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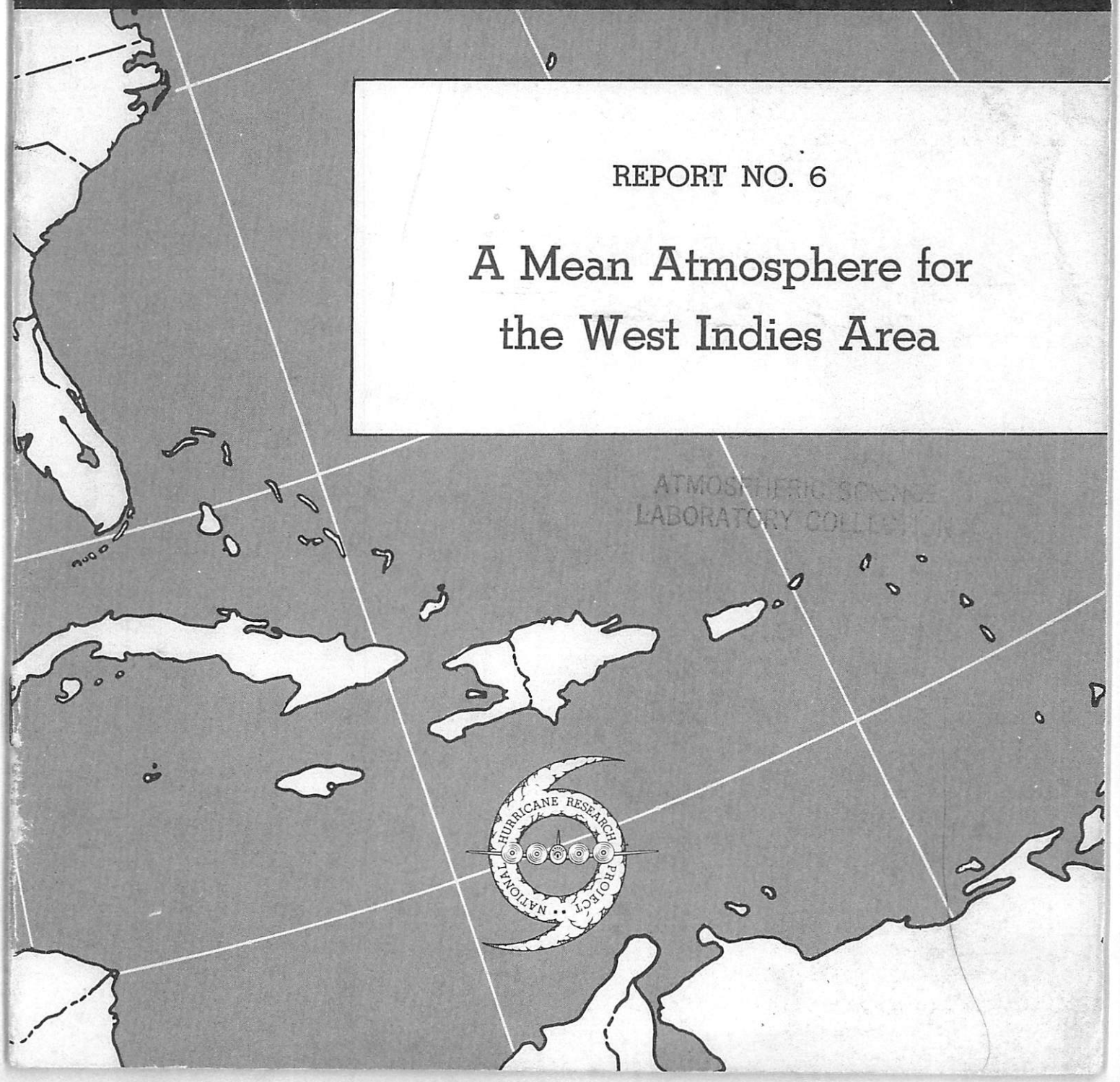

REPORT NO. 6

# A Mean Atmosphere for the West Indies Area

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, Secretary
WEATHER BUREAU
F. W. Reichelderfer, Chief

NATIONAL HURRICANE RESEARCH PROJECT

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by

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West Palm Beach, Fla.

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Commerce-Weather Bureau, Washington, D. C.

# A MEAN ATMOSPHERE FOR THE WEST INDIES AREA

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## ABSTRACT

Mean aerological data for the West Indies area, based on 10-year records for three stations, are presented in tabular form. The mean data are compared with those previously presented and some of the interesting climatological features are discussed.

## INTRODUCTION

Departures from the officially-adopted standard atmospheres are so large in the Tropics that these mean soundings lose much of their usefulness as a reference or baseline. For purposes of altimetry the adopted standards must be accepted, but for applications in synoptic meteorology special mean soundings have been prepared for tropical areas (Schacht [1]; U. S. Weather Bureau [2]; Colón [3]). 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 still encounters the same type of difficulty as in using the U. S. Standard Atmosphere in the Tropics. The new set of aerological data presented in this report avoids this difficulty by providing 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 addition to providing data on a seasonal basis, the new mean soundings have other features which recommend their use in preference to those previously prepared. They are based on a considerably longer period of record and use is made of observations during recent years when the 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.).

## PROCESSING OF DATA

The mean monthly aerological records for the 10-year period 1946-1955 for Miami, Fla; San Juan, P. R. and Swan Island - the same stations selected by Schacht [1] - have been used in preparing the mean soundings for the West Indies area. Only the nighttime soundings (0300 GMT) have been used, because of inhomogeneities in the daytime data arising from the different methods of correcting for radiation effects during the 10-year period. Mean values of the temperature and humidity have been computed for each station 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.

The mean temperature and humidity data for the three stations were combined to obtain mean monthly and mean annual soundings which will be considered representative of the West Indies area. The plotted soundings were then 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 are at different elevations so that the surface pressure could not be simply averaged. Also, a reduction of mean surface pressures to sea level would not have been a simple procedure since it would have been necessary to handle each station separately and to have had a complete record of all changes in the station elevation. Some of the comparison discussed below indicates that the use of the 1000-mb. height could not have introduced significant errors.

Processing of the humidity data required special considerations 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 16 observations are available, and in addition, statistical values are used in the cases where "motorboating" is reported. 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 of the monthly mean 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 a relatively minor effect on the height computations.

Mean temperatures for levels above 100 mb. are based almost entirely on observations made during the last five years of the period. In the early part of the record, there were very few monthly means recorded for these levels, although temperature means were computed from as few as five observations. At the three stations only about 30 percent of the daily soundings reached the 100-mb. surface in 1949, compared to 60 percent in 1952 and 80 percent in 1955. The number of soundings reaching the 30-mb. surface increased from less than 15 percent in 1949 to about 30 percent in 1955. Means are not shown for any levels above 30 mb. since even in recent years only a small percentage of the soundings attained these heights.

## THE MEAN AEROLOGICAL DATA

The monthly and annual temperature, height, and humidity data for the West Indies area for the 10-year period are shown in tables 1-3. Tabulations of mean monthly temperature and humidity data are also shown for the three stations (tables 4-9), but height computations have not been carried out for the individual stations. These tabulations contain the essential information

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 |

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 |

which this report intends to convey. The following discussion, while outlining various limitations of the data, will compare the results with previous computations of mean conditions in the Tropics, and will point up 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 make 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 (tables 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, at Miami the difference between the warmest and coldest month at middle tropospheric levels is as great as 6°C. compared to 1° to 2° C. variations at the other stations (tables 4, 6, 8). Thus, use of another station as far north as Miami in place of San Juan or Swan Island would have resulted in somewhat different mean values for the

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 |

winter months. This type of limitation, which is common 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 small 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 were much more numerous. For instance, a definite bias could have been introduced if the soundings reached 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 5-year period 1951-1955 revealed small differences from the 10-year means. The 5-year means showed slightly warmer values amounting to 0.1° C. at 200 and 150 mb., and 0.3° C. at 100 mb.; the largest individual difference was 0.6° C. This check suggests that the use of the monthly averages based on relatively few observations had a minor effect on the 10-year 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 determined 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 determine the magnitude of the deviation between these computed heights and the heights obtained by simply averaging the height data for the individual months. Nearly all differences were 10 feet or less and the maximum value was only 25 feet. This would suggest that, at least over a long period of record, both the height and temperature data can be averaged in the preparation of mean soundings without introducing significant inconsistencies.

## COMPARATIVE RESULTS

Colón [3] 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 [1]. For this purpose, it was necessary to convert Schacht's mean data, which was given at 1-km. levels, to make it applicable to the standard pressure surfaces. The following comparison makes use of the converted data prepared by Colón.

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

The deviations of the temperature values from those computed by Schacht are less than 0.5° C. through a deep layer of the troposphere extending from 850 to 150 mb. (fig. 1). The indicated 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, local effects at the radiosonde observation sites are important in accounting for this difference. Effects of this type which may have been important include the transfer of the station at San Juan from downtown to the airport in 1949, and a considerable clearing of forest near the Swan Island site in about 1945.

The largest temperature deviations shown by figure 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 percent of the months had as many as five soundings reaching the 100-mb. level and less than 10 percent of the monthly records listed 80-mb. data. In contrast, in the period 1952-55 from 50 to 90 percent of the

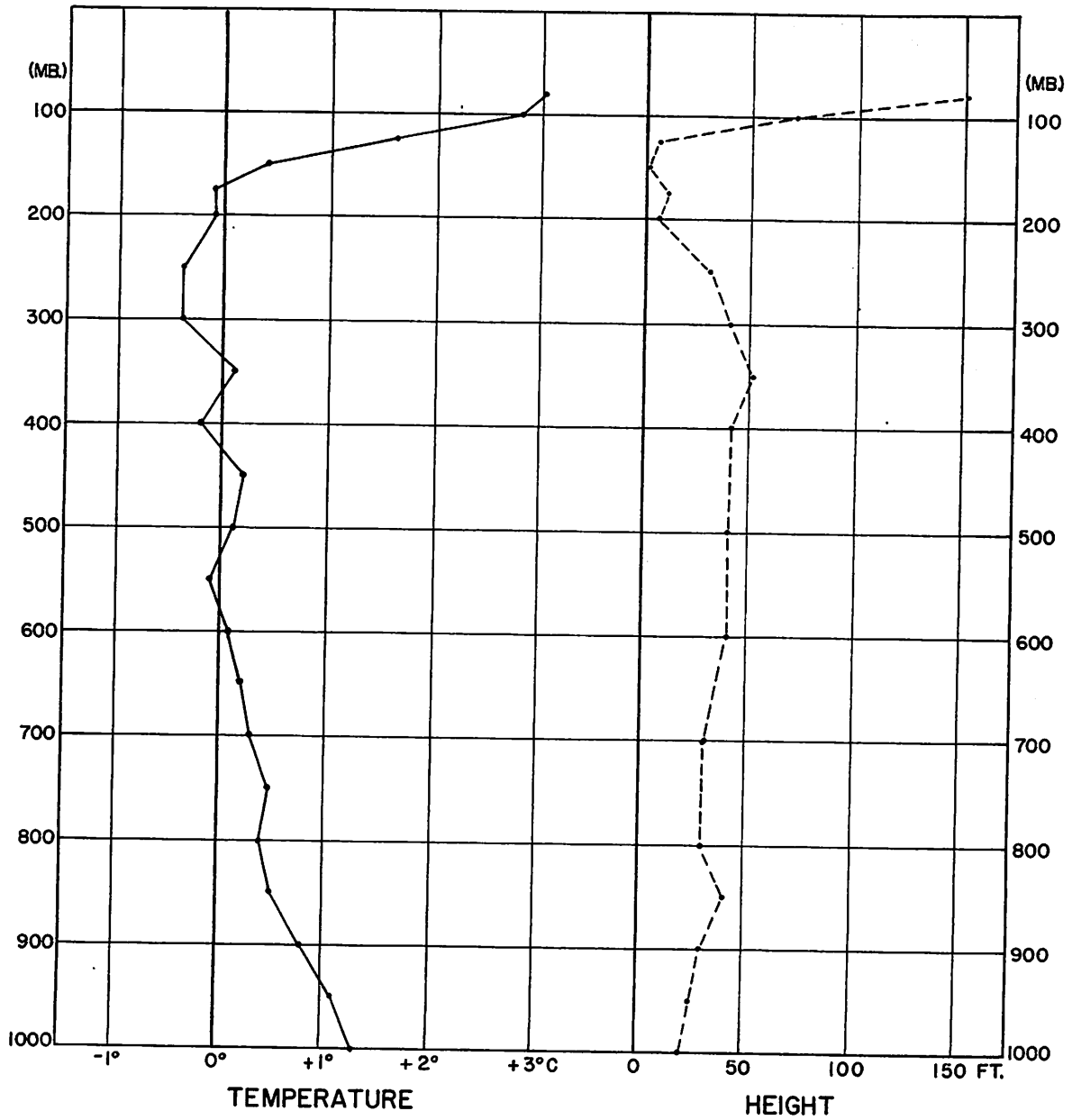


Figure 1. - Deviations of the mean August-October temperature and pressure-height data (tables 1, 3) from Schacht's mean data.

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. The colder temperatures shown by Schacht may have resulted from very low upper tropospheric temperatures reported by Swan Island during the years 1940 through 1943, which were subsequently found to be in error.[1] This difficulty arose from a faulty

[1] According to information provided by Mr. R. H. Simpson who was stationed at Swan Island during part of this period. The Weather Bureau has since corrected these erroneous temperatures.

Table 4--Mean temperature (°C) at standard pressure surfaces for San Juan, Puerto Rico. All values above the dashed line are negative.

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 58.5 | 56.5 | 55.6 | 54.1 | 54.2 | 52.2 | 53.8 | 54.0 | 54.7 | 55.9 | 54.9 | 56.1 |
| 40 | 62.1 | 61.9 | 60.6 | 58.5 | 56.8 | 56.8 | 57.0 | 57.3 | 58.2 | 59.0 | 59.6 | 60.6 |
| 50 | 66.7 | 66.6 | 66.1 | 63.9 | 60.6 | 60.6 | 60.2 | 60.3 | 61.3 | 62.0 | 63.1 | 65.5 |
| 60 | 71.8 | 71.5 | 72.2 | 69.6 | 64.9 | 64.4 | 63.2 | 63.4 | 64.6 | 66.2 | 67.5 | 70.3 |
| 80 | 78.9 | 78.7 | 78.0 | 76.6 | 72.9 | 70.7 | 69.9 | 70.2 | 70.5 | 73.2 | 77.2 | 78.2 |
| 100 | 76.8 | 77.1 | 76.9 | 76.2 | 75.8 | 73.0 | 72.3 | 73.5 | 73.6 | 76.1 | 77.4 | 77.2 |
| 125 | 71.1 | 71.0 | 71.1 | 71.9 | 73.6 | 72.7 | 70.0 | 71.2 | 72.0 | 73.6 | 72.9 | 71.4 |
| 150 | 65.5 | 65.4 | 65.5 | 67.3 | 67.9 | 68.7 | 67.0 | 66.9 | 67.5 | 67.9 | 67.5 | 66.4 |
| 175 | 59.8 | 59.8 | 60.0 | 61.1 | 61.4 | 62.7 | 62.2 | 61.4 | 61.5 | 61.5 | 61.1 | 60.5 |
| 200 | 54.5 | 54.3 | 54.5 | 55.0 | 55.3 | 56.4 | 56.3 | 55.3 | 55.3 | 55.1 | 54.9 | 54.8 |
| 250 | 44.4 | 43.9 | 44.3 | 44.0 | 43.6 | 44.4 | 44.7 | 43.6 | 43.5 | 43.3 | 43.4 | 44.0 |
| 300 | 35.4 | 35.1 | 35.5 | 34.4 | 33.7 | 34.2 | 34.6 | 33.5 | 33.4 | 33.2 | 33.5 | 34.5 |
| 350 | 27.4 | 27.2 | 27.2 | 26.2 | 25.4 | 25.7 | 25.9 | 24.9 | 25.0 | 24.7 | 25.0 | 26.2 |
| 400 | 20.1 | 20.1 | 19.8 | 19.1 | 18.4 | 18.5 | 18.4 | 17.6 | 17.8 | 17.5 | 17.8 | 19.0 |
| 450 | 13.7 | 13.5 | 13.1 | 12.8 | 12.5 | 12.5 | 12.4 | 11.5 | 11.9 | 11.5 | 11.6 | 12.7 |
| 500 | 8.0 | 7.9 | 7.4 | 7.4 | 7.3 | 7.2 | 7.1 | 6.4 | 6.8 | 6.3 | 6.5 | 7.3 |
| 550 | 3.1 | 3.0 | 2.6 | 2.7 | 2.8 | 2.7 | 2.9 | 2.1 | 2.3 | 2.0 | 2.1 | 2.7 |
| 600 | 1.0 | 1.1 | 1.6 | 1.3 | 1.1 | 1.2 | 0.8 | 1.6 | 1.8 | 2.0 | 1.6 | 1.3 |
| 650 | 4.5 | 4.5 | 5.2 | 4.7 | 4.7 | 4.8 | 4.7 | 5.1 | 5.5 | 5.6 | 5.1 | 4.9 |
| 700 | 7.3 | 7.5 | 8.0 | 7.5 | 8.0 | 8.3 | 8.4 | 8.8 | 8.9 | 8.9 | 8.4 | 7.9 |
| 750 | 9.5 | 9.8 | 9.8 | 10.0 | 10.8 | 11.4 | 11.8 | 12.0 | 12.0 | 11.9 | 11.2 | 10.5 |
| 800 | 11.0 | 11.2 | 11.2 | 12.0 | 13.3 | 14.1 | 14.5 | 14.7 | 14.7 | 14.5 | 13.6 | 12.3 |
| 850 | 13.2 | 13.0 | 13.3 | 14.3 | 15.8 | 16.4 | 16.6 | 17.1 | 17.3 | 17.2 | 16.1 | 14.5 |
| 900 | 16.2 | 16.0 | 16.2 | 17.1 | 18.5 | 19.1 | 19.4 | 19.9 | 20.1 | 20.0 | 19.0 | 17.6 |
| 950 | 19.6 | 19.3 | 18.9 | 20.2 | 21.4 | 22.1 | 22.4 | 22.8 | 23.0 | 23.0 | 22.0 | 20.8 |
| 1000 | 22.9 | 22.5 | 22.7 | 23.4 | 24.4 | 25.2 | 25.6 | 25.9 | 25.6 | 25.5 | 24.7 | 23.9 |
| Sfc. | 23.4 | 23.2 | 23.5 | 24.3 | 25.2 | 25.8 | 26.3 | 26.5 | 25.9 | 25.7 | 24.9 | 24.1 |

Table 5--Mean humidity (per cent) at standard pressure surfaces for San Juan, Puerto Rico.

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | | | | | 39 | 44 | | | 40 | | | |
| 450 | | | | | 38 | 41 | | 31 | 40 | | | |
| 500 | | | | | 40 | 40 | 35 | 36 | 44 | 39 | | |
| 550 | | | | | 40 | 39 | 36 | 37 | 46 | 43 | | |
| 600 | | | | | 44 | 43 | 41 | 43 | 50 | 46 | 37 | |
| 650 | | | | | 46 | 47 | 44 | 48 | 53 | 52 | 42 | 34 |
| 700 | 33 | | 28 | 40 | 50 | 50 | 47 | 52 | 60 | 58 | 48 | 44 |
| 750 | 45 | 44 | 42 | 47 | 60 | 54 | 51 | 55 | 63 | 65 | 58 | 53 |
| 800 | 65 | 62 | 60 | 64 | 69 | 63 | 63 | 66 | 70 | 72 | 71 | 68 |
| 850 | 78 | 77 | 73 | 73 | 77 | 74 | 76 | 76 | 76 | 77 | 78 | 78 |
| 900 | 81 | 80 | 78 | 77 | 81 | 80 | 81 | 82 | 80 | 80 | 82 | 80 |
| 950 | 80 | 79 | 79 | 79 | 82 | 82 | 82 | 83 | 81 | 81 | 81 | 80 |
| 1000 | 77 | 77 | 77 | 78 | 81 | 82 | 81 | 82 | 82 | 83 | 81 | 79 |
| Sfc. | 79 | 79 | 78 | 79 | 83 | 84 | 83 | 83 | 85 | 85 | 84 | 82 |

calibration of the ground equipment and led to appreciable errors only at very cold temperatures. It is not known whether Schacht was cognizant of this difficulty and made appropriate correction to the Swan Island temperature data at the upper tropospheric levels.

Differences between the relative humidities given by the Schacht and the August-October averages from table 2 are quite small. The new set of data give slightly higher values at all levels but the maximum deviation is only 4 percent.

## 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 are quite similar at the three stations, as can be verified by reference to tables 4-9, and 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 figure 2 on which the mean annual sounding has been plotted along with the maximum and minimum values 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

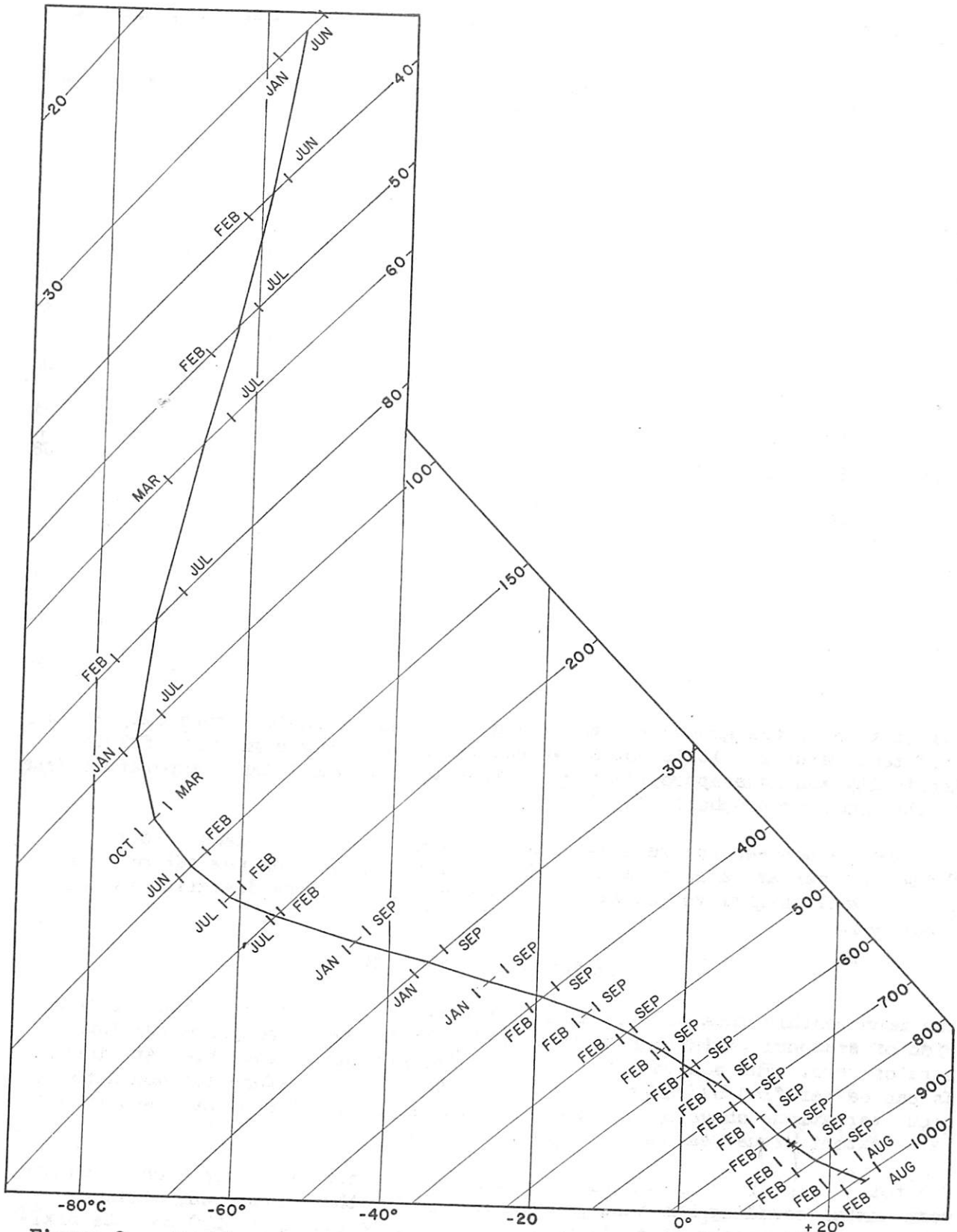


Figure 2. - Tephigram plot of mean annual temperature data (table 1). The maximum and minimum monthly values and the months of occurrence are shown at each level.

Table 6--Mean temperature (°C) at standard pressure surfaces for Swan Island, W. I. All values above the dashed line are negative.

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 56.6 | 57.8 | 56.5 | 55.3 | 53.8 | 53.5 | 53.8 | 54.8 | 55.1 | 55.8 | 56.1 | 56.1 |
| 40 | 60.9 | 62.2 | 62.2 | 59.6 | 58.6 | 56.3 | 57.1 | 57.2 | 58.4 | 59.1 | 60.0 | 60.5 |
| 50 | 65.6 | 66.5 | 67.5 | 64.2 | 62.9 | 61.1 | 60.3 | 60.6 | 61.2 | 62.0 | 63.0 | 65.3 |
| 60 | 71.1 | 72.2 | 72.1 | 69.7 | 66.9 | 65.1 | 63.8 | 64.1 | 64.9 | 66.0 | 67.6 | 71.9 |
| 80 | 80.0 | 78.7 | 78.1 | 77.0 | 75.7 | 71.9 | 69.9 | 70.4 | 70.9 | 72.9 | 76.9 | 78.8 |
| 100 | 77.7 | 77.3 | 77.2 | 76.2 | 77.6 | 75.0 | 72.1 | 73.8 | 76.2 | 77.7 | 77.9 | 77.4 |
| 125 | 71.5 | 71.6 | 71.4 | 71.9 | 73.7 | 73.7 | 72.2 | 72.7 | 74.4 | 74.8 | 74.1 | 72.1 |
| 150 | 65.5 | 65.6 | 65.9 | 66.9 | 67.6 | 68.8 | 68.6 | 67.8 | 68.3 | 68.4 | 68.4 | 66.7 |
| 175 | 59.9 | 59.9 | 60.2 | 60.9 | 60.6 | 61.6 | 62.1 | 61.4 | 61.2 | 61.4 | 61.7 | 61.2 |
| 200 | 54.8 | 54.5 | 54.6 | 54.8 | 54.1 | 54.8 | 55.5 | 54.8 | 54.5 | 54.2 | 55.1 | 55.6 |
| 250 | 45.2 | 44.4 | 44.1 | 43.6 | 42.2 | 42.7 | 43.4 | 42.8 | 42.2 | 42.4 | 43.2 | 44.4 |
| 300 | 35.6 | 35.1 | 34.7 | 33.9 | 32.4 | 32.5 | 33.3 | 32.8 | 32.1 | 32.3 | 33.0 | 34.6 |
| 350 | 27.0 | 26.8 | 26.3 | 25.1 | 24.1 | 24.1 | 24.9 | 24.4 | 23.8 | 23.8 | 24.5 | 25.9 |
| 400 | 19.4 | 19.5 | 18.8 | 18.2 | 17.1 | 17.2 | 17.9 | 17.4 | 16.9 | 16.8 | 17.4 | 18.6 |
| 450 | 12.9 | 12.9 | 12.1 | 11.9 | 11.2 | 11.5 | 12.3 | 11.7 | 11.4 | 11.3 | 11.5 | 12.3 |
| 500 | 7.3 | 7.2 | 6.4 | 6.5 | 6.3 | 6.8 | 7.4 | 6.8 | 6.6 | 6.3 | 6.5 | 7.0 |
| 550 | 2.7 | 2.4 | 1.5 | 1.8 | 1.9 | 2.5 | 2.9 | 2.3 | 2.2 | 2.0 | 2.1 | 2.3 |
| 600 | 1.1 | 1.7 | 2.6 | 2.2 | 2.0 | 1.6 | 1.2 | 1.7 | 1.8 | 1.9 | 1.8 | 1.7 |
| 650 | 4.7 | 5.1 | 6.1 | 5.5 | 5.6 | 5.4 | 5.0 | 5.4 | 5.7 | 5.6 | 5.4 | 5.2 |
| 700 | 7.5 | 7.6 | 9.0 | 8.5 | 9.0 | 9.1 | 8.6 | 9.0 | 9.2 | 8.9 | 8.7 | 8.2 |
| 750 | 9.9 | 9.8 | 11.1 | 11.1 | 12.0 | 12.3 | 12.0 | 12.2 | 12.5 | 11.9 | 11.5 | 10.6 |
| 800 | 12.0 | 11.9 | 13.1 | 13.7 | 14.7 | 15.1 | 14.9 | 15.1 | 15.5 | 14.0 | 14.0 | 12.7 |
| 850 | 14.4 | 14.4 | 15.5 | 16.4 | 17.4 | 17.8 | 17.5 | 17.9 | 18.3 | 17.6 | 16.6 | 15.2 |
| 900 | 17.5 | 17.3 | 18.1 | 19.1 | 19.9 | 20.4 | 20.3 | 20.7 | 21.1 | 20.5 | 19.4 | 18.2 |
| 950 | 20.7 | 20.4 | 21.0 | 21.7 | 22.9 | 23.1 | 23.1 | 23.6 | 23.9 | 23.3 | 22.4 | 21.4 |
| 1000 | 24.1 | 23.8 | 24.4 | 25.1 | 25.9 | 26.3 | 26.7 | 26.7 | 26.9 | 26.5 | 25.6 | 24.8 |
| Sfc. | 24.7 | 24.4 | 25.1 | 25.8 | 26.5 | 26.9 | 26.8 | 27.2 | 27.2 | 26.7 | 26.0 | 25.2 |

Table 7--Mean humidity (per cent) at standard pressure surfaces for Swan Island, W. I.

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | | | | | | 48 | 43 | 40 | 46 | 40 | | |
| 450 | | | | | | 49 | 44 | 40 | 48 | 44 | | |
| 500 | | | | | 34 | 51 | 46 | 43 | 52 | 46 | | |
| 550 | | | | | 35 | 54 | 47 | 45 | 54 | 51 | 38 | |
| 600 | | | | | 39 | 54 | 48 | 50 | 57 | 56 | 43 | |
| 650 | | | | | 41 | 54 | 51 | 51 | 57 | 60 | 49 | |
| 700 | 40 | | | 35 | 45 | 55 | 53 | 56 | 60 | 64 | 53 | 42 |
| 750 | 46 | 48 | 37 | 45 | 52 | 58 | 56 | 60 | 64 | 69 | 59 | 54 |
| 800 | 62 | 61 | 52 | 55 | 59 | 64 | 63 | 64 | 68 | 72 | 70 | 65 |
| 850 | 75 | 71 | 64 | 63 | 68 | 72 | 72 | 72 | 73 | 76 | 77 | 74 |
| 900 | 78 | 77 | 73 | 72 | 76 | 78 | 78 | 78 | 78 | 79 | 80 | 78 |
| 950 | 81 | 80 | 81 | 80 | 82 | 83 | 83 | 81 | 81 | 83 | 82 | 80 |
| 1000 | 78 | 78 | 78 | 79 | 81 | 84 | 83 | 82 | 82 | 82 | 80 | 78 |
| Sfc. | 78 | 78 | 78 | 79 | 81 | 84 | 84 | 83 | 83 | 84 | 81 | 79 |

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 1.5° C. Relative maxima occur at 850 and 350 mb. with spreads of almost 4° C. The spread increases to somewhat larger values at levels above 200 mb. and the absolute maximum of almost 9° C. 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 figure 2 and, in addition, provides details of the seasonal variations. The rather complicated character of the temperature range as a function of altitude is shown clearly by this figure. Similarly, the reversal of the normal seasonal temperature variation at upper tropospheric levels and its relation to variations at adjacent levels are quite apparent.

The seasonal variations at most levels are not too different from what might be obtained from figure 2 by assuming linear changes between the warmest and coldest months. However, at some levels especially in the middle and upper troposphere, there is a definite tendency for flat maxima and minima with

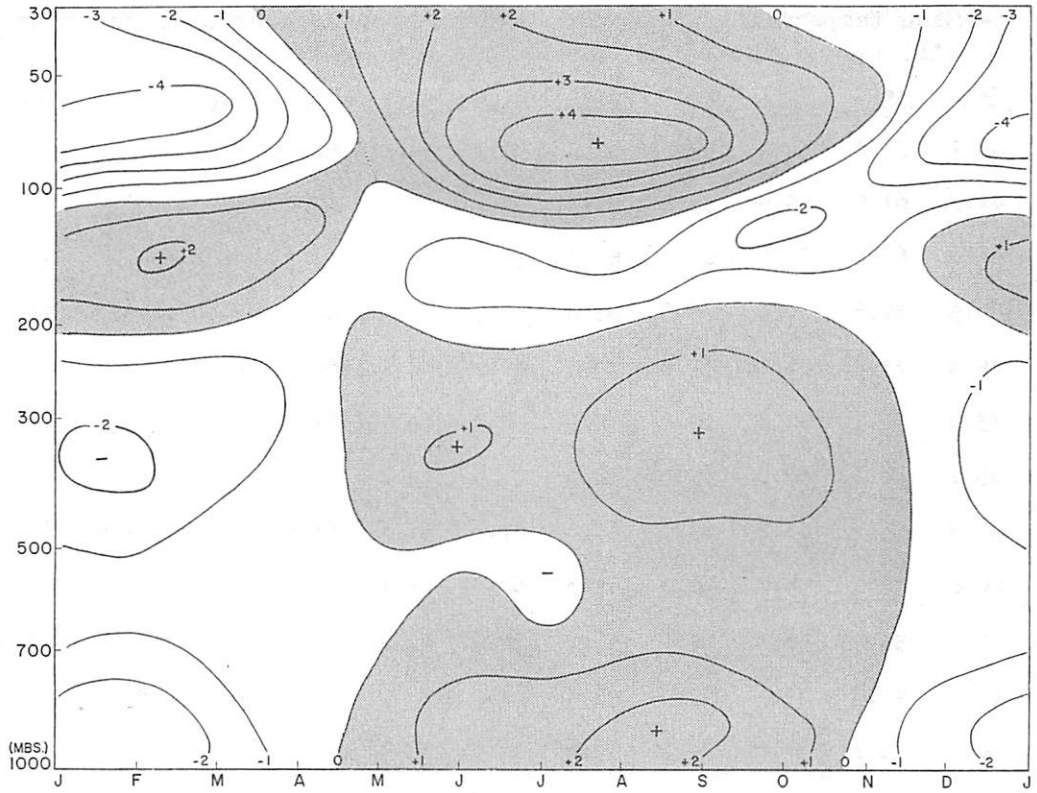


Figure 3. - Monthly temperature anomalies (° C.) from the annual means for West Indies area.

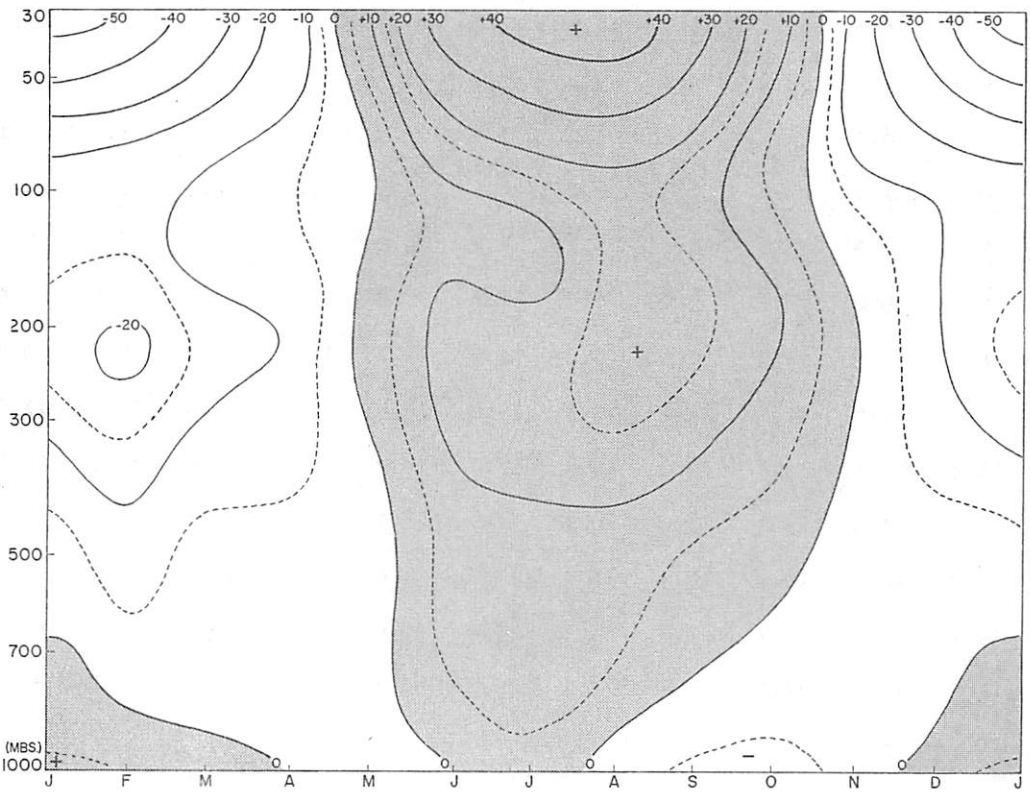


Figure 4. - Monthly pressure-height anomalies (tens of feet) from the annual means for West Indies area.

Table 8--Mean temperature (°C.) at standard pressure surfaces for Miami, Fla. All values above the dashed line are negative.

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 59.7 | 57.2 | 55.1 | 52.8 | 52.7 | 52.2 | 52.9 | 52.2 | 52.3 | 53.1 | 54.8 | 56.0 |
| 40 | 61.9 | 61.0 | 59.9 | 57.2 | 56.1 | 56.4 | 55.7 | 55.4 | 56.5 | 56.9 | 58.0 | 59.6 |
| 50 | 66.0 | 65.2 | 65.4 | 62.0 | 60.3 | 59.2 | 59.6 | 59.7 | 59.8 | 60.4 | 61.3 | 64.0 |
| 60 | 69.5 | 69.8 | 69.9 | 66.6 | 63.8 | 62.3 | 62.5 | 62.0 | 62.6 | 63.5 | 65.0 | 67.8 |
| 80 | 74.3 | 73.9 | 74.2 | 71.4 | 70.2 | 67.7 | 67.0 | 66.8 | 66.7 | 69.8 | 71.4 | 74.0 |
| 100 | 73.8 | 72.7 | 72.6 | 70.6 | 70.9 | 70.8 | 69.4 | 71.0 | 72.0 | 73.7 | 74.3 | 73.5 |
| 125 | 69.1 | 68.3 | 68.0 | 67.0 | 68.9 | 70.9 | 70.2 | 70.6 | 72.4 | 72.4 | 71.4 | 69.7 |
| 150 | 64.6 | 63.4 | 63.7 | 63.9 | 65.6 | 67.3 | 67.6 | 66.8 | 67.4 | 67.5 | 67.1 | 65.4 |
| 175 | 60.0 | 59.2 | 59.7 | 60.7 | 61.3 | 62.0 | 62.1 | 61.2 | 61.3 | 61.5 | 62.1 | 61.5 |
| 200 | 56.4 | 55.5 | 56.1 | 57.0 | 56.3 | 56.0 | 55.9 | 55.0 | 54.8 | 55.5 | 56.5 | 56.8 |
| 250 | 47.3 | 47.6 | 47.4 | 47.3 | 45.7 | 44.1 | 44.0 | 43.1 | 42.7 | 44.0 | 45.7 | 46.7 |
| 300 | 38.1 | 38.7 | 37.8 | 37.7 | 36.1 | 34.0 | 33.8 | 33.1 | 32.6 | 34.1 | 36.0 | 37.2 |
| 350 | 29.8 | 30.4 | 29.8 | 29.4 | 27.9 | 25.6 | 25.4 | 24.7 | 24.2 | 25.8 | 27.8 | 28.9 |
| 400 | 22.4 | 23.0 | 21.9 | 21.9 | 20.7 | 18.6 | 18.4 | 17.8 | 17.2 | 18.8 | 20.6 | 21.7 |
| 450 | 15.9 | 16.5 | 15.4 | 15.7 | 14.5 | 12.8 | 12.6 | 12.1 | 11.5 | 12.8 | 14.4 | 15.4 |
| 500 | 10.1 | 11.0 | 9.9 | 10.2 | 9.2 | 7.8 | 7.7 | 7.2 | 6.7 | 7.6 | 8.8 | 9.8 |
| 550 | 5.2 | 6.1 | 5.2 | 5.5 | 4.6 | 3.4 | 3.4 | 2.8 | 2.4 | 3.2 | 4.1 | 5.0 |
| 600 | 0.9 | 1.8 | 1.0 | 1.3 | 0.6 | 0.5 | 0.5 | 1.2 | 1.5 | 0.8 | 0.1 | 0.7 |
| 650 | 2.7 | 1.9 | 2.8 | 2.5 | 3.1 | 4.2 | 4.2 | 4.9 | 5.2 | 4.5 | 3.8 | 3.0 |
| 700 | 6.0 | 5.0 | 6.2 | 5.9 | 6.5 | 7.7 | 7.8 | 8.5 | 8.6 | 7.8 | 6.9 | 6.1 |
| 750 | 8.4 | 7.6 | 9.0 | 8.9 | 9.7 | 11.0 | 11.1 | 11.8 | 11.7 | 10.6 | 9.4 | 8.8 |
| 800 | 10.4 | 9.6 | 11.4 | 11.4 | 12.6 | 14.0 | 14.2 | 14.8 | 14.5 | 13.2 | 11.6 | 10.7 |
| 850 | 11.8 | 11.3 | 13.4 | 13.8 | 15.5 | 17.0 | 17.2 | 17.9 | 17.4 | 15.9 | 13.6 | 12.3 |
| 900 | 14.1 | 13.5 | 15.4 | 16.4 | 18.5 | 19.9 | 20.1 | 20.8 | 20.3 | 18.8 | 16.0 | 14.6 |
| 950 | 16.7 | 16.4 | 18.0 | 19.3 | 21.3 | 22.6 | 23.0 | 23.7 | 23.2 | 21.7 | 18.9 | 17.4 |
| 1000 | 19.4 | 19.2 | 20.7 | 22.2 | 24.1 | 25.4 | 26.0 | 26.5 | 26.0 | 24.4 | 21.6 | 20.2 |
| Sfc. | 19.2 | 19.2 | 21.0 | 22.7 | 24.6 | 25.8 | 26.3 | 26.7 | 26.2 | 24.5 | 21.3 | 19.6 |

Table 9--Mean humidity (per cent) at standard pressure surfaces for Miami, Florida.

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 350 | | | | | | | 37 | 34 | | | | |
| 400 | | | | | | 43 | 48 | 47 | 46 | 39 | | |
| 450 | | | | | | 44 | 50 | 48 | 48 | 39 | | |
| 500 | | | | | | 48 | 52 | 50 | 50 | 41 | | |
| 550 | | | | | 35 | 50 | 55 | 54 | 53 | 44 | | |
| 600 | | | | | 40 | 54 | 58 | 58 | 55 | 44 | | |
| 650 | | | 30 | 38 | 44 | 56 | 60 | 59 | 58 | 47 | | |
| 700 | | | 34 | 38 | 47 | 59 | 60 | 61 | 61 | 52 | 36 | 39 |
| 750 | 32 | 32 | 37 | 43 | 52 | 61 | 63 | 63 | 66 | 59 | 43 | 41 |
| 800 | 43 | 46 | 44 | 52 | 57 | 66 | 68 | 68 | 71 | 68 | 53 | 50 |
| 850 | 60 | 60 | 55 | 63 | 63 | 70 | 73 | 71 | 74 | 75 | 65 | 62 |
| 900 | 71 | 68 | 66 | 70 | 67 | 74 | 77 | 75 | 78 | 77 | 73 | 71 |
| 950 | 74 | 72 | 72 | 72 | 73 | 77 | 79 | 78 | 80 | 79 | 75 | 74 |
| 1000 | 74 | 73 | 74 | 73 | 75 | 78 | 79 | 79 | 80 | 79 | 75 | 74 |
| Sfc. | 79 | 79 | 76 | 75 | 77 | 81 | 82 | 82 | 84 | 82 | 80 | 80 |

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 [4]) 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 during this season in the vicinity of the 150-mb. level.

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 is also noted in the temperature data for all three stations (tables 4, 6, 8) and apparently is a significant climatological feature. This anomaly in the seasonal temperature trend appears to be associated with the rather large decrease in mean monthly rainfall which is observed from June to July throughout much of the West Indies area.

The temperature variations which arise from seasonal variations in the heights of the pressure surfaces probably contribute to some of the minor irregularities shown by figure 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 occur 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 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 10 percent at the surface to 25 percent at the highest levels for which mean values are available during all months of the year.

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.

## APPLICATION TO OTHER AREAS

The mean sounding for the rainy season of the western Pacific prepared by Colón [3] agreed quite closely with the data presented by Schacht [1] and therefore shows only minor differences from an August-October mean prepared from tables 1-3. Differences between the data presented by Colón and Schacht were 0.5° C. or less between 950 and 350 mb., but at the upper tropospheric levels the Pacific data averaged about 1° C. colder. However, the stations used were at lower latitudes than those used in the Atlantic and the colder temperatures could have been expected. In fact, data taken very near the equator in the Pacific in recent years suggest that the 100-mb. temperature during some months may average 5° to 6° C. colder than the minimum 100-mb. values given in table 1.

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. Significant differences 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 temperature deviations are likely near the tropopause, and systematic differences in the pressure-height values could be expected at lower levels because of the lower sea level pressures in these areas.

## ACKNOWLEDGMENTS

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