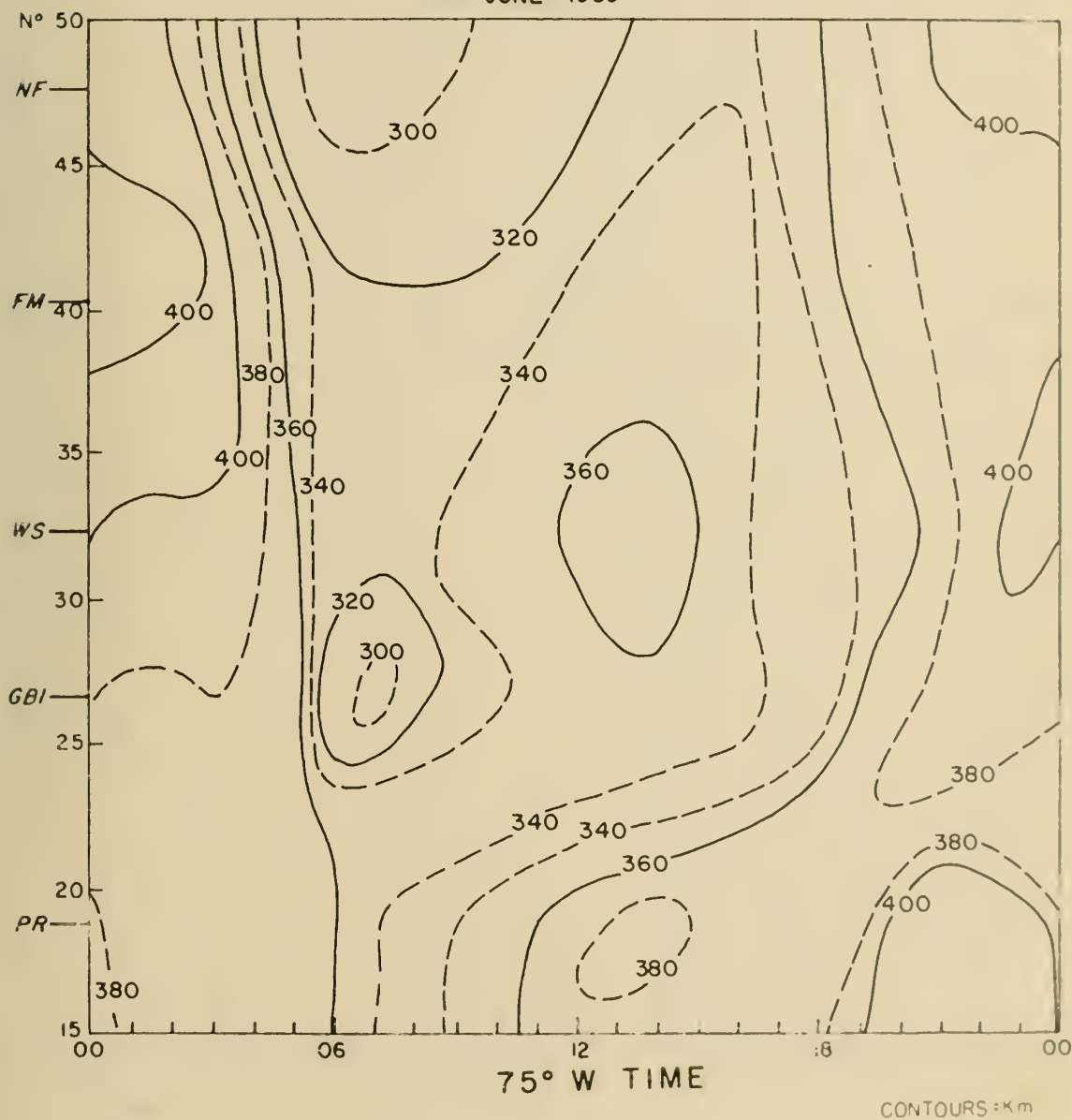
MAXIMUM ELECTRON DENSITY  
NMAX

JUNE 1959



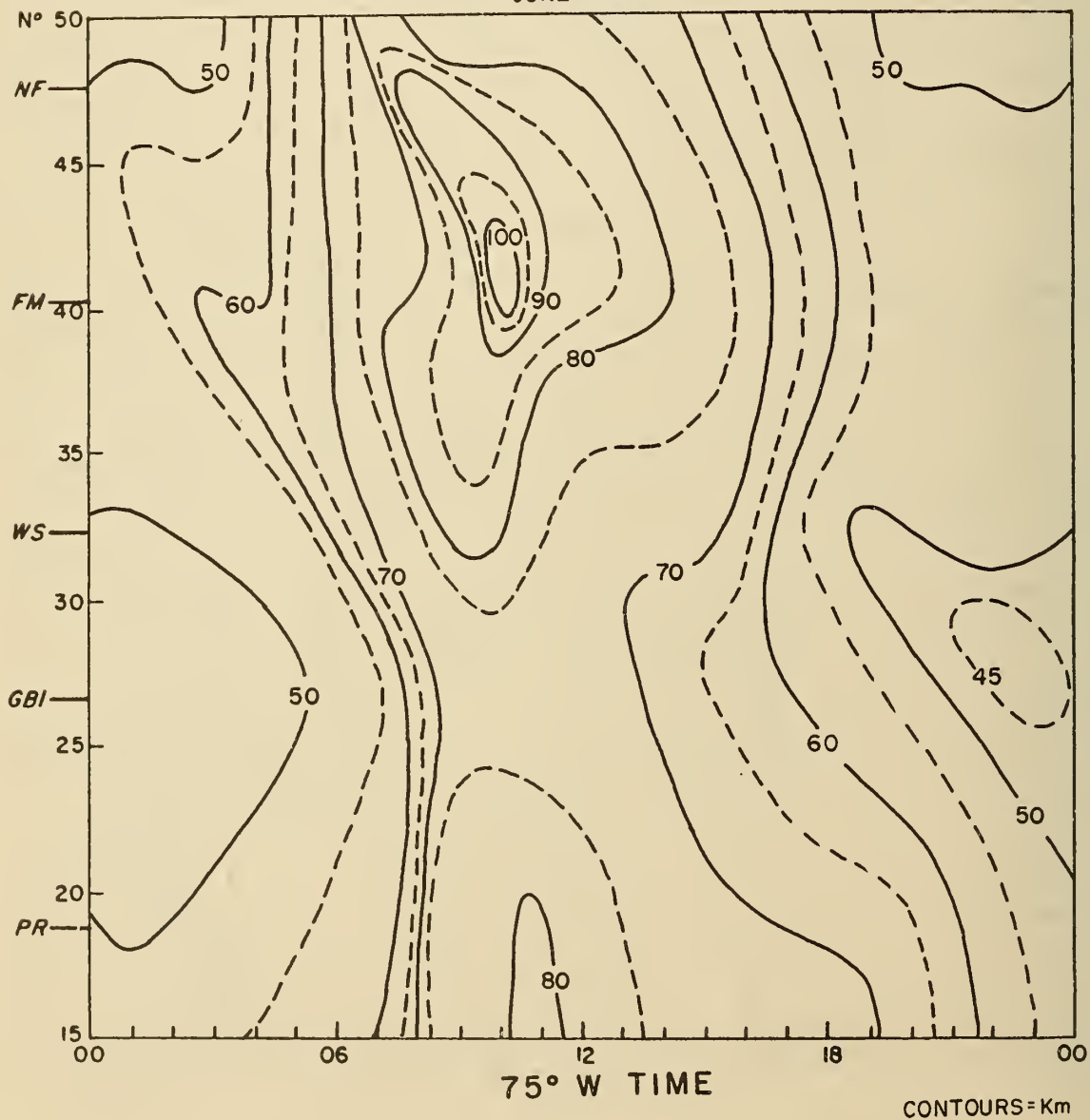
HEIGHT OF MAXIMUM ELECTRON DENSITY  
HMAX

JUNE 1959

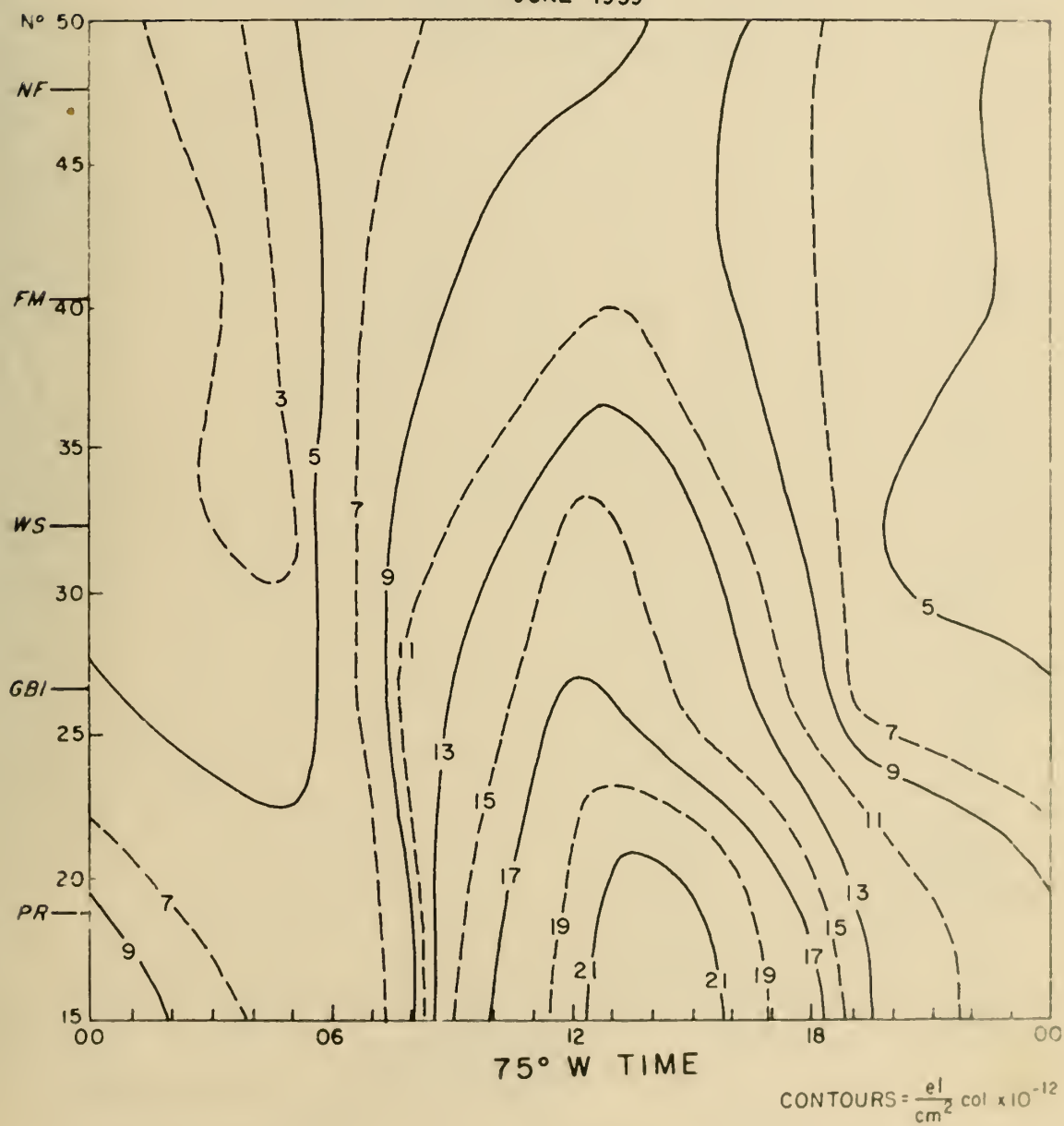


QUARTER THICKNESS OF F-REGION PEAK  
SCAT

JUNE 1959

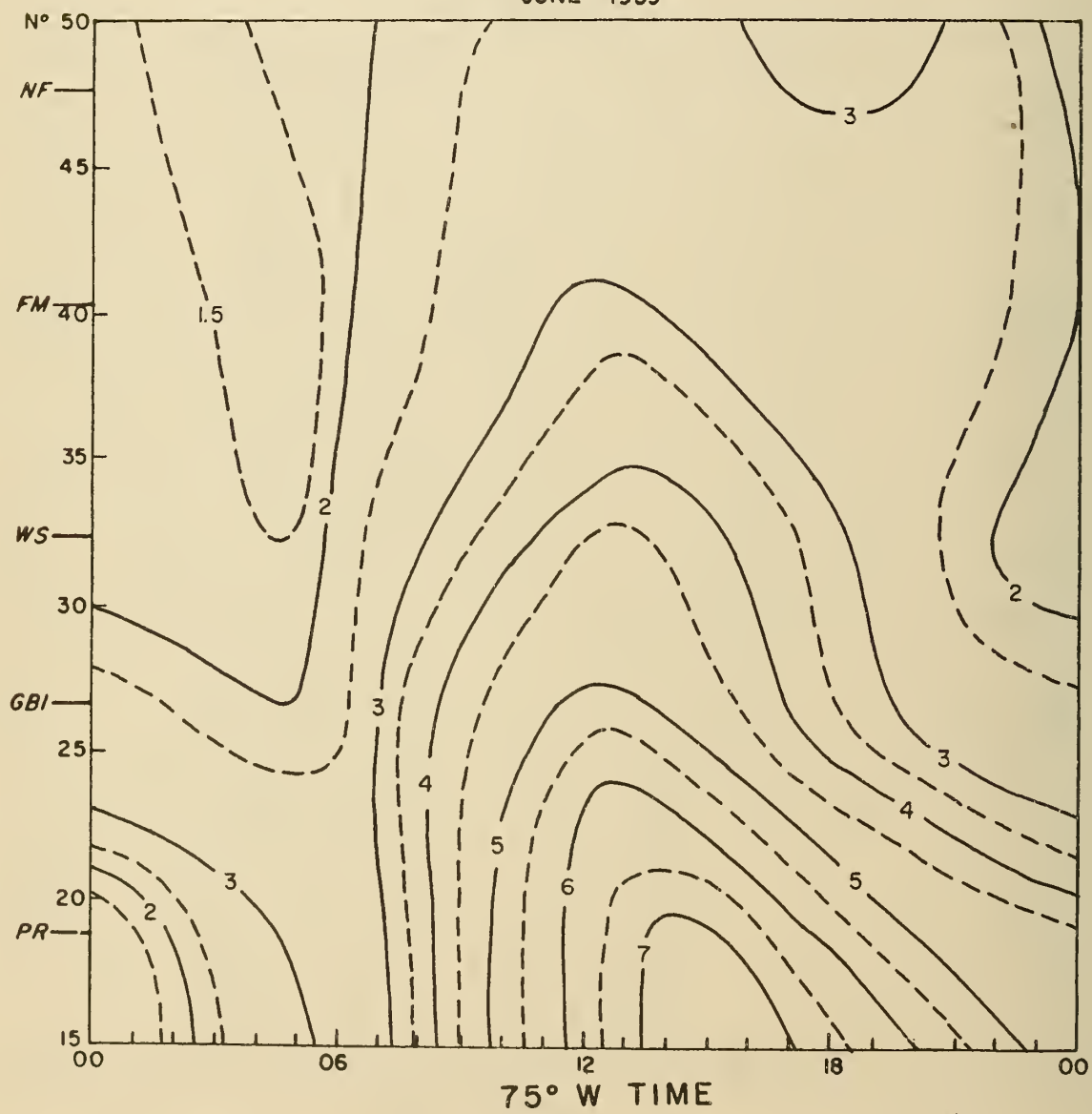


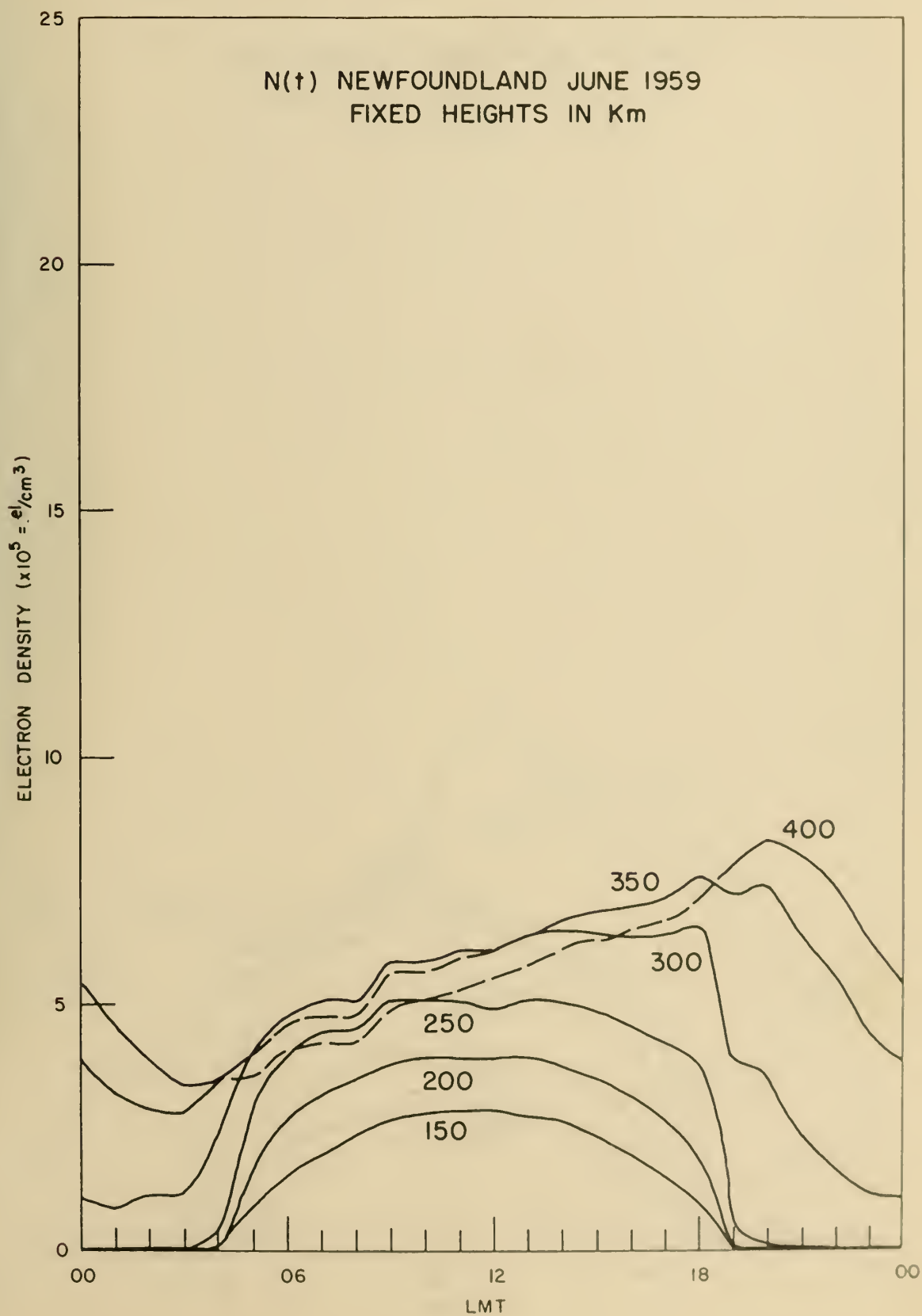
ELECTRON DENSITY INTEGRATED TO HEIGHT OF MAXIMUM  
ELECTRON DENSITY  
SHMAX  
JUNE 1959

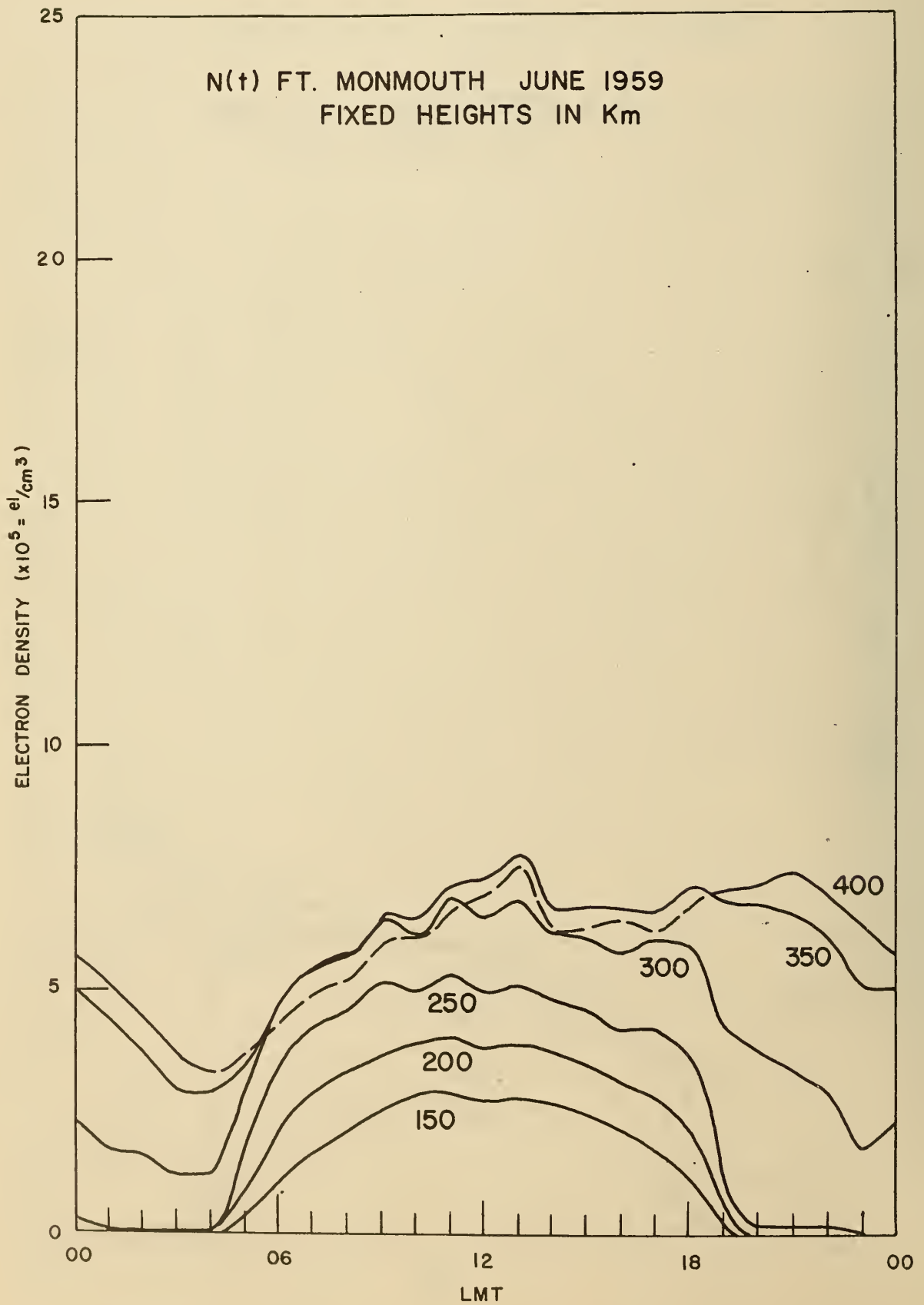


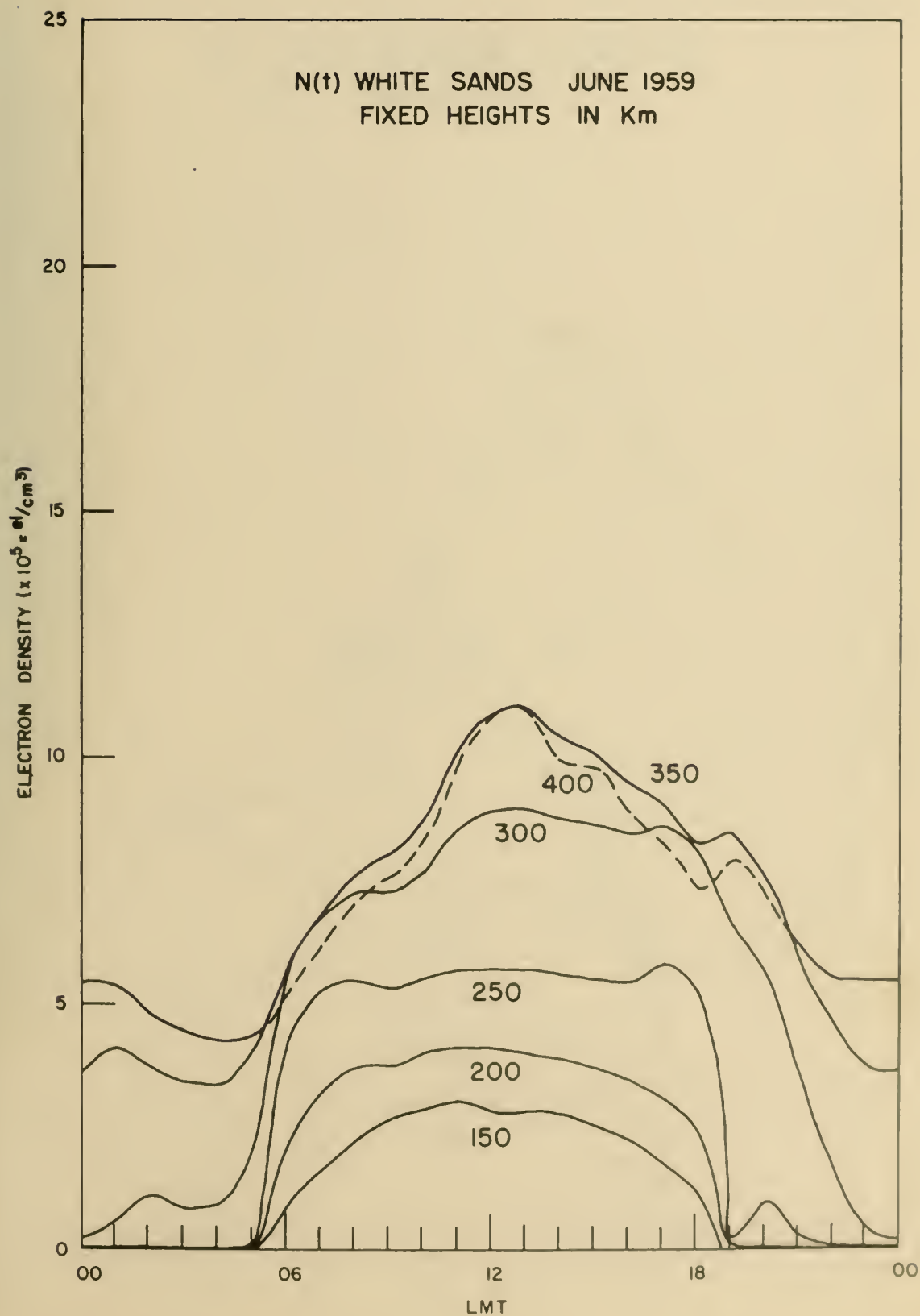
ELECTRON DENSITY INTEGRATED TO INFINITY  
SHINF

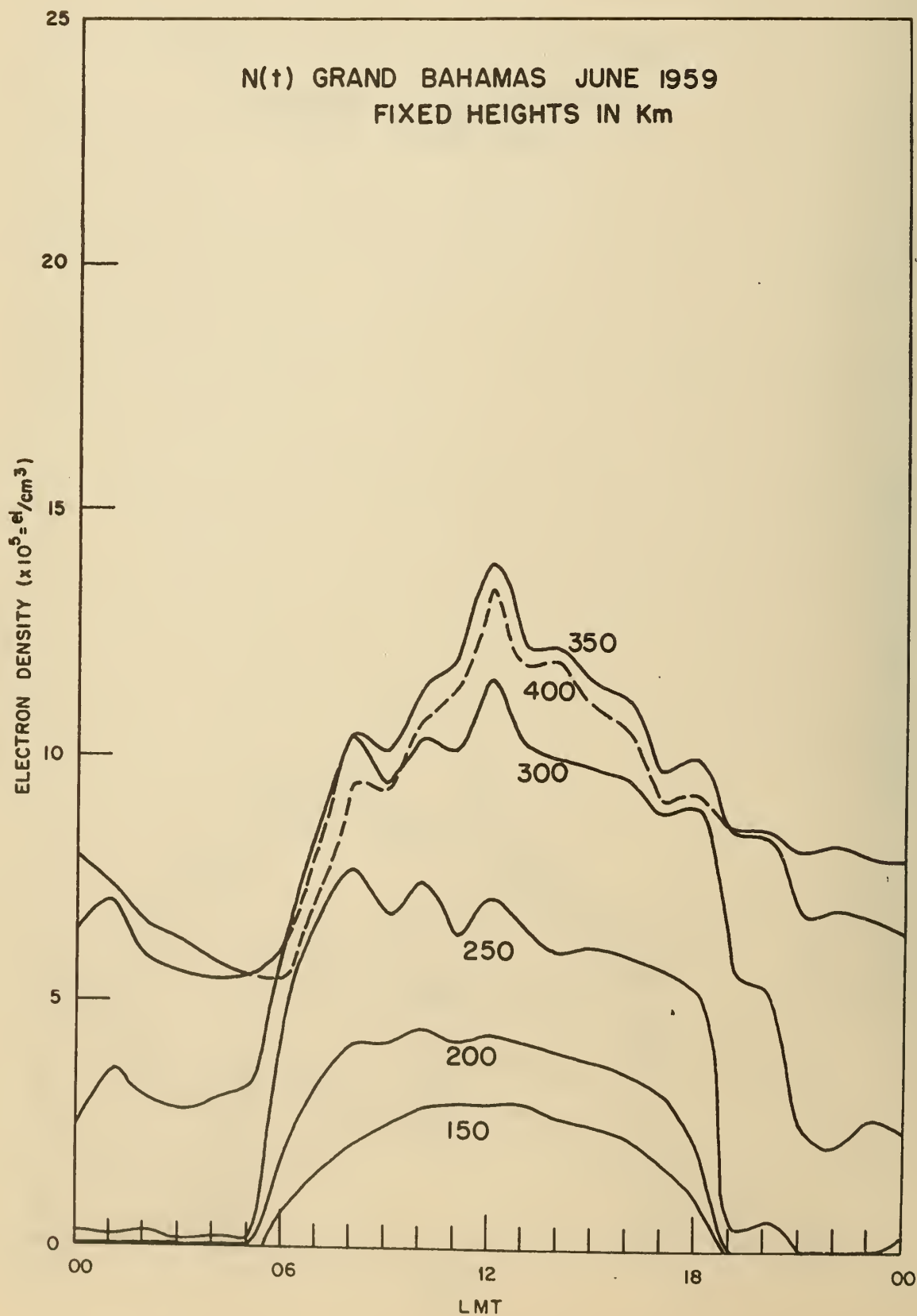
JUNE 1959

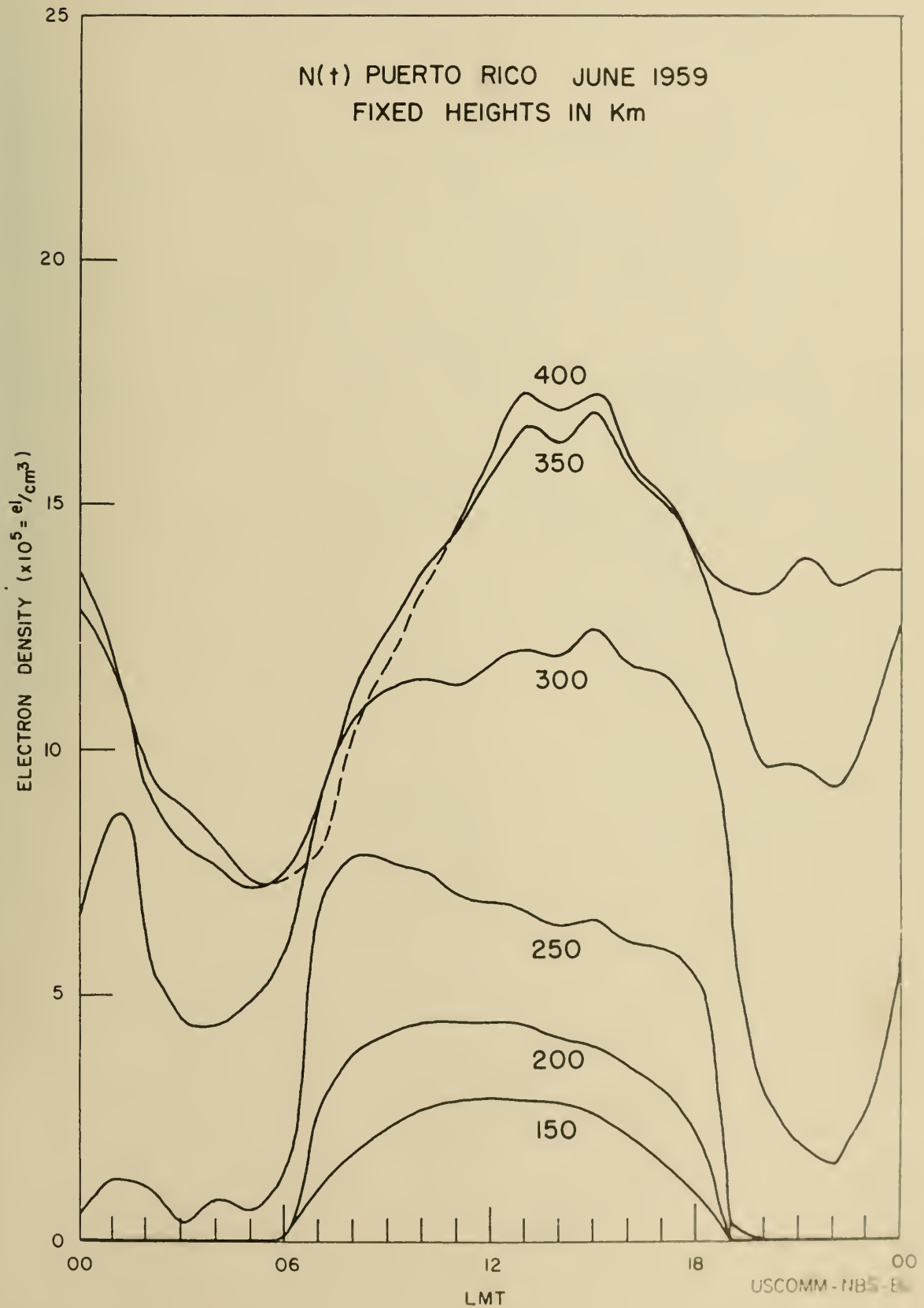
CONTOURS =  $\frac{eI}{cm^2} \text{ col.} \times 10^{-13}$

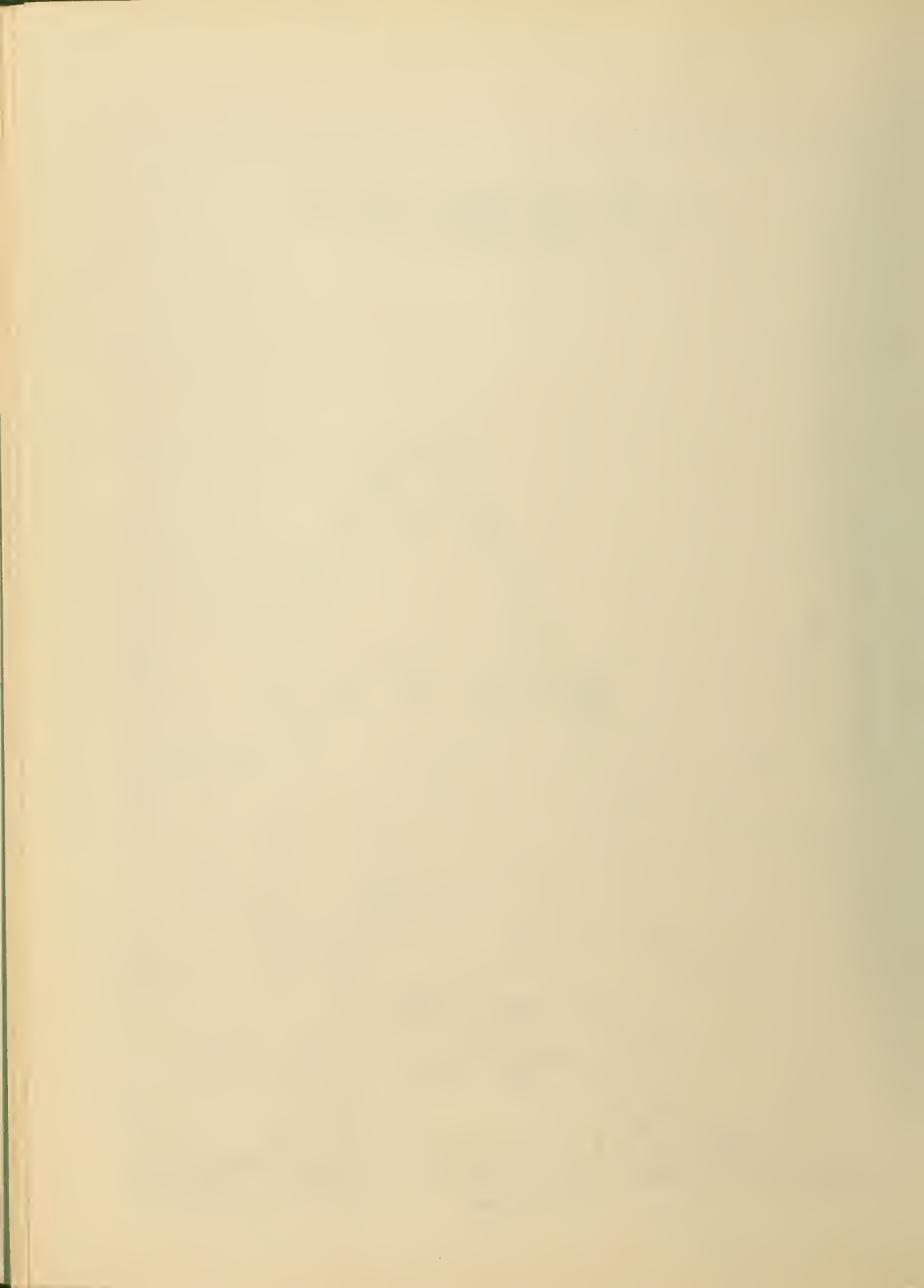












**U. S. DEPARTMENT OF COMMERCE**

Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS

A. V. Astin, *Director*



**THE NATIONAL BUREAU OF STANDARDS**

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

**WASHINGTON, D.C.**

Electricity, Resistance and Reactance, Electrochemistry, Electrical Instruments, Magnetic Measurements, Dielectrics.

Metrology, Photometry and Colorimetry, Refractometry, Photographic Research, Length, Engineering Metrology, Mass and Scale, Volumetry and Densimetry.

Heat, Temperature Physics, Heat Measurements, Cryogenic Physics, Equation of State, Statistical Physics.

Radiation Physics, X-ray, Radioactivity, Radiation Theory, High Energy Radiation, Radiological Equipment, Nucleonic Instrumentation, Neutron Physics.

Analytical and Inorganic Chemistry, Pure Substances, Spectrochemistry, Solution Chemistry, Analytical Chemistry, Inorganic Chemistry.

Mechanics, Sound, Pressure and Vacuum, Fluid Mechanics, Engineering Mechanics, Rheology, Combustion Controls.

Organic and Fibrous Materials, Rubber, Textiles, Paper, Leather, Testing and Specifications, Polymer Structure, Plastics, Dental Research.

Metallurgy, Thermal Metallurgy, Chemical Metallurgy, Mechanical Metallurgy, Corrosion, Metal Physics, Mineral Products, Engineering Ceramics, Glass, Refractories, Enameled Metals, Crystal Growth, Physical Properties, Constitution and Microstructure.

Building Research, Structural Engineering, Fire Research, Mechanical Systems, Organic Building Materials, Codes and Safety Standards, Heat Transfer, Inorganic Building Materials.

Applied Mathematics, Numerical Analysis, Computation, Statistical Engineering, Mathematical Physics.

Data Processing Systems, Components and Techniques, Digital Circuitry, Digital Systems, Analog Systems, Applications Engineering.

Atomic Physics, Spectroscopy, Radiometry, Solid State Physics, Electron Physics, Atomic Physics.

Instrumentation, Engineering Electronics, Electron Devices, Electronic Instrumentation, Mechanical Instruments, Basic Instrumentation.

Physical Chemistry, Thermochemistry, Surface Chemistry, Organic Chemistry, Molecular Spectroscopy, Molecular Kinetics, Mass Spectrometry, Molecular Structure and Radiation Chemistry.

• Office of Weights and Measures.

**BOULDER, COLO.**

Cryogenic Engineering, Cryogenic Equipment, Cryogenic Processes, Properties of Materials, Gas Liquefaction, Ionosphere Research and Propagation, Low Frequency and Very Low Frequency Research, Ionosphere Research, Prediction Services, Sun-Earth Relationships, Field Engineering, Radio Warning Services.

Radio Propagation Engineering, Data Reduction Instrumentation, Radio Noise, Tropospheric Measurements, Tropospheric Analysis, Propagation-Terrain Effects, Radio-Meteorology, Lower Atmosphere Physics.

Radio Standards, High Frequency Electrical Standards, Radio Broadcast Service, Radio and Microwave Materials, Atomic Frequency and Time Interval Standards, Electronic Calibration Center, Millimeter Wave Research, Microwave Circuit Standards.

Radio Systems, High Frequency and Very High Frequency Research, Modulation Research, Antenna Research, Navigation Systems, Space Telecommunications.

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

