Relative Humidity in Tropical Weather Systems

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ABSTRACT

Relative humidity and temperature information is presented for satellite-observed western Pacific and West Indies summertime cloud clusters, cloud cluster environments, clear regions, typhoons, and pre-typhoon cloud clusters. Information is stratified by weather system, region, and time of day. Data are presented as differences from the Jordan (1958) mean summertime West Indies sounding. Inner weather system deviations of humidity and temperature are also given.

1. Introduction

For a variety of reasons it is important that we know the typical moisture amounts and variations within tropical weather systems. The large water vapor variations between the trade wind and the equatorial trough regions is well known. The degree of humidity variation between and within individual region cloud clusters and clear regions is less well understood. This journal note describes these typical individual weather system humidity conditions.

Deficiency in observations prevents a representative description of *individual* tropical weather systems. In order to learn of the moisture characteristics of tropical systems one must, at this time, perform a composite study of many systems with the same characteristics. Jordan's (1958) 10-year and 3-station (Miami, San Juan, and Swan Island) mean monthly West Indies sounding has been one of the most quoted papers in tropical meteorology. Jordan's data have been widely used as data input to tropical numerical models and in other studies. But the conditions of the mean tropical sounding are usually not representative of the conditions within the typical tropical cloud cluster, storm, or clear area. The importance of humidity on cumulus convection requires that we learn as much as we can about its usual value and variations within selective weather systems.

2. Data sources

The data network regions in the western Pacific (6–20°N) and West Indies (12–28°N) have been consulted. These are the only satisfactory oceanic tropical regions that have a reasonably dense upper air sounding network. Relative humidity information is presented in composited form for five different types of tropical weather systems. These are:

1) The satellite observed 4° wide (or 2° radius) *cloud cluster* [as defined in the Madison, Wis., special GARP (1968) study report on tropical disturbances] in the Western Pacific and in the West Indies.
2) *Cloud cluster environment* or variable cloud region defined as the area from 2°–6° radius around the satellite-observed 2° radius cluster center.
3) *Clear regions* between the cloud clusters with no cloudiness as seen from satellite pictures.
4) *Typhoons*, the region 0°–8° around the typhoon center but outside the cyclone center or eye as determined by reconnaissance flights of the U. S. Air Force and Navy during the five years 1966 through 1970.
5) *Pre-typhoon* cloud clusters, or cloud clusters which develop into typhoons within 1–3 days in the western Pacific. Maximum winds within these clusters are <30 kt at the time of observation.

The positions of the centers of the cloud clusters and clear regions were determined from U. S. Weather Bureau ESSA satellite pictures for the two-year period November 1966–October 1968. All available rawinsonde data were composited with respect to the individual weather systems, as seen in Fig. 1. This compositing technique has been discussed previously in a paper by Williams and Gray (1973) and Ruprecht and Gray (1974). Humidity data have been carefully analyzed from rawinsondes taken at 00Z and 12Z. In accordance with the observed daily westward progression of the cloud clusters and the information of Wallace (1970) and Chang (1970), it was assumed that the weather systems move westward at a velocity of ~6°

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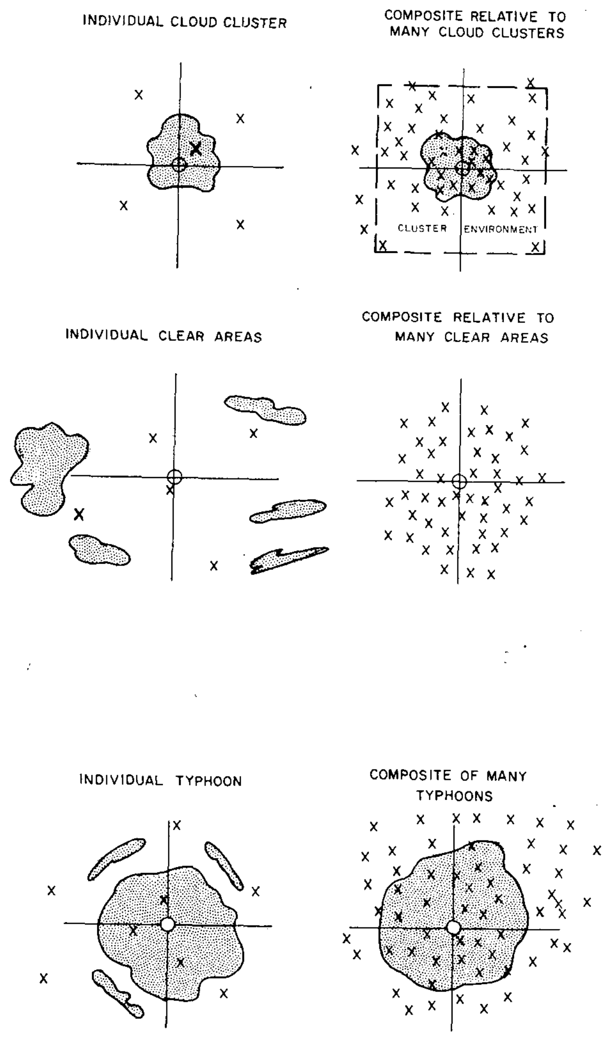

FIG. 1. Demonstration of method of compositing rawinsondes (denoted by x's) around cloud clusters and clear regions whose centers are indicated by the open circles.

longitude per day. Station locations relative to the satellite pictures were adjusted accordingly. The nearest in time, nighttime rawinsonde observations were taken 7 h (~22LT or 12Z) after the satellite picture time (~15 LT) in the western Pacific region and 5 h after (~20 LT or 00Z) the satellite picture time (~15 LT) in the West Indies area. Because of their prominence during the summer portion of the year, the cloud cluster and typhoon composited information is presented only for this season. Cloud cluster and clear area information is presented for the period June through September. The typhoon data are given from May through December, the pre-typhoon data for the whole year. The rawinsonde data are from standard U. S. sondes and were obtained from the National Weather Records Center, Asheville, N. C. Typhoon position reports were obtained from the Annual Reports of the U. S. Air Force-Navy Joint Typhoon Warning Center (1966–1970). Table 1 portrays the number of rawinsonde reports for each weather system.

TABLE 1. Number of rawinsonde reports in the data sample.

	00Z	12Z
1. Cloud clusters (0–2° radius)		
Western Pacific	74	79
West Indies	45	32
2. Cluster environment (2–6° radius from cluster center)		
Western Pacific	431	409
West Indies	301	278
3. Clear regions		
Western Pacific	72	70
West Indies	125	164
4. Typhoons of western Pacific		
Eye-wall to 2° radius	28	35
4 to 8° radius	330	320
5. Pre-typhoon clusters		
0–2° radius	8	26
Total	1414	1413

3. Results

The results of the mean humidity profiles for the above defined weather systems are shown in Figs. 2 and 3 and Table 2. Due to the errors of the daytime radiational heating of the hygristor, only nighttime mean moisture values are shown. Values are presented as differences from the summertime (June–September) mean West Indies sounding, as published by C. L. Jordan in 1958. Positive values mean that the relative humidity of the individual weather systems is greater than the Jordan mean. Note that:

1) The relative humidity is nearly the same in the boundary layer (up to 950 mb) for all weather

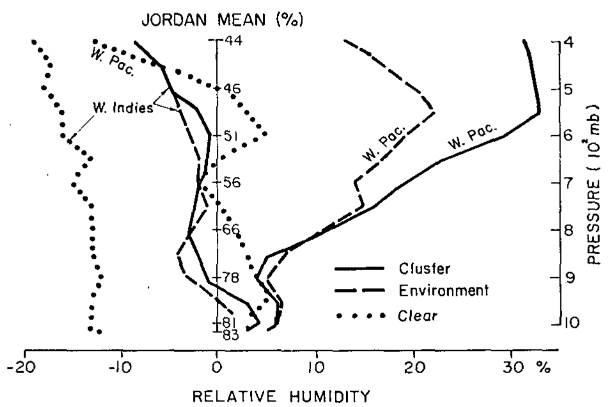

FIG. 2. Differences in relative humidity of tropical weather systems from the Jordan (1958) mean West Indies summer sounding.

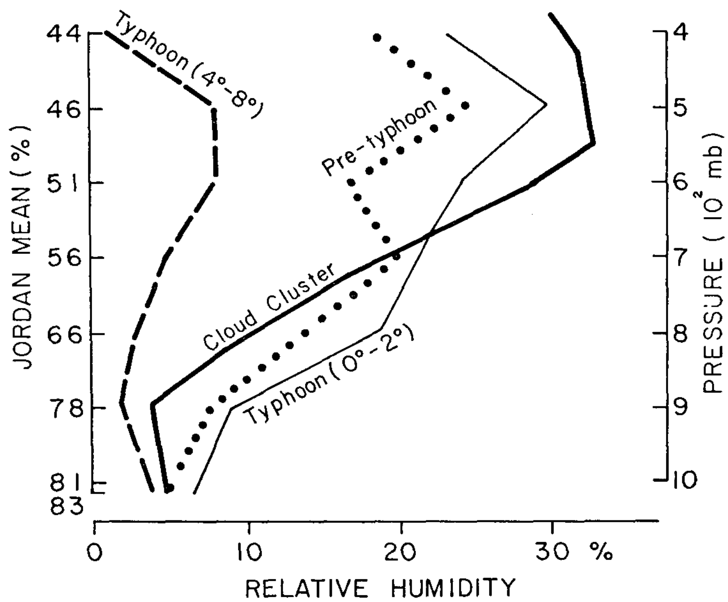

FIG. 3. Differences in relative humidity of western Pacific weather systems from the Jordan (1958) mean West Indies summer sounding.

systems in both regions, except for the clear areas in the West Indies.

2) At middle tropospheric levels, western Pacific systems have significantly higher relative humidities than the cluster systems of the West Indies. Up to 400 mb the western Pacific cloud cluster relative humidity is greater than 70%.
3) The humidity of the cloud cluster environment is nearly as high as the cloud cluster itself.
4) The inner typhoon (0°–2° radius) and the pre-typhoon cloud clusters show moisture characteristics very similar to those of the typical cloud cluster.

a. Inner weather system humidity variability

To show the inner weather system variability of relative humidities, Table 3 and Figs. 4 and 5 have been prepared. This table and these figures show the mean humidity deviations within each of the classified weather systems. By assuming a normal distribution of the relative humidity deviations, the mean deviation (~0.8 of the standard deviation) encompasses ~56% of the observations. Except in the boundary layer where the relative humidities are very high, the deviations closely approximate a normal distribution. The maximum and minimum values are an average of the three highest and

TABLE 2. Nighttime relative humidities as differences from the mean tropical summer atmosphere of Jordan (1958).

Jordan (1958)		Western Pacific (12Z)			West Indies (00Z)			Typhoon (12Z)		Pre-typhoon
Pressure (mb)	RH (%)	Cloud cluster	Cluster environment	Clear areas	Cloud cluster	Cluster environment	Clear areas	Eye-wall-2°	4–8°	0–2°
Sfc	83	5	5	2	3	3	−12	7	2	5
1000	81	6	6	2	4	3	−13	—		6
950	81	6	6	5	3	0	−13	8	3	7
900	78	4	5	4	−1	−3	−12	9	2	8
850	73	5	7	3	−2	−4	−13	15	2	9
800	66	11	11	2	−3	−3	−13	19	3	14
750	59	16	15	0	−2	−1	−13	24	5	16
700	56	19	14	−2	−2	−2	−15	21	5	20
650	53	23	17	0	−1	−2	−13	21	7	16
600	51	29	19	5	−1	−3	−16	24	8	17
550	48	33	22	3	−2	−4	−16	26	9	21
500	46	31	20	1	−5	−6	−18	30	8	25
450	44	30	17	−7	−6	−8	−17	24	5	24
400	44	28	13	−13	−9	−10	−19	23	1	18

TABLE 3. Inner weather system mean deviations of nighttime relative humidities.

	Western Pacific (12Z) Cloud cluster	Western Pacific (12Z) Cluster environment	Western Pacific (12Z) Clear areas	West Indies (00Z) Cloud cluster	West Indies (00Z) Cluster environment	West Indies (00Z) Clear areas	Typhoon (12Z) Eye-wall-2°	Typhoon (12Z) 4–8°
Sfc	5	5	6	9	7	10	5	7
1000	4	4	5	8	7	9	—	6
950	6	6	5	7	9	11	6	7
900	9	8	10	9	10	12	7	10
850	11	10	12	12	12	14	8	12
800	10	10	16	16	15	15	9	14
750	10	11	16	17	17	15	9	15
700	13	13	16	20	18	14	11	16
650	11	14	17	19	20	16	13	17
600	11	17	19	21	21	16	14	18
550	15	20	21	22	22	16	18	20
500	16	21	21	22	21	14	15	19
450	16	22	16	20	19	13	20	18
400	12	22	15	15	17	13	17	16

three lowest values. The unexpected result as seen in Table 3 is that the mean deviations for all weather systems are about the same—being approximately 15%. These large relative humidity variations are believed to be a result of:

1) The natural differences within satellite observed tropical cloud clusters some clusters are very moist, others are in a dying or quiescent stage where only layered clouds are present.
2) Strong downdraft drying conditions often present in and around areas of strong cumulus convection within the cluster. Zipser (1969) has previously shown examples of this type of cluster downdraft drying.

The smaller deviation of cloud cluster humidity is probably due to the high absolute moisture values. Large positive deviations cannot appear. A more detailed discussion of these inner weather system humidity variations is given in a paper by Ruprecht and Gray (1974).

b. Temperature characteristics

In addition to the relative humidities, the mean weather system temperature differences from the mean summertime tropical West Indies sounding of Jordan (1958) were also calculated. Temperatures values are listed in Table 4. Below 600 mb these differences are very small, nearly always less than 1°C. Large differences are observed only above 150 mb indicating the height differences of the tropopause. As a systematic feature, it can be seen that the Western Pacific weather systems are always slightly warmer and the West Indies cloud cluster and environment slightly cooler than the Jordan mean. Above 175–150 mb these temperature features reverse. As expected, the typhoon average temperature is much higher than the Jordan mean above 700 mb and very much cooler at 100 mb and 80 mb. The 100 mb and 80 mb cooling is believed to be due to tropopause height increase from Cb overshooting tops. The mean deviations of the temperatures within each separate weather system are small and are not shown

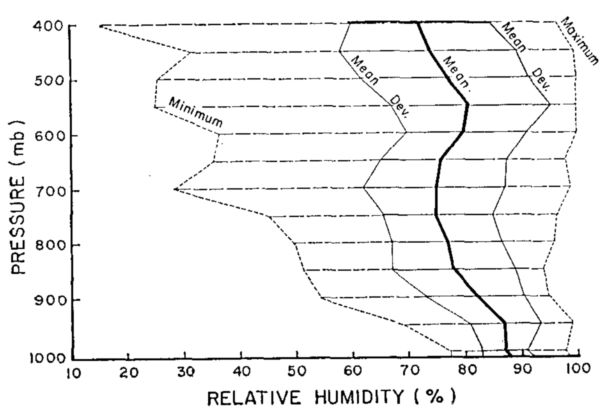

FIG. 4. Mean and extreme deviations of relative humidity within western Pacific cloud clusters.

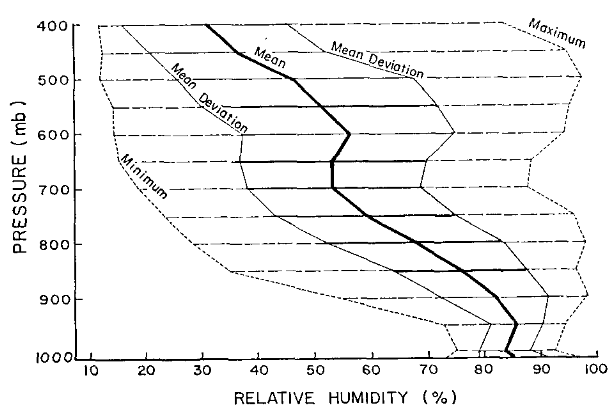

FIG. 5. Mean and extreme deviations of relative humidity within western Pacific clear regions.

Table 4. Nighttime temperatures differences from the mean summer tropical atmosphere as portrayed by Jordan (1958).

		West Pacific (12Z)			West Indies (00Z)			Typhoon	
	Jordan	Cloud cluster	Cluster environment	Clear areas	Cloud cluster	Cluster environment	Clear areas	Eye-wall-2°	4–8°
Sfc	26.5	−0.4	−0.3	0.0	−1.1	−1.8	2.6	−0.8	−0.6
1000	26.1	−0.2	−0.1	0.4	−1.1	−1.5	2.1	−0.3	−0.4
950	23.1	0.1	0.3	0.6	−0.9	−0.9	1.6	0.3	0.3
900	20.2	0.5	0.5	0.5	−0.7	−0.6	1.3	0.4	0.4
850	17.4	0.8	0.7	0.7	−0.8	−0.6	1.2	0.6	0.6
800	14.7	0.7	0.7	0.7	−0.8	−0.7	0.9	0.9	0.8
750	11.8	0.7	0.7	1.1	−0.7	−0.7	0.7	1.1	1.1
700	8.6	0.8	0.8	1.3	−0.7	−0.7	0.5	1.5	1.4
650	5.0	0.7	0.9	1.2	−0.7	−0.7	0.6	2.0	1.7
600	1.3	0.7	0.9	1.0	−0.8	−0.7	0.5	2.2	2.7
550	−2.7	1.0	1.0	1.1	−0.7	−0.6	0.6	2.7	1.9
500	−7.1	1.4	1.3	1.3	−0.5	−0.6	0.6	3.1	2.2
450	−12.0	1.6	1.5	1.5	−0.7	−0.9	0.4	3.5	2.3
400	−17.8	2.0	1.8	1.8	−0.8	−1.0	0.1	4.2	2.3
350	−24.9	2.3	2.1	2.0	−1.1	−1.1	0.2	4.7	2.8
300	−33.4	2.5	2.3	2.1	−0.5	−0.8	0.4	5.0	3.2
250	−43.4	2.1	2.3	2.0	−1.8	−0.8	0.6	5.0	3.2
200	−55.4	1.1	1.3	1.9	−0.4	−0.3	1.2	4.2	2.9
175	−61.2	−0.4	−0.2	0.8	−0.4	−0.2	1.2	2.6	1.7
150	−67.6	−1.5	−1.5	−0.2	1.0	1.1	1.9	0.7	0.7
125	−71.9	−4.1	−4.4	−3.2	2.0	2.0	1.7	−3.2	−2.6
100	−72.7	−4.8	−5.3	−6.1	1.8	2.3	0.8	−6.9	−5.9
80	−69.4	−3.5	−3.5	−3.5	1.3	1.7	0.7	−5.8	−4.8

here. They are mostly less than 0.7°C, and nearly constant with height (see Ruprecht and Gray, 1974).

c. *Diurnal range of values*

In the last few years it has become obvious that the U. S. Weather Bureau and the military AN/AMT-R sondes (which were used in this study) give unrealistic humidity differences between day and night. Much of this diurnal variation of relative humidity is likely due to night-day difference in rawinsonde package hygristor heating. Differences can also be partly accounted for by the fact that Jordan used 03Z and 15Z soundings (~22 LT and 10 LT) for his study, while this study uses 00Z and 12Z soundings. Special tests by Morrissey and Brousaides (1970) and Ostapoff *et al.* (1970) indicate that these diurnal differences are due to direct solar heating of the rawinsonde carbon strip. This leads to significant decrease of the measured daytime humidity values. Table 5 contains the night (12Z or ~22 LT) and day (00Z or ~10 LT) differences of relative humidities and temperatures for the western Pacific cloud cluster, clear areas, and typhoons. Except for the surface layer, the mean temperature differences are negligible.

By contrast, day vs night relative humidity differences were between 5 and 25%. Only small diurnal (3 to 10%) differences in humidity are present in the cloud clusters below 600 mb. This small diurnal difference is apparently due to a diminution of the direct solar radiation on the humidity sensors below the cluster middle level cloud decks. Above 600 mb in the cluster and in the clear areas, significant (10 to 25%) diurnal differences are found. The smaller diurnal humidity variations above 500 mb are believed to be the result of the difficulty of accurate humidity measurement when the values are as low as they typically are at upper levels. The typhoon data shows, in general, smaller night-day effects. In the lower layers the differences are in good agreement with those of the cloud cluster. Likewise, these smaller typhoon variations are probably due to the Cb-induced thick cirrus

Table 5. Night minus day differences of the relative humidities (%) and temperatures (°C) for western Pacific weather systems.

	Western Pacific					
	Cluster		Clear areas		Typhoon (0–2°)	
	ΔRH	Δ*T*	ΔRH	Δ*T*	ΔRH	Δ*T*
Sfc	4	−1.3	13	−3.1	4	0.4
1000	3	−0.7	14	−1.9	—	—
950	3	−0.1	17	−0.1	5	0.1
900	6	0.0	18	−0.1	5	0.0
850	4	0.3	19	−0.2	8	−0.3
800	5	0.0	18	−0.4	10	−0.2
750	6	0.1	14	−0.2	13	−0.4
700	8	0.1	14	−0.1	12	−0.6
650	8	−0.1	15	−0.4	7	−0.4
600	13	−0.1	18	−0.4	7	−0.2
550	19	−0.2	15	−0.5	8	−0.4
500	21	−0.2	16	−0.5	11	−0.6
450	25	−0.4	9	−0.5	8	−0.6
400	25	−0.4	7	−0.3	12	−0.3

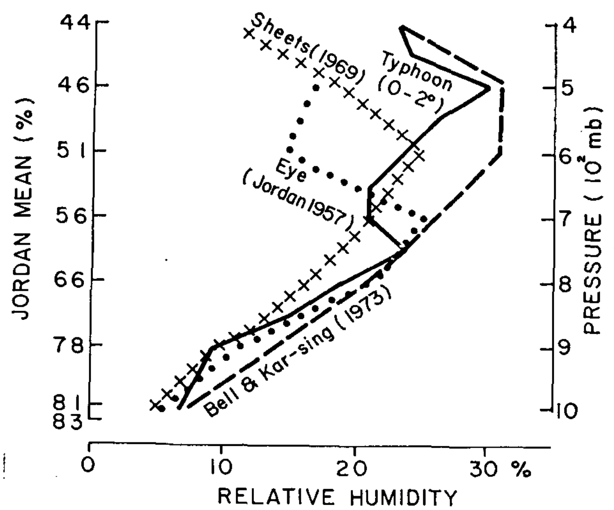

FIG. 6. Differences of relative humidity in typhoon/hurricane from the Jordan (1958) mean West Indies summer sounding.

layers, which shield the rawinsonde from the direct solar insolation.

d. Typhoon humidity and temperature

Stratification of the typhoon data allowed averaging by 2° radial bands extending from the eye wall to 8°. As expected, the inner 2° radius demonstrates a higher humidity than the 4–8° radius. Both radial belts show higher humidity than the Jordan (1958) mean tropical atmosphere (Fig. 3). A general increase in humidity deviations with height also occurs (Table 3) as with the cloud cluster. Such deviations are believed to be due to strong downdraft drying, which is continually occurring between areas of strong convection. Night and day humidity differences average about 8%. As expected, typhoon temperatures are considerably higher at middle and upper tropospheric levels than those shown by the Jordan mean tropical atmosphere. A comparison of this data with other typhoon/hurricane sounding data by other researchers is made in Fig. 6. This includes the data of:

1) Sheets (1969), who considered ~100 soundings within 100 n mi of hurricane centers in the West Indies.
2) Jordan (1957), who also studied hurricane eye soundings. He has presented information on 39 dropsondes in six hurricanes.
3) Bell and Kar-sing (1973), who presented information on more than 100 upper air observations for 00Z within 185 km radius of typhoon centers.

As might be expected, all soundings were more moist than the Jordan West Indies mean. These differences amount to about 10–20% in the lower troposphere and about 20 to 30% in the middle troposphere.

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