SOME OBJECTIVE QUANTITATIVE CRITERIA FOR SUMMER SHOWERS AT MIAMI, FLORIDA

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Original manuscript received June 23, 1952; final revision received October 28, 1953

ABSTRACT

A brief review of previous efforts in Florida and elsewhere to cope with the problem of summer air mass showers is followed by a new attempt to apply to the Miami problem empirical methods of determining the combined effect of several often contradictory shower parameters. Employing the hypothesis that criteria differ seasonally, geographically, and diurnally, this study classifies Miami summer soundings into four rainfall producing types for each of the two diurnal periods and presents averaged dry bulb, wet bulb, and dew point temperatures by 50-mb. intervals to 450 mb. for each type. In addition the heights of the 700-mb. surface and of the freezing level, together with corresponding changes by half days up to three days, are recorded by types. From these and related data, inductive reasoning suggests mechanisms for endemic shower types, and parameters are selected for determining precipitation during the 12-hour period following either sounding. Probability curves that represent also quantitative rainfall are drawn from four summer seasons' data. Contingency tables are given for the dependent objective data, two seasons' independent objective data, and one season of corresponding 12-hour forecasts. In terms of skill score the subjective forecasts are found to be inferior at 1500 GMT and slightly superior at 0300 GMT. Principal conclusions include the finding that Miami showers are more closely related to the absolute humidity through a broad layer centered near 800 mb. than to moisture in higher or in surface levels, and that heavier showers may be inhibited by excessive absolute humidity above 650 mb.

CONTENTS

THE MIAMI SHOWER PROBLEM

It is now well known by weathermen that their middle latitude tools are of little use in the Tropics. A central problem of tropical meteorology therefore is to find suitable methods and techniques for analysis and prediction. Among the few low latitude map features that have been seriously appraised for diagnostic and forecasting value, perhaps the best known are the 24-hour isallobaric pattern and the easterly wave. However, Byers and Rodebush [1] found traveling synoptic features "too rare or remote to account for typical weather patterns over the [Florida] peninsula." Similar conclusions have been reached by others, and some difficulties in using easterly waves as forecasting aids have been reported by Folling [2] and by Durham et al [3].

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Palmer and Ellsaesser [4] recommended abandonment of conventional surface pressure analysis in lower latitudes, even in those of the United States, and urged direct analysis of the wind field, which can be observed directly with less error where the diurnal pressure variation is large. Unfortunately, the kind of streamline microanalysis suggested is difficult and subjective at best, and especially so over the oceans from which much summer convective activity crosses the Florida east coast.

Despite these handicaps, it is easy to produce high forecasting scores at Miami when these are measured as a percentage of rain-no rain predictions. These reflect generally monotonous and unusually fine weather in which conditions can be depended on to repeat for a few days. It is a different story when forecasts are graded only on days of change; the percentage correct drops close to zero. More as a rule than as the exception, rains of 6 to 10 inches fall on the same generalized shower forecasts that often precede days of little or no rain.

The complex nature of the Miami problem was noted several years ago by Abrams [5], who wrote that "aside from frontal showers, Miami is affected by both daytime and nocturnal convective activity . . . shower periods are *usually* detectable if a careful watch is kept on the sounding which will show up the *characteristic rise in the height of the moist layer*" (italics mine). A study by the United States Weather Bureau [6] has shown that between 0000 and 0600 EST Miami has more summer thunderstorms than any other part of peninsular Florida except Key West; that between 0600 and 1200 EST Miami leads in thunderstorm activity; while in the period 1200–2400 EST Miami has fewer thunderstorms than any other part of peninsular Florida except Key West. Despite this, the majority of Miami thunderstorms occur in the afternoon. A later study by Bovinett [7] of July thunderstorms at Weather Bureau Office, Miami (1945 through 1948) also shows that these are far more common between the hours of 1100 and 1700 EST.

Two local rainy season shower types have been described by Thomas [8]. The first is associated with a deep easterly current which produces showers and thunderstorms mostly at night and during the forenoon; the second has shallow southerly winds veering to southwest below 10,000 feet, producing afternoon thundershowers which develop over land southwest of the airport. "In both cases," he states, ". . . relatively little activity is to be expected if a stable layer and dry air are present below 8000 feet." Bovinett's study showed that in July 1946 and 1947 southwesterly winds at 850 mb. produced thunderstorms only in the afternoon; south and southeasterly winds, at any hour but chiefly between 1200 and 1600 EST; easterly winds, only between 0700 and 1100 EST (except rarely between 1600 and 2000 EST). Other directions gave few or no thunderstorms.

The role of classical parameters in these showers has been obscure. Hurley [9], in a study of summer thunderstorms at Banana River, Fla., noted that (1) the surface to 650-mb. average lapse rate for thunderstorm days differed from that for other days by only 1.2° C., (2) there was no reliable correlation between positive and negative energy areas and thunderstorm frequency, (3) there appeared to be no correlation between wind shear and thunderstorm frequency, (4) a relatively thick layer of moist air—3,000 to 4,000 meters—was necessary for widespread thunderstorm activity. The last observation, singularly in agreement with others noted above, offered perhaps the best clue for identification of thundery days. A few years later Baum [10] concluded that occurrence or nonoccurrence of Florida thunderstorms could not be determined by purely thermodynamic considerations, even when the moisture content was taken into account. A study by the United States Weather Bureau [6] reported average lapse rates to be coincident for those stations reporting showers and/or thunderstorms and those not doing so, and Chalker [11] obtaining similar results concluded that the effect of the lapse rate is greatly overshadowed by the role of relative humidity in many cases. Beebe [12] reported from Atlanta the abandonment of the parcel method as a forecasting tool. Further evidence that criteria for air mass thunderstorms were not everywhere in accord with classical concepts came from a study by Means [13], who found a relationship between thunderstorms and "cross pattern" trends in the central United States; charts presented in support of this relationship show plainly that the large May-July increase in thunderstorm activity in northwestern Florida is unrelated to this factor.

The work of Gentry [14] offered for the first time a systematic analysis of the Miami showers as related to the wind field, humidity, and convergence at selected levels. A test of his method in 1950 at the Miami Flight Advisory Weather Service Unit showed that it offered improvement over current forecasts, particularly on a skill basis. A disadvantage of the method was the subjectivity inherent in streamline analysis. Nevertheless, the paper demonstrated, after the methods of Brier [15], Thompson [16] and others, an effective means of solving empirically the old riddle of the group effect of many and contradictory rain parameters.

As results to be presented in this study often can be interpreted in terms of diurnal convergence patterns, some findings of recent studies of this factor should be kept in mind. In 1948 Byers and Rodebush [1], seeking a sounder theory of Florida thunderstorm activity, discovered a pronounced 1600 EST diurnal maximum of convergence at 1,000 feet at the centroid of a wind triangle made up of Jacksonville, Miami, and Tampa, produced by afternoon sea breezes entering the peninsula from both sides. Along the Gulf coast, where the double effect did not operate, both convergence and thunderstorm activity were halved. Day [17] has shown that (for July and August 1951) the diurnal convergence pattern over much of southeast Florida is related to but not identical with that reported by Byers and Rodebush for interior Florida. The 1,000-foot convergence maximum occurs instead at 1000 EST, with divergence beginning at 4,000 to 5,000 feet.[1] A daily daytime trigger appears to exist in this part of the State too, but it is much less pronounced and intense, and probably effective only if upper air moisture distribution is just right. Thus if large scale diurnal vertical movement must be taken into account in understanding the showers of the peninsular interior, it seems that smaller scale but regular vertical motion is also a factor to be reckoned with in understanding the conditions of summer showers along the lower east coast. Individual standards of critical moisture distribution may exist over different parts of the peninsula: over the interior, where the strongest afternoon lift is felt, the air rising into the 500-mb. level would be subject to warming by latent heat found at 1000 EST near 650 or 700 mb., while near Miami a higher level, say 550 or 600 mb. would often affect late afternoon positive areas. (Evidence that just such levels at Miami are critical in the production of heavier afternoon showers will be presented in fig. 10c).

Day's data show that at 2200 EST divergence is the rule below 5,000 feet in the area studied. We are then in need of a unique explanation of the troublesome showers that occur in the early hours after midnight. Forecasting of these almost invariably has depended on the forecaster's night vision and observational alertness rather than on sophisticated techniques.

A few other research findings will be mentioned because

[1] The diurnal variation in convergence at these levels explains a local empirical rule regarding a rather dependable failure of middle clouds to persist through the afternoon.

they dovetail into the Miami data to be reported below. According to Showalter [18] tornadoes require, among other things, a layer of moist air near the surface usually extending upward to a level below 10,000 feet, where a distinct dry tongue is favorable. Tillotson [19], comparing the relationship of Denver showers to both the 700-mb. mixing ratio and the averaged value from the surface to 700 mb., reported the *lower* values as better related to thunderstorm activity. Means [13] states "thunderstorm activity seems to be damped *under the warm lid aloft at 700 mb.* in areas where the greatest advance of isotherms at that level has occurred." Lastly, we note that Malkus [20, 21], Stommel [22] and others of the Woods Hole Oceanographic Institution have observed that trade cumulus do not show the well defined, classical columns of unsaturated, warm air rising from deep in the layer of air under the cloud. This group has constructed a tentative model of these clouds showing entrainment of drier air into their windward *sides*. (All italics mine).

THE PROBLEM REAPPROACHED

Data compiled by the United States Weather Bureau [6] presented evidence suggesting that shower criteria are not uniform in space and time. Thunderstorm-producing soundings for July 1942 at Oklahoma City showed slightly lower mixing ratios below 850 mb., with markedly higher values between 800 and 400 mb. at both 1100 and 2300 EST. At Washington, however, such thundery soundings showed considerably higher mixing ratios at all levels below 400 mb. at 1100 EST and differed hardly at all from non-thunderstorm soundings at 2300 EST. These findings are neither particularly consistent with each other nor with such uses as Miami forecasters have learned to make of the Miami sounding. Among the several possible explanations of this fact the following idea has been adopted as a working hypothesis in the preparation of this paper: *shower criteria differ geographically, diurnally, and seasonally.*

In the belief that an investigation was warranted in the Miami area, a detailed study of the Miami soundings for July and August 1950 was made by the author. Confinement of the present approach to the Miami shower problem to these narrow limits appears to be justified, although the following objections might be raised: (1) no account is taken of the wind field, which is of great importance in determining when and if showers will occur at Miami, (2) radiosonde data are not representative of anything more than a very limited section of time and space and cannot be assumed reliable on this account, (3) radiosonde data are themselves subject to large enough errors to nullify efforts to use them, and (4) 2 months is a relatively short period on which to base a study.

Objection (1) is met in part by the following considerations: Although the wind field is a basic source of weather, its direct analysis over oceanic areas is highly subjective. There is a possibility of getting equivalent results from close study of the sounding itself, since it is a product of the wind field. Because low level convergence through a deep layer results in high moisture content, a conservative factor like the mixing ratio may be taken as an index of this convergence, one that has the great advantage of being objective. Similarly, changes in lapse rate may be considered a function of the wind field and hence to some extent a measure of it. It is far from the purpose of this paper to urge that raob analysis be substituted for careful appraisal of the winds aloft; the analysis should instead be added to it. Indeed the ideal solution, one far beyond the time resources of the author, would incorporate additional wind and other parameters to provide for scientific appraisal of all the important shower indices. The present study was limited to raob factors because these must be separately analyzed if we are ever to learn their significance.

Objection (2) has already been considered in part in the discussion of objection (1). Is it likely that the diurnal convergence cycle shown by Day to exist near the centroid and probably generally within an equilateral triangle over 200 miles on its side would often be operative in Opa Locka but not in Coral Gables? Or that the 700-mb. height falls to be studied would often be found over Miami Beach but not Hialeah? This objection amounts to asserting that these conditions are commonplace. With regard to our primary purpose—determining some of the conditions of our *heavier* showers—it seems reasonable to assume that such conditions are rare.

Objection (3) leads us to note that all radiosond observations used were taken after the introduction of lithium chloride hygrometers of less lag than the mechanical type, and after the introduction of instruments less subject to solar radiation. Of course, even the newer instruments are less than perfect, as are observers. Nevertheless, according to the United States Weather Bureau [23], compatibility tests (sponsored by the Air Coordinating Committee) of the several types of radiosondes in use in the United States showed that for all constant-pressure levels up through 400 mb., 61 percent of plotted temperature points agreed within 1° C. and 91 percent within 2° C., and 90 percent of relative humidity points agreed within 10 percent. These tolerances even if aggravated by transmissional errors, are not such as to invalidate practical use of radiosonde data, especially in a study like the present one in which average values are used. The evidence rather indicates that instrumental and observational techniques have already surpassed professional skill in using observational data.

Objection (4) is not pertinent to the purposes of the present study. On the contrary, the relatively short period of 2 months was chosen deliberately. Within this period was a series of several wet and dry spells of the kind forecasters are expected to identify and foresee. If statistical differences are not plainly evident in the soundings of this short period, doubt must attach to their use at all in day-to-day shower forecasting, since any statistical defects inherent in a 60-day period are multiplied many times over in the shorter period of 1 day.

These considerations seemed to justify the detailed study of the Miami soundings for July and August 1950, and the investigation was started in the fall of 1950. Soundings associated with hurricanes, missing data, or frontal weather (rare in summer) were eliminated. At first, 0300 and 1500 GMT values were lumped together, with tantalizing results that merely suggested that improvement could be had by separating the two diurnal types. These results together with the following consideration led to the final plan to study separately the 0300 GMT and 1500 GMT soundings: It is basic to know precisely what type sounding is required for immediate rain (other factors assumed favorable). If we lack such basic knowledge, any attempt to forecast from trends in either soundings or wind field seems futile. A corollary of this principle: we will have to learn to anticipate these heavy showers by 5 hours before we can hope to do so for 5, or for 30, days.

Soundings for the 2 times were classified into 4 groups according as they produced a total rainfall of zero, trace through 0.05 in., 0.06 through 0.99 in., or ≥ 1.00 in. at the Miami Weather Bureau Office and Weather Bureau Airport Station, combined within the 12-hour period beginning shortly after the sounding was made. (Periods were not quite coincident, being 0130 to 1330 EST and 1330 to 0130 EST at WBAS, and 0000 to 1200 EST and 1200 to 2400 EST at WBO.) The four types will be referred to as D, W, WW, and WWW soundings. Data recorded were dry bulb temperature, wet bulb temperature, and dew point at 50-mb. intervals from 1000 through 450 mb. In addition, the height of the 700-mb. surface, together with the corresponding tendency for periods of 12, 24, 36, 48, 60, and 72 hours preceding were recorded, as well as the pressure in millibars of the freezing level and similar tendency increments up to a period of 72 hours.

Inclusion of the freezing level resulted from a study of the August 1–5, 1950 soundings, which revealed a diurnal pattern in freezing level movement which changed phase by one-half day 36 hours before a heavy rain. This and other evidence suggested that the soundings themselves sometimes offer evidence of vertical movement that would be most difficult to detect in other ways. Just how much of these temperature changes may be due to advection, how much to daytime temperature error, and how much to vertical movement would be a considerable problem in itself, but it seems reasonable to assume that under stagnant summer conditions, at least, no small part of it represents vertical movement.

In classifying the soundings it was noted that WBO and WBAS rainfall closely paralleled each other most of the time. Although these stations are some five miles apart, classifications would have been essentially the same had either WBO or WBAS rainfall been used separately (with standards halved) instead of totally. The chief reason for using figures from both offices was to provide a more representative coverage in space.

THE 0300 GMT SOUNDINGS

SHOWER CHARACTERISTICS

Principal findings will be presented in a few selected tables and figures. We might expect to find significant differences in rainfall-producing ability of the soundings if we compare mixing ratios. In figure 1a we see such a comparison, from 1,000 through 500 mb., for WWW types only, with the 0300 GMT values as the arbitrary standard, and 1500 GMT values shown on a horizontal scale in gm/kg. deviation from the standard. For example, at 950 mb. we see that 1500 GMT WWW soundings averaged 1.9

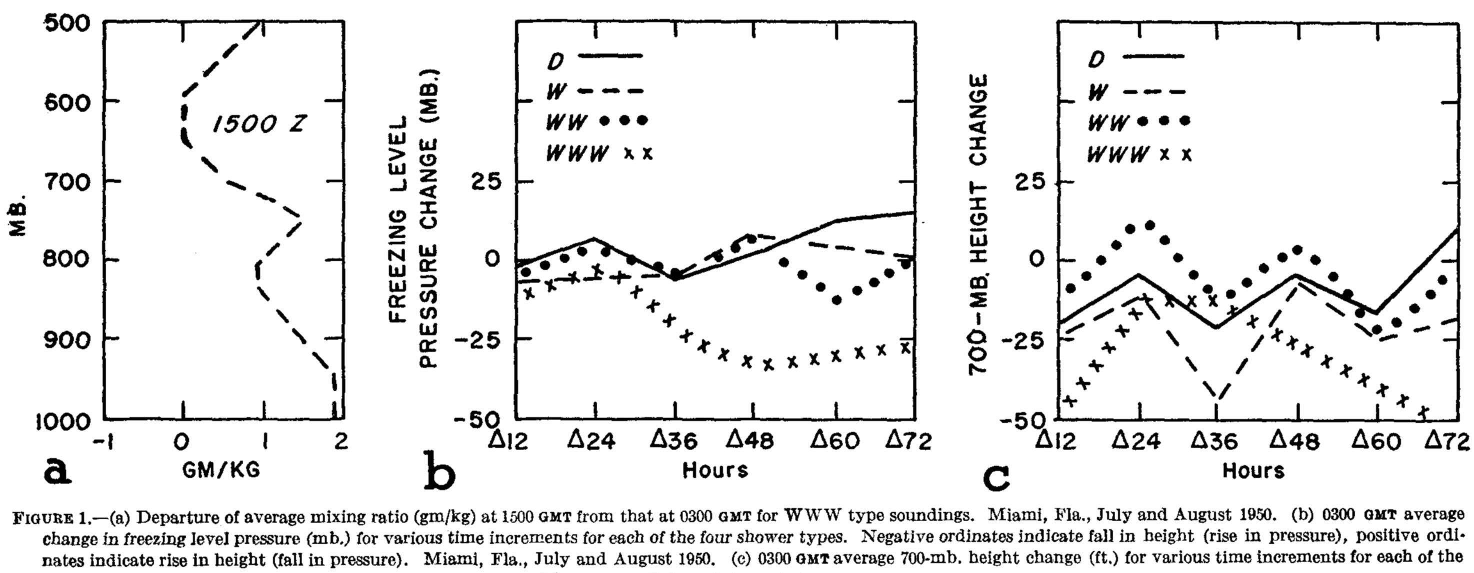

FIGURE 1.—(a) Departure of average mixing ratio (gm/kg) at 1500 GMT from that at 0300 GMT for WWW type soundings. Miami, Fla., July and August 1950. (b) 0300 GMT average change in freezing level pressure (mb.) for various time increments for each of the four shower types. Negative ordinates indicate fall in height (rise in pressure), positive ordinates indicate rise in height (fall in pressure). Miami, Fla., July and August 1950. (c) 0300 GMT average 700-mb. height change (ft.) for various time increments for each of the four shower types. Height falls are negative, rises positive. Miami, Fla., July and August 1950.

gm/kg. higher in moisture than did 0300 GMT WWW ascents. This extra moisture in low levels, together with the relative dryness at 600 and 650 mb. shown by 1500 GMT soundings, suggests that deep convective instability, particularly in low levels, distinguishes afternoon from early morning shower types. From Day's data [17], we note that ordinarily divergence prevails in low levels at 0300 GMT, which would render ineffective from a rainfall-producing standpoint any extra moisture in these low levels. At 1500 GMT however, convergence prevails in these levels, and we see from figure 1a that extra moisture in the low levels is indeed associated with the heaviest rains.

Figure 1b depicts the freezing level tendencies shown by the four shower types at 0300 GMT. Considering the WWW type, it is read in this way: on an average, WWW showed a 12-hour fall in freezing level of 12 mb. (−12, as from 600 to 612 mb.); a 24-hour fall of −1; a 36-hour fall of −22; etc. For the 72-hour change it will be noted that only D soundings had an average rise (+7) while both W and WW averaged no change, and WWW showed large falls of −25 mb. The 3-day freezing level tendency appears, then, to offer possibilities in separating shower types. (Note the diurnal movement apparent especially in WW values; this may be partly due to temperature errors caused by radiational warming of the instrument at 1500 GMT.)

Figure 1c shows similar data for the 700-mb. heights at 0300 GMT. Here the diurnal tendencies are even more pronounced. Changes for 72 hours again offer the best separation, with D, WW, W, and WWW lined up in that order, and with appreciable separation of D from WWW.

In table 1 are average temperatures (°C.) for the four types at 0300 GMT for levels from 1,000 to 450 mb. If these values are plotted on a suitable thermodynamic chart, we see that D, W, and WW lapse rates effectively coincide; that WWW differs in presenting steeper lapse rates above the level of 800 mb., fanning out to a difference of about 2° C. at 450 mb. Steep lapse rates are associated only with the heaviest showers.

TABLE 1.—*0300 GMT average temperatures (° C.) at 50-mb. pressure intervals for the four shower types. Miami, Fla., July and August. 1950*

Pressure \ Type	WWW	WW	W	D
(mb.)	(°C.)	(°C.)	(°C.)	(°C.)
450	−14.0	−11.7	−12.2	−12.3
500	−8.8	−6.8	−7.2	−6.9
550	−4.2	−3.0	−2.7	−2.8
600	−.2	.6	1.0	.7
650	3.4	4.4	4.4	4.3
700	6.8	8.1	8.2	8.0
750	10.4	11.0	11.3	11.3
800	13.6	14.0	14.2	14.4
850	16.4	17.2	17.2	17.5
900	19.6	20.0	20.3	20.3
950	22.4	22.6	22.9	23.1
1,000	25.8	26.0	25.8	26.0

TABLE 2.—*0300 GMT average wet-bulb temperatures (° C.) at 50-mb, intervals for the four shower types. Miami, Fla., July and August 1950*

Pressure \ Type	WWW	WW	W	D
(mb.)	(°C.)	(°C.)	(°C.)	(°C.)
500	−11.4	−10.2	−10.5	−10.8
550	−7.2	−6.3	−6.3	−7.3
600	−3.5	−3.2	−2.6	−3.6
650	0	.1	.5	−.6
700	3.5	4.0	3.9	3.1
750	6.2	7.1	7.3	6.6
800	10.0	10.6	10.5	10.0
850	13.5	14.2	13.6	13.4

Table 2 shows corresponding wet bulb data. These too must be plotted to be evaluated; we are then in a position to compare convective stability. Contrasting D with W, we see appreciable contrasts only in the level from 550 to 500 mb.; W against WW shows no appreciable difference; and WWW, as contrasted to WW, shows great stability differences between 600 and 500 mb. only. We may conclude that light showers following 0300 GMT soundings are associated with slight decreases in convective stability between 550 and 500 mb.; that the factors causing light showers to become moderate are related principally to other considerations; and lastly that the heaviest showers again require further decreases in convective

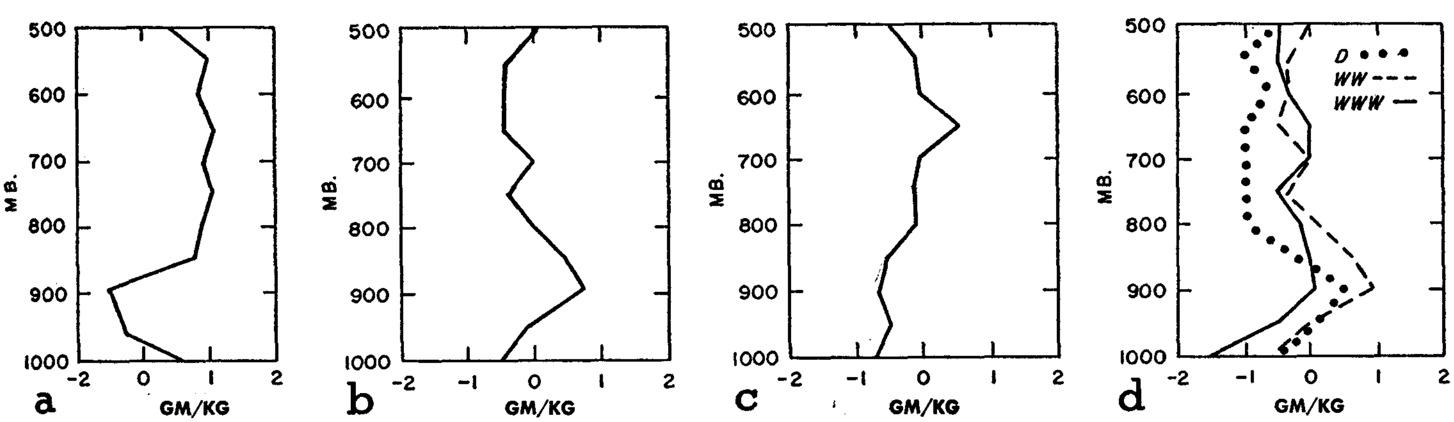

FIGURE 2.—Comparisons between average mixing ratios (gm/kg) for the four types of soundings for 0300 GMT, Miami, Fla., July and August 1950. (a) deviation of W type from D type, (b) deviation of WW type from W type, (c) deviation of WWW type from WW type, and (d) deviation of D, WW, and WWW types from W type (combination of data from figs. a, b, and c).

TABLE 3.—*0300* GMT *average dewpoints (° C.) at 50-mb. intervals for the four shower types. Miami, Fla., July and August 1950*

Pressure \ Type	WWW	WW	W	D
(mb.)	(°C.)	(°C.)	(°C.)	(°C.)
450	−22.5	−21.0	−21.6	−23.0
500	−18.8	−16.0	−16.2	−18.3
550	−12.2	−11.8	−10.4	−14.5
600	−7.8	−7.7	−6.9	−9.3
650	−3.2	−4.5	−3.3	−6.4
700	.7	.6	.5	−1.8
750	3.5	3.8	4.2	2.6
800	8.2	8.7	8.4	6.7
850	11.8	12.5	11.8	11.0
900	14.8	15.7	14.8	15.5
950	18.2	18.7	18.7	19.0
1,000	20.5	21.3	21.8	21.4

TABLE 4.—*0300* GMT *average freezing level (mb.) and average 700-mb. height (ft.) for the four shower types. Miami, Fla., July and August 1950*

Type	Freezing level	700-mb. height
	Mb.	*Feet*
D	587	10,547
W	585	10,497
WW	591	10,524
WWW	602	10,510

stability through a deeper layer from 600 to 500 mb. Returning again to Day's data we are not surprised to note that control of these early morning showers rests in fairly high levels. With normal divergence at 0300 GMT

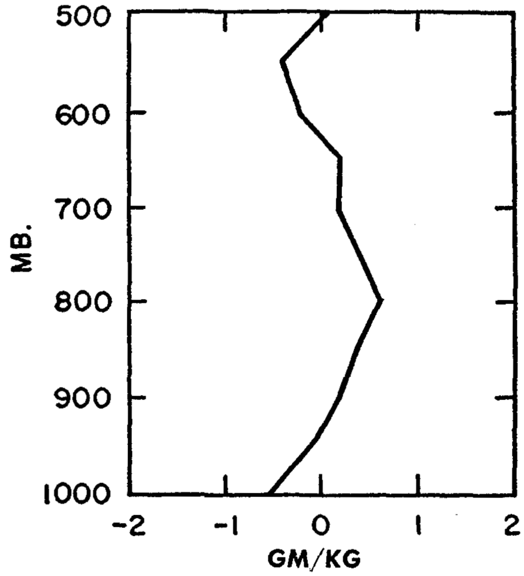

FIGURE 3.—0300 GMT deviation of average mixing ratio (gm/kg) for shower type sounding (W, WW, WWW combined) from that for D type. Miami, Fla., July 1951.

in low levels, it is believed these night showers would ordinarily have to develop within the more flexible layers of 14,000 to 18,000 feet.

Table 3, presenting dewpoint data, is conveniently analyzed by converting to mixing ratio and plotting on a relative scale where differences can be magnified. In

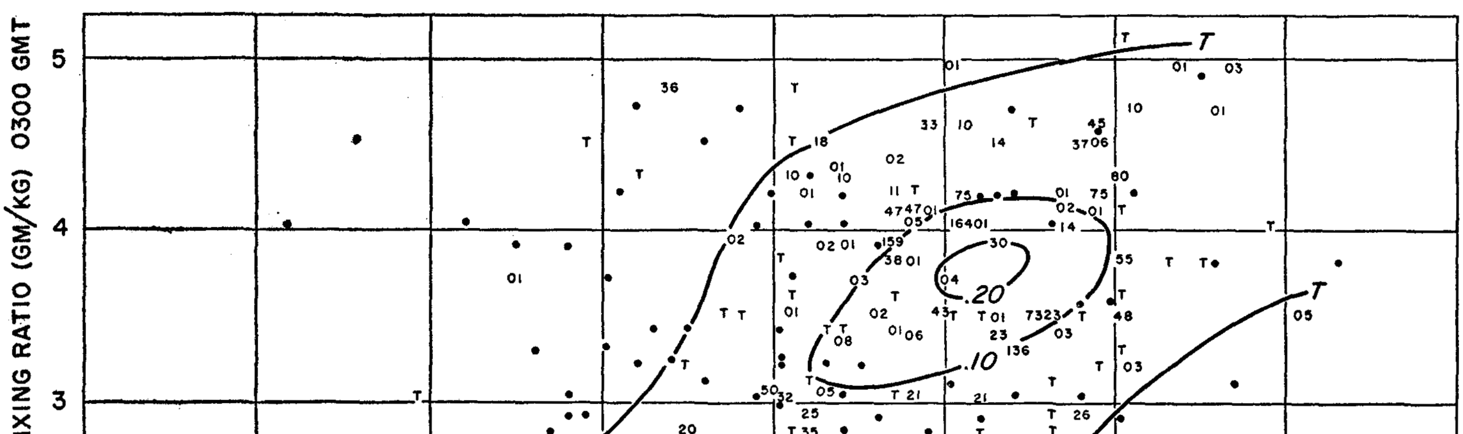

FIGURE 4.—Scatter diagram showing plots of rainfall (average of amounts at WBO and WBAS, Miami, Fla.) during the 12-hour period immediately following the 0300 GMT sounding from which the mixing ratio coordinate values were taken. Dot indicates no rain; T, a trace; and number, a measurable amount (in hundredths of an inch). The empirical curves are isograms of median values of rainfall amounts but may also be interpreted as rainfall frequency: ≥0.20 in. represents a frequency of 85%, and ≤trace a frequency of <50%. Dependent data: July and August 1948–51.

figure 2a, this is done for D and W. Evidently a surge of absolute humidity in the deep layer between 850 and 550 mb. is a characteristic difference in these types. Of particular interest is the "bite" removed at and below 900 mb., which emphasizes that these levels have little to do with producing rain at this time of day when divergence prevails here.

In figure 2b WW is similarly compared with W. As the mixing ratio difference (centered near 700 mb.) between D and W (fig. 2a) is augmented in lower levels—i. e. 900 mb.—the light showers become moderate. Again we note the heavy "bite" in very low levels, which are still plainly unrelated to shower activity.

Figure 2c similarly compares WWW and WW. Here the middle level increase in mixing ratio is augmented at 650 mb., just above the original (fig. 2a) center at 700 mb., producing a mixing ratio surge in the deep layer from 900 to 650 mb. capable of producing heavy showers. In figure 2d, figures 2a, b, and c are combined into a single diagram, with W as the arbitrary standard. This was used because we are aiming chiefly at finding the features that distinguish light showers from heavy showers. Of great interest is the relative drying at 500, 550, and 600 mb. associated with the heavier showers. This indicates that convective instability is a factor in producing the heaviest showers, a fact previously noted.

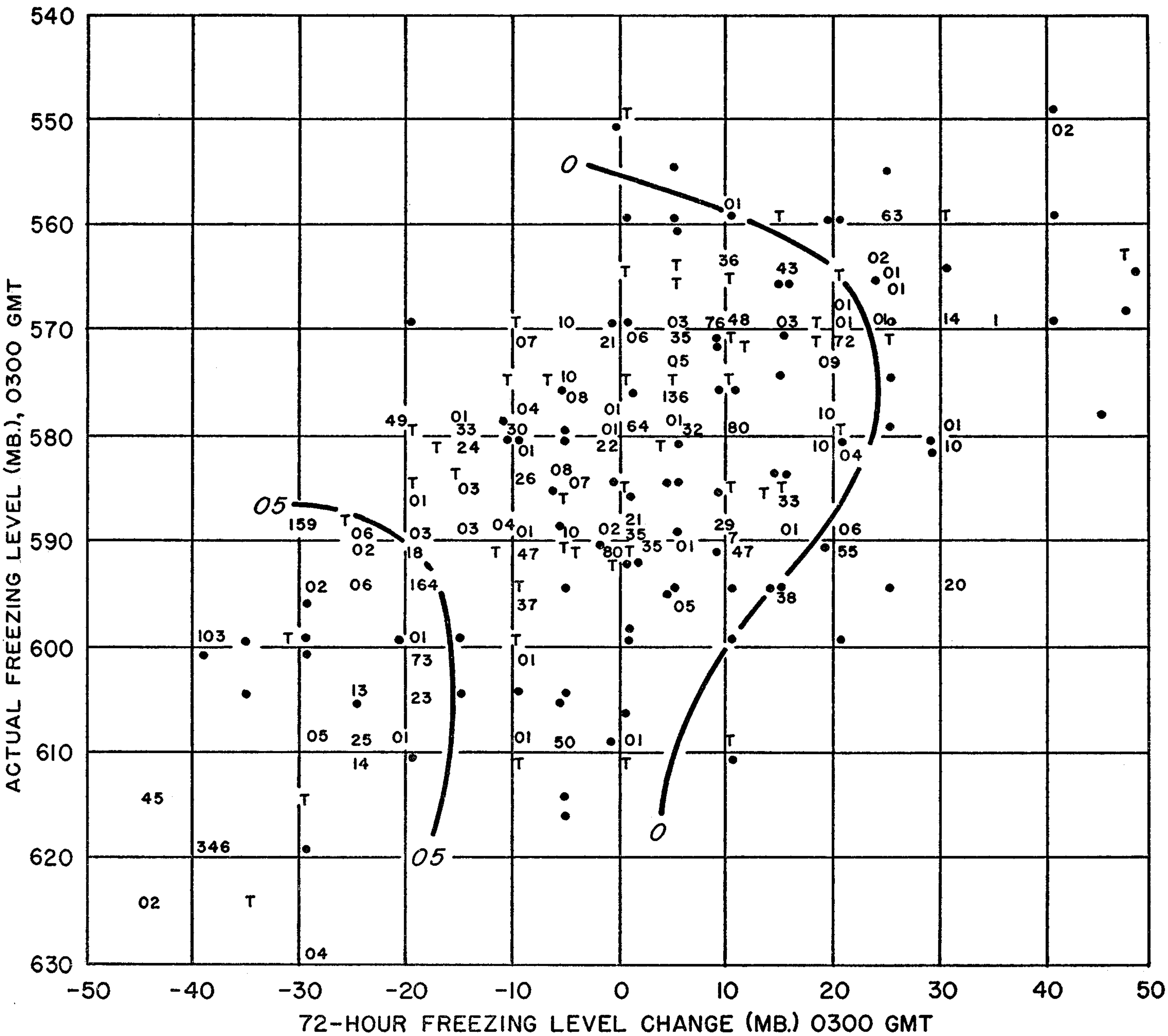

FIGURE 5.—Scatter diagram showing plots of Miami rainfall (as in fig. 4) during the 12-hour period following the 0300 GMT sounding to which the freezing level and freezing level change coordinates correspond. Negative abscissa indicates a fall in height (rise in pressure); positive, a rise in height (fall in pressure). Isograms are interpreted as in figure 4. Dependent data: July and August 1948–51.

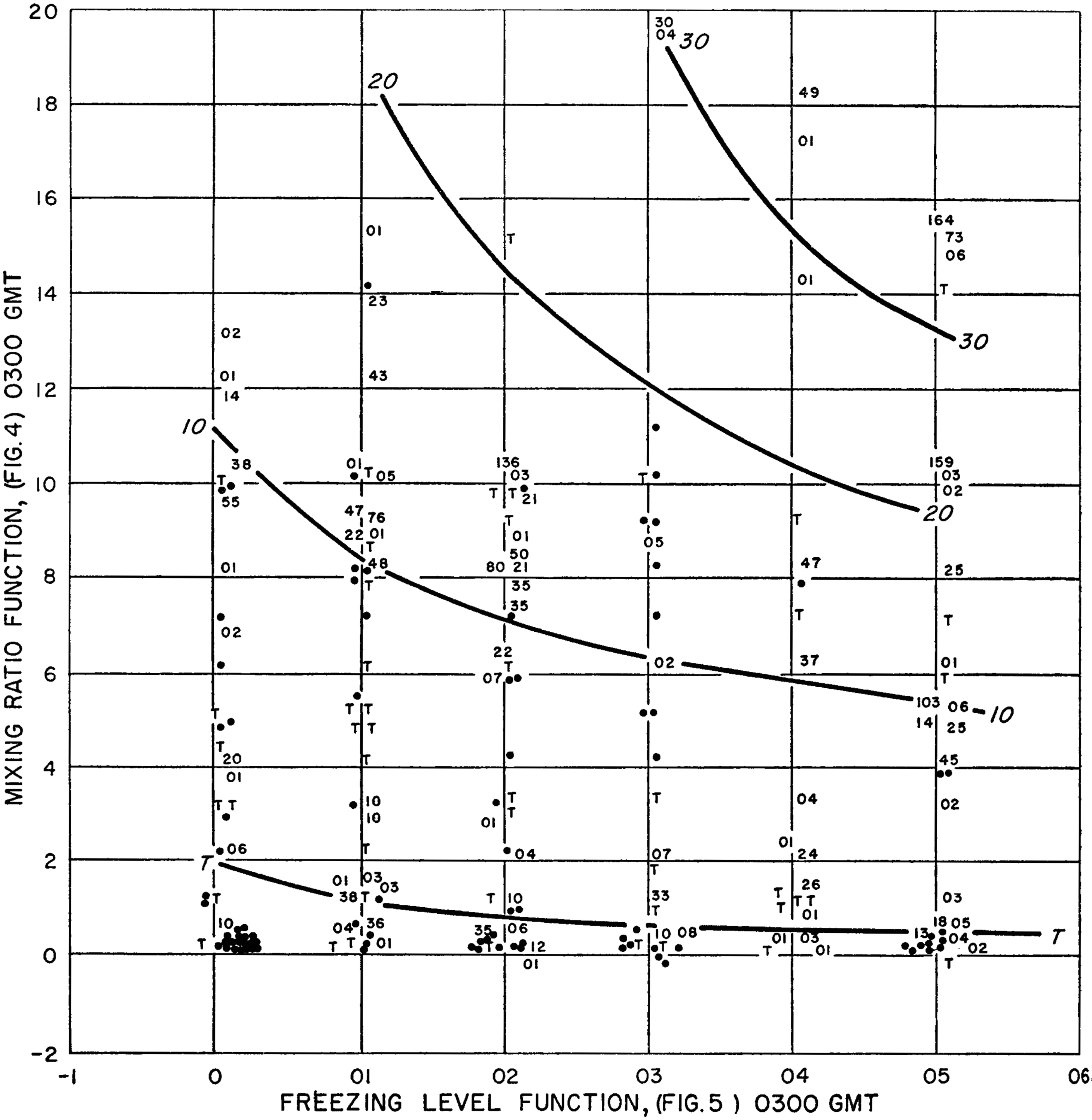

FIGURE 6.—Scatter diagram showing Miami rainfall (as in fig. 4) for the 12-hour period following the 0300 GMT sounding, plotted against the mixing ratio function from figure 4 and the freezing level function from figure 5. Isograms are interpreted as in figure 4. Dependent data: July and August 1948–51.

Table 4 presents, by types, the freezing level and 700-mb. height averages. Note that the heaviest showers had the lowest freezing levels (i. e. highest pressure) with W, WW, and WWW lining up in that order. The 700-mb. heights also, except for the anomalous position of W, present a pattern of increasing shower activity with lowering heights.

In figure 3 is presented evidence from a different year (July 1951) as a check on the validity of the relative drying noted in figure 2d. Data in figure 3 present all shower types in a single group contrasted with non-shower types. The principal difference consists in an 800-mb. mixing ratio surge, together with the relative drying at 550 and 600 mb.

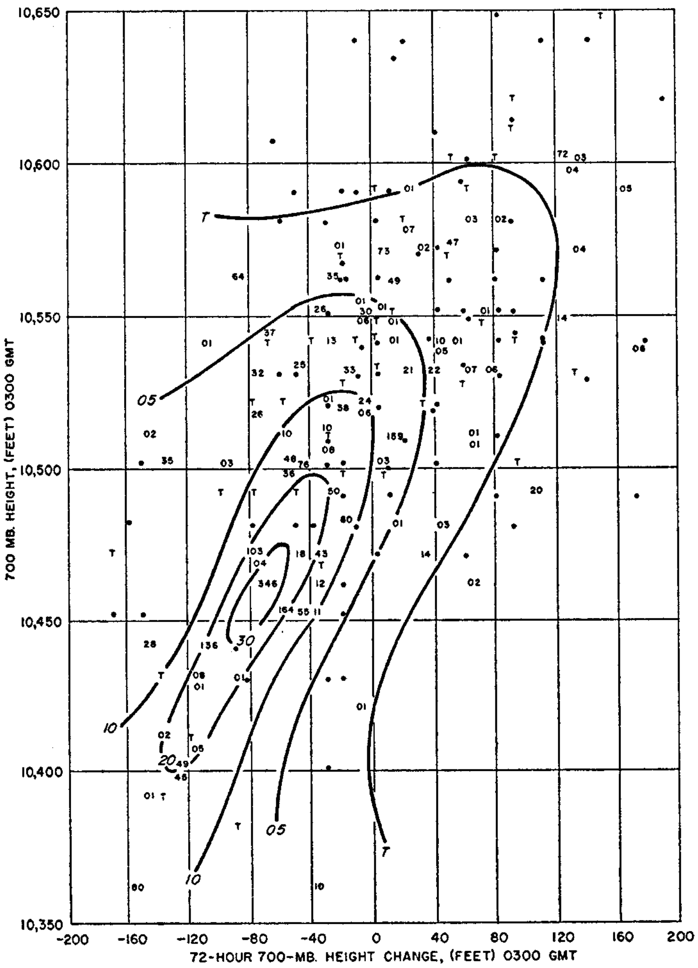

FIGURE 7.—Scatter diagram showing plots of Miami rainfall (as in fig. 4) for the 12-hour period following the 0300 GMT sounding to which the 700-mb. height coordinate values correspond. Isograms are interpreted as in figure 4. Dependent data: July and August 1948–51.

An interesting check on data in tables 1 and 3 is the computation from them of the Showalter stability index [24] for the four types of 0300 GMT soundings. Results are given below:

Type	D	W	WW	WWW
Stability index	2.6	2.0	2.0	0.9

The quantitative value of the index is obvious. We may also note that 0300 GMT summer values are usually much less than the 3.00 generally considered suspect for shower activity.

OBJECTIVE FORECASTING AID

Figure 4 is an objective forecasting aid based on differences noted in the 0300 GMT soundings. The forecast period is of course limited to that used in defining the shower types—the 12-hour period beginning immediately after the sounding is completed. The empirical curves incorporate data from three additional years—1948, 1949, and 1951— making in all four summer seasons. Although raobs have been made at Miami since 1941, some doubt attaches to temperatures given by daytime soundings made before 1947, which means that for best accuracy in 0300 and 1500 GMT data comparisons the period used is almost as long as data presently available will permit. Abscissas represent mixing ratio in the layer from 850 to 650 mb., averaged graphically.[2] Ordinates represent a similarly determined average for the layer 600–500 mb. Isograms drawn are median values for the 12-hour rainfall resulting (an average of Weather Bureau Airport Station and Weather Bureau Office). As a check, rainfall probability values were also entered at various points on the original scatter diagrams. These values were so closely related to the quantitative values that it seemed possible to let a single set of curves serve a double purpose. Median values of 0.20 in. or more represent probability of about 0.85; values of trace or less, a probability of less than 0.50.

Figure 5 is another objective aid prepared by plotting the actual pressure of the freezing level against the 3-day change in this parameter (an increase in pressure is considered negative, corresponding to a physical fall in height of the level). As will be noted from the highest median, 0.05 in., this "freezing level function" has much less quantitative significance than does the "mixing ratio function."

In figure 6, the result from figure 4 is plotted against the result from figure 5. Increased accuracy resulting from the combination is apparent from the higher median, 0.30. Figure 7 represents a fresh start with two new parameters, the 700-mb. height against the 72-hour change in this height. In figure 8 the results from figures 6 and 7 are combined into a single index that can be considered a function of the six parameters. Although median lines of 0.05, 0.10 and 0.20 were drawn on the original figure it was felt that there would be less misinterpretation of these meanings if only regions of "none", "light", and "heavy" showers were indicated. Also, the variability within the "light" region is much greater because only the heavier showers represent general conditions.

A parameter that was tested and rejected was the intercept in millibars of the $-10°$ C. isotherm on the adiabatic chart with the temperature sounding curve. Evidently the *observed* lapse rate in these levels is less important than the *impending* one.

THE 1500 GMT SOUNDINGS

SHOWER CHARACTERISTICS

Figure 9a presents the freezing level movements for the four shower types. These data offer little help in identifying types—certainly less than was seen in figure 2 for 0300 GMT.

[2] A small transparent ruler is laid on the adiabatic chart with its edge parallel to the constant specific humidity lines and crossing the dew-point curve near the middle of the layer. From extremities of the layer, perpendiculars are dropped from the dewpoint to the ruler which is then moved left or right without altering its slope until a point is found such that the sum of the areas enclosed by the ruler edge, the perpendicular and the mixing ratio curve on the left equals that on the right. If the curve is a straight line, the average can be taken, for practical purposes, to be the value at 750 mb.

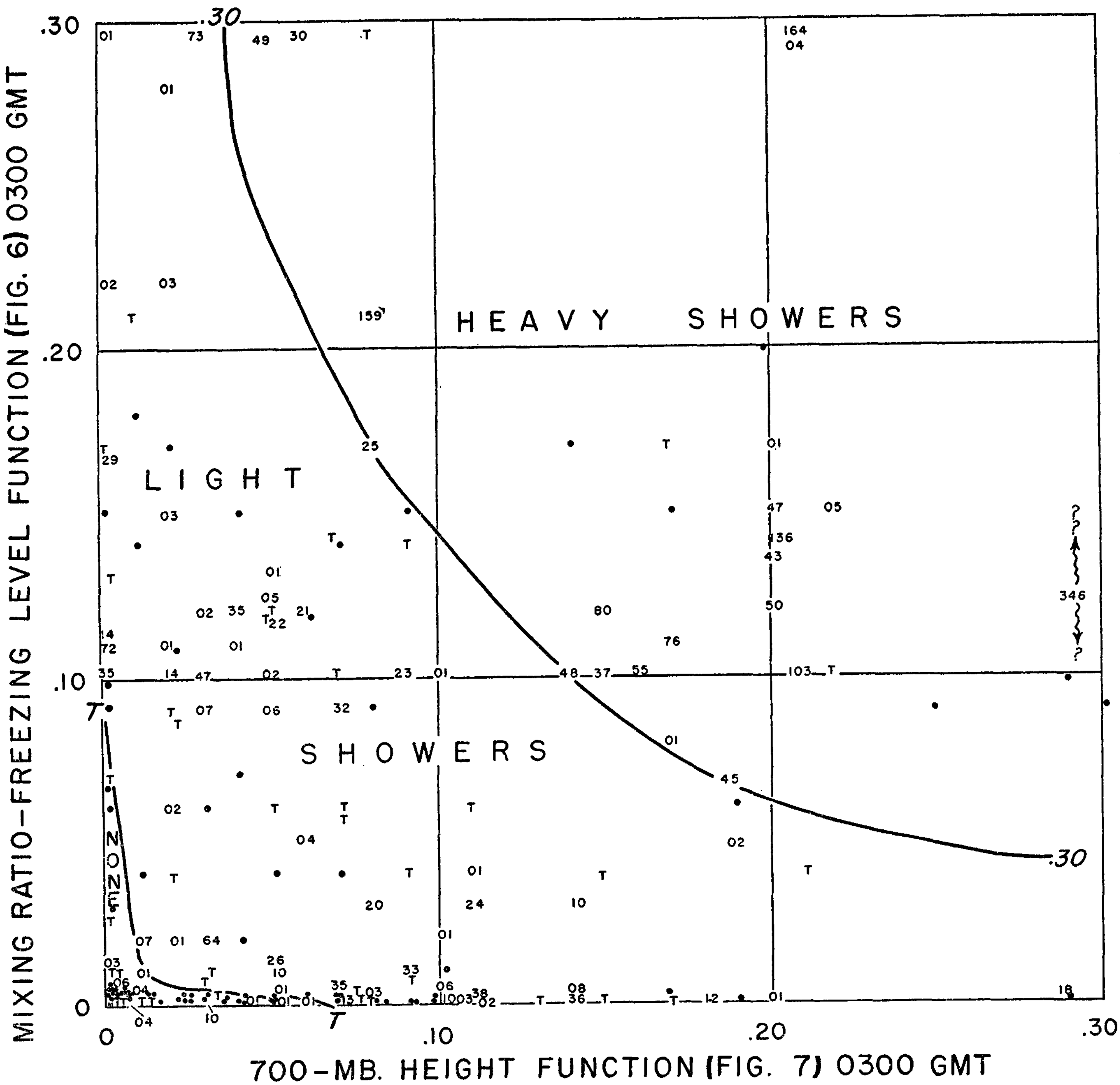

FIGURE 8.—Scatter diagram showing Miami rainfall (as in fig. 4) for the 12-hour period following the 0300 GMT sounding, plotted against the mixing ratio-freezing level function from figure 6 and the 700-mb. height function from figure 7. Isograms, now a function of six parameters, are interpreted as in figure 4. Dependent data: July and August 1948–51.

Figure 9b is of interest when compared to figure 1c, which it resembles only slightly. The zigs of one are the zags of the other. Again we note that 3-day falls tend to distinguish WWW but this time with less suggestion of continuous quantitative significance (D falls between W and WW). The overall downward slope of WWW to the right is perhaps meaningful; note that these heaviest showers occurred just after 12-hour rises of 50 feet and 72-hour falls of 25 feet—that is, on a strong rise following a gradual 3-day fall. This fits accepted patterns of easterly waves, with maximum convergence just after wave crest passage. However a test of this slope as a parameter proved disappointing. Probably a few large values affected the averages in figure 9b enough to suggest qualities less typical than exceptional.

Table 5 gives temperature averages for the four type 1500 GMT soundings. Plotted on an adiabatic chart they show the following contrasts: W lapse rates, as com-

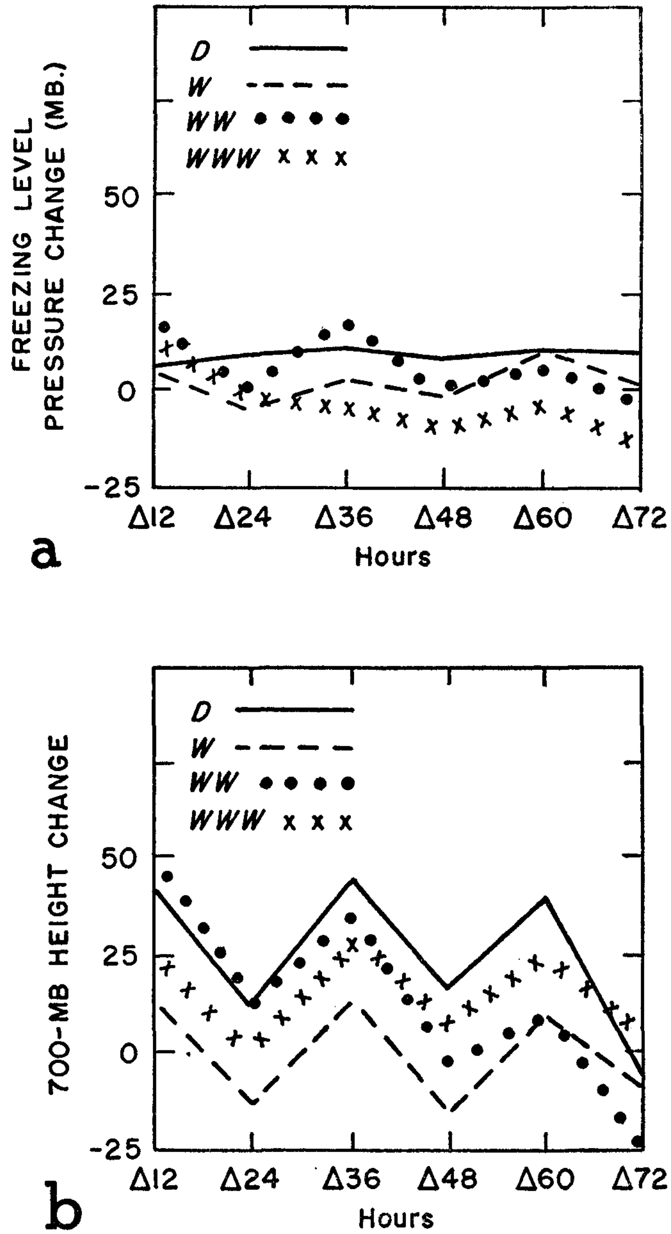

FIGURE 9.—(a) 1500 GMT average change in freezing level pressure (mb.) for various time increments for each of the four shower types. Negative ordinates indicate fall in height (rise in pressure); positive ordinates indicate rise in height (fall in pressure). Miami, Fla., July and August 1950. (Compare with fig. 1b for 0300 GMT soundings.) (b) 1500 GMT average 700-mb. height change (ft.) for various time increments for each of the four shower types. Height falls are negative, rises positive. Miami, Fla., July and August 1950. (Compare with fig. 1c for 0300 GMT soundings.)

pared to D, are slightly steeper from 1,000 to 850 mb., nearly identical from 850 to 600 mb., and again slightly steeper from 600 to 500 mb. Considering W as against WW, temperature curves are about a degree apart up to 600 mb., with the paradox of stabler lapse rates for WW between 600 and 550, and with nearly identical curves above this. One way of partially separating these types on a basis of temperature distribution is to mark the level of intersection of $\theta=343.5°$ with the temperature curve; this gives 700, 750, and 820 mb. for D, W, and WW, respectively, and 770 mb. for WWW. Thus an intercept of 750 mb. or lower is associated with showers, and this

TABLE 5.—*1500 GMT average temperatures (° C.) at 50-mb. intervals for the four shower types. Miami, Fla., July and August 1950*

Pressure \ Type	WWW	WW	W	D
(mb.)	(° C.)	(° C.)	(° C.)	(° C.)
450	−11.7	−11.6	−11.9	−11.7
500	−6.8	−6.8	−7.2	−6.4
550	−2.8	−2.2	−2.8	−2.4
600	1.8	.5	1.4	1.5
650	5.0	4.1	5.1	5.5
700	8.2	7.5	8.6	8.8
750	11.2	10.4	11.6	12.3
800	14.5	13.6	14.6	15.3
850	17.5	16.6	17.3	18.1
900	21.0	19.6	20.3	21.0
950	23.8	22.6	23.7	23.7
1,000	27.5	26.0	27.3	27.1

TABLE 6.—*1500 GMT average wet-bulb temperatures (° C.) at 50-mb. intervals for the four shower types. Miami, Fla., July and August 1950*

Pressure \ Type	WWW	WW	W	D
(mb.)	(° C.)	(° C.)	(° C.)	(° C.)
500	−9.5	−9.2	−10.6	−10.7
550	−5.5	−5.9	−6.2	−7.0
600	−2.8	−2.3	−2.4	−3.4
650	.7	.9	1.2	−.3
700	4.8	3.9	4.1	3.0
750	8.5	6.9	6.8	6.0
800	12.0	10.6	10.4	9.2
850	14.8	13.8	13.5	12.6

relationship is partly quantitative. This intercept was used as a forecasting parameter.

Table 6 similarly presents wet-bulb temperatures. Plotting these we get, for D against W, considerably greater convective instability for W between 650 and 500 mb. For W against WW the curves are about identical except between 550 and 500 mb., where WW oddly shows greater stability. Comparing WW and WWW, much greater instability is manifest for WWW between the 750 and 600-mb. levels. Important differences shown by wet-bulb temperatures between 0300 and 1500 GMT soundings seem to include a requirement for deep convective instability through a layer from 750 to 500 mb. for afternoon rains, while night showers require instability in a higher layer, at 600 mb. and above. Because of the 0300 GMT divergence near the surface, night showers are controlled principally in higher levels. (A paper by Gentry and Moore [25] offers evidence that most of these night showers do not, as is often suggested, form over the Gulf Stream and move inland, but instead begin over sections well west of the coastline.)

Table 7 gives the 1500 GMT dewpoint values. Reducing these as before to mixing ratios and contrasting D and W in figure 10a, we note that a mixing ratio surge of between one and two gm/kg. in the deep layer between 900 and 650 mb. distinguishes the two types. The "bite" at 950 mb. and below is of interest, particularly since we cannot this time explain it as associated with low level divergence. There may exist in the atmosphere a level of maximum moisture transportability—that is, a level where day-to-day mixing ratio changes are at a maximum.

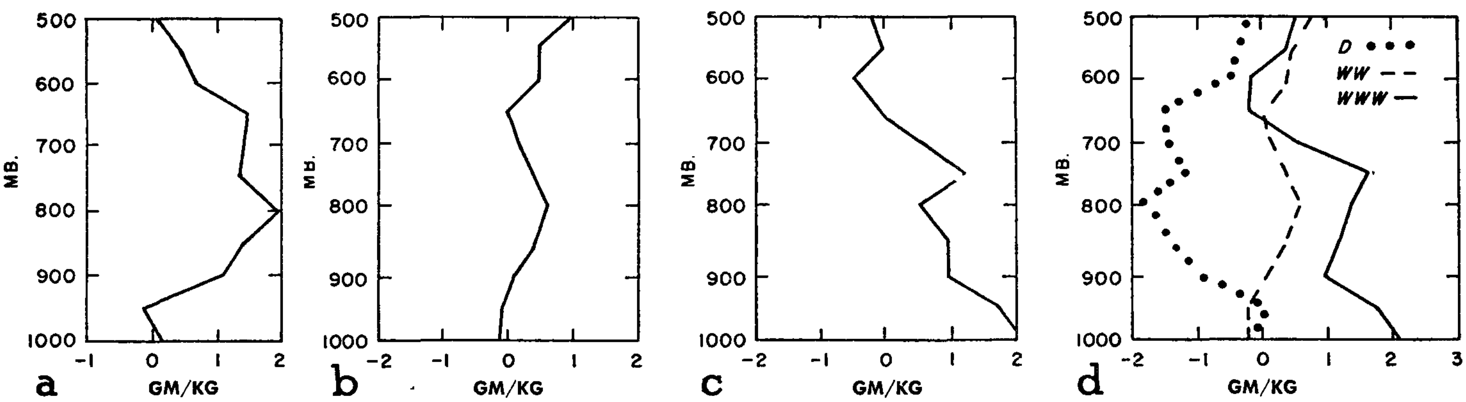

FIGURE 10.—Comparisons between average mixing ratios (gm/kg) for the four types of soundings for 1500 GMT, Miami, Fla., July and August 1950. (a) Deviation of W type from D type, (b) deviation of WW type from W type, (c) deviation of WWW type from WW type, and (d) deviation of D, WW, and WWW types from W type (combination of data from figs. a, b, and c.)

TABLE 7.—*1500* GMT *average dew points (° C.) at 50-mb. intervals for the four shower types. Miami, Fla., July and August 1950*

Pressure \ Type	WWW	WW	W	D
(mb.)	(°C.)	(°C.)	(°C.)	(°C.)
450	−18.5	−18.2	−21.8	−23.6
500	−13.5	−12.3	−17.2	−18.5
550	−9.0	−9.6	−11.4	−14.4
600	−8.0	−6.4	−7.7	−10.5
650	−3.0	−2.2	−2.6	−7.1
700	2.0	.9	−.3	−3.2
750	6.5	3.8	2.7	−.3
800	9.8	8.7	7.5	3.6
850	13.0	11.9	11.4	9.3
900	16.2	15.3	15.1	13.3
950	20.0	18.0	18.2	18.4
1,000	22.5	20.3	20.6	20.4

In low levels, more source moisture is available, but due to surface friction it is less free to be carried about, while in higher levels available moisture falls off as wind speed increases. Thus a point of maximum efficiency could be shown to exist. Or perhaps the fact that the principal differences in figure 10a appear near the 800-mb. level—a point almost exactly halfway between the surface and the freezing level—is of significance because it is in the middle of this important layer. The fact of the relative unimportance of surface levels to the development of trade cumulus has been recognized by the group at Woods Hole [20–22] in developing the concept of entrainment, as discussed previously.

Figure 10b contrasts W and WW. The surge at 800 mb. continues, but with an important qualification: at 650 mb. there is no increase. This relative drying effect has been encountered and discussed before. Since at 1500 GMT there is normally low level convergence, it is evident that a very large column of air is gently rising, and our smaller shower cell is simply rising more rapidly than is the surrounding air—a situation that could still allow much relative motion between the parcel and its surroundings. Hence there appears a need to consider positive area from a standpoint not of *observed* 1500 GMT 500-mb. temperatures but rather of *later* temperatures, say at 2000 GMT, when the daily upsurge (and shower activity) has almost reached its peak. It is at this time that our smaller parcel will enter these levels, and it will sometimes be the latent heat in lower levels of 650 and 700 mb. that determines the thermal environment of the shower top.

Figure 10c gives characteristics of WWW, the kind of showers that cause the most concern and which it was a purpose of this paper to identify. The surge in mixing ratio at 800 mb. persists somewhat, but we note when comparing it to WW a *thickening* of the surge to include levels just above and just below 800-mb. The 1,000-mb. level, with the greatest surge of all, fully utilizes the diurnal convergence present here. It is apparent that we are here dealing with cumulus clouds of a more classical type, with entrainment somewhat less significant and surface moisture important to extensive vertical development. The familiar relative drying is evident not only at 650 mb. but clear up to 500 mb. as well, providing deep and intense convective instability that is easily triggered by the regular daily upsurge. Under such conditions we would expect the heaviest rains to cover a rather large area for at least two reasons: (*a*) moisture distribution in the

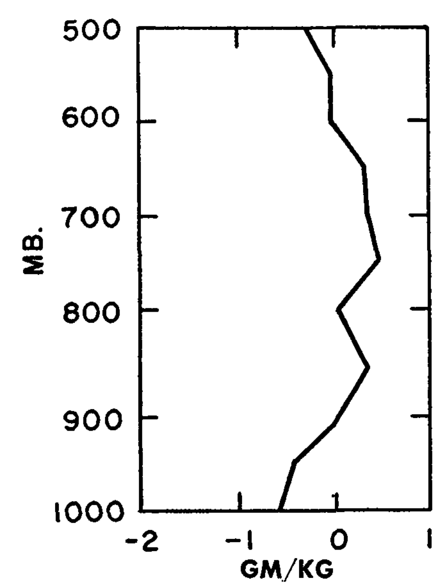

FIGURE 11.—1500 GMT deviation of average mixing ratio (gm/kg) for shower type soundings (W, WW, WWW combined) from that for D type. Miami, Fla., July 1951.

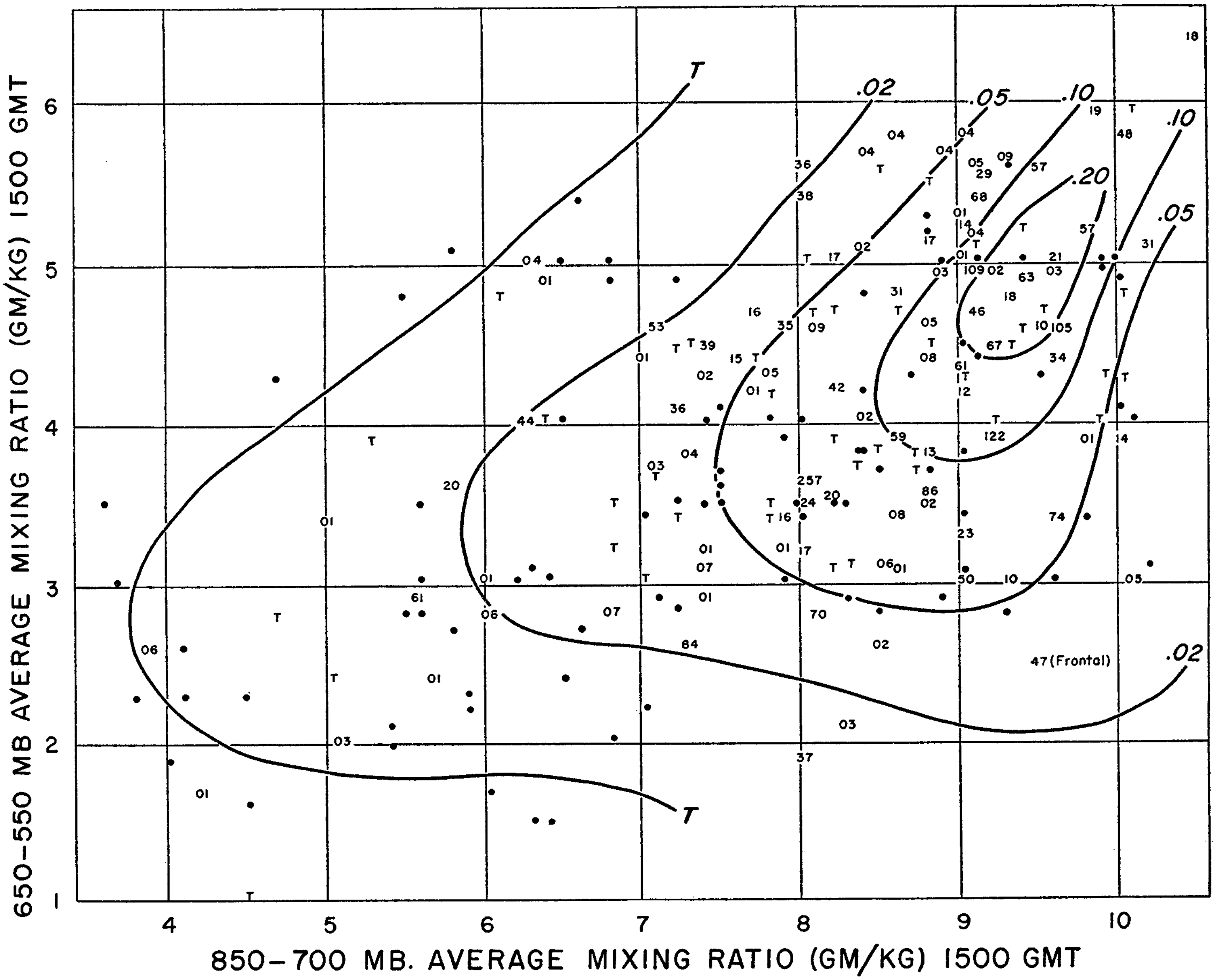

FIGURE 12.—Scatter diagram showing plots of Miami rainfall (as in fig. 4) during the 12-hour period immediately following the 1500 GMT soundings from which the mixing ratio coordinate values were taken. Isograms are interpreted as in figure 4. Dependent data: July and August 1948–51.

sounding is a function of a wind field common to most of southeast Florida, (*b*) the diurnal low level convergence is a product of land-sea contrast likewise common to most of southeast Florida.

Figure 10d sums up the previous three figures for convenience in comparing all four types. It will be noted that the 750- and 800-mb. levels provide the best overall index of shower intensity. Also we see that only the heaviest showers are related to low level mixing ratio. (This is a weakness of the forecasting parameter to be used, which considers only the 850- to 700-mb. layer). Relative drying in high levels seems to intensify the showers, and too much moisture in these levels inhibits them. This offers an explanation of an old idea that it is safe to forecast improvement once it has rained hard for a few minutes—that is, after the cumulonimbus has fanned out enough moisture in higher levels to abruptly alter the convective stability of the much larger, gently rising column that constitutes its environment. Also, of course, great expanses of middle clouds sharply retard surface insolation. Each large shower thus eventually signs its own death warrant. Can anyone recall *two* successive cloudbursts in southern Florida in a single half day?

In table 8 are presented freezing level and 700-mb. data for 1500 GMT corresponding to those of table 4 for 0300 GMT. Interesting as some of these values are, none seems to offer enough skill to warrant use as a parameter. In figure 11 are presented independent data from July 1951 as a check on the reality of the relative drying near 600 mb. associated with heavier showers. As in its counterpart figure 3, all shower types were considered as one type and compared to dry averages.

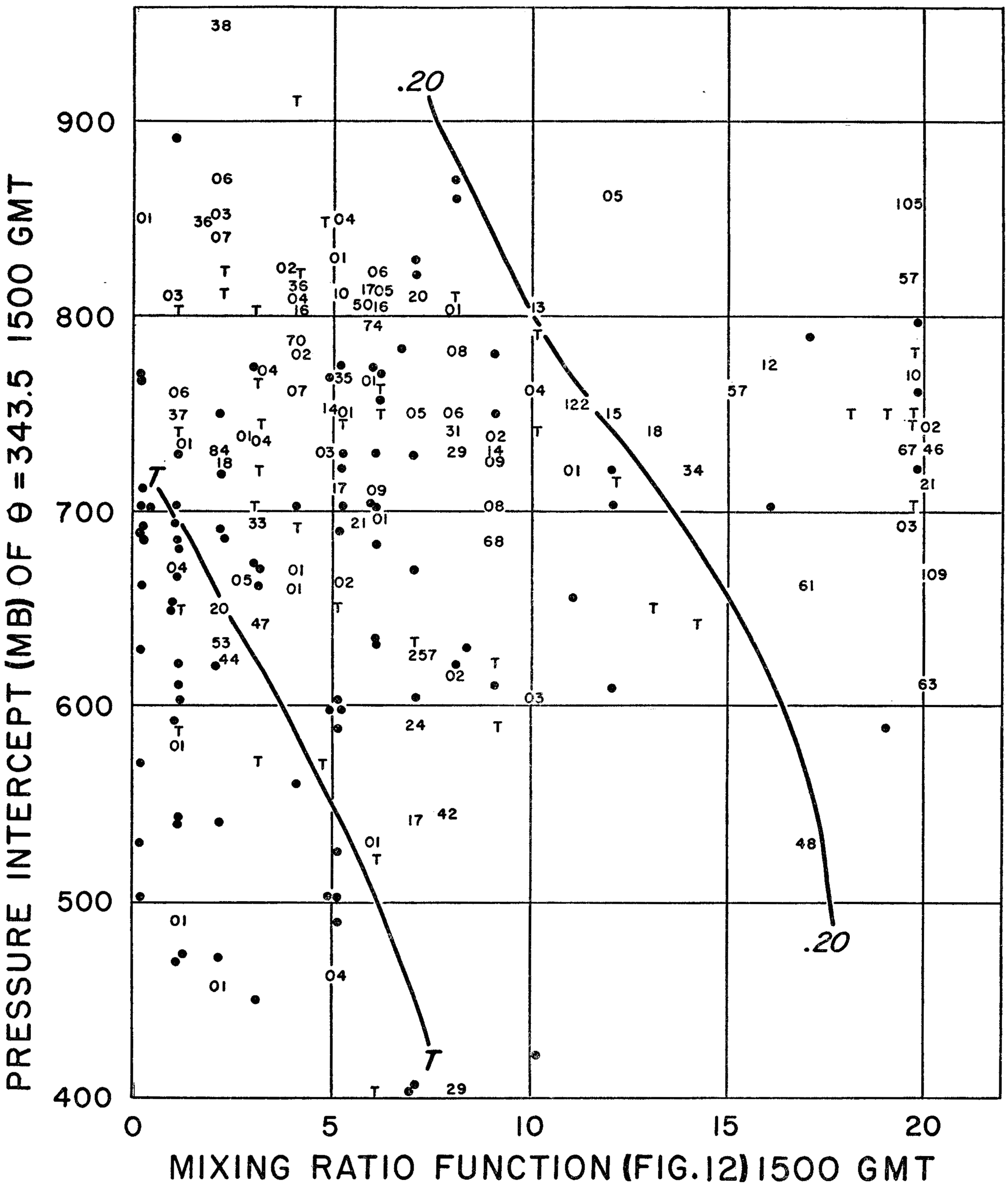

FIGURE 13.—Scatter diagram showing Miami rainfall (as in fig. 4) for the 12-hour period following the 1500 GMT sounding, plotted against the 1500 GMT pressure intercept of $\theta=343.5°$ and the mixing ratio function from figure 12. Isograms, now a function of three parameters, are interpreted as in figure 4. Dependent data: July and August 1948–1951.

TABLE 8.—*1500* GMT *average freezing level (mb.) and average 700-mb. height (ft.) for the four shower types. Miami, Fla., July and August 1950*

Type	Freezing level	700-mb. height
	Mb.	*Feet*
D	581	10, 555
W	583	10, 545
WW	590	10, 542
WWW	575	10, 527

Computing the Showalter stability index as before, with data from tables 5 and 7 for 1500 GMT, results are as follows:

Type	D	W	WW	WWW
Stability Index	4. 2	2. 3	2. 8	1. 6

Again the quantitative relation of the index to shower type is apparent. The anomalous position of WW could perhaps be improved by use of a larger sample.

OBJECTIVE FORECASTING AID

Only three parameters were selected in preparing objective aids for 1500 GMT. Figure 12 gives 12-hour rainfall as a function of mixing ratio averages in the two layers 850–700 mb. and 650–550 mb. In comparing this to figure 4 we note agreement on several points: (1) there is a region of maximum rainfall, (2) the contours suggest that the effect of increasing beyond certain limits the mixing ratio in the higher stratum is to reduce rainfall, (3) the highest medians are the same (0.20 in.) indicating comparable skill from mixing ratio parameters at both times of day.

In figure 13 we combine the value gotten from figure 12 with the "lapse rate" parameter, defined as the height (expressed in millibars) of the lowest reasonable intercept (highest pressure) of $\Theta=343.5°$ with the 1500 GMT temperature sounding curve. (In cases of marked temperature inversions, use the highest intercept (lowest pressure); with an irregular temperature curve smooth as necessary.) The curves of figure 13 give a final quantitative estimate for ensuing 12-hour rainfall.

The limitations in the criteria employed in the objective forecasting aids have already been considered in the discussion of objections to limiting this study to the use of radiosonde data. Another kind of objection might be made at this point: the chances of hitting on the most effective combination of six parameters as used for 0300 GMT data are slim, as there are 45 possible ways to combine them as in this paper. It is here that theory can be of much help in suggesting logical relationships and eliminating the need for testing meaningless combinations.

VERIFICATION

Several tests of the objective aids were made. Results for dependent data are summarized in contingency tables in table 9, and for independent data in table 10. Corresponding subjective forecasts regularly issued by the Miami WBAS during July and August 1952 were graded for comparison. Miami terminal aviation forecasts for the periods 0000–1200 EST and 1200–2400 EST were compared to objective forecasts made from 0300 GMT and 1500 GMT data respectively. Although the coded soundings are not transmitted until after the issuance of Miami terminal forecast, essential data were available locally to forecasters at the time of preparation of the forecast. Since the subjective forecasts are difficult to interpret quantitatively, only rain–no rain aspects were considered. Results are summarized in table 11. It is evident that during this period the objective forecasts were considerably better than subjective ones at 1500 GMT, and not quite as good at 0300 GMT.

Figure 14 presents graphically the correlation between the objective forecasts and observed rainfall for selected

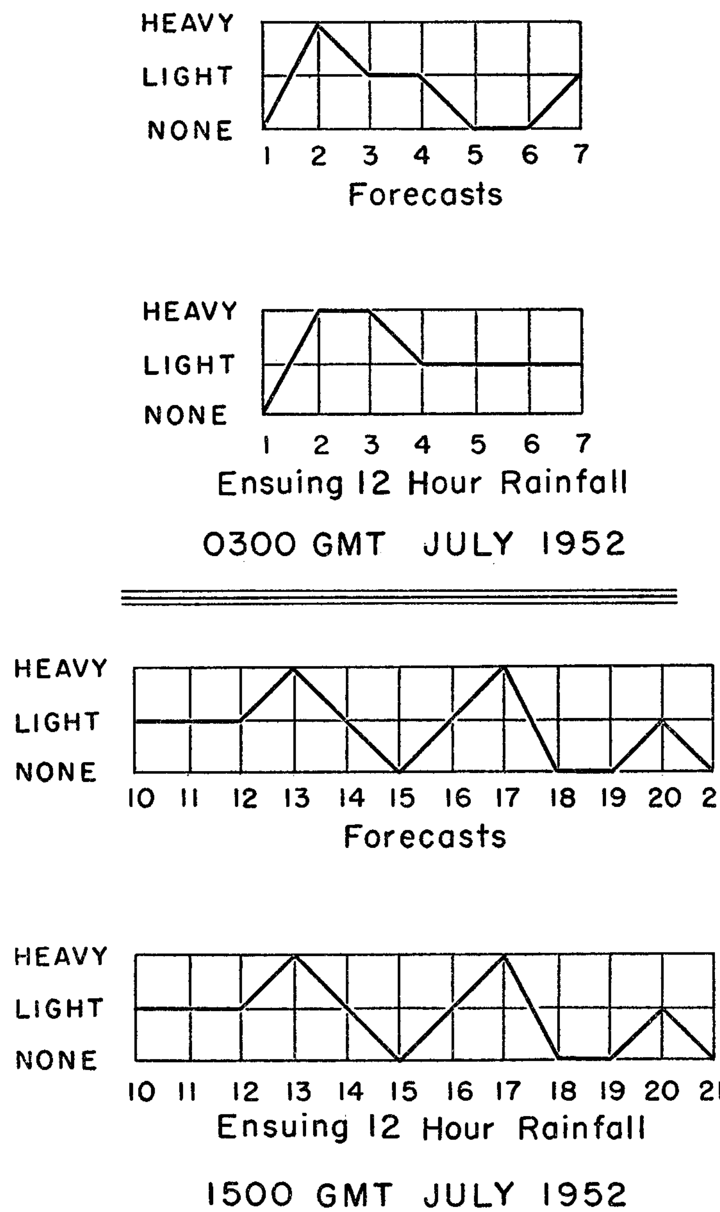

FIGURE 14.—Graphical comparison between objective forecasts and observed rainfall at Miami, Fla. for selected periods in July 1952. Abscissas are dates; ordinates, shower types as defined in figures 8 and 13.

TABLE 9.—*Verification of objective forecasts, dependent data*

July and August, 1948–51

0300 GMT

Forecast: "rain" or "no rain"
Criterion: trace line on figure 8

Observed	Forecast: Rain	No rain	Total
Rain	107	16	125
No rain	42	41	83
Total	149	57	206
Percent correct	72	72	72

Skill score 0.37.

Forecast: "heavy rain" or "not heavy rain"
Criterion: 0.30 line on figure 8

Observed	Forecast: Heavy rain	Not heavy rain	Total
Heavy rain	15	11	26
Not heavy rain	13	167	180
Total	28	178	206
Percent correct	53	94	88

Skill score 0.49.

1500 GMT

Forecast: "rain" or "no rain"
Criterion: trace line on figure 13

Observed	Forecast: Rain	No rain	Total
Rain	127	13	140
No rain	52	38	90
Total	179	51	230
Percent correct	71	75	72

Skill score 0.36.

Forecast: "heavy rain" or "not heavy rain"
Criterion: 0.20 line on figure 13

Observed	Forecast: Heavy rain	Not heavy rain	Total
Heavy rain	14	20	34
Not heavy rain	20	176	196
Total	34	196	230
Percent correct	41	90	83

Skill score 0.31.

TABLE 10.—*Verification of objective forecasts, independent data*

July 1952

0300 GMT

Forecast: "rain" or "no rain"
Criterion: trace line on figure 8

Observed	Forecast: Rain	No rain	Total
Rain	16	5	21
No rain	3	7	10
Total	19	12	31
Percent correct	84	58	74

Skill score 0.44.
Original skill score (dependent data) 0.37.

Forecast: "heavy rain" or "not heavy rain"
Criterion: 0.30 line on figure 8

Observed	Forecast: Heavy rain	Not heavy rain	Total
Heavy rain	1	1	2
Not heavy rain	2	27	29
Total	3	28	31
Percent correct	34	96	90

Skill score 0.33.
Original skill score (dependent data) 0.49.

1500 GMT

Forecast: "rain" or "no rain"
Criterion: trace line on figure 13

Observed	Forecast: Rain	No rain	Total
Rain	16	0	16
No rain	9	6	15
Total	25	6	31
Percent correct	64	100	71

Skill score 0.40.
Original skill score (dependent data) 0.36.

Forecast: "heavy rain" or "not heavy rain"
Criterion: 0.20 line on figure 13

Observed	Forecast: Heavy rain	Not heavy rain	Total
Heavy rain	3	1	4
Not heavy rain	2	25	27
Total	5	26	31
Percent correct	60	96	90

Skill score 0.62.
Original skill score (dependent data) 0.31.

TABLE 10.—*Verification of objective forecasts, independent data*—Continued

August 1952

0300 GMT

Forecast: "rain" or "no rain"
Criterion: trace line on figure 8

Observed	Forecast: Rain	Forecast: No rain	Forecast: Total
Rain	14	4	18
No rain	7	6	13
Total	21	10	31
Percent correct	67	60	65

Skill score 0.25.
Original skill score (dependent data) 0.37.

Forecast: "heavy rain" or "not heavy rain"
Criterion: 0.30 line on figure 8

Observed	Forecast: Heavy rain	Forecast: Not heavy rain	Forecast: Total
Heavy rain	0	0	0
Not heavy rain	6	25	31
Total	6	25	31
Percent correct	0	100	81

Skill score 0/0.
Original skill score (dependent data) 0.49.

1500 GMT

Forecast: "rain" or "no rain"
Criterion: trace line on figure 13

Observed	Forecast: Rain	Forecast: No rain	Forecast: Total
Rain	18	0	18
No rain	8	5	13
Total	26	5	31
Percent correct	69	100	74

Skill score 0.42.
Original skill score (dependent data) 0.36.

Forecast: "heavy rain" or "not heavy rain"
Criterion: 0.20 line on figure 13

Observed	Forecast: Heavy rain	Forecast: Not heavy rain	Forecast: Total
Heavy rain	0	6	6
Not heavy rain	2	23	25
Total	2	29	31
Percent correct	0	79	74

Skill score −0.13.
Original skill score (dependent data) 0.31.

July and August 1952 combined

0300 GMT

Forecast: "rain" or "no rain"
Criterion: trace line on figure 8

Observed	Forecast: Rain	Forecast: No rain	Forecast: Total
Rain	30	9	39
No rain	10	13	23
Total	40	22	62
Percent correct	75	59	69

Skill score 0.34.
Original skill score (dependent data) 0.37.

Forecast: "heavy rain" or "not heavy rain"
Criterion: 0.30 line on figure 8

Observed	Forecast: Heavy rain	Forecast: Not heavy rain	Forecast: Total
Heavy rain	1	1	2
Not heavy rain	8	52	60
Total	9	53	62
Percent correct	11	98	85

Skill score 0.13.
Original skill score (dependent data) 0.49.

1500 GMT

Forecast: "rain" or "no rain"
Criterion: trace line on figure 13

Observed	Forecast: Rain	Forecast: No rain	Forecast: Total
Rain	34	0	34
No rain	17	11	28
Total	51	11	62
Percent correct	67	100	73

Skill score 0.41.
Original skill score (dependent data) 0.36.

Forecast: "heavy rain" or "not heavy rain"
Criterion: 0.20 line on figure 13

Observed	Forecast: Heavy rain	Forecast: Not heavy rain	Forecast: Total
Heavy rain	3	7	10
Not heavy rain	4	48	52
Total	7	55	62
Percent correct	43	87	82

Skill score 0.25.
Original skill score (dependent data) 0.31.

TABLE 11.—*Verification of subjective forecasts of "rain" or "no rain" for July and August 1952. Compare with corresponding contingency table in table 10.*

0300 GMT

Observed	Forecast: Rain	Forecast: No rain	Forecast: Total
Rain	29	10	39
No rain	8	15	23
Total	37	25	62
Percent correct	78	60	71

Skill score 0.39.
Skill score for comparable objective forecasts 0.34.

1500 GMT

Observed	Forecast: Rain	Forecast: No rain	Forecast: Total
Rain	25	9	34
No rain	14	14	28
Total	39	23	62
Percent correct	64	61	63

Skill score 0.24.
Skill score from comparable objective forecasts 0.41.

periods in July 1952. That the agreement was not this good most of the time is evident from the skill scores; however, the fact that it was possible for any forecasts to stay so closely in phase with rapidly changing weather for even this short period is encouraging.

Since the preparation of the original manuscript, verification data for July, August, and September 1–20, 1953 have been compiled. These additional independent data have been combined with the independent data for July and August 1952 and are summarized in table 12.

CONCLUSIONS

Principal findings of this study may be summarized briefly as follows:

(1) The Showalter stability index is of quantitative value in the Miami area.

(2) Low level (1,000–900 mb.) mixing ratios are valueless in predicting summer showeriness at Miami following 0300 GMT, but are of value following 1500 GMT.

(3) Miami summer showers following 0300 GMT require an initial surge of absolute humidity from 850 to 550 mb., and these showers become heavier as this surge is intensified at 900 mb. and lessened at 750–550 mb.

(4) Miami summer showers following 1500 GMT require an initial surge of absolute humidity from 900 to 650 mb. and centered on 800 mb., and these showers become heavier as this surge is thickened and intensified (mostly at 750 and 1,000 mb.) and lessened at 650–500 mb.

(5) Three-day freezing levels and tendencies at 0300 GMT are of some quantitative value in summer shower forecasting at Miami.

TABLE 12.—*Verification of objective forecasts, independent data, July and August 1952, July, August, and September 1–20, 1953*

0300 GMT

Forecast: "rain" or "no rain"
Criterion: trace line on figure 8

Observed	Forecast: Rain	Forecast: No rain	Forecast: Total
Rain	73	18	91
No rain	25	26	51
Total	98	44	142
Percent correct	75	59	70

Skill score 0.32.
Original skill score (dependent data) 0.37.

Forecast: "heavy rain" or "not heavy rain"
Criterion: 0.30 line on figure 8

Observed	Forecast: Heavy rain	Forecast: Not heavy rain	Forecast: Total
Heavy rain	3	5	8
Not heavy rain	14	120	134
Total	17	125	142
Percent correct	18	96	87

Skill score 0.17.
Original skill score (dependent data) 0.49.

1500 GMT

Forecast: "rain" or "no rain"
Criterion: trace line on figure 13

Observed	Forecast: Rain	Forecast: No rain	Forecast: Total
Rain	72	6	78
No rain	43	18	61
Total	115	24	139
Percent correct	63	75	65

Skill score 0.23.
Original skill score (dependent data) 0.36.

Forecast: "heavy rain" or "not heavy rain"
Criterion: 0.20 line on figure 13

Observed	Forecast: Heavy rain	Forecast: Not heavy rain	Forecast: Total
Heavy rain	8	16	24
Not heavy rain	14	101	115
Total	22	117	139
Percent correct	36	86	78

Skill score 0.22.
Original skill score (dependent data) 0.31.

(6) Three-day 700 mb. heights and tendencies at 0300 GMT are of similar value.

Of greatest interest perhaps is the relationship between slight high level relative drying and intensified shower activity. Although convective instability has been related to tornado activity, there has been to my knowledge no suggestion that this is also related to ordinary air mass showers.

It is also significant that in summer the Showalter stability index values as computed from the Miami data are practically always within the range usually considered thundery. Nevertheless perhaps half our summer days are quite dry. A value of 1 or 2 is needed here to produce the activity gotten by 3 or 4 elsewhere, and our night criteria are a little different from daytime ones. This is offered as evidence in support of the hypothesis proposed early in this paper. Such an idea, indeed, is implicit in the writings of experienced forecasters like Hallenbeck [26], who stated "I am convinced that the only way in which any appreciable improvement in the accuracy of weather forecasts can be attained is to assign each forecaster to a limited territory . . . *and keep him there*" (italics his). If this hypothesis stands, there appears a need to inhibit the nomadic tendencies of forecasters and to provide them with time and incentives to explore and record for their successors the peculiarities of their own regions.

In the approach to the Miami shower problem presented here, the surface has only been scratched and more work is needed. It would be desirable to incorporate wind parameters and raob criteria into a single system, to extend the 1500 GMT mixing ratio parameter down to the 1,000-mb. level, and to improve the accuracy of the curves as time and additional data permit.

ACKNOWLEDGMENTS

Thanks are due Mr. Stanley Day for his interest and help. Valuable advice and help was also provided by Mr. R. C. Gentry, Mr. Wilmer L. Thompson, and Mr. Jack C. Thompson.

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