MEAN SOUNDINGS FOR THE WEST INDIES AREA

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ABSTRACT

Mean aerological data for the West Indies area have been prepared from ten-year records for three stations. Mean monthly height, temperature and relative humidity data are tabulated for constant pressure surfaces. More detailed information, including density, potential temperature and specific humidity, is shown for the mean annual and the mean "hurricane season" soundings. The mean data are compared with those previously presented and some of the interesting climatological features are discussed.

1. Introduction

In the tropics, departures from the officially adopted standard atmospheres are so large that mean soundings lose much of their usefulness as a reference. For purposes of altimetry the standard atmospheres are used in the tropics despite their limitations but special mean soundings have been prepared for use in synoptic meteorology (Schacht, 1946; U. S. Weather Bureau, 1948; Colón, 1953). These soundings were prepared primarily for use in connection with tropical cyclones and, accordingly, used data only from the summer and autumn months. Consequently, in using these soundings during the colder months the synoptic meteorologist encounters the same type of difficulty as in using the U. S. Standard Atmosphere.

The new set of aerological data presented in this report provides mean data for all seasons of the year. This has been done by computing mean monthly soundings which can be used individually or combined into seasonal means in any way that may be appropriate for the purpose at hand. In this report, detailed data are presented for mean annual and mean "hurricane season" soundings.

In addition to providing data on a seasonal basis, the new set of mean soundings have other features which recommend their use in preference to those previously prepared. A considerably longer period of record has been used in computing the means and use has been made of observations during recent years when soundings have reached the upper tropospheric and lower stratospheric levels with much greater regularity. These data from recent years have permitted the extension of the mean soundings to the 30-mb surface (roughly 78,000 ft).

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2. Processing of data

The mean monthly aerological records for the ten-year period 1946–1955 for Miami, Florida; San Juan, Puerto Rico and Swan Island—the same stations selected by Schacht (1946)—have been used in preparing the mean soundings for the West Indies area. Only the night time soundings (0300 GCT) have been used because of inhomogeneities in the daytime data arising from the different methods of correcting for radiation effects during the ten-year period. Mean values of the temperature and humidity have been computed for each month of the year at the standard levels used in the climatological records. The interval between levels is 50 mb between 1000 and 200 mb and progressively decreases at the higher levels.

Soundings prepared from the mean temperature and humidity data were used for the determination of the heights of the standard pressure surfaces. The mean 1000-mb height has been used as the beginning point in computing the mean pressure-height data. The computation was handled in this way because the three stations were at different elevations so that the surface pressure could not be simply averaged. Some of the comparisons made below indicate that the use of the 1000-mb height could not have introduced significant errors.

Processing of the humidity data required special consideration because of the fact that reports are always missing when the humidity is low. For the climatological records mean monthly humidities are computed for individual months if as many as sixteen observations are available and, in addition, statistical values are used in the cases where the humidity was low enough that the radiosonde was "motorboating." The values used in these cases are the average threshold values for "motorboating" at the appropriate temperatures. The preparation of humidity data for the mean soundings made use of an arbitrary procedure similar to that employed in the computation of the monthly means. Averages were computed only if there were values for six or more years out of the ten-year period; also, in computing means, the missing years were assigned the lowest value during the period of record appropriate to the level and month. The use of statistical values in computing the means was directed at reducing the bias introduced by the lack of observations in all cases of low humidity. Bias of this type arises mainly at levels above 700 mb where the moisture content has only a very small effect on the height computations.

3. The mean aerological data

The monthly and annual temperature, height, and relative humidity data for the West Indies area for the ten-year period are shown in tables 1–3.[2] Data in more detail, including density, potential temperature, specific humidity and equivalent potential temperature, are presented for the mean annual West Indies sounding in table 4. A similar detailed tabulation of mean data for the "hurricane season," arbitrarily defined as the four-month period July through October, is shown in table 5. These tabulations contain the essential information which this report intends to convey. The following discussion outlines various limitations of the data, compares the results with previous computations of mean conditions in the tropics, and points out some of the more interesting climatological features shown by the mean soundings.

The combination of aerological data to form averages for some area and time period often results in mean soundings which are not typical of conditions throughout the area used. For example, the soundings made at many individual stations in the United States bear little resemblance to the U. S. Standard Atmosphere during any season of the year. The smaller geographical and seasonal variability in the tropics makes mean soundings for these areas much more representative of the conditions that may be expected at any given time and place.

Mean conditions in summer are quite similar at the three stations used in this study and there is little doubt that the averages for the West Indies area (table 1–3) approximate quite closely the mean which might have been obtained had there been a large number of stations uniformly spaced over the area. However, the means are somewhat less representative in winter because of geographical differences. For example, the differences between the warmest and coldest month at middle tropospheric levels were as great at 6C at Miami compared to 1 to 2C variations at the other stations. Thus, use of another station as far north as Miami instead of San Juan or Swan Island would have resulted in somewhat different mean values for the winter months. This type of limitation, which is com-

[2] Mean temperature and relative humidity data for the individual stations were given in the preprinted version of this article (Jordan, 1957).

TABLE 1. Mean temperature (°C) at standard pressure surfaces for West Indies area. All values above the dashed line are negative.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
30	58.3	57.2	55.7	54.1	53.6	52.6	53.5	53.7	54.0	55.0	55.3	56.1	54.9
40	61.6	61.7	60.9	58.4	57.2	56.5	56.6	56.6	57.7	58.3	59.2	60.2	58.7
50	66.1	66.1	66.3	63.4	61.3	60.3	60.0	60.2	60.8	61.5	62.5	64.9	62.7
60	70.8	71.2	71.4	68.6	65.2	63.9	63.2	63.2	64.0	65.3	66.7	70.0	66.9
80	77.7	77.1	76.8	75.0	72.9	70.1	68.9	69.1	69.4	72.0	75.2	77.0	73.4
100	76.1	75.7	75.6	74.3	74.8	72.9	71.3	72.8	73.9	75.9	76.5	76.0	74.6
125	70.6	70.3	70.2	70.3	72.1	72.4	70.8	71.5	72.9	73.6	72.8	71.1	71.5
150	65.2	64.8	65.0	66.0	67.0	68.3	67.7	67.2	67.7	67.9	67.7	66.2	66.7
175	59.9	59.6	60.0	60.9	61.1	62.1	62.1	61.3	61.3	61.4	61.6	61.1	61.0
200	55.2	54.8	55.1	55.6	55.2	55.7	55.9	55.0	54.9	54.9	55.5	55.7	55.3
250	45.6	45.3	45.3	45.0	43.8	43.7	44.0	43.2	42.8	43.2	44.1	45.0	44.2
300	36.4	36.3	36.0	35.3	34.1	33.6	33.9	33.1	32.7	33.2	34.2	35.4	34.5
350	28.1	28.1	27.8	26.9	25.8	25.1	25.4	24.7	24.3	24.8	25.8	27.0	26.1
400	20.6	20.9	20.2	19.7	18.7	18.1	18.2	17.6	17.3	17.7	18.6	19.8	18.9
450	14.2	14.3	13.5	13.5	12.7	12.3	12.4	11.8	11.6	11.8	12.5	13.5	12.8
500	8.5	8.7	7.9	8.0	7.6	7.3	7.4	6.8	6.7	6.7	7.3	8.0	7.6
550	3.7	3.8	3.1	3.3	3.1	2.9	3.1	2.4	2.3	2.4	2.8	3.3	3.0
600	0.4	0.3	1.1	0.7	0.8	1.1	0.8	1.5	1.7	1.6	1.2	0.8	1.0
650	4.0	3.8	4.7	4.2	4.5	4.8	4.6	5.1	5.5	5.2	4.8	4.4	4.6
700	6.9	6.7	7.7	7.3	7.8	8.4	8.3	8.8	8.9	8.5	8.0	7.4	7.9
750	9.3	9.1	10.0	10.0	10.8	11.6	11.6	12.0	12.1	11.5	10.7	10.0	10.7
800	11.1	10.9	11.9	12.4	13.5	14.4	14.5	14.9	14.9	13.9	13.1	11.9	13.1
850	13.1	12.9	14.1	14.8	16.2	17.1	17.1	17.6	17.7	16.9	15.4	14.0	15.6
900	15.9	15.6	16.6	17.5	19.0	19.8	19.9	20.5	20.5	19.7	18.1	16.8	18.3
950	19.0	18.7	19.3	20.4	21.8	22.6	22.8	23.4	23.4	22.6	21.1	19.9	21.2
1000	22.1	21.8	22.6	23.6	24.8	25.6	26.1	26.4	26.2	25.5	24.0	23.0	24.3
Sfc.	22.4	22.3	23.2	24.3	25.4	26.2	26.5	26.8	26.4	25.6	24.1	23.0	24.7

mon to all mean soundings, should be recognized in making use of the data for the cooler months. In particular, it places restrictions on the use of the mean West Indies data as a standard for other tropical areas.

The smaller number of reports at the upper tropospheric levels which went into the computation of the monthly means in the early years raises the question whether these values should have been given equal weight with those from recent years when the observations have been more numerous. In fact, mean temperatures for levels above 100 mb are based almost entirely on observations made during the last five years of the period. At the three stations only about 30 per cent of the daily soundings reached the 100-mb surface in 1949, compared to 60 per cent in 1952 and 80 per cent in 1955. The number of soundings reaching the 30-mb surface increased from less than 15 per cent in 1949 to about 30 per cent in 1955. A definite bias could have been introduced by giving equal weight to all years if the few soundings in early years tended to attain the higher levels more frequently during periods when the upper tropospheric temperatures were warmest. However, averages of the 200-, 150- and 100-mb data for the months January, April, July, and October for the five-year period 1951–1955 revealed differences from the 10-yr means of 0.3C or less. This check suggests that the use of the monthly averages based on relatively few observations had a minor effect on the 10-yr means. However, during some months at the highest levels the values in table 1 are based on data from only three years from each station. For this reason all values at levels above 60 mb are probably somewhat different than might be obtained from a longer and more complete record.

The mean height data presented in table 3 were prepared by working up the soundings obtained from the mean temperature and humidity data. A check was made at three levels (700, 500, and 200 mb) to deter-

TABLE 2. Mean humidity (per cent) at standard pressure surfaces for West Indies area.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
400						45			44				
450						45	44	40	45				
500						46	46	43	49	42			
550					37	48	47	45	51	46			
600					41	50	49	50	54	49			
650					44	52	52	53	56	53			
700				38	47	55	53	56	60	58	46	42	47
750	41	41	39	45	55	58	57	59	64	64	53	49	52
800	57	56	52	57	62	64	65	66	70	71	65	61	62
850	71	69	64	66	69	72	74	73	74	76	73	71	71
900	77	75	72	73	75	77	79	78	79	79	78	76	77
950	78	77	77	77	79	81	81	81	81	81	79	78	79
1000	76	76	76	77	79	81	81	81	81	81	79	77	79
Sfc.	79	79	77	78	80	83	83	83	84	84	82	80	81

TABLE 3. Mean heights of standard pressure surfaces (tens of feet) for West Indies area. Sea-level pressure (SLP) is expressed in millibars as deviations from 1000.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
30	7774	7780	7794	7818	7843	7869	7874	7877	7864	7842	7816	7793	7830
40	7185	7189	7200	7218	7242	7265	7271	7275	7264	7244	7219	7200	7233
50	6736	6740	6750	6763	6783	6804	6811	6815	6805	6787	6764	6748	6777
60	6381	6382	6392	6400	6415	6434	6441	6445	6437	6420	6399	6388	6412
80	5831	5832	5841	5844	5851	5865	5870	5874	5866	5855	5840	5836	5851
100	5411	5410	5419	5419	5423	5433	5435	5441	5436	5428	5418	5414	5424
125	4983	4982	4989	4990	4996	5003	5003	5011	5008	5002	4992	4986	4996
150	4624	4622	4629	4630	4639	4648	4646	4655	4654	4647	4637	4628	4638
175	4312	4309	4318	4319	4329	4340	4338	4346	4346	4339	4328	4318	4328
200	4035	4033	4041	4043	4054	4066	4064	4071	4070	4063	4053	4043	4053
250	3558	3554	3563	3566	3575	3586	3586	3592	3589	3583	3574	3565	3574
300	3153	3148	3156	3158	3165	3176	3176	3181	3177	3172	3164	3158	3165
350	2797	2792	2799	2800	2804	2816	2815	2819	2815	2811	2804	2799	2806
400	2478	2473	2479	2479	2481	2493	2493	2495	2491	2488	2482	2479	2484
500	1923	1918	1923	1923	1924	1933	1934	1935	1930	1928	1924	1922	1926
600	1451	1447	1450	1450	1450	1459	1461	1460	1456	1453	1450	1450	1453
700	1041	1036	1038	1038	1038	1046	1049	1046	1042	1039	1038	1038	1040
800	678	674	674	674	673	679	682	678	674	673	672	674	675
850	510	507	506	506	505	509	513	509	505	503	504	506	507
900	350	348	347	346	344	348	352	347	343	342	344	347	347
1000	52	51	49	46	43	46	49	45	40	39	43	48	46
SLP	18.5	18.0	17.1	16.3	15.0	15.9	17.1	15.4	14.0	13.8	15.2	16.8	16.3

mine the magnitude of the difference between these computed heights and the heights obtained by simply averaging the height data for the individual months. Nearly all differences were ten feet or less and the maximum value was only 25 ft. Similarly, the computed heights shown for the mean "hurricane season" sounding (table 5) did not deviate from the average of the July–October heights by as much as 15 ft at any level. These checks suggest that, at least over a long period of record, both the height and temperature data may be averaged in the preparation of mean soundings without introducing significant inconsistencies.

TABLE 4. Mean annual West Indies sounding data for isobaric surfaces. Mean values of height (H), temperature (T), density (ρ), potential temperature (θ), equivalent potential temperature (θ_E), relative humidity (f), and specific humidity (q) are tabulated.

P (mb)	H (m)	H (ft)	T (°C)	ρ (kg/m³)	θ (°A)	θ_E (°A)	f (%)	q (g/kg)
30	23,867	78,305	−54.9	0.048	594			
40	22,047	72,335	−58.7	0.065	538			
50	20,658	67,775	−62.7	0.083	495			
60	19,546	64,125	−66.9	0.101	461			
80	17,836	58,515	−73.4	0.140	411			
100	16,535	54,245	−74.6	0.175	383			
125	15,227	49,955	−71.5	0.216	365			
150	14,137	46,380	−66.7	0.253	355			
175	13,193	43,285	−61.0	0.287	349			
200	12,353	40,530	−55.3	0.319	345			
250	10,894	35,740	−44.2	0.380	340			
300	9647	31,650	−34.5	0.438	337			
350	8553	28,060	−26.1	0.493	334			
400	7573	24,845	−18.9	0.548	330			
450	6682	21,925	−12.8	0.602	327			
500	5870	19,260	− 7.6	0.656	324			
550	5123	16,810	− 3.0	0.709	320			
600	4427	14,530	1.0	0.762	317			
650	3779	12,400	4.6	0.814	314			
700	3171	10,405	7.9	0.865	311	323	42	4.5
750	2599	8525	10.7	0.917	308	324	52	5.6
800	2058	6750	13.1	0.970	305	325	62	7.3
850	1545	5070	15.6	1.020	302	328	71	9.3
900	1057	3470	18.3	1.070	300	331	77	11.5
950	590	1935	21.2	1.116	299	334	79	13.2
1000	141	465	24.3	1.161	298	336	79	15.2
1016.3	0	0	24.7	1.180	297	337	81	15.6

TABLE 5. Mean West Indies sounding data for "hurricane season" (July–October). Data are shown in the same form as in table 4.

P (mb)	H (m)	H (ft)	T (°C)	ρ (kg/m³)	θ (°A)	θ_E (°A)	f (%)	q (g/kg)
30	23,971	78,645	−54.0	0.048	597			
40	22,139	72,635	−57.3	0.065	542			
50	20,743	68,055	−60.6	0.082	500			
60	19,620	64,370	−63.9	0.100	468			
80	17,883	58,670	−69.8	0.137	418			
100	16,568	54,355	−73.5	0.174	386			
125	15,260	50,065	−72.2	0.217	364			
150	14,177	46,510	−67.6	0.254	354			
175	13,236	43,425	−61.5	0.288	348			
200	12,396	40,670	−55.2	0.320	345			
250	10,935	35,875	−43.3	0.379	342			
300	9682	31,765	−33.2	0.434	338			
350	8581	28,155	−24.8	0.490	335			
400	7595	24,920	−17.7	0.545	332			
450	6703	21,990	−11.9	0.599	328	333	42	1.4
500	5888	19,315	− 6.9	0.653	324	332	45	2.1
550	5138	16,855	− 2.5	0.707	321	331	47	3.2
600	4442	14,575	1.4	0.760	318	328	50	3.6
650	3792	12,440	5.1	0.811	315	328	54	4.6
700	3182	10,440	8.6	0.862	312	329	57	5.8
750	2609	8560	11.8	0.913	309	330	61	7.1
800	2063	6770	14.6	0.964	307	331	68	8.4
850	1547	5075	17.3	1.013	304	334	74	11.0
900	1054	3460	19.8	1.062	302	338	79	13.0
950	583	1915	23.0	1.108	300	341	81	15.3
1000	132	435	26.0	1.152	299	345	81	17.6
1015.1	0	0	26.3	1.167	298	345	84	18.2

4. Comparative results

Colón (1953) prepared a mean sounding for the rainy season of the western Pacific and carried out a rather detailed comparison with the mean data presented by Schacht (1946). For this purpose, it was necessary to convert Schacht's mean data, which were given at one-km levels, to make them applicable to the standard pressure surfaces. The following comparison makes use of the converted data prepared by Colón.

The mean data prepared by Schacht (1946) were based on soundings made during August, September and October of the years 1941–1944 at the same three stations used in this study. Therefore, for comparison, averages were computed for the period August through October from the data presented in tables 1–3.[3]

The deviations of the mean August–October temperature values from those computed by Schacht were less than 0.5C through a deep layer of the troposphere extending from 850 to 150 mb (fig. 1). The apparent increase in the mean temperature near the surface between the two periods was not evident from the climatological records of surface conditions at the three stations. Apparently, changes in local conditions at the radiosonde observation sites contributed to such differences. For example, the transfer of the station at San Juan from downtown to the airport and a considerable clearing of forest near the Swan Island site may have been important.

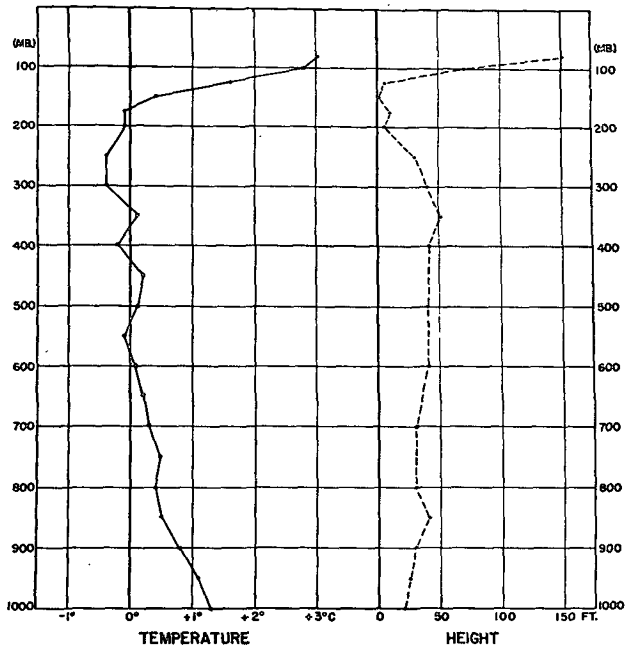

FIG. 1. Deviations of the mean August–October temperature and pressure-height data (tables 1, 3) from Schacht's mean data.

[3] This set of data showed only very small differences from the "hurricane season" sounding (table 5).

The largest temperature deviations shown by fig. 1 occur at the highest levels. The number of reports available to Schacht which reached the 100- and 80-mb levels must have been very small since even in the years 1946–1948 less than 25 per cent of the months had as many as five soundings reaching the 100-mb level and less than ten per cent of the monthly records listed 80-mb data. In contrast, in the period 1952–1955 from 50 to 90 per cent of the daily observations reached the 80-mb level during the individual months. Therefore, there can be little doubt that the means provided by the new set of data are more reliable at these higher levels.

Differences between the relative humidities given by the Schacht and the August–October averages from table 2 were quite small. The new set of data gave slightly higher values at all levels but the maximum deviation was only four per cent.

5. Climatological features

The mean monthly data provide an opportunity for a rather detailed examination of seasonal variations at various levels in the troposphere and lower stratosphere. The seasonal trends were quite similar at the three stations; therefore, the month-to-month variations shown by the mean West Indies data reflect, at least to a large extent, true seasonal changes for the area.

The total range in mean monthly temperature is shown by fig. 2 on which the mean annual sounding has been plotted along with the maximum and minimum values at each level and the months of their occurrence. At levels up to 250 mb the maximum temperatures were found in August and September and the minimum values in January and February. A nearly complete reversal is shown in the upper troposphere with the maximum in February and March and the minimum in June and July. In the stratosphere the pattern is similar to that in the lower and middle troposphere except that the warmest values are attained in June and July rather than in August and September.

The range in the mean monthly temperature is smallest at the 600-mb and 200-mb levels with magnitudes of less than 1.5C Relative maxima occur at 850 and 350-mb with spreads of almost 4C. The spread increases to somewhat larger values at levels above 200-mb and the absolute maximum of almost 9C is found at 80-mb. There is a gradual decrease above this level but the spread is still larger than at any of the tropospheric levels.

An analysis of the anomalies of the monthly temperatures (fig. 3) brings out more clearly some of the features discussed in connection with fig. 2 and, in particular, shows the complicated character of the seasonal changes of temperature as a function of altitude.

The seasonal variations at the highest and lowest levels are not too different from what might be obtained from fig. 2 by assuming linear changes between the warmest and coldest months. However, at some of the intermediate levels there is a definite tendency for flat maxima and minima with deviations of the same sign persisting for more than half the year. The seasonal change patterns are most complicated in the 150- to 80-mb layer where the major tropopause variations occur. The tropopause in the West Indies region is highest and coldest in the winter months (Riehl, 1954) as indicated by the anomaly pattern at the 100-mb surface. The lower and somewhat sharper tropopauses found during the summer months account for the negative anomalies shown in the vicinity of the 150-mb level at this season.

A definite irregularity in the seasonal trend in late spring and early summer is shown by the anomalies at most tropospheric levels (fig. 3). This reversal of the normal trend was also noted in the temperature data for all three stations and apparently is a significant climatological feature. It is interesting that this anomaly in the seasonal temperature trend coincides with a rather large decrease in mean monthly rainfall throughout much of the West Indies area.

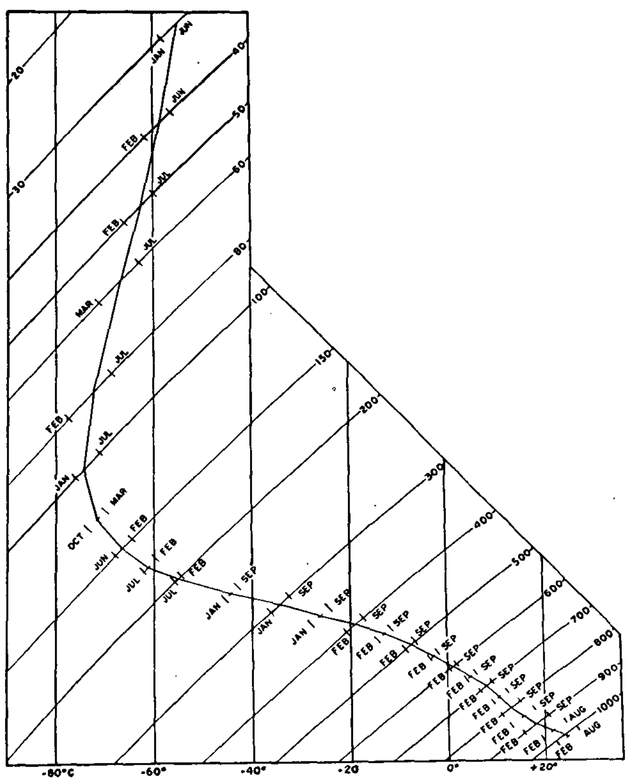

FIG. 2. Tephigram plot of mean annual temperature data (table 1). The maximum and minimum monthly values and the months of occurrence are shown at each level.

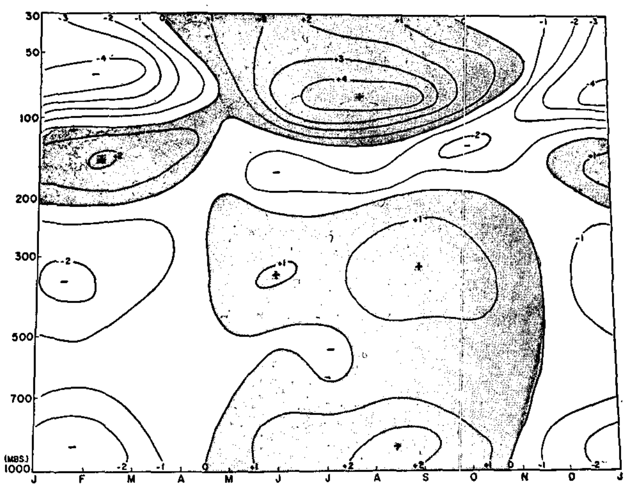

FIG. 3. Monthly temperature anomalies (C) from the annual means for West Indies area.

The temperature variations which arise from seasonal variations in the heights of the pressure surfaces contribute to some of the minor irregularities shown by fig. 3. However, to a large extent, the height field shows seasonal variations in phase with those of the temperature field. The interrelationship of these fields is readily apparent from a comparison of the monthly height anomalies (fig. 4) with the temperature anomalies (fig. 3). At levels above 700-mb, a definite annual oscillation is indicated with maximum heights in August; minimum heights are shown in February in the troposphere and in January in the stratosphere. The height field shows a complicated pattern in the lower levels which is not closely associated with the seasonal temperature changes. At these levels, there are maxima in January and July and minima in April–May and October–November. The amplitude of the seasonal oscillation of the height values increases from 850-mb upward and a relative maximum amounting

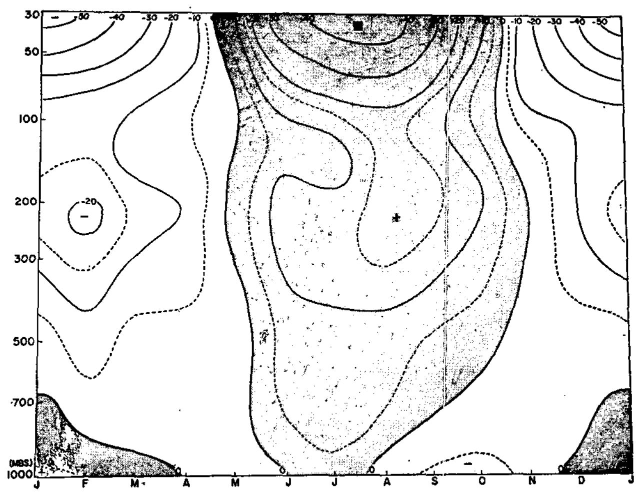

FIG. 4. Monthly pressure-height anomalies (tens of feet) from the annual means for West Indies area.

to nearly 400 ft is attained at the 200-mb level. The inverse temperature variation in the upper troposphere leads to a reduction in the amplitude of the seasonal height between 200 and 100 mb, but at higher levels the normal trend is again established and the range increases with height and attains an amplitude of over 1000 ft at the 30-mb surface.

The mean relative humidity data (table 2) show relatively small seasonal changes in the lower levels with maximum values in October and minimum values in March. The range in the mean monthly values increases from less than ten per cent at the surface to 25 per cent at the highest levels with complete data. The increase of moisture at the middle troposphere levels during the summer months is quite marked. At these levels the maximum values are attained in June and again in September in close agreement with the months of maximum rainfall over much of the area.

6. Application of results in other areas

The temperatures shown for the mean "hurricane season" sounding (table 5) depart only slightly, throughout most of the troposphere, from the mean values for the rainy season of the western Pacific (June–September), prepared by Colón (1953). In fact, below 200 mb there are no differences as great as 0.5C between the two sets of data. However, in the vicinity of the tropopause the Pacific temperatures were over 4C colder. Apparently this feature arises because of differences in latitude of the stations used in preparing the two sets of mean data. The fact that the Pacific stations were 10° latitude further south also contributed toward lower surface pressures and somewhat higher relative humidities.

In general, it would appear that the mean data presented in this report could be used, at least during the summer months, as a good approximation to the mean conditions in similar climatic regimes in other parts of the tropics. Clearly, the mean monthly soundings for the West Indies area are representative of a much broader latitude belt in summer than in winter. Significant differences from the West Indies soundings could be expected in the eastern portion of tropical oceans where low level temperatures are colder and lapse rates are more stable. Near the equator, fairly large temperatures deviations are likely in the vicinity of the tropopause and systematic differences in the pressure-height values should be expected because of the lower sea level pressures in these areas.

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