NBS

Technical Note 40-9

MEAN ELECTRON DENSITY VARIATIONS OF THE QUIET IONOSPHERE NO. 9—NOVEMBER 1959

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

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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J. W. Wright, L. R. Wescott, and D. J. Brown
Central Radio Propagation Laboratory
NBS Boulder Laboratories
Boulder, Colorado

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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 November are illustrated graphically. This report is the ninth of a series illustrating the electron density variations in the mean quiet ionosphere between latitudes 15°N and 50°N along the 75°W meridian.

MEAN ELECTRON DENSITY VARIATIONS OF THE QUIET IONOSPHERE No. 9 - November 1959

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Central Radio Propagation Laboratory

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 foE, foF1, foF2), 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 hmax F2) 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)
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

	Geomag. Coordinates			Geog. Coordinates	
	fH	Lat.	Dip		
St. Johns, Newf.	1.38 Mc/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, but it should be pointed 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 November data is given on Page 11. The table on the following page identifies the quantities appearing on the tabulation.

Quantity	Units	Remarks
Average Electron Density (N)	$x10^3$ = electron/cm^3 (10^{-5} on maps)	Body of table; given at each 10 km of height from the lowest hmin to 950 km.
NMAX	$x10^3$ = electron/cm^3 (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	$x10^{10}$ = electrons/cm^2 column (10^{-12} on maps)	Obtained by averaging the integration of the individual profiles between the limits HMIN and HMAX.
SHINF	$x10^{-10}$ = electrons/cm^2 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 hmax F2 is obtained, the virtual height at Nmax being immeasurable. A useful procedure is to fit the portion near hmax F2 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 $N_A = 2.82\,HN_{max}$ 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. Included here are three such graphical forms prepared from the tabulations described in Section II.

A. Vertical cross sections of the ionosphere along the 75°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°W geographic meridian, for the month of November 1959. Contours are parametric in "plasma" frequency (f_N) related to electron density N by

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

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°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°W meridian. Similar maps for the peak density, Nmax; its height, hmax; its characteristic thickness, Scat; the total electron content to Nmax, Shmax; and the estimated total electron content, Shinf, 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 hmax F2 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 requires 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; Martyn 1956) have investigated the equilibrium height (of hmax) 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 hmax 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 is gratefully acknowledged.

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AVERAGE ELECTRON DENSITY KP BELOW 4.5

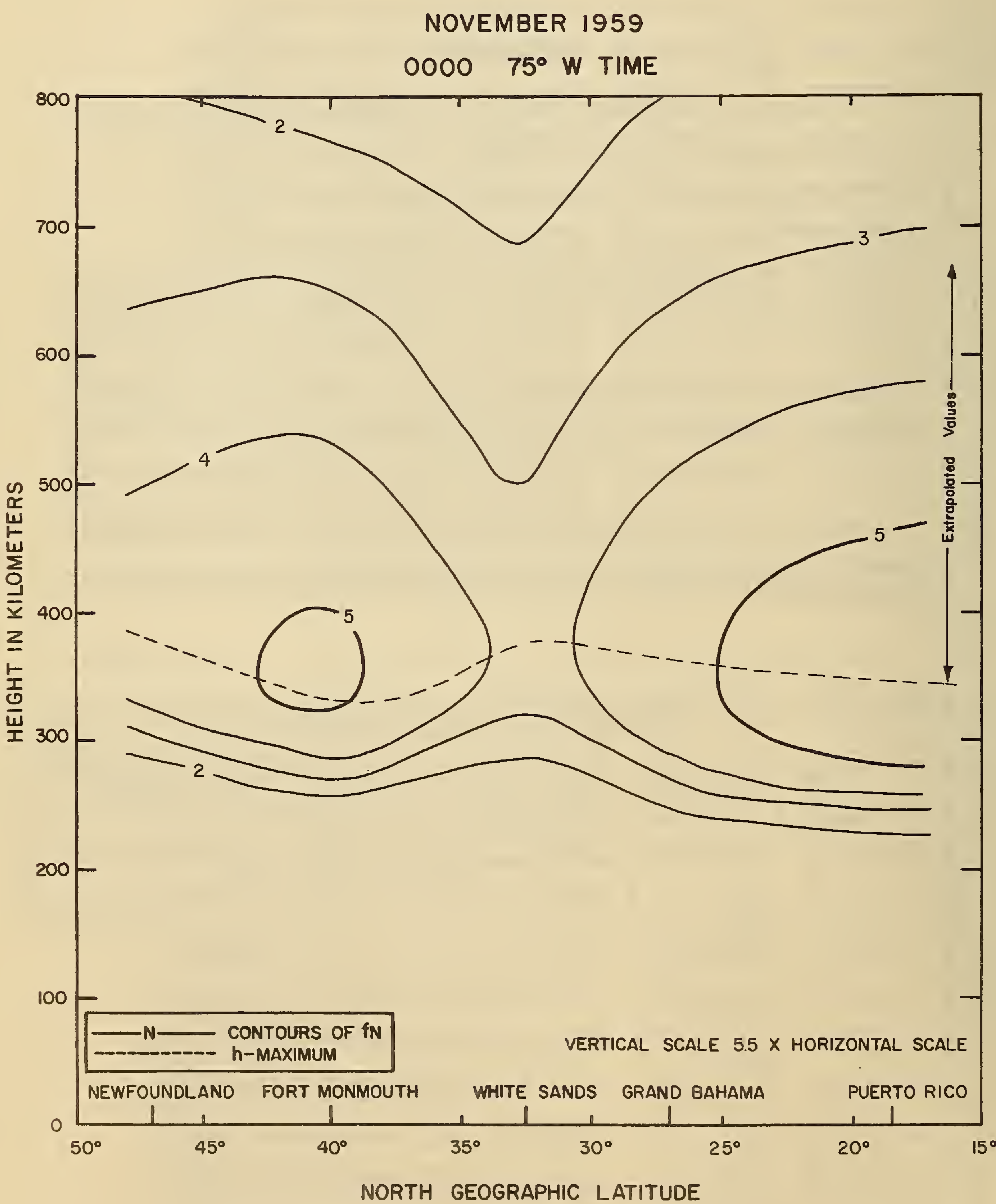
PUERTO RICO 60 W NOV 1959

TIME	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
COUNT	23	23	22	22	22	21	23	17	24	22	22	26
HMIN	232	233	225	208	232	253	233	185	112	111	110	109
RATIO	6.2	6.8	7.2	7.3	4.1	4.6	4.9	7.4	5.3	5.2	4.7	4.5
SCAT	41.7	37.1	35.7	38.8	74.6	58.6	55.0	33.3	41.9	42.1	48.0	49.1
NMAX	428	378	337	241	163	156	178	679	1330	1813	1982	1984
HMAX	324	315	302	285	373	371	345	275	277	279	289	292
SHMAX	235	185	157	119	156	124	131	315	880	1229	1517	1591
SHINF	1442	1250	1109	800	614	564	633	2230	4631	6345	7109	7188
KM												
950	30.7	25.8	21.7	14.5	15.4	14.4	14.2	38.5	75.9	104	120	122
900	39.4	33.2	27.8	18.5	19.8	18.4	18.1	49.4	97.4	134	154	157
850	50.5	42.5	35.6	23.7	25.3	23.6	23.3	63.4	125	172	198	201
800	64.8	54.5	45.7	30.4	32.4	30.2	29.8	81.3	160	220	254	258
750	82.9	69.8	58.5	39.0	41.4	38.6	38.2	104	205	282	325	330
700	106	89.2	74.9	49.9	52.6	49.2	48.7	133	263	362	416	423
650	135	114	95.5	63.7	66.5	62.4	61.9	171	336	462	531	540
600	171	144	121	81.0	83.1	78.4	78.3	217	428	589	676	687
550	215	181	153	102	102	97.3	97.9	275	542	746	856	869
500	266	226	191	128	122	118	120	346	681	937	1073	1088
490	277	235	200	133	126	122	125	362	711	979	1120	1136
480	288	245	208	139	130	126	130	378	743	1023	1170	1186
470	300	255	217	145	134	130	135	395	776	1068	1220	1236
460	311	264	226	151	137	134	139	412	809	1114	1271	1288
450	322	274	235	157	140	138	144	429	843	1161	1324	1341
440	334	284	244	163	143	141	149	447	878	1209	1377	1394
430	345	294	253	170	146	145	153	465	913	1257	1431	1448
420	356	304	262	176	148	148	157	483	949	1306	1485	1502
410	366	314	271	182	149	150	161	502	984	1356	1539	1556
400	376	323	279	188	150	152	165	520	1020	1405	1592	1609
390	386	331	288	194	150	153	168	539	1056	1454	1645	1661
380	394	340	296	200	150	153	171	557	1091	1502	1696	1712
370	401	347	303	206	148	152	173	574	1125	1549	1745	1761
360	407	353	310	211	146	149	174	591	1158	1594	1792	1806
350	411	357	317	216	143	145	175	608	1189	1637	1835	1849
340	411	360	322	221	138	138	174	623	1217	1676	1875	1886
330	407	359	326	225	132	129	171	637	1243	1712	1909	1919
320	399	355	328	228	125	118	166	649	1265	1744	1938	1946
310	384	346	326	231	118	103	159	659	1283	1770	1959	1965
300	364	330	320	232	109	87.9	148	667	1296	1790	1972	1975
290	335	307	308	232	98.5	72.6	134	673	1305	1803	1973	1971
280	298	276	286	230	87.3	55.0	116	671	1307	1804	1950	1939
270	252	241	256	224	79.4	41.1	95.0	656	1297	1778	1889	1868
260	197	198	215	211	70.7	31.7	69.4	616	1265	1712	1783	1755
250	141	153	166	190	61.8	21.7	50.8	546	1195	1599	1632	1601
240	88.2	97.5	116	160	52.3	16.1	36.8	431	1084	1426	1437	1415
230	47.3	54.1	69.1	120	39.7	11.4	22.0	301	923	1198	1215	1199
220	21.9	21.1	30.2	76.1	29.1	7.0	10.0	192	735	931	974	970
210	7.1	5.0	8.7	34.2	20.3	3.9	1.6	113	550	699	758	766
200	1.2	.1	1.8	4.4	11.0	.6		67.0	401	518	580	604
190					2.5			46.4	291	394	453	485
180								33.6	214	309	365	398
170								26.2	166	250	300	333
160								22.4	135	205	251	282
150								20.3	116	172	212	240
140								18.6	107	151	183	205
130								15.1	100	139	166	183
120								11.0	89.1	127	151	170
110									6.9	36.3	51.2	74.2

AVERAGE ELECTRON DENSITY KP BELOW 4.5

PUERTO RICO 60 W NOV 1959

TIME	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
COUNT	23	23	23	23	19	12	26	26	24	23	24	23
HMIN	109	109	110	109	111	120	209	202	205	227	226	231
RATIO	4.2	4.1	3.9	3.9	4.1	4.4	5.2	5.4	5.2	5.4	5.5	5.8
SCAT	52.8	55.5	60.0	61.2	57.8	55.8	50.9	46.7	49.6	47.0	46.4	44.2
NMAX	1881	1854	1810	1745	1728	1584	1520	1099	745	632	534	479
HMAX	304	309	319	323	321	317	322	315	322	338	332	332
SHMAX	1675	1710	1760	1729	1594	1340	1036	713	514	401	337	287
SHINF	6982	6939	6865	6652	6469	5808	5325	3814	2614	2183	1842	1638
KM												
950	123	125	127	126	123	111	109	76.2	54.2	48.2	40.0	35.7
900	158	160	163	161	158	142	139	97.7	69.5	61.8	51.3	45.7
850	202	205	209	207	202	183	179	125	89.1	79.2	65.8	58.6
800	260	263	269	265	259	234	229	161	114	102	84.3	75.1
750	333	336	344	340	332	300	293	206	146	130	108	96.1
700	425	430	440	434	424	383	375	263	187	166	138	123
650	543	549	560	553	541	489	478	335	238	211	175	156
600	690	697	711	701	686	620	606	426	302	267	222	198
550	871	879	895	882	863	781	762	536	379	335	279	249
500	1087	1095	1112	1095	1072	971	947	667	470	414	344	308
450	1333	1340	1353	1328	1304	1182	1150	812	569	499	415	371
440	1384	1390	1402	1375	1351	1225	1191	842	589	515	429	384
430	1435	1440	1451	1422	1397	1268	1232	871	609	532	442	397
420	1486	1490	1499	1468	1443	1310	1272	900	628	547	455	409
410	1537	1540	1546	1512	1487	1351	1311	929	646	562	468	420
400	1586	1587	1591	1554	1530	1390	1348	956	664	576	480	431
390	1634	1633	1633	1594	1570	1428	1383	982	680	589	491	441
380	1679	1677	1673	1630	1607	1463	1416	1006	695	601	500	451
370	1722	1717	1708	1663	1641	1494	1445	1029	708	610	508	458
360	1761	1754	1740	1691	1670	1522	1470	1048	719	617	514	464
350	1796	1785	1766	1713	1694	1545	1490	1065	727	621	516	468
340	1826	1812	1785	1728	1711	1563	1505	1077	730	620	514	468
330	1850	1832	1797	1736	1722	1574	1513	1084	729	613	506	464
320	1866	1844	1800	1732	1723	1578	1510	1083	722	595	491	453
310	1874	1843	1787	1712	1705	1566	1487	1072	706	567	468	433
300	1867	1825	1753	1671	1663	1532	1439	1045	678	526	438	404
290	1836	1779	1693	1607	1592	1473	1363	997	636	468	401	364
280	1772	1701	1606	1518	1499	1389	1255	923	579	398	354	313
270	1668	1599	1495	1405	1381	1277	1114	825	508	317	301	260
260	1533	1469	1363	1276	1245	1145	936	708	428	234	243	198
250	1370	1320	1214	1136	1098	997	729	573	338	158	186	133
240	1195	1155	1058	983	939	838	507	428	246	101	130	78.7
230	1020	987	902	834	781	676	288	286	162	51.4	75.2	35.0
220	852	828	759	699	633	521	133	156	93.6	23.0	38.4	14.5
210	704	683	629	582	505	388	44.8	69.6	45.7	10.7	14.3	3.7
200	585	561	522	481	399	280	3.8	17.3	14.7	4.2	4.5	1.1
190	489	466	434	395	313	201		.5	1.6	.1	.5	
180	411	390	361	324	250	147						
170	349	331	302	268	202	113						
160	298	282	253	222	167	92.0						
150	255	241	215	187	141	79.7						
140	218	209	186	163	124	72.4						
130	192	186	169	148	116	66.7						
120	178	173	158	138	107	55.5						
110	100	78.0	74.2	57.0	21.2	3.1						


NOVEMBER 1959
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HEIGHT IN KILOMETERS
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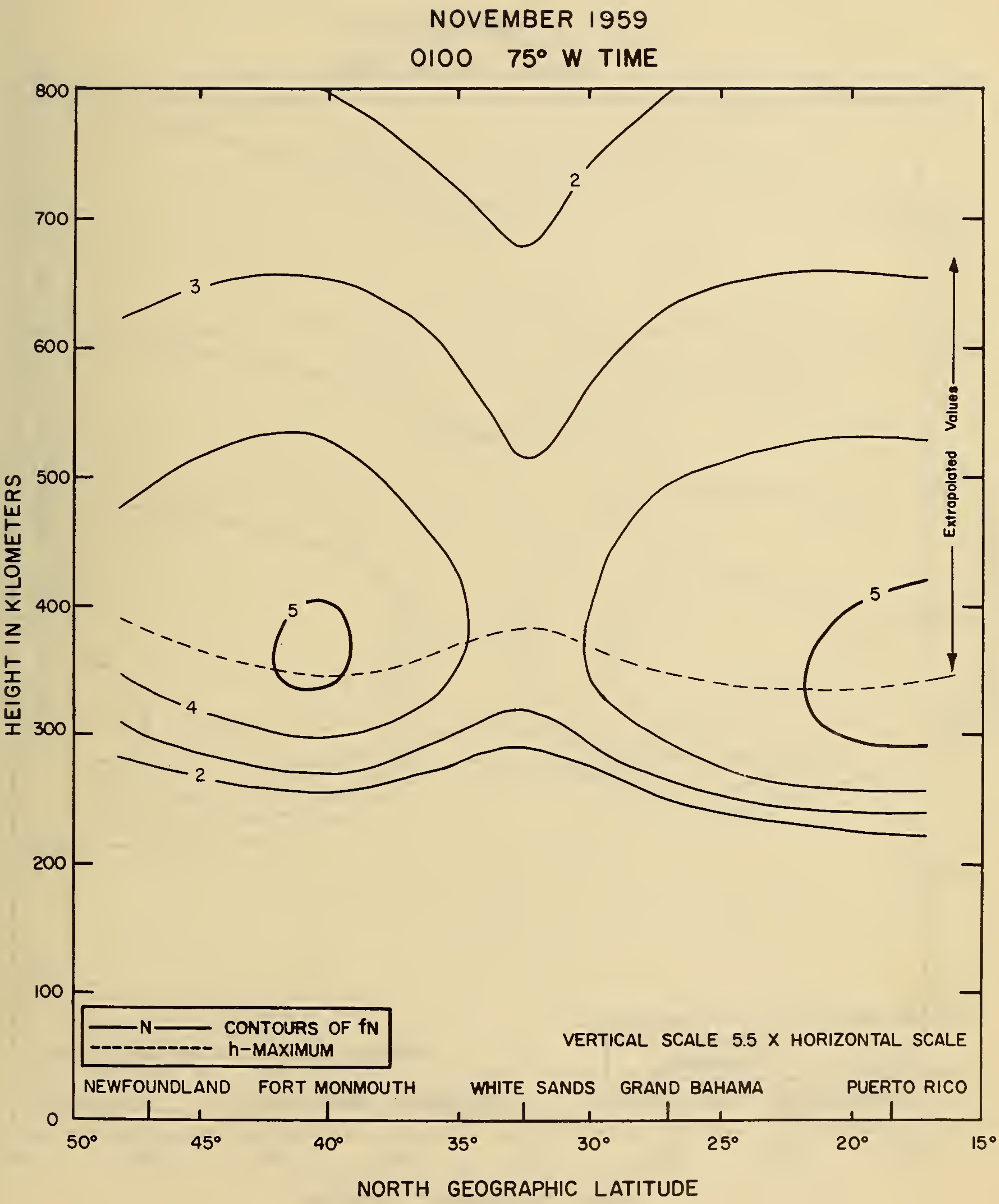
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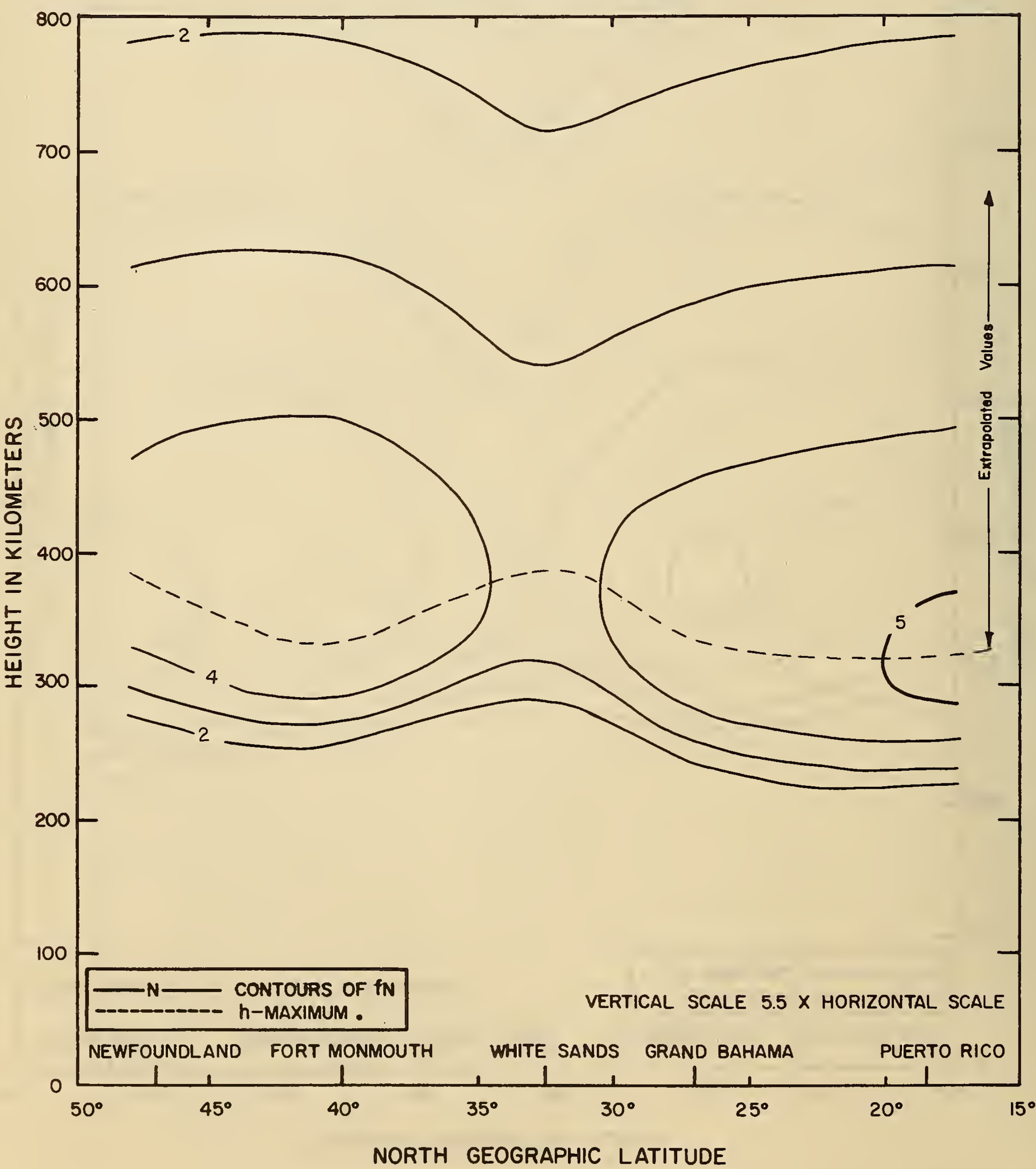
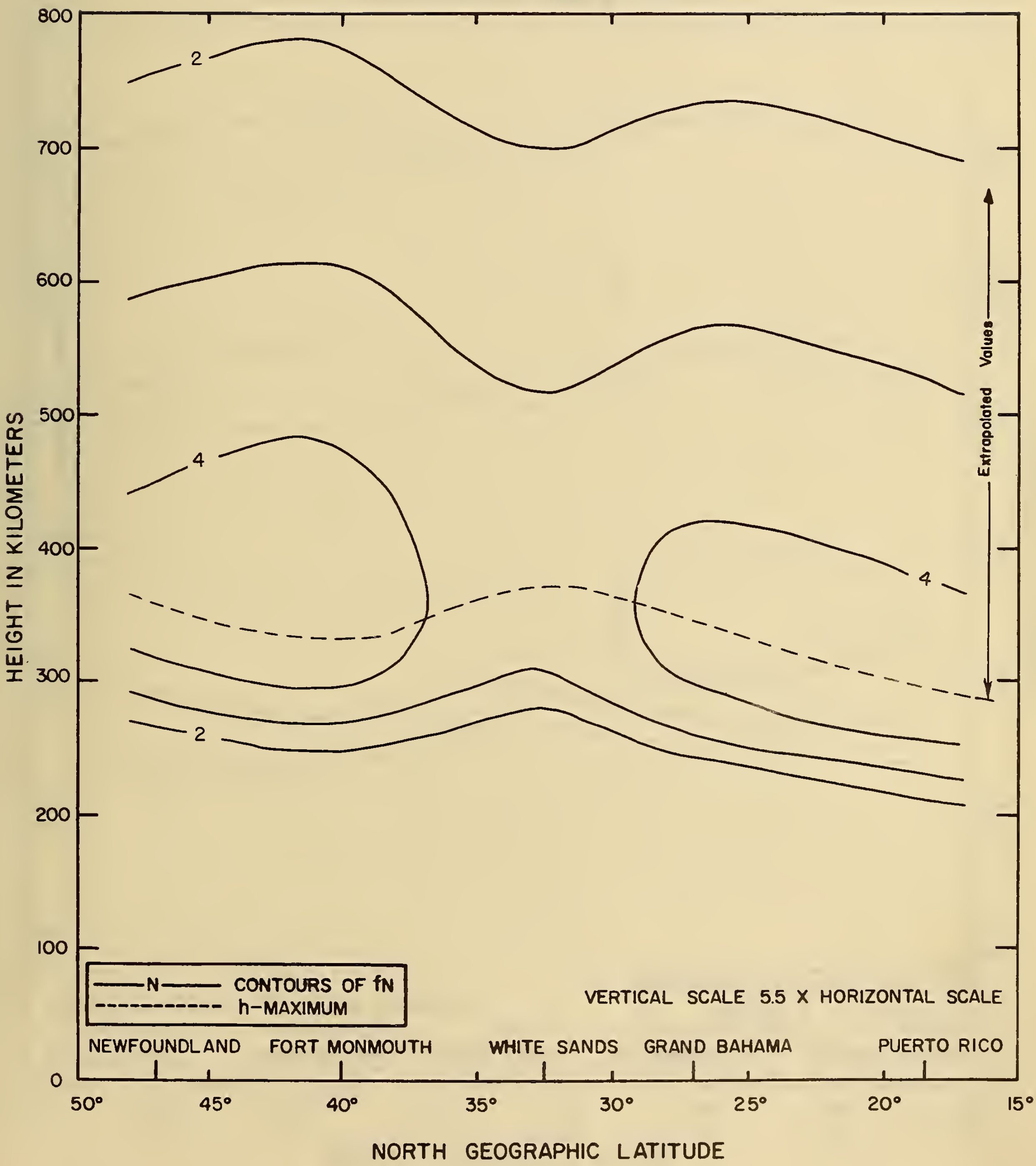
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
2
3
5
4
2
5
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

NOVEMBER 1959

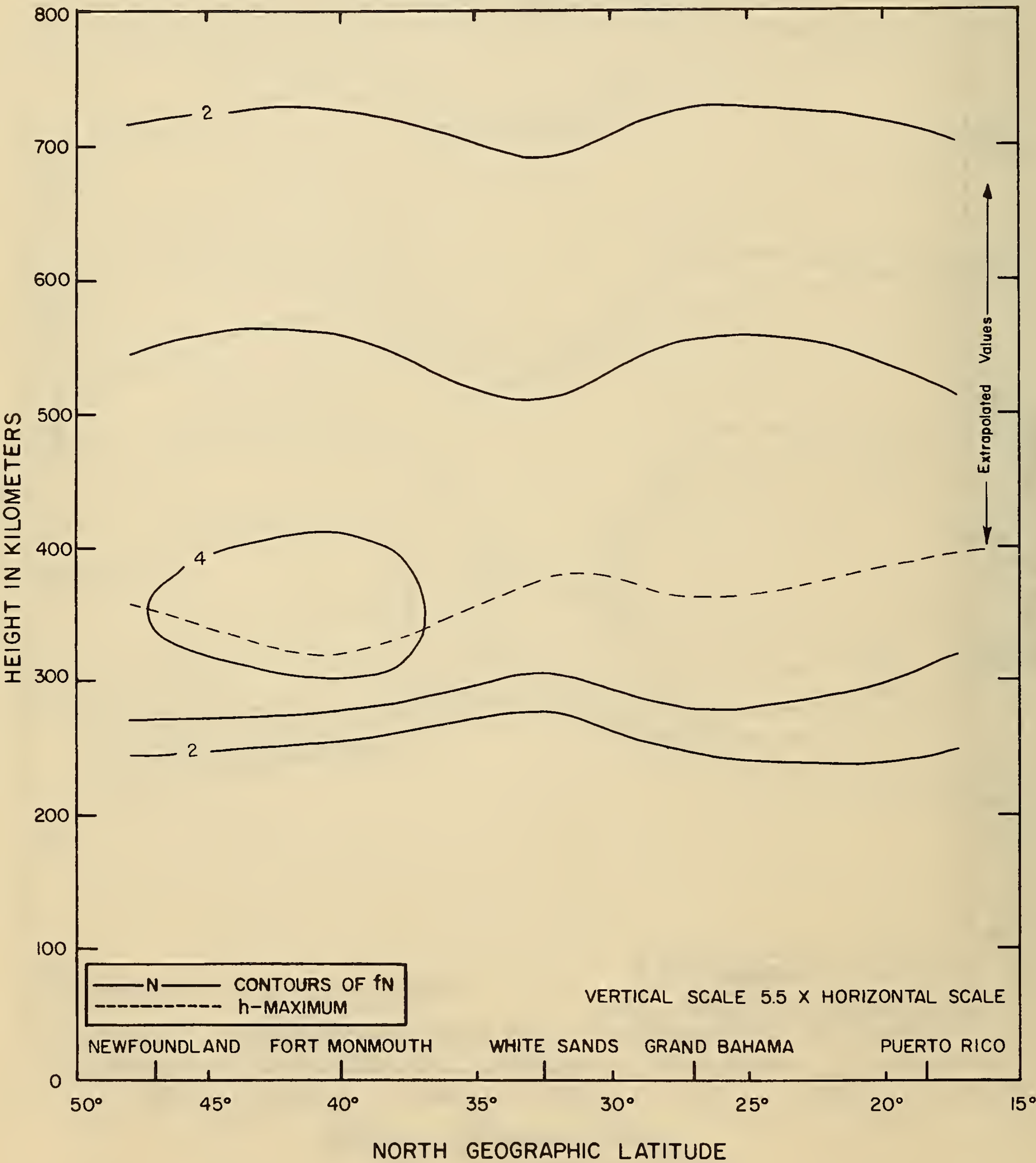
0200 75° W TIME



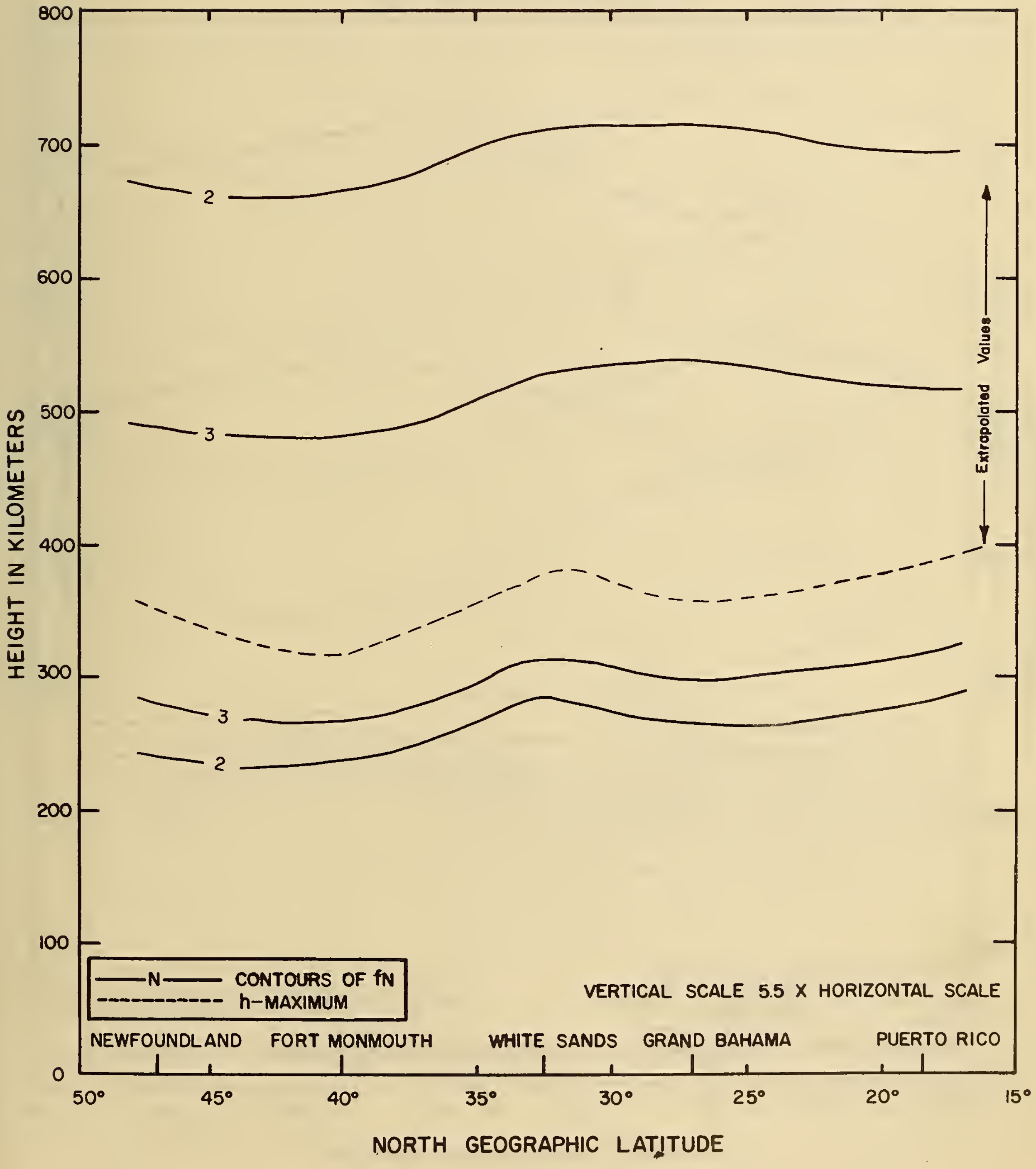
NOVEMBER 1959
0300 75° W TIME

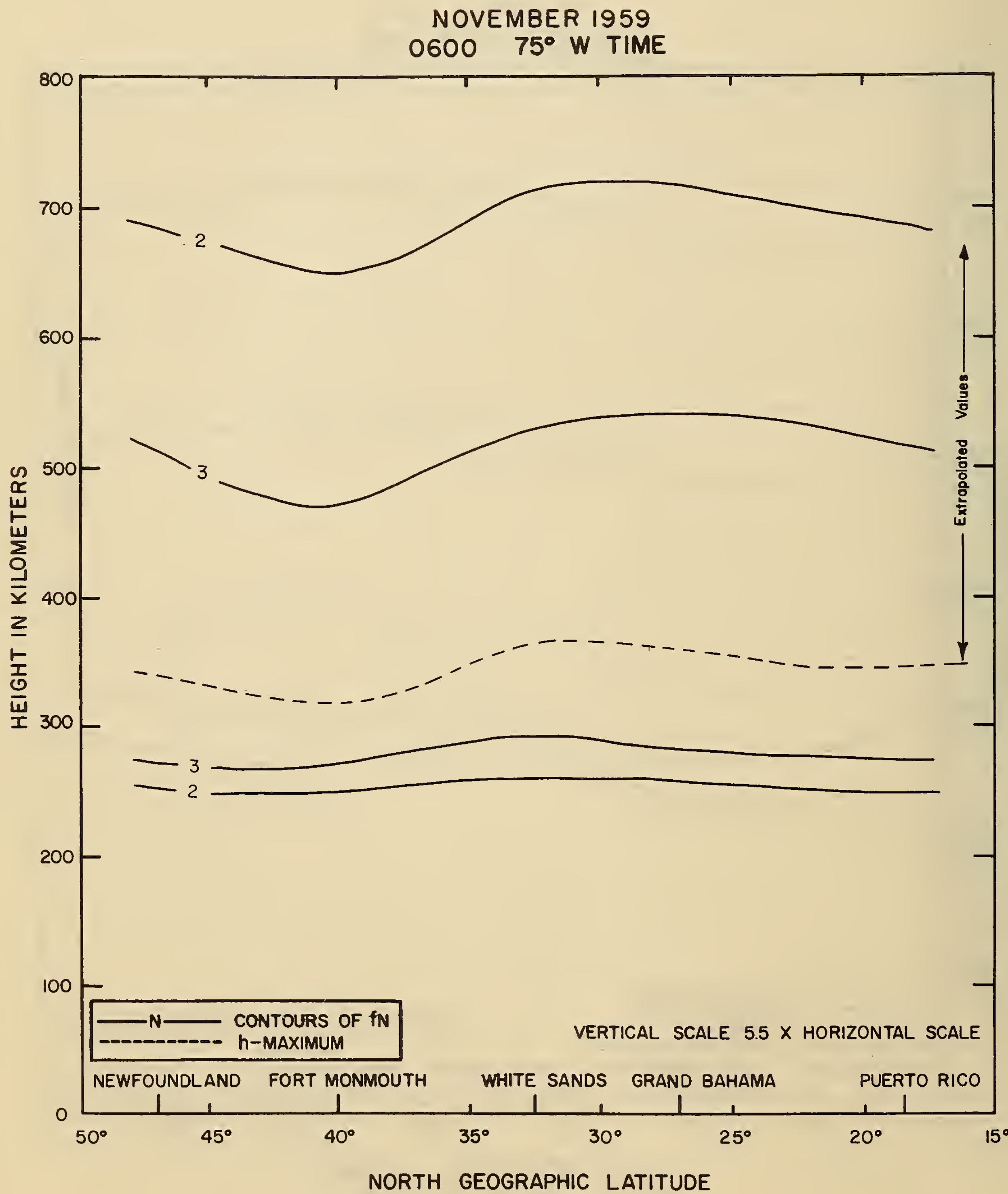


NOVEMBER 1959
0400 75° W TIME

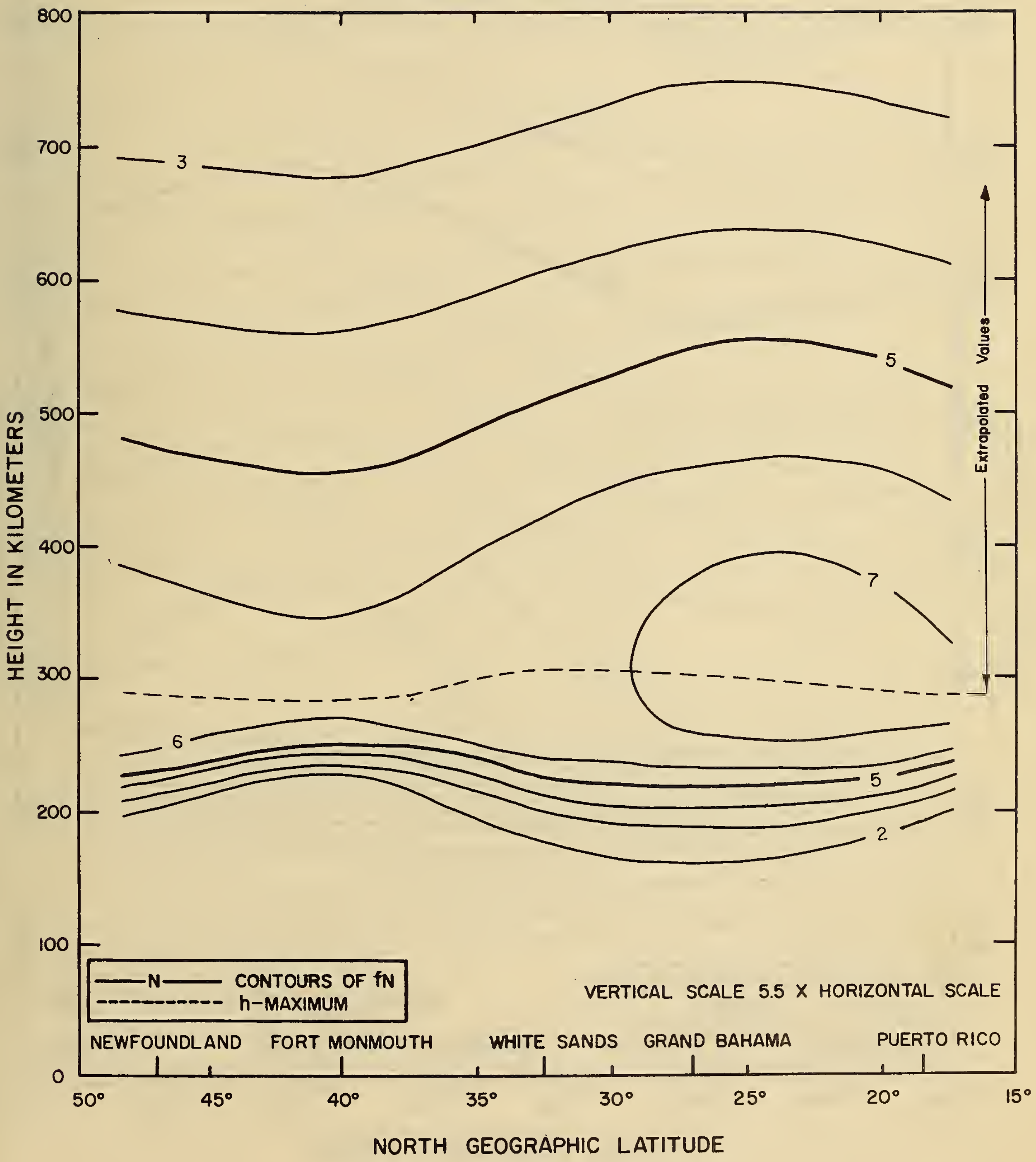


NOVEMBER 1959
0500 75° W TIME

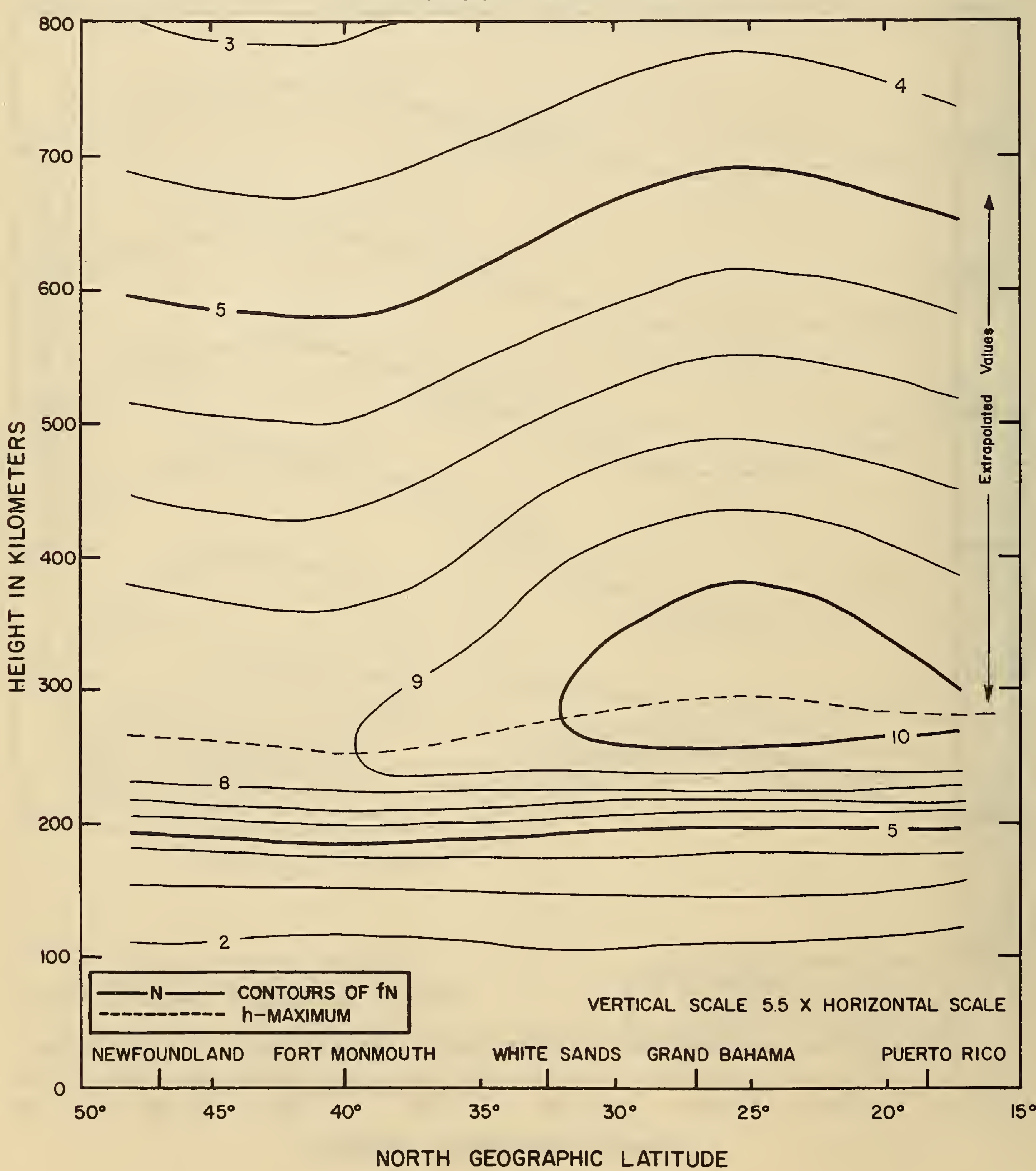


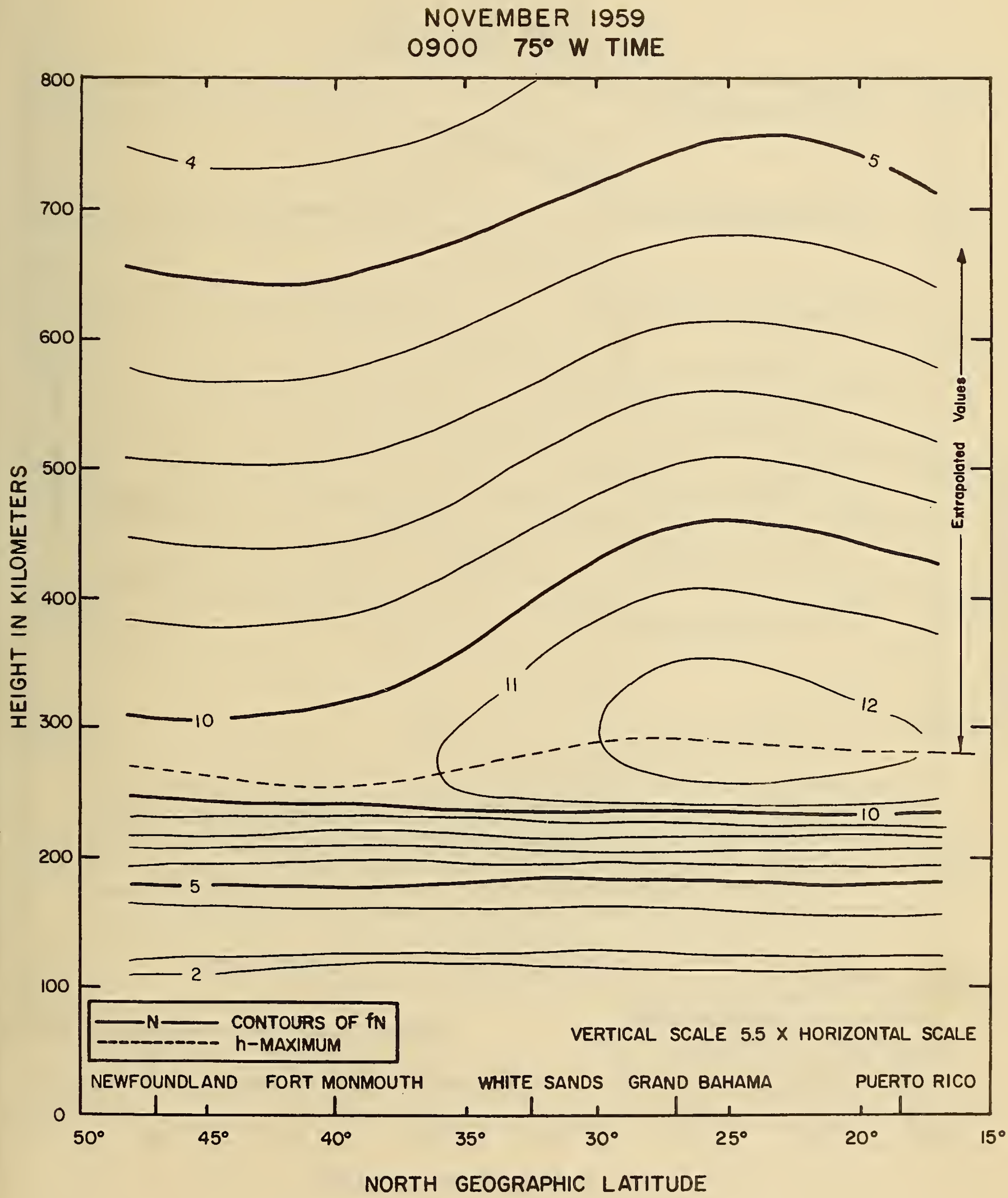

NOVEMBER 1959
0600 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
2
3
3
2
Extrapolated Values
—N— CONTOURS OF fN
- - - - - h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

NOVEMBER 1959
0700 75° W TIME

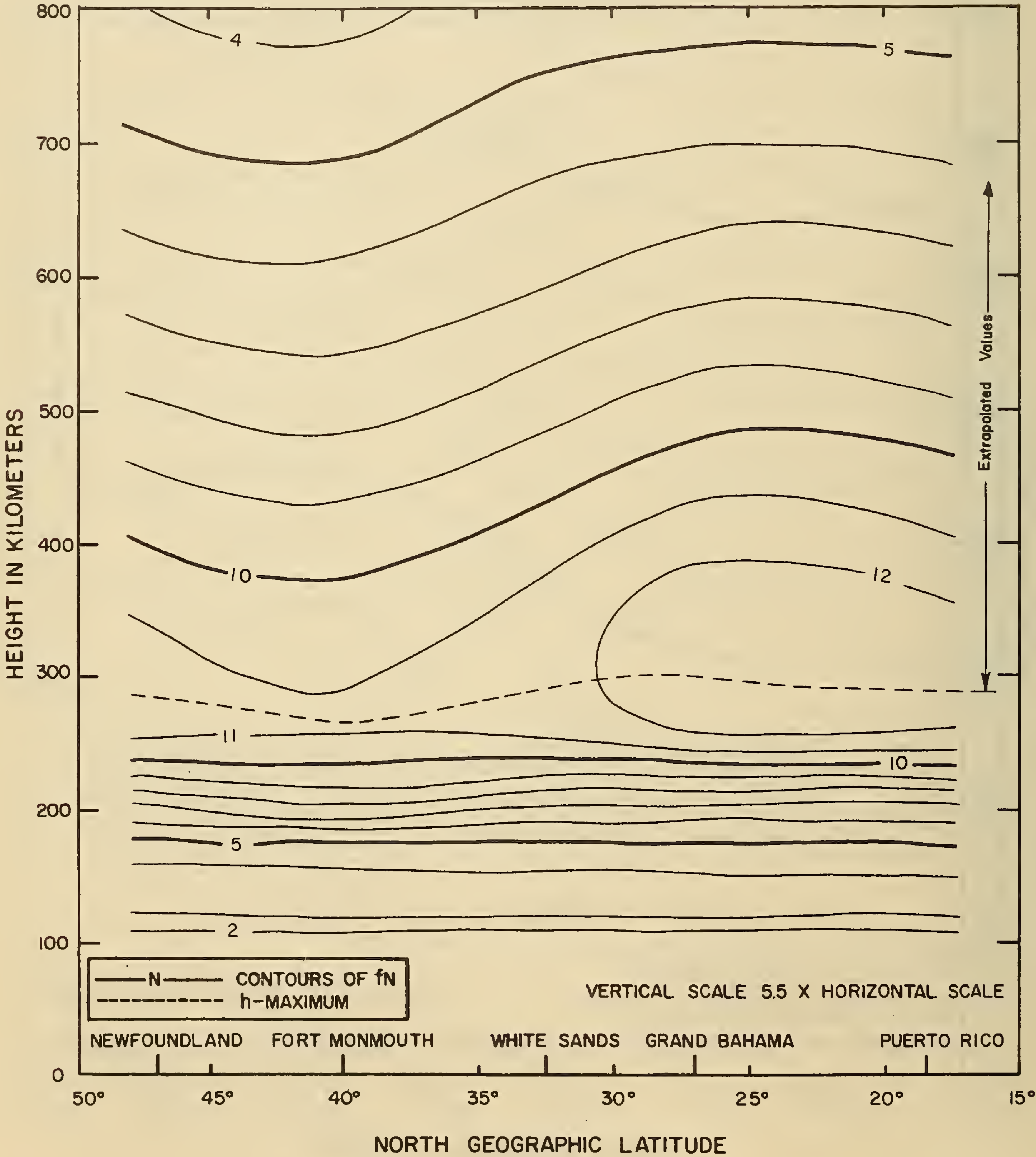


NOVEMBER 1959
0800 75° W TIME

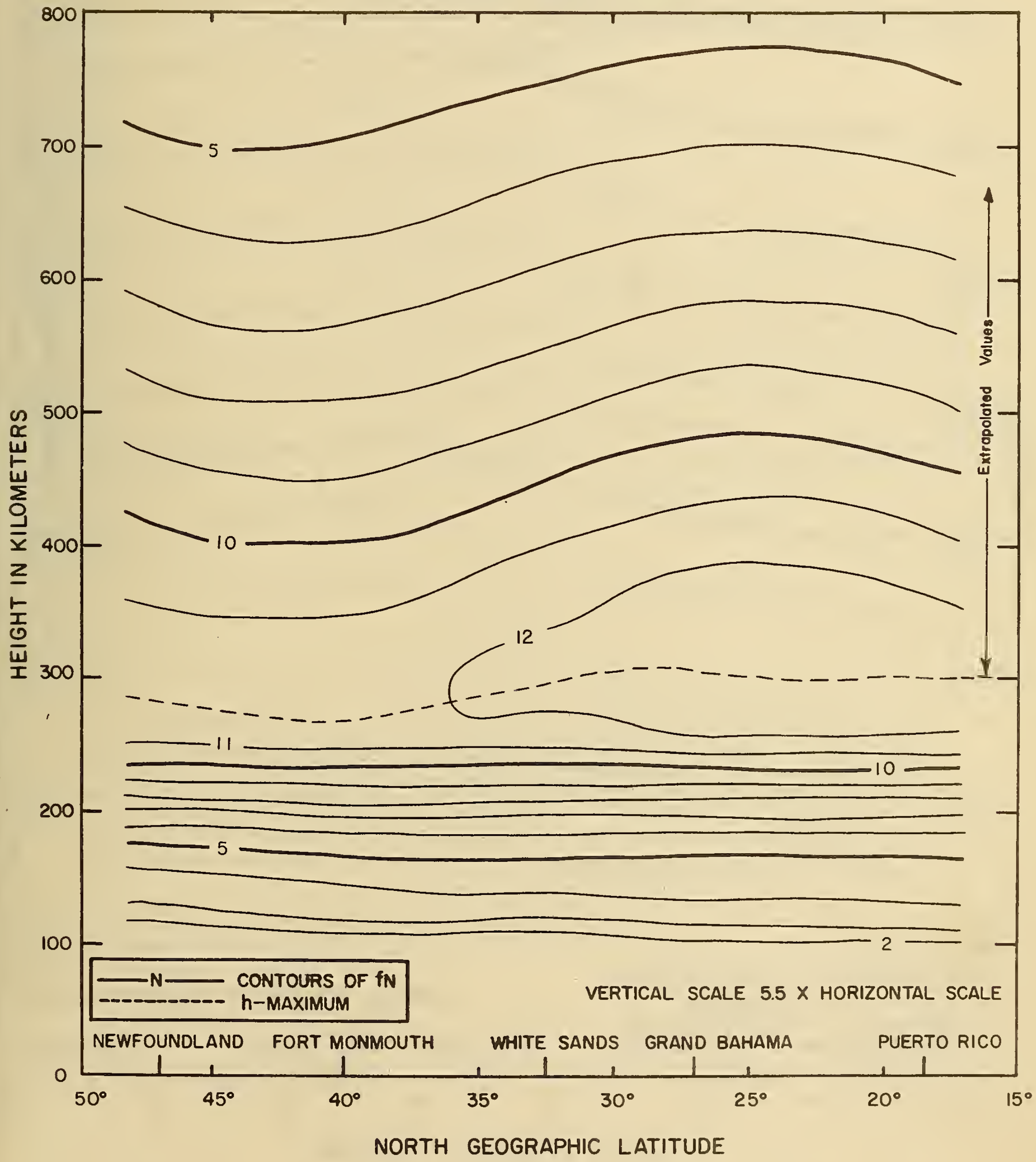


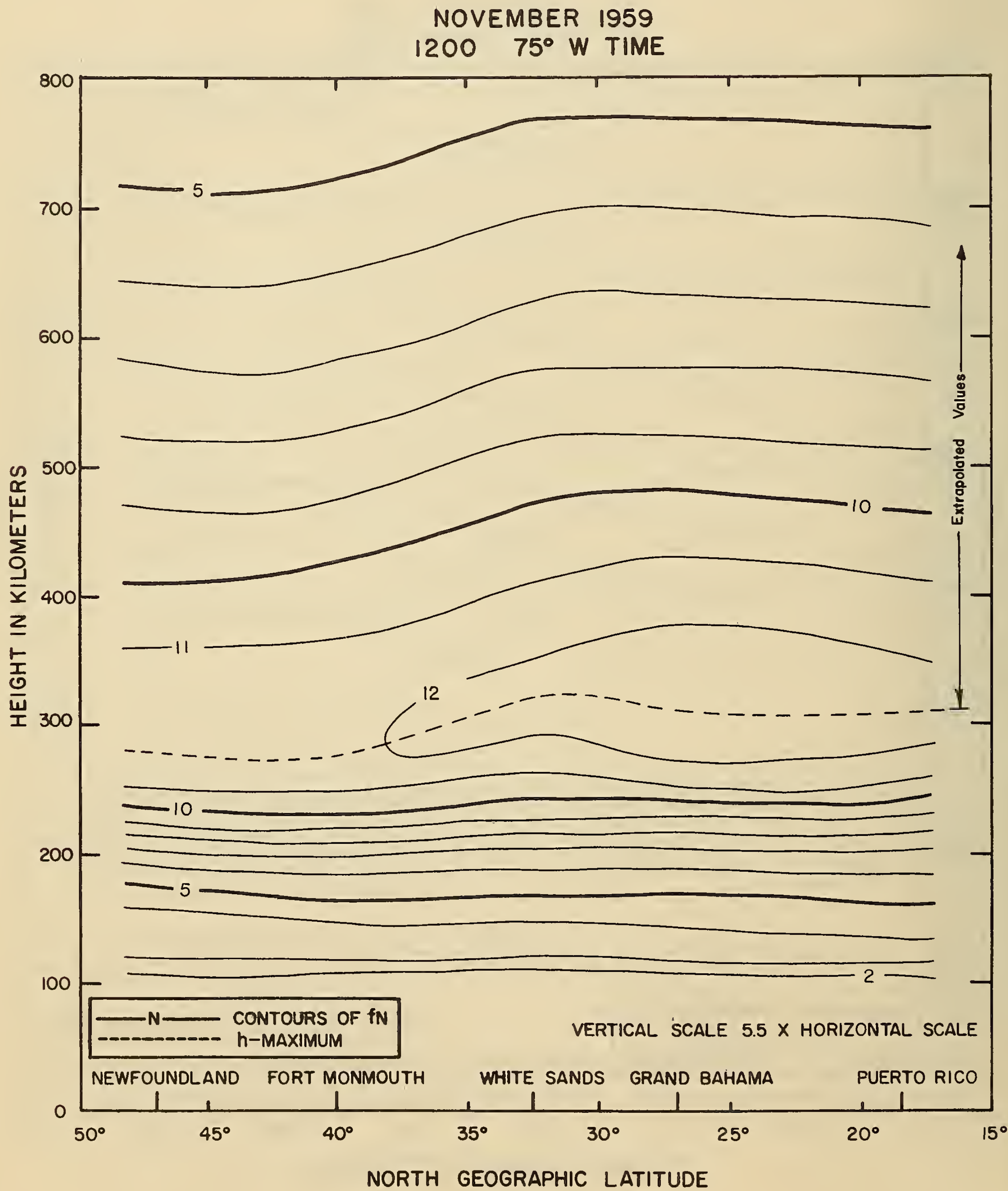

NOVEMBER 1959
0900 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
11
12
10
5
2
Extrapolated Values
CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

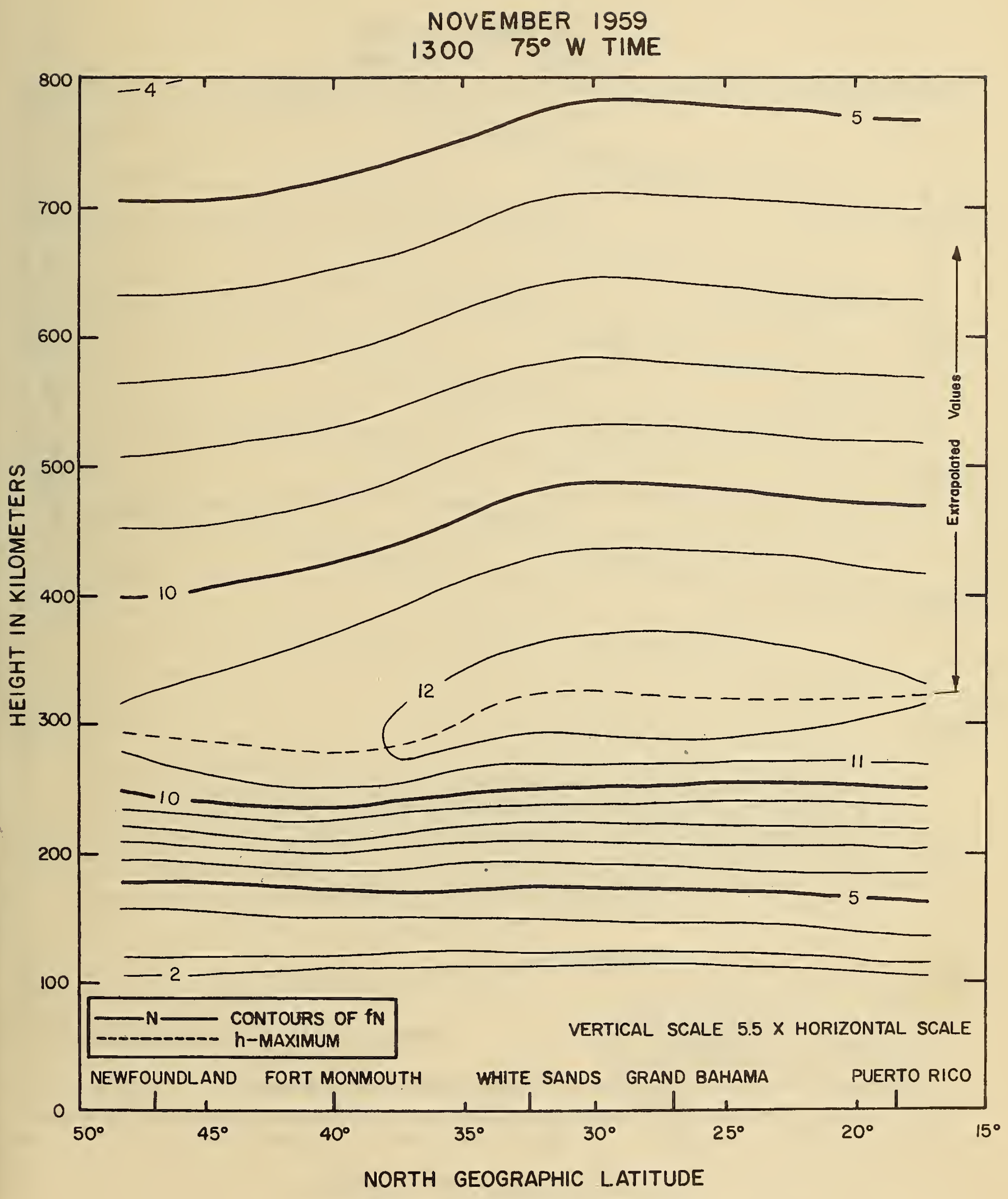
NOVEMBER 1959
1000 75° W TIME



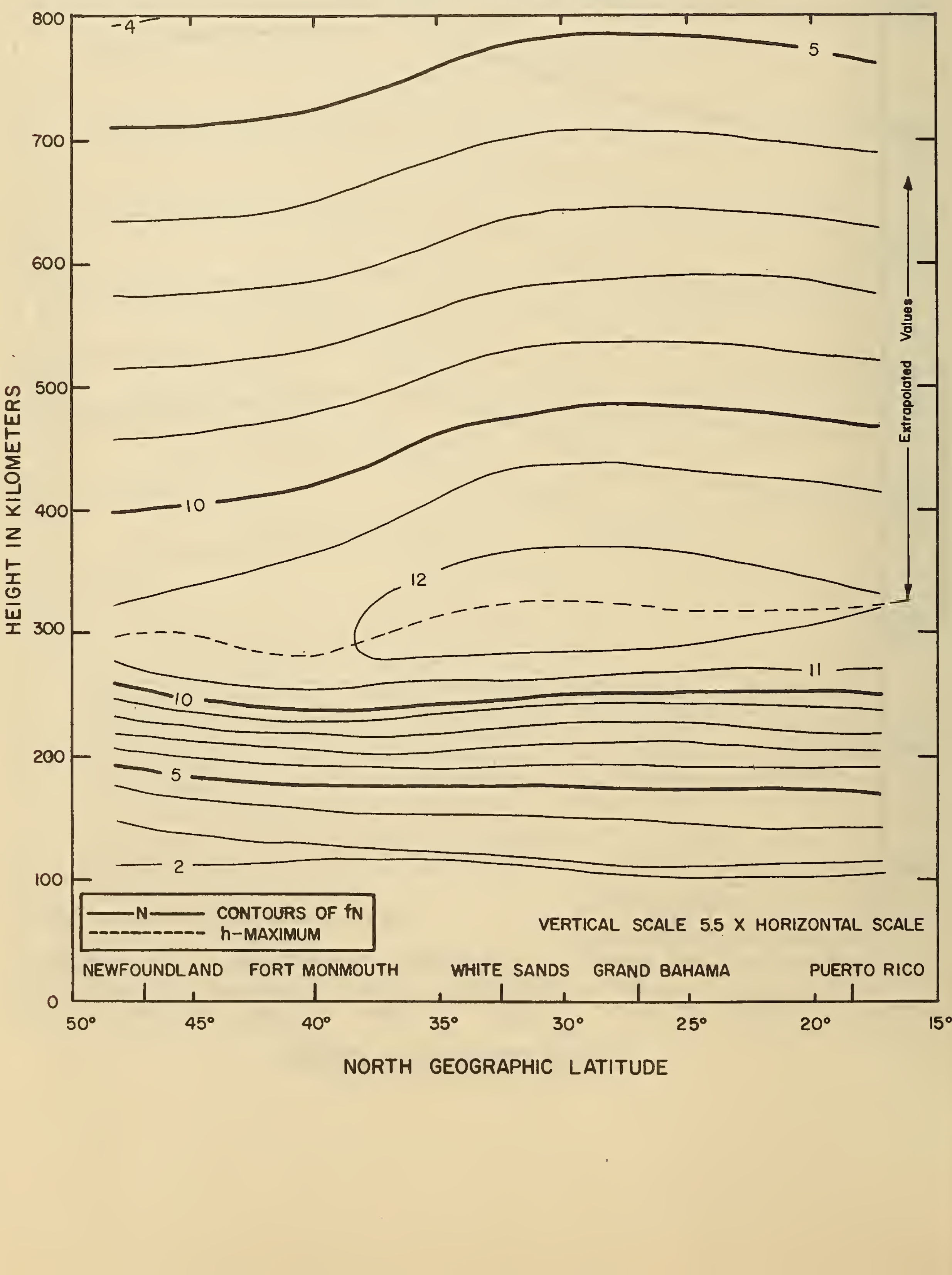
NOVEMBER 1959
1100 75° W TIME



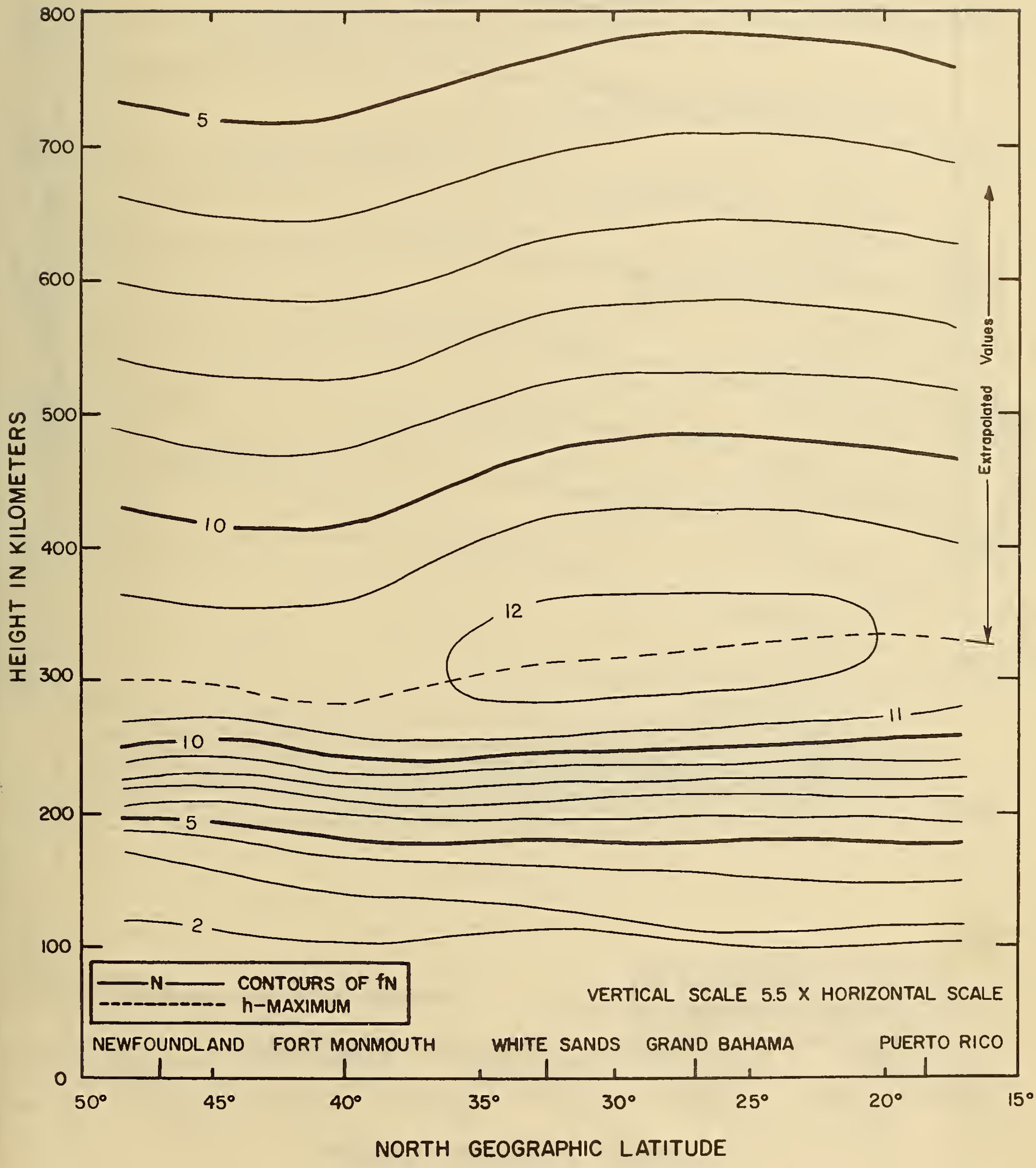

NOVEMBER 1959
1200 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
5
10
11
12
10
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

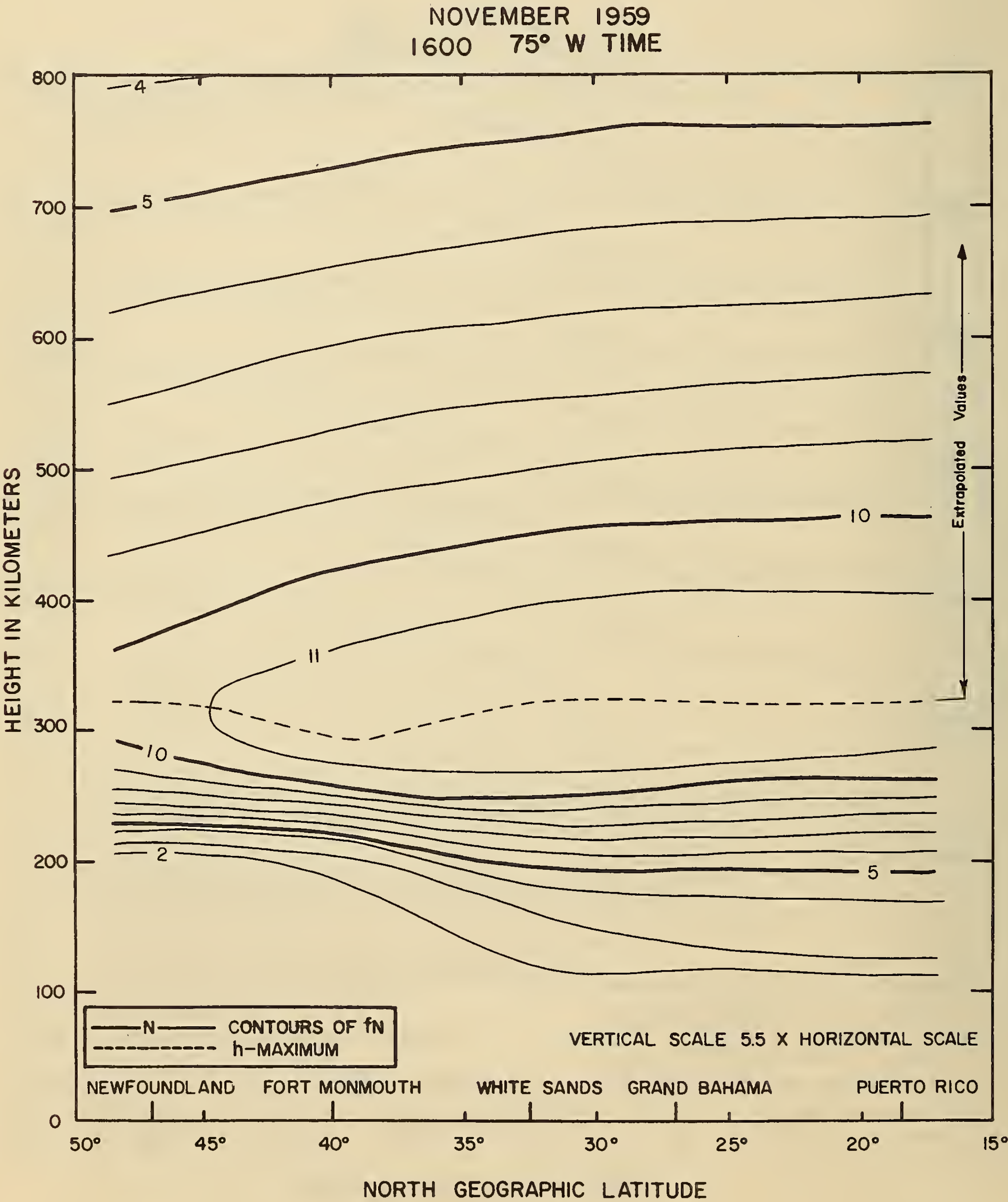

NOVEMBER 1959
1300 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
12
11
10
5
2
Extrapolated Values
—N— CONTOURS OF fN
----- h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

NOVEMBER 1959
1400 75° W TIME

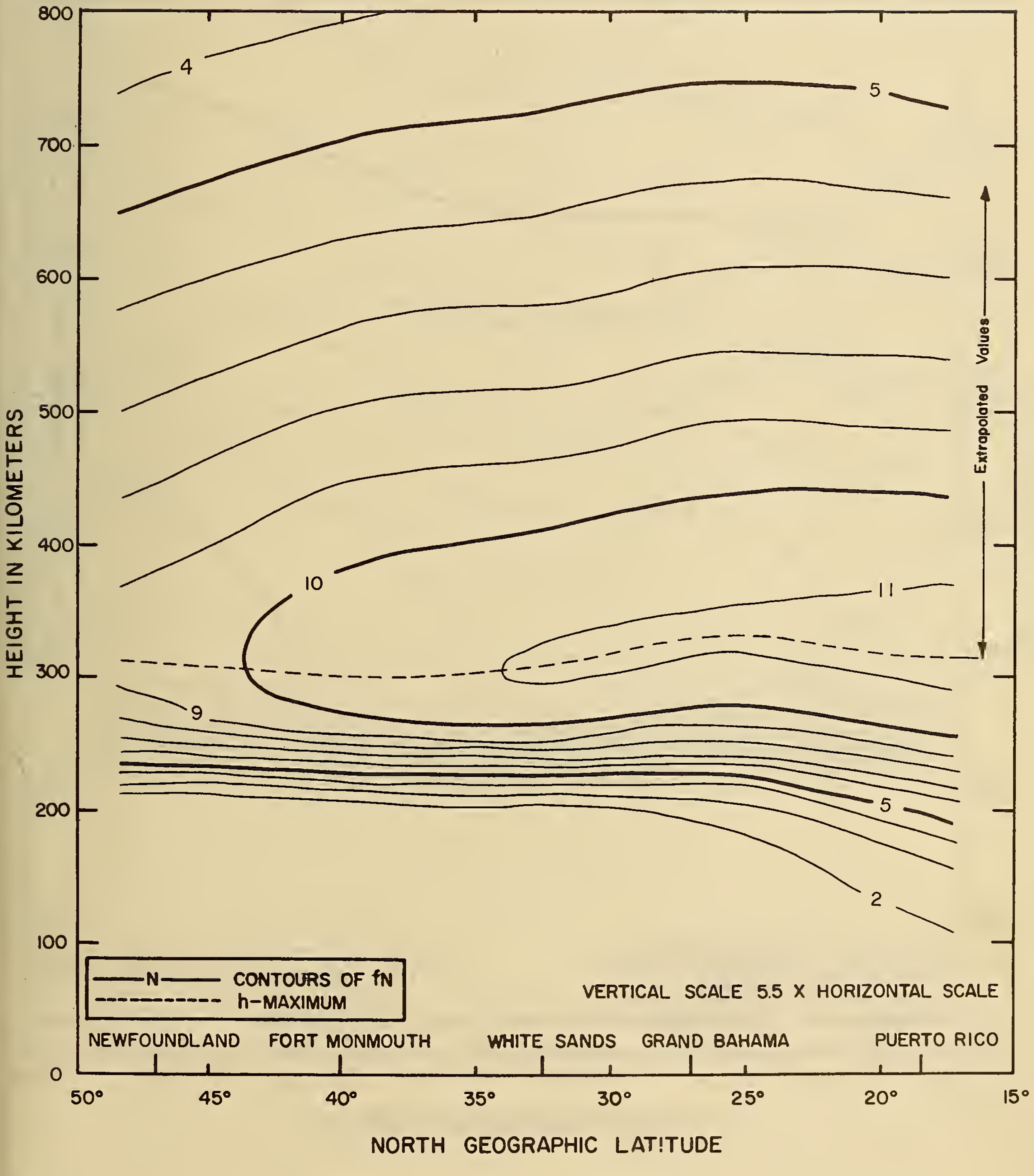


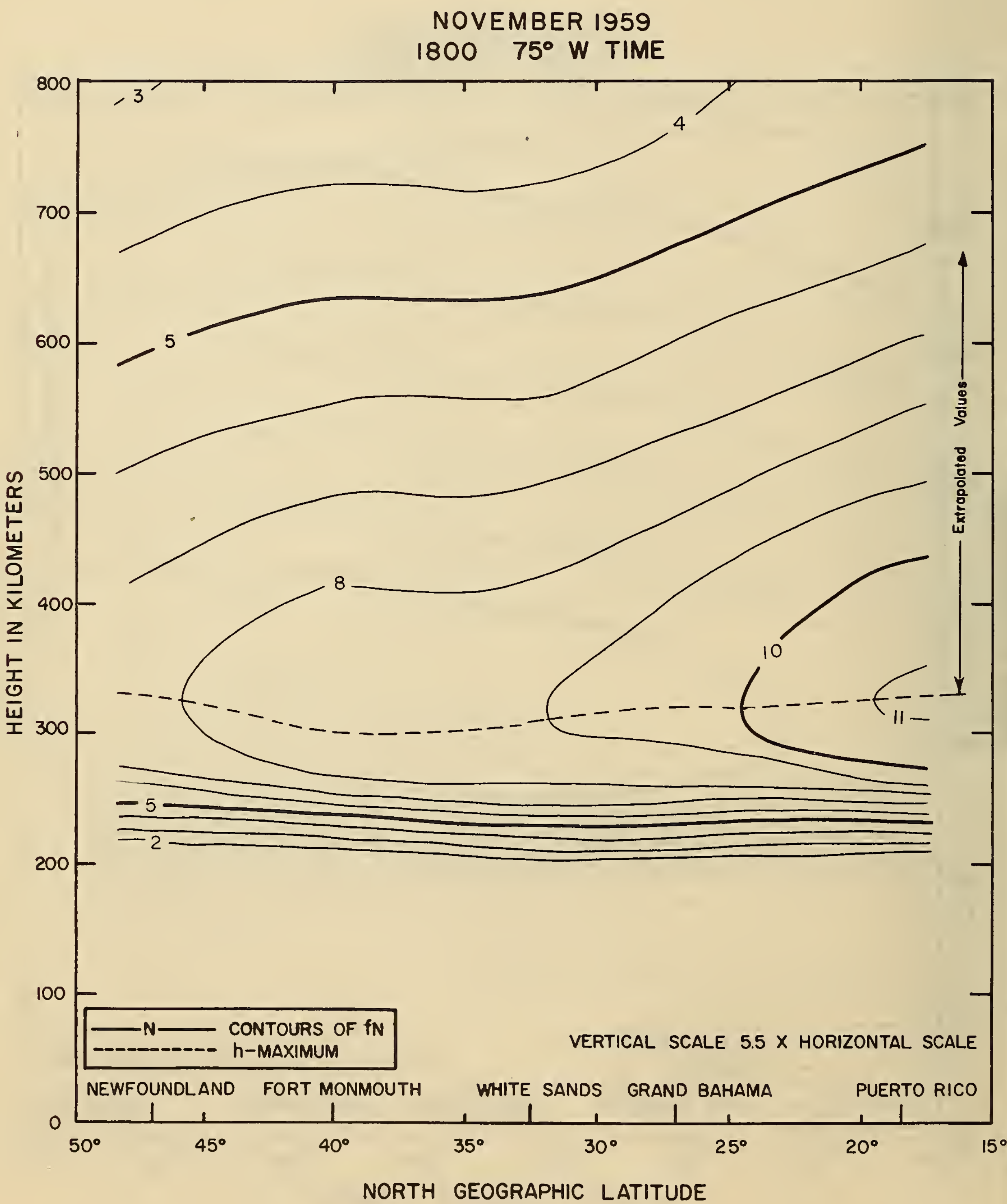
NOVEMBER 1959
1500 75° W TIME



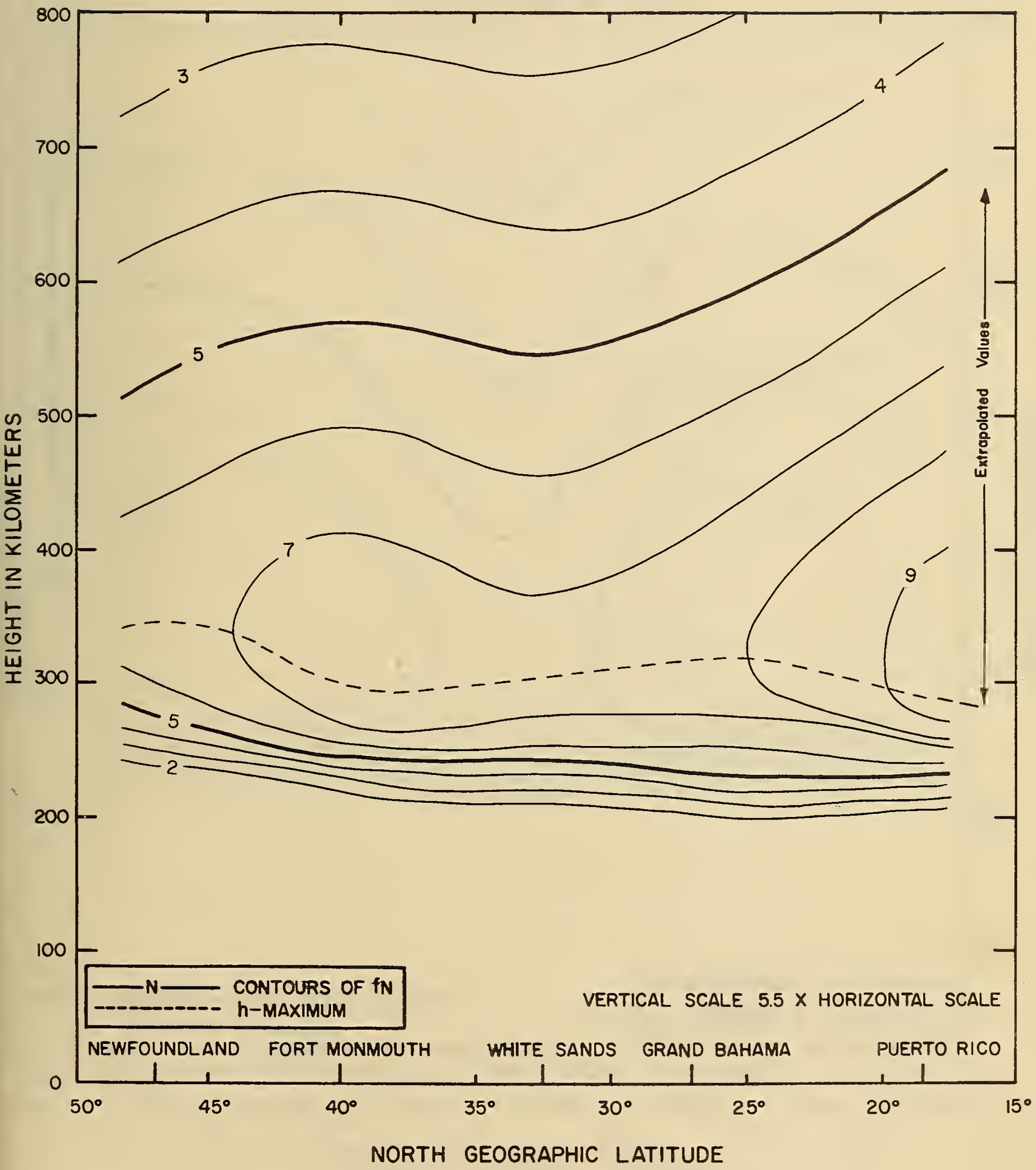

NOVEMBER 1959
1600 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
11
10
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

NOVEMBER 1959
1700 75° W TIME



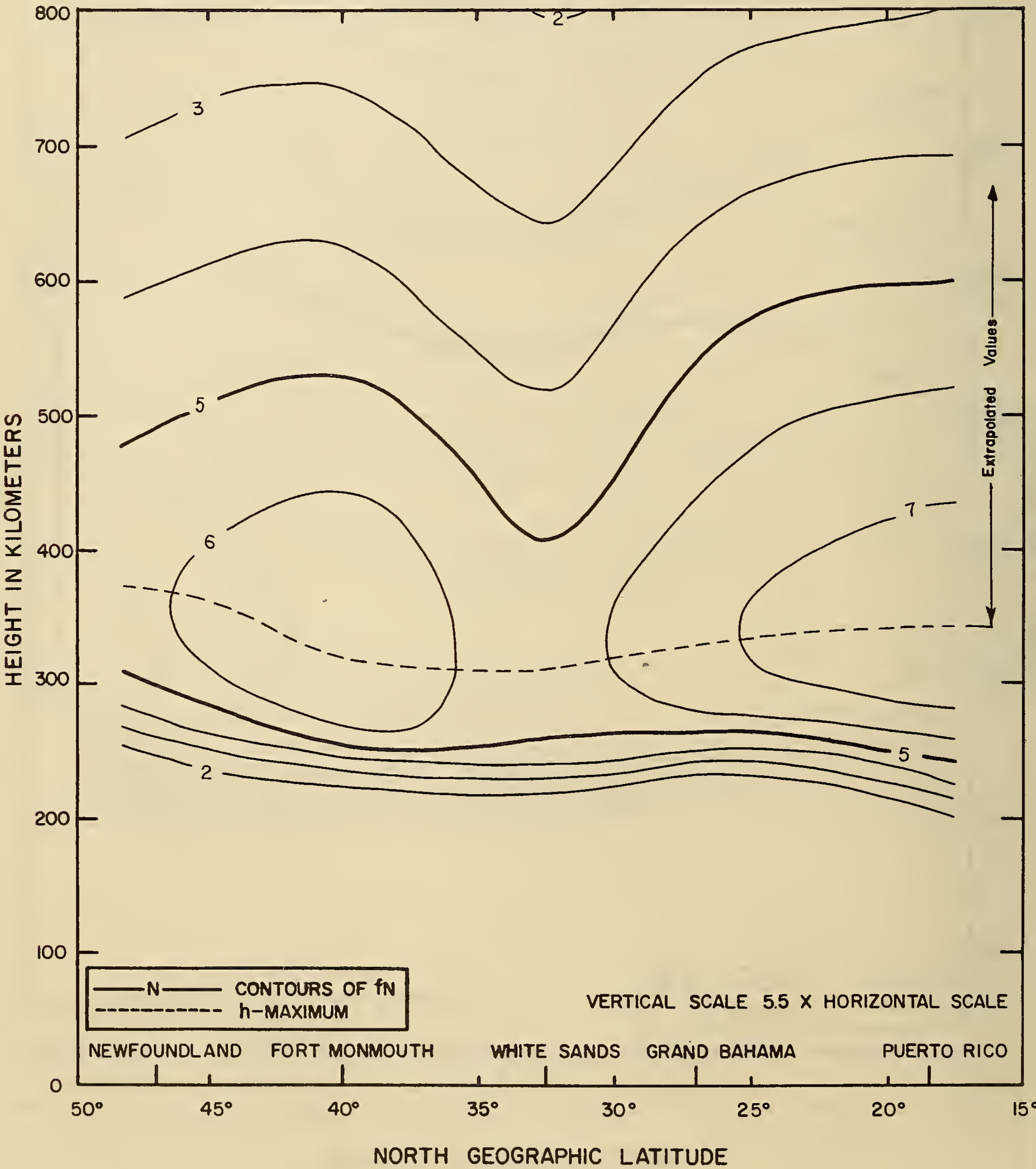

NOVEMBER 1959
1800 75° W TIME
800
700
600
500
400
300
200
100
0
HEIGHT IN KILOMETERS
3
4
5
8
10
11
5
2
Extrapolated Values
CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

NOVEMBER 1959
1900 75° W TIME

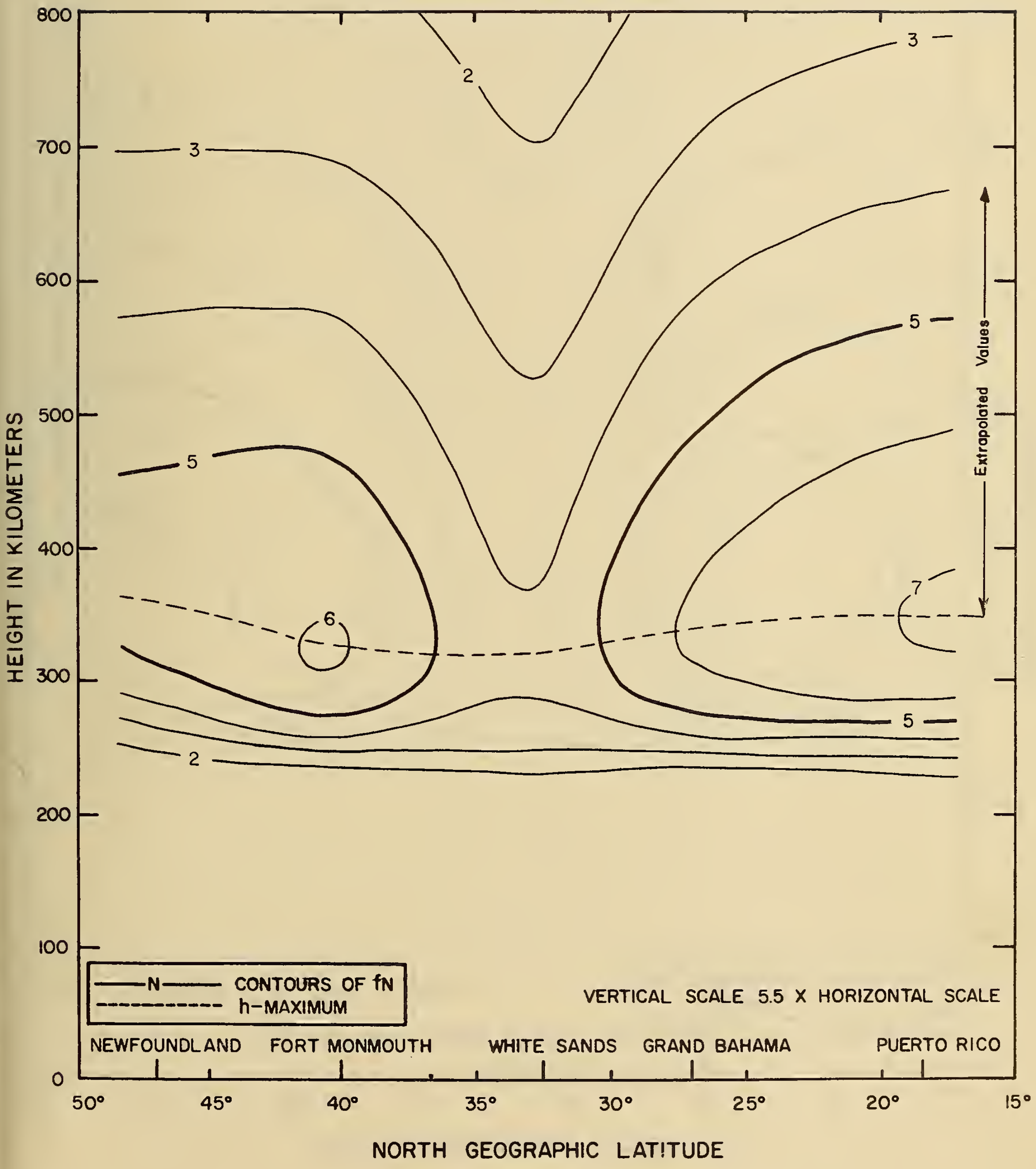


NOVEMBER 1959

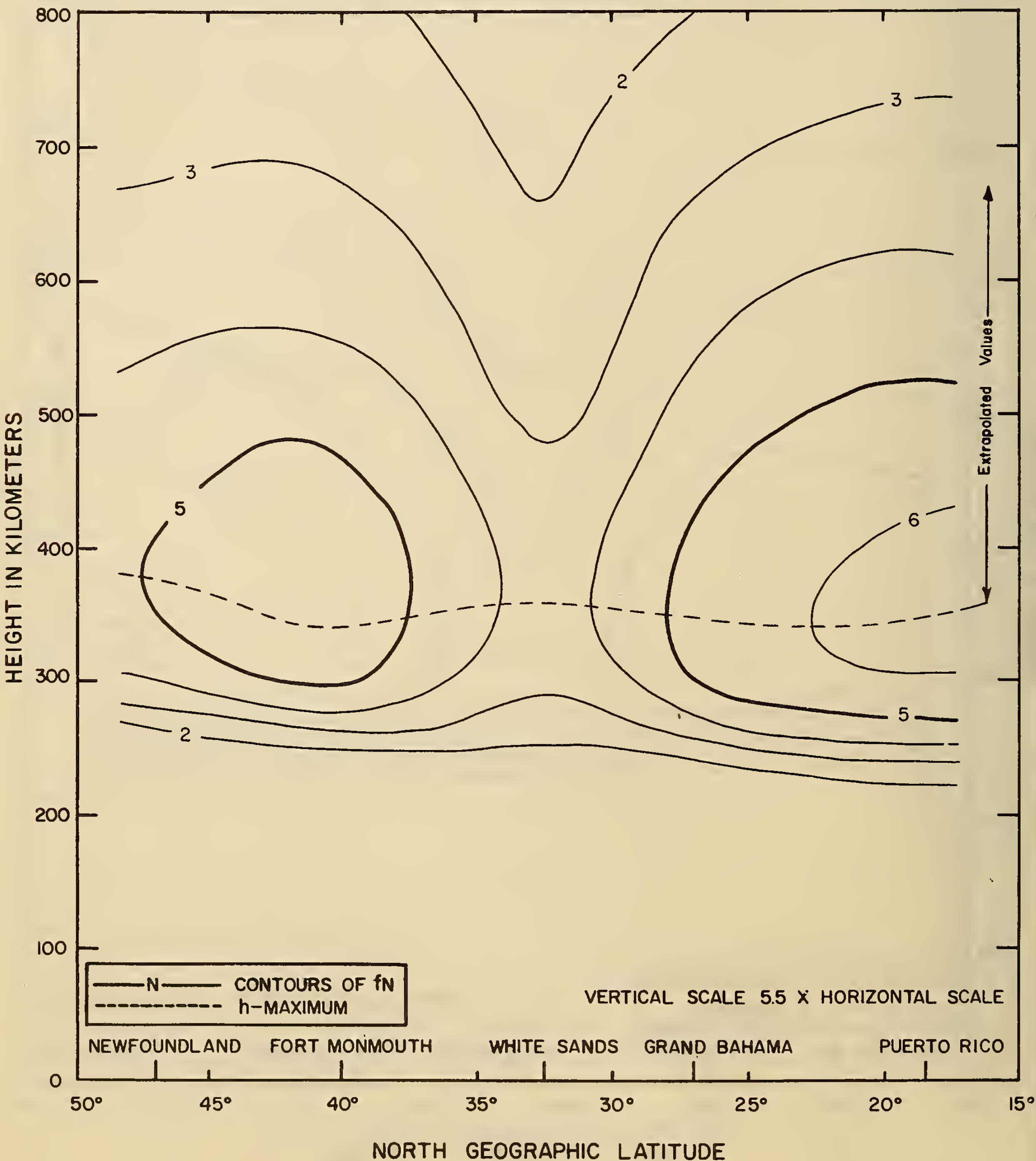
2000 75° W TIME



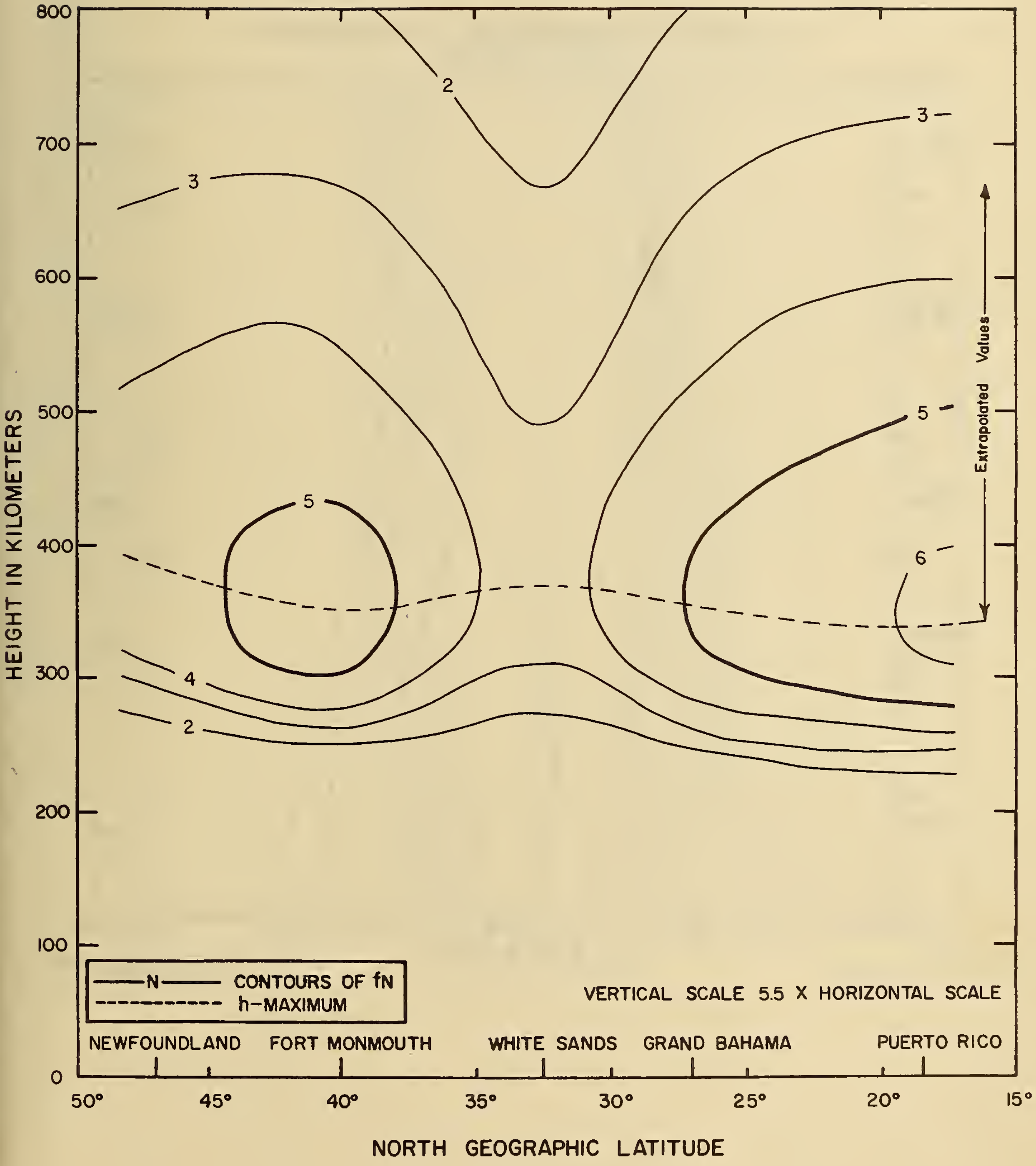
NOVEMBER 1959
2100 75° W TIME

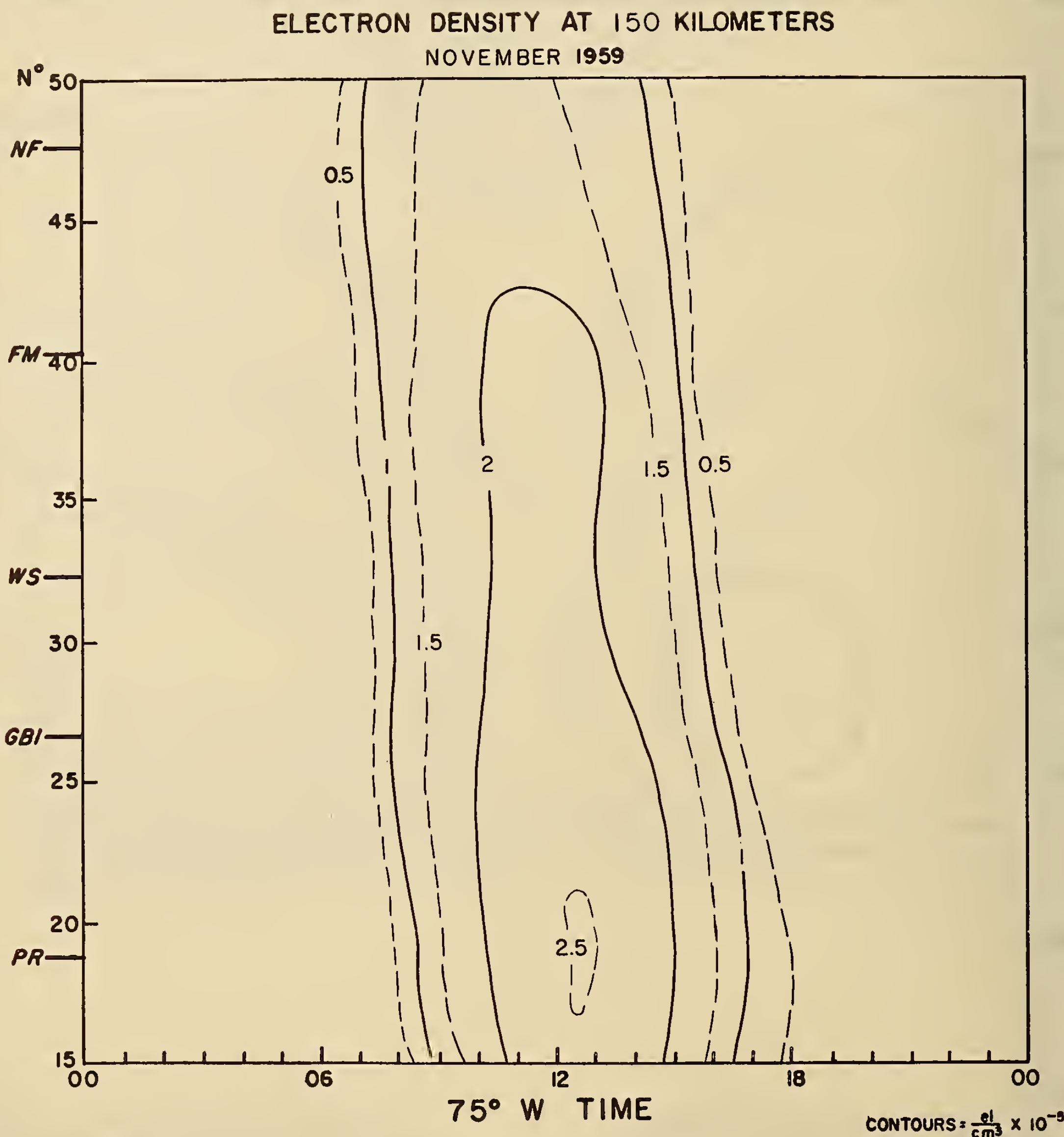


NOVEMBER 1959
2200 75° W TIME

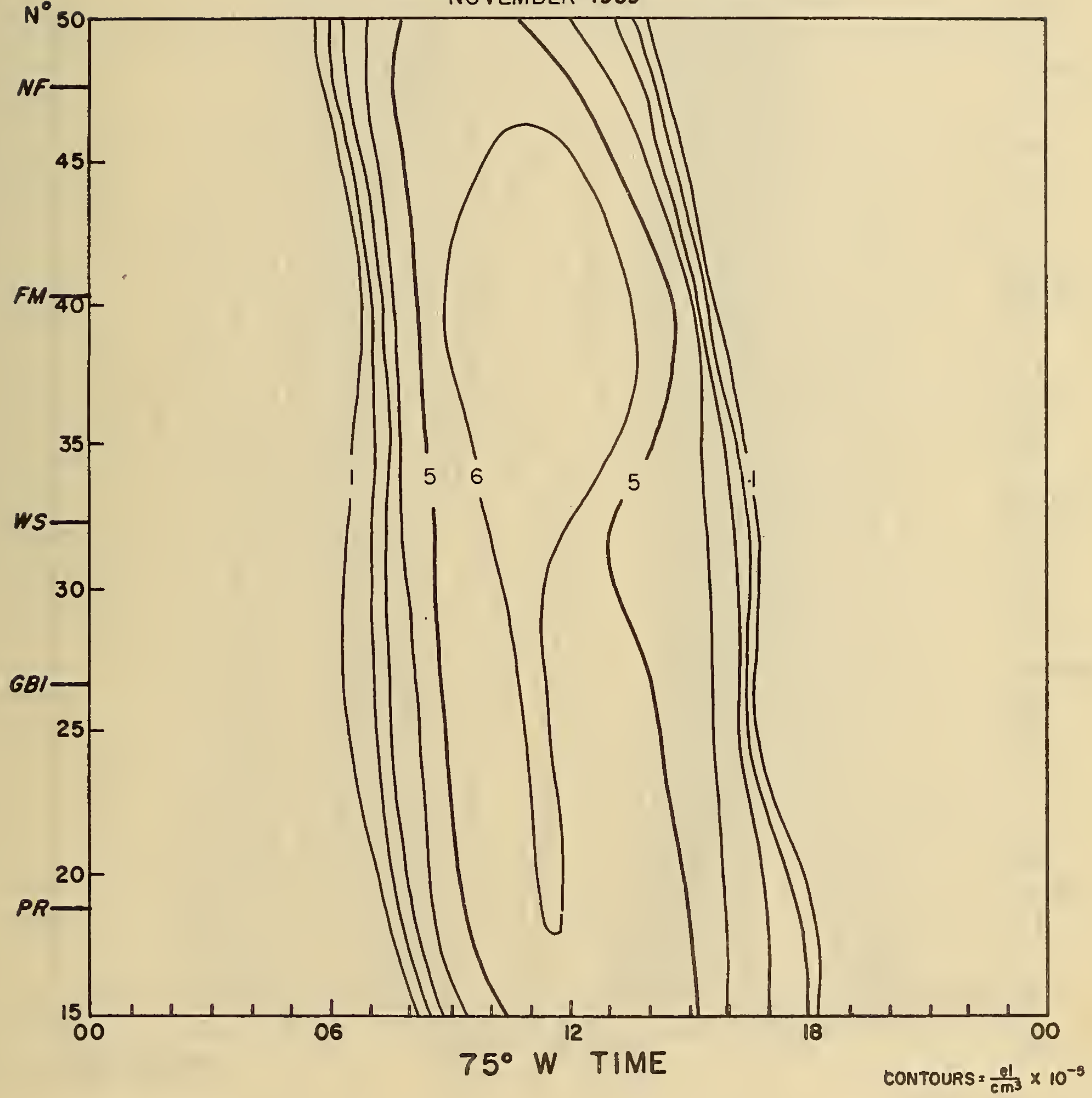


NOVEMBER 1959
2300 75° W TIME

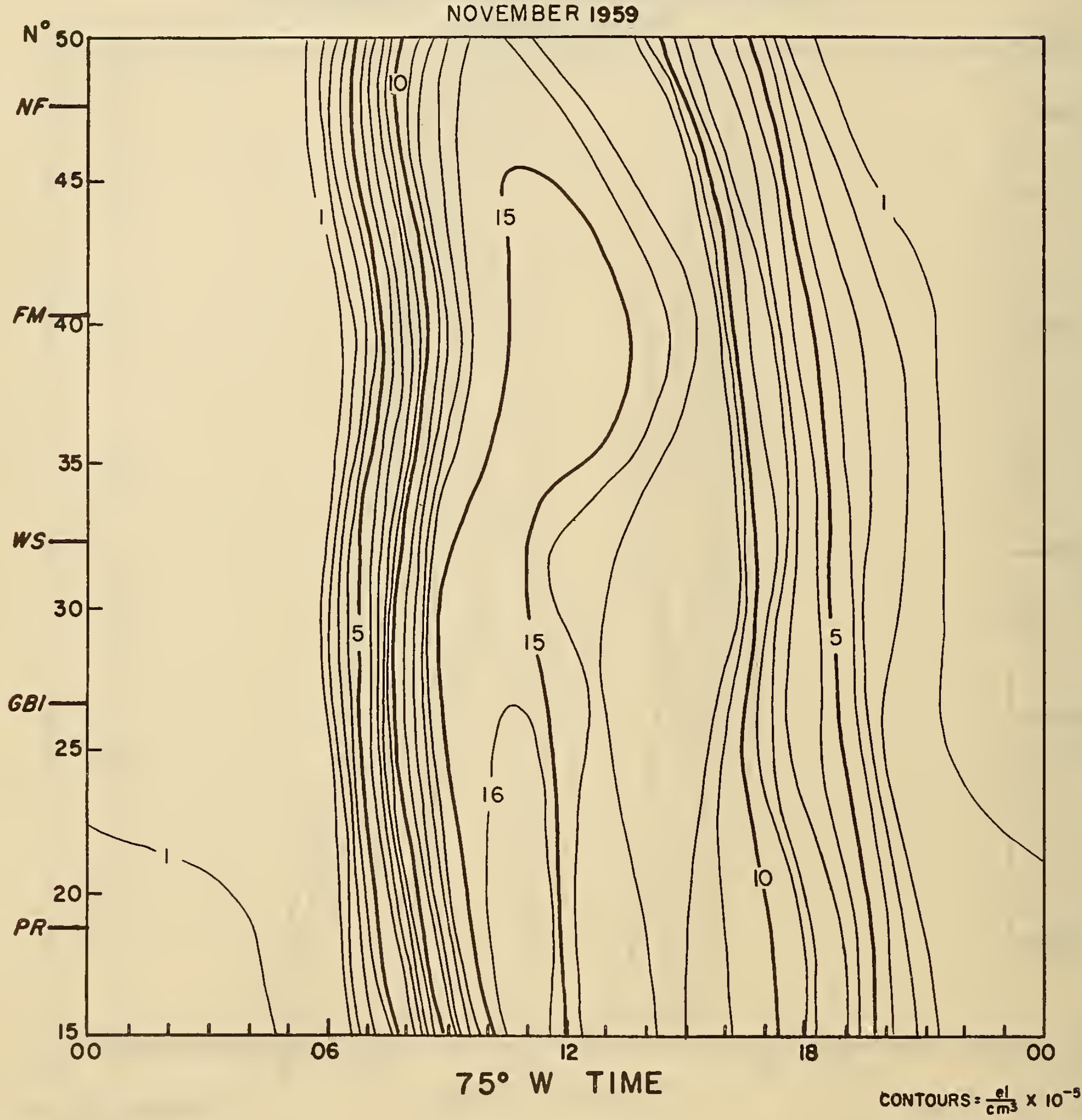



ELECTRON DENSITY AT 150 KILOMETERS
NOVEMBER 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
0.5
1
1.5
2
2.5
1.5
0.5
00
06
12
18
00
75° W TIME
CONTOURS = el/cm³ × 10⁻⁵

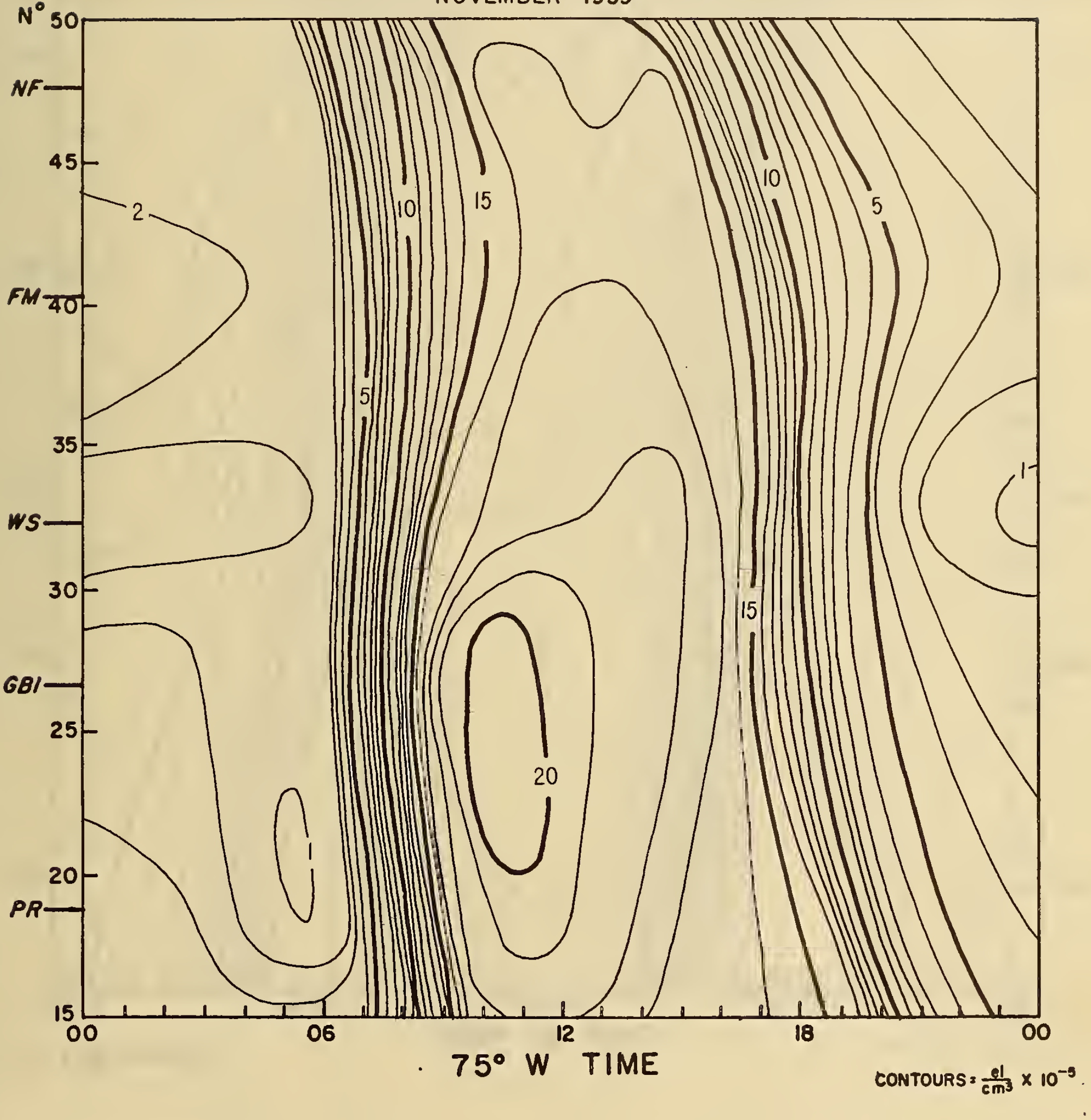
ELECTRON DENSITY AT 200 KILOMETERS
NOVEMBER 1959



ELECTRON DENSITY AT 250 KILOMETERS
NOVEMBER 1959

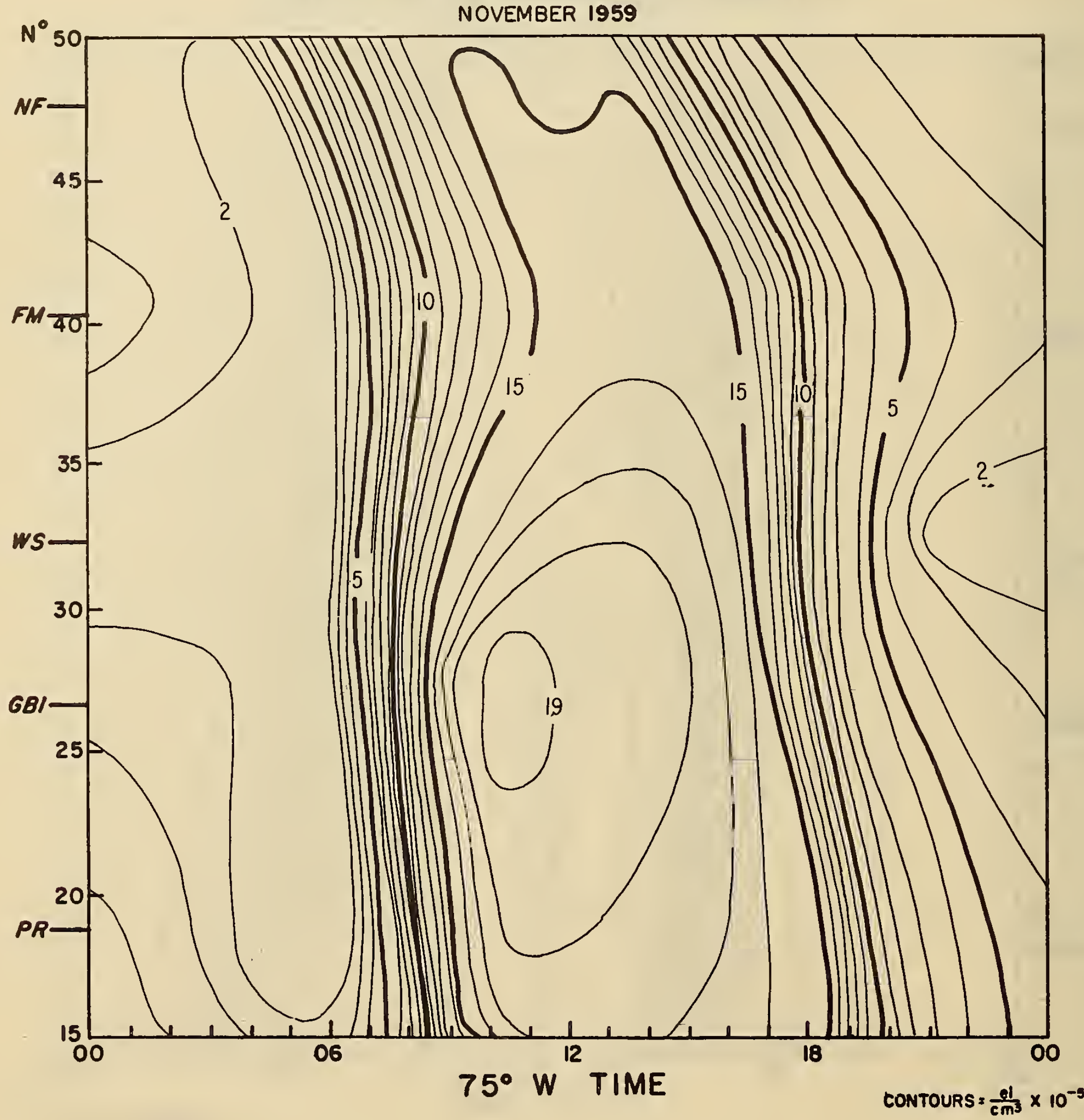


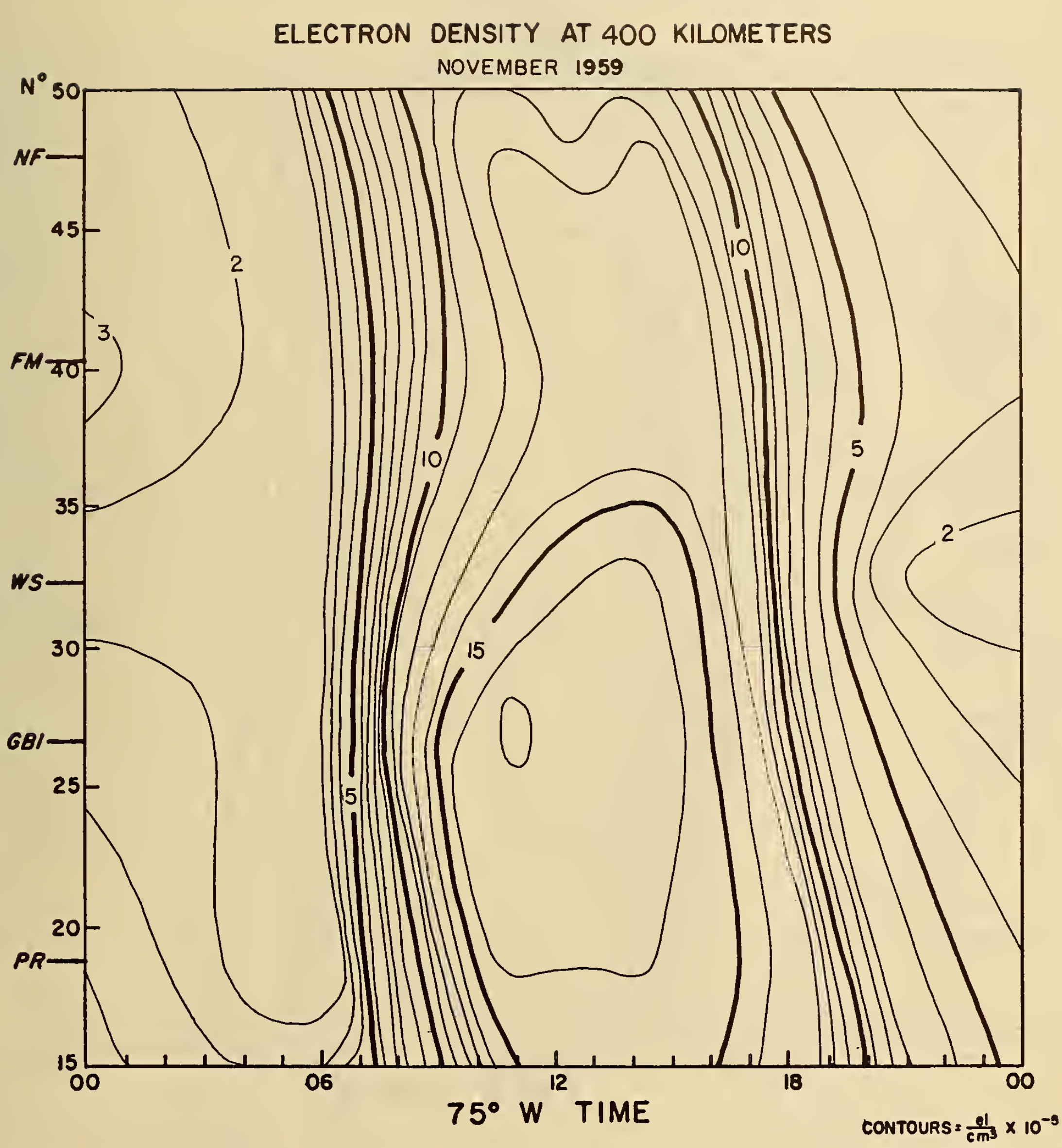
ELECTRON DENSITY AT 300 KILOMETERS
NOVEMBER 1959



ELECTRON DENSITY AT 350 KILOMETERS

NOVEMBER 1959

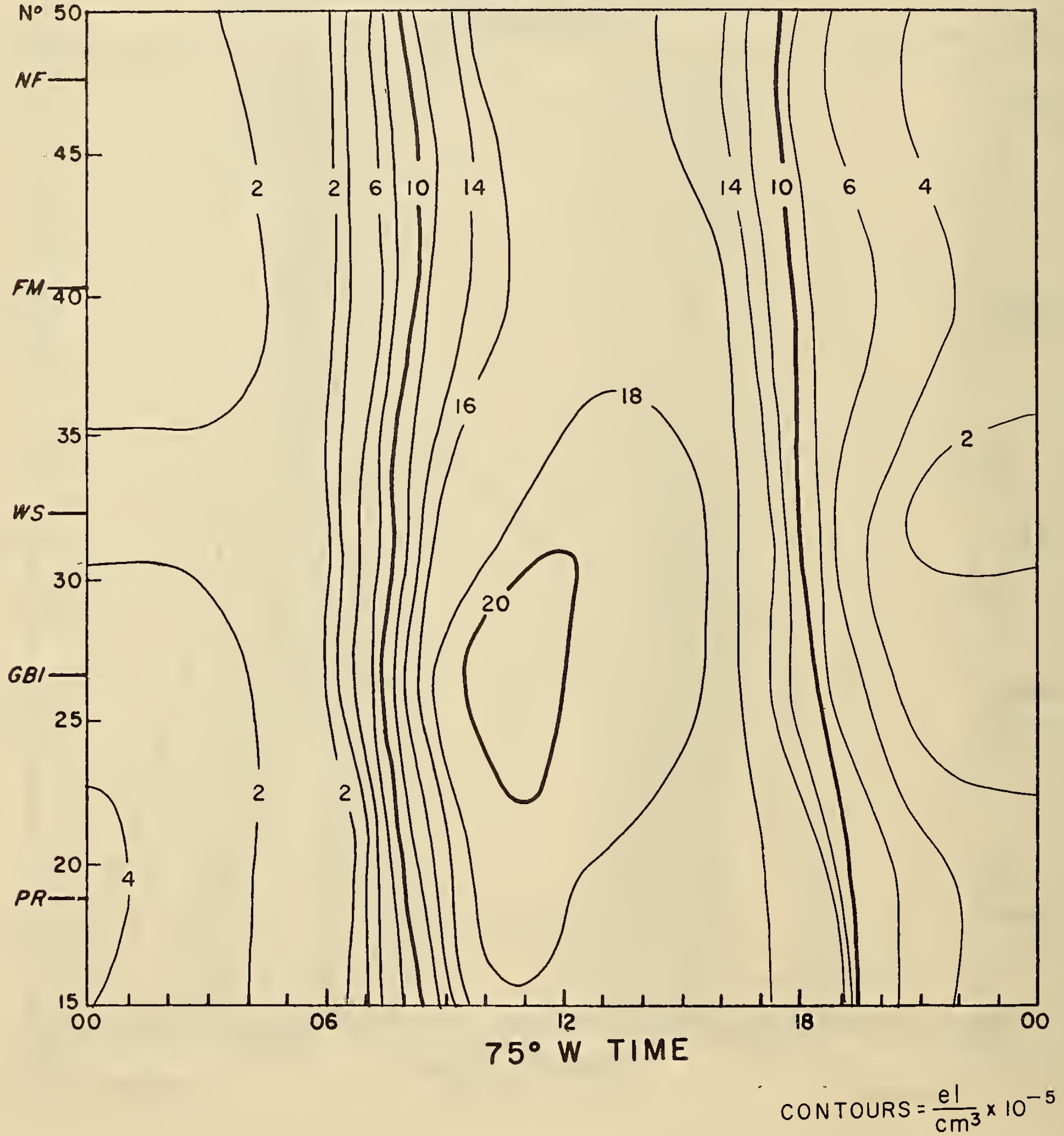



ELECTRON DENSITY AT 400 KILOMETERS
NOVEMBER 1959
N° 50
NF
45
40
FM
35
WS
30
GBI
25
20
PR
15
00
06
12
18
00
75° W TIME
CONTOURS: el/cm³ x 10⁻⁵
2
3
10
15
5
10
5
2

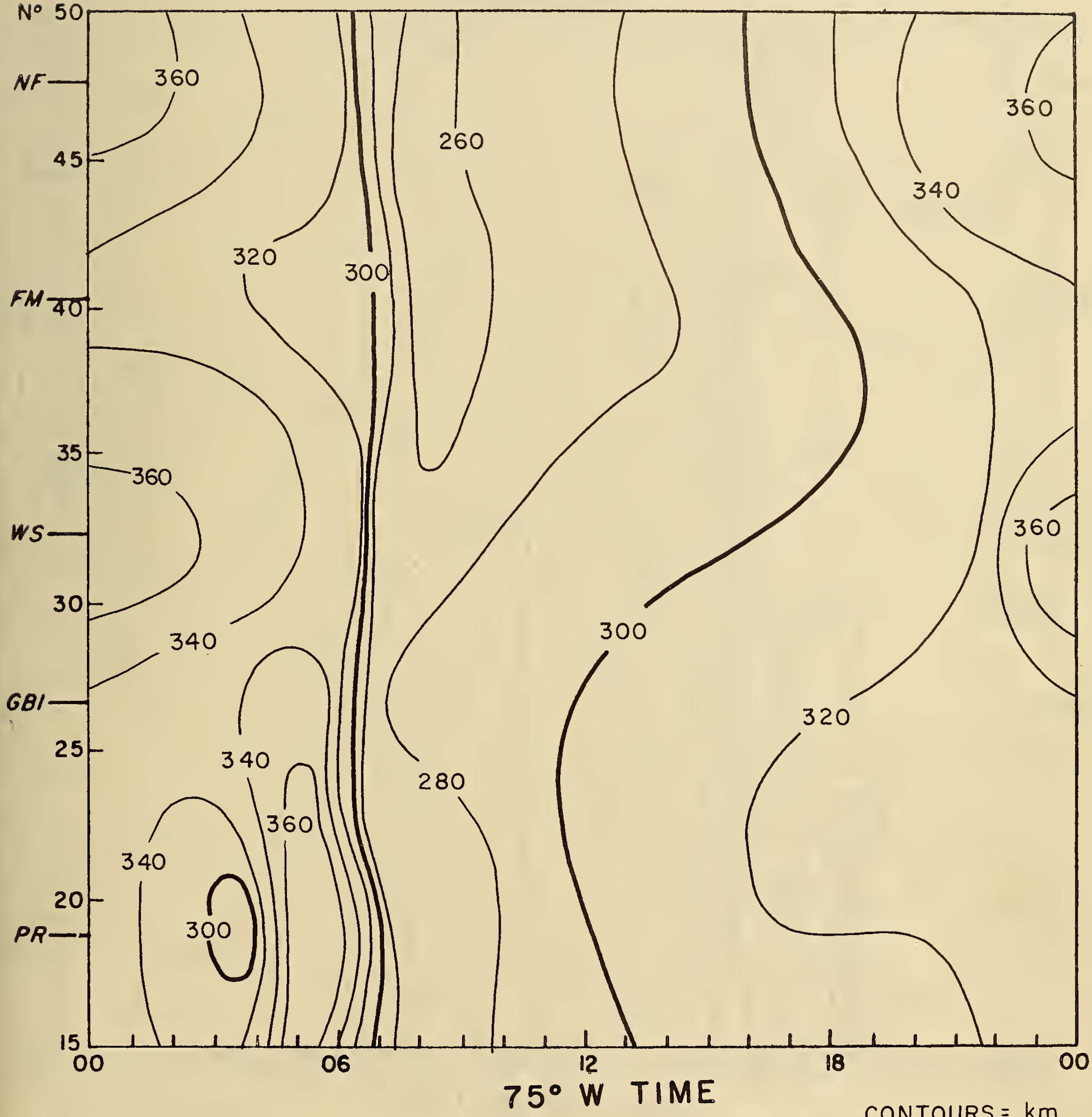
MAXIMUM ELECTRON DENSITY

NMAX

NOVEMBER 1959



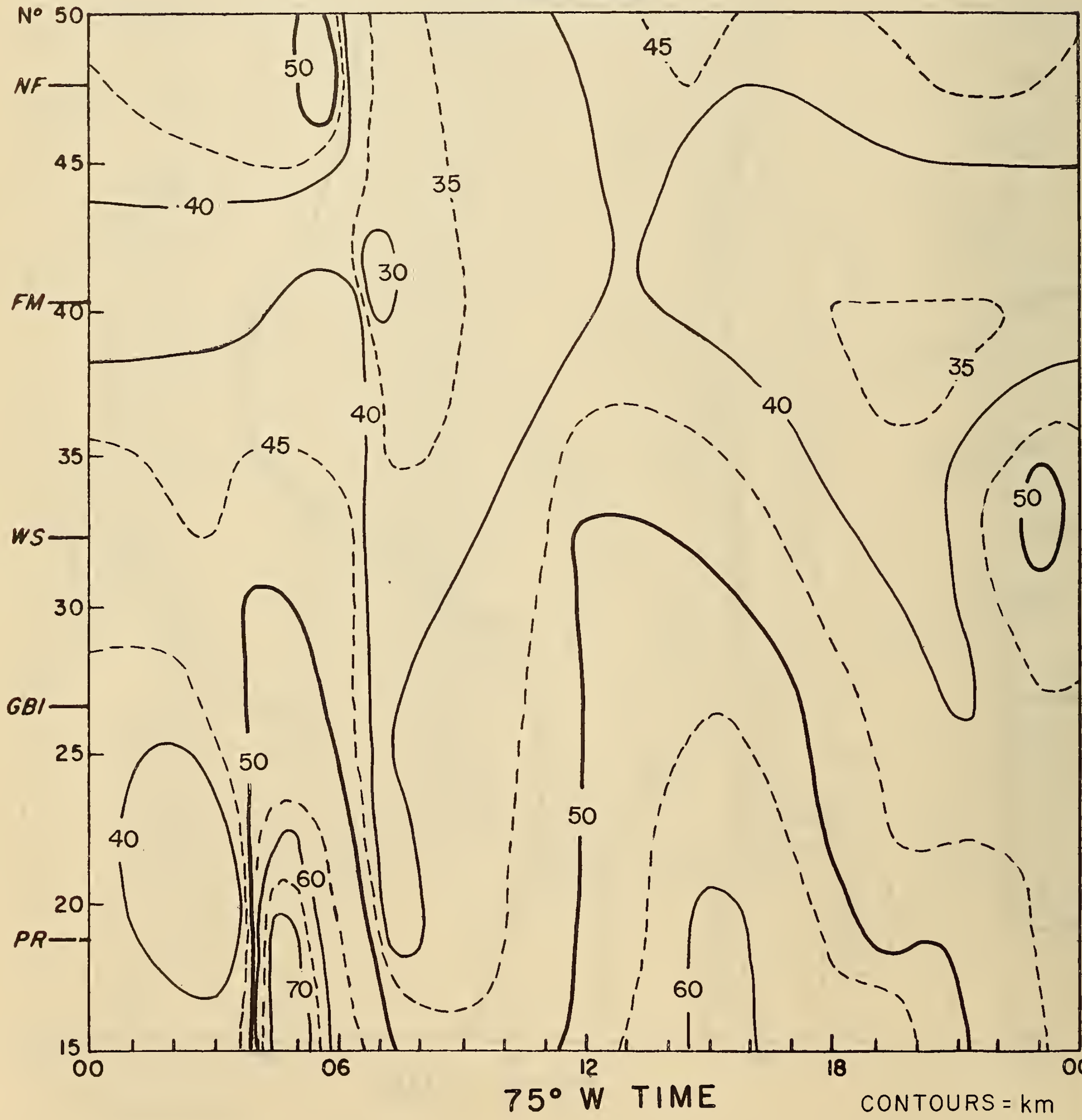
HEIGHT OF MAXIMUM ELECTRON DENSITY
HMAX
NOVEMBER 1959



QUARTER THICKNESS OF F-REGION PEAK

SCAT

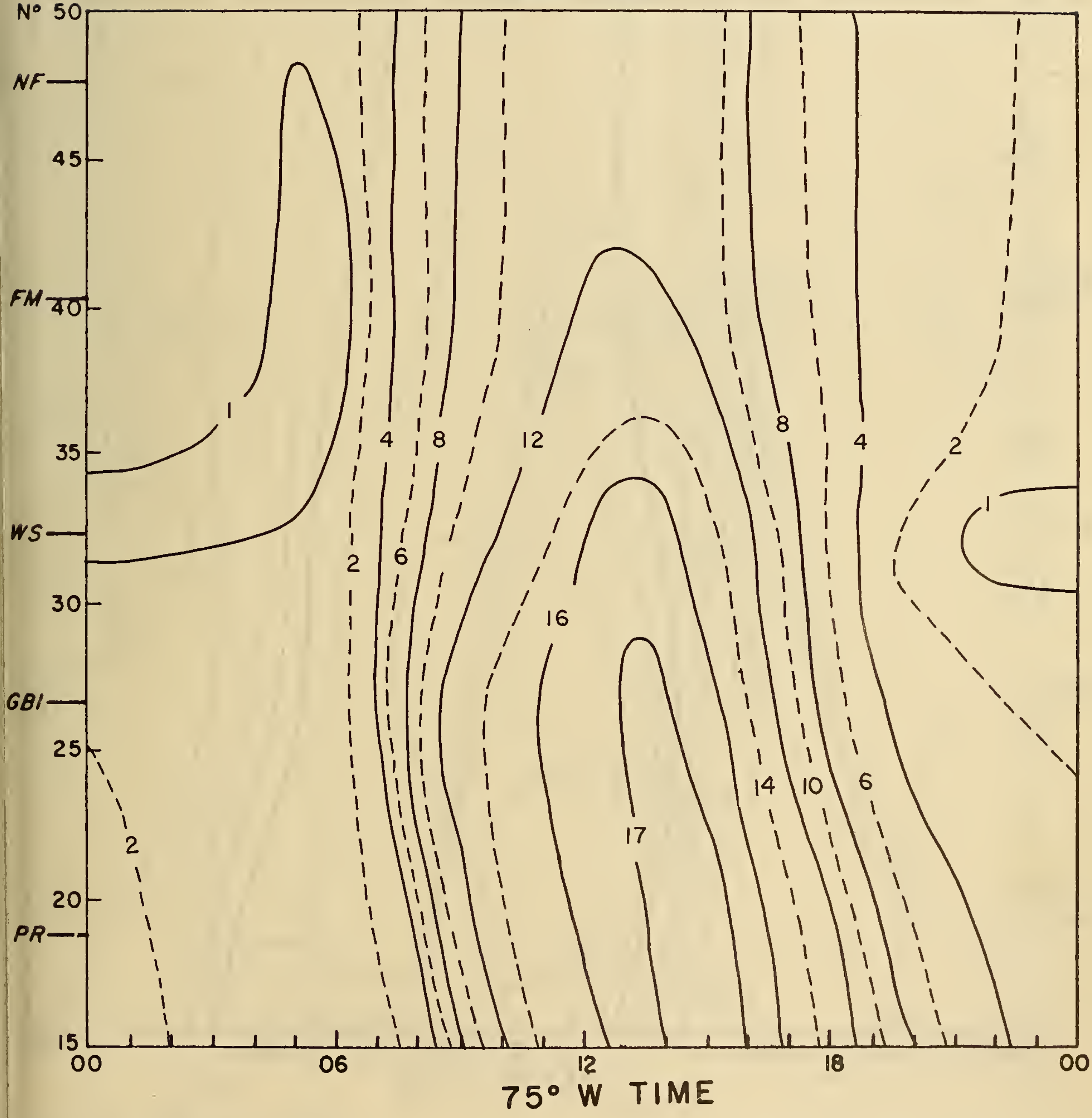
NOVEMBER 1959



ELECTRON DENSITY INTEGRATED TO HEIGHT OF MAXIMUM ELECTRON DENSITY

SHMAX

NOVEMBER 1959

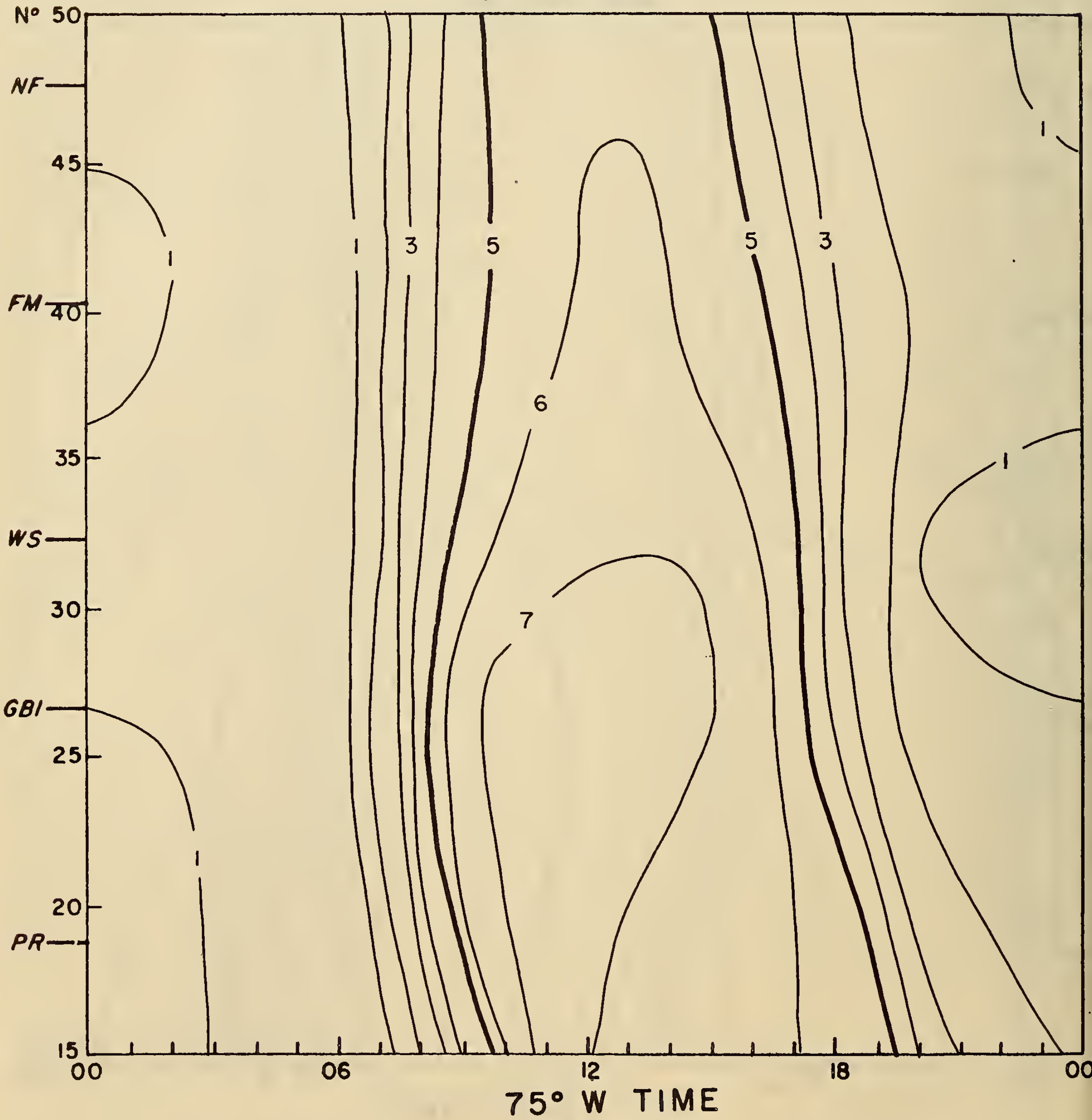


CONTOURS = $\frac{el}{cm^2}$ col. x 10^{-12}

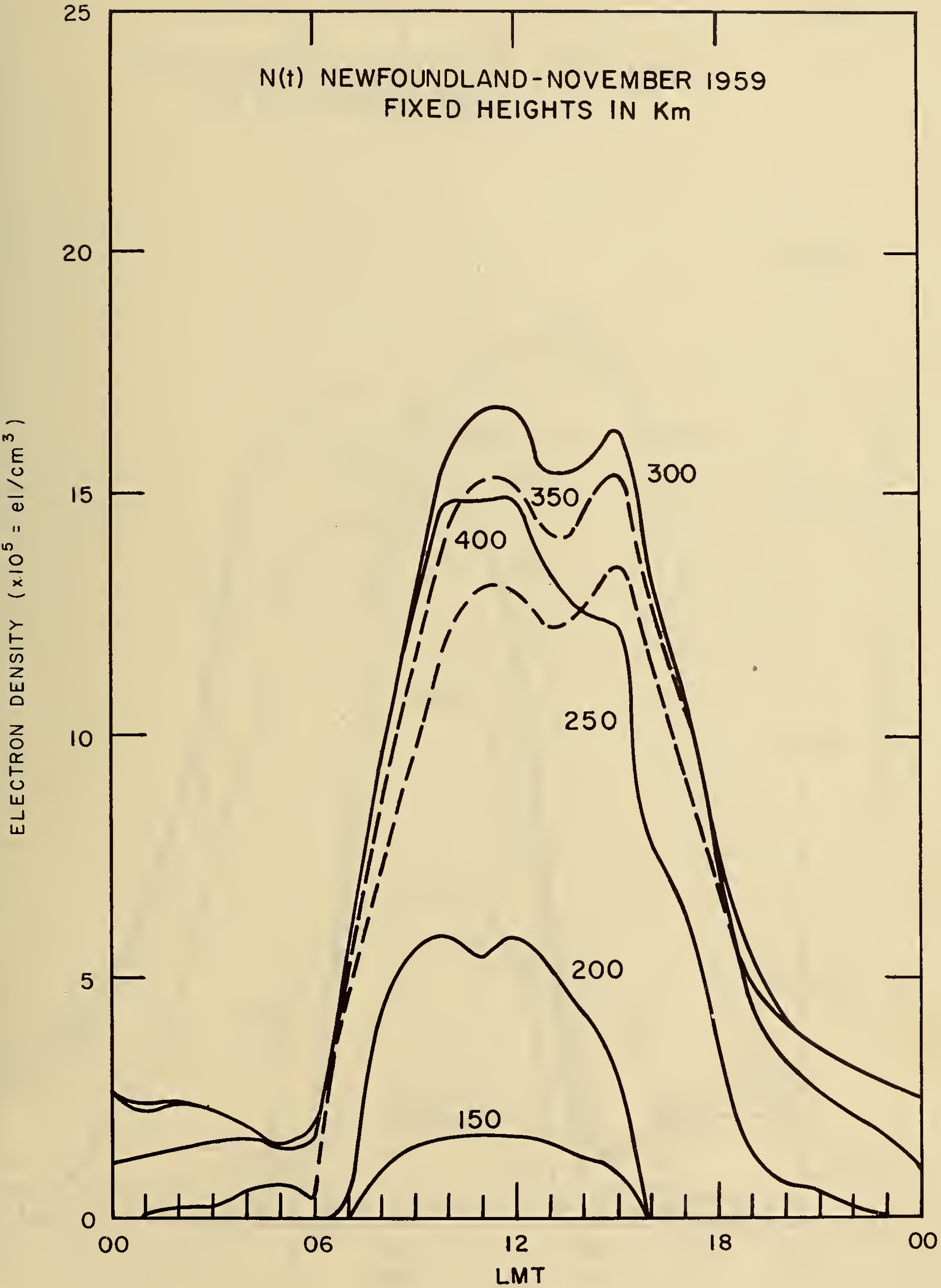
ELECTRON DENSITY INTEGRATED TO INFINITY

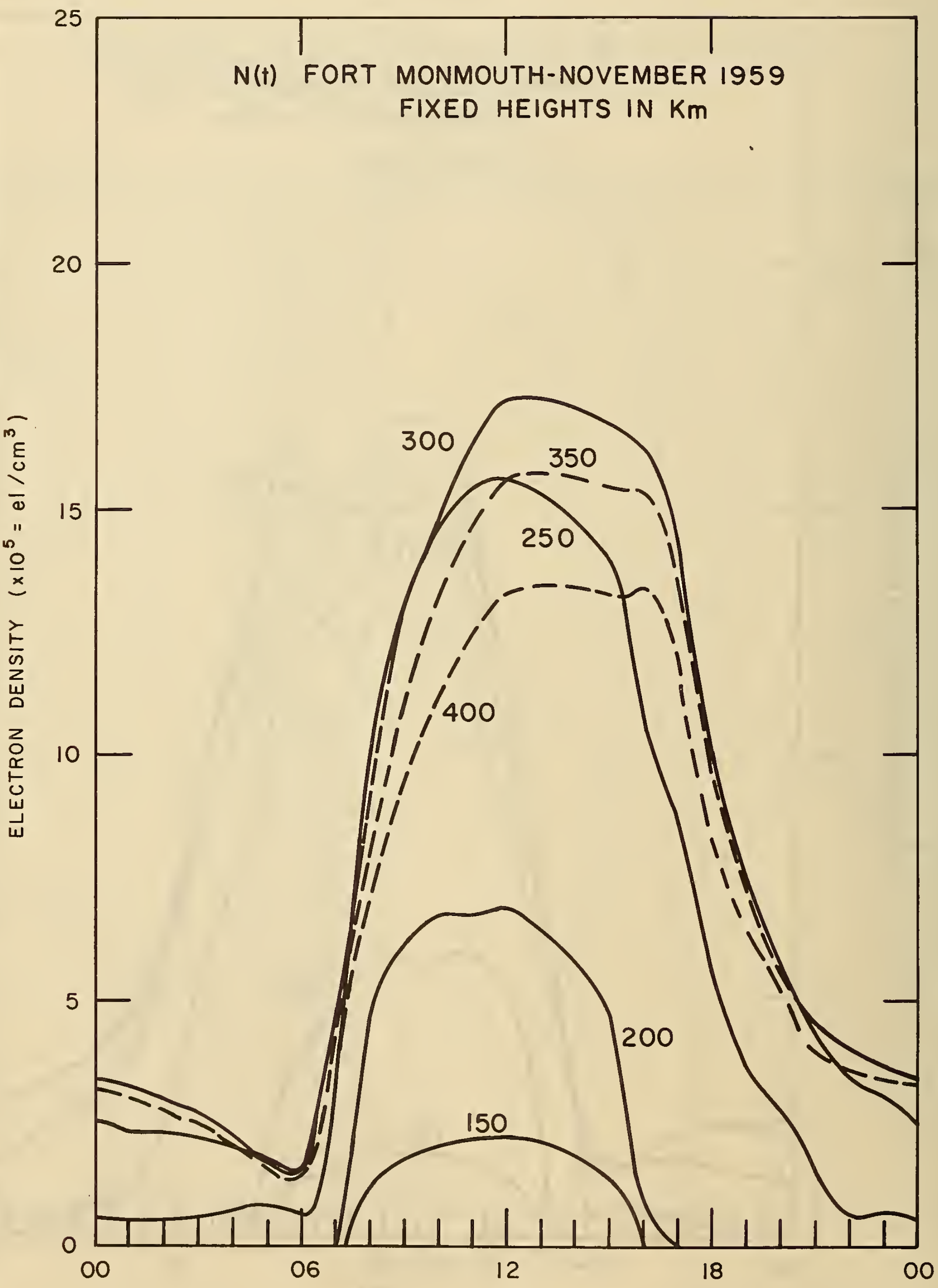
SHINF

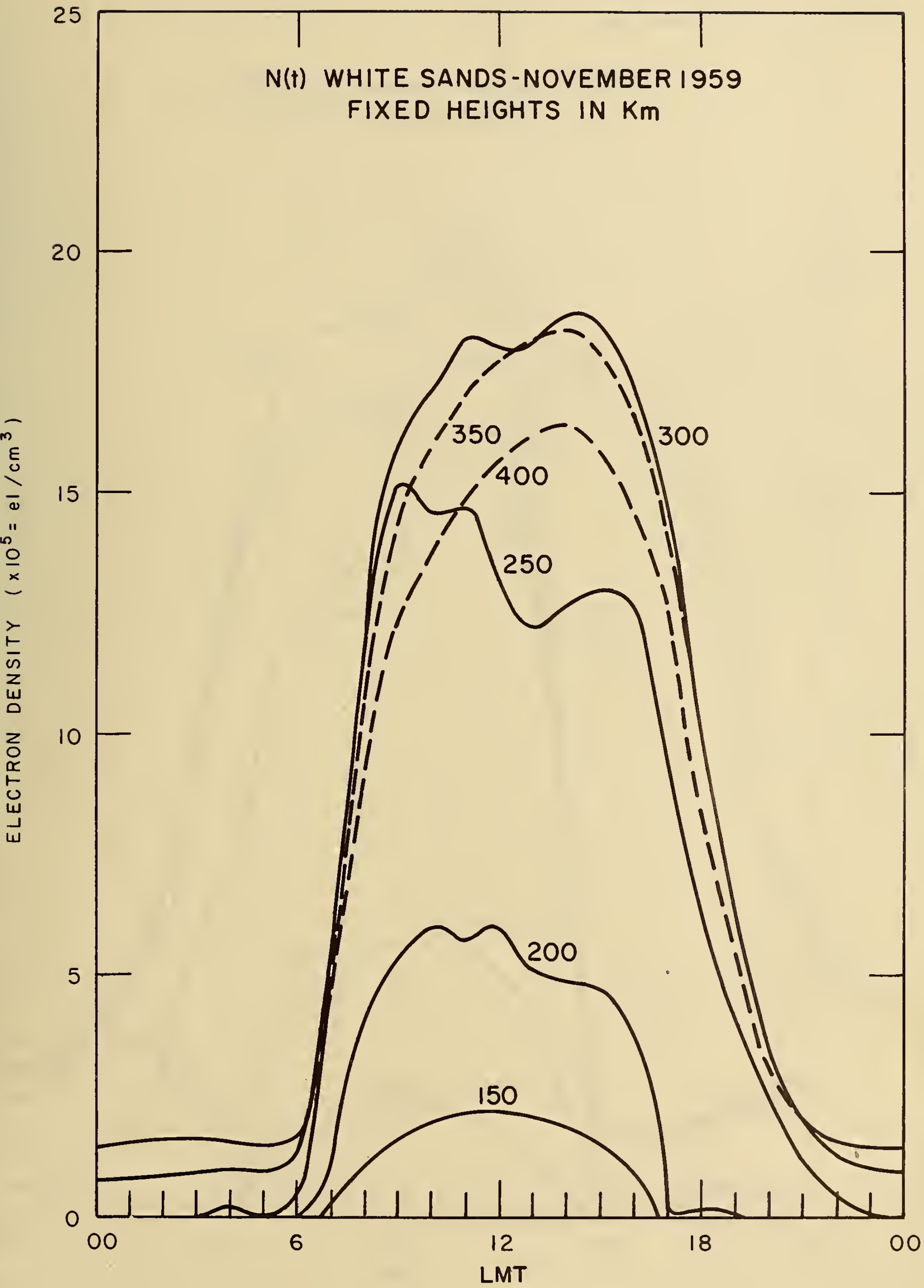
NOVEMBER 1959

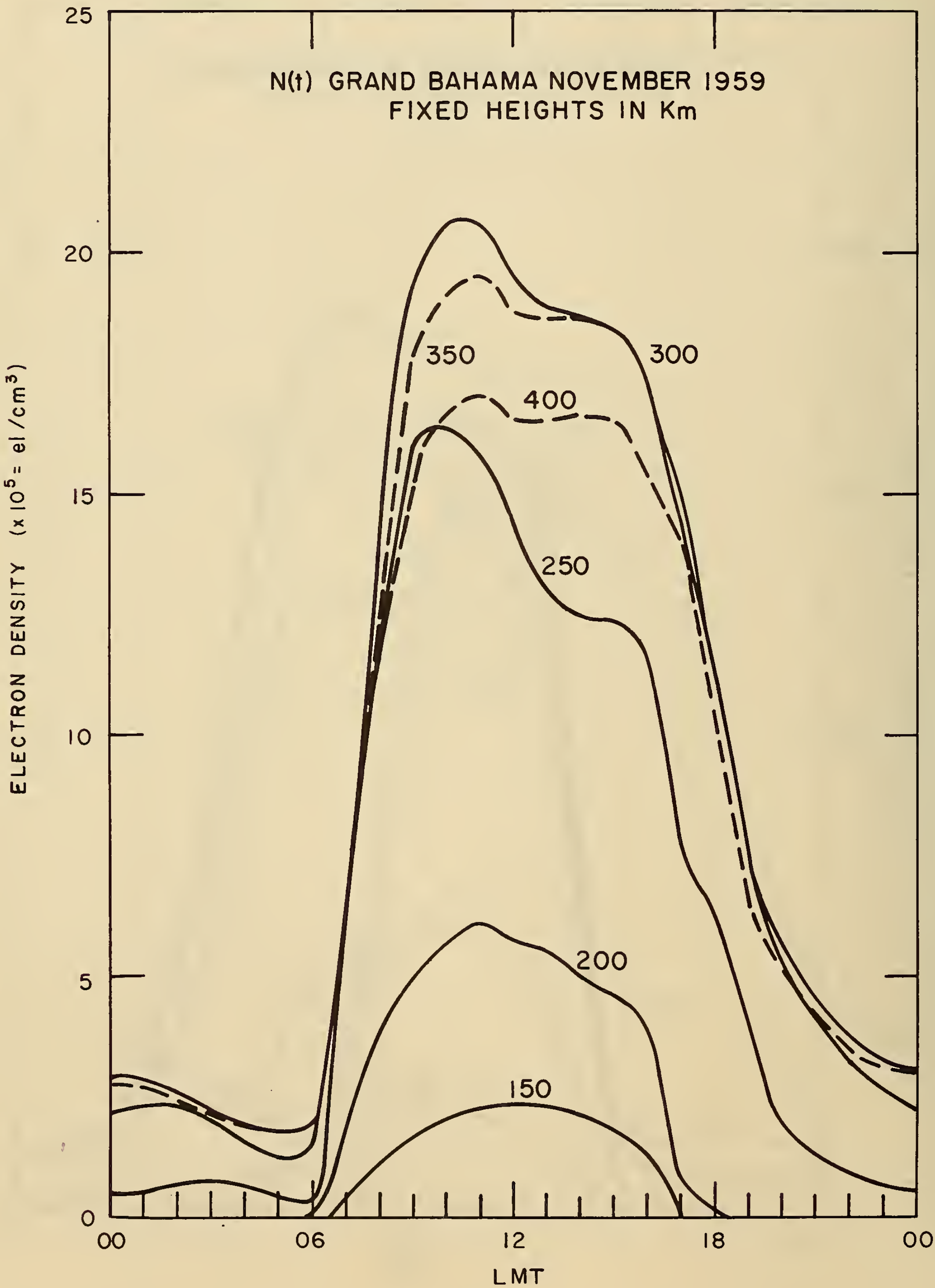


CONTOURS = $\frac{el}{cm^2}$ col. x 10^{-1}

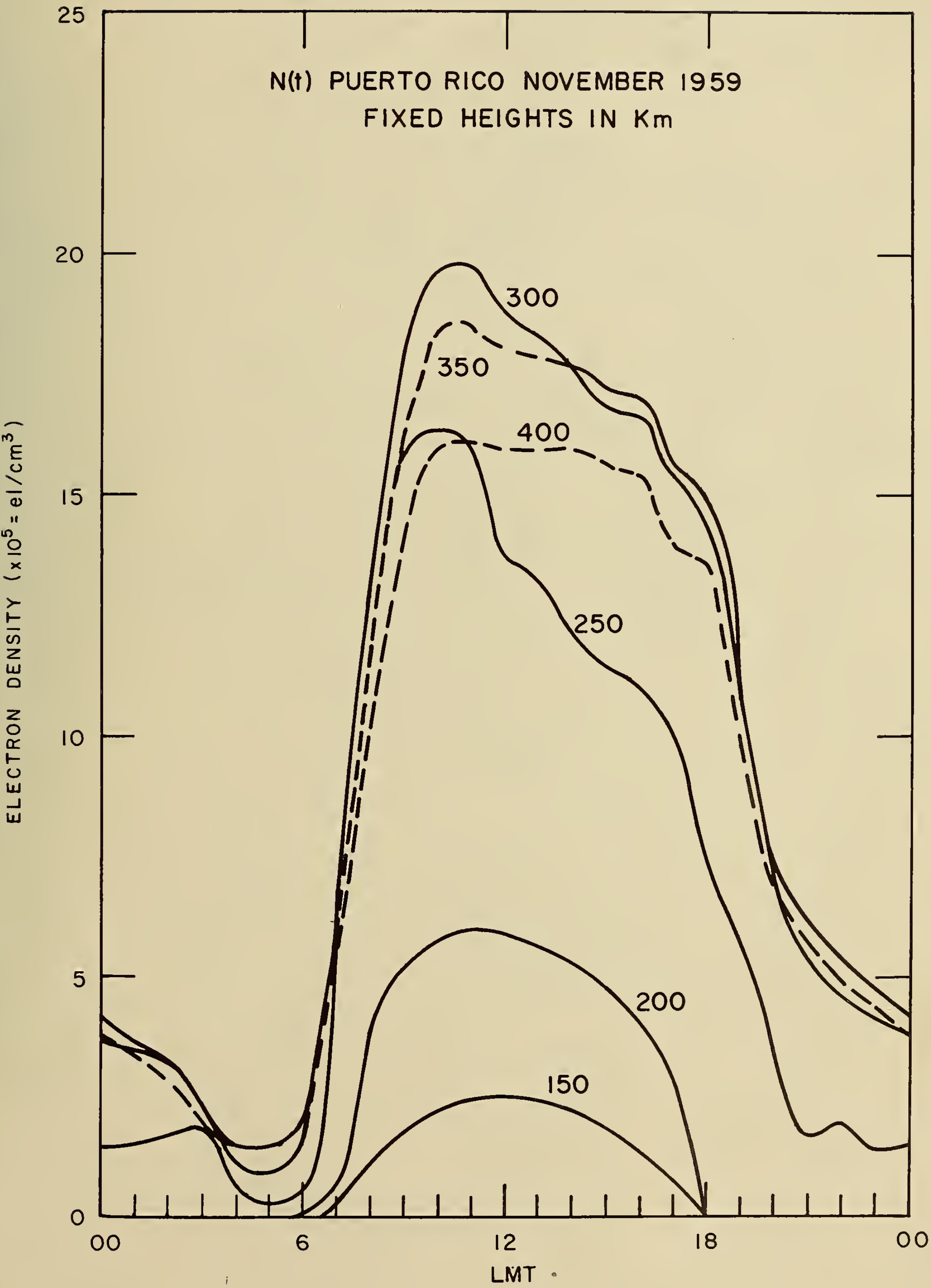

N(t) NEWFOUNDLAND-NOVEMBER 1959
FIXED HEIGHTS IN Km
300
350
400
250
200
150
ELECTRON DENSITY (x10^5 = el/cm^3)
25
20
15
10
5
0
00
06
12
18
00
LMT


N(t) FORT MONMOUTH-NOVEMBER 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x10^5 = el/cm^3)
25
20
15
10
5
0
300
350
250
400
200
150
00
06
12
18
00
LMT


N(t) WHITE SANDS-NOVEMBER 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x10^5 = el/cm^3)
25
20
15
10
5
0
350
300
400
250
200
150
00
6
12
18
00
LMT



N(t) GRAND BAHAMA NOVEMBER 1959
FIXED HEIGHTS IN Km
25
20
15
10
5
0
ELECTRON DENSITY (x 10^5 = el/cm^3)
350
300
400
250
200
150
00
06
12
18
00
LMT


N(t) PUERTO RICO NOVEMBER 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x10⁵ = el/cm³)
25
20
15
10
5
0
300
350
400
250
200
150
00
6
12
18
00
LMT

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. High Voltage.

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. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

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

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Microscopy and Diffraction. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

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

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Far Ultraviolet Physics. Solid State Physics. Electron Physics. Atomic Physics. Plasma Spectroscopy.

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

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Elementary Processes. Mass Spectrometry. Photochemistry and Radiation Chemistry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering Laboratory. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

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

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Research. Radiodetermination.

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

RADIO STANDARDS LABORATORY

Radio Physics. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Millimeter-Wave Research.

Circuit Standards. High Frequency Electrical Standards. High Frequency Calibration Services. High Frequency Impedance Standards. Microwave Calibration Services. Microwave Circuit Standards. Low Frequency Calibration Services.

NBS