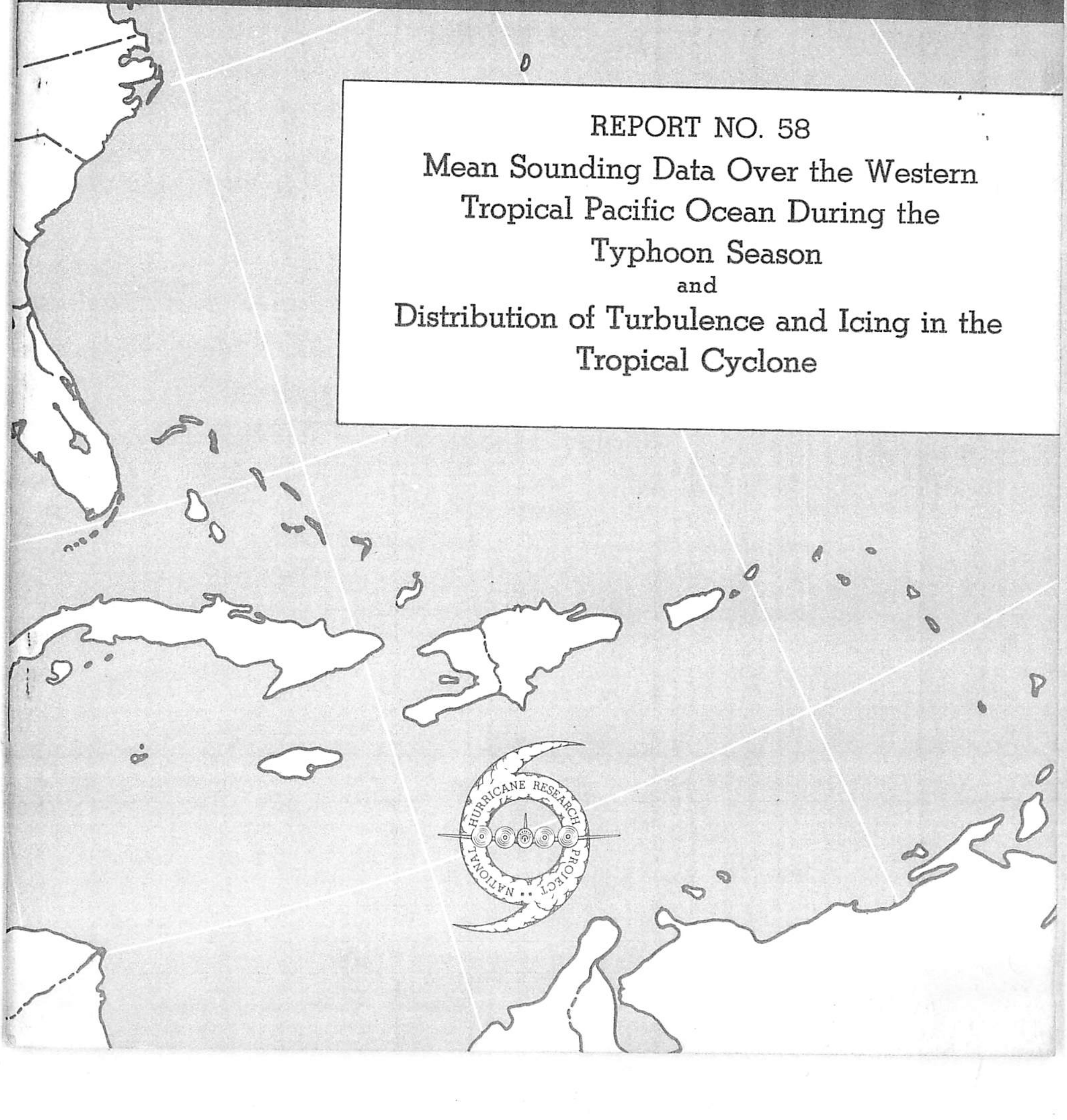
NATIONAL HURRICANE RESEARCH PROJECT

REPORT NO. 58

Mean Sounding Data Over the Western Tropical Pacific Ocean During the Typhoon Season
and
Distribution of Turbulence and Icing in the Tropical Cyclone



U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, Secretary
WEATHER BUREAU
F. W. Reichelderfer, Chief

NATIONAL HURRICANE RESEARCH PROJECT

REPORT NO. 58

Mean Sounding Data Over the Western Tropical Pacific Ocean During the Typhoon Season

by
Kenji Shimada
Japan Meteorological Agency

and

Distribution of Turbulence and Icing in the Tropical Cyclone

by
Z. Hashiba
Aviation Weather Service, Tokyo International Airport

(These reports prepared under contract Cwb-10229 with U. S. Weather Bureau,
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Washington, D. C.
October 1962

NATIONAL HURRICANE RESEARCH PROJECT REPORTS

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CONTENTS

MEAN SOUNDING DATA OVER THE WESTERN TROPICAL PACIFIC OCEAN DURING THE TYPHOON SEASON

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Japan Meteorological Agency

ABSTRACT

Monthly mean values of height, temperature, and dew point at standard pressure surfaces for the typhoon season, July to October, of the years 1957, 1958, and 1959, were tabulated for fourteen stations in the western tropical Pacific Ocean. Stations were combined into four groups to obtain representative data for four areas in the western tropical Pacific. Mean soundings for these areas are compared with each other and with mean soundings for the Gulf of Mexico and the West Indies.

Monthly instability indices were computed for each area. The seasonal trend of the instability index for the Mid-Pacific area shows a good correlation with the trend of the frequency of tropical storms during the typhoon season.

1. INTRODUCTION

During the summer and fall seasons, streamline analyses at the 700-mb. surface in the domain bounded by the 90°E. meridian, the 40°N. parallel, the 162°W. meridian, and the 22°S. parallel, are made in the Forecast Section of the Japan Meteorological Agency. The sparseness of the wind data over the tropical Pacific causes analysts much difficulty in detecting such tropical disturbances as easterly waves, shear lines, small cyclonic and anticyclonic vortices, and tropical depressions.

In such sparse data regions, therefore, the 24-hour 700-mb. height change is used as an auxiliary tool in streamline analysis. The standard atmosphere or the monthly mean sounding values of height, temperature, and dew point, however, would be more useful, because the deviation from the standard not only represents the synoptic sequence of events, but also furnishes climatic information. Therefore, data from fourteen stations in the western tropical Pacific (fig. 1) were used to construct mean soundings representative of the typhoon season, June to October.

2. PROCESSING OF DATA

The monthly mean temperatures, dew points, and heights, at the selected pressure levels for the fourteen stations listed in table 1 were obtained by simply averaging the records for 1957, 1958, and 1959, from the Northern Hemisphere Data Tabulations, Synoptic Weather Maps, Part II (U. S. Weather Bureau) and the Aerological Data of Japan (for Marcus Island only).

The data for Marcus Island were obtained by means of the Japanese radiosondes. Corrections for height, temperature, and dew point, therefore have been applied to these data so that they may be compared with the data for other stations measured with United States radiosondes. The correction values given in table 2 are after Matsuhashi and Arai [4,5].

The data, tabulated in table 3, are entirely based on the 1200 GMT observations so that radiation errors need not be considered. The observations are scheduled at local times varying from 2058 at Koror to 0047 at Johnston Island. The relative mean diurnal differences over that 4-hour period are so small [5, 8, 10] that they may be considered negligible.

3. MEAN AEROLOGICAL DATA

The monthly mean values of temperature, dew point, and height at the standard pressure surfaces for the fourteen stations are shown in table 3 (following the text).

According to table 3, thermal conditions at Yap, Koror, Guam, Truk, and Ponape are rather uniform and the month-to-month changes are small. A mean sounding obtained by averaging the data for Koror, Yap, and Guam is, therefore, representative of normal conditions over the Caroline Islands and the Marianas, while the mean sounding consisting of data from Eniwetok, Kwajalein, and Majuro is typical of conditions over the Marshall Islands area. These two mean soundings are shown in table 4 (following the text).

The data for Marcus Island and those for Iwo Jima are almost the same (table 3). The mean sounding (table 4) obtained by averaging the data for these two stations is taken to be representative of thermal conditions over the trade wind region of the western North Pacific during the summer through fall season.

There exists a semipermanent trough, throughout the warmer seasons, which extends from the Hawaiian Islands to the northwestern part of the Marshall Islands through the Wake area. This trough, named the Mid-Pacific trough by Ramage [7], plays an important role in the formation of tropical storms. The temperatures in the middle and upper troposphere at Midway Island and Wake Island show a remarkable fall in midsummer, July to August. This temperature fall in midsummer is one of the most important features of the Mid-Pacific trough region. A mean sounding obtained by averaging the data for Midway and Wake is, therefore, used to represent thermal conditions over the Mid-Pacific trough region (table 4).

Comparisons between the monthly mean soundings for these four areas are carried out in the following section. The areas are indicated in figure 1.

Table 1. - Station nomenclature

Station	WMO index number	Latitude	Longitude	Elev. (m.)
Midway Island	91 066	28°13'N	177°22'W	13
Iwo Jima, Volcano Islands	91 115	24 47 N	141 20 E	106
Marcus Island	91 131	24 17 N	153 58 E	17
Guam, Mariana Islands	91 217	13 33 N	144 50 E	162
Wake Island	91 245	19 17 N	166 39 E	4
Eniwetok Island, Marshall Islands	91 250	11 20 N	162 20 E	3
Johnston Island	91 275	16 44 N	169 31 W	2
Truk, Caroline Islands	91 334	07 27 N	151 50 E	2
Ponape, Caroline Islands	91 348	06 58 N	158 13 E	46
Kwajalein Atoll, Marshall Islands	91 366	08 43 N	167 44 E	3
Majuro Atoll, Marshall Islands	91 376	07 06 N	171 24 E	3
Koror, Peletiu Island, Palau Islands	91 408	07 21 N	134 29 E	33
Yap Island, Caroline Islands	91 413	09 31 N	138 08 E	17
Canton Island, Phoenix Islands	91 700	02 46 S	171 43 W	4

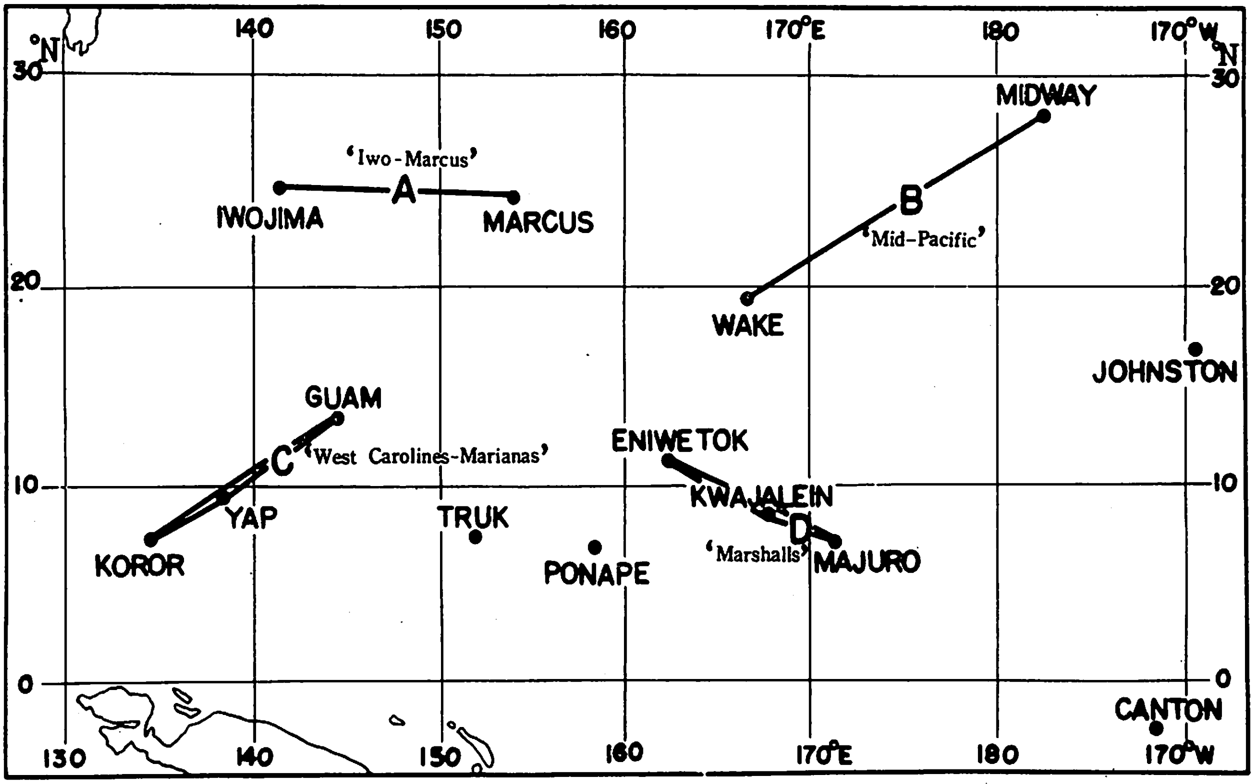

Figure 1. - Station location and grouping into representative areas.

Table 2. - Correction values applied to the data for Marcus Island

Pressure (mb.)	Temp. (°C.)	Dew Point (°C.)	Height (m.)
1000	0	0	0
850	0	0	0
700	0	0	0
500	0	0	10
400	-1.0	-1.0	3
300	-1.5	-1.5	-4
250	-2.0		-17
200	-2.0		-30
150	-2.0		-50
100	-1.5		-70

4. COMPARISONS OF THERMAL CONDITIONS IN THE FOUR AREAS

The heights of the standard pressure levels in the West Carolines-Marianas area are greater in the middle and lower stratosphere than those in the Marshalls area during the four months, July to October. In the middle and upper troposphere the height differences undergo a reversal (table 5). The temperatures in the layer below the 150-mb. level are higher in Iwo-Marcus than in the Mid-Pacific throughout the typhoon season, with the largest differences in July or August. The mixing ratios in Iwo-Marcus are larger at all levels below 300 mb. than those for the Mid-Pacific throughout the season investigated. The cold temperatures in the Mid-Pacific suggest cold advection from the northwestern Pacific into the Mid-Pacific area in association with the Mid-Pacific trough.

Next the mean values of height, temperature, and mixing ratio for the West Carolines-Marianas area are compared with those for the Marshalls. The West Carolines-Marianas area is slightly warmer than the Marshalls area at all levels except the 1000-mb. level and shows generally higher moisture content. This difference suggests that heat and moisture are transferred to the trade as it flows downstream.

Temperatures at upper tropospheric levels at Iwo-Marcus are lower than in the West Carolines-Marshalls. The height differences between the two areas are very small in the middle and lower troposphere throughout the typhoon season. As to moisture, mixing ratios in the 1000-300-mb. layer at Iwo-Marcus are smaller than in the West Carolines-Marianas. Especially in the layer near 400 mb., the difference in mixing ratios amounts to about 50 percent of the values for the West Carolines-Marianas.

Figure 2 presents a comparison of the seasonal change in temperature at various levels for the four groups of stations.

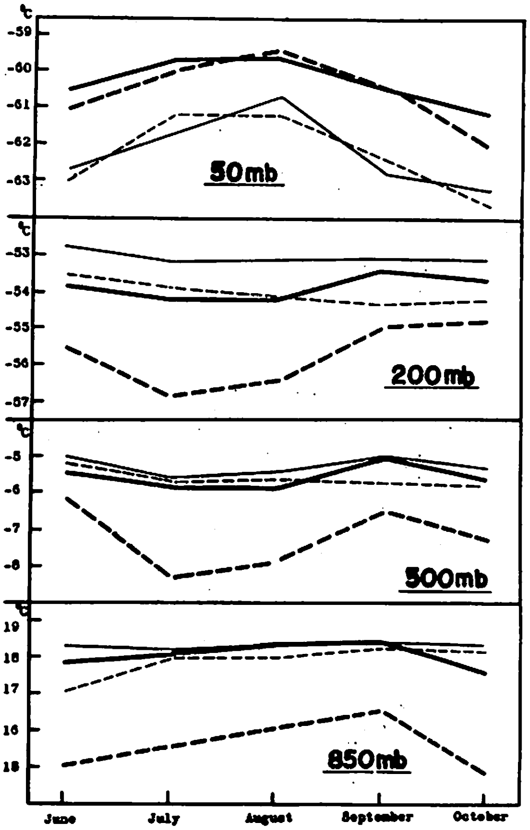

Figure 2. - Seasonal variations of the temperature at 850, 500, 200, and 50 mb., for Iwo-Marcus (heavy solid line), Mid-Pacific (heavy broken line), West Carolines-Marianas (thin solid line), and Marshalls (thin broken line). The temperature at 50 mb. for Iwo-Marcus is based only on the data for Iwo Jima.

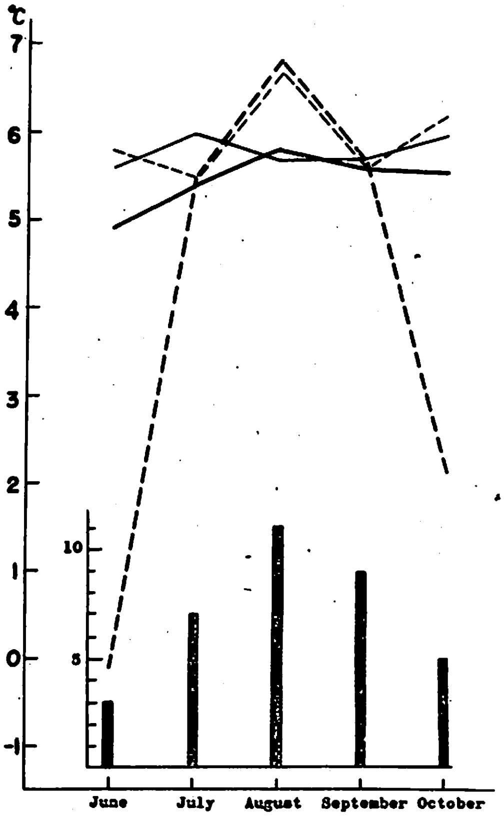

Figure 3. - Instability indices for Iwo-Marcus (heavy solid line), Mid-Pacific (heavy broken line), West Carolines-Marianas (thin solid line), and Marshalls (thin broken line), and total number of tropical storms which formed during three years 1957-1959 in the domain given in figure 1.

5. INSTABILITY

Instability indices were computed for Iwo-Marcus, the Mid-Pacific, the West Carolines-Marianas, and the Marshalls in order to examine the relationship between the vertical instability and the frequency of typhoon formation. The instability index is defined by the temperature difference $T^{300}_{1000} - T_{300}$, where T^{300}_{1000} is the temperature of a parcel lifted pseudo-adiabatically from the 1000-mb. surface to the 300-mb. surface, and T_{300} is the mean temperature at the 300-mb. level.

As shown in figure 3, the indices for the West Carolines-Marianas and for the Marshalls are large positive values throughout the typhoon season, and their month-to-month changes are small.

The instability indices for Iwo-Marcus and Mid-Pacific also are positive with the largest values in August. The month-to-month change of the indices appears to show a good correlation, in a qualitative sense, with the frequency of tropical storm formation in the Pacific also shown in figure 3. The index for the Mid-Pacific shows a remarkable rise between June and July and a rapid fall between September and October. This remarkable seasonal trend of the index is considered to depend mainly upon the variation of the temperature and dew point at the 1000-mb. surface because the temperature at 300 mb. varies little through the typhoon season.

The good correlation of the frequency of typhoon formation with the stability index for the Mid-Pacific area, or Mid-Pacific trough region, implies that tropical disturbances or easterly waves are likely to originate in that region. On the other hand, the instabilities in the West Carolines-Marianas and in the Marshalls are very large throughout the typhoon season, but the seasonal variation is small.

Positive value of the instability index, therefore, is considered as a necessary, but not sufficient, condition for typhoon formation.

6. COMPARISON OF THE MEAN SOUNDINGS FOR IWO-MARCUS WITH THOSE FOR THE GULF OF MEXICO AREA

Hebert and Jordan [2] in 1959 presented mean aerological data for the Gulf of Mexico area. Iwo Jima and Marcus are located at nearly the same latitude as the Gulf of Mexico. According to Tachi [9], Iwo-Marcus is one of the most favored areas for storms in August through October and this is true also of the Gulf of Mexico.

The deviations of the values for Iwo-Marcus in the Pacific from similar values for the Gulf of Mexico area are shown in table 6. The mean temperature values for Iwo-Marcus are consistently higher in the troposphere above the 850-mb. level than those for the Gulf of Mexico area. The same is true of dew point values.

7. COMPARISON OF THE MEAN SOUNDINGS FOR THE WEST CAROLINES-MARIANAS WITH THOSE FOR THE WEST INDIES AREA

Jordan in 1958 [3] presented mean aerological data for the West Indies area. According to Tachi [9], the Carolines-Marianas is the most favored area for the formation of tropical storms in the Pacific Ocean, corresponding to the West Indies in the Atlantic [6]. The West Carolines-Marianas area is therefore compared with the West Indies.

The deviations of mean values for the West Carolines-Marianas from those for the West Indies area are shown in table 7. The temperature values for the West Carolines-Marianas are higher in the troposphere above the 850-mb. level

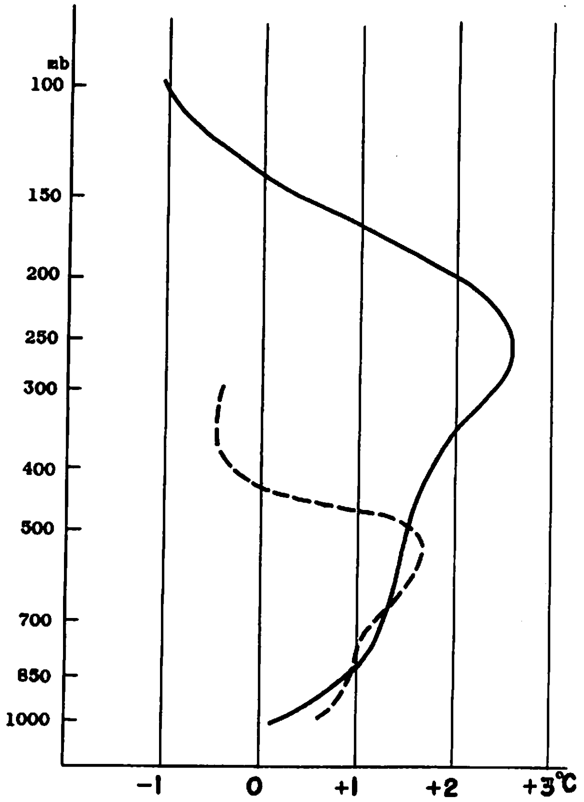

Figure 4. - Deviations of the mean June -September temperature (solid line) and dew-point (dashed) data from Colón's mean data.

←

than those for the West Indies area. In the lower stratosphere, the reverse is the case.

8. COMPARISON WITH THE DATA PREPARED BY COLÓN

Colón [1] prepared a mean sounding for the rainy season, June to September, over the western tropical Pacific. These data were based on soundings made during June to September of the years 1943-1947, at the three stations Koror, Guam, and Kwajalein. For comparison, therefore, averages have been computed for the period, June through September, from the data presented in table 3.

The deviations of the mean June-September temperature values from those computed by Colón are shown in figure 4. The largest deviation of temperature is 2.6°C. at the 250-mb. level. Through the deep layer between 850 mb. and 150 mb. the deviation varies from 0.5°C. to 2.6°C., and dew point deviations also show similar variations in the layer between 850 and 500 mb. The deviations of the dew point at 400 mb. and 300 mb. are -0.4°C.

The differences between the temperatures given by Colón and the new set of data are too large to be explained by climatic variation. They perhaps result from the variance of the radiosonde instruments used during the periods 1943-47 and 1956-59.

ACKNOWLEDGMENTS

The writer is indebted to Dr. Arakawa for giving the opportunity to make this report, and to Miss Ikenaga, Miss Fukazawa, and Miss Ozaki for the compilation of the basic aerological data.

REFERENCES

1. J. A. Colón, "The Mean Summer Atmosphere of the Rainy Season Over the Western Tropical Pacific Ocean," Bulletin of the American Meteorological Society, vol. 34, No. 7, Sept. 1953, pp. 333-334.

2. P. J. Hebert and C. L. Jordan, "Mean Soundings for the Gulf of Mexico Area," Monthly Weather Review, vol. 87, No. 6, June 1959, pp. 217-221.

3. C. L. Jordan, "Mean Soundings for the West Indies Area," Journal of Meteorology, vol. 15, No. 1, Feb. 1958, pp. 91-97.

4. S. Matsuhashi and E. Arai, "On the Comparison in the Far East Between Japan's and the Other Countries' Radiosondes," (First Report) Tenki, vol. 7, No. 9, 1960, pp. 257-261. (In Japanese.)

5. S. Matsuhashi and E. Arai, "On the Comparison in the Far East Between Japan's and the Other Countries' Radiosondes," (Second Report), Tenki, vol. 7, No. 11, 1960, pp. 349-355. (In Japanese.)

6. U. S. Weather Bureau, "West Indian Hurricanes," Mariners Weather Log, vol. 1, No. 4, July 1957, pp. 73-83.

7. C. S. Ramage, "Hurricane Development," Scientific Report No. 3, Contract AF19 (604)-1942, University of Hawaii, June 1958, 30 pp.

8. H. Riehl, Tropical Meteorology, McGraw-Hill Book Co., Inc., New York, 1954, 392 pp.

9. T. Tachi, "Some Statistical Studies on Tropical Cyclones in the Western North-Pacific Ocean," Scientific Report No. 7, Contract Cwb-993, Meteorological Research Institute, Japan Meteorological Agency, 1961.

10. N. E. LaSeur and C. L. Jordan, A Typical Weather Situation of the Typhoon Season, Department of Meteorology, University of Chicago, Mar. 1952, 24 pp.

Table 3. - Mean values of temperature, dew point, and height at standard pressure surfaces for:

MIDWAY

	Jun.			Jul.			Aug.		
Pressure (mb)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)
1000	21.8	17.1	151	23.1	20.2	168	24.1	21.0	156
850	14.2	8.8	1,542	14.5	11.1	1,598	14.8	11.4	1,558
700	8.3	- 5.1	3,170	6.7	- 3.4	3,189	6.8	- 2.9	3,180
500	- 6.8	-19.4	5,876	- 9.2	-22.2	5,876	- 8.6	-20.4	5,868
400	-18.1	-30.7	7,583	-21.0	-32.7	7,566	-20.2	-31.8	7,561
300	-34.1	-45.6	9,667	-36.9	-48.4	9,621	-36.4	-47.2	9,625
250	-44.1		10,915	-47.0		10,859	-46.4		10,862
200	-56.6		12,366	-58.1		12,298	-57.5		12,309
150	-67.4		14,136	-65.2		14,070	-64.7		14,092
100	-72.0		16,547	-65.7		16,528	-66.3		16,555
50	-59.3		20,760	-59.2		20,789	-58.4		20,821
25	-49.4		25,204	-49.6		25,285	-49.9		25,243

	Sept.			Oct.		
Pressure (mb)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)
1000	24.4	20.6	135	21.4	17.0	140
850	15.6	11.0	1,537	12.6	9.7	1,527
700	8.7	- 2.0	3,167	6.8	- 6.1	3,143
500	- 7.0	-20.9	5,876	- 8.6	-22.8	5,836
400	-18.6	-29.9	7,582	-20.0	-33.2	7,532
300	-34.6	-43.8	9,662	-36.2	-47.7	9,618
250	-44.5		10,910	-45.6		10,837
200	-55.6		12,369	-55.6		12,291
150	-65.9		14,141	-61.9		14,085
100	-70.8		16,570	-72.7		16,509
50	-59.4		20,790	-61.3		20,686
25				-51.8		25,084

Table 3. - Continued

GUAM

Pressure (mb)	Jun. Temp. (°C)	Jun. D.P. (°C)	Jun. Height (g.p.m.)	Jul. Temp. (°C)	Jul. D.P. (°C)	Jul. Height (g.p.m.)	Aug. Temp. (°C)	Aug. D.P. (°C)	Aug. Height (g.p.m.)
1000	25.1	23.1	100	24.8	23.7	96	24.8	23.9	86
850	17.9	12.5	1,517	18.1	13.3	1,512	18.5	14.6	1,505
700	10.1	- 1.1	3,147	9.7	2.1	3,514	9.9	3.4	3,149
500	- 5.2	-13.2	5,882	- 6.0	- 8.1	5,871	- 5.6	-12.6	5,870
400	-15.7	-30.1	7,603	-16.2	-27.0	7,588	-15.8	-23.7	7,588
300	-31.0	-45.0	9,727	-31.1	-41.9	9,693	-30.7	-39.4	9,696
250	-41.2		10,975	-41.0		10,960	-40.3		10,964
200	-53.3		12,454	-53.4		12,440	-53.2		12,445
150	-67.5		14,242	-68.1		14,226	-67.9		14,235
100	-77.9		16,603	-77.2		16,586	-76.5		16,592
50	-62.8		20,706	-62.1		20,720	-61.4		20,739
25	-51.7		25,085	-51.1		25,128	-52.3		25,135

Pressure (mb)	Sept. Temp. (°C)	Sept. D.P. (°C)	Sept. Height (g.p.m.)	Oct. Temp. (°C)	Oct. D.P. (°C)	Oct. Height (g.p.m.)
1000	24.7	24.0	83	24.7	24.2	88
850	18.6	14.8	1,506	18.5	14.5	1,508
700	9.9	4.7	3,151	10.3	2.7	3,153
500	- 5.4	-11.8	5,874	- 5.5	-10.9	5,876
400	-15.6	-22.5	7,596	-15.9	-25.2	7,595
300	-30.6	-37.4	9,706	-30.8	-40.4	9,702
250	-40.6		10,976	-40.9		10,972
200	-52.8		12,458	-53.1		12,449
150	-67.4		14,250	-67.1		14,244
100	-77.2		16,618	-78.8		16,606
50	-62.7		20,751	-63.0		20,691
25				-53.0		25,071

Table 3. - Continued

IWO JIMA

Pressure (mb)	Jun. Temp. (°C)	Jun. D.P. (°C)	Jun. Height (g.p.m.)	Jul. Temp. (°C)	Jul. D.P. (°C)	Jul. Height (g.p.m.)	Aug. Temp. (°C)	Aug. D.P. (°C)	Aug. Height (g.p.m.)
1000	26.4	22.7	106	26.9	22.2	103	26.9	22.2	96
850	18.4	11.8	1,522	18.8	11.8	1,521	19.0	13.7	1,516
700	10.2	- 0.6	3,169	10.6	0.6	3,165	10.4	0.6	3,169
500	- 5.0	-19.4	5,887	- 5.3	-16.5	5,888	- 5.2	-17.5	5,883
400	-15.5	-29.5	7,608	-15.6	-29.8	7,605	-15.8	-28.8	7,603
300	-30.3	-43.3	9,714	-30.6	-43.4	9,713	-31.0	-43.5	9,708
250	-40.4		10,996	-40.5		10,981	-41.0		10,976
200	-52.7		12,497	-52.8		12,445	-53.0		12,453
150	-66.2		14,261	-65.1		14,227	-66.0		14,250
100	-75.2		16,647	-72.4		16,660	-72.9		16,653
50	-60.5		20,796	-59.6		20,857	-59.6		20,848
25	-50.1		25,214	-51.1		25,275	-49.9		25,310

Pressure (mb)	Sep. Temp. (°C)	Sep. D.P. (°C)	Sep. Height (g.p.m.)	Oct. Temp. (°C)	Oct. D.P. (°C)	Oct. Height (g.p.m.)
1000	26.8	22.3	101	26.0	21.7	126
850	19.1	12.8	1,518	17.7	10.7	1,538
700	11.1	0.5	3,164	9.9	- 1.7	3,177
500	- 4.5	-17.0	5,893	- 5.9	-21.6	5,894
400	-15.6	-27.9	7,619	-17.1	-32.5	7,606
300	-30.5	-41.7	9,720	-32.2	-46.2	9,701
250	-40.4		10,694	-41.9		10,962
200	-52.0		12,490	-53.1		12,437
150	-65.1		14,288	-65.4		14,235
100	-75.2		16,687	-76.0		16,633
50	-60.4		20,842	-61.1		20,753
				-50.3		25,173

Table 3. - Continued

JOHNSTON

Pressure (mb)	Jun. Temp. (°C)	Jun. D.P. (°C)	Jun. Height (g.p.m.)	Jul. Temp. (°C)	Jul. D.P. (°C)	Jul. Height (g.p.m.)	Aug. Temp. (°C)	Aug. D.P. (°C)	Aug. Height (g.p.m.)
1000	24.6	20.5	127	25.2	21.1	123	25.9	20.9	111
850	15.3	11.3	1,532	16.1	13.0	1,530	15.6	12.7	1,524
700	10.2	-10.4	3,114	9.2	- 4.8	3,162	9.3	- 2.7	3,159
500	- 5.4	-25.2	5,885	- 5.7	-22.7	5,879	- 5.7	-20.9	5,876
400	-17.2	-33.0	7,612	-17.7	-31.5	7,593	-16.6	-32.8	7,591
300	-32.5	-44.9	9,692	-33.0	-42.7	9,683	-31.5	-44.7	9,688
250	-42.2		10,950	-42.7		10,935	-42.0		10,947
200	-54.1		12,422	-54.5		12,404	-53.9		12,431
150	-67.4		14,211	-67.2		14,191	-67.2		14,208
100	-74.7		16,593	-73.4		16,578	-74.0		16,592
50	-62.9		20,729	-61.2		20,750	-60.0		20,769
25	-52.4		25,161	-51.8		25,156	-52.1		25,167

Pressure (mb)	Sept. Temp. (°C)	Sept. D.P. (°C)	Sept. Height (g.p.m.)	Oct. Temp. (°C)	Oct. D.P. (°C)	Oct. Height (g.p.m.)
1000	26.0	21.4	107	26.2	22.4	113
850	17.0	12.0	1,519	17.0	14.0	1,527
700	9.9	- 2.7	3,155	9.4	- 1.7	3,128
500	- 6.0	-18.8	5,872	- 6.4	-21.1	5,876
400	-16.8	-29.6	7,581	-18.0	-31.4	7,594
300	-31.9	-42.2	9,682	-33.0	-45.2	9,669
250	-42.1		10,940	-42.6		10,888
200	-54.1		12,410	-54.0		12,397
150	-67.1		14,202	-66.8		14,184
100	-75.0		16,579	-75.6		16,571
50	-62.1		20,727	-62.6		20,696
25				-51.8		25,084

Table 3. - Continued

ENIWETOK

	Jun.			Jul.			Aug.		
Pressure (mb)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)
1000	26.5	23.2	95	26.7	23.3	89	27.3	23.7	84
850	17.8	13.3	1,510	18.0	14.5	1,507	18.2	14.7	1,503
700	10.1	0.2	3,153	9.9	2.2	3,148	9.8	3.4	3,145
500	- 5.3	-18.3	5,870	- 5.9	-14.0	5,868	- 5.7	-14.7	5,864
400	-15.5	-27.8	7,594	-16.3	-25.7	7,584	-16.7	-26.8	7,581
300	-31.0	-42.9	9,699	-31.4	-40.8	9,685	-31.5	-42.4	9,683
250	-40.8		10,965	-41.6		10,948	-41.8		10,944
200	-53.4		12,441	-53.5		12,421	-54.4		12,415
150	-67.4		14,232	-71.0		14,206	-68.6		14,196
100	-77.7		16,597	-76.6		16,567	-76.4		16,549
50	-63.1		20,682	-62.1		20,703	-61.4		20,703
25	-51.6		25,061	-51.9		25,093	-51.8		25,069

	Sept.			Oct.		
Pressure (mb)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)
1000	27.6	23.8	84	26.2	23.6	87
850	18.7	15.3	1,504	18.3	14.4	1,508
700	10.2	4.2	3,151	9.6	3.4	3,150
500	- 5.5	-12.5	5,874	- 5.8	-13.1	5,867
400	-15.8	-24.5	7,594	-16.3	-24.2	7,583
300	-31.2	-40.1	9,696	-31.8	-40.0	9,688
250	-41.3		10,960	-41.8		10,944
200	-53.7		12,428	-54.3		12,417
150	-68.0		14,219	-68.2		14,198
100	-77.1		16,587	-78.8		16,584
50	-62.3		20,711	-64.1		20,640
25				-53.7		24,995

Table 3. - Continued

WAKE

	Jun.			Jul.			Aug.		
Pressure (mb)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)
1000	25.5	22.1	135	26.2	22.7	126	26.5	22.9	115
850	15.9	11.4	1,545	16.6	13.2	1,540	17.3	13.3	1,531
700	9.7	- 7.2	3,181	8.8	- 0.9	3,175	8.7	1.4	3,167
500	- 5.3	-24.2	5,902	- 7.1	-20.3	5,882	- 7.0	-18.0	5,874
400	-17.3	-34.7	7,618	-18.1	-30.2	7,589	-17.6	-28.9	7,581
300	-33.1	-46.7	9,705	-33.5	-45.6	9,676	-33.2	-44.7	9,671
250	-42.8		10,967	-43.5		10,930	-43.3		10,926
200	-54.4		12,435	-55.5		12,394	-55.3		12,391
150	-66.3		14,226	-68.3		14,173	-68.0		14,171
100	-75.9		16,609	-71.6		16,565	-72.0		16,566
50	-61.9		20,735	-60.6		20,763	-60.3		20,761
25	-51.6		25,167	-51.2		25,171	-51.1		25,178

	Sept			Oct.		
Pressure (mb)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)
1000	26.9	23.4	110	26.4	23.8	117
850	17.6	13.4	1,527	17.2	13.1	1,533
700	9.8	- 0.3	3,167	9.7	- 2.4	3,171
500	- 5.8	-19.0	5,887	- 5.8	-21.3	5,890
400	-17.0	-29.8	7,603	-16.9	-31.5	7,605
300	-32.5	-43.9	9,700	-32.6	-45.0	9,700
250	-42.5		10,959	-42.6		10,959
200	-54.2		12,430	-53.9		12,430
150	-67.0		14,220	-66.8		14,223
100	-75.4		16,605	-78.1		16,597
50	-61.2		20,765	-62.4		20,691
25				-52.1		25,097

Table 3. - Continued

MARCUS

	Jun.			Jul.			Aug.		
Pressure (mb)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)
1000	25.8	22.3	140	26.8	22.9	127	26.8	23.0	117
850	17.4	11.7	1,552	17.4	13.9	1,542	17.7	14.1	1,534
700	9.8	- 1.7	3,191	9.4	1.8	3,180	9.3	3.3	3,173
500	- 5.7	-19.9	5,919	- 6.2	-14.3	5,903	- 6.4	-13.8	5,897
400	-17.7	-30.8	7,626	-17.7	-26.2	7,609	-17.6	-26.1	7,603
300	-33.0	-44.3	9,717	-32.9	-39.3	9,710	-33.2	-41.1	9,696
250	-43.5		10,968	-43.4		10,954	-43.6		10,946
200	-51.1		12,431	-55.5		12,416	-55.3		12,408
150	-63.8		14,208	-69.0		14,186	-67.6		14,186
100	-73.6		16,582	-73.4		16,565	-73.4		16,575

	Sept.			Oct.		
Pressure (mb)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)
1000	26.9	23.2	123	26.3	22.5	126
850	17.9	14.2	1,540	17.5	13.1	1,540
700	10.4	1.7	3,183	10.4	- 0.6	3,181
500	- 5.3	-17.2	5,906	- 5.3	-22.7	5,904
400	-17.5	-28.8	7,617	-17.8	-34.5	7,613
300	-33.5	-41.5	9,713	-33.4	-46.3	9,705
250	-43.4		10,969	-43.4		10,959
200	-54.6		12,437	-54.3		12,429
150	-66.7		14,213	-66.4		14,221
100	-76.2		16,613	-77.6		16,601

Table 3. - Continued

PONAPE

	Jun.			Jul.			Aug.		
Pressure (mb)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)
1000	26.5	20.0	81	26.2	24.0	80	26.3	24.0	75
850	18.1	14.7	1,496	18.1	14.1	1,499	17.8	14.0	1,494
700	9.8	3.9	3,143	9.9	4.3	3,141	9.4	3.9	3,135
500	- 5.0	-11.6	5,868	- 5.6	-12.1	5,861	- 5.5	-12.6	5,857
400	-15.0	-21.0	7,591	-15.7	-23.5	7,582	-15.8	-23.7	7,574
300	-33.5	-38.7	9,703	-30.7	-38.8	9,656	-30.6	-38.1	9,686
250	-39.9		10,974	-40.8		10,958	-40.9		10,955
200	-52.5		12,456	-53.1		12,437	-53.2		12,436
150	-67.3		14,231	-67.9		14,229	-67.0		14,227
100	-78.7		16,608	-78.5		16,583	-78.2		16,582
50	-62.2		20,691	-60.6		20,733	-60.8		20,742
25	-52.1		25,055	-52.0		25,149	-51.5		25,172

	Sept.			Oct.		
Pressure (mb)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)
1000	25.2	23.6	78	25.5	23.5	81
850	18.2	14.1	1,497	18.3	14.0	1,500
700	9.6	4.5	3,139	9.7	3.9	3,142
500	- 5.6	-12.2	5,859	- 5.6	-12.2	5,862
400	-15.6	-24.1	7,579	-15.7	-24.0	7,583
300	-30.7	-38.5	9,689	-30.6	-39.0	9,692
250	-40.8		10,958	-40.9		10,957
200	-53.3		12,436	-53.4		12,430
150	-68.0		14,226	-67.9		14,227
100	-77.9		16,576	-79.4		16,577
50	-62.9		20,705	-63.1		20,682
				-53.6		25,035

Table 3. - Continued

TRUK

Pressure (mb)	Jun. Temp. (°C)	Jun. D.P. (°C)	Jun. Height (g.p.m.)	Jul. Temp. (°C)	Jul. D.P. (°C)	Jul. Height (g.p.m.)	Aug. Temp. (°C)	Aug. D.P. (°C)	Aug. Height (g.p.m.)
1000	26.8	23.8	88	26.6	23.6	89	26.9	23.6	83
850	18.6	14.2	1,524	18.5	14.7	1,512	18.3	14.7	1,503
700	10.1	3.5	3,154	9.9	4.7	3,151	9.9	4.7	3,148
500	- 5.1	-17.9	5,886	- 5.3	-11.4	5,872	- 5.3	-11.8	5,871
400	-15.3	-22.8	7,640	-15.5	-22.9	7,592	-15.4	-24.0	7,595
300	-30.1	-39.0	9,718	-30.6	-38.0	9,701	-30.4	-38.2	9,705
250	-40.3		10,989	-40.8		10,968	-40.7		10,972
200	-52.1		12,471	-53.9		12,446	-53.2		12,450
150	-62.3		14,252	-67.8		14,236	-66.7		14,245
100	-79.3		16,625	-78.1		16,689	-77.4		16,600
50	-63.0		20,712	-61.0		20,731	-61.0		20,718
25	-52.6		25,058	-51.9		25,145	-52.1		25,166

Pressure (mb)	Sept. Temp. (°C)	Sept. D.P. (°C)	Sept. Height (g.p.m.)	Oct. Temp. (°C)	Oct. D.P. (°C)	Oct. Height (g.p.m.)
1000	26.5	23.6	86	26.4	23.7	85
850	18.7	14.7	1,507	18.7	14.6	1,508
700	10.0	4.8	3,153	10.1	4.7	3,152
500	- 5.2	-11.1	5,877	- 5.3	-11.6	5,879
400	-15.3	-23.2	7,601	-15.3	-22.6	7,612
300	-30.3	-38.2	9,713	-30.4	-37.7	9,716
250	-40.5		10,964	-40.7		10,875
200	-53.1		12,464	-53.5		12,456
150	-67.6		14,256	-67.8		14,255
100	-77.5		16,609	-80.0		16,602
50	-62.6		20,748	-62.8		20,697
25				-52.8		25,096

Table 3. - Continued

KWAJALEIN

	Jun.			Jul.			Aug.		
Pressure (mb)	Temp. (⁰C)	D.P. (⁰C)	Height (g.p.m.)	Temp. (⁰C)	D.P. (⁰C)	Height (g.p.m.)	Temp. (⁰C)	D.P. (⁰C)	Height (g.p.m.)
1000	26.7	24.0	91	26.7	23.9	89	26.9	24.1	83
850	17.9	14.4	1,508	18.0	14.3	1,506	17.9	14.7	1,501
700	9.8	1.7	3,154	9.7	4.5	3,147	9.6	3.9	3,141
500	- 5.2	-14.3	5,873	- 5.8	-12.7	5,864	- 5.6	-12.0	5,858
400	-16.0	-24.8	7,591	-16.5	-24.9	7,579	-16.4	-25.5	7,575
300	-31.5	-40.6	9,694	-32.0	-40.1	9,675	-32.0	-40.6	9,673
250	-41.9		10,956	-42.3		10,935	-42.3		10,954
200	-54.5		12,429	-55.0		12,400	-54.9		12,409
150	-69.8		14,211	-69.2		14,177	-69.2		14,176
100	-76.5		16,576	-77.5		16,528	-77.7		16,532
50	-63.5		20,661	-61.0		20,674	-61.3		20,673
25	-50.4		25,062	-48.9		25,140	-51.3		25,084

	Sept.			Oct.		
Pressure (mb)	Temp. (⁰C)	D.P. (⁰C)	Height (g.p.m.)	Temp. (⁰C)	D.P. (⁰C)	Height (g.p.m.)
1000	26.9	23.5	85	26.9	23.6	92
850	17.8	14.8	1,504	17.9	14.6	1,508
700	9.4	4.6	3,143	9.7	5.1	3,150
500	- 5.8	-11.8	5,863	- 6.0	-13.0	5,867
400	-16.4	-25.6	7,580	-16.6	-24.1	7,581
300	-32.2	-40.9	9,674	-32.2	-37.8	9,677
250	-42.2		10,935	-42.5		10,938
200	-54.9		12,405	-55.0		12,402
150	-69.0		14,183	-69.1		14,171
100	-77.3		16,551	-77.0		16,531

Table 3. - Continued

MAJURO

	Jun.			Jul.			Aug.		
Pressure (mb)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)
1000	26.8	23.9	91	26.7	23.5	92	27.0	23.5	85
850	18.0	14.4	1,509	17.9	13.7	1,509	17.9	13.8	1,507
700	10.1	3.5	3,153	9.6	3.1	3,151	9.7	3.3	3,145
500	- 5.1	-12.7	5,876	- 5.4	-13.4	5,871	- 5.5	-13.3	5,864
400	-15.5	-23.7	7,593	-15.7	-25.0	7,591	-15.7	-24.6	7,584
300	-30.0	-39.1	9,710	-30.7	-39.2	9,699	-30.6	-39.0	9,693
250	-40.3		10,981	-40.9		10,967	-40.7		10,962
200	-52.8		12,462	-53.3		12,446	-53.1		12,440
150	-67.4		14,258	-67.9		14,236	-67.5		14,236
100	-77.4		16,622	-78.3		16,592	-78.3		16,594
50	-62.5		20,688	-60.5		20,762	-60.6		20,747
25	-52.3		25,062	-50.8		25,152	-52.1		25,151

	Sept.			Oct.		
Pressure (mb)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)	Temp. (°C)	D.P. (°C)	Height (g.p.m.)
1000	26.7	23.6	87	26.8	23.5	86
850	18.0	13.7	1,507	18.3	13.4	1,507
700	9.7	3.5	3,146	9.8	4.3	3,150
500	- 5.5	-12.0	5,867	- 5.6	-12.8	5,870
400	-15.7	-23.6	7,585	-15.9	-23.6	7,588
300	-30.8	-37.8	9,694	-30.8	-38.6	9,696
250	-41.1		10,961	-41.0		10,982
200	-53.6		12,438	-53.4		12,442
150	-68.3		14,225	-68.3		14,231
100	-78.6		16,564	-79.7		16,578
50	-61.5		20,717	-62.9		20,668
25	-52.3		25,113	-53.5		25,039

Table 3. - Continued
KOROR

Pressure (mb)	Jun. Temp. (°C)	Jun. D.P. (°C)	Jun. Height (g.p.m.)	Jul. Temp. (°C)	Jul. D.P. (°C)	Jul. Height (g.p.m.)	Aug. Temp. (°C)	Aug. D.P. (°C)	Aug. Height (g.p.m.)
1000	26.9	24.3	85	26.6	24.5	85	26.4	24.0	81
850	18.6	15.1	1,507	18.2	14.7	1,502	18.1	14.8	1,511
700	10.0	4.7	3,151	9.8	4.7	3,144	9.6	4.6	3,140
500	- 4.8	-11.9	5,878	- 5.3	-11.2	5,863	- 5.2	-11.5	5,867
400	-14.9	-23.4	7,603	-15.5	-22.3	7,584	-15.7	-22.6	7,582
300	-29.9	-39.2	9,719	-30.2	-38.0	9,693	-30.5	-37.7	9,691
250	-39.9		10,991	-40.2		10,963	-40.8		10,960
200	-52.3		12,474	-53.0		12,443	-53.0		12,439
150	-66.9		14,371	-67.7		14,229	-67.5		14,232
100	-78.7		16,643	-77.4		16,596	-77.2		16,591
50	-62.5		20,725	-61.8		20,750	-60.2		20,754
25	-51.7		25,073	-52.1		25,067	-51.6		25,175

Pressure (mb)	Sept. Temp. (°C)	Sept. D.P. (°C)	Sept. Height (g.p.m.)	Oct. Temp. (°C)	Oct. D.P. (°C)	Oct. Height (g.p.m.)
1000	26.2	24.1	84	26.5	24.2	85
850	18.3	14.6	1,502	18.5	14.7	1,506
700	9.6	4.7	3,145	9.9	4.5	3,147
500	- 5.7	-10.9	5,865	- 5.2	-13.0	5,869
400	-15.8	-22.0	7,584	-15.4	-24.8	7,591
300	-30.6	-38.0	9,696	-30.6	-39.4	9,700
250	-40.6		10,961	-40.6		10,968
200	-53.2		12,439	-52.9		12,445
150	-67.7		14,227	-67.3		14,233
100	-78.3		16,582	-80.1		16,588
50	-62.2		20,711	-63.1		20,688
				-52.5		25,407

Table 3. - Continued

YAP

Pressure (mb)	Jun. Temp. (°C)	Jun. D.P. (°C)	Jun. Height (g.p.m.)	Jul. Temp. (°C)	Jul. D.P. (°C)	Jul. Height (g.p.m.)	Aug. Temp. (°C)	Aug. D.P. (°C)	Aug. Height (g.p.m.)
1000	27.2	24.3	88	26.2	24.2	82	26.8	24.6	72
850	18.3	13.8	1,508	18.2	14.5	1,501	18.3	14.9	1,492
700	10.2	2.3	3,160	9.5	4.0	3,143	10.0	4.4	3,137
500	- 5.0	-14.0	5,878	- 5.6	-11.4	5,862	- 5.5	-11.8	5,859
400	-15.2	-25.5	7,603	-15.1	-22.8	7,605	-15.7	-23.2	7,579
300	-30.1	-39.6	9,701	-30.5	-38.6	9,693	-30.4	-36.9	9,689
250	-40.4		10,987	-40.2		10,962	-40.6		10,948
200	-52.7		12,468	-53.3		12,441	-53.1		12,439
150	-67.1		14,267	-68.0		14,232	-67.8		14,228
100	-78.8		16,630	-77.4		16,586	-77.0		16,582
50	-62.9		20,707	-61.1		20,729	-60.2		20,741
25	-52.0		25,058	-51.2		25,138	-51.3		25,152

Pressure (mb)	Sept. Temp. (°C)	Sept. D.P. (°C)	Sept. Height (g.p.m.)	Oct. Temp. (°C)	Oct. D.P. (°C)	Oct. Height (g.p.m.)
1000	26.1	24.4	78	26.3	24.4	77
850	18.6	14.9	1,497	18.3	15.0	1,498
700	9.8	5.0	3,141	9.9	4.2	3,107
500	- 5.5	-11.1	5,861	- 5.3	-12.9	5,842
400	-15.6	-22.3	7,582	-15.9	-24.6	7,643
300	-30.4	-37.5	9,687	-30.4	-39.4	9,664
250	-40.7		10,961	-40.9		10,944
200	-53.1		12,441	-53.4		12,428
150	-67.8		14,232	-67.8		14,233
100	-78.3		16,588	-80.2		16,555
50	-63.1		20,709	-63.2		20,627
				-53.6		24,996

Table 3. - Continued

CANTON

Pressure (mb)	Jun. Temp. (°C)	Jun. D.P. (°C)	Jun. Height (g.p.m.)	Jul. Temp. (°C)	Jul. D.P. (°C)	Jul. Height (g.p.m.)	Aug. Temp. (°C)	Aug. D.P. (°C)	Aug. Height (g.p.m.)
1000	26.8	23.2	92	26.6	22.8	90	26.8	22.8	88
850	18.0	11.9	1,509	17.8	13.5	1,507	17.7	10.8	1,503
700	10.4	- 1.8	3,151	10.0	- 3.6	3,147	9.9	- 3.6	3,143
500	- 5.0	-16.7	5,875	- 5.7	-21.7	5,866	- 5.6	-22.6	5,873
400	-15.3	-31.0	7,596	-15.7	-32.5	7,585	-15.6	-32.7	7,582
300	-30.8	-44.5	9,706	-31.3	-43.3	9,690	-31.1	-45.0	9,687
250	-40.9		10,975	-41.7		10,955	-41.5		10,952
200	-53.0		12,454	-54.6		12,430	-53.8		12,427
150	-67.6		14,246	-68.3		14,283	-68.2		14,216
100	-81.2		16,596	-80.2		16,561	-80.2		16,561
50	-62.1		20,655	-61.6		20,683	-61.5		20,705
25	-50.4		25,222	-52.3		25,075	-52.9		25,097

Pressure (mb)	Sept. Temp. (°C)	Sept. D.P. (°C)	Sept. Height (g.p.m.)	Oct. Temp. (°C)	Oct. D.P. (°C)	Oct. Height (g.p.m.)
1000	26.4	22.4	91	26.6	22.4	88
850	17.5	10.5	1,506	18.0	10.3	1,510
700	9.8	- 3.5	3,147	10.2	- 4.4	3,150
500	- 5.5	-22.5	5,865	- 5.5	-21.8	5,870
400	-15.7	-33.6	7,590	-15.6	-33.7	7,591
300	-31.0	-45.1	9,695	-30.9	-45.7	9,719
250	-41.5		10,974	-41.1		10,966
200	-53.7		12,437	-53.4		12,476
150	-68.3		14,227	-68.0		14,260
100	-79.6		16,577	-80.8		16,397
50	-63.4		20,717	-63.2		20,673
25				-53.1		25,041

Table 4. - Mean sounding data at standard pressure surfaces for:

IWO-MARCUS

	Jun.						Jul.						Aug.					
Pressure (mb)	T (^{0}C)	D.P. (^{0}C)	H (g.p.m.)	θ (^{0}A)	q (g/kg)	θ_e (^{0}A)	T (^{0}C)	D.P. (^{0}C)	H (g.p.m.)	θ (^{0}A)	q (g/kg)	θ_e (^{0}A)	T (^{0}C)	D.P. (^{0}C)	H (g.p.m.)	θ (^{0}A)	q (g/kg)	θ_e (^{0}A)
1000	26.1	22.5	123	299	17.4	341	26.9	22.6	115	300	17.5	342	26.9	22.6	107	300	17.5	342
850	17.9	11.8	1,537	305	10.1	329	18.1	12.9	1,532	305	11.0	331	18.4	13.9	1,523	306	11.9	335
700	10.0	- 1.2	3,180	314	6.0	328	10.0	1.2	3,173	314	6.0	328	9.9	2.0	3,171	314	6.4	329
500	- 5.4	-19.7	5,903	326	1.6	330	- 5.8	-15.4	5,896	326	2.3	332	- 5.8	-15.7	5,890	327	2.3	332
400	-16.6	-30.2	7,617	334	0.8	336	-16.7	-28.2	7,607	334	0.9	336	-16.7	-27.3	7,603	334	1.0	337
300	-31.7	-43.8	9,716	342	0.3	343	-31.8	-41.4	9,712	342	0.4	343	-32.1	-42.3	9,702	341	0.4	342
250	-42.0		10,983	344			-42.0		10,968	344			-42.1		10,961	344		
200	-53.9		12,474	349			-54.2		12,431	348			-54.2		12,431	348		
150	-67.0		14,235	356			-67.6		14,207	355			-66.8		14,218	356		
100	-75.9		16,615	382			-72.9		16,613	387			-73.2		16,614	387		

	Sept.						Oct.					
Pressure (mb)	T (^{0}C)	D.P. (^{0}C)	H (g.p.m.)	θ (^{0}A)	q (g/kg)	θ_e (^{0}A)	T (^{0}C)	D.P. (^{0}C)	H (g.p.m.)	θ (^{0}A)	q (g/kg)	θ_e (^{0}A)
1000	26.9	22.8	112	300	17.9	343	26.2	22.1	126	299	17.1	340
850	18.5	13.5	1,529	306	11.6	334	17.6	11.9	1,539	305	10.3	330
700	10.8	1.1	3,172	314	6.0	328	10.2	- 1.2	3,179	314	5.0	326
500	- 4.9	-17.1	5,900	327	2.0	332	- 5.6	-22.2	5,899	326	1.2	329
400	-16.6	-28.4	7,618	334	0.9	336	-17.5	-33.5	7,610	332	0.6	333
300	-32.0	-41.7	9,713	341	0.4	342	-32.8	-46.3	9,703	340	0.2	340
250	-41.9		10,983	344			-42.7		10,961	344		
200	-53.3		12,464	349			-53.7		12,433	349		
150	-65.9		14,231	358			-65.9		14,228	358		
100	-75.7		16,650	382			-76.8		16,617	380		

Table 4. - Continued

MID-PACIFIC

	Jun.						Jul.						Aug.					
Pressure (mb)	T (°C)	D.P. (°C)	H (g.p.m.)	θ (°A)	q (g/kg)	θe (°A)	T (°C)	D.P. (°C)	H (g.p.m.)	θ (°A)	q (g/kg)	θe (°A)	T (°C)	D.P. (°C)	H (g.p.m.)	θ (°A)	q (g/kg)	θe (°A)
1000	23.7	19.6	143	297	14.5	332	24.7	21.5	147	298	16.4	337	25.3	22.0	136	299	16.9	340
850	15.1	10.1	1,544	303	9.4	326	15.6	12.2	1,569	303	12.8	329	16.1	12.4	1,545	304	10.9	330
700	9.0	- 6.2	3,176	313	3.9	322	7.8	- 2.2	3,182	312	4.5	323	7.8	- 0.8	3,174	311	5.2	323
500	- 6.1	-21.8	5,889	325	1.3	328	- 8.2	-21.3	5,879	323	1.4	326	- 7.8	-19.2	5,871	323	1.6	327
400	-17.7	-32.2	7,601	332	0.6	333	-19.6	-31.5	7,578	330	0.7	332	-18.9	-30.4	7,571	331	0.7	333
300	-33.6	-46.2	9,686	338	0.2	338	-35.2	-47.0	9,649	335	0.2	335	-34.8	-46.0	9,648	336	0.2	336
250	-43.5		10,941	341			-45.3		10,895	338			-44.9		10,894	339		
200	-55.5		12,401	345			-56.8		12,316	343			-56.4		12,350	343		
150	-66.9		14,181	355			-66.8		14,122	355			-66.4		14,132	355		
100	-74.0		16,578	384			-68.7		16,547	393			-69.2		16,561	393		
50	-61.0		20,748				-59.9		20,776				-59.4		20,7[illegible]			
25	-50.5		25,186				-50.4		25,228				-50.5		25,211			

	Sept.						Oct.					
Pressure (mb)	T (°C)	D.P. (°C)	H (g.p.m.)	θ (°A)	q (g/kg)	θe (°A)	T (°C)	D.P. (°C)	H (g.p.m.)	θ (°A)	q (g/kg)	θe (°A)
1000	25.7	22.0	123	299	16.9	340	23.9	20.4	129	297	15.5	334
850	16.6	12.2	1,532	304	10.8	330	14.9	11.4	1,530	302	10.1	326
700	9.3	- 1.2	3,167	313	5.0	325	8.3	- 4.3	3,157	312	4.0	322
500	- 6.4	-20.0	5,882	325	1.6	329	- 7.2	-22.1	5,863	324	1.3	327
400	-17.8	-29.9	7,594	332	0.8	334	-18.5	-32.4	7,569	331	0.6	332
300	-33.6	-43.9	9,685	338	0.3	339	-34.4	-46.4	9,659	337	0.2	337
250	-43.5		10,935	341			-44.1		10,898	340		
200	-54.9		12,400	346			-54.8		12,361	346		
150	-66.5		14,181	355			-65.9		14,154	356		
100	-73.1		16,588	386			-75.4		16,553	382		
50	-60.3		20,741				-61.9		20,689			
25							-52.0		25,091			

Table 4. - Continued

WEST CAROLINES-MARIANAS

	Jun.						Jul.						Aug.					
Pressure (mb)	T (°C)	D.P. (°C)	H (g.p.m.)	θ (°A)	q (g/kg)	θ_e (°A)	T (°C)	D.P. (°C)	H (g.p.m.)	θ (°A)	q (g/kg)	θ_e (°A)	T (°C)	D.P. (°C)	H (g.p.m.)	θ (°A)	q (g/kg)	θ_e (°A)
1000	26.4	23.9	91	300	19.0	346	25.9	24.1	88	299	19.4	346	26.0	24.2	80	299	19.5	346
850	18.3	13.8	1,511	305	11.8	333	18.2	14.2	1,505	305	12.2	334	18.3	14.8	1,503	305	12.7	335
700	10.1	2.0	3,153	314	6.3	329	9.7	3.6	3,147	313	7.1	330	9.8	4.1	3,142	313	7.3	330
500	- 5.0	-13.0	5,879	327	2.8	334	- 5.6	-10.2	5,865	327	3.5	335	- 5.4	-12.0	5,865	327	3.0	334
400	-15.3	-26.0	7,603	335	1.2	338	-15.6	-24.0	7,592	335	1.4	338	-15.7	-23.2	7,583	335	1.4	338
300	-30.3	-41.3	9,716	343	0.3	344	-30.6	-39.5	9,693	342	0.4	343	-30.5	-38.0	9,692	342	0.5	343
250	-40.5		10,984	346			-40.5		10,962	346			-40.6		10,957	345		
200	-52.8		12,465	348			-53.2		12,441	348			-53.1		12,440	348		
150	-67.2		14,293	354			-67.6		14,229	353			-67.7		14,232	353		
100	-78.5		16,625	376			-77.3		16,589	378			-76.9		16,588	379		
50	-62.7		20,713				-61.7		20,733				-60.6		20,745			
25	-51.8		25,072				-51.5		25,111				-51.7		25,154			

	Sept.						Oct.					
Pressure (mb)	T (°C)	D.P. (°C)	H (g.p.m.)	θ (°A)	q (g/kg)	θ_e (°A)	T (°C)	D.P. (°C)	H (g.p.m.)	θ (°A)	q (g/kg)	θ_e (°A)
1000	25.7	24.2	82	299	19.5	346	25.8	24.3	83	299	19.1	345
850	18.5	14.8	1,502	306	12.5	336	18.4	14.7	1,504	305	12.5	335
700	9.8	4.8	3,146	314	7.8	333	10.0	3.8	3,136	314	7.1	331
500	- 5.5	-11.3	5,867	326	3.2	334	- 5.3	-12.3	5,862	326	2.9	333
400	-15.7	-22.3	7,587	335	1.6	339	-15.7	-24.9	7,582	335	1.2	338
300	-30.5	-37.7	9,697	342	0.5	343	-30.6	-39.7	9,689	342	0.4	343
250	-40.6		10,966	345			-40.8		10,961	345		
200	-53.0		12,443	349			-53.1		12,438	348		
150	-67.6		14,231	353			-67.4		14,237	354		
100	-77.9		16,596	377			-79.7		16,588	373		
50	-62.7		20,724				-63.1		20,669			
25			25,139				-53.0		25,621			

Table 4. - Continued

MARSHALLS

	Jun.						Jul.						Aug.					
Pressure (mb)	T (^{0}C)	D.P. (^{0}C)	H (g.p.m.)	θ (^{0}A)	q (g/kg)	θe (^{0}A)	T (^{0}C)	D.P. (^{0}C)	H (g.p.m.)	θ (^{0}A)	q (g/kg)	θe (^{0}A)	T (^{0}C)	D.P. (^{0}C)	H (g.p.m.)	θ (^{0}A)	q (g/kg)	θe (^{0}A)
1000	26.7	23.7	92	300	18.9	345	26.7	23.6	90	300	18.8	345	27.1	23.8	84	300	18.9	345
850	17.9	14.0	1,509	305	12.0	334	18.0	14.2	1,507	305	12.1	334	18.0	14.4	1,504	305	12.2	334
700	10.0	1.8	3,153	314	6.3	329	9.7	3.3	3,149	313	7.0	330	9.7	3.5	3,144	313	7.0	330
500	- 5.2	-15.1	5,873	327	2.4	333	- 5.7	-13.4	5,868	326	2.7	332	- 5.6	-13.3	5,862	326	2.7	332
400	-15.7	-25.4	7,595	335	1.1	338	-16.2	-25.2	7,585	334	1.2	337	-16.3	-25.6	7,580	334	1.2	337
300	-30.8	-40.9	9,701	342	0.4	343	-31.3	-40.0	9,686	341	0.4	342	-31.4	-40.7	9,683	341	0.4	342
250	-41.0		10,967	345			-41.6		10,950	344			-41.6		10,953	344		
200	-53.6		12,445	347			-53.9		12,422	347			-54.1		12,421	347		
150	-68.2		14,234	352			-69.4		14,206	350			-68.4		14,203	351		
100	-77.9		16,598	377			-77.5		16,554	377			-77.5		16,558	377		
50	-63.0		20,677				-61.2		20,701				-61.1		20,708			
25	-51.4		25,062				-50.5		25,128				-51.7		25,101			

	Sept.						Oct.					
Pressure (mb)	T (^{0}A)	D.P. (^{0}C)	H (g.p.m.)	θ (^{0}A)	q (g/kg)	θe (^{0}A)	T (^{0}C)	D.P. (^{0}C)	H (g.p.m.)	θ (^{0}A)	q (g/kg)	θe (^{0}A)
1000	27.3	22.7	85	301	17.8	344	26.6	23.6	88	300	18.8	345
850	18.3	15.1	1,504	305	12.9	336	18.2	14.1	1,507	305	12.0	334
700	9.8	4.4	3,147	313	7.6	331	9.7	4.3	3,150	313	7.6	331
500	- 5.7	-12.2	5,869	326	2.9	333	- 5.8	-13.0	5,868	326	2.8	333
400	-16.1	-25.1	7,587	334	1.2	337	-16.3	-24.0	7,584	334	1.4	337
300	-31.2	-40.5	9,681	341	0.4	342	-31.6	-38.8	9,687	341	0.4	342
250	-41.8		10,948	344			-41.8		10,955	344		
200	-54.3		12,417	346			-54.2		12,420	347		
150	-68.1		14,201	352			-68.5		14,200	352		
100	-77.2		16,569	378			-78.5		16,554	376		
50	-62.3		20,711				-63.5		20,654			
							-53.6		25,017			

Table 5.1. - Deviations of mean sounding data for Iwo-Marcus from mean sounding data for Mid-Pacific area

	Jun.			Jul.			Aug.			Sept.			Oct.		
ressure (mb)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)
1000	2.4	2.9	-20	2.2	1.1	-32	1.6	0.6	-29	1.2	1.0	-11	2.3	1.6	- 3
850	2.8	0.7	- 7	2.5	0.2	-37	2.3	1.0	-42	1.9	0.8	- 4	2.7	0.2	9
700	1.0	2.1	4	2.2	1.4	- 9	2.1	1.2	- 3	1.5	1.0	5	1.9	1.0	22
500	0.7	0.3	14	2.4	0.9	17	2.0	0.7	19	1.5	0.4	18	1.6	-0.1	36
400	1.1	0.2	16	2.9	0.2	29	2.2	0.4	32	1.2	0.1	24	1.0	0.0	41
300	1.9	0.1	30	3.4	0.2	43	2.7	0.2	54	1.6	0.1	31	1.6	0.0	44
250	1.5		42	3.3		73	2.8		67	1.6		48	1.4		63
200	1.6		73	2.6		85	2.2		81	1.6		64	1.1		72
150	-0.1		54	-0.8		85	-0.4		86	0.6		62	0.0		74
100	-1.9		37	-4.2		66	-4.0		53	-2.5		62	-1.4		64

Table 5.2. - Deviations of mean sounding data for West Carolines-Marianas area from mean sounding data for Marshalls area

	Jun.			Jul.			Aug.			Sept.			Oct.		
Pressure (mb)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)
1000	-0.3	0.1	- 1	-0.8	0.6	- 2	-1.1	0.6	- 4	-1.6	1.7	- 3	-0.8	0.3	- 5
850	-0.4	-0.2	2	0.2	0.1	- 2	0.3	0.5	- 1	0.2	0.4	- 2	0.2	0.4	- 3
700	0.1	0.0	0	0.0	0.1	- 2	0.1	-0.6	- 2	0.0	0.2	- 1	0.3	-0.5	-14
500	0.2	0.4	6	0.1	0.8	- 3	0.2	0.3	3	0.2	0.3	- 2	0.5	0.1	- 6
400	0.4	0.1	8	0.6	0.2	7	0.6	0.2	3	0.4	0.4	0	0.6	-0.2	- 2
300	0.5	-0.1	15	0.7	0.0	7	0.9	0.1	9	0.7	0.1	16	1.0	0.0	- 2
250	0.5		17	1.1		12	1.0		4	1.2		18	1.0		6
200	0.8		20	0.7		19	1.0		19	1.3		26	1.1		18
150	1.0		59	1.8		23	0.7		29	0.5		30	1.1		37
100	0.6		27	0.2		35	0.6		30	-0.7		27	-1.2		34
50	0.3		36	-0.5		32	0.5		37	-0.4		13	-0.4		15

Table 5.3. - Deviations of mean sounding data for Iwo-Marcus area from mean sounding data for West Carolines-Marianas area

	Jun.			Jul.			Aug.			Sept.			Oct.		
Pressure (mb)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)
1000	-0.3	-1.6	42	1.0	-1.5	27	0.9	-2.0	27	1.2	-1.6	30	0.4	-2.0	43
850	-0.4	-1.7	26	-0.1	-1.2	27	0.1	-0.8	0	0	-0.9	27	-0.8	-2.2	35
700	-0.1	-0.3	27	0.3	-1.1	26	0.1	0	29	1.0	-1.8	26	0.2	-2.1	43
500	-0.4	-1.2	24	-0.2	-1.2	31	-0.4	-0.7	25	0.6	-1.2	33	-0.3	-1.7	37
400	-1.3	-0.4	14	-1.1	-0.5	15	-1.0	-0.4	20	-0.9	-0.7	31	-1.8	-0.6	28
300	-1.6	0	0	-1.2	0	19	-1.6	-0.1	10	-1.5	-0.1	16	-2.2	-0.2	14
250	-1.5		- 1	-1.5		6	-1.5		4	-1.3		17	-2.1		0
200	-1.1		- 9	-1.0		-10	-1.1		- 9	-0.3		21	-0.6		5
150	0.2		-58	0		-22	0.1		-14	1.7		20	1.5		9
100	2.5		-10	4.4		24	3.7		26	2.2		54	2.9		29

Table 5.4. - Deviations of mean sounding data for Mid-Pacific area from mean sounding data for Marshalls area

	Jun.			Jul.			Aug.			Sept.			Oct.		
Pressure (mb)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)
1000	-3.0	-4.4	51	-2.0	-2.4	57	-1.8	-2.0	52	-1.6	-0.9	38	-2.7	-3.3	41
850	-2.8	-2.6	35	-2.4	-1.3	62	-1.9	-1.3	41	-1.7	-2.1	28	-3.3	-1.9	23
700	-1.0	-2.4	23	-1.9	-2.4	33	-1.9	-1.8	30	-0.5	-2.6	20	-1.4	-3.6	7
500	-0.9	-1.1	16	-2.5	-1.3	11	-2.2	-1.1	9	-0.7	-1.3	13	-1.4	-1.5	- 5
400	-2.0	-0.5	6	-3.4	-0.5	- 7	-2.6	-0.5	- 9	-1.7	-0.4	7	-2.2	-0.8	-15
300	-2.8	-0.2	-25	-3.9	-0.2	-37	-3.4	-0.2	-35	-2.4	-0.1	0	-2.8	-0.2	-28
250	-2.5		-26	-3.7		-55	-3.3		-59	-1.7		-13	-2.3		-57
200	-1.9		-44	-2.9		-76	-2.3		-71	-0.6		-17	-0.6		-59
150	1.3		-53	2.6		-84	2.0		-71	1.6		-13	2.6		-46
100	3.9		-20	8.8		- 7	8.3		3	4.1		19	3.1		- 1
50	2.0		71	1.3		75	1.7		83	2.0		30	1.6		35

Table 6. - Deviations of mean sounding data for Iwo-Marcus from mean sounding data for the Gulf of Mexico area

		Jun.			Jul.			Aug.			Sept.			Oct.	
Pressure (mb)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)
1000	0.3	0.1	- 4	0.7	-0.3	-23	0.3	-0.4	-23	1.1	0.4	-10	2.7	2.9	- 8
850	-0.4	0.6	- 6	-0.5	1.0	-24	-0.1	2.0	-27	0.6	1.4	- 8	1.9	2.1	3
700	0.9	1.3	0	1.0	0.5	-23	0.5	0.8	-20	1.7	0.4	- 3	2.2	0.9	14
500	1.5	-0.1	5	1.0	-0.9	- 7	0.6	0.3	-13	1.4	0	14	2.1	-0.1	36
400	1.5	0	22	1.0	-0.5	4	0.6	0.1	-11	0.6	0	20	1.7	0.1	47
300	1.9		37	1.4		14	0.5		2	0.7		23	1.6		65
250	1.4		51	1.2		15	0.5		- 1	0.3		33	1.2		74
200	1.0		79	0.9		14	0		1	0.6		42	1.0		82
150	-0.5		89	-0.9		6	-0.6		2	0.7		40	0.4		88
100	-3.2		32	-2.7		- 5	-2.2		-22	-2.6		41	-3.0		79

Table 7. - Deviations of mean sounding data for West Carolines-Marianas from mean sounding data for the West Indies area

		Jun.			Jul.			Aug.			Sept.			Oct.	
Pressure (mb)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)	ΔT (°C)	Δq (g/kg)	ΔH (m)
1000	0.8	1.9	-49	-0.2	1.8	-52	-0.4	1.7	-57	-0.5	1.7	-40	0.3	2.1	-36
850	1.2	1.5	-40	1.1	1.6	-59	0.7	1.9	-48	0.8	1.4	-37	1.5	1.7	-27
700	1.7	0.9	-35	1.4	2.0	-50	1.0	1.6	-46	0.9	1.8	-30	1.5	1.3	-31
500	2.3	0.5	-13	1.8	1.2	-30	1.4	0.7	-33	1.2	0.8	-25	1.4	0.6	-15
400	2.8	0.3	4	2.6		- 7	1.9		-22	1.6	0.8	- 6	2.0		- 1
300	3.3		36	3.3		-13	2.6		- 4	2.2		14	2.6		21
250	3.2		54	3.5		-32	2.6		17	2.2		27	2.4		40
200	2.9		72	2.7		-54	1.9		32	1.9		38	1.8		-46
150	1.1		126	0.1		-68	-0.5		44	0.1		46	0.5		73
100	-5.6		65	-6.0		-23	-4.1		4	-4.0		27	-3.8		143
50	-2.4		-27	-1.7		-27	-0.4		25	-1.9		-16	-1.6		-21

DISTRIBUTION OF TURBULENCE AND ICING IN THE TROPICAL CYCLONE

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1. INTRODUCTION

Over the western Pacific in the Northern Hemisphere, tropical cyclones are so numerous in summer and autumn, especially in August and September, that we can readily find one or more of them on daily Pacific weather charts. There have been not a few cases in which regular flights over the routes from Tokyo to Hongkong, Manila, Biak, Wake, and Honolulu were obliged to delay their departure or arrival times or to deviate from their regular routes to avoid a tropical cyclone with its severe turbulence and icing. Therefore it is important for safe flying to examine the distribution of turbulence and icing associated with the movement and intensity of tropical cyclones.

For such a study we used the eye fix reports of U.S. Air Force reconnaissance flights for the period of 2-1/2 years from January 1959 to June 1961, and AIREPs collected from civil aircraft which landed at Tokyo International Airport. The collecting area of the information covers a region from 90°E. to 180°E. in the Northern Hemisphere.

Table 1 shows the frequency of formation of tropical cyclones during the period examined. Classification in this table follows that of the United States Typhoon Warning Center. In the Column "Tropical depression" are included only those that were named and/or observed by weather reconnaissance flights.

Table 1. - Frequency of formations of tropical cyclone

Type of tropical cyclone	1959 (Jan.-Dec.)	1960 (Jan.-Dec.)	1961 (Jan.-Jun.)	Total
Typhoon (max wind $>$ 64 kt.)	17	19	4	40
Tropical storm (34-63 kt.)	7	7	5	19
Tropical depression ($\leq$ 33 kt.)	7	3	2	12
Total	31	29	11	71

2. TURBULENCE

T. Ochi [1] investigated the distribution of turbulence within the area of a typhoon and pointed out that severe turbulence is occasionally observed in its north and south quadrants. Using the data available here we also examined the distribution of turbulence as a function of: (a) type of tropical cyclones, (b) altitude of reconnaissance flights, and (c) direction of movement of tropical cyclones.

2.1. Turbulence in relation to types of tropical cyclones and altitudes of reconnaissance flights

Table 2 shows the frequency of turbulence observations obtained from eye fix reports made by United States reconnaissance flights at varying flight levels as related to the surface maximum winds of tropical cyclones. Data are for the flight altitudes used, according to United States Typhoon Warning Service standing operation procedures. They are classified as follows:

(a) The 1500-ft. level is used for locating and reconnoitering a tropical cyclone, or for approaching a weak tropical cyclone, but it is never used when wind speeds are 64 kt. or more.

(b) The 7,000-10,000-ft. level (700 mb.), or higher, is used for almost all reconnaissance flights.

(c) The 17,000-19,000-ft. level (500 mb.) is used when a typhoon reconnaissance flight is required over land or within a distance of 60 n.mi. of the Philippines, Formosa, Japan, or Korea. In all cases at least an 8,000-ft. terrain clearance should be maintained.

Values at the 31,000-39,000-ft. level in table 2 are those obtained by special reconnaissance flights during the year 1959.

From table 2 the following points are noted:

(a) At the 1500-ft. level, the frequency of severe turbulence is comparatively great. However, very few observations were available at this level.

(b) The frequency of turbulence is greatest between 7,000 and 10,000 feet. The stronger the surface maximum wind speed, the heavier the turbulence becomes, resulting in more frequent turbulence observations.

(c) At levels between 17,000 and 19,000 feet, the intensity of turbulence is generally weaker than at 7,000-10,000-ft. levels.

(d) At levels greater than 31,000 ft., turbulence is still observed, but the frequency of "NIL" becomes a little greater than at the levels between 7,000 and 19,000 ft.

Table 2. - Frequency of turbulence observations in relation to types of tropical cyclones and flight altitudes. Parentheses indicate the percentage of turbulence observations.

Maximum surface wind	Tropical depression and storm < 63 kt.				Typhoon 64 to 99 kt.				Typhoon > 100 kt.			
Height \ TURBC	SVR	MDT	LGT	NIL	SVR	MDT	LGT	NIL	SVR	MDT	LGT	NIL
31,000 to 39,000 ft.					2 (15)	3 (23)	4 (31)	4 (31)	0 (0)	2 (18)	7 (64)	2 (18)
17,000 to 19,000 ft.					0 (0)	3 (25)	7 (58)	2 (17)	0 (0)	4 (44)	4 (44)	1 (11)
7,000 to 10,000 ft.	1 (1)	33 (34)	47 (48)	16 (16)	9 (5)	45 (27)	99 (59)	14 (8)	11 (8)	69 (48)	63 (43)	2 (1)
1,500 ft.	5 (56)	0 (0)	1 (11)	3 (33)								

2.2 Turbulence in relation to the direction of movement of tropical cyclones.

A. Data from reconnaissance flights

Weather reconnaissance aircraft penetrate into a tropical cyclone to locate the eye if possible, and transmit the eye fix reports which include a short description of the turbulence with its intensity and quadrant. We obtained those reports and classified them according to intensity, quadrant, and the type and the direction of movement of tropical cyclones as shown in table 3. Under the column marked "all" in this table are listed those cases where turbulence was observed simultaneously in all quadrants.

Table 3 indicates that there is no striking tendency for turbulence to occur particularly in the forward quadrant of a tropical cyclone. We can only say that when a tropical cyclone moves north and northeastward a little more turbulence can be found in the forward quadrant than in any other part of the storm. Thus, turbulence observations in this table do not show any particular directional tendency. The absence of such a tendency may be explained by the following consideration. Around the center of a tropical cyclone there are rain bands and wall clouds in which considerable turbulence is usually found. Reconnaissance aircraft have to penetrate into or break through these bands to get to the center from all quadrants. Naturally they encounter turbulence, and sometimes in all quadrants.

From table 3 the following conclusions are also found:

(a) In the south quadrant of typhoons and tropical storms, turbulence may be severe.

Table 3. - Frequency of turbulence observations in different sectors of the storm in relation to the direction of movement of the tropical cyclone.

		Quadrant																																EYE				ALL				NIL
		N				NE				E				SE				S				SW				W				NW												
Turbulence		L	M	S	T	L	M	S	T	L	M	S	T	L	M	S	T	L	M	S	T	L	M	S	T	L	M	S	T	L	M	S	T	L	M	S	T	L	M	S	T	
Typhoon movement	W	3	6	0	9	1	2	0	3	7	2	0	9	2	1	0	3	4	2	0	6	1	1	0	2	3	2	0	5	2	2	1	5	1	0	1	2	3	4	0	7	4
	NW	10	8	1	19	11	4	3	18	8	13	2	23	3	2	0	5	4	11	5	20	3	4	1	8	5	9	2	16	2	5	1	8	2	3	0	5	10	11	0	21	6
	N	11	3	1	15	3	3	1	7	8	4	1	13	8	0	0	8	5	4	1	10	5	2	0	7	7	2	0	9	2	3	0	5	0	1	0	1	5	1	0	6	2
	NE	2	1	3	6	3	2	1	6	3	0	0	3	2	0	0	2	5	0	1	6	2	1	0	3	3	0	0	3	1	2	0	3	1	0	0	1	3	2	0	5	6
	E	0	1	0	1	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Stationary	1	1	0	2	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	2	0	0	2	4	0	0	4	2	0	0	2	0	0	0	0	0	0	0	0	2
	Total	27	20	5	52	20	11	5	36	26	20	3	49	16	3	0	19	18	17	7	42	13	8	1	22	22	14	2	38	9	12	2	23	4	4	1	9	21	18	0	39	20
Tropical Storm		6	10	0	16	4	2	0	6	5	6	0	11	4	2	0	6	3	5	2	10	1	3	0	4	2	6	0	8	1	1	0	2	2	2	0	4	9	3	1	13	17
Tropical Depression		1	0	0	1	0	0	0	0	1	1	0	2	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	3	0	1	4	2

Note: L = Light, M = Moderate, S = Severe, T = Total observations

(b) The most turbulence is found in the north quadrant and the next most in the east quadrant.

(c) In well-developed typhoons turbulence is not severe in all quadrants at the same time.

(d) Clear air turbulence is often observed in the eye of a typhoon and is sometimes moderate, sometimes severe.

B. Data from civil aircraft

Weather reconnaissance aircraft usually make a survey flight near the center of a cyclone, making penetration and Walker pattern flying (c.f. Typhoon Warning Service SOP), while civil aircraft generally make a detour in order to avoid violent weather conditions near the center. Accordingly, the reports from the former represent special features of the center, those from the latter indicate the character of the surrounding area of a typhoon.

Figure 1 shows the horizontal distribution of turbulence encountered by civil aircraft near typhoons and tropical storms. In interpreting figure 1, attention must be drawn to the fact that the data of the central part (about 200-km. radius) were obtained in flights at altitude greater than 30,000 ft. and in tropical storms where the intensity was generally weak. In addition, more than half of the aircraft from which data were obtained flew in the southwest to northeast semicircle of tropical cyclones. Therefore observations are not symmetrically distributed in all quadrants.

We first divided the area of a typhoon into 16 sectors with straight directional lines and then drew concentric circles 100 kilometers apart from one another, thus making grids. In each grid we plotted symbols indicating the intensity of the turbulence encountered by the aircraft. Likewise we plotted an x where an aircraft passed without turbulence.

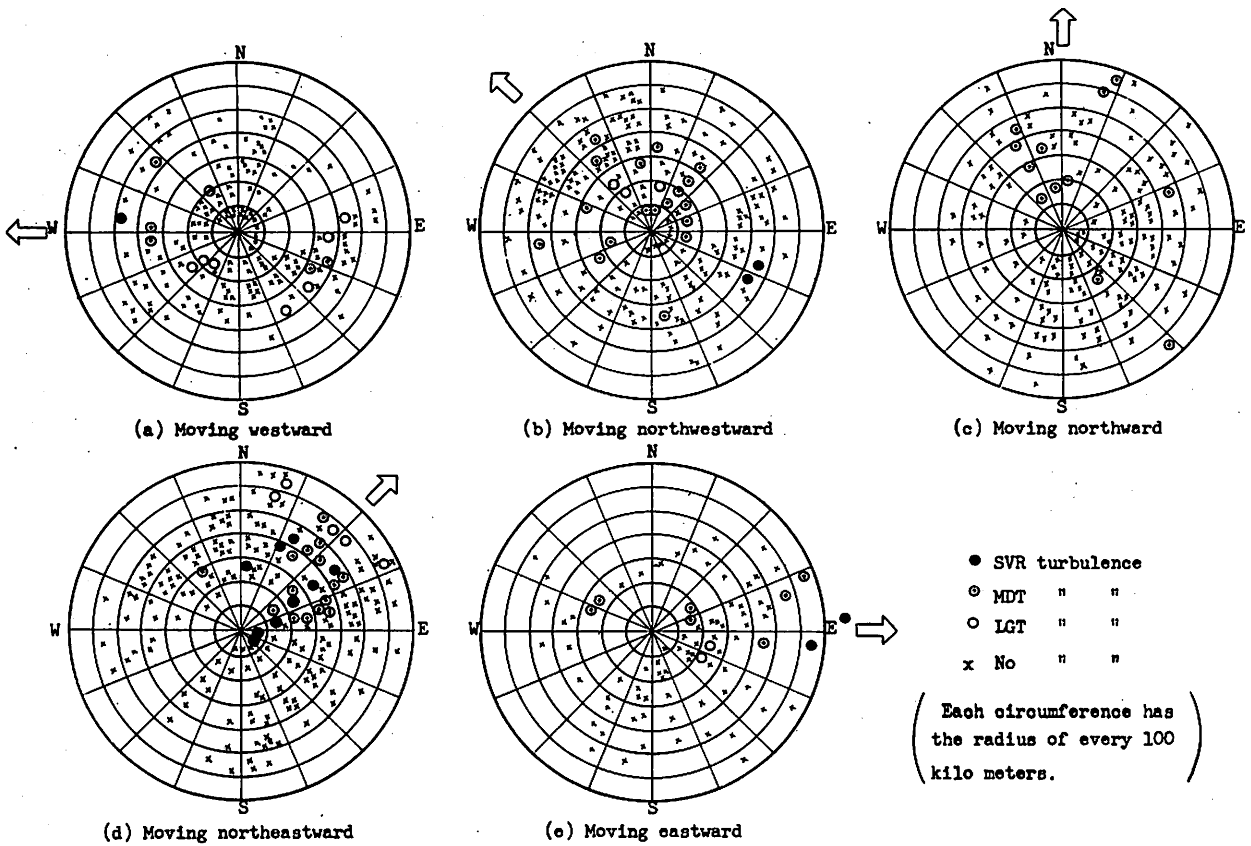
From figure 1 we can draw the following conclusions:

(a) It is apparent that turbulence is observed most frequently in the forward sector of a tropical cyclone, except when it is moving west or northwestward.

(b) When a typhoon or a tropical storm is moving west or northwestward the turbulence accompanying it is intensified. In this stage we can recognize many spiral rain bands around the eye on the radar. However, once it recurves northeast or eastward, it gradually takes on the character of an extratropical cyclone, and all rain bands are gathered in front of the storm.

(c) On either side of a moving tropical cyclone or typhoon, turbulence is less frequent. Moderate or severe turbulence is somewhat more frequent in the rear sector.

Figure 2 shows two pictures of radar echoes transcribed from "Typhoon Observations by Meteorological Radar" by S. Otsuka [2]. One is a picture of the typhoon Alice in the decaying stage. From the time Alice was located far



(a) Moving westward

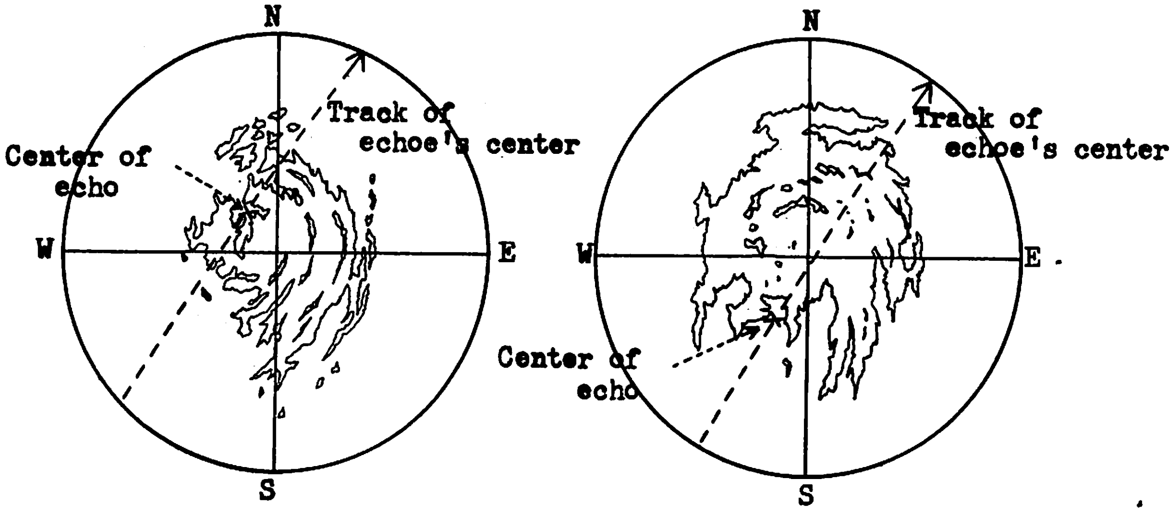
(b) Moving northwestward

(c) Moving northward

(d) Moving northeastward

(e) Moving eastward

Figure 1. - Horizontal distribution of turbulences in tropical cyclones.



Echo of Typhoon "Alice"
June 23, 1958, 1025I

Echo of Typhoon "Ida"
September 26, 1958, 2330I

Figure 2. - Example of radar echo for tropical cyclone.

off the south coast of Central Japan, it was accompanied by a long rain band starting from just north of the center to the east side and stretching to the south. The other picture is of Ida in the decaying stage. In this picture rain bands apparently gathered in front of the cyclone.

Thus each tropical cyclone has a different type of rain band, which may change through the developing and decaying stages. However, generally speaking, rain bands most often stretch from the east side to the south (see fig.2); for this reason, when an aircraft traverses the south or south-southeast portion of the tropical cyclone, it crosses a rain band and encounters turbulence.

From the above examination of data from weather reconnaissance flights and civil aircraft, the following conclusions may be made.

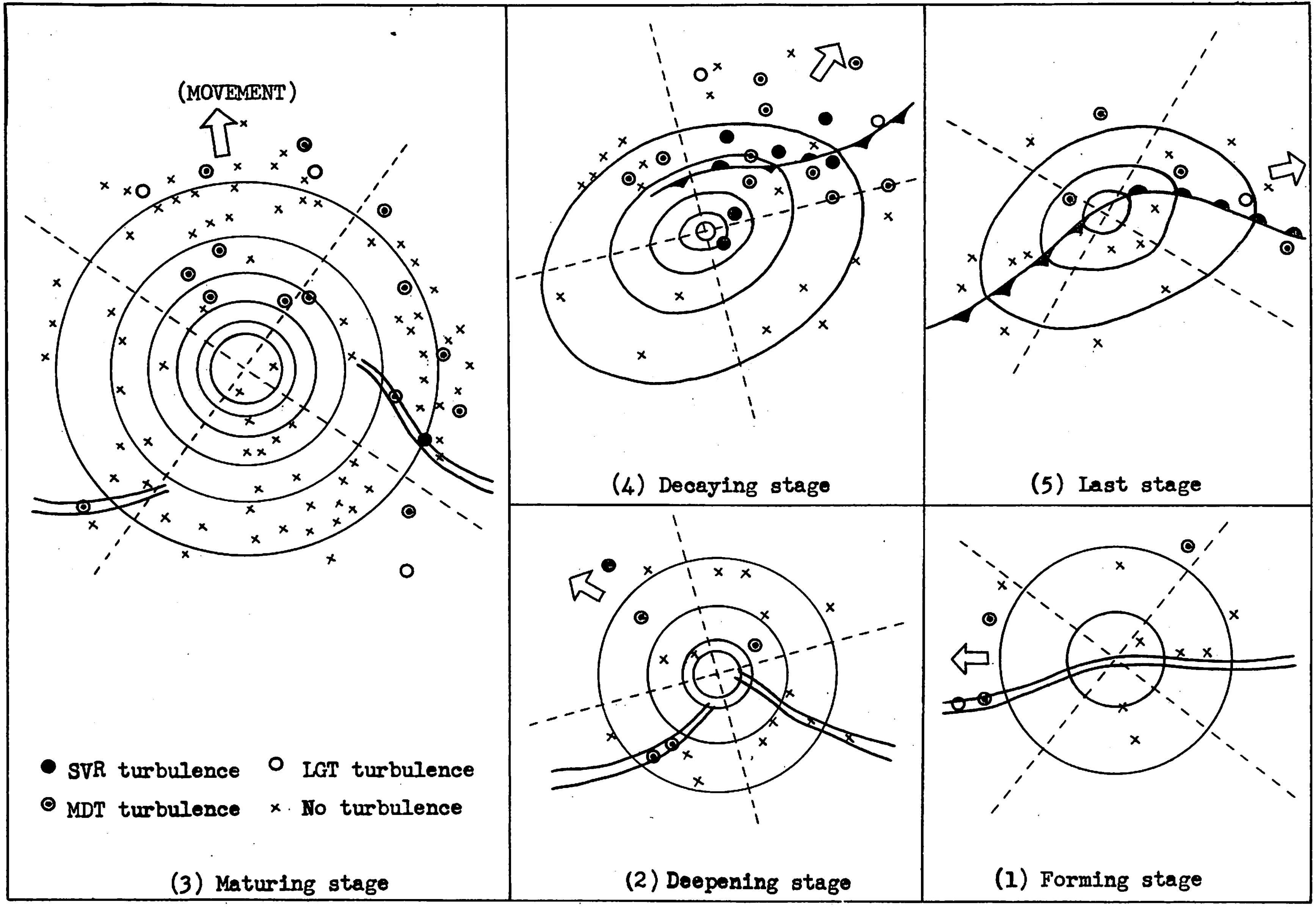
(a) In the central part of a tropical cyclone, the strongest turbulence is observed by aircraft crossing wall clouds around the eye. The wall clouds surround the eye especially in the intensifying stage, so that turbulence is observed regardless of the direction of motion of the cyclone.

(b) However, in the surrounding area of a tropical cyclone, turbulence is quite often observed in the forward sector of the cyclone, especially when it moves to the northeast or east.

For reference in our forecasting work, we prepared figure 3, which illustrates the distribution of turbulence in models for each stage of the life of a tropical cyclone:

(a) Forming Stage

In the transition period from tropical depression to tropical storm, the



(3) Maturing stage

(4) Decaying stage

(2) Deepening stage

(5) Last stage

(1) Forming stage

Figure 3. - Distribution of turbulence in models for each stage through the life of a tropical cyclone.

cyclone generally travels west or northwestward along the intertropical convergence zone (ITC) stretching from east to west.

(b) Deepening Stage

Almost all tropical storms develop into typhoons, and their centers deepen rapidly. The direction of motion is usually northwest or westward.

(c) Maturing Stage

In this stage occur the deepest central pressure and the strongest surface maximum wind. The direction of motion is usually toward the northwest or north.

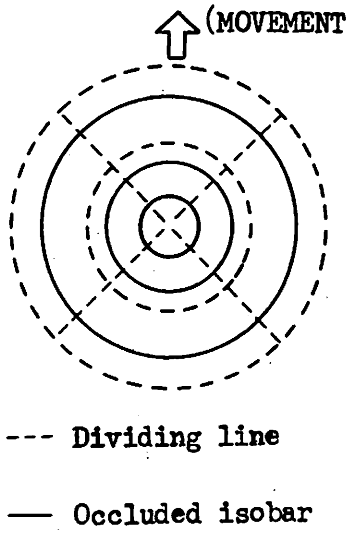


Figure 4. - Division of tropical cyclone (8 sections).

(d) Decaying Stage

North of latitude 25°N. a typhoon usually recurves northeastward under the influence of an approaching polar front from the north, and weakens to a tropical storm.

(e) Last Stage

As the approaching polar front comes near the cyclone's center, the cyclone changes eventually to an extratropical storm as a consequence of cold and warm frontogenesis. The direction of motion is usually northeast or eastward.

In figure 3, we have plotted the location of observed turbulence for each of the five stages of the cyclone. When aircraft did not observe any turbulence an x was plotted in the appropriate section on the map, as shown in figure 4.

With the aid of figure 3 we can draw the following conclusions:

In Forming and Deepening Stages

Turbulence is frequently observed in or near cumulonimbus clouds which develop in the periphery of a tropical cyclone, rather than near its center. When the tropical cyclone is weak, turbulence is infrequently observed, even near the center, by flights at the 1500-ft. level. In the model illustrations (1), (2), and (3) of figure 3, there are ITC's stretching to the east and west. When we check the frequency of turbulence observations by aircraft crossing the ITC's recognizable on the weather chart, the following results are obtained:

On the west side	6 times in 11 passages (55 percent)
On the east side	3 times in 13 passages (23 percent)

This shows that the frequency of turbulence is greater in the ITC's stretching westward from the center than eastward.

In the Maturing Stage

In the well-developed stage, turbulence is quite often observed on the east side and in the forward quadrant of a tropical cyclone.

In the Decaying Stage

In this stage, turbulence is observed quite often in the forward quadrant of a cyclone, or in the north semicircle, and is frequently severe. With the approach of the polar front, turbulence increases in the vicinity of the front. Nine out of sixteen flights flown across the front encountered turbulence (56 percent). In the flights over the front the greatest frequency of turbulence observations is found in the forward sector of the cyclone (83 percent), next on the east side (43 percent), and then on the west side (33 percent). From this fact we infer that few clouds develop in the west portion of the moving cyclone, and that a cold front is not active there yet.

In the Last Stage

As a tropical cyclone gradually changes to an extratropical one, turbulence is often observed in the vicinity of the front, just as in the case of an extratropical cyclone.

Radar echoes of the tropical cyclone will be needed to verify these conclusions. However, it is difficult to obtain all the radar data necessary. At present, for our forecasting work, we can only use the classification system suggested by the models of figure 3.

3. ICING

3.1 Icing in relation to altitude and temperature

In an active tropical cyclone, the probability of icing is great in consequence of the strong ascending currents and the development of cumulonimbus clouds. However, aircraft may readily avoid the danger of icing by maintaining altitudes at which temperatures are above 0°C. or lower than -20°C.

Table 4 shows the relation of icing to the flight altitude. This table was based on the 56 reports from civil aircraft which flew in the area of typhoons and tropical storms where temperatures were 0°C. or below.

Table 4. - Number of cases of icing reported at various flight altitudes in typhoons and tropical storms.

Intensity of icing	11,000 to 15,000 ft.	16,000 to 20,000 ft.	21,000 to 30,000 ft.	31,000 to 40,000 ft.	Total
Moderate icing	0	6	1	0	7
Light icing	3	8	3	2	16
No icing	2	15	5	11	33
Total of flights	5	29	9	13	56

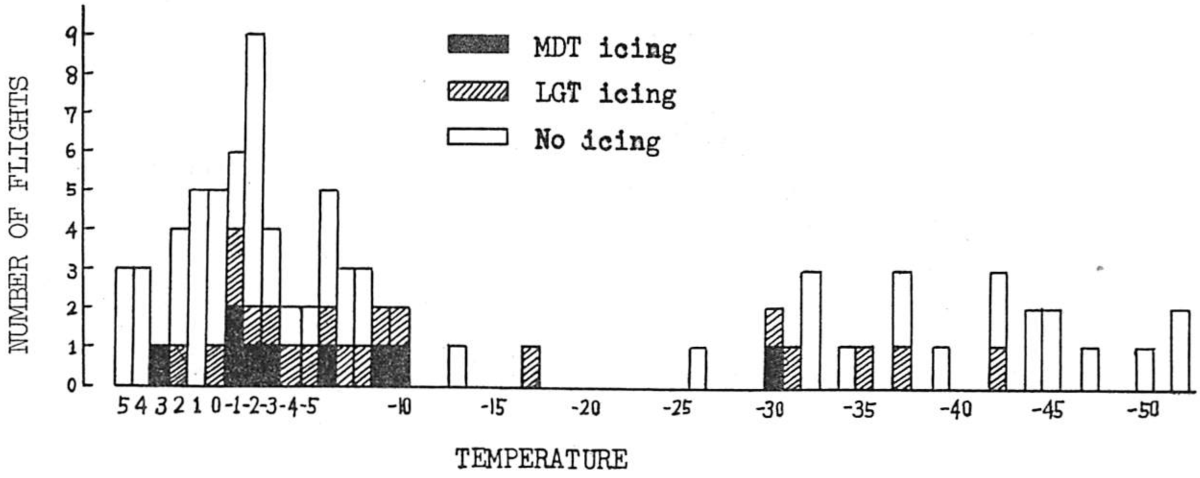


Figure 5. - Temperature and icing in tropical storms and typhoons.

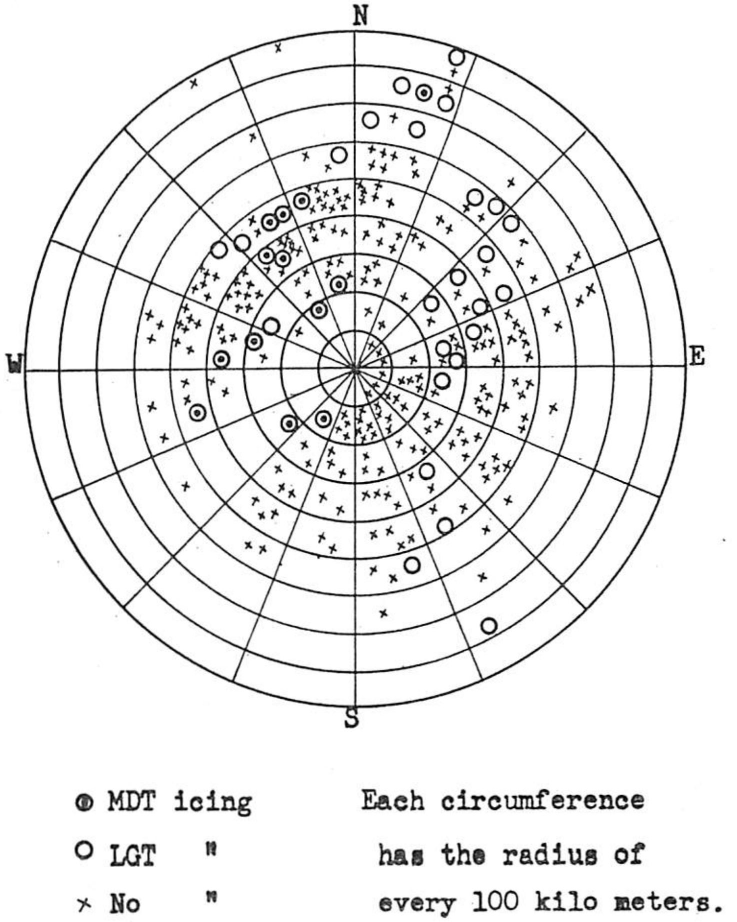
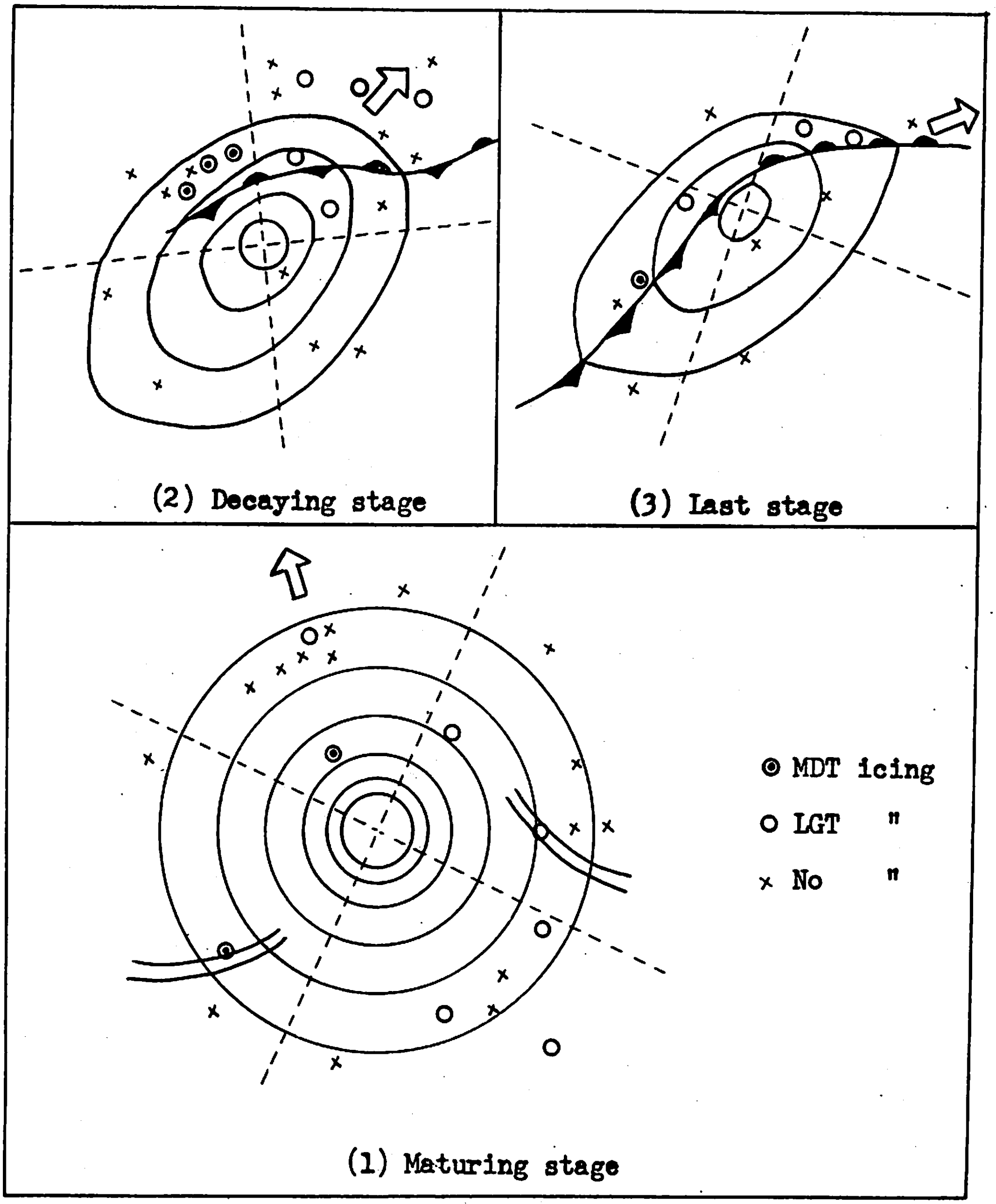


Figure 6. - Horizontal distribution of icing in tropical cyclones.


(2) Decaying stage

(3) Last stage

(1) Maturing stage

Figure 7. - Distribution of icing in models for three stages in the life of tropical cyclone.

Figure 5 shows the relation between icing and temperature. The frequency of icing is greater in tropical storms than in typhoons at altitudes lower than 25,000 ft. But all observations of icing at altitudes higher than 25,000 ft. or at temperatures lower than -15°C. were in typhoons.

In figure 5, two occurrences of icing are reported at temperatures warmer than 0°C. These may be due to instrumental errors, or to super-cooled water drops falling from levels above 15,000 ft. Further, we must take note that icing is sometimes observed at quite low temperatures, i.e., at high altitudes, although the frequency is not great.

3.2 Distribution of icing in typhoons and tropical storms

Figure 6 shows the horizontal distribution of icing observed by civil aircraft which flew at levels colder than -1°C.. in the typhoon areas. Icing is observed in all quadrants, though it is a little less frequent in the sector from east to southwest. Light icing is observed in the eastern semicircle, while most of the moderate icing is concentrated in the western quadrants. This suggests that the influx of cold air is a cause of the strong icing.

The horizontal distribution of icing for the final three stages in the life of a tropical cyclone is shown in figure 7. Models for the forming and developing stages are omitted because of the few data available.

Maturing Stage

Icing appears in all quadrants.

Decaying Stage

Almost all of the icing is found in the northern semicircle, especially in the precipitating area of the northeastern quadrant.

The most intense icing is observed in the cold air of the northwestern quadrant.

Last Stage

Icing is often observed in the vicinity of cold and warm fronts or on the north side of a tropical cyclone as it changes into an extratropical storm.

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REFERENCES

1. T. Ochi, "On the Turbulence and Cloud in Typhoons Observed by Aircraft," Aeronautic Meteorological Symposium, 14th Mar. 1958.

2. S. Otsuka, "Typhoon Observations by Meteorological Radar," Tenki, vol.5, No. 11, 1958.

3. R. H. Simpson, "Exploring the Eye of Typhoon Marge," Bulletin of the American Meteorological Society, vol. 33, No. 7, Sept. 1952, pp. 286-298.