THUNDERSTORM FORECASTING IN THE ATLANTA, GA., AREA

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ABSTRACT

A quasi-objective method is presented for predicting the occurrence of thunderstorms in the Atlanta area during the 12-hour period beginning at 1330 EST in the months of July and August. Variables measuring moisture, stability, and circulation patterns at the 850- and 700-mb. levels are combined through the use of scatter diagrams to determine a tentative forecast. These "forecasts" were checked on two seasons of independent data and in actual use during four additional seasons. The independent data were later added to the dependent data and it was found that neither the analysis of the scatter diagrams nor the accuracy of the forecasts showed any appreciable change.

CONTENTS

INTRODUCTION

Forecasting the occurrence of thunderstorms is a problem which confronts forecasters in the Atlanta area almost daily during the summer season. Thunderstorms are evidently a result of many combinations of meteorological variables so that a complete solution to this problem would be exceedingly complex. Carlin [1], in his study of thunderstorms for Atlanta, relates their occurrence to several variables including sea level pressure, 3-hour pressure change, dewpoint, and temperature. He found that the values associated with the highest frequency of thunderstorm occurrence were those near the normal. Data showing the nonoccurrence of thunderstorms when these conditions were met were not compiled. Thus, while his report may be useful for the climatological information presented, it is of little help in actual forecasting because its use would result in too many forecasts of thunderstorms. His report concludes with the suggestion that thunderstorms in the area usually can be forecast by means of the parcel method of evaluating the Atlanta sounding, but our analysis of a large number of Atlanta soundings does not confirm this conclusion.

Norton [2] suggests several subjective aids to the forecaster in this area but such aids do not, in general, accurately indicate the relative weight to be applied to the different meteorological variables. In fact, unless such rules or aids are carefully tested, they may be misleading at times.

There are, however, numerous variables that the forecaster employs to arrive at a forecast but whose relative importance from one situation to another is not well understood. The purpose of this study was to measure some of these variables and then to weigh them in an objective manner so that the forecaster, with this aid, might quickly and easily arrive at a tentative forecast which is fairly good in itself. In the development of this aid, an attempt was made to satisfy the following four requirements: (1) The variables should be measured in as nearly objective a manner as possible. (2) The variables should be ones in common use so the forecaster may have opportunity to improve upon the aid through subjective reasoning. (3) The accuracy of the aid, when it is used as a forecast method in itself, should not be appreciably inferior to that of conventional forecasting. (4) The aid should be simple so that the forecaster does not spend a disproportionate part of his time arriving at a tentative forecast.

Subject to these requirements, the following procedure was adopted in developing the forecast aid. Measures of selected variables were compiled and then plotted on various scatter diagrams and finally combined into one diagram to produce a "forecast." The "forecasts" cover the 12-hour period from 1330 EST to 0130 EST. All data used in making the "forecasts" were taken from the 0300 GMT constant pressure and 0130 EST surface maps. The occurrence of thunderstorms was determined from the present or past weather on the subsequent 1930 EST and 0130 EST surface maps. Since the observations at the airport are not necessarily representative of the weather over the Atlanta area, a "thunderstorm day" was arbitrarily defined as one in which thunderstorms occurred at two or more of the five stations, Chattanooga, Birmingham, Macon, Augusta, and Atlanta, or, if one thunderstorm and two or more showers occurred at any of these stations. This area is larger than is desirable but still preferable to verifying on what occurs at a single station. The months of July and August of 1943, 1944, and 1945 were used to construct the scatter diagrams and the same months of 1946 and 1947 were used as test data.

SELECTION OF VARIABLES

A survey of thunderstorm occurrences at Atlanta shows that the majority occur during the afternoon and evening with relatively few occurrences during the morning hours. Since there are practically no warm frontal passages and few cold frontal passages in this area during the summer season, an important factor contributing to thunderstorm formation would seem to be diurnal heating, either directly or indirectly. However, the insolation available for afternoon heating is nearly constant during these months so that temperature advection and cloud cover play an important part. The use of the parcel method of evaluating the Atlanta sounding is of considerable help to the forecaster but he has been disappointed in these results all too frequently. Our experience suggests that heating from the surface during the daylight hours is not enough in itself to result in widespread thundershowers and thus is in agreement with findings of Byers and Rodebush [3] for Florida thunderstorms. Evidently, there are other factors which determine the difference between isolated thundershowers and numerous ones and which, at the same time, are more easily utilized and measured in an objective study.

At least three other factors which are important in forecasting thunderstorms in this area are (1) the humidity of the air mass, (2) its stability, and (3) the circulation aloft which will result in modification of the first two factors.

The surface dew point at 0130 EST at Atlanta was used as a measure of the humidity of the surface air mass. From a total of 158 cases, it was found that in the 15 cases when the dew point was less than 61° F., no thunderstorms were reported. Therefore, all cases with dew points below 61° were considered as "no-thunderstorm" forecasts and were not further considered. The humidity aloft was measured simply by the mixing ratio (dew points since January 1, 1949) at 850 and 700 mb. from the 0300 GMT sounding at Atlanta. A measure of stability was obtained through the temperature difference between 850 and 500 mb. at 0300 GMT at Atlanta. The change in stability was measured by the 24-hour change in this temperature difference and is positive with increasing instability.

The circulation aloft at both the 850- and 700-mb. levels over a line between Atlanta and Memphis was classified as flat gradient, cyclonic, or anticyclonic according to the following criteria: Flat gradient case—the average winds reported across the line were less than Beaufort force 3; cyclonic case—the average winds were force 3 or stronger and shifted cyclonically across this line, or the contour lines indicated a definite cyclonic shift and had a gradient of at least force 3; anticyclonic case—reported winds were force 3 or stronger with an anticyclonic wind shift or straight flow across this line, and, in this case, the anticyclonic or straight flow prevailed across this line. Some subjectivity is hereby injected into this scheme but this method seemed preferable to any other measure of the circulation that could be devised at the time.

COMBINATION OF VARIABLES

Thus, seven variables have been found which are considered here as measures of factors associated with thunderstorms. As the hypothesis of the relation of these variables to the subsequent occurrence of thunderstorms does not suggest their order of combination, they were paired in 12 scatter diagrams in what seemed to be a logical order. That is, for each of the circulation types, the moisture value at 850 mb. was plotted on a scatter diagram against that at 700 mb., and stability was plotted against the change in stability and the relationships to thunderstorm occurrence were analyzed. There are, of course, many other possible combinations of these variables but the one used here seemed to be satisfactory and no attempt was made to improve the study through different combinations of the same variables.

These variables were combined as shown schematically in figure 1. Six scatter diagrams were used (fig. 2) in which the mixing ratio at 850 mb. (W_{850}) was plotted against that at 700 mb. (W_{700}), but only two of these are used on any one date. The mixing ratios were plotted on one of these diagrams, figure 2a, 2b, or 2c, according

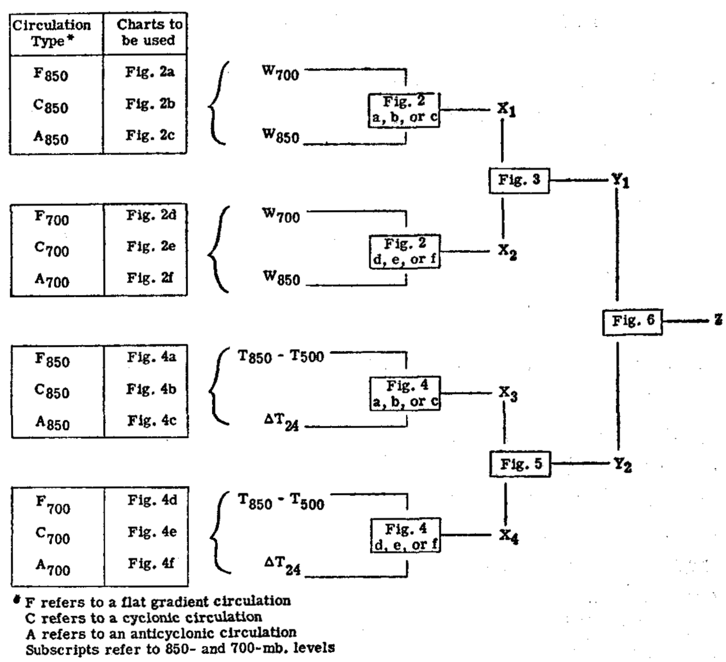

Figure 1.—Schematic diagram showing combination of variables. See text for definition of variables.

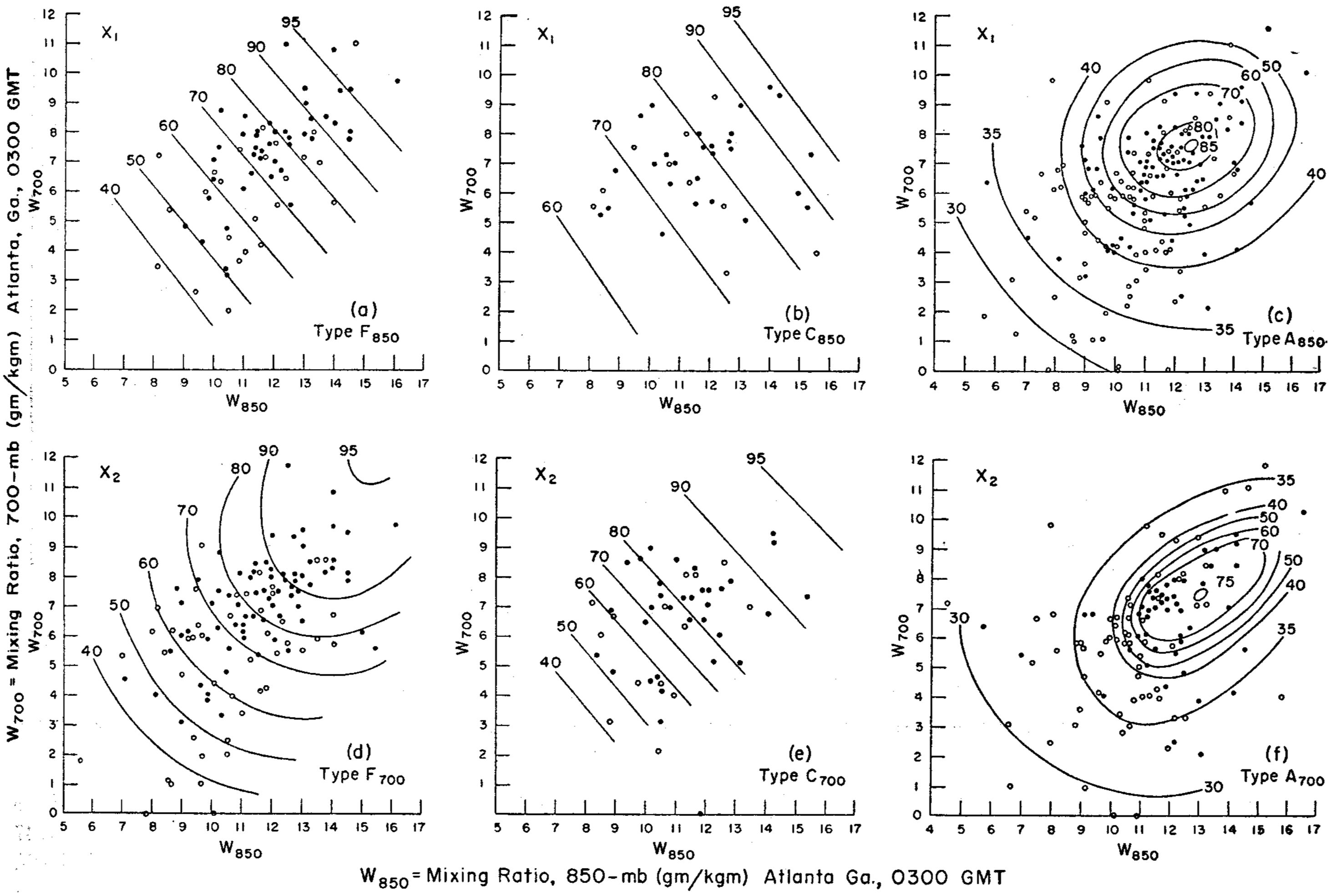

Figure 2.—Diagrams showing probability of "thunderstorm days" for three classes of circulation at 850 and at 700 mb. from five seasons of data. The observed weather, "thunderstorm day" (●) or "no-thunderstorm day" (○), is plotted as a function of the mixing ratio at 850 and 700 mb. The solid lines represent isopleths of frequency of thunderstorm occurrence and define variables X_1 and X_2 which are plotted as coordinates in figure 3.

to the circulation (flat (F), cyclonic (C), or anticyclonic (A)) at the 850-mb. level. Next, these same data were plotted on one of three other diagrams, figure 2d, 2e, or 2f, depending upon the 700-mb. circulation. Then isopleths of equal frequency of thunderstorm occurrence were drawn on each of these six diagrams. Thus, two probabilities, X_1 and X_2 of the occurrence of thunderstorms were obtained for each date from these humidity and circulation data. These probabilities were combined into another scatter diagram, shown in figure 3, and probability lines again drawn, resulting in one probability, Y_1, which depends upon the humidity and circulation at both the 850- and 700-mb. levels.

Six other scatter diagrams, figure 4, were utilized to combine the measure of stability ($T_{850}-T_{700}$) and the 24-hour change in stability (ΔT_{24}). The procedure was the same as that used in the case of mixing ratios. The stability measure was plotted against the stability change on one of these diagrams, figure 4a, 4b, or 4c, depending upon the circulation at 850 mb. These same data were plotted on figure 4d, 4e, or 4f, according to the circulation at 700 mb. Isopleths of equal frequency of thunderstorms as related to these variables were drawn on these diagrams and resulted in two more probabilities, X_3 and X_4, for each date. These two probabilities were combined into the single diagram shown in figure 5 and resulted in one probability, Y_2, which depends upon the stability, change in stability, and circulation at 850 and 700 mb. Finally, this probability (Y_2) from figure 5 was combined with the probability based upon humidity and circulation (Y_1) from figure 3 into the forecast diagram shown in figure 6 which gave a final probability, Z.

VERIFICATION OF METHOD

Figure 6 was used to determine a "forecast" for the Atlanta area. Using a probability of 50 percent or greater as a forecast of a "thunderstorm day", the skill

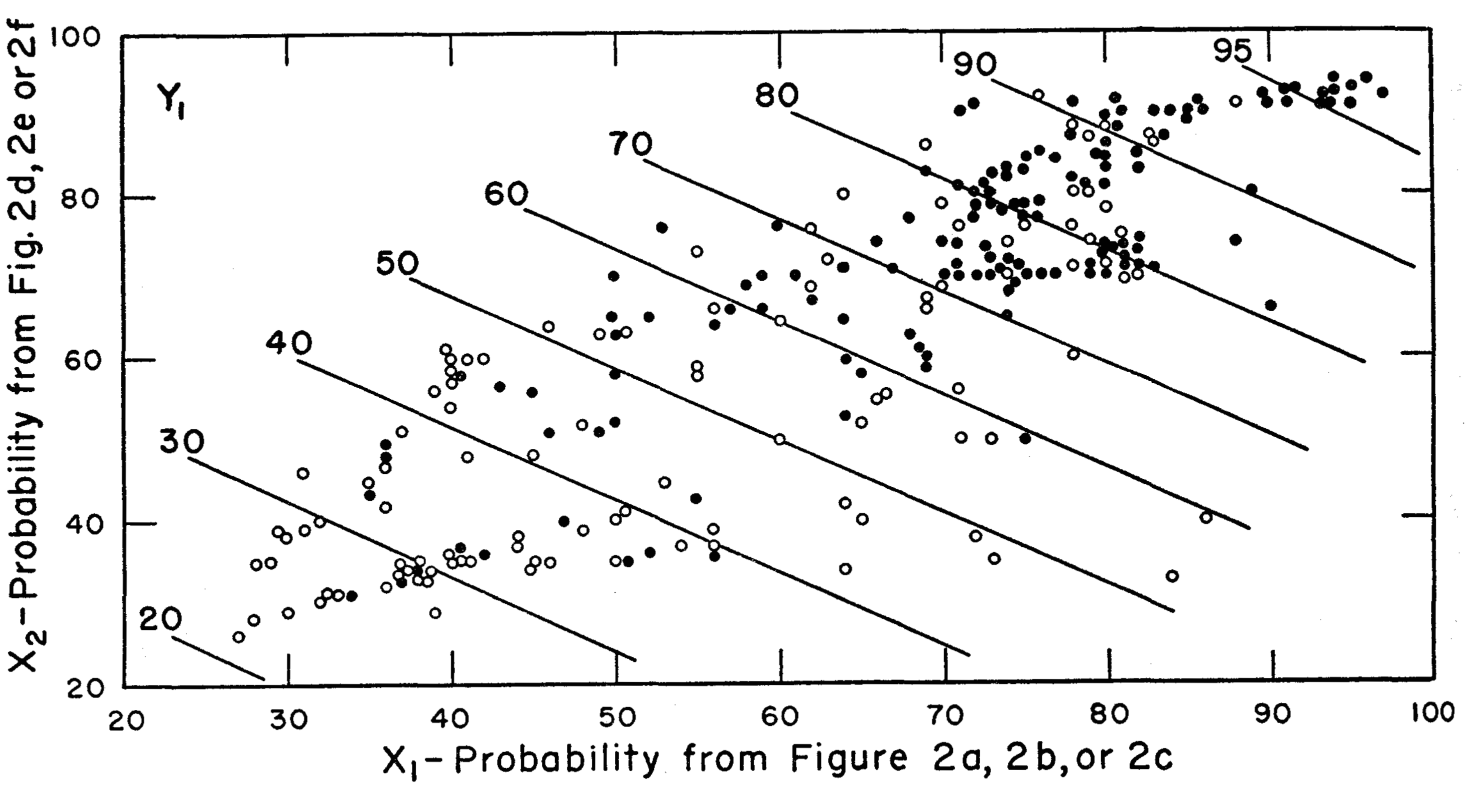

FIGURE 3.—Diagram showing probability of "thunderstorm days" as a function of X_1 (from fig. 2a, 2b, or 2c) and X_2 (from fig. 2d, 2e, or 2f). The solid lines represent isopleths of frequency of thunderstorm occurrence and define a variable Y_1, which is plotted as the abscissa in figure 6.

TABLE 1.—*Contingency tables showing verification of objective forecasts based on (a) dependent data, (b) independent data, and (c) data for a period of actual use*

(a) Dependent data 1943, 1944, 1945		Forecast: Thunderstorm	Forecast: No thunderstorm	Total	
Observed	Thunderstorm	73	6	79	Skill score: .62
	No thunderstorm	24	55	79	Percent correct: 81
	Total	97	61	158	

(b) Independent data 1946, 1947		Forecast: Thunderstorm	Forecast: No thunderstorm	Total	
Observed	Thunderstorm	54	8	62	Skill score: .56
	No thunderstorm	19	43	62	Percent correct: 78
	Total	73	51	124	

(c) Actual use data 1948, 1949, 1950, 1951		Forecast: Thunderstorm	Forecast: No thunderstorm	Total	
Observed	Thunderstorm	126	13	139	Skill score: .53
	No thunderstorm	43	66	109	Percent correct: 77
	Total	169	79	248	

score[1] for dependent data was .62 with 81 percent of the cases correctly forecast. The seasons 1946 and 1947 were used to test this forecasting aid as a method in itself. Again using a probability of 50 percent or greater as a forecast of a "thunderstorm day", the skill score was .56 with 78 percent of the cases correctly forecast. This aid was in actual use during the 1948, 1949, 1950, and 1951 seasons and the skill score for these four seasons was .53 with 77 percent of the cases correctly forecast. Contingency tables showing these verification results are given in table 1.

A direct comparison between the "forecasts" from this aid when tested as a method and the official forecasts for the Atlanta area is not entirely valid as there are differences in area and, further, the official forecasts for Atlanta do not express a categorical forecast of thunderstorms or no-thunderstorms. However, a subjective verification of the official forecasts suggests little real differences in the overall accuracy between the forecasts by conventional methods and those from this aid when considered as a method.

[1] The skill score, S, as used here is defined as

$$S=\frac{C-E}{T-E}$$

where C=number of correct forecasts, E=number of forecasts expected to be correct due to chance, and T=total number of forecasts. The value of E for forecasts of "thunderstorm days" and "no-thunderstorms" is given by

$$E=PF+N\,(1-F)$$

where P=number of forecasts of "thunderstorm days" during the period covered by the forecasts, N=number of forecasts of "no-thunderstorms" during this period, F=relative frequency of occurrence of thunderstorm days during this period.

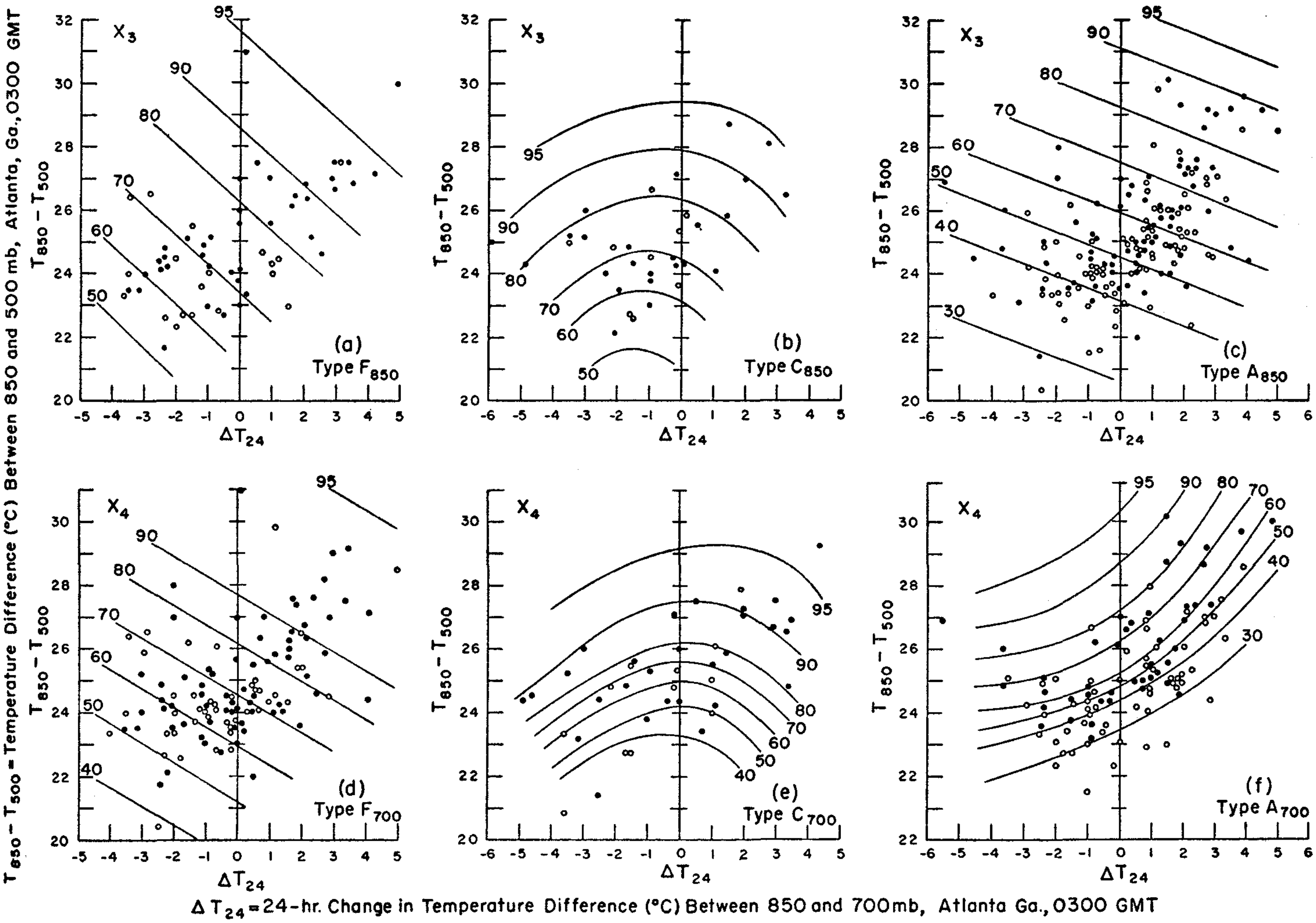

FIGURE 4.—Diagram showing probability of "thunderstorm days" for three classes of circulation at 850 and 700 mb. from five seasons of data. The observed weather is plotted as a function of the temperature difference between 850 and 500 mb. and the 24-hour change in this temperature difference. The solid lines represent isopleths of frequency of thunderstorm occurrence and define variables X_3 and X_4 which are plotted as coordinates in figure 5.

The original scatter diagrams contained data from only three seasons. Then after the independent data had been used in checking this study, these data were added to the diagrams and they were reanalyzed. However, there were no important differences either in the analysis or the results, so the diagrams shown here and those in use at Atlanta contain five seasons of data. The accuracy during the 1948, 1949, 1950, and 1951 seasons was not appreciably different from the independent data so it seems that any increase in the sample size would not materially affect the results of this study.

FURTHER INVESTIGATIONS

Some other measures of the circulation and humidity values were attempted but the results were not encouraging. An indication of the sea level pressure distribution might be the position of the Bermuda High, or a cell from this High that has moved westward. Two months of data (July and August, 1943) were used and a thunderstorm or no-thunderstorm symbol plotted on a map at the apparent center of any sea level High over the southeastern United States or as far eastward as Bermuda. There was no marked differentiation between the thunderstorm or no-thunderstorm cases.

Presumably the moisture which will move over a station or an area is of more importance than the original humidity values. An attempt was made to estimate the moisture values upstream that would be advected over the Atlanta area. But, as most forecasters in this area know, moisture values on the constant pressure charts do not move in an orderly fashion over this area during the summer season. Presumably this difficulty is largely due to convection. Advective moisture values as used here apparently contribute nothing more and also introduce other problems and so were not further considered.

As it might be expected that the direction of the wind flow aloft would have some relation to thunderstorm occurrences, two seasons of data (July and August, 1943

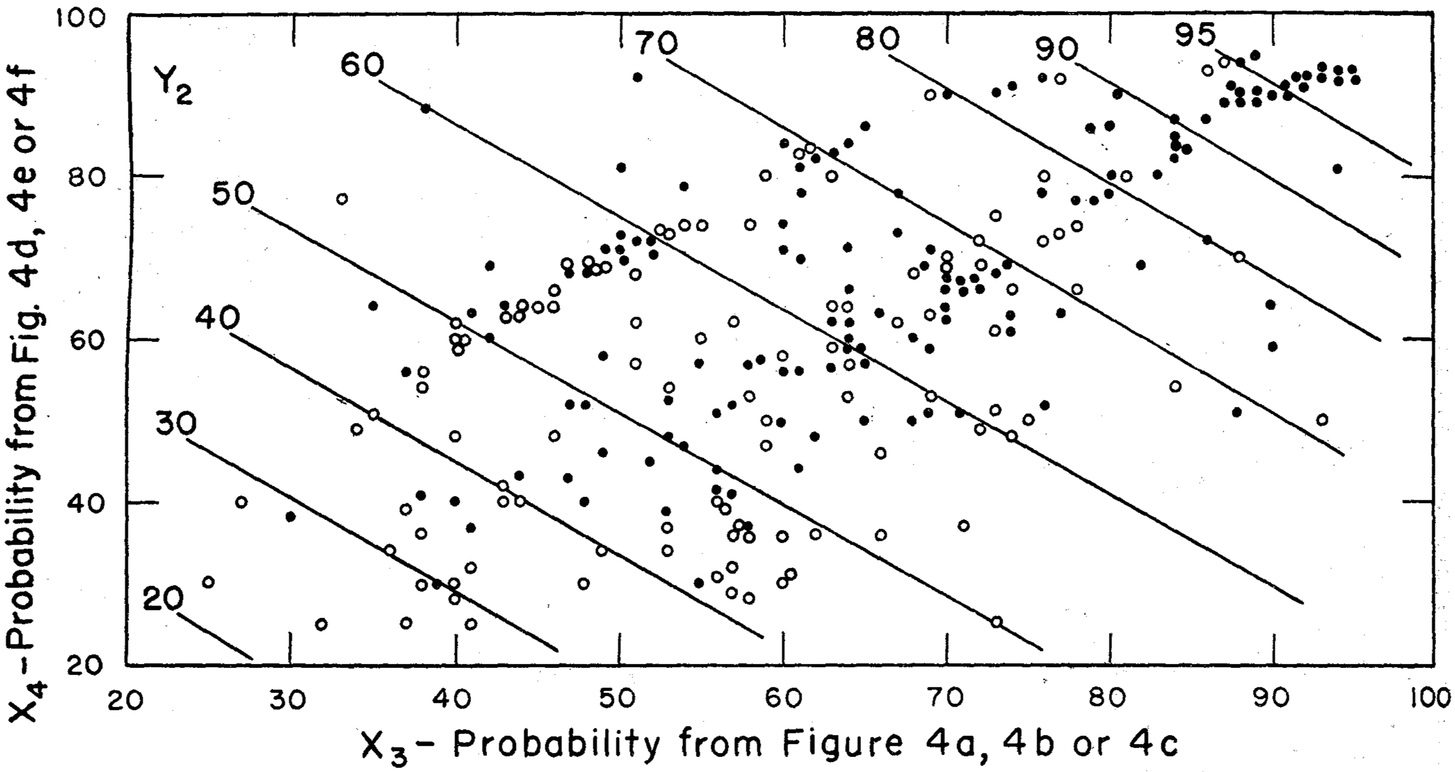

FIGURE 5.—Diagram showing probability of "thunderstorm days" as a function of X_3 (from fig. 4a, 4b, or 4c) and X_4 (from fig. 4d, 4e, or 4f). The solid lines represent isopleths of frequency of thunderstorm occurrence and define a variable Y_2, which is plotted as the ordinate in figure 6.

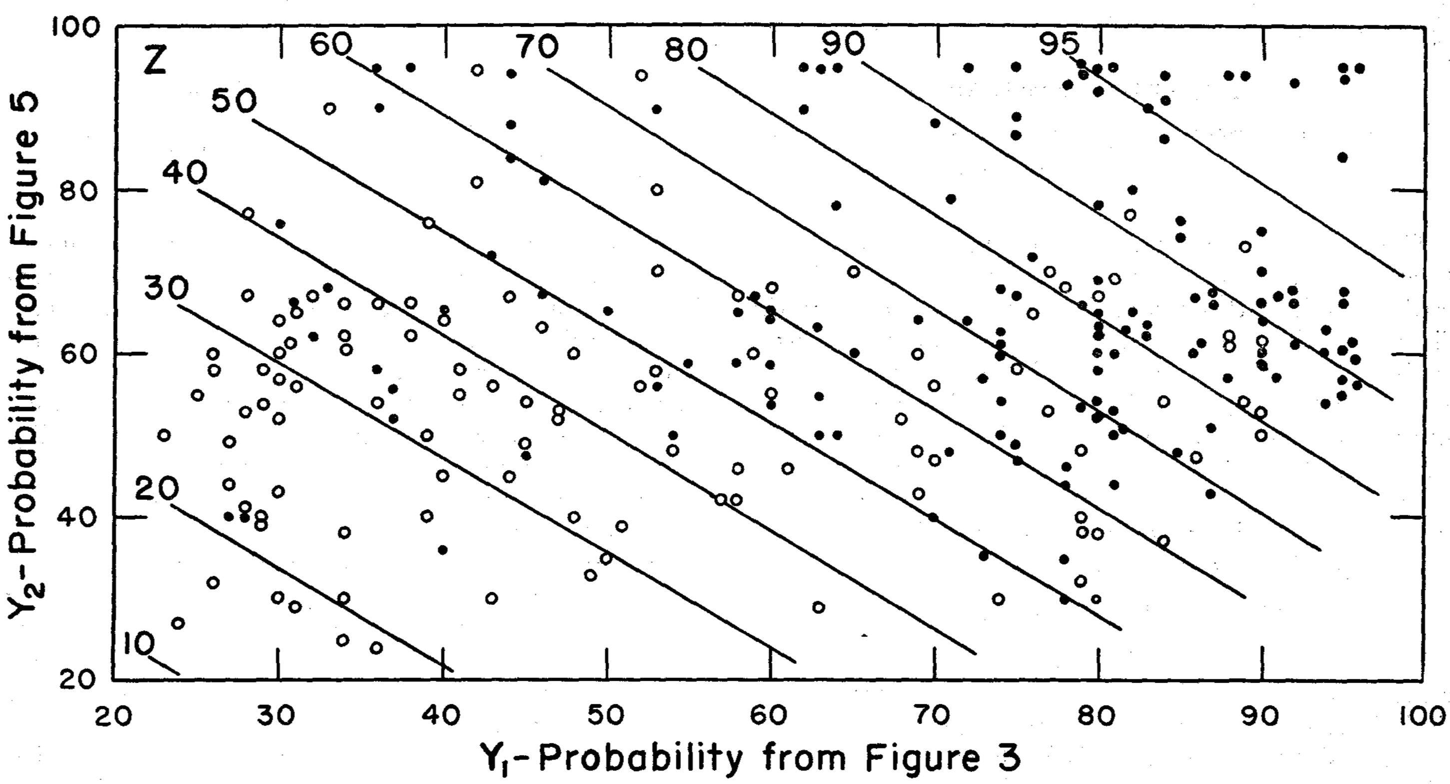

FIGURE 6.—Diagram showing probability (Z) of "thunderstorm days" as a function of Y_1 (from fig. 3) and Y_2 (from fig. 5). The 50 percent probability line was used to determine a categorical "forecast" for the Atlanta area.

and 1945) were compiled and studied for such a relationship. With winds at the 700-mb. level between south and west, 15 "thunderstorm days" occurred in 17 cases. Winds from other directions showed little promise in separating thunderstorm from no-thunderstorm days and wind speed appeared to be unimportant in all cases. Because wind data at this level is sometimes not available and the relationship was not particularly good as tested here, no further attempt was made toward utilizing wind directions in this study.

The moisture and stability measures in this study were taken from the Atlanta sounding only, so it should be expected that if there were thundershowers in the vicinity at the time of the sounding, the probability of thunderstorms given by the graphs would be high. This was found to be generally true. During the 1949 season there were 34 days with thunderstorms or lightning reported at Atlanta during the afternoon or evening and 31 forecasts for "thunderstorm days" for the following day resulted on these diagrams. Of the ten errors made by the diagrams during this season, seven followed thunderstorms at Atlanta on the previous day. Evidently a large portion of the errors are caused in this manner. Future work on this study should therefore take into account whether or not a thunderstorm occurred in the vicinity at the time of the sounding, but our attempts to utilize advective moisture have thus far proven inadequate.

CONCLUSION

The principal advantage of this forecast aid lies in its simple application along with relatively good forecast results. While the "forecast" is based largely upon the sounding at Atlanta, the forecaster is in a position to determine probable changes in this sounding with time and thus improve upon the accuracy achieved by the aid alone. And, as already suggested, less consideration should be given to those cases which follow thunderstorms in the Atlanta vicinity near the time of the sounding.

The question of when and where thunderstorms will occur, particularly over the airport at Atlanta, is still unanswered although the probability increases as the number of thunderstorms increases. In general, the number of thunderstorms in the Atlanta area is proportional to the probability of occurrence as found in this study.

Study on shower and thunderstorm forecasting in this area is being continued with these principal objectives: (1) to reduce the size of the area used for verification; (2) to incorporate more upper air data into the study; (3) to improve the accuracy of shower forecasts with, if necessary, less emphasis upon the occurrence of thunder itself.

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