



Technical Note

No. 40 - 2

Boulder Laboratories

MEAN ELECTRON DENSITY VARIATIONS OF THE QUIET IONOSPHERE

2 - APRIL 1959

BY J. W. WRIGHT AND L. A. FINE



U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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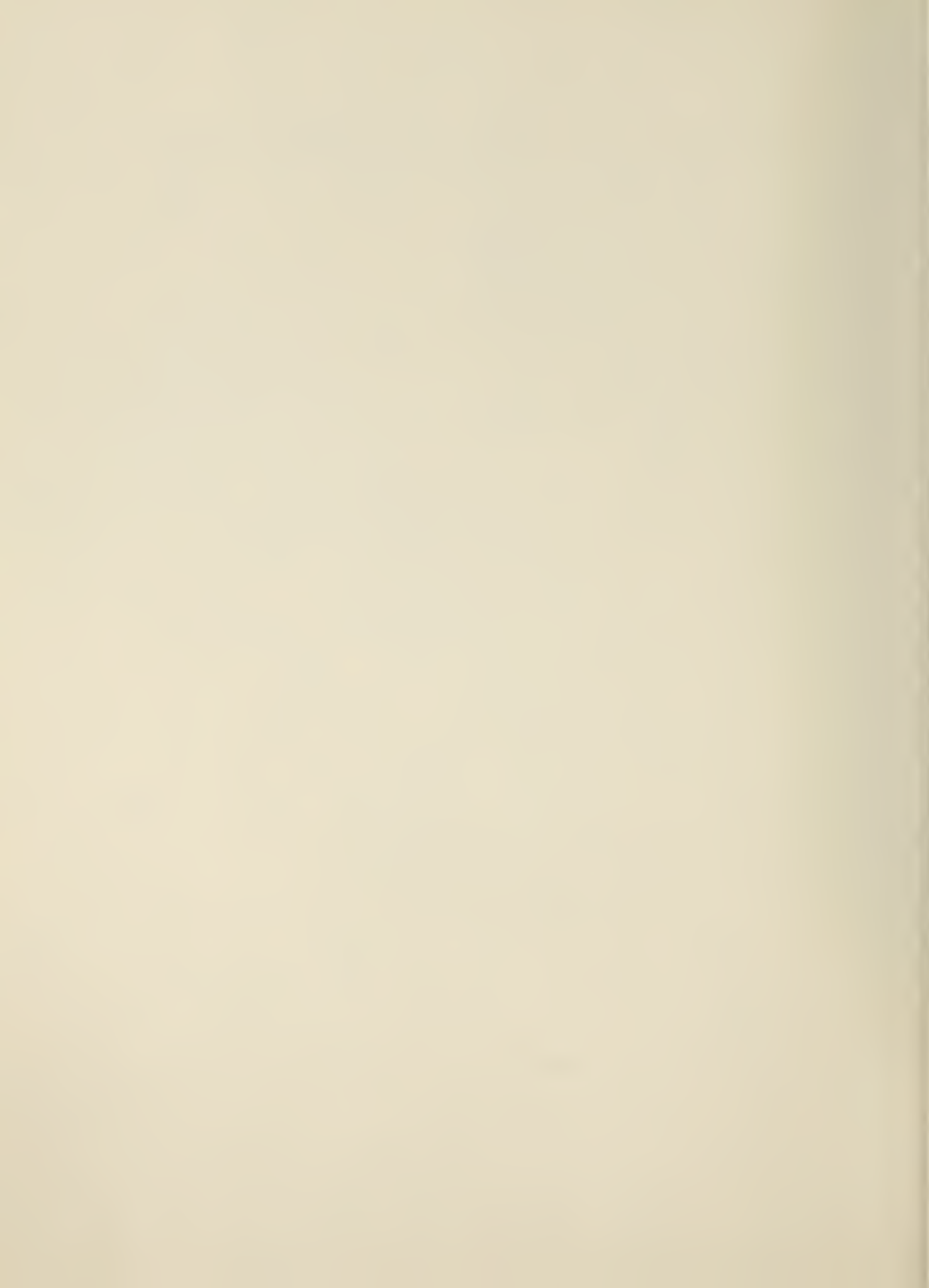
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2 - APRIL 1959

By J. W. Wright and L. A. Fine
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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 April are illustrated graphically. This report is the second 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.

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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 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 in cooperation with the U. S. Army Signal Ionosphere Stations of the Signal Radio Propagation Agency, 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 (U. S. Army Signal Corps, April 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)

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.

This report contains these 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 April 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)	$\times 10^3 = \text{electron/cm}^3$	Body of table; given at each 10 km of height from the lowest hmin to 950 km.
NMAX	$\times 10^3 = \text{electron/cm}^3$	The mean value of Nmax.
COUNT		Count of the number of profiles entering the 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.
SHMAX	$\times 10^{10} = \text{electrons/cm}^2 \text{ column}$ (10^{12} on maps)	Obtained by averaging the integration of the individual profiles between the limits HMIN and HMAX.
SHINF	$\times 10^{10} = \text{electrons/cm}^2 \text{ column}$ (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 $N_A = 2.82 H N_{max}$ 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° 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 March 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° 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, 300, 350, 400 km), contours of electron density are drawn in the latitude vs. local time plane. To the extent to which longitude variations 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, N_{max} ; its height, h_{max} ; the total electron content to n_{max} , Sh_{max} and the estimated total electron content, Sh_{inf} , 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_{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.

Acknowledgements

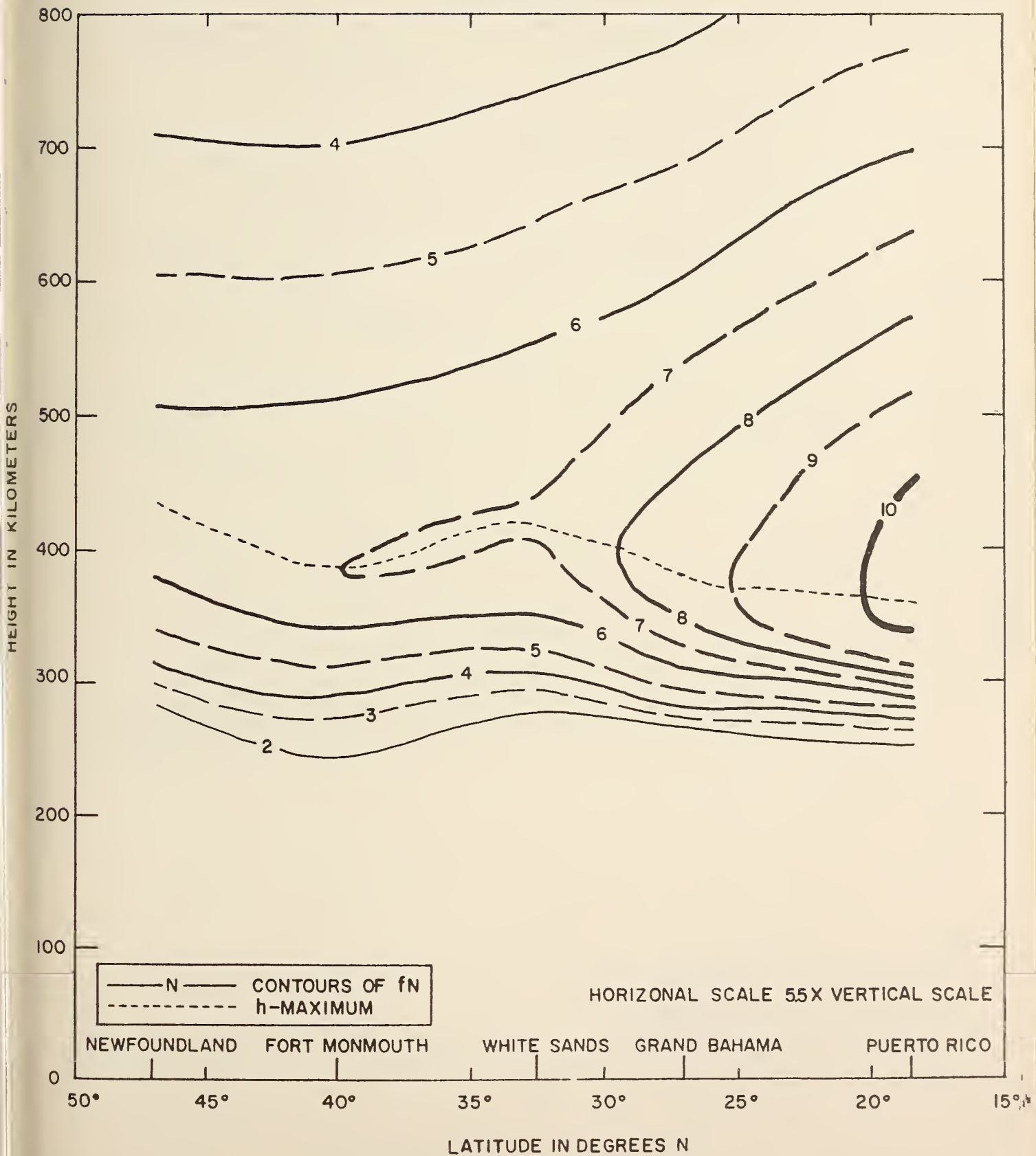
We are indebted to Mr. A. H. Shapley, Assistant Chief of the Radio Propagation Physics Division for guidance in the course of this program, and to Dr. H. H. Howe for the development of the computer programs upon which the whole system heavily depends. The cooperation of the U. S. Army Signal Radio Propagation Agency, in particular, the enthusiastic assistance of Mr. F. H. Dickson (Chief) and Mr. H. F. Busch (Chief, Field Operations), is essential to the success of the program and is gratefully acknowledged.

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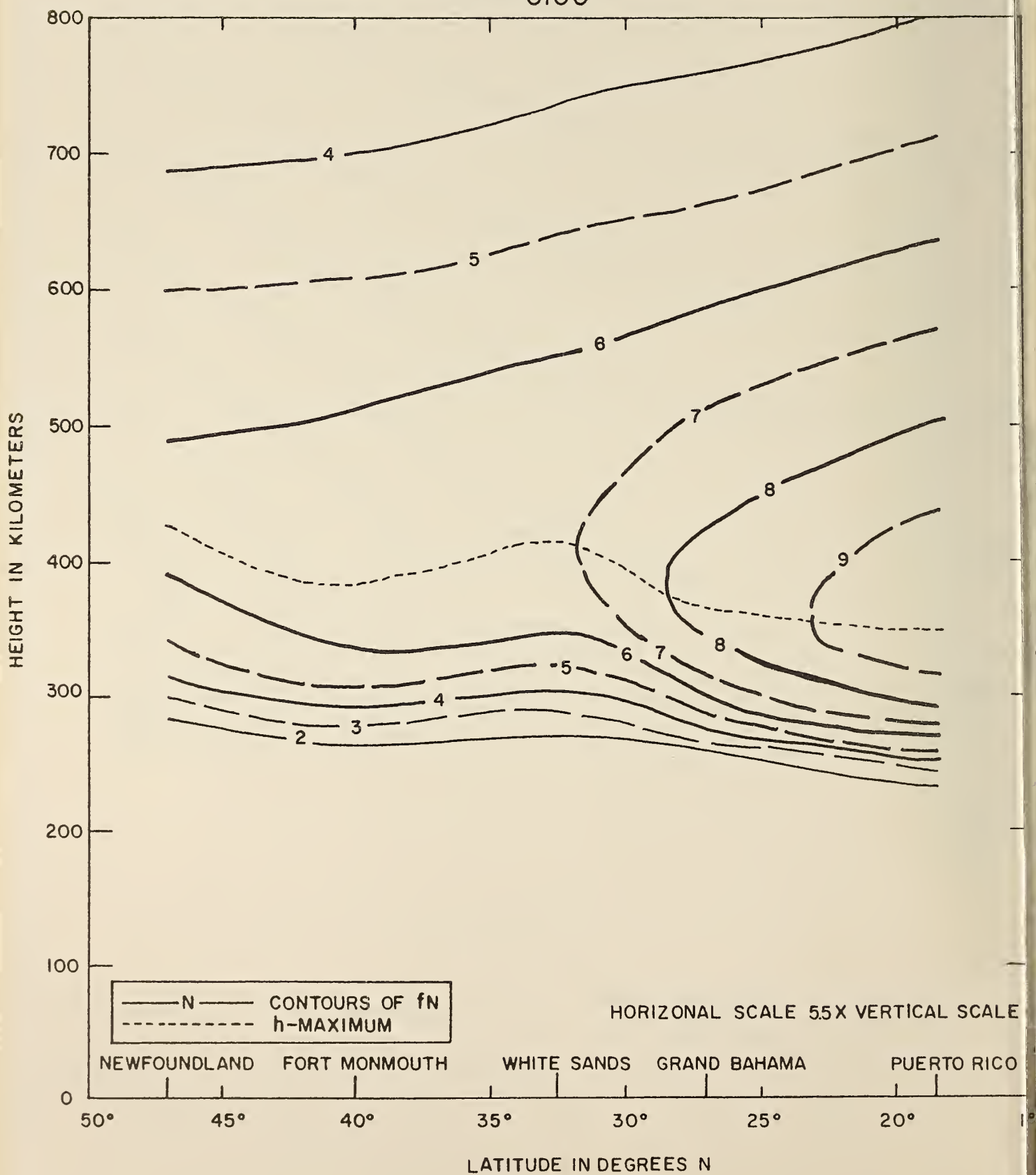
AVERAGE ELECTRON DENSITY													KP BELOW 4.5													
PUERTO RICO													APR 1959													
60 W													60 W													
TIME	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	TIME	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	
COUNT	263	246	228	228	239	243	266	114	110	110	110	109	25	25	24	26	25	21	14	24	25	20	210	220	2300	
HMIN	263	246	228	228	239	243	266	114	110	110	110	109	109	110	110	110	110	110	200	243	250	267	273	274		
RATIO	5.5	5.4	5.0	4.6	4.5	4.6	4.7	4.1	4.0	3.8	3.7	3.5	3.5	3.4	3.4	3.3	3.3	3.3	4.1	4.3	4.2	4.5	4.8	4.9		
NMAX	1441	1310	1055	835	717	654	699	1180	1681	2049	2212	2418	2537	2535	2433	2272	2110	1927	1709	1705	1573	1565	1522	1514		
HMAX	368	353	340	367	377	380	383	517	517	517	517	517	517	358	364	369	375	374	378	376	383	406	399	395		
SHMAX	908	852	765	667	583	531	545	1092	1608	2039	2343	2722	2862	2921	2892	2778	2572	2312	1752	1480	1428	1258	1146	1088		
SHINP	4974	4549	3740	3023	2605	2376	2515	4421	6349	7820	8584	9544	10018	10017	9859	9518	8756	7748	7136	6289	5480	5672	5441	5359		
KM																										
950	130	109	85.6	72.8	67.7	63.9	68.6	83.1	118	150	169	201	217	223	220	211	195	181	178	165	171	170	161	155		
1000	166	140	110	93.4	86.8	82.0	87.9	106	151	192	217	257	278	286	282	270	250	232	229	212	220	219	206	199		
900	213	180	141	120	111	105	113	137	193	246	279	330	356	366	361	346	321	298	293	272	282	280	264	255		
850	273	230	180	153	142	134	144	175	248	313	357	423	453	469	462	443	411	381	375	348	360	358	337	326		
800	349	294	231	196	182	172	184	224	318	404	457	540	580	593	600	591	567	525	487	479	444	459	457	430		
750	444	376	294	250	232	218	234	286	406	516	584	690	744	765	753	722	669	621	611	565	584	580	547	530		
700	563	477	374	317	293	276	296	365	518	657	743	877	900	947	956	916	849	787	774	716	736	732	691	669		
650	709	602	472	399	368	346	372	463	657	833	941	1107	1192	1224	1203	1152	1067	988	973	898	918	913	863	837		
600	881	752	590	497	456	426	458	583	827	1047	1180	1383	1487	1524	1496	1429	1324	1266	1216	1111	1123	1117	1059	1029		
550	1071	921	725	606	551	511	551	725	1028	1299	1458	1698	1551	1589	1559	1488	1379	1275	1256	1156	1165	1160	1100	1069		
500	1109	956	753	628	570	528	569	755	1072	1353	1517	1763	1617	1656	1623	1549	1435	1326	1307	1202	1208	1202	1141	1109		
490	1148	991	781	650	589	544	587	786	1116	1407	1577	1829	1683	1732	1689	1610	1492	1378	1359	1248	1250	1244	1182	1150		
480	1185	1026	809	672	607	559	604	818	1161	1463	1637	1895	1730	1791	1754	1672	1549	1430	1410	1294	1291	1285	1223	1190		
470	1222	1061	837	693	624	574	621	849	1206	1518	1697	1960	1800	1860	1821	1734	1607	1482	1462	1340	1332	1326	1263	1229		
460	1257	1095	864	714	641	587	636	881	1252	1574	1757	2023	1889	1929	1887	1795	1664	1524	1514	1386	1371	1364	1301	1268		
450	1290	1127	891	753	656	600	649	913	1297	1629	1816	2085	1956	1998	1952	1856	1720	1585	1564	1430	1408	1401	1338	1305		
440	1321	1158	916	752	670	610	661	945	1343	1684	1874	2145	2026	2066	2017	1916	1775	1654	1614	1473	1442	1436	1373	1340		
430	1349	1188	940	769	682	619	671	976	1387	1737	1930	2200	2093	2132	2080	1973	1829	1682	1662	1514	1473	1467	1406	1374		
420	1373	1215	963	784	692	624	679	1006	1431	1789	1983	2252	2228	2258	2197	2080	1928	1770	1759	1589	1524	1518	1460	1450		
410	1406	1259	1001	805	700	625	682	1063	1512	1894	2096	2398	2422	2369	2299	2169	2011	1842	1823	1648	1552	1547	1495	1465		
400	1412	1274	1015	810	698	618	675	1089	1549	1926	2118	2371	2388	2369	2299	2169	2011	1842	1823	1648	1552	1547	1495	1465		
390	1381	1285	1030	806	676	586	639	1132	1612	1994	2179	2408	2437	2389	2341	2205	2044	1892	1875	1684	1543	1535	1499	1471		
380	1335	1274	1027	795	653	559	607	1149	1637	2018	2198	2439	2490	2457	2376	2234	2070	1891	1871	1691	1520	1505	1483	1457		
370	1265	1251	1015	774	623	525	566	1162	1656	2035	2206	2390	2430	2503	2420	2262	2096	1912	1896	1686	1480	1453	1447	1428		
360	1169	1207	992	745	583	485	515	1170	1668	2041	2198	2345	2370	2518	2524	2425	2262	2096	1907	1888	1668	1424	1380	1380		
350	1038	1139	956	704	535	439	455	1171	1671	2033	2169	2274	2360	2524	2521	2417	2241	2079	1888	1861	1631	1349	1285	1305		
340	877	1047	904	653	477	392	381	1164	1662	2005	2113	2214	2350	2513	2497	2312	2200	2042	1851	1812	1573	1257	1171	1198		
330	690	923	836	591	412	341	307	1145	1636	1951	2029	2049	2340	2497	2443	2317	2134	1985	1794	1743	1492	1149	1033	1065		
320	499	767	749	520	343	286	237	1113	1589	1870	1918	1793	2049	2413	2359	2229	2043	1908	1718	1651	1391	1021	882	905		
310	318	590	646	442	273	229	176	1066	1521	1764	1785	1703	2049	2310	2297	2107	1931	1810	1623	1539	1272	880	716	725		
300	168	395	526	340	198	176	125	1001	1429	1629	1632	1556	2049	2310	2297	2107	1931	1810	1623	1539	1272	880	716	725		
290	65.0	219	401	277	130	127	81.6	821	1316	1473	1426	1376	2049	2310	2297	2107	1931	1810	1623	1539	1272	880	716	725		
280	17.7	79.8	276	132	76.8	82.2	45.5	821	1182	1300	1298	1196	2049	2310	2297	2107	1931	1810	1623	1539	1272	880	716	725		
270	1.0	18.6	1.59	120	36.2	46.7	20.1	711	1039	1120	1125	1029	2049	2310	2297	2107	1931	1810	1623	1539	1272	880	716	725		
260	2.1	71.9	62.4	15.3	23.7	5.1	591	591	884	939	939	884	2049	2310	2297	2107	1931	1810	1623	1539	1272	880	716	725		
250	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6		
240	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6		
230	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6		
220	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6		
210	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6		
200	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6	2.8	5.2	1.6		
190	1.98	360	436	483	494	198	360	436	483	494	198	360	436	483	494	198	360	436	483	494	198	360	436	483		
180	148	284	361	410	430	117	226	301	350	375	95.2	185	253	301	327	200	564	557	539	500	453	352	47.9			
170	117	226	301	350	375	95.2	185	253	301	327	200	564	557	539	500	453	352	47.9	352	47.9	352	47.9	352	47.9		
160	99.2	185	253	301	327	200	564	557	539	500	453	352	47.9	352	47.9	352	47.9	352	47.9	352	47.9	352	47.9	352		
150	87.6	156	214	258	284	87.6	156	214	258	284	180	444	435	480	446	395	297	374.9	297	374.9	297	374.9	297	374.9		
140	80.2	136	186	224	246	80.2	136	186	224	246	180	444	435	480	446	395	297	374.9	297	374.9	297	374.9	297	374.9		
130	74.2	124	167	198	218	74.2	124	167	198	218	170	393	388	375	346	295	208	263.2	208	263.2	208	263.2	208	263.2		
120	61.7	114	151	182	202	61.7	114	151	182	202	160	347	344	330	303	254	176	23.2	176	23.2	176	23.2	176	23.2		
110	3.0	43.1																								

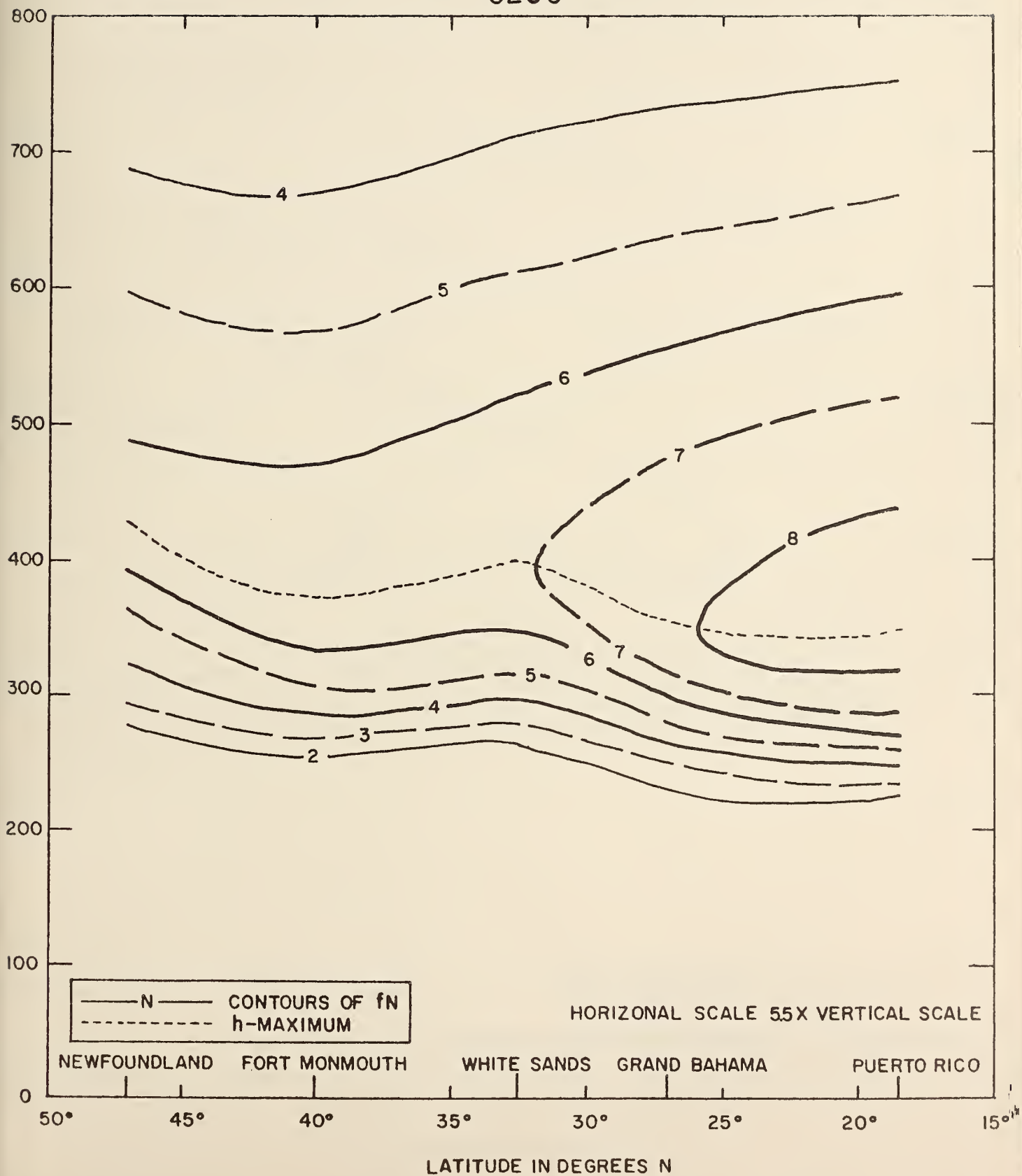
AVERAGE ELECTRON DENSITY													KP BELOW 4.5													
PUERTO RICO													60 W													
TIME	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300														
COUNT	25	25	24	26	25	21	14	24	27	27	27	27														
HMIN	109	110	110	110	110	110	200	243	250	267	273	274														
RATIO	3.5	3.5	3.4	3.3	3.3	3.3	4.1	4.3	4.2	4.5	4.8	4.9														
NMAX	2537	2535	2433	2372	2110	1927	1909	1705	1573	1565	1522	1514														
HMAX	358	364	369	375	370	378	383	406	399	395	386															
SHMAX	2862	2921	2875	2952	2734	2152	1480	1420	1258	1146	1088															
SHMIN	1001810072	9755	9187	8576	7748	7136	6289	5858	5672	5441	5359															
KM																										
217	223	220	211	195	181	178	165	171	170	161	155															
950	278	286	282	270	250	232	229	212	220	219	206	199														
900	278	286	282	270	250	232	229	212	220	219	206	199														
850	356	366	361	346	321	298	293	272	282	280	264	255														
800	456	460	462	443	411	381	375	348	360	358	337	326														
750	583	600	591	567	525	487	479	444	459	457	430	417														
700	744	765	753	722	669	621	611	565	584	580	547	530														
650	945	971	956	916	849	787	774	716	736	732	691	669														
600	1122	1224	1203	1152	1067	988	973	898	918	913	863	837														
550	1487	1524	1456	1429	1324	1224	1206	1111	1123	1117	1059	1029														
540	1551	1589	1559	1488	1379	1275	1256	1156	1165	1160	1100	1069														
530	1617	1656	1623	1549	1432	1326	1307	1202	1208	1202	1141	1109														
520	1683	1723	1689	1610	1492	1378	1359	1248	1250	1244	1182	1150														
510	1751	1791	1754	1672	1549	1430	1410	1294	1291	1285	1223	1190														
500	1820	1860	1821	1734	1607	1482	1462	1340	1332	1326	1263	1229														
490	1889	1929	1887	1795	1664	1534	1514	1386	1371	1364	1301	1268														
480	1958	1998	1952	1856	1720	1585	1564	1430	1408	1401	1338	1305														
470	2026	2066	2017	1916	1770	1634	1614	1473	1442	1436	1373	1340														
460	2093	2132	2080	1973	1829	1682	1662	1514	1473	1467	1406	1374														
450	2159	2197	2140	2028	1880	1728	1707	1553	1501	1495	1435	1404														
440	2222	2258	2197	2080	1928	1770	1750	1589	1524	1518	1460	1429														
430	2282	2316	2251	2121	1971	1808	1789	1620	1541	1536	1480	1450														
420	2338	2369	2299	2169	2011	1842	1823	1648	1552	1547	1495	1465														
410	2389	2416	2341	2205	2044	1870	1852	1669	1553	1548	1502	1473														
400	2437	2457	2376	2234	2070	1892	1875	1684	1543	1535	1499	1471														
390	2481	2490	2403	2254	2090	1917	1891	1691	1520	1505	1483	1457														
380	2500	2513	2420	2262	2096	1912	1896	1686	1480	1453	1447	1428														
370	2518	2524	2425	2264	2096	1912	1896	1686	1480	1453	1447	1428														
360	2524	2521	2412	2240	2079	1888	1861	1631	1349	1275	1198	1212														
350	2525	2497	2377	2200	2042	1851	1812	1573	1257	1251	1135	1120														
340	2477	2443	2317	2134	1985	1794	1743	1492	1149	1033	1065	1100														
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320	2317	2247	2117	1931	1810	1623	1539	1232	880	716	725	804														
310	2193	2106	1980	1801	1694	1514	1405	1132	732	543	539	626														
300	2042	1946	1823	1658	1565	1400	1250	976	581	380	360	438														
290	1867	1770	1655	1503	1429	1273	1091	804	429	238	211	266														
280	1679	1584	1483	1345	1287	1147	911	618	296	132	93.1	130														
270	1489	1399	1311	1196	1140	1017	717	438	187	67.7	37.7	42.4														
260	1303	1226	1145	1005	1002	889	521	268	103	31.7	18.2	11.3														
250	1127	1067	996	915	875	771	333	139	45.3	15.4	8.4	2.7														
240	972	928	870	800	763	663	182	46.7	16.6	8.5	4.0															
230	838	809	762	705	667	578	120	14.0	2.7	4.4	2.1															
220	728	711	676	626	586	488	83.7																			
210	638	628	603	559	516	417	62.3																			
200	564	557	539	500	453	352	47.9																			
190	501	495	480	446	395	297	31.9																			
180	444	439	425	394	341	249	31.0																			
170	393	388	375	346	295	208	26.2																			
160	347	344	330	303	254	176	23.2																			
150	306	303	290	264	221	151	21.3																			
140	267	265	254	232	193	134	20.0																			
130	238	236	226	207	173	124	19.0																			
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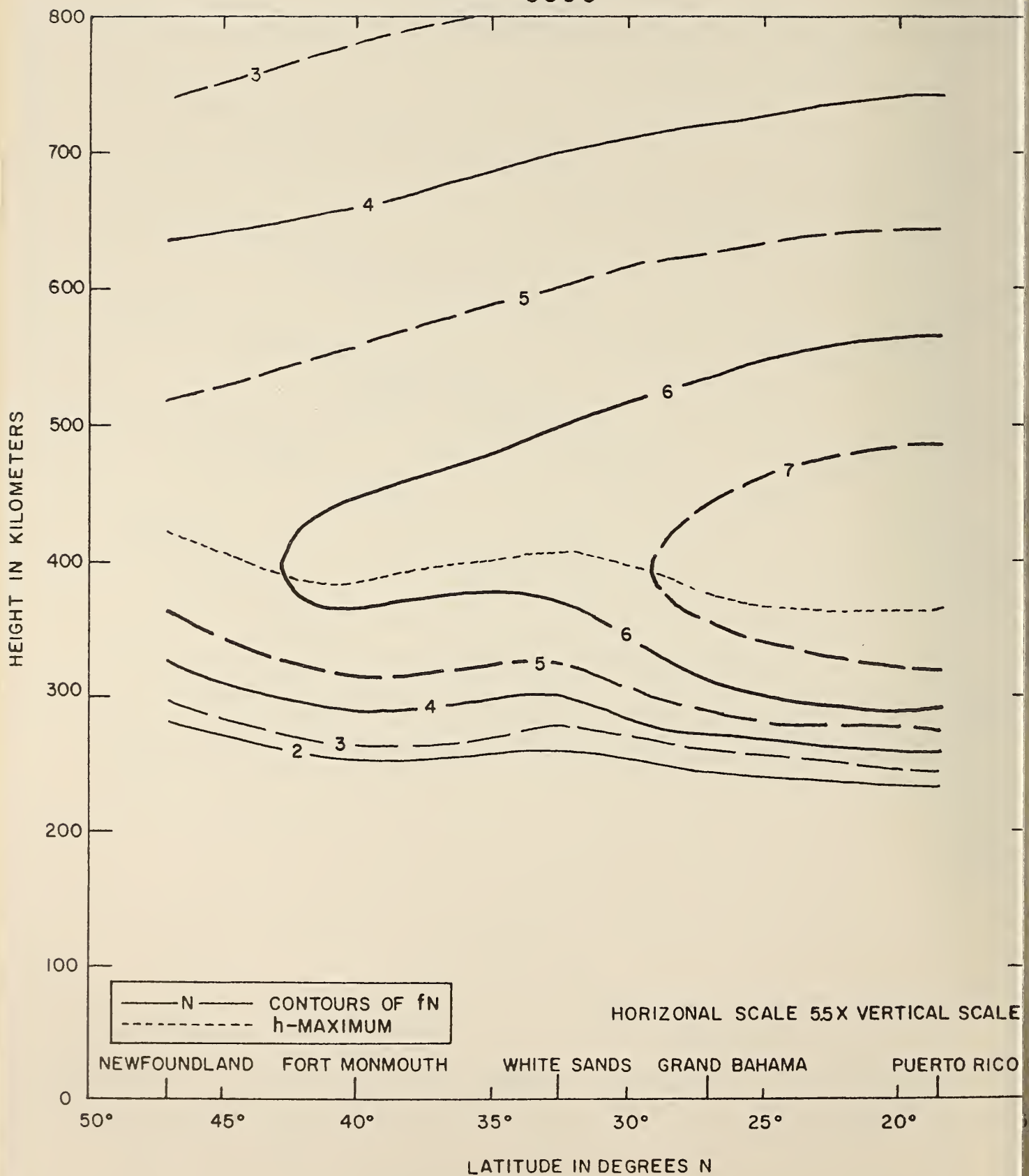
APRIL 1959
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APRIL 1959

0100

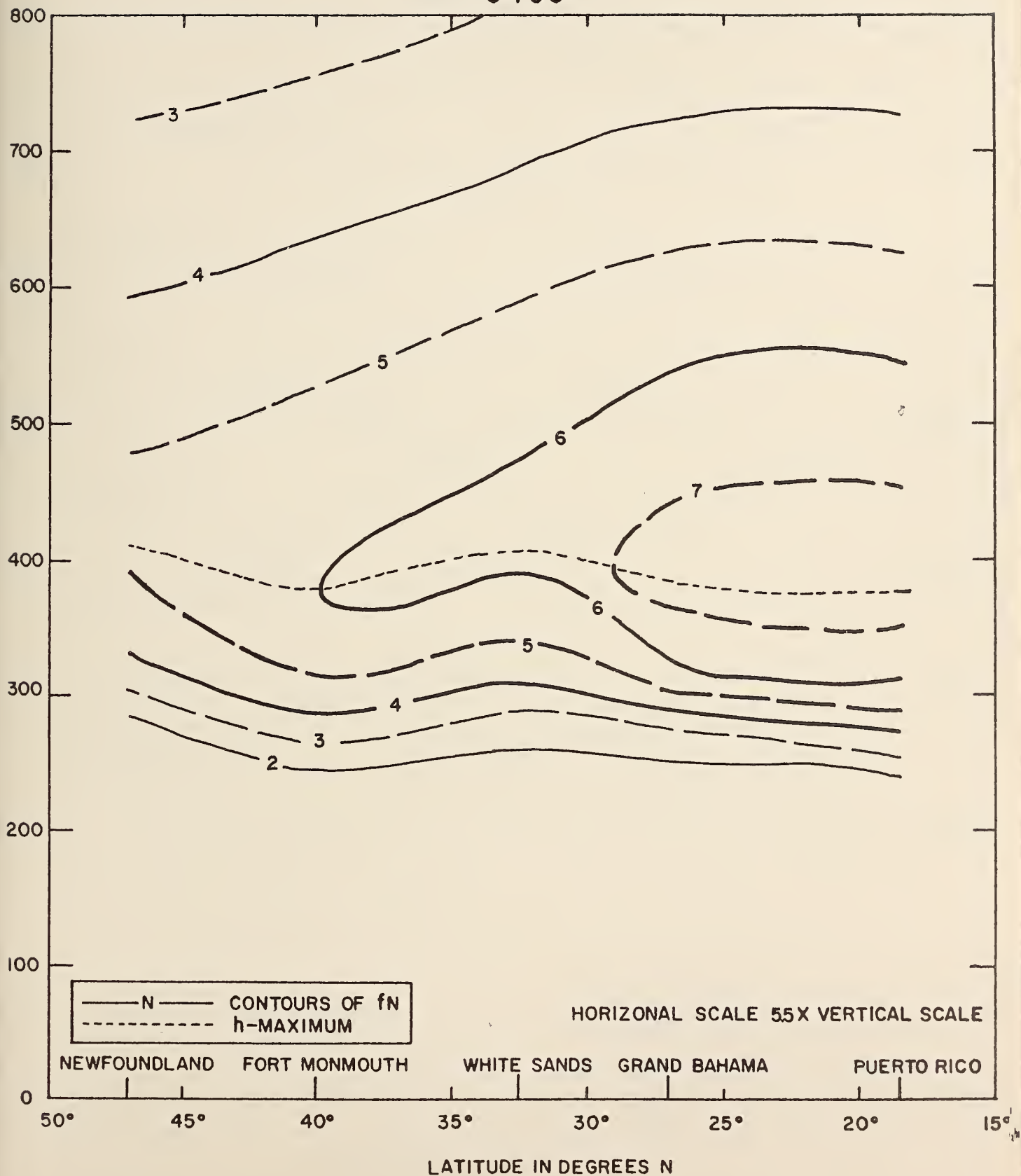


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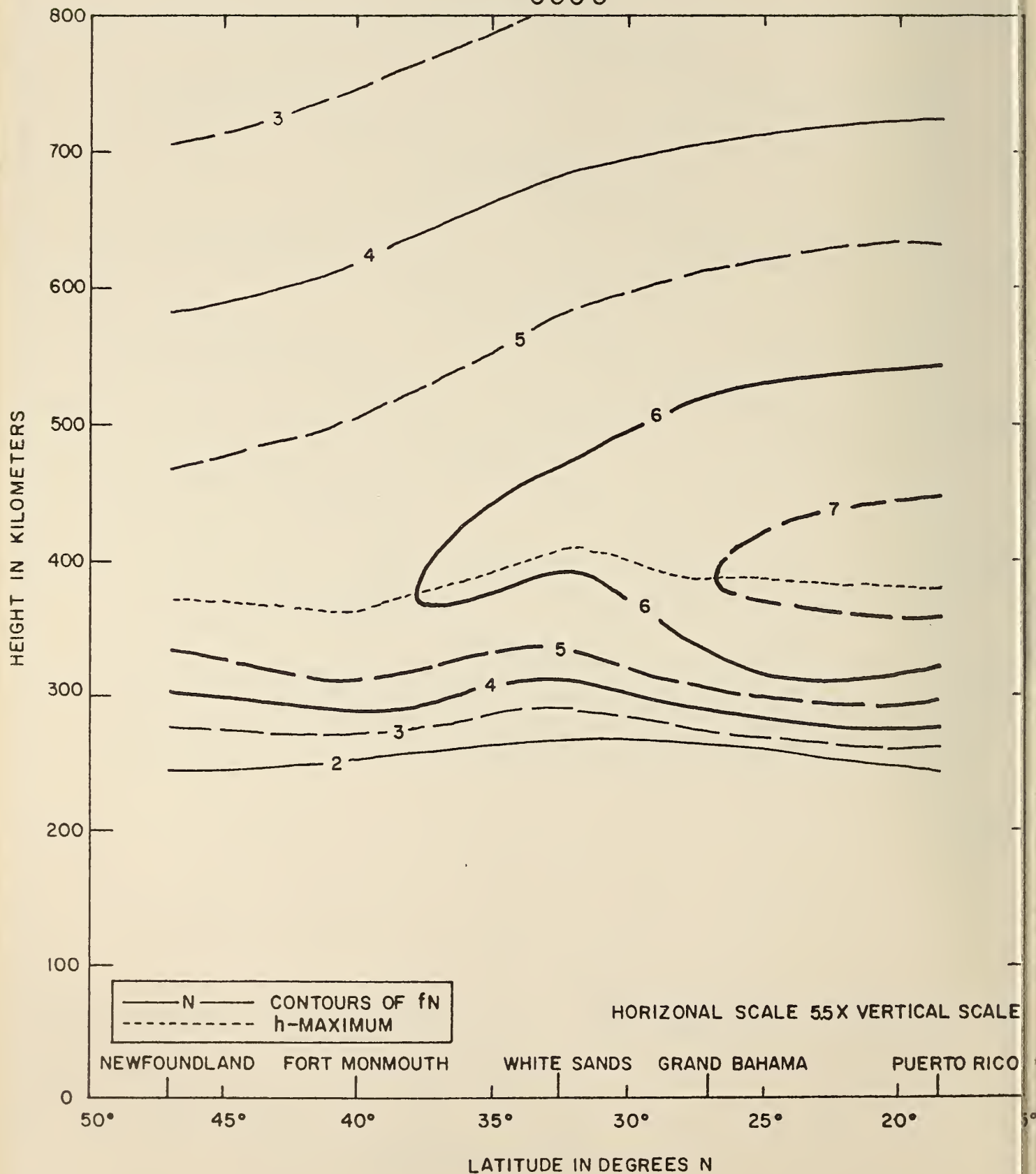
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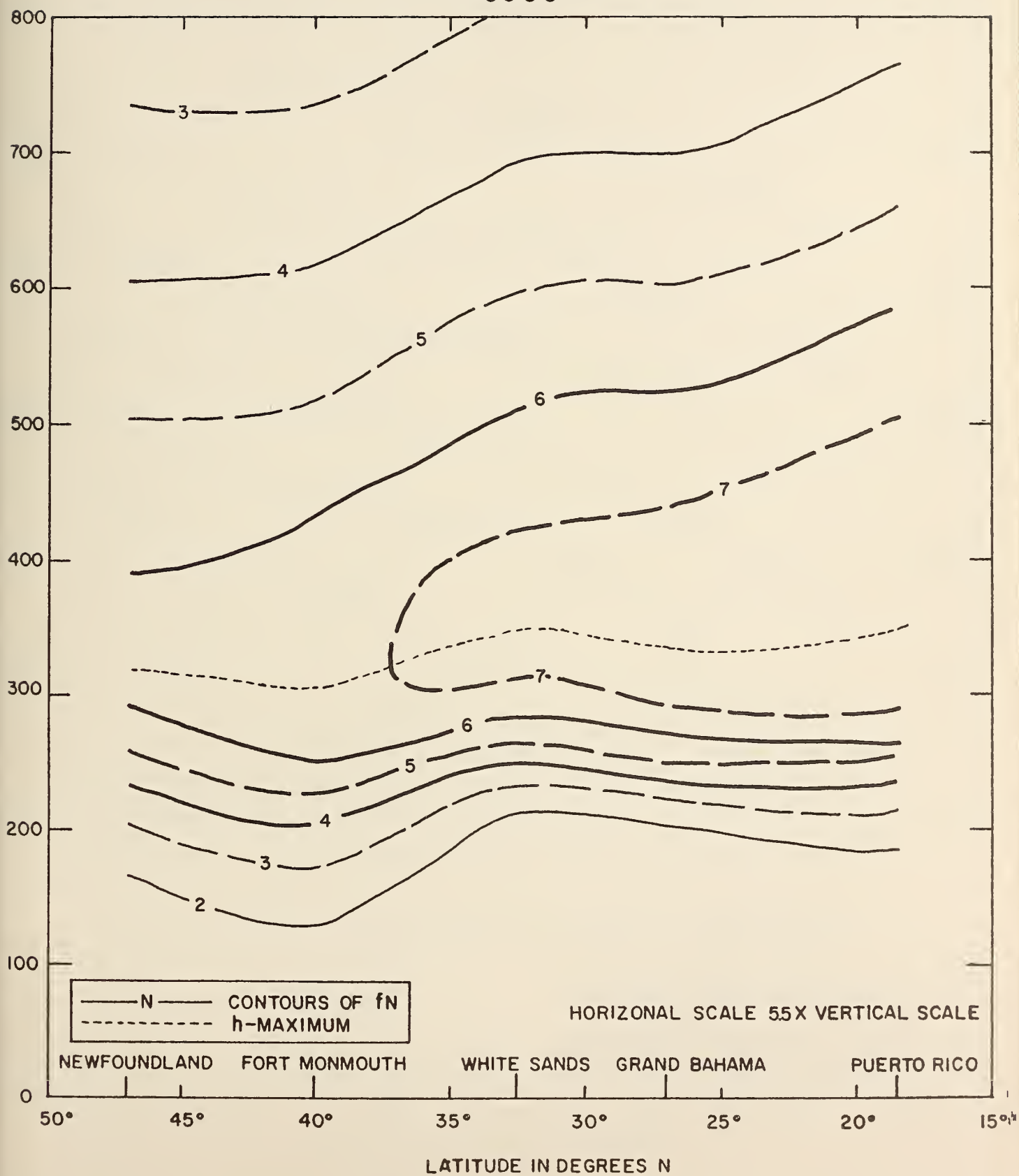
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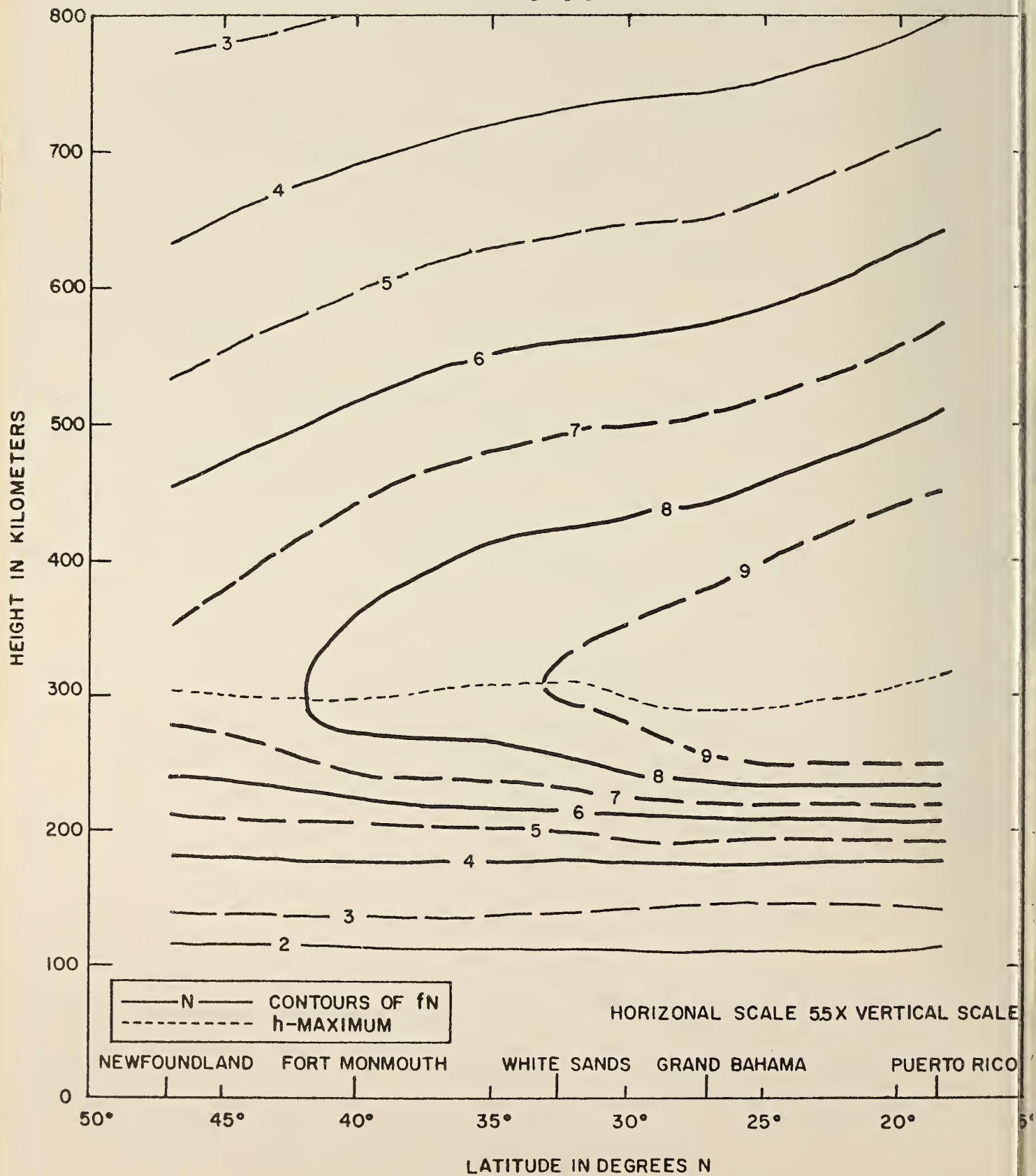


APRIL 1959

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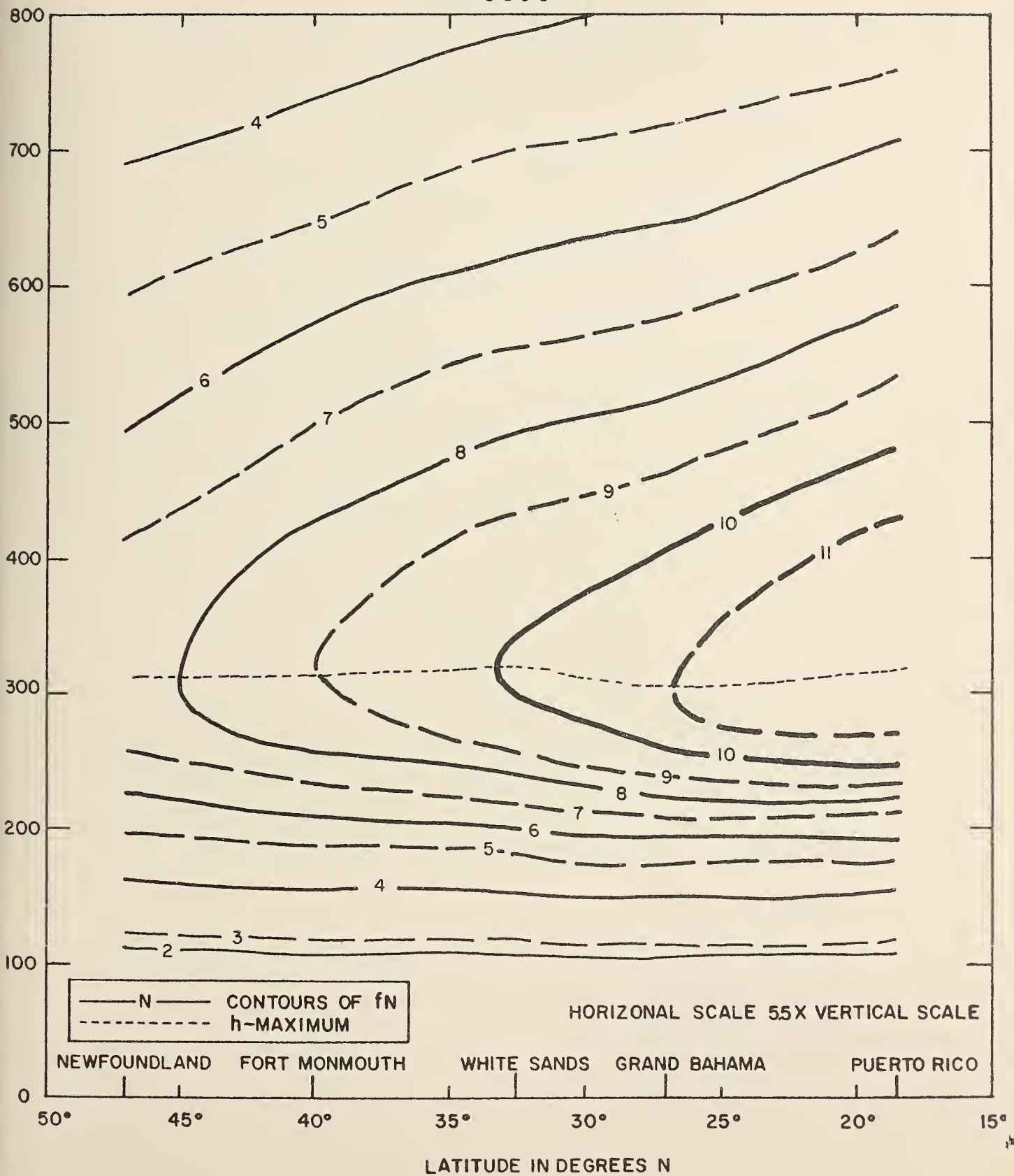


APRIL 1959
0600

APRIL 1959
0700

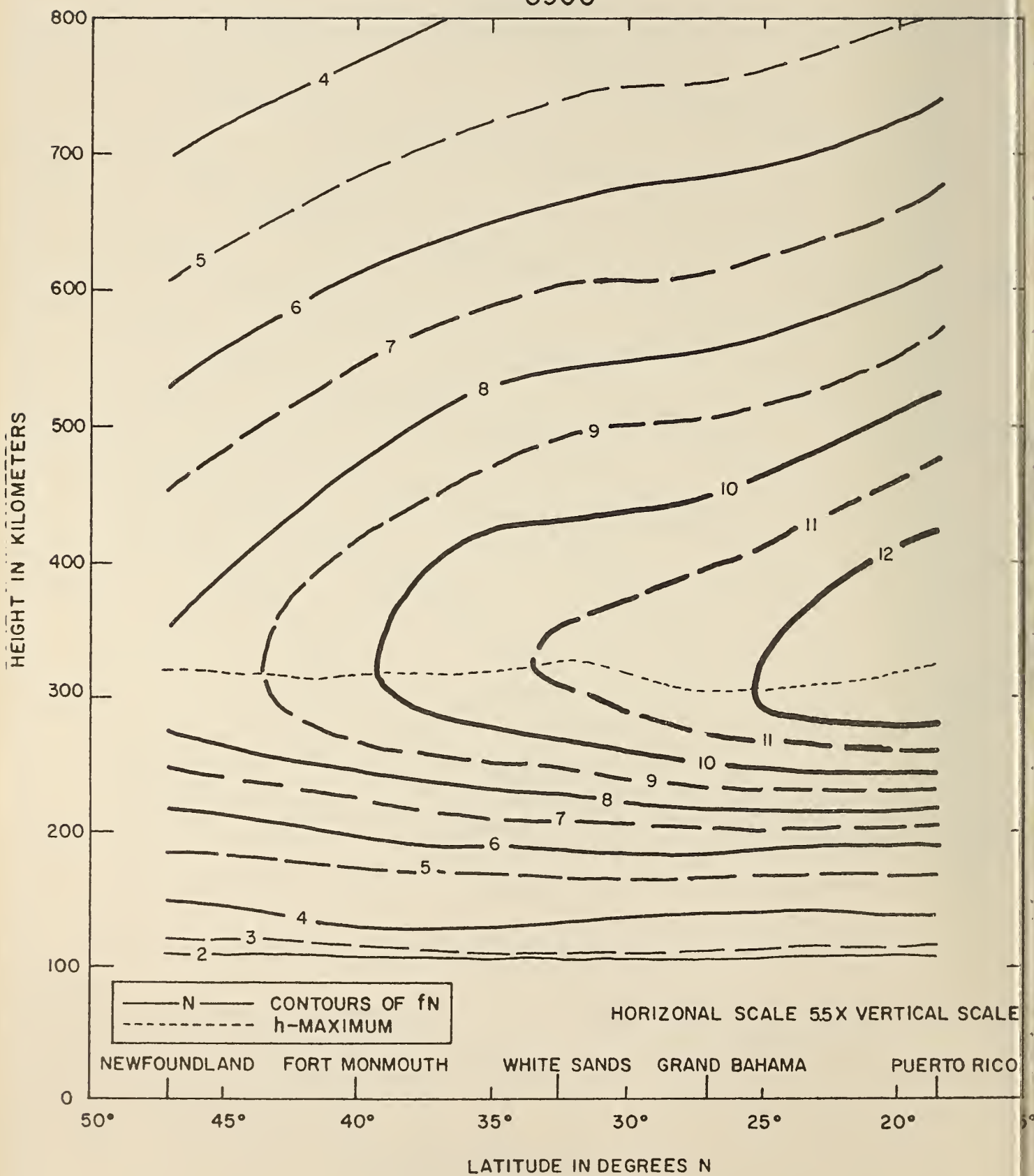
APRIL 1959

0800



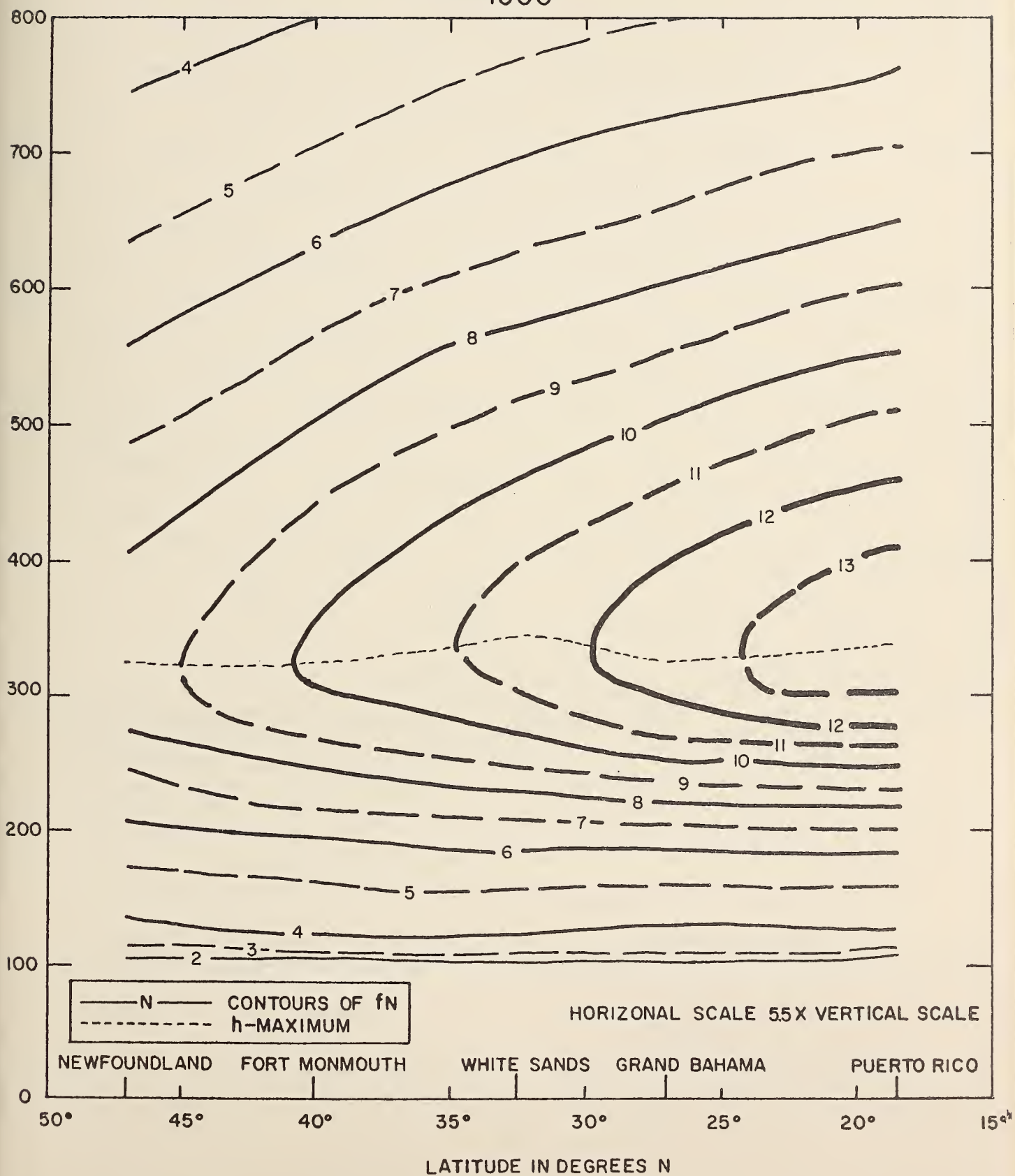
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0900

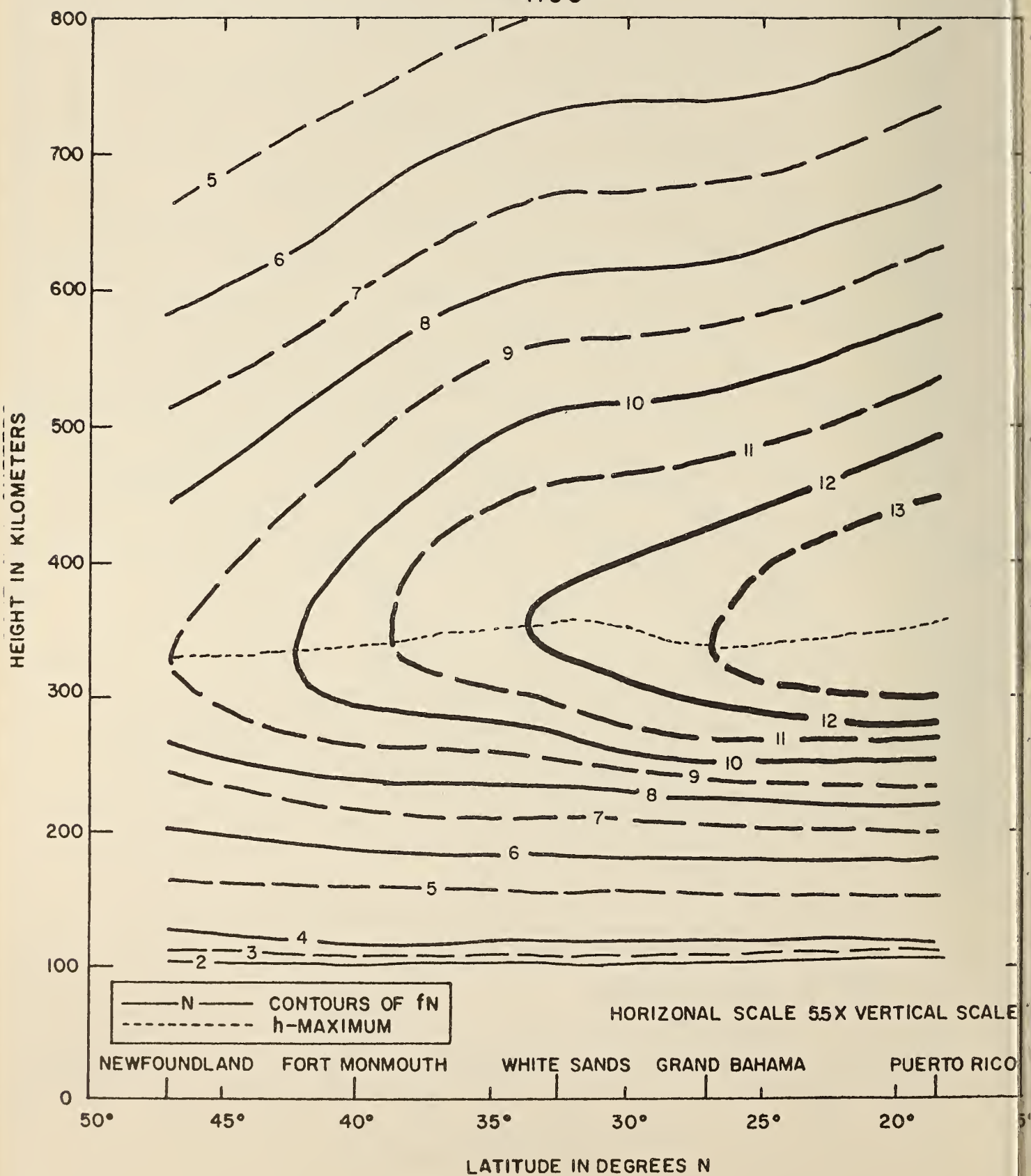


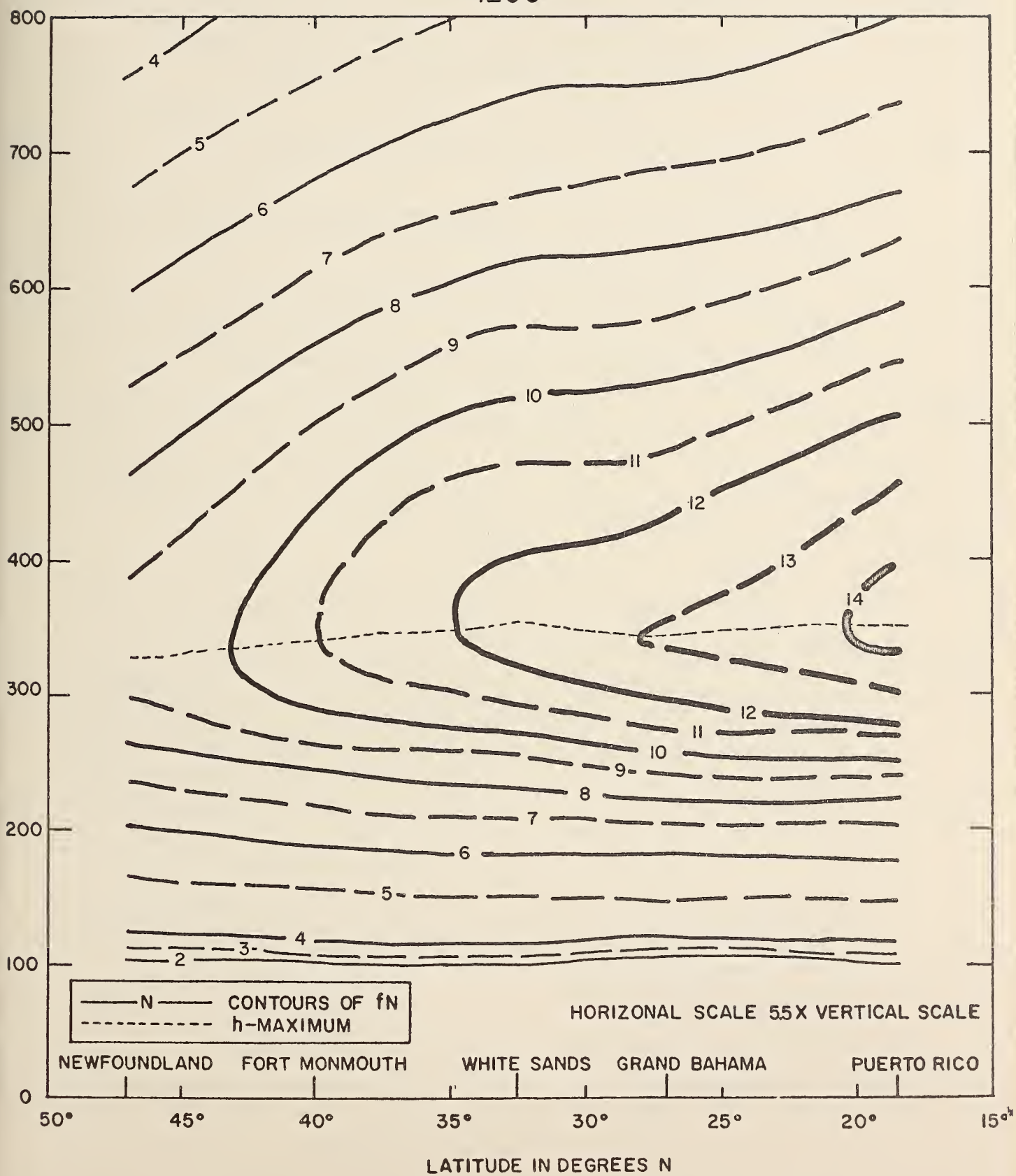
APRIL 1959

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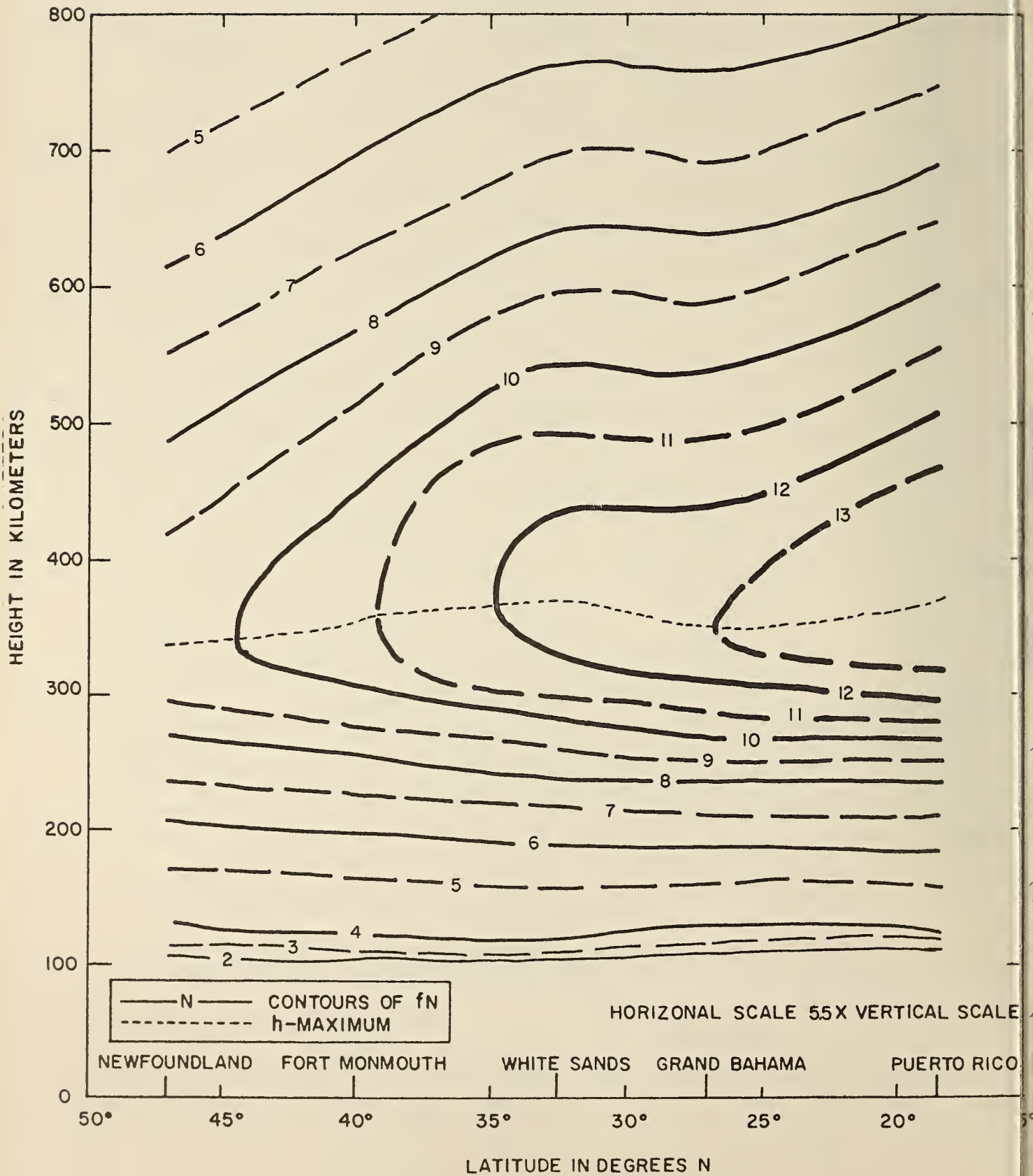


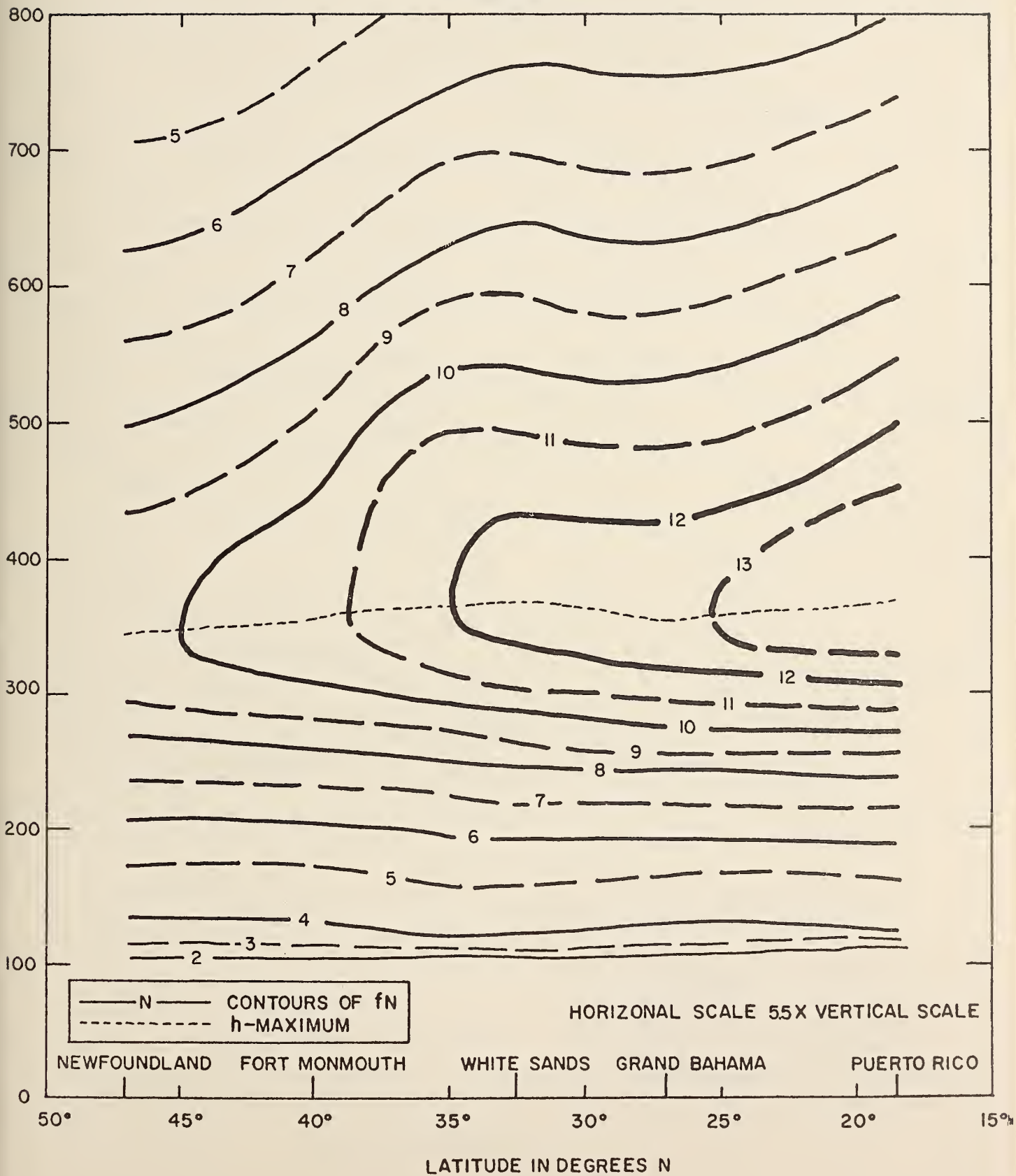
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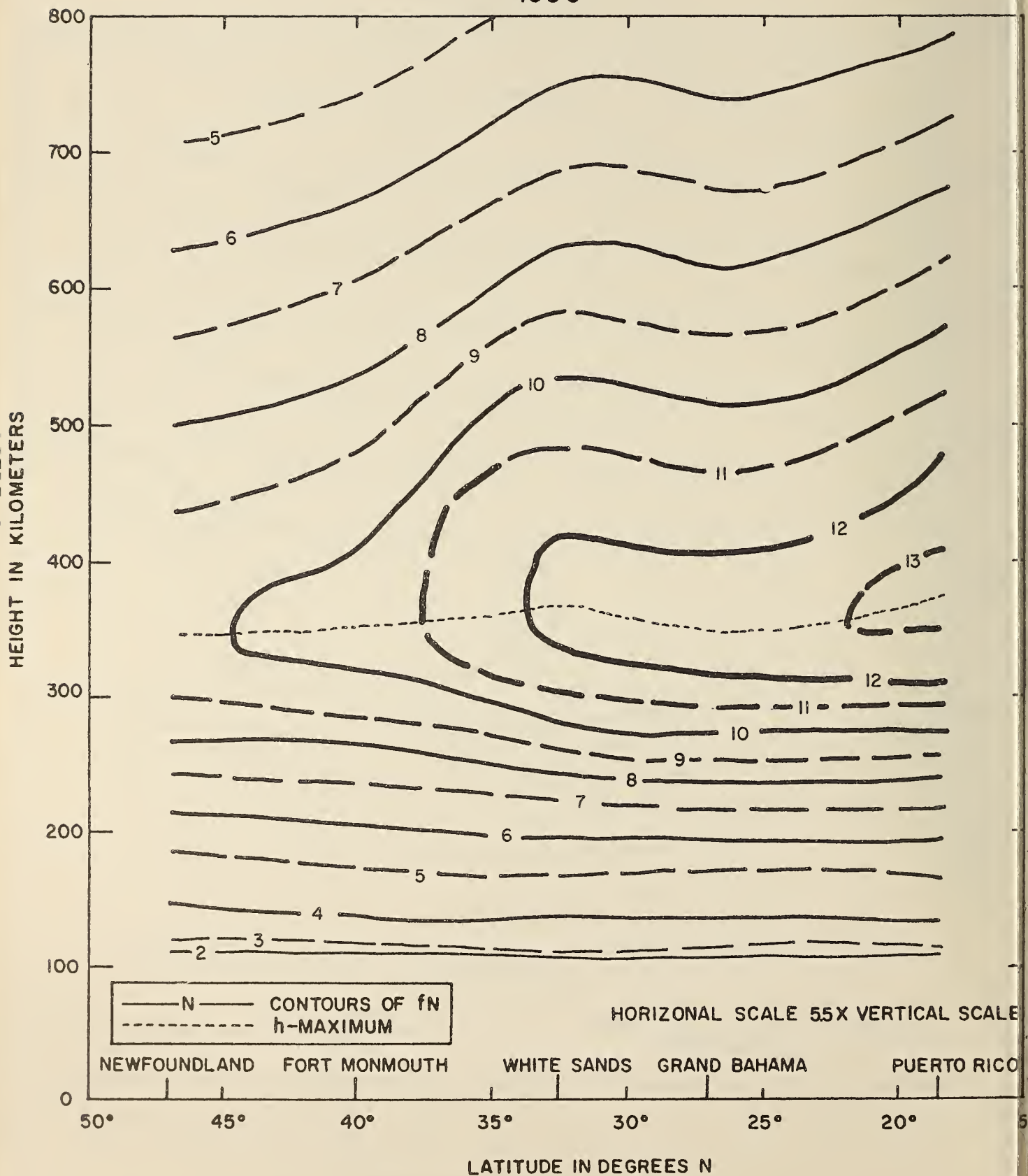
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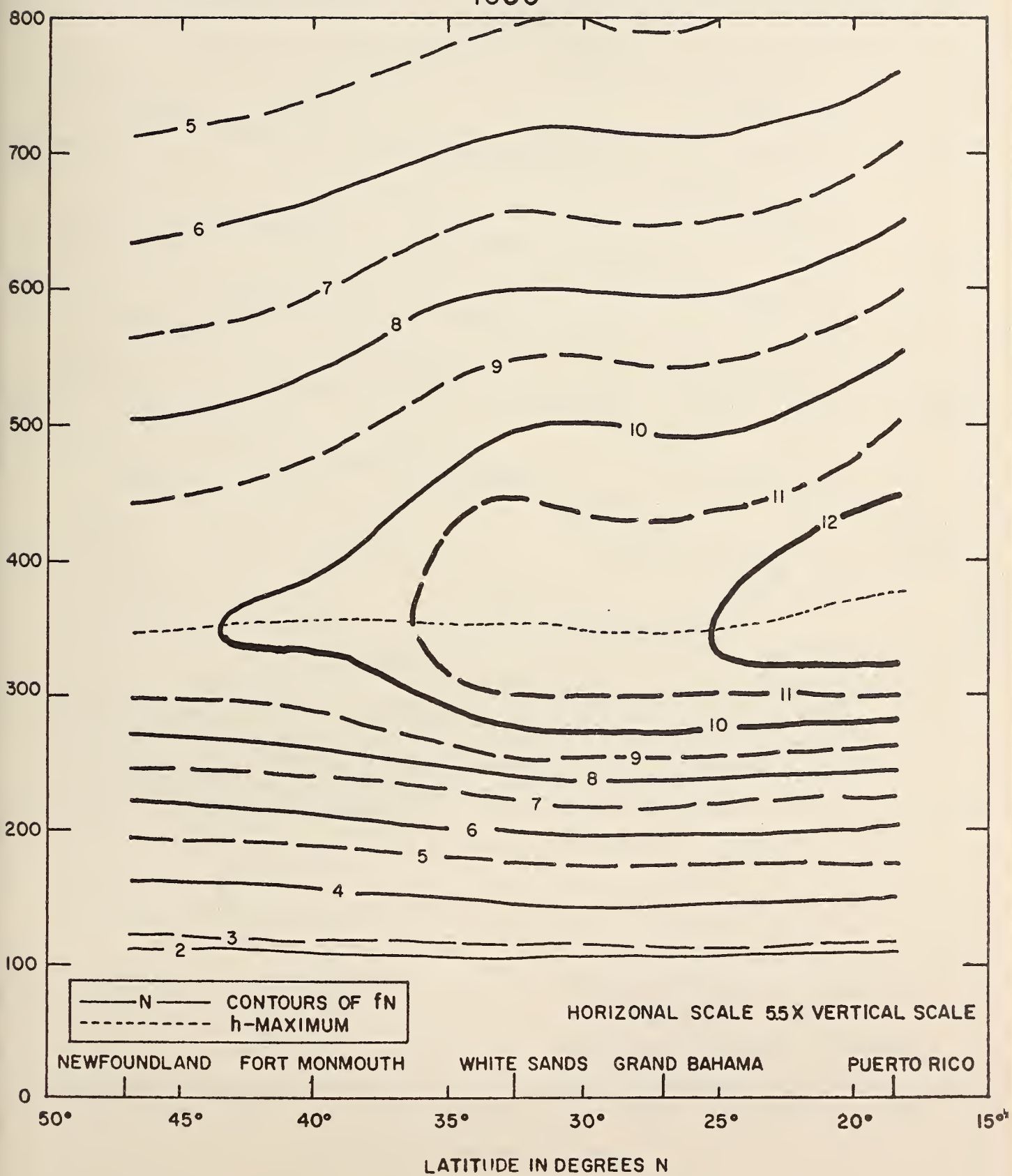


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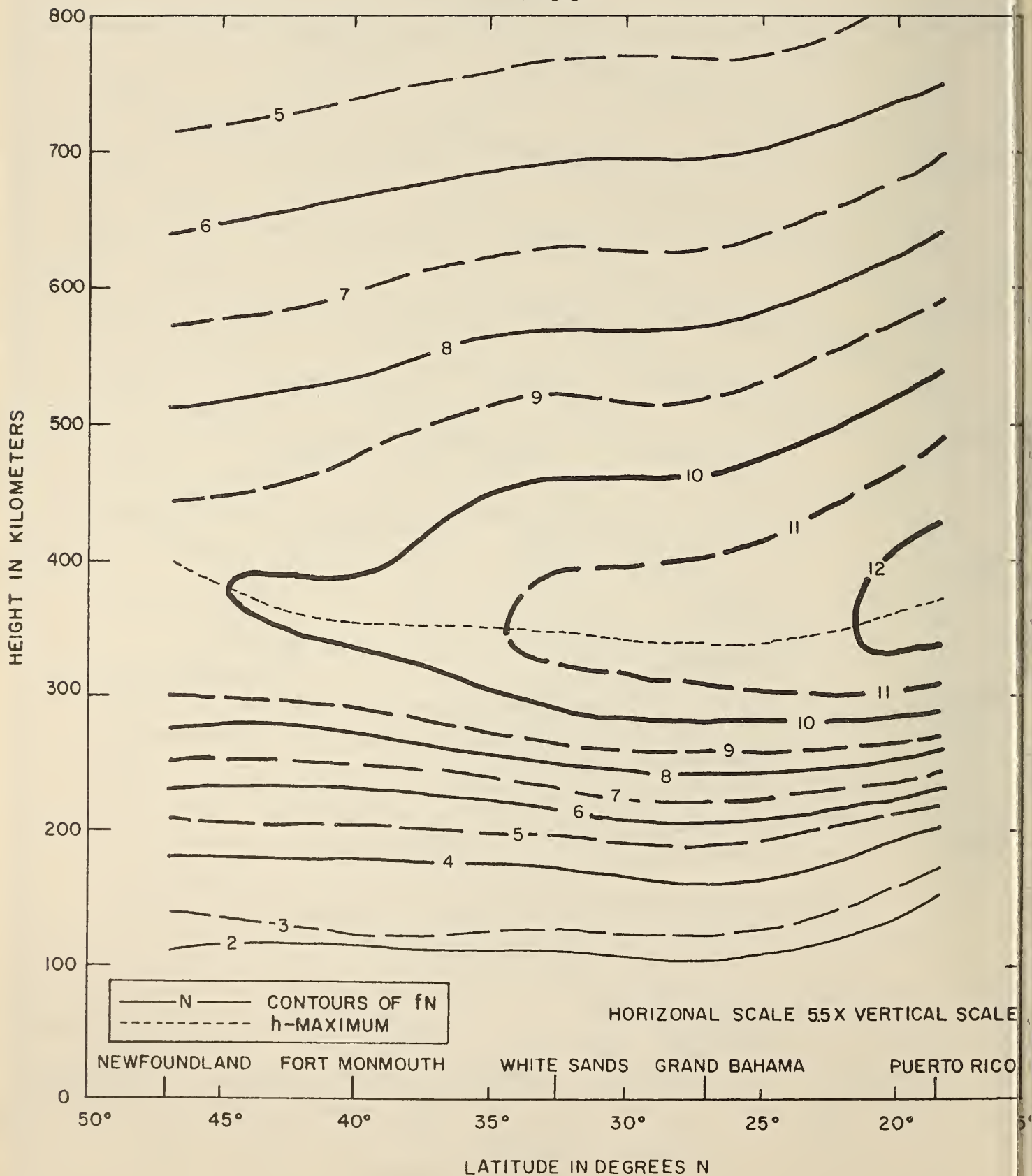
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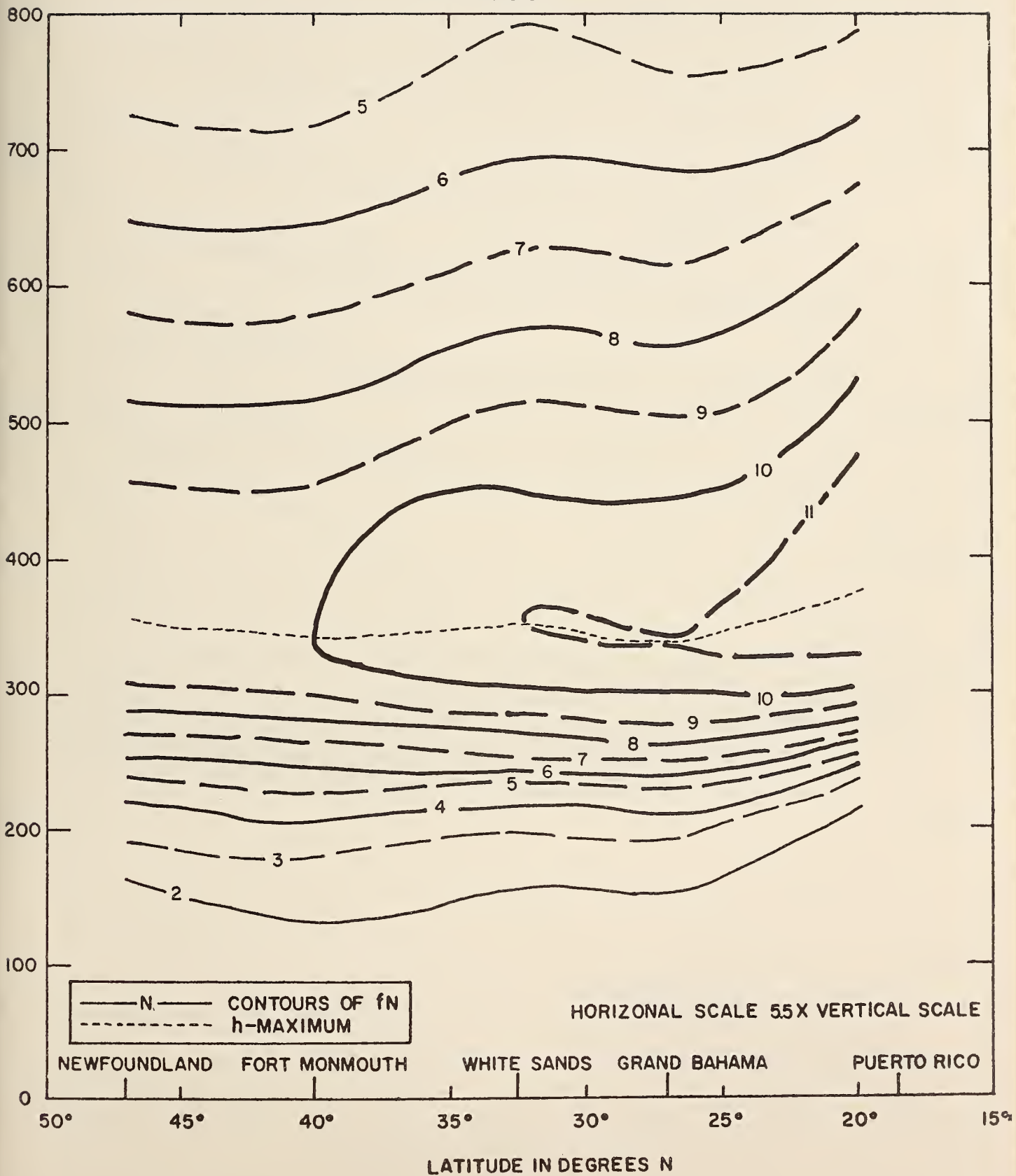
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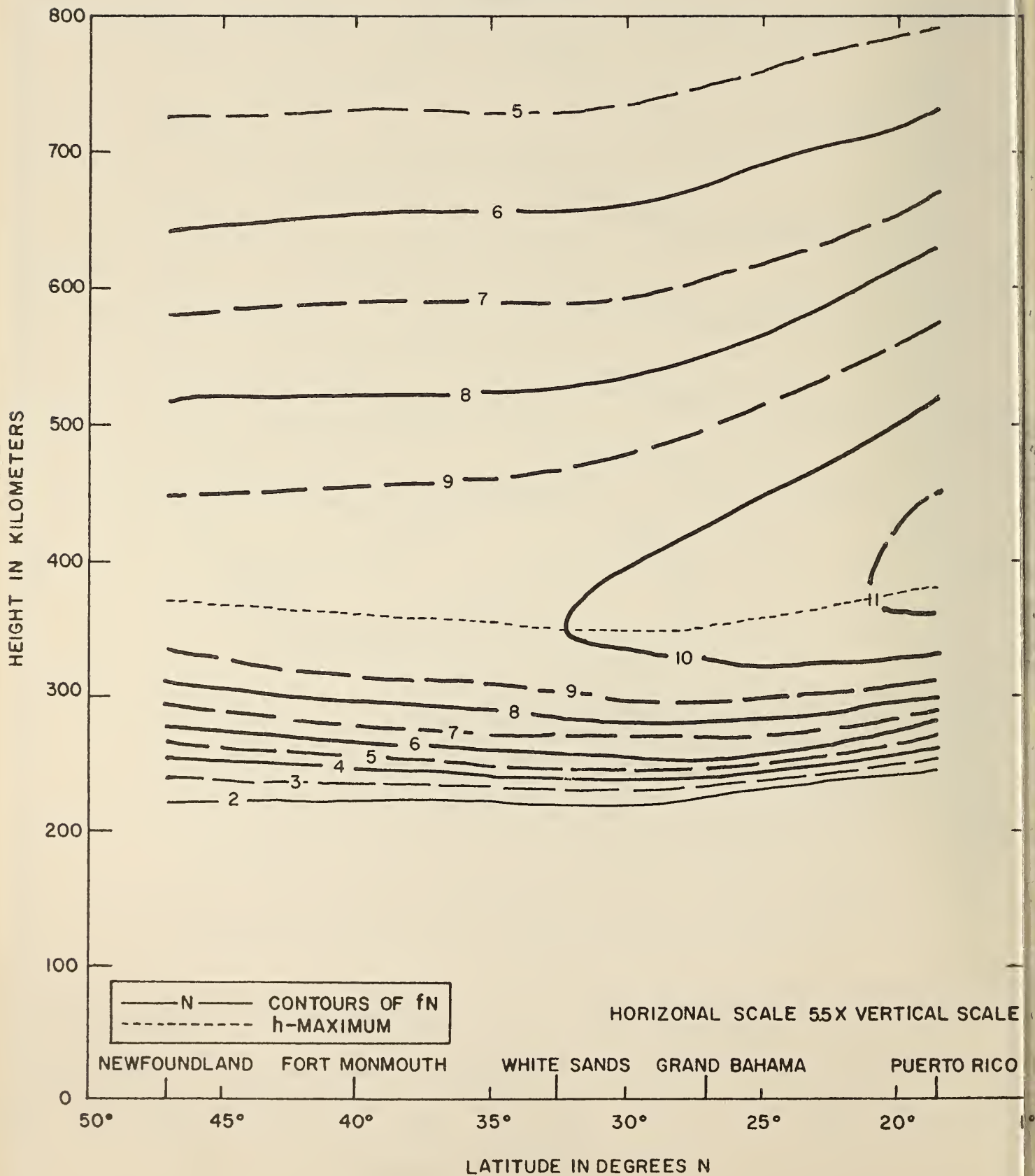


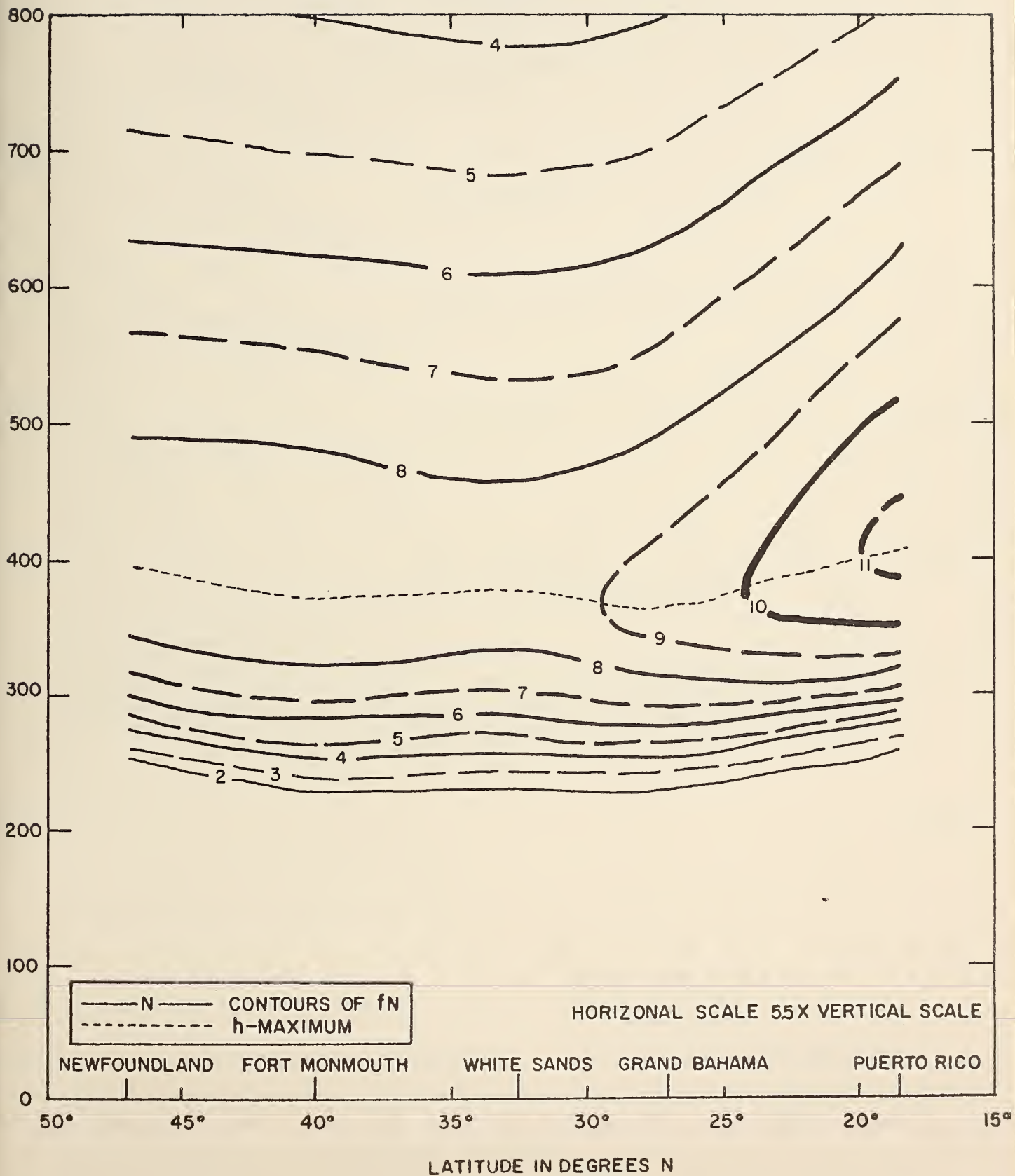
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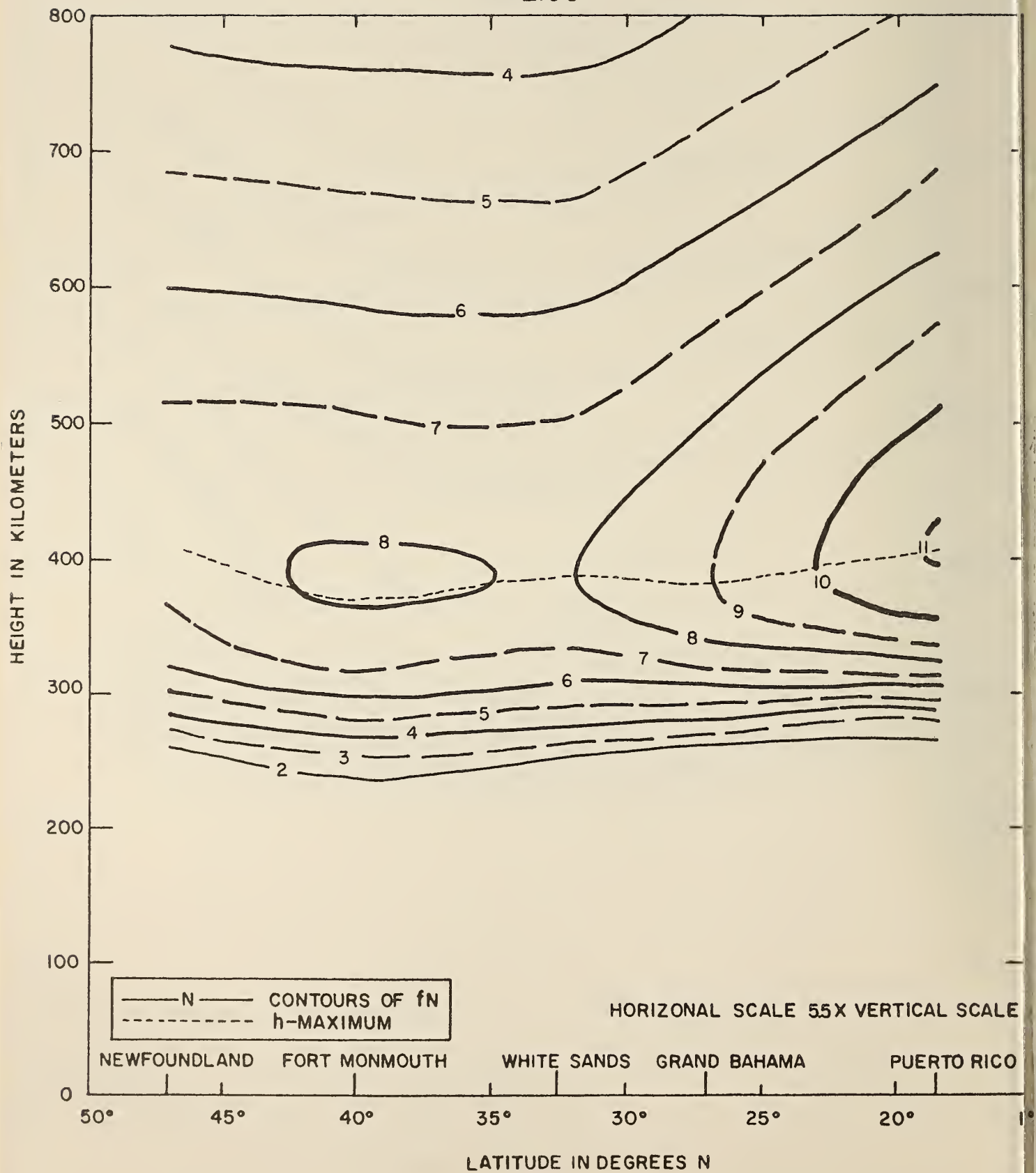


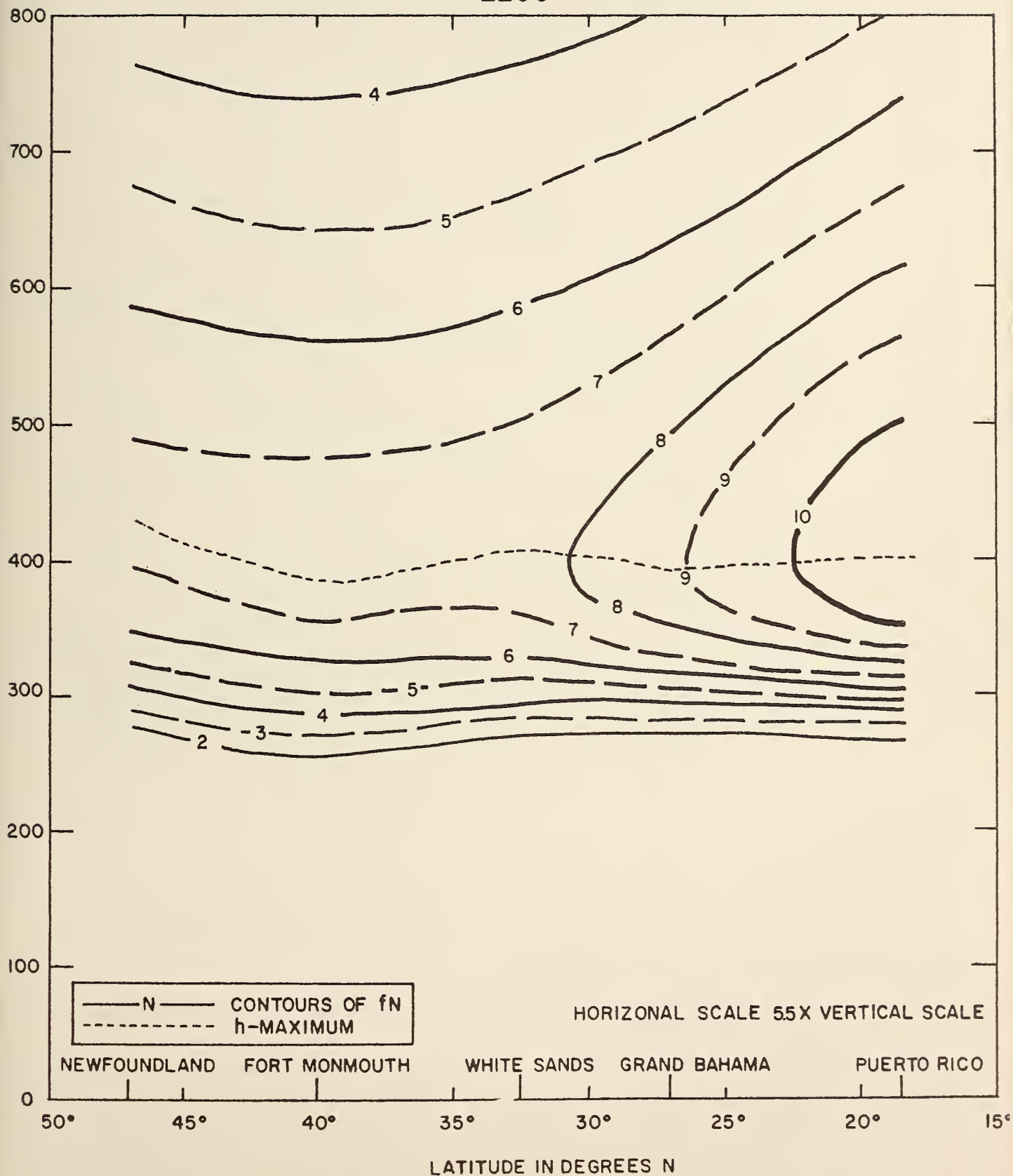
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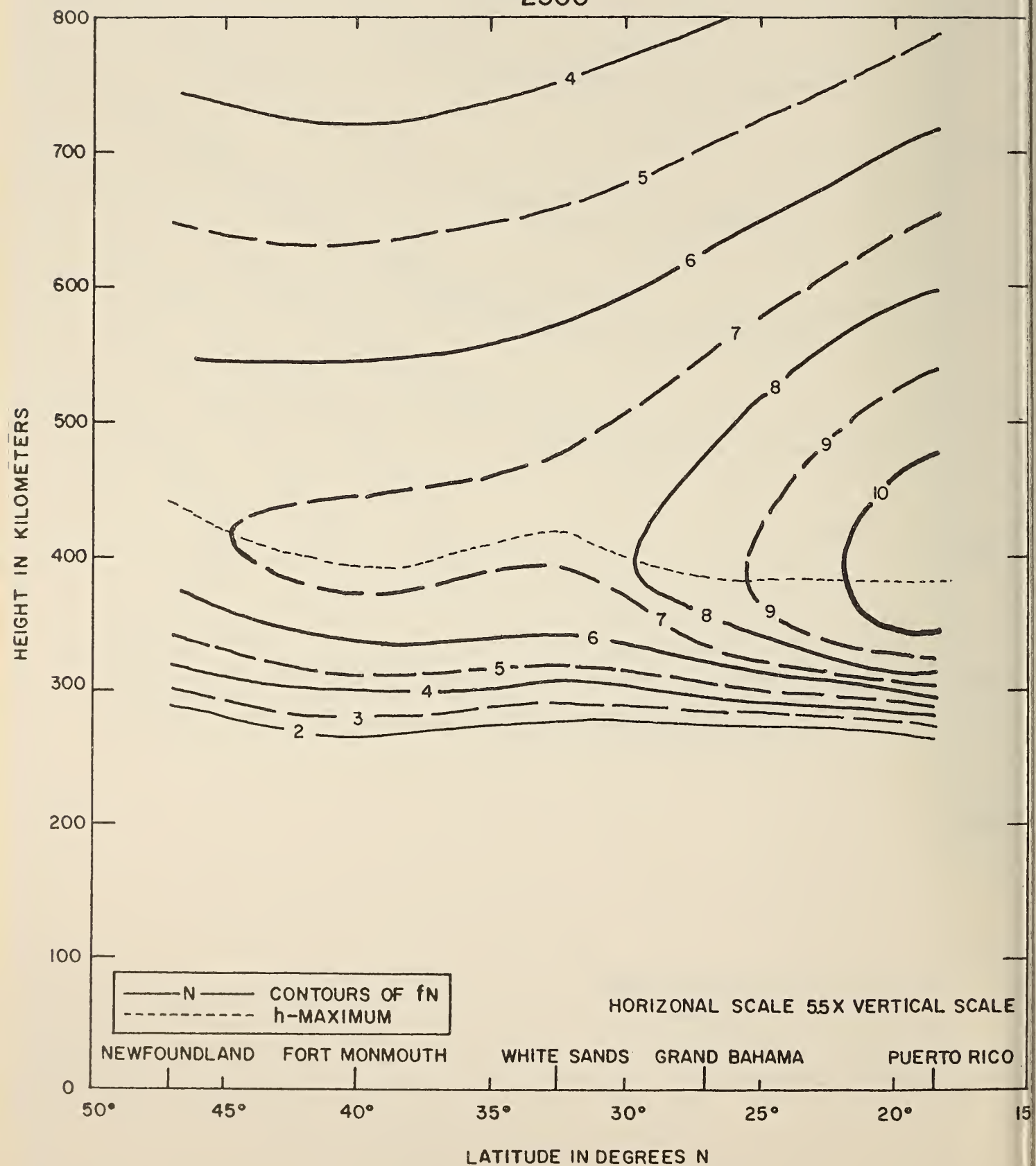


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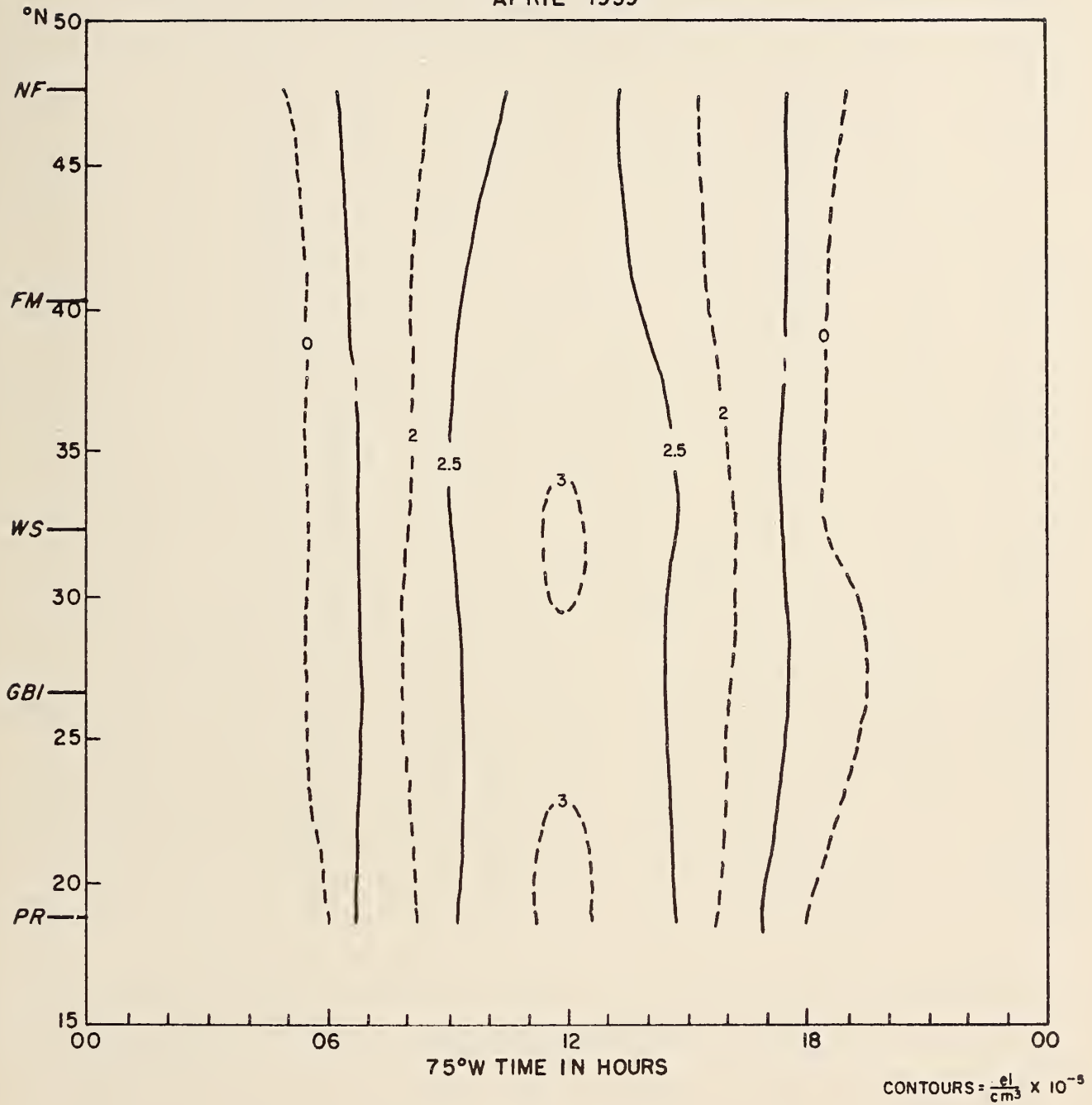
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APRIL 1959
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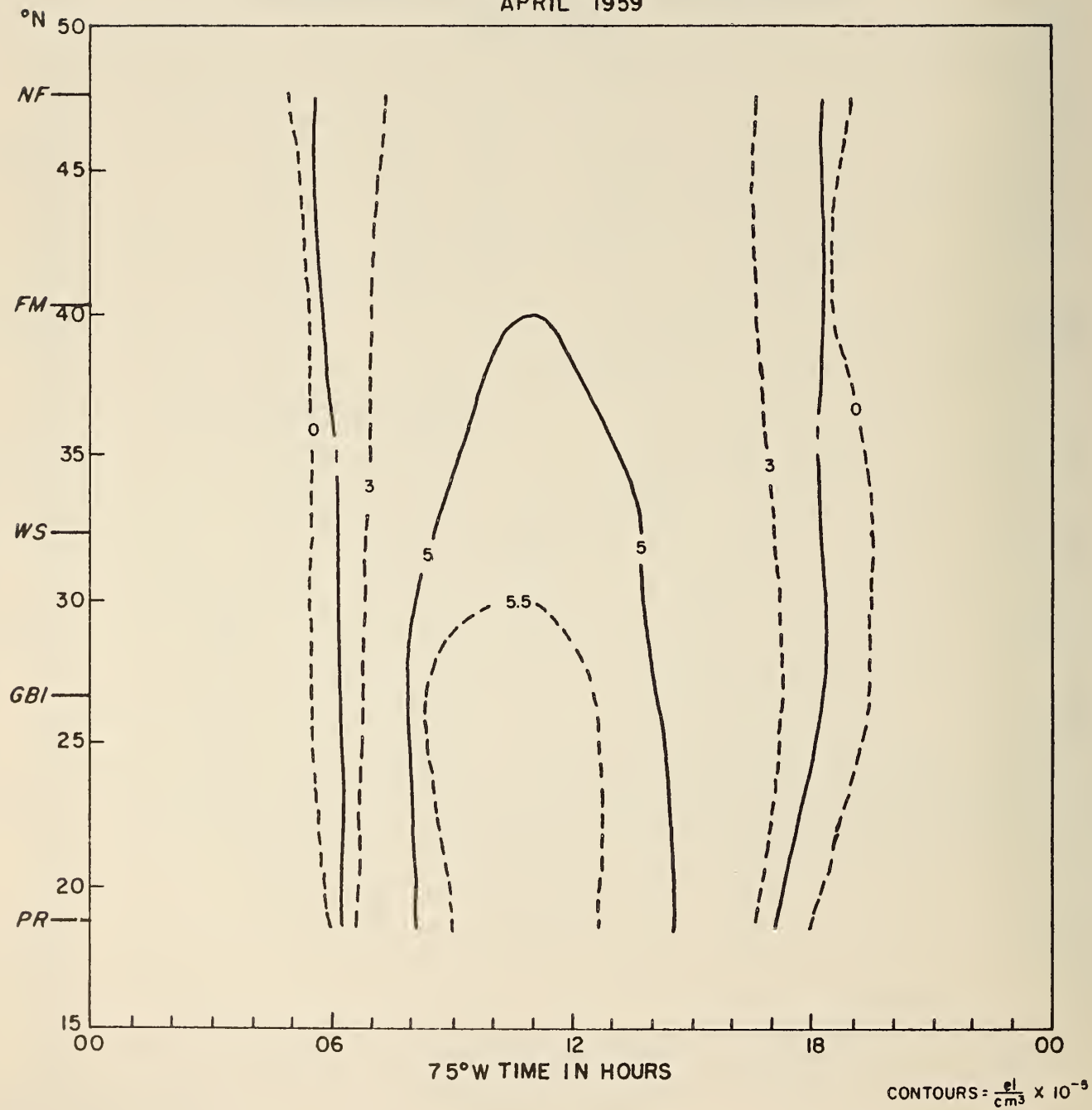
APRIL 1959
2200

APRIL 1959
2300

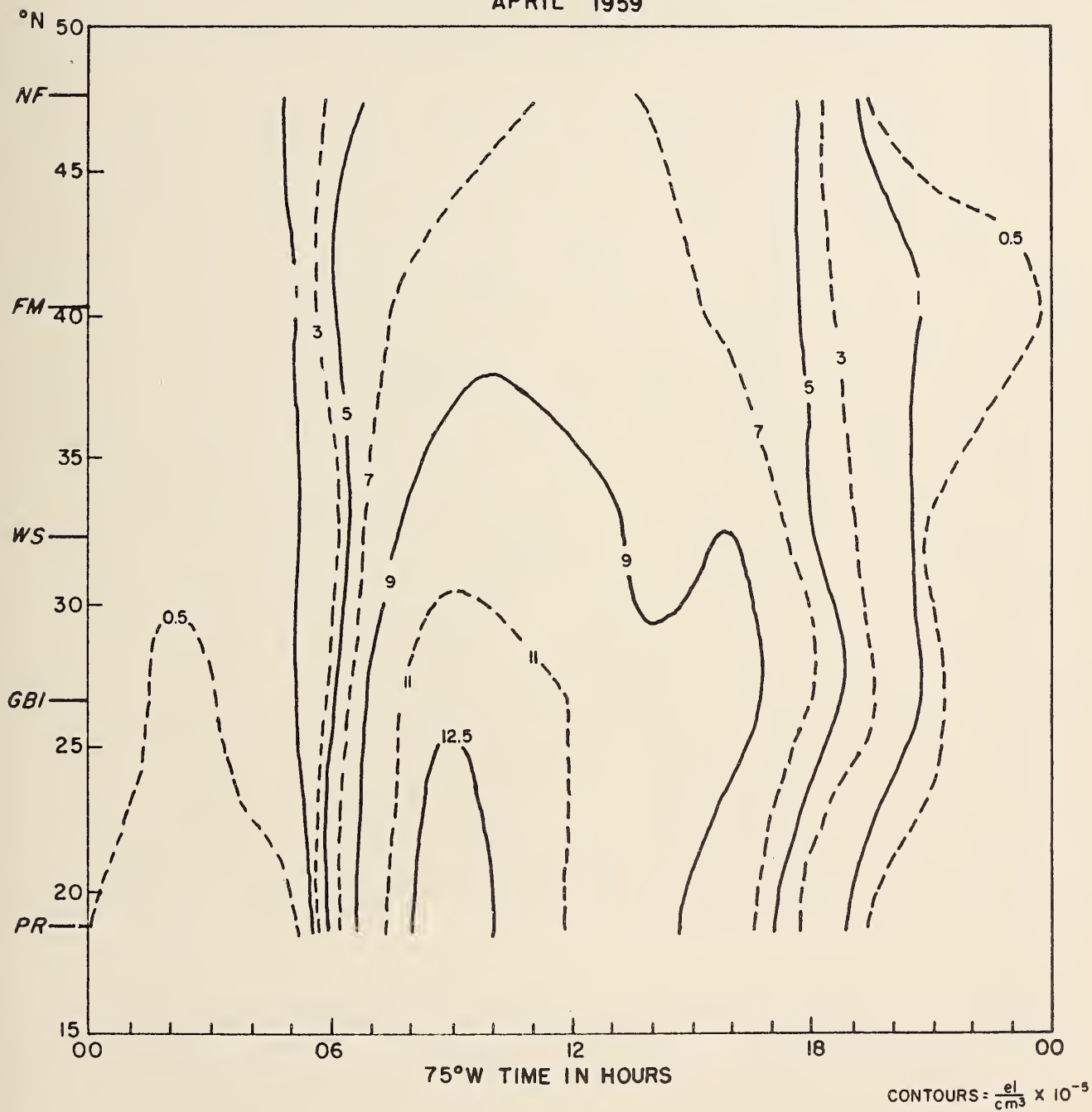
ELECTRON DENSITY AT 150 KILOMETERS
APRIL 1959



ELECTRON DENSITY AT 200 KILOMETERS
APRIL 1959

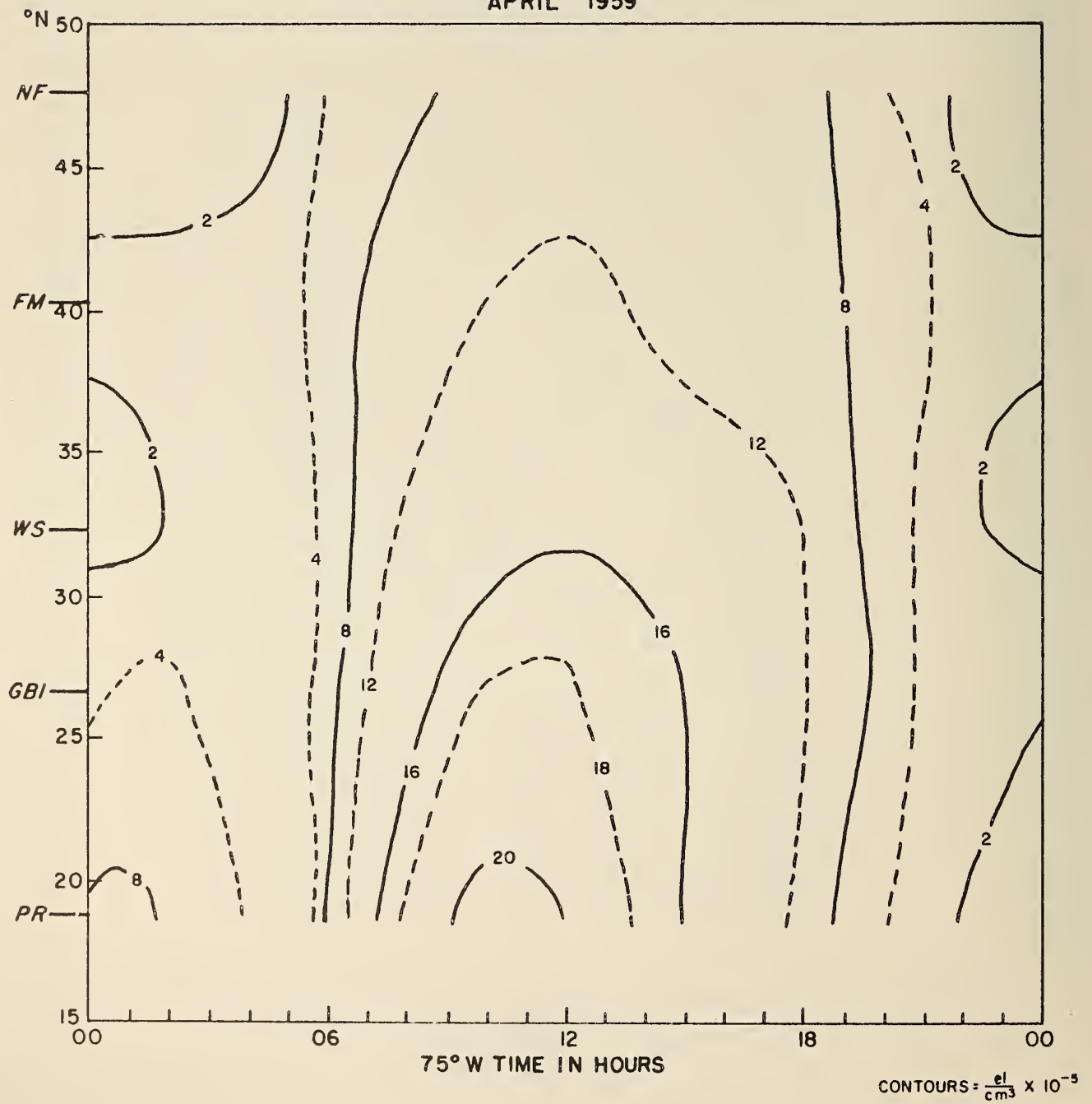


ELECTRON DENSITY AT 250 KILOMETERS
APRIL 1959



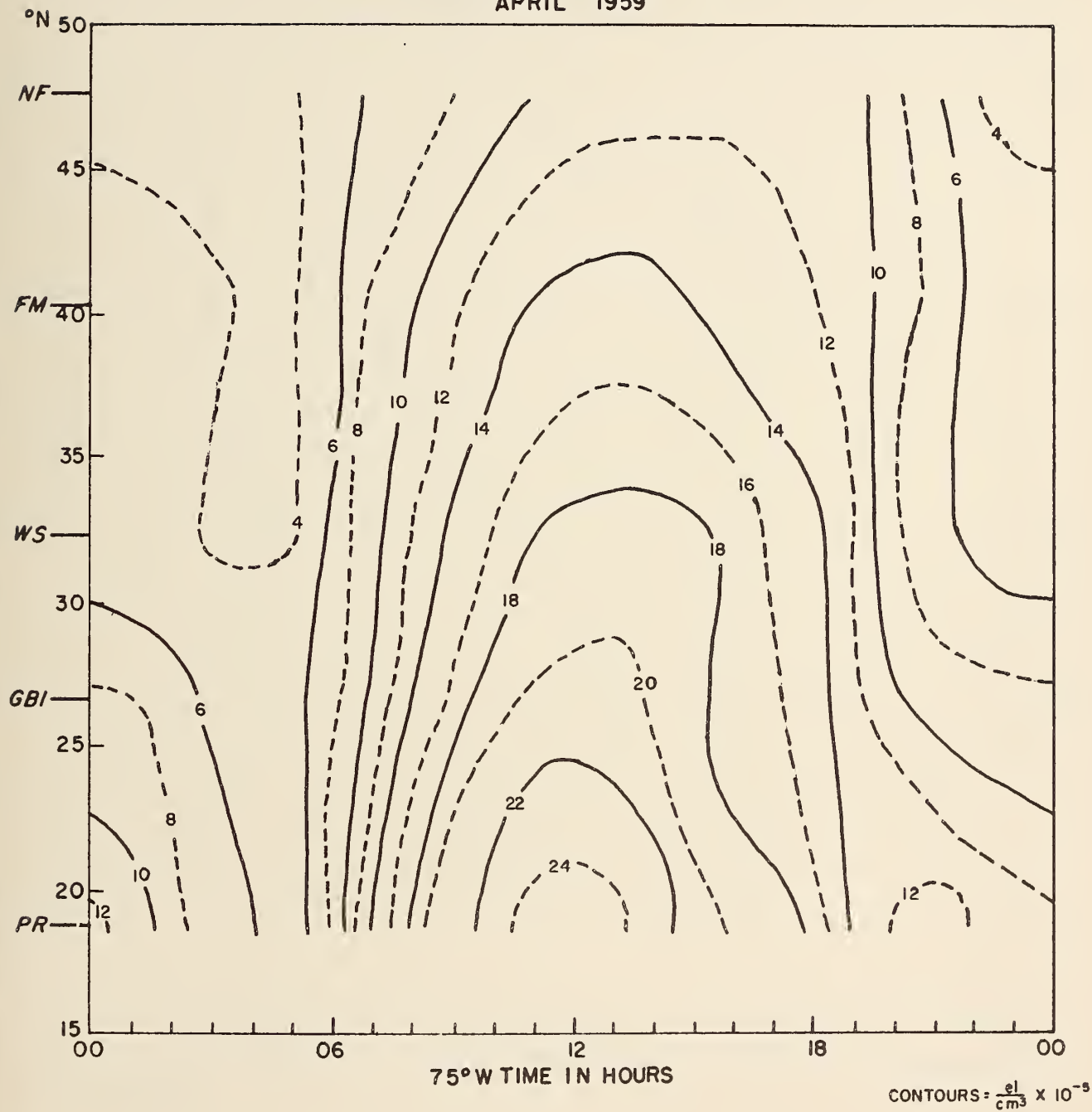
ELECTRON DENSITY AT 300 KILOMETERS

APRIL 1959



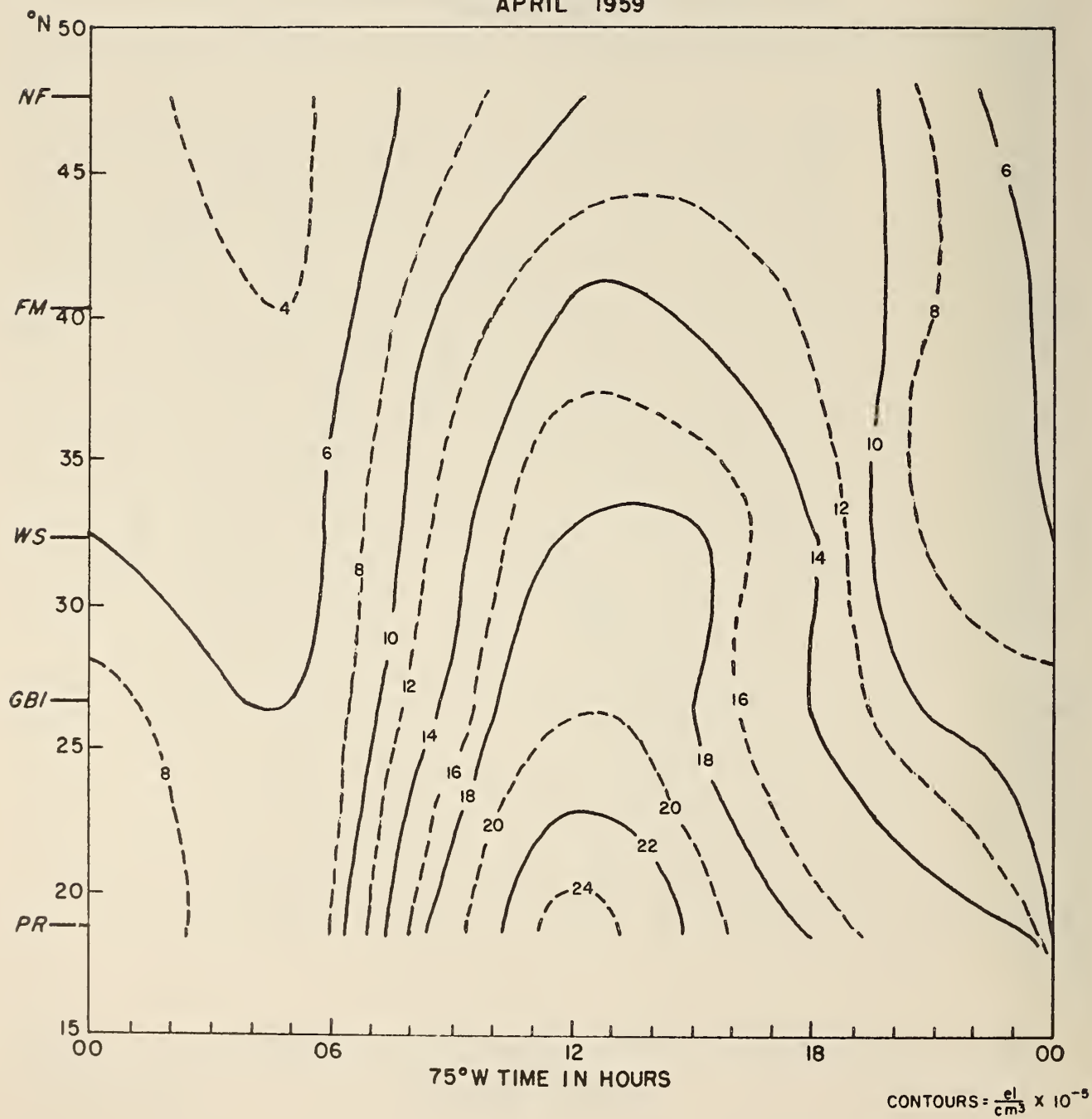
ELECTRON DENSITY AT 350 KILOMETERS

APRIL 1959

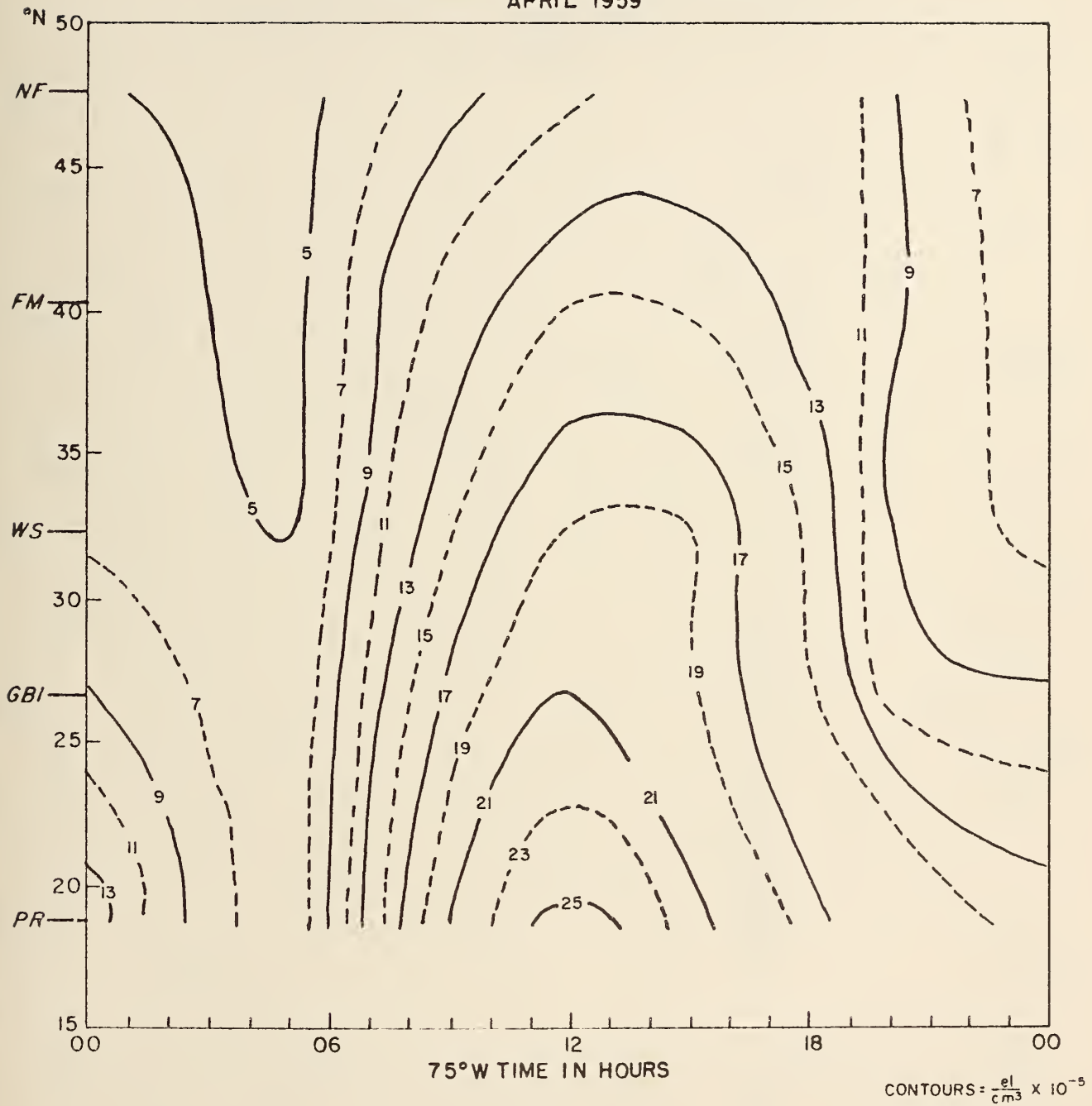


ELECTRON DENSITY AT 400 KILOMETERS

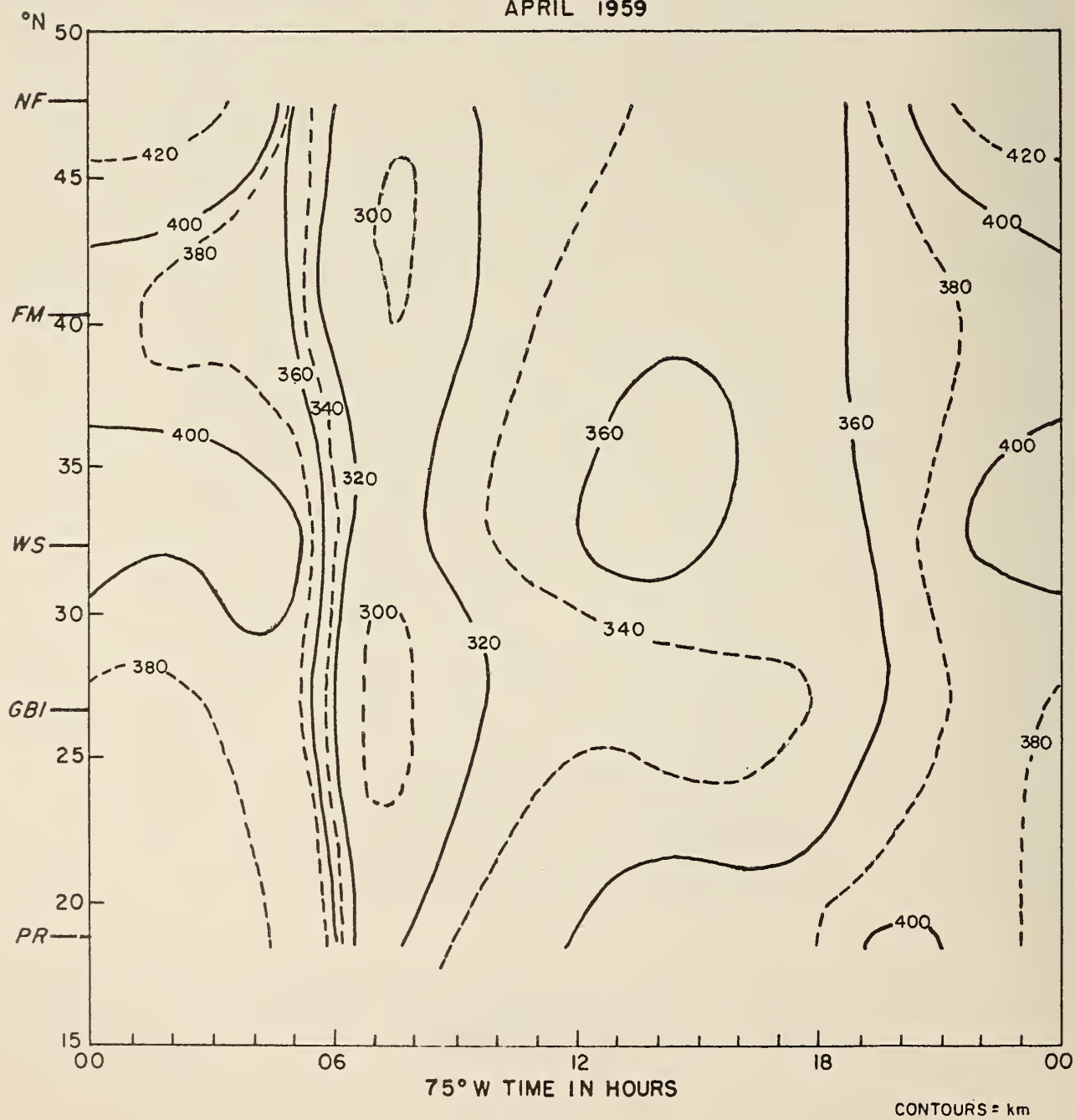
APRIL 1959



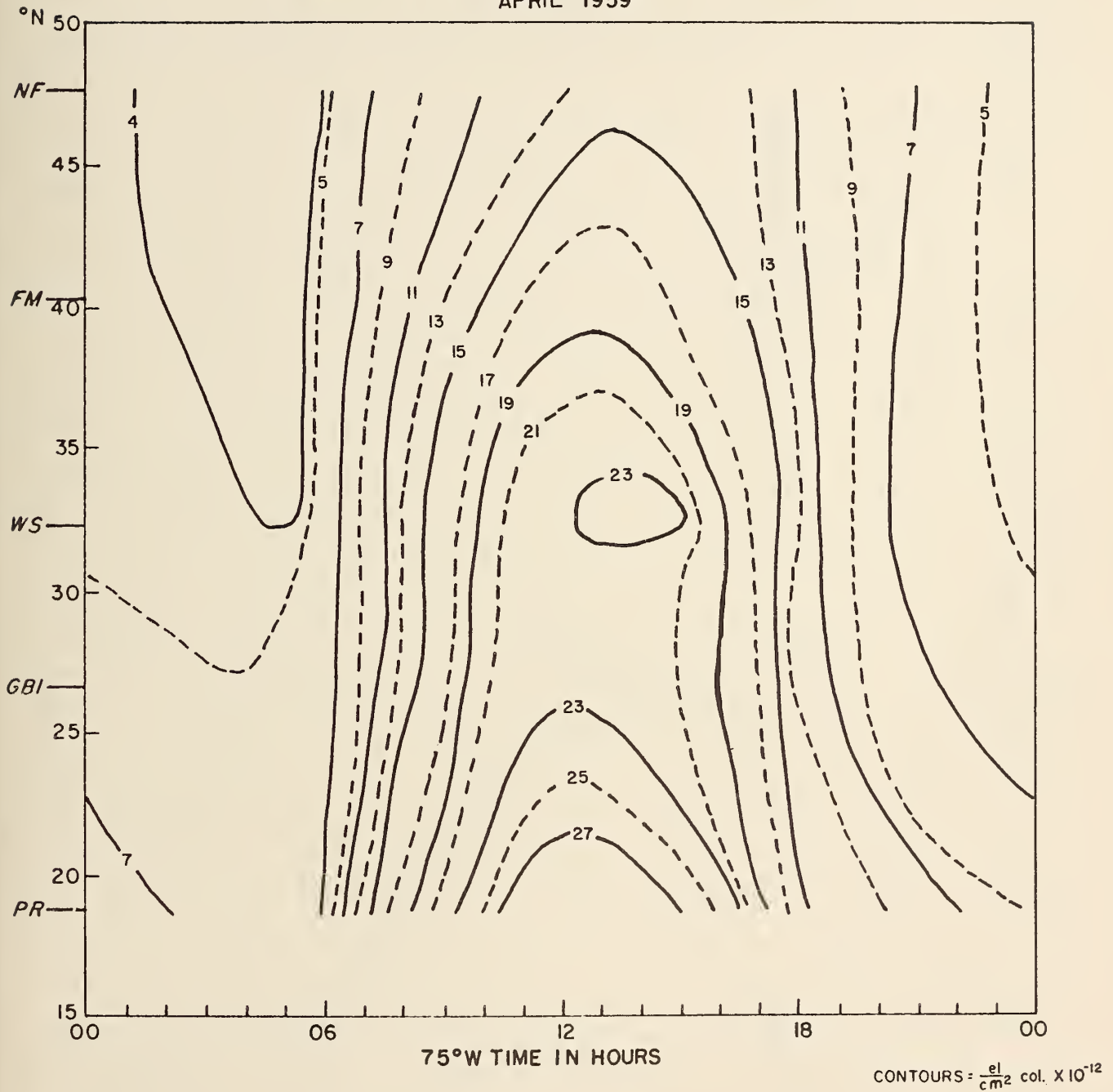
MAXIMUM ELECTRON DENSITY
APRIL 1959



HEIGHT OF MAXIMUM ELECTRON DENSITY
APRIL 1959

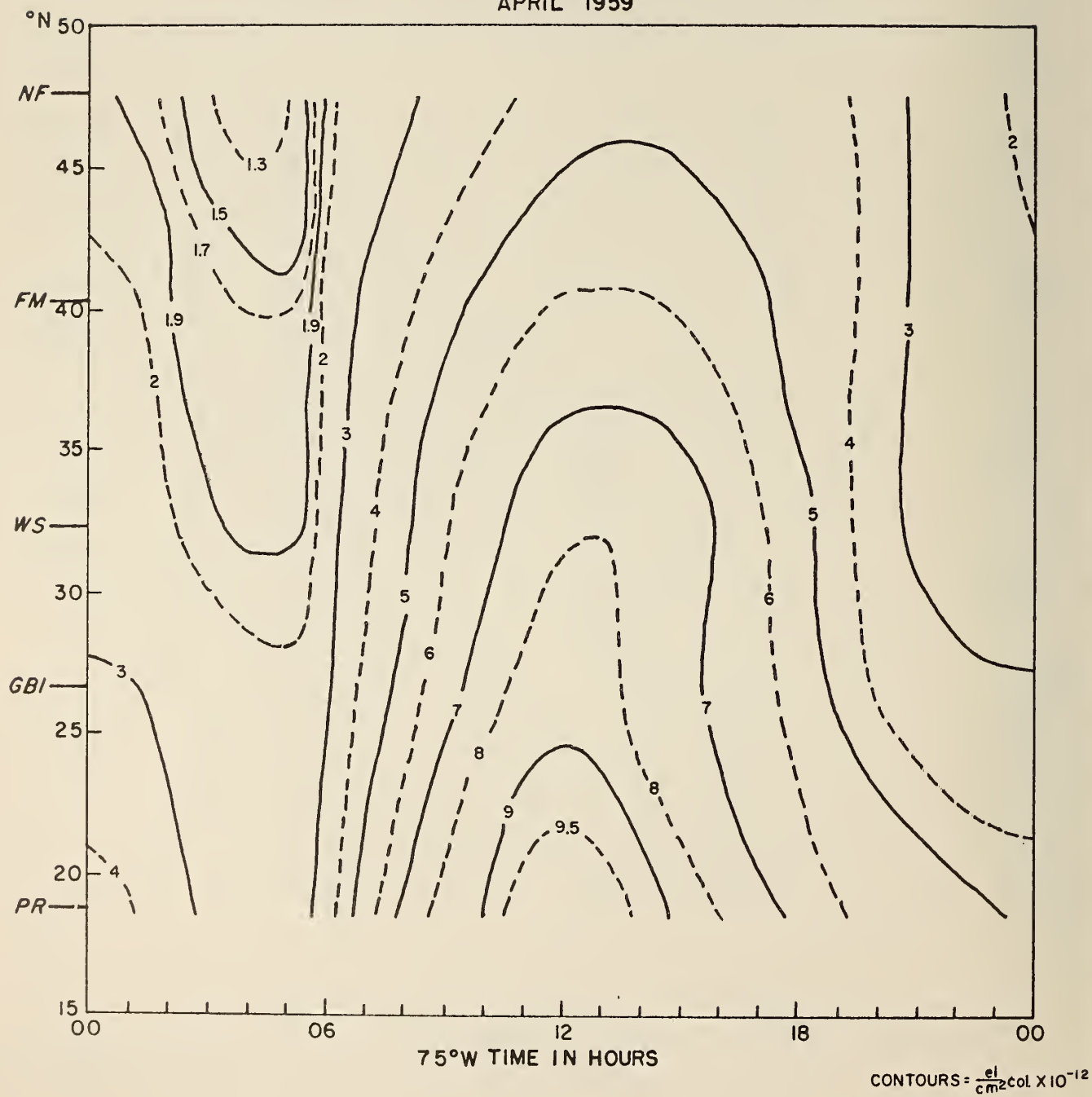


ELECTRON DENSITY INTEGRATED TO
HEIGHT OF MAXIMUM ELECTRON DENSITY
APRIL 1959

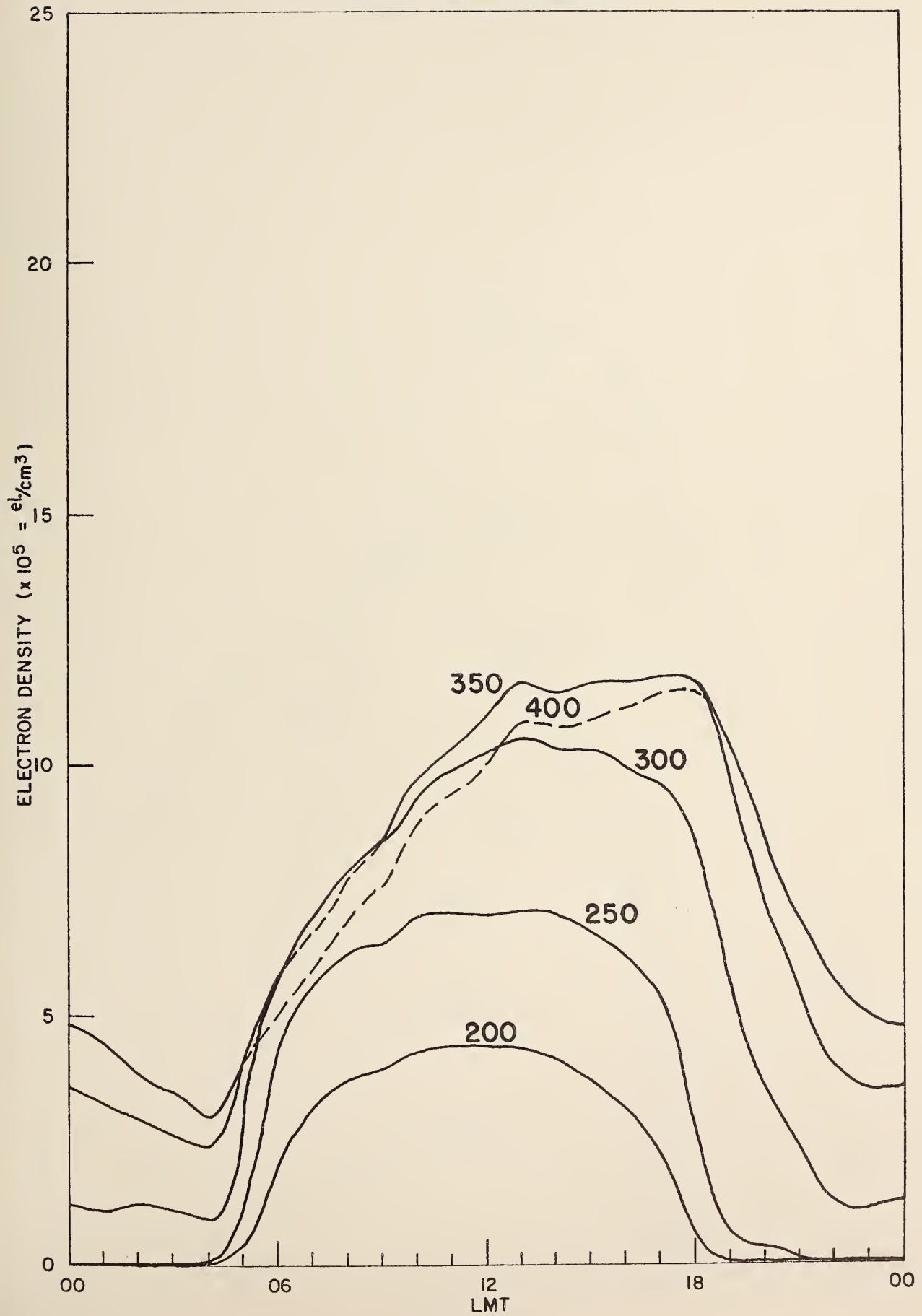


ELECTRON DENSITY INTEGRATED TO INFINITY

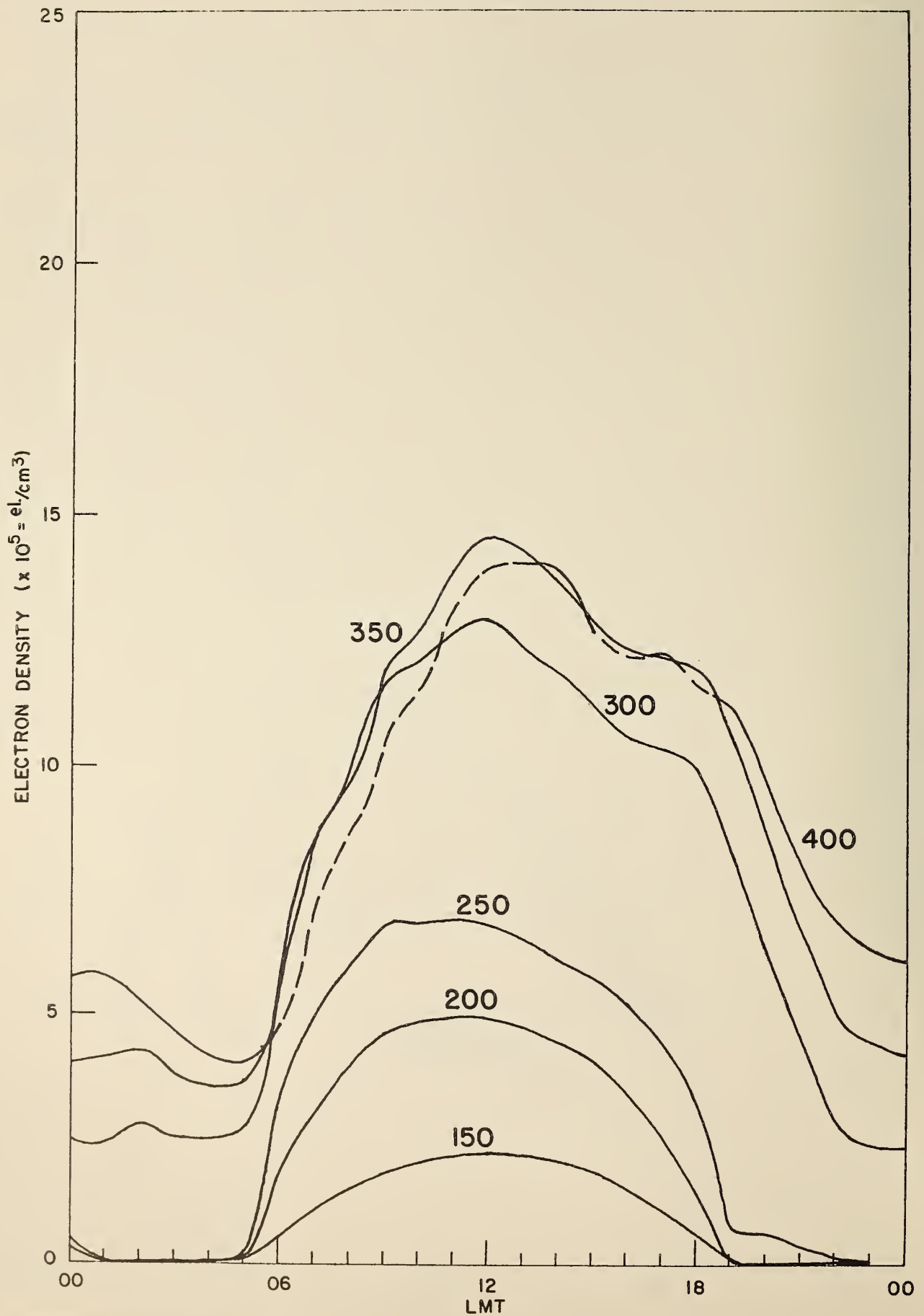
APRIL 1959



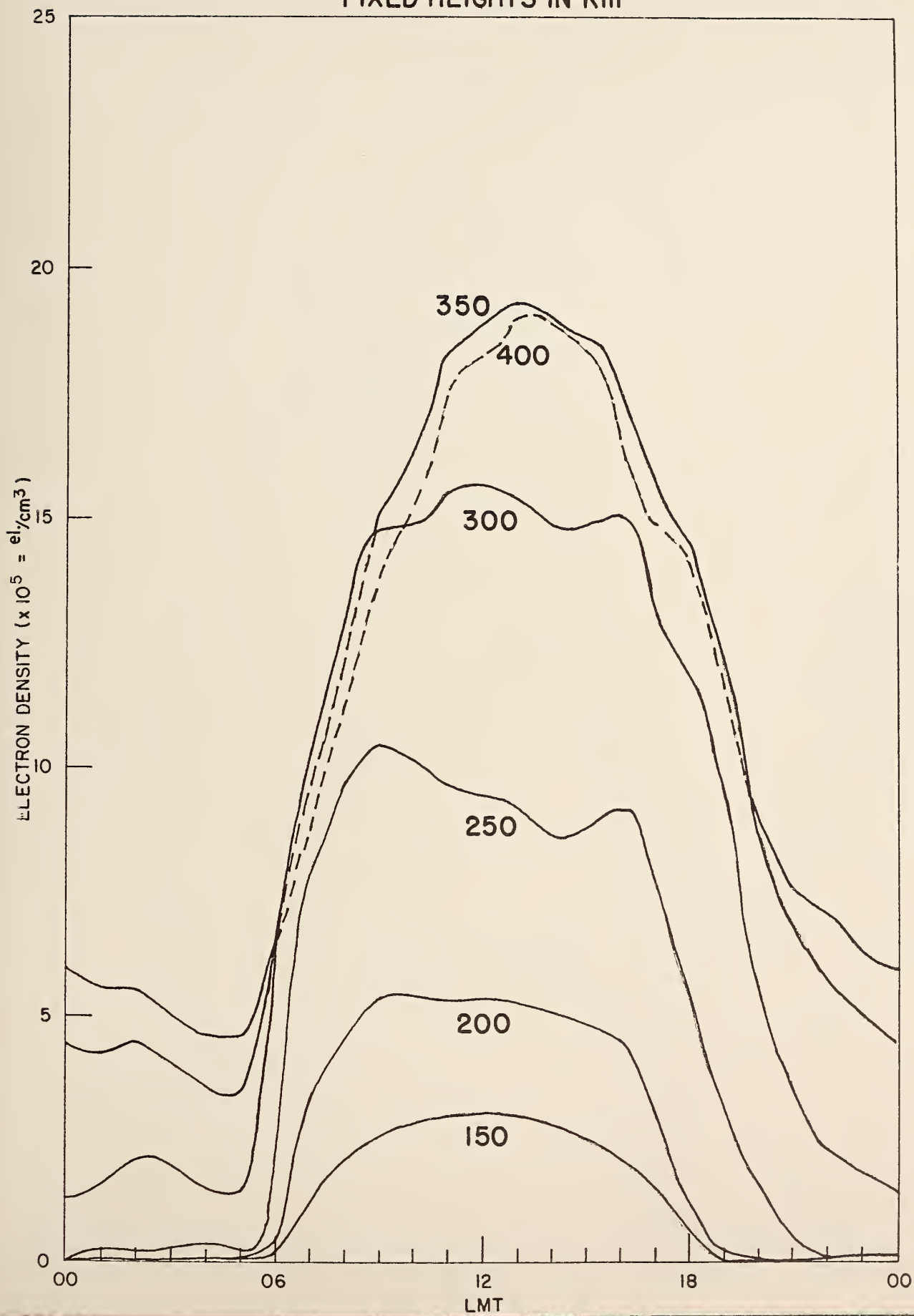
N(t) ST. JOHNS, NEW FOUNDLAND APRIL 1959
FIXED HEIGHTS IN Km



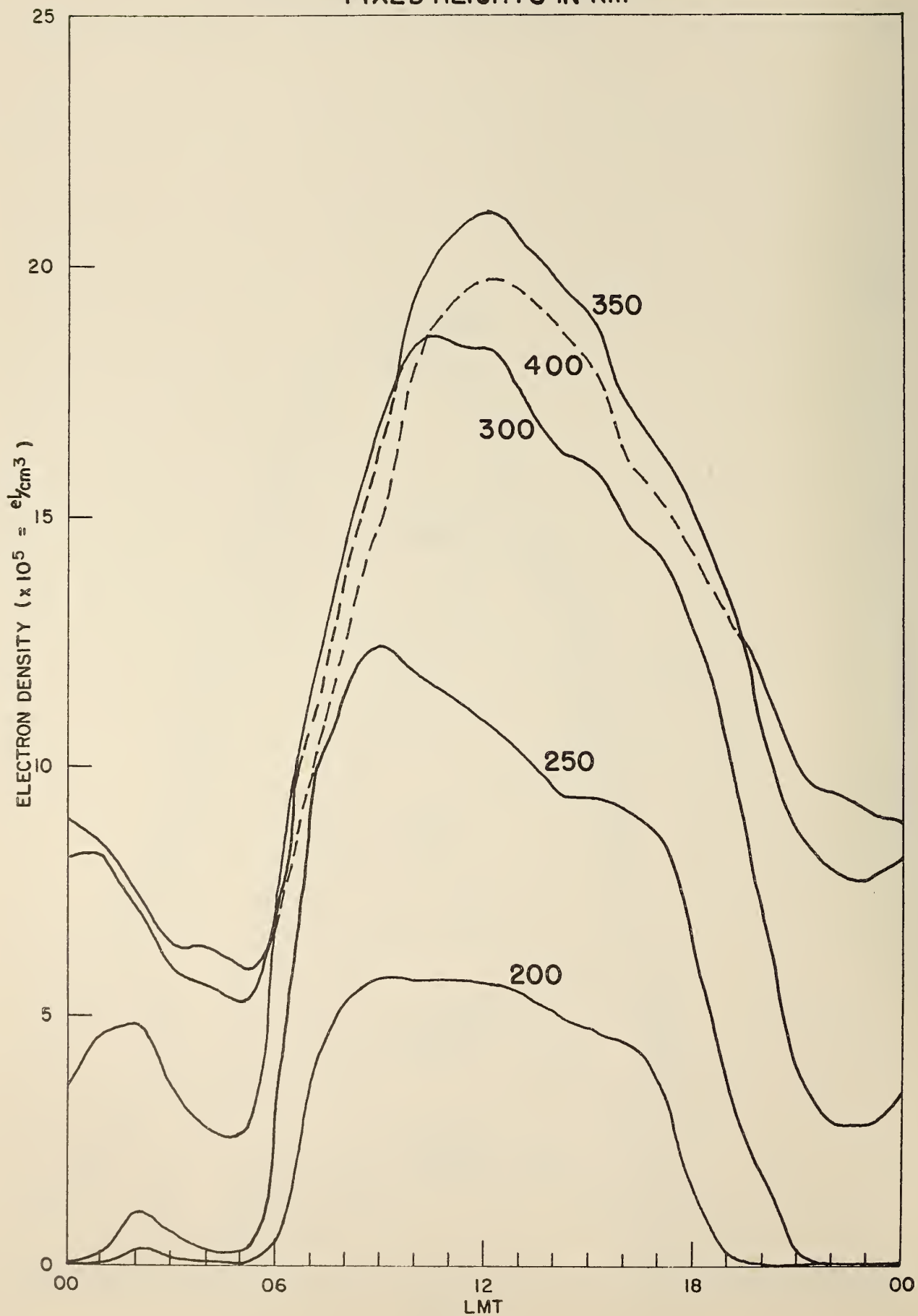
N(†) FORT MONMOUTH APRIL 1959
FIXED HEIGHTS IN Km



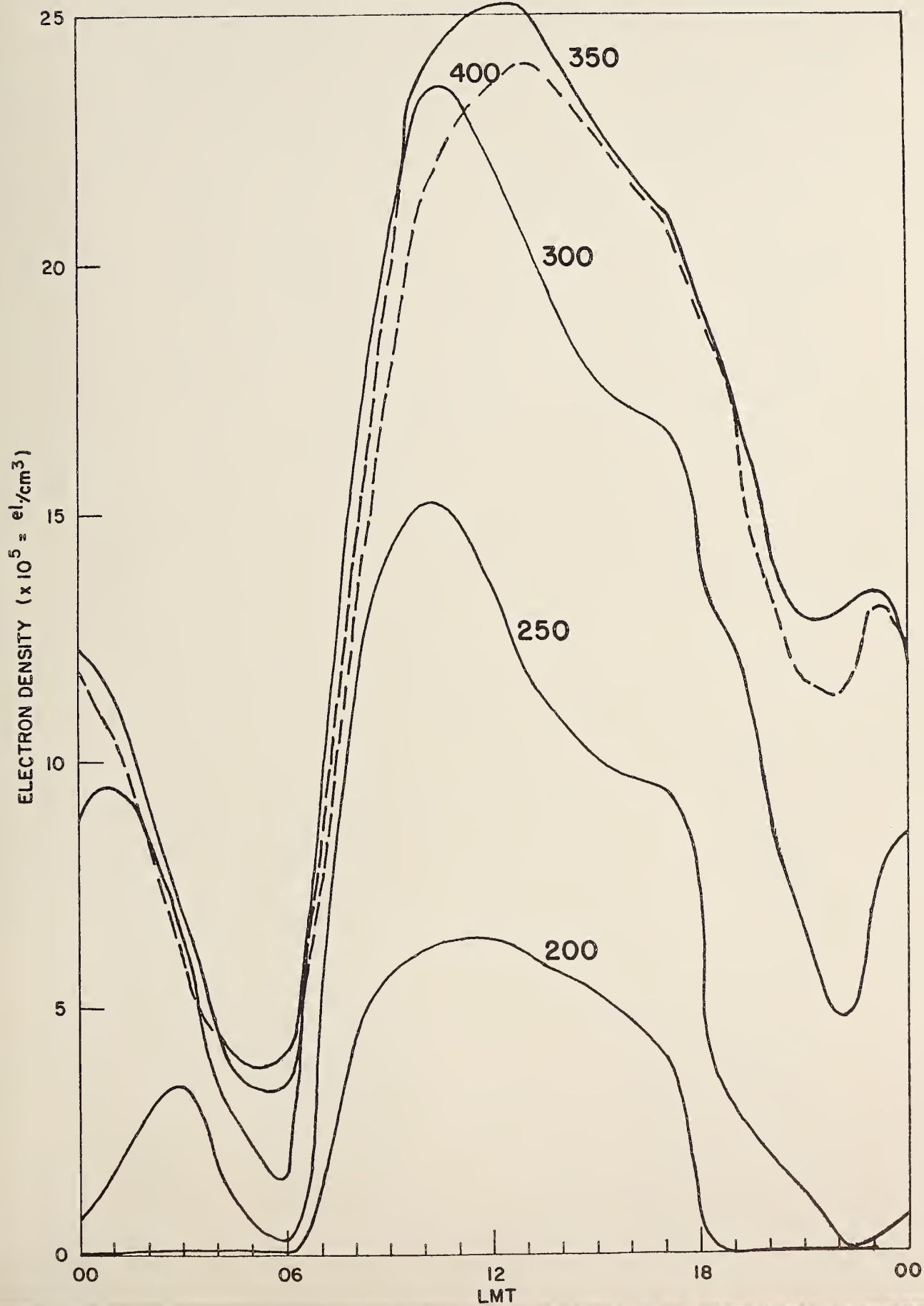
N(t) WHITE SANDS APRIL 1959
FIXED HEIGHTS IN Km

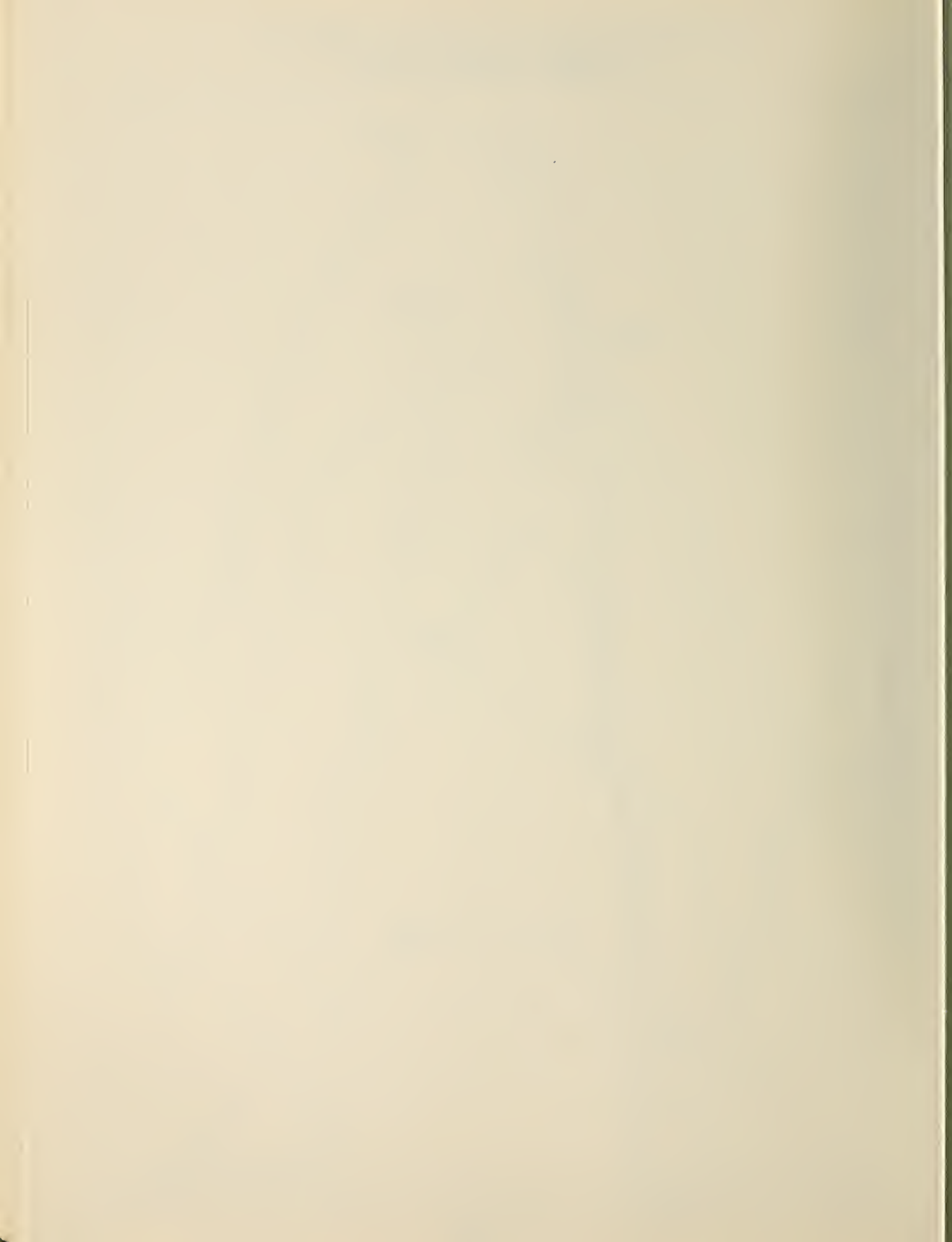


N(†) GRAND BAHAMA ISLAND APRIL 1959
FIXED HEIGHTS IN Km



N(t) PUERTO RICO APRIL 1959
FIXED HEIGHTS IN Km





U.S. DEPARTMENT OF COMMERCE

Frederick H. Mueller, *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 and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Photographic Technology. Length. Engineering Metrology.

Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. 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. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer. Concreting Materials.

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

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.

• Office of Basic Instrumentation.

• Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VLF Research. Radio Warning Services. Airglow and Aurora. Radio Astronomy and Arctic Propagation.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Research. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation Obstacles Engineering. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.

Radio Communication and Systems. Low Frequency and Very Low Frequency Research. High Frequency and Very High Frequency Research. Ultra High Frequency and Super High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Systems Analysis. Field Operations.



