Analysis of satellite-observed tropical cloud clusters

II. Thermal, moisture and precipitation

By EBERHARD RUPRECHT[1] and WILLIAM M. GRAY, *Dept. of Atmospheric Science, Colorado State University, Fort Collins, Colorado, USA*

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ABSTRACT

This paper discusses the temperature, relative humidity, and rainfall characteristics of the summertime satellite-observed tropical weather systems in the Western Pacific and the West Indies. Comparisons are made with the Jordan (1958) mean West Indies sounding. Practically no temperature differences are found between the cloud cluster, the cloud cluster environment, and the clear regions. The primary differences between these weather systems is in the middle level moisture contents. It is shown that the typical variability of individual soundings parameters within each weather system type is larger than the mean parameter difference between systems. The rainfall within the tropical cloud cluster is shown to be highly concentrated. A large diurnal variation of cloud cluster rainfall and convergence is shown and discussed.

1. Introduction

For a variety of reasons it is important that we know of the typical temperature and moisture values and their 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 temperature and humidity variation between and within individual region cloud clusters and clear regions is less well understood. This paper (Part II), an analysis of the tropical cloud cluster, attempts to describe these typical tropical weather system temperature and humidity conditions.

The space and time resolution in upper air 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 has been widely used as data input to tropical numerical models and in other studies. But the conditions of the mean tropical sounding may not necessarily be representative of the conditions within the typical tropical cloud area or clear region. The importance of temperature and humidity on cumulus convection requires that we learn as much as we can about their usual values and typical variations within selective tropical weather systems.

[1] On leave from the Institute of Meteorology University of Bonn, FRG; present affiliation University of Köln.

2. Western Pacific and West Indies temperature, moisture and precipitation fields

2.1. *Temperature and pressure-height*

Virtual temperature differences between the average cloud cluster and its environment are negligible. At no level are they as much as 1°C. Temperature differences between the clear regions and the cloud clusters are also very small. No regular or significant patterns were found.

Tables 1 and 2 give information on Western Pacific and West Indies summertime temperature, virtual temperature and pressure-height and their differences between the cloud cluster, cloud cluster environment and clear regions. In all regions the temperatures and pressure-heights show no significant differences. These results do not change whether one uses the virtual or actual temperature.

Table 1. *Actual* (t) *and virtual* (t_v) *temperature and pressure-height* (z) *for Western Pacific cloud clusters. Differences of virtual temperatures* (Δt_v) *and pressure-heights* (Δz) *of the cloud cluster from its immediate environment and from the clear regions are also shown. All data are taken at 00 Z(~ 10 LT)*

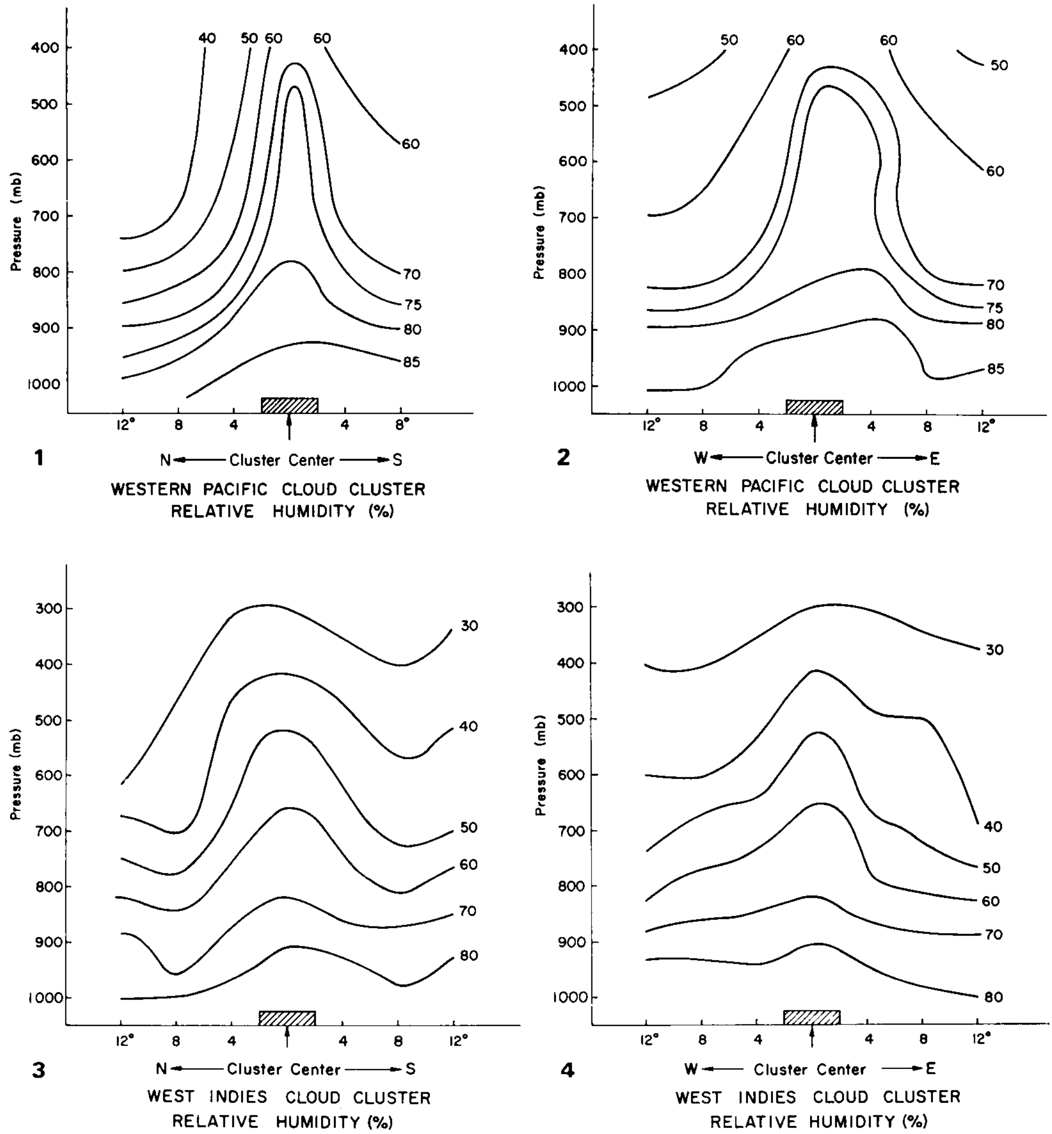
	Temperatures (°C)				Pressure-heights (m)		
Pressure (mb)	Cluster t	Cluster t_v	Envir. minus cluster (Δt_v)	Clear minus cluster (Δt_v)	Cluster (z)	Envir. minus cluster (Δz)	Clear minus cluster (Δz)
sfc	27.0	30.4	0.6	1.7			
1 000	26.4	29.6	0.3	1.2	90	−1	8
950	23.1	25.8	0.0	−0.2	540	0	11
900	20.3	22.6	0.0	−0.4	1 010	−1	9
800	15.2	17.0	−0.1	−0.3	2 070	−1	8
700	9.3	10.5	0.0	0.3	3 150	−1	9
600	2.3	3.1	0.0	0.5	4 410	0	11
500	− 5.3	− 4.8	0.1	0.0	5 860	1	13
400	−15.2	−15.0	−0.1	0.5	7 590	0	11
300	−29.9	−29.9	−0.2	−1.2	9 700	−1	4
250	−40.1	−40.1	−0.3	−1.0	10 970	−2	−1
200	−52.9	−52.9	−0.2	−0.3	12 450	−4	−6
150	−68.1	−68.1	0.2	0.8	14 240	−3	−3
100	−79.2	−79.2	0.2	−0.2	16 590	−1	5

Table 2. *Actual* (t) *and virtual* (t_v) *temperature and pressure-height* (z) *for the West Indies cloud clusters. Differences of virtual temperatures* (Δt_v) *and pressure-heights* (Δz) *of the cloud cluster from its immediate environment and from the clear regions are also shown. All data are taken at 12 Z (~ 07 LT)*

	Temperatures (°C)				Pressure-heights (m)		
Pressure (mb)	Cluster t	Cluster t_v	Envir. minus cluster (Δt_v)	Clear minus cluster (Δt_v)	Cluster (z)	Envir. minus cluster (Δz)	Clear minus cluster (Δz)
sfc	24.6	27.6	0.2				
1 000	24.4	27.3	0.2	0.5	140	1	− 2
950	21.7	24.3	0.2	−1.0	580	4	0
900	18.9	21.0	0.1	−1.2	1 060	1	− 5
800	13.5	14.9	−0.1	−1.4	2 060	2	− 9
700	7.3	8.3	−0.1	0.5	3 170	2	−11
600	0.2	0.8	0.0	1.2	4 430	3	− 6
500	− 8.0	− 7.7	0.0	0.6	5 870	3	− 1
400	−19.0	−18.9	0.0	0.2	7 570	3	2
300	−34.3	−34.3	0.1	−0.3	9 650	5	3
250	−44.3	−44.3	0.2	0.0	10 890	5	2
200	−55.8	−55.8	0.4	0.4	12 350	8	4
150	−66.3	−66.3	0.2	0.1	14 140	7	3
100	−71.6	−71.6	0.2	−3.6	16 550	7	−13

2.2. *Humidity*

Of all parameters, relative humidity best defines the cluster. Figs. 1–4 show how the cluster center relative humidity at middle levels is much higher than in the environment. Below 900 mb the fluctuations are very small. These large middle level humidity variations have also been reported by Reed & Recker (1971) and Riehl & Pearce (1968). Daytime humidity values which are shown have been corrected for solar thermistor heating. The method for this correction is discussed by Ruprecht (1975).

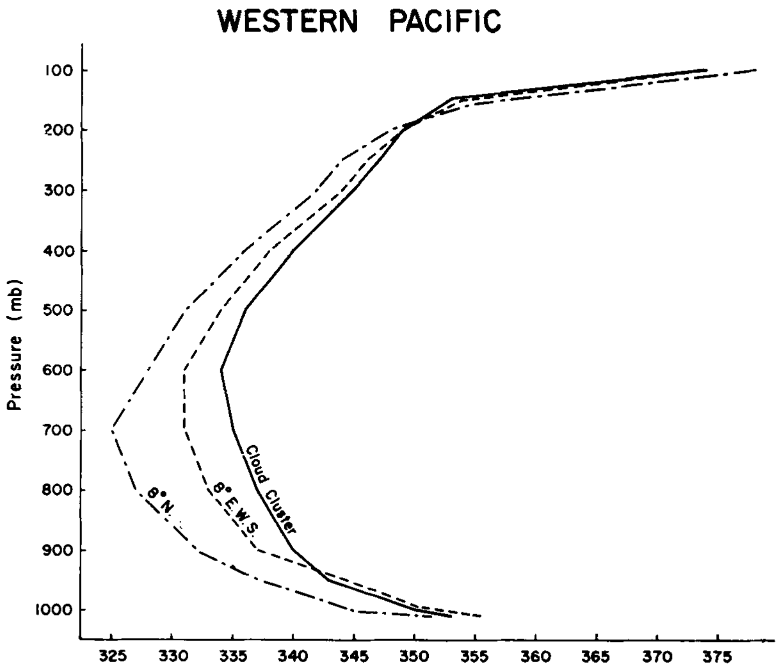


Figs. 1–4. North–south and west–east vertical cross-sections of relative humidity with respect to Western Pacific (above) and West Indies (below) cloud clusters.

2.3. *Vertical distribution of θ_e*

Figs. 5 and 6 portray equivalent potential temperatures. Their variations, because of the lack of temperature variation, are due primarily to water vapor content differences. In both regions the θ_e profiles 8° E, W and S of the cloud cluster center agreed at all levels. Thus, only one average profile is given. The same is true for the θ_e profiles of the Western Pacific clear region and for the area 8° N of the cluster center. Although Western Pacific clusters have higher humidity than West Indies ones, differences in the vertical θ_e gradient between each region are quite small.

It is obvious that the increased humidity of the cluster leads to a decrease in the vertical gradient of θ_e. This was expected. This common fill-in of the middle evel θ_e with increased



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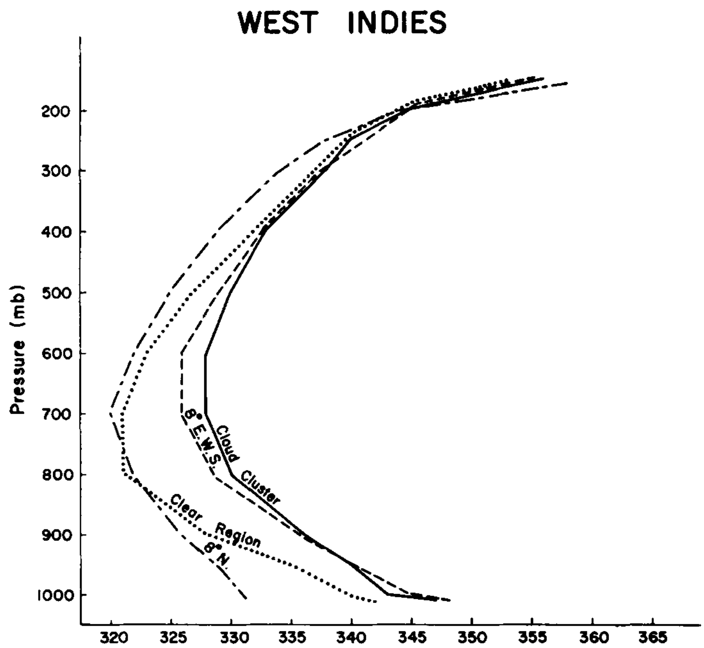

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Figs. 5–6. Vertical profiles of θ_e for various weather systems and places relative to the weather systems of the Western Pacific and West Indies. E.W.S.N. stands for east, west, south and north of the cloud cluster center.

cumulus convection is well known over land areas. It appears to be a common occurrence with all tropical weather systems.

2.4. *Character of rainfall underneath Western Pacific summer clusters*

In order to study the characteristic precipitation associated with the cloud cluster, summertime Western Pacific hourly rainfall intensities underneath clusters were analyzed. The rainfall data was from the 10 Western Pacific rawinsonde stations south of 20° N. The period of study was June through September for 1967 and 1968. Most of these stations are atolls or small islands. The island influence on the rainfall, especially when cluster systems are overhead, is believed to be small. As expected, the character of the rainfall underneath the clusters was highly variable. The daily rainfall for the cloud cluster days shows that:

1) ~7% of the station observations had no rainfall at all during the whole period which the cluster was over them,
2) 20% of the stations showed rainfall of less than 2.5 mm during the period which the cluster was over them,
3) the most frequent station cluster rainfall amounts were 10 to 40 mm, and
4) in a number of cases individual clusters give station rainfall as high as 100 mm.

These large differences emphasize the local concentration of rainfall within the clusters and the differences between clusters. Some satellite-observed clusters have very little rainfall within them.[1]

The typical size and speed of the cloud cluster (~6–8 m/sec) limit its duration above an observing station to about 16–20 hours. In order to estimate the average rainfall output of a cluster we analyzed the hourly rainfall values in five hour segments centered on the 00 Z (~10 LT) and 12 Z (~22 LT) rawinsonde times. Hourly rainfall amounts were gathered from 2 hours before to 3 hours after rawinsonde release times within the cluster.

[1] The second author has flown over cloud clusters in the Truk and Ponape area in June 1970 and observed a number of them with extensive middle cloud layers but no active Cb convection. The satellite pictures used in this study would show the middle cloudiness but not the lack of Cb activity.

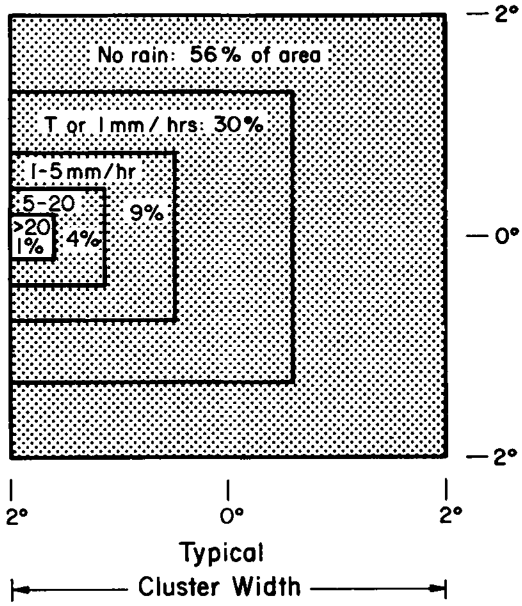

Fig. 7. Area distribution of rainfall intensity within the typical Western Pacific cloud cluster.

Space distribution. With the hourly precipitation amounts and by assuming that the cluster rain areas move uniformly over the stations at 6° longitude per day (i.e. 15 knots) one is able to derive area distributions of the rainfall intensity. Fig. 7 shows the percentage of the horizontal cluster area which is occupied by various rainfall intensities. Fig. 7 does not mean all the rainfall is concentrated in this particular small quadrant at the leading edge of the cluster, but that this is typical of the cluster rainfall. At times the rain may be more randomly distributed. 56% of the cluster area reports no precipitation. 30% reports only a trace or light rain (<1 mm/hr). 9% report rainfall between 1–5 mm/hr. Only 5% of the cluster area has rainfall intensities greater than 5 mm/hr. About 1% of the cluster are has rain with intensity greater than 20 mm/hr. This agrees with radar observations in other tropical regions as discussed by Lopez (1973), Martin & Suomi (1972), and Ruprecht et al. (1974).

This space distribution of precipitation leads to an average 4° diameter cluster rainfall of ~2.5 cm/day. As previously discussed by Williams & Gray (1973) about 80% of this precipitation can be accounted for by horizontal advection into the cluster from its sides and

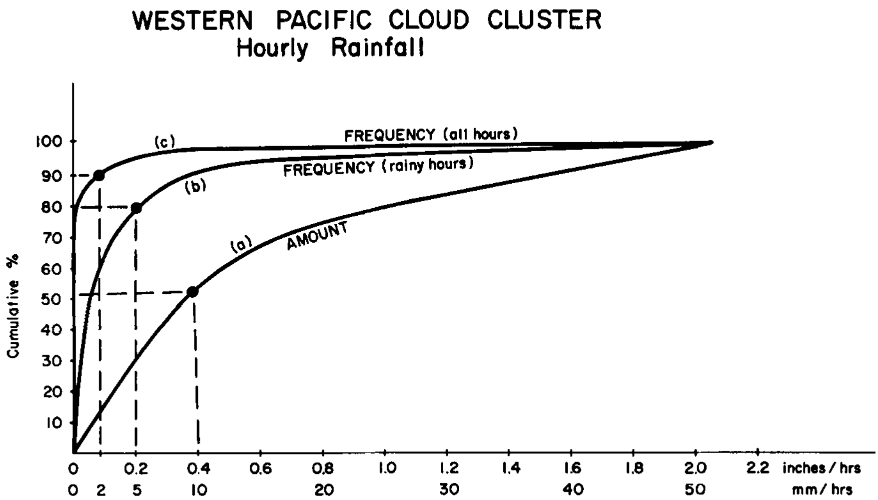

Fig. 8. Western Pacific cloud cluster cumulative rainfall vs. hourly rainfall intensity. Curve *a* is for total rainfall amount. Curves *b* and *c* portray the cumulative frequency of rainfall vs. rainfall intensity for rainy hours (curve *b*) and for all hours (curve *c*).

the remaining 20% by local evaporation from the sea.

Rain frequency vs. intensity. Fig. 8 portrays three classes of cloud cluster cumulative rainfall percentage vs. hourly rainfall intensity for the Western Pacific clusters. Curve *a* shows the total amount of cluster precipitation vs. rainfall intensity. The dot on this curve means that about 50 percent of the total cluster precipitation is accounted for by hourly rainfall intensities greater than 10 mm/hr (0.4 inches/hr). The other half of the precipitation comes from hourly rainfall intensities of less than 10 mm per hour. Curve *b* shows the cumulative cluster frequency of rainfall vs. rainfall intensity. The dot on curve *b* means that 80% of the time that rainfall was measured in the cluster, the intensity of the hourly rainfall was less than 5 mm/hr. On 20% of the times that rainfall was reported, the hourly intensity was greater than 5 mm/hr. Curve *c* shows the cumulative precipitation frequency for both rain and non-rain time periods underneath the cluster. The dot on this curve means that only 10% of the time a station is under a cluster its hourly precipitation intensity is greater than 2 mm/hr. During 90% of the time surface reports under a cluster give no rain, or if there was rain the intensity was less than 2 mm/hr. These cluster precipitation results agree well with the typical rainfall statistics for the tropics that have previously been discussed by Atkinson (1971) and Riehl (1954). About half of the cluster rainfall occurs in heavy showers during only 10% of the time rain is reported. Approximately half of the cluster rainfall occurs in heavy rain episodes during only 2% of the under cluster observational times.

3. Diurnal variation of Western Pacific rainfall and convergence

The hourly rainfall around 00 Z and 12 Z was also analyzed for diurnal differences. The period treated was June through September 1967 and 1968. It was quite surprising to find that the mean hourly rainfall during the five hour period around 00 Z (07–12 LT) is more than twice as much as the rainfall around the five hour period of 12 Z (19–24 LT). We also examined the five hour rainfall around 00 Z and 12 Z for the cloud cluster environment and then for all available Western Pacific stations whether associated with cluster or not. Table 3 gives the percentage of rainfall which fell in each five hour period straddling the 00 Z and 12 Z time periods.

A striking (70 vs. 30%) diurnal rainfall variation is observed for the cloud clusters. Morning (07–12 LT) rainfall amounts are two and a half times greater than early evening amounts (19–

Table 3. *Weather system comparison of percent of rainfall which occurs in 5 hour period straddling 00 Z vs. the 5 hour period straddling 12 Z. All data are for the Western Pacific during months of June through September*

	Cloud cluster	Cloud cluster environment	All stations
5 hours straddling 00 Z (~10 LT)	~70 %	~60 %	~57 %
5 hours straddling 12 Z (~22 LT)	~30 %	~40 %	~43 %

24 LT). Other rainfall not directly associated with the cloud clusters also shows these higher morning amounts but the percentage differences are less. These results are primarily due to the presence of more intense morning showers. Table 4 portrays diurnal rain intensity differences between morning and evening in percent. The large diurnal difference in evening vs. morning heavy shower activity is clearly evident.

These higher Western Pacific morning cluster rainfall values are well substantiated by the cluster divergence profiles shown in Fig. 9. The magnitude of 00 Z (10 LT) surface to 400 mb convergence and upper tropospheric divergence

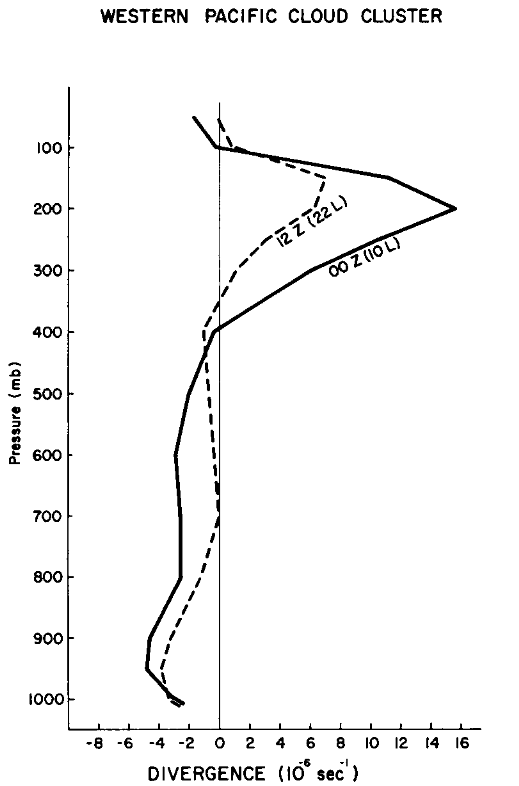

Fig. 9. Diurnal variation of Western Pacific cloud cluster divergence.

is about twice as large as it is at 12 Z. These diurnal differences should not be associated with diurnal atoll and island daytime heating It would be absurd to associate such large 200 mb 00 Z vs. 12 Z divergence differences with local atoll-island influences. This diurnal divergence is largely locally balanced by opposite divergence in the surrounding clear regions.

If cloud cluster middle tropospheric convergence is primarily due to mass input into deep cumulus up- and downdrafts, then the much weaker 12 Z middle tropospheric convergence can be interpreted as due to fewer deep cumulus at this time period. These large cluster diurnal variations of both rainfall and divergence thus appear to be mutually consistent and lend confidence to the separate results.

We believe these diurnal convergence and precipitation differences are directly related to the diurnal variation in the net tropospheric

Table 4. *Comparison of Western Pacific frequency of various rainfall intensities in the morning vs. early evening*

Rain intensities	5 hrs straddling 00 Z (~07–12 LT)	5 hrs straddling 12 Z (~19–24 LT)
Cluster precipitation		
Precipitation		
> 1.0 cm/hr	~75 %	~25 %
0.25–1.0 cm/hr	~60 %	~40 %
T to 0.1 cm/hr	~55 %	~45 %
All stations—clusters and non-clusters		
Precipitation		
T and ≤ 0.1 cm/hr	50 %	50 %
0.1–0.5 cm/hr	55 %	45 %
0.5–1.0 cm/hr	57 %	43 %
1.0–2.0 cm/hr	60 %	40 %
> 2.0 cm/hr	70 %	30 %

Table 5. *Nighttime relative humidities (June–September) as differences from the mean tropical summer atmosphere of Jordan (1958)*

mb	Jordan RH (%)	Western Pacific (12 Z) Cloud cluster	Western Pacific (12 Z) Cluster environ.	Western Pacific (12 Z) Clear areas	West Indies (00 Z) Cloud cluster	West Indies (00 Z) Cluster environ.	West Indies (00 Z) Clear areas
Sfc	83	5	5	2	3	3	−12
1 000	81	6	6	2	4	3	−13
950	81	6	6	5	3	0	−13
900	78	4	5	4	−1	−3	−12
850	73	5	7	3	−2	−4	−13
800	66	11	11	2	−3	−3	−13
750	59	16	15	0	−2	−1	−13
700	56	19	14	−2	−2	−2	−15
650	53	23	17	0	−1	−2	−13
600	51	29	19	5	−1	−3	−16
550	48	33	22	3	−2	−4	−16
500	46	31	20	1	−5	−6	−18
450	44	30	17	−7	−6	−8	−17
400	44	28	13	−13	−9	−10	−19

radiational cooling and the resulting differences in the clear region sinking between the cloud clusters. At night there is no solar heating to counteract the continuously long-wave cooling in the lower troposphere of about 1.8°C/day (Cox, 1971). During the daylight hours, solar warming of ~0.8°C/day reduces the net lower half of the troposphere radiational cooling to about ~1.0 °C/day. The atmosphere does not directly cool at these radiation prescribed rates but rather establishes an adiabatic sinking motion between the cloud clusters. This sinking motion is thus 1½ to 2 times as large at night as during the daytime. The mass compensation for this extra between-the-clusters sinking results in extra upward motion in the clusters. There is often a 3–6 hour lag in this response. Thus, the maximum cluster precipitation and convergence is often displaced from its maximum and minimum values in the early morning and early afternoon to the late morning and early evening. A paper by Jacobson & Gray (1976) discusses these diurnal variations in greater detail.

4. Variability of individual soundings

4.1. *Humidity characteristics*

The mean summertime humidity profiles for the three classes of weather systems are shown in Table 5. Due to the errors of the daytime radiational heating of the hygristor only nighttime mean moisture values are given—see Ruprecht (1975) for more discussion. Values are presented as differences from the summertime (June–September) mean West Indies soundings as published by C. L. Jordan (1958). Positive values mean the relative humidities of the individual weather systems are greater than the Jordan mean.

The average nighttime relative humidity for the Western Pacific cloud cluster is very high. At 400 mb it averages no less than 72%. Above 600 mb these mean cluster humidities are 30% larger than those quoted by Jordan (1958) for the mean summertime West Indies. For the Western Pacific cloud cluster the Jordan values are too low. For the West Indies, however, his values agree well with out cluster results but are too high for the clear regions. The cloud cluster boundary layer shows a nearly constant relative humidity of 87% which indicates large boundary layer mixing.

4.2. *Temperature characteristics*

In addition to the relative humidities the average weather system temperature differences from the mean summertime tropical West Indies sounding of Jordan (1958) were also calculated. Temperature values are listed in Table 6. Below 600 mb these differences are very small, nearly always less than 1°C. Large differences

Table 6. *Nighttime temperature differences (June–September) from the mean summer tropical atmosphere as portrayed by Jordan (1958) in °C*

mb	Jordan T (°C)	West Pacific (12 Z) Cloud cluster	Cluster environ.	Clear areas	West Indies (00 Z) Cloud cluster	Cluster environ.	Clear areas
Sfc	26.5	−0.4	−0.3	0.0	−1.1	−1.8	2.6
1 000	26.1	−0.2	−0.1	0.4	−1.1	−1.5	2.1
950	23.1	0.1	0.3	0.6	−0.9	−0.9	1.6
900	20.2	0.5	0.5	0.5	−0.7	−0.6	1.3
850	17.4	0.8	0.7	0.7	−0.8	0.6	1.2
800	14.7	0.7	0.7	0.7	−0.8	0.7	0.9
750	11.8	0.7	0.7	1.1	−0.7	−0.7	0.7
700	8.6	0.8	0.8	1.3	−0.7	−0.7	0.5
650	5.0	0.7	0.9	1.2	−0.7	−0.7	0.6
600	1.3	0.7	0.9	1.0	−0.8	−0.7	0.5
550	−2.7	1.0	1.0	1.1	−0.7	−0.6	0.6
500	−7.1	1.4	1.3	1.3	−0.5	−0.6	0.6
450	−12.0	1.6	1.5	1.5	−0.7	−0.9	0.4
400	−17.8	2.0	1.8	1.8	−0.8	−1.0	0.1
350	−24.9	2.3	2.1	2.0	−1.1	−1.1	0.2
300	−33.4	2.5	2.3	2.1	−0.5	−0.8	0.4
250	−43.4	2.1	2.3	2.0	−1.8	−0.8	0.6
200	−55.4	1.1	1.3	1.9	−0.4	−0.3	1.2
175	−61.2	−0.4	−0.2	0.8	−0.4	−0.2	1.2
150	−67.6	−1.5	−1.5	−0.2	1.0	1.1	1.9
125	−71.9	−4.1	−4.4	−3.2	2.0	2.0	1.7
100	−72.7	−4.8	−5.3	−6.1	1.8	2.3	0.8
80	−69.4	−3.5	−3.5	−3.5	1.3	1.7	0.7

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.

Some of these differences from the Jordan mean sounding can be accounted for by Jordan's use of 03 Z and 15 Z soundings (~22 LT and 10 LT) while we employed 00 Z (19 LT) and 12 Z (07 LT) data.

4.3. *Inner weather system parameter variability*

It is generally accepted that meteorological parameters can undergo large variations in the tropics. These variations are, however, usually assumed to apply to differences between the ITCZ and the trade wind zones or between tropical disturbances and their surrounding environments. The basic question now arises: How large are the parameter variations within each weather system compared with the mean difference of parameters between systems?

Relative humidity variability. Except in the boundary layer where the relative humidities are very high, the individual sounding humidity deviations from the mean closely approximated a normal distribution. These deviations averaged 5–10% in the lower troposphere and 15–25% in the middle troposphere (see the paper by Gray et al. (1975) for more discussion).

These large relative humidity variations are believed to result from:

1) Strong downdraft drying which can occur in and around areas of strong cumulus convection. Zipser (1969) has previously shown examples of this type of cluster downdraft drying.

2) The natural differences within the tropical cloud clusters. Some clusters are very moist, others are in a dying or quiescent stage where only layered clouds are present.

Parameter differences between weather systems vs. interior parameter variability. Fig. 10 compares mean parameter differences between the separate weather systems with interior weather system parameter deviations. Summertime (June–September) temperature, relative hu-

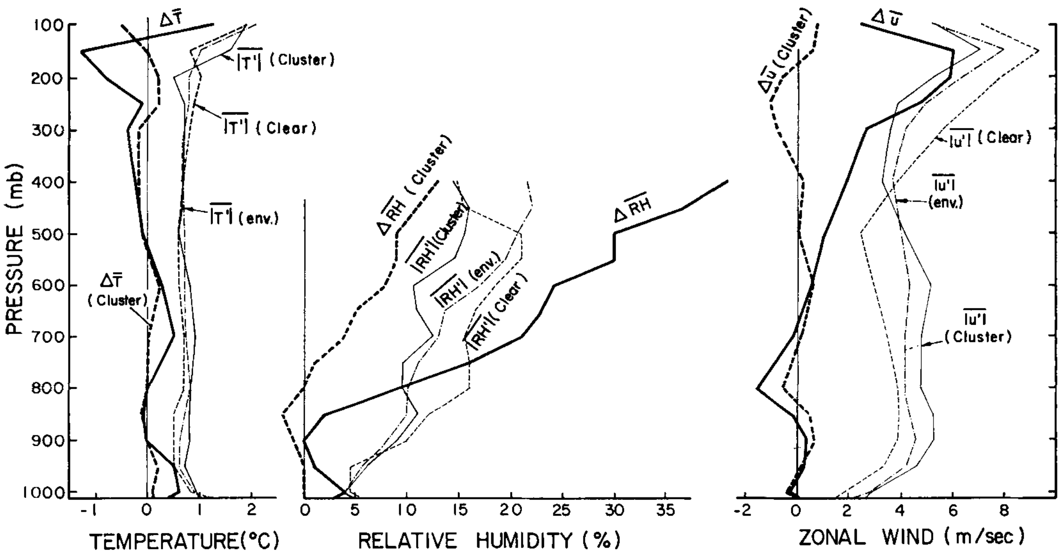

Fig. 10. Differences between the Western Pacific weather system averages and the mean deviation within each weather system type. Temperature (T), relative humidity (RH) and zonal wind (u) are treated. Δ^- denotes mean parameter differences between the cloud cluster and the clear region. Δ^- *(cluster)* denotes the mean parameter difference between the cloud cluster (0–2° radius) and the cloud cluster environment. ′, primes refer to mean deviation of individual parameters from the inner-weather system average, *(env.)* stands for the cloud cluster environment.

midity, and zonal wind comparisons are shown. The heavy solid lines compare the cloud cluster and the clear areas, the heavy dashed lines compare the cloud cluster (0–2° radius) and its surrounding 2 to 6° radius environment. The thin solid, thin dashed lines, and the dashed-dotted lines show the mean deviations within the cloud cluster, clear area and cluster environment regions, respectively.

It was unexpected that the temperature variations within each weather system (~ ±1°C) would be 3 to 10 times larger than the mean temperature differences between systems (~ ±0.2°C) and be constant with height—see the left side of Fig. 10.

Except in the upper troposphere the inner weather system variations of zonal wind (~ ±5 m/sec) are also much larger than the mean zonal wind differences between systems (~ ±1–2 m/sec)—see the right side of this figure.

The inner system relative humidity deviations are also larger than the mean differences between systems except in the case of the middle level cluster minus clear region values. The middle part of this figure shows that the inner weather system relative humidity variations are typically 2–5 times larger than the mean relative humidity differences between the cluster and the cluster environment. At individual places and times the tropical troposphere is in a highly variable state. Individual site observations often may not be representative of the mean or synoptic state of the atmosphere. Individual rawinsondes cannot well distinguish between a tropical cloud cluster, its environment, or a tropical clear region.

Processes responsible for parameter deviations. These large parameter deviations are believed to be primarily a result of the large vertical mass recycling which is occurring within the tropical troposphere. The frequent development of downdrafts associated with cumulus convection is felt to be the primary genesis mechanism of the vertical recycling. To date, direct observational evidence of the downdraft has been rare. The data from this study gives clear evidence of the likely existence of very substantial downdrafts.

5. Discussion

These two papers will, hopefully, aid in setting an observational framework for future cloud cluster studies. We hope that it has shown that routine tropical data, when augmented by the satellite, can be profitably used for significant knowledge gains.

Our observations lead us to conclude that:

1. There are significant parameter differences between the Western Pacific and West Indies clusters.

2. Soundings within individual weather system types exhibit greater variability (except for middle level relative humidity) than the mean parameter differences between systems.

3. There are large diurnal variations in Western Pacific cloud cluster convergence and rainfall. This is primarily a result of local cluster-clear region compensation. The magnitude of this diurnal variation was quite unexpected. It is likely to be present in other oceanic regions.

4. The importance of the cumulus-scale influences on the cluster vorticity budget is fundamental. This supports previous speculations on the probable importance of cumulus scale influences on the broader scale motions and the necessity to correctly parameterize these influences in the cumulus convective atmosphere so that they can be properly dealt with from synoptic-scale observations.

5. As expected, the cluster rainfall is very highly concentrated in only a very small percent of the cluster area.

6. Cloud clusters cannot always be associated with traveling easterly waves. Some clusters are well identified with systematic variations of the meridional wind components as would occur with traveling waves in the trades. Many other cloud clusters are not associated with systematic changes in the meridional winds. (There are a number of semantical questions which have to be sorted out before this can be generally resolved. How should we define these waves?)

Compositing technique. An auxillary purpose of these two papers has been to show that meaningful physical insights into the structure and dynamics of meso-scale tropical systems can be gained even though the data network used to obtain this information is of a course scale.

The compositing technique of this paper is different than that employed by the U. of Washington group under Professor R. Reed (Reed & Recker, 1971) or by the method used by the UCLA group under Professor M. Yanai (Yanai et al., 1973). The Reed group has composited their data with respect to meridional wind changes as indicated by the presence of easterly waves. They average these waves by combining trough positions, etc. Their averaging is independent of cloudiness. As we have found, the typical cloud cluster is not necessarily associated with systematic changes in the meridional wind. The Yanai group has averaged the soundings over a selective Marshall Island area of $\sim 10°$ width. Their results are simultaneously averaged over both cloud and clear regions. Cloud and clear regions are not isolated and treated separately as in this study. Thus, differences must be expected in comparing these results with those obtained by the Reed and Yanai groups.

Organization of Cb convection. The tropospheric vertical wind shear patterns in the two regions are significantly different. Lack of strong cloud cluster vertical wind shear in the Western Pacific indicates (and the observations generally support this) that Cb convection is typically not well organized in squall lines. Here the vertical shear of the zonal wind can be either positive or negative. The zonal vertical shear of the West Indies, on the other hand, is nearly always positive and is typically larger. This implies that Cb convection in the West Indies should more often be organized in squall lines. Observations indicate that this is the case.

Study's major shortcomings. This study could obviously not deal with the individual weather system. This is believed to be its major shortcoming. There are likely to be significant differences between individual cloud cluster systems. Some of our clusters likely did not exhibit active cumulus convection at the time of observation. Some may have been made up of only middle-level cloudiness. The authors hope to next perform some delineation of clusters by rainfall intensity. The lacking information on the variability of Cb activity within different cluster systems should be forthcoming from the GATE project and from new satellite systems. The authors next hope to stratify clusters by intensity of Cb activity.

Our budgets apply to mean 4°-scale cluster conditions. Most active clusters will exhibit vertical circulations more intense than the ones reported here.

Future research. There is much more useful data compositing which can be accomplished in the Western Pacific and West Indies data networks. This study has accomplished only a very small bit of what can be done. In particular, the new satellite techniques now permit the direct sampling of the individual Cb elements. Clusters can now be stratified by their degree of deep cumulus activity. The authors believe that a significant expansion of our knowledge on tropical weather systems can be gained from the vast amounts of already existing observations. There are still many important tropical meteorology questions which only the long term existing data networks can answer. We will hopefully pool our knowledge from both data sources and obtain a reasonable research balance between old and new data sources.

For more detailed discussion one can also refer to the Colorado State University Department of Atmospheric Science report No. 219 by Ruprecht & Gray (1974).

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АНАЛИЗ СКОПЛЕНИЙ ТРОПИЧЕСКИХ ОБЛАКОВ, НАБЛЮДАЕМЫХ СО СПУТНИКОВ. ЧАСТЬ II. ТЕМПЕРАТУРНЫЕ ХАРАКТЕРИСТИКИ, ВЛАЖНОСТЬ, ОСАДКИ

Настоящая статья рассматривает температурные характеристики, относительную влажность и осадки, связанные с тропическими погодными системами, наблюдаемыми со спутников в летнее время в западной части Тихого океана и в Вест-Индии. Проводится сравнение со средними данными Джордана (1958) по зондированию в Вест-Индии. Не было обнаружено практически никакой разницы в температуре между скоплениями облаков, окружающими их областями и безоблачными районами. Главное различие между этими погодными системами проявляется в значении влажности на среднем уровне. Показано, что типичная изменчивость зондируемых параметров внутри каждого типа больше, чем средняя разность параметров между системами. Показано, что выделение осадков в скоплении тропических облаков сильно концентрировано. Показано и обсуждено существование большой суточной изменчивости осадков и конвергенции в облачных скоплениях.