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NMC OFFICE NOTE 48

RELATION BETWEEN MONTHLY MEAN CLOUDINESS AND PRECIPITATION

by

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Introduction

The work summarized in this report is essentially an up-dating of an earlier study by Taubensee (1964) designed to provide an approximate relationship between precipitation and cloudiness for use in a thermodynamic model for long-range forecasting experiments (Adem, 1965).

The main differences between this and the study of Taubensee are that the latter made use of average cloudiness and total precipitation for the two seasons summer 1962 and winter 1962-63 and for 44 stations distributed over a large part of the Northern Hemisphere; whereas this study is based mainly on monthly values for 48 stations within the coterminous United States (U. S.), and for the two individual months January and July 1968.

These differences make it difficult if not impossible to compare the two studies, or to decide whether or not the new results should be used in preference to the earlier ones. Nevertheless, it can be said in summary that both studies arrive at essentially the same conclusion: There is a very poor correlation between mean cloudiness and total precipitation, so that the weak relationship should be used only as a stop-gap measure pending the development of a more exact method for generating, within the model, cloudiness and precipitation independently of one another.

Both studies suggest that "normalizing" the anomalies of cloudiness and precipitation, by dividing by their respective climatological means ("normals"), does not help at all. A more effective method of normalization will be discussed in the conclusions.

Data Processing and Results

Forty-eight weather stations were selected, evenly distributed over the U. S., and their anomalies of precipitation and cloudiness were determined for the months of January and July 1968 from published data (ESSA, 1968). The climatic normals of precipitation are for the 30-year period 1931 to 1960; while the cloudiness normals were for different number/of years, varying from 5 to 30 or more. These inhomogeneous and inconsistent normals probably lead to poorer results than might otherwise have been obtained.

"Scatter diagrams," or plots, of one anomaly against the other are shown as Figures 1 and 2. The data have been separated into 3 different areas of the U. S. (see symbol designators on the figures), but visual inspection suggests no important differences in the relationships from one sector to another. Therefore, only the relationship indicated by the whole data sample will be discussed in the following paragraphs.

The rather small (linear least squares) correlation coefficients relating the two parameters (0.55 for winter and 0.33 for summer) are made evident by the large scatter of the points. This rather poor

relationship is due mainly to the fact that (as pointed out by Taubensee) many of the clouds are non-precipitating types. However, the non-uniformity of the cloud normals probably accounts for a significant but unknown fraction of this scatter.

It will be noted, in both months, that when the precipitation anomalies are unusually large, the corresponding cloud anomalies tend to be less than they are for smaller precipitation anomalies. This may be due to the possibility that during months with heavy precipitation, most of it falls from relatively short-lived cumiliform clouds, which cover less of the sky, on the average, but are more efficient rainfall producers than the stratiform clouds. This effect also tends to reduce the linear correlation coefficient.

Lines of best fit (shown in the figures) were determined by the method of least squares, and are defined as lines bisecting the two linear regression lines (also shown). A line of best fit is preferable to either of the regression lines if the objective is to discover the best physical linear relationship between any two variables. However, if the objective is to estimate or predict one parameter from the other, then one or the other of the two regression lines should be used. Thus, if cloudiness is to be estimated from precipitation, the regression line having the smaller slope (the one with coefficients a and b) should be used; whereas if precipitation is to be estimated from cloudiness, the other regression line (coefficients c and d) is the proper one.

In the thermodynamic model, the total water content of precipitation is considered equivalent to and may therefore be expressed in terms of the heat of condensation, using a fixed latent heat of vaporization of 600 cal gr^{-1}. For this reason, the summary of the coefficients of the lines of best fit, and those of the regressions of cloudiness as a function of precipitation, shown in Table 1 are given in terms of the heat of condensation (G5) in cal cm^{-2} day^{-1} (ly/day). The coefficients corresponding to Taubensee's lines of best fit are included for comparison. It should be pointed out that Taubensee determined the lines of best fit by visual inspection, and did not compute the regression lines.

The differences in the coefficients of the lines of best fit between Taubensee's and the present study may be due to a number of factors, including the previously-stated differences in the data sources and in the methods for obtaining the lines. There is no simple criterion to decide which is better.

A special word should be said about the coefficients e and a. These are all positive and (except for one case) about the same magnitude, implying that when the anomaly of precipitation is zero the anomaly of cloudiness is slightly positive. The consistency of this result is rather misleading, in view of the fact that these coefficients can appear only as a result of random sampling errors and the non-representativeness of the normals. If the results had been worked up from a long homogeneous sample at each station, in which the normal value of each parameter is

defined as the sample mean for each station and calendar month, then the coefficients a and e would have to be zero by definition. For this reason it is recommended that these coefficients be omitted for use in the model.

Some Additional Results

Some additional results were obtained using 325 values of average cloudiness and precipitation for each of 25 5-degree squares over the U.S. and for the 13 months February 1967 to February 1968. These data had already been compiled for two other projects (Clapp, 1970 a and b).

Since the anomalies of the two parameters were not computed, and since the data are for only one year and for a wide variety of local climates, it is not possible to obtain a relationship between cloudiness and precipitation which correctly accounts for changing seasons and climate; nor can the results be compared directly with those discussed in the previous section. Nevertheless, it is felt that the results are an interesting supplement to the previous ones.

A simple plot of cloudiness against precipitation for all 325 cases (not shown) reveals an almost random scatter with practically zero correlation. However, when the data are separated by classes of ground (surface) albedo (a parameter also computed as part of the other studies) interesting relationships emerge, probably due to the fact that the surface albedo is related to the climatic normals of cloudiness and precipitation.

In Figures 3 and 4, the solid dots are plots of cloudiness vs precipitation for the winter months of 1967 and 1968 and the summer months of 1967, for all cases having surface albedoes between 8 and 11 percent (the lowest albedo category). The full lines are lines of best fit for these data, drawn in by "eye." The dashed lines (or the curve) are drawn to fit the data for the next higher surface albedo categories, but that data is not plotted.

In both winter and summer the lines of best fit appear to separate naturally into two segments at a precipitation amount of about 4-1/2 inches. Below this value cloudiness increases with rainfall at about the same rate as that obtained previously (compare the slope of the lines of best fit in the lower left of Figures 3 and 4 with those in the lower right of Figures 1 and 2); while at higher precipitation values cloudiness decreases with increasing precipitation. No doubt this reversed slope is exaggerated because of the inability to remove the climatological normals, but it probably also reflects the same dependence of cloud type on precipitation, as suggested previously.

In summer, the relationship between cloudiness and precipitation for surface albedoes between 12 and 20 percent (dashed curve) appears to depart from the line of best fit for the lowest albedo category (solid line) when precipitation is small, but coincides with the latter as precipitation increases. In winter, the line of best fit for surface albedoes between 12 and 16 percent appears to be quite different from the others.

At higher surface albedoes for both summer and winter, and for all cases in the other two seasons, the correlation between the two parameters is too poor to establish a meaningful relationship. It is not known whether or not the poor results for spring and fall will also be revealed when anomalies of the two parameters are related.

Conclusions

An effort has been made to bring up to date the relationship between monthly mean cloudiness and total precipitation. The results, and a comparison with a previous study by Taubensee (1964), are summarized in Table 1 and in Figures 1 and 2. In general, the new results confirm the previous work of Taubensee. The only really new finding is that the tendency for cloudiness to increase with increasing precipitation appears to break down and become reversed for extremely large precipitation anomalies, perhaps due to a basic change in the relative frequency of the different cloud types. However, failure to consider this reversal probably will not adversely affect predictions from the present version of the thermodynamic model, because the predicted anomalies of condensation heating tend to be very small.

Perhaps a small improvement in the relationship between the two parameters might have been achieved if they had been properly normalized by expressing them as percentiles (equally probable classes), rather than by the chosen (but incorrect) method of dividing by the climatological normals. However, while quintiles (20-percent classes) of monthly total

precipitation over the globe are available for many land stations and for many years (World Meteorological Organization, volume for each year), corresponding percentiles of monthly-mean cloudiness are apparently non-existent. These can be worked up using available historical files of mean cloudiness (e.g. ESSA, volume for each year), but the considerable work involved is not justified, because the corresponding necessary percentile class limits of precipitation are unavailable over the sea.

Instead, it is recommended that mean cloudiness be statistically related directly to the mean temperatures predicted by the model. A source of monthly mean cloudiness anomalies for the eastern North Pacific is currently being worked up each month from data of the National Marine Fisheries Service (formerly Bureau of Commercial Fisheries). The 13-month record of mean cloudiness over the U.S. (discussed previously) can also be used for this purpose. Plans are presently underway to look into this matter.

Table 1: Coefficients of lines relating the anomalies of cloudiness (E_{DN}) and heat of condensation (G_{5DN}) for selected months or seasons. Cloudiness is expressed in 100ths of sky covered and heat of condensation in ly/day.

Author	Data from:	Lines of Best Fit	
		e	f
Clapp	U.S., January 1968	2.37	0.199
Taubensee	N.H., Winter, 1962-63	8.00	0.330
Clapp	U.S., July 1968	2.15	0.118
Taubensee	N.H., Summer 1962	1.90	0.195

		Regression Equation	
		a	b
Clapp	U.S., January 1968	1.95	0.093
Clapp	U.S., July 1968	2.11	0.024

References

Adem, J., Experiments aiming at monthly and seasonal numerical weather prediction. Monthly Weather Review, vol. 93, No. 8, August 1965, pp. 495-503.

Clapp, P. F., Modification of an empirical short-wave radiation formula using satellite observations. (Unpublished report of Extended Forecast Division; submitted for publication), December 1970, 25 pp.

Clapp, P. F., Estimating monthly precipitation from satellite data. NMC Office Note 46, November 1970, 12 pp.

ESSA (Environmental Science Services Administration, now NOAA), Local Climatological Data, Annual Summary, 1968 (other volumes for each year).

Taubensee, R. E., Seasonal precipitation related to cloudiness. (Unpublished study, Extended Forecast Division, NMC, ESSA), November 1964, 6 pp.

World Meteorological Organization, Monthly Climatic Data for the World, WMO and ESSA (NOAA), Asheville, N. C., U.S.A. (volume for each year).

Figures

Fig. 1. - January 1968. Monthly anomalies of precipitation related to cloudiness for 48 stations over coterminous United States. Heavy line (with coefficients e and f) is line of best fit; light line (a and b), regression of cloudiness on precipitation; light line (c and d), regression of precipitation on cloudiness. See figure for definition of symbols and units.

Fig. 2. - July 1968. Monthly anomalies of precipitation related to cloudiness for 48 stations over coterminous United States. See Fig. 1 for legend.

Fig. 3. - Winter (Dec. and Feb. 1967, Jan. and Feb. 1968). Average monthly precipitation related to cloudiness for 5-degree "squares" over coterminous United States. Plotted data are for all cases with surface albedo of 8 to 11 percent, with corresponding lines of best fit (solid); equations for each line segment are below lines. Dashed line of best fit is for all cases with surface albedo 12 to 16 percent (data not shown). See figure for units.

Fig. 4. - Summer (June, July and Aug. 1967). Average monthly precipitation related to cloudiness for 5-degree "squares" over coterminous United States. Dashed curve of best fit is for cases with light precipitation having surface albedo 16 to 20 percent (data not shown). Otherwise legend same as for Fig. 3.

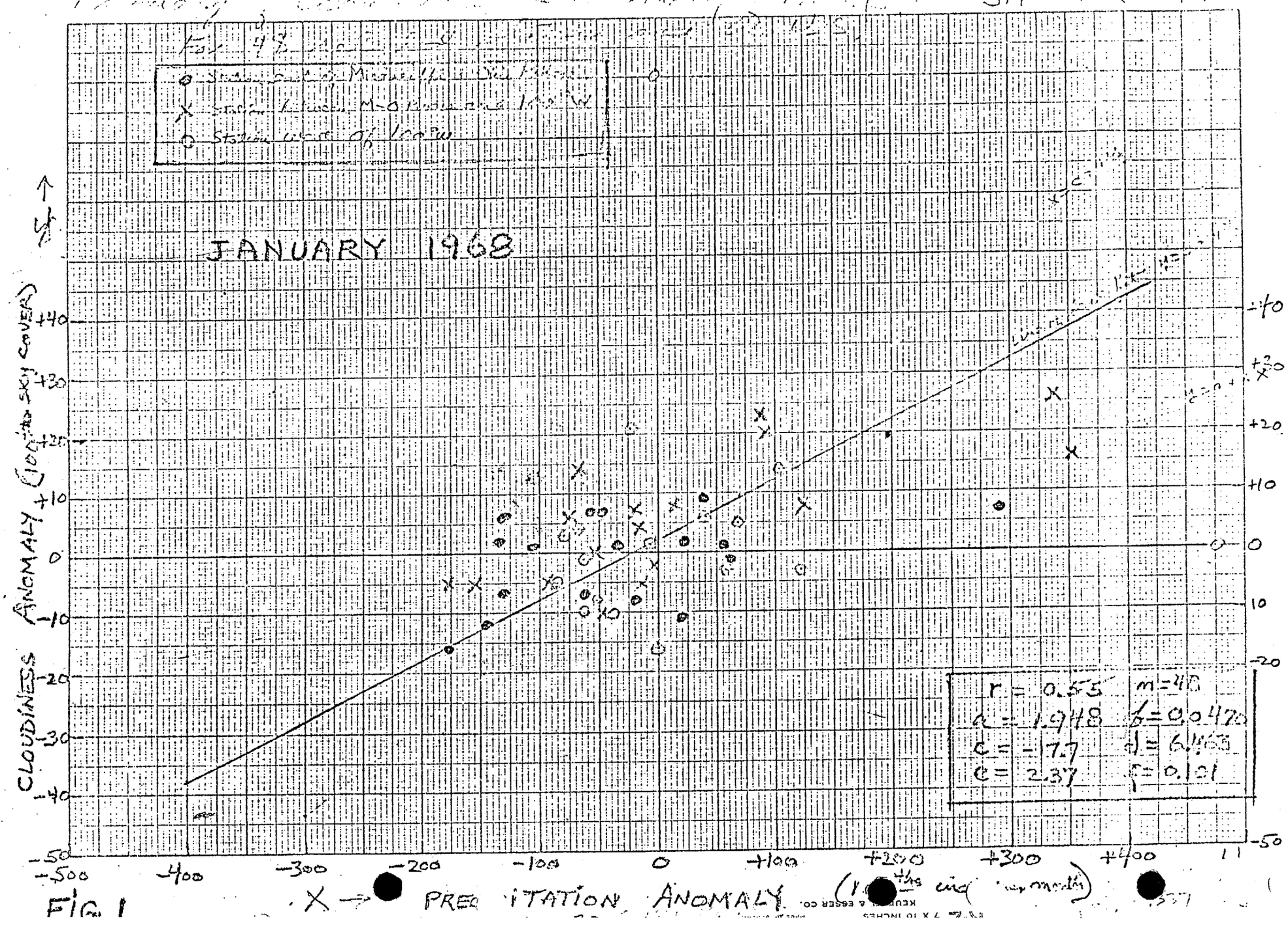
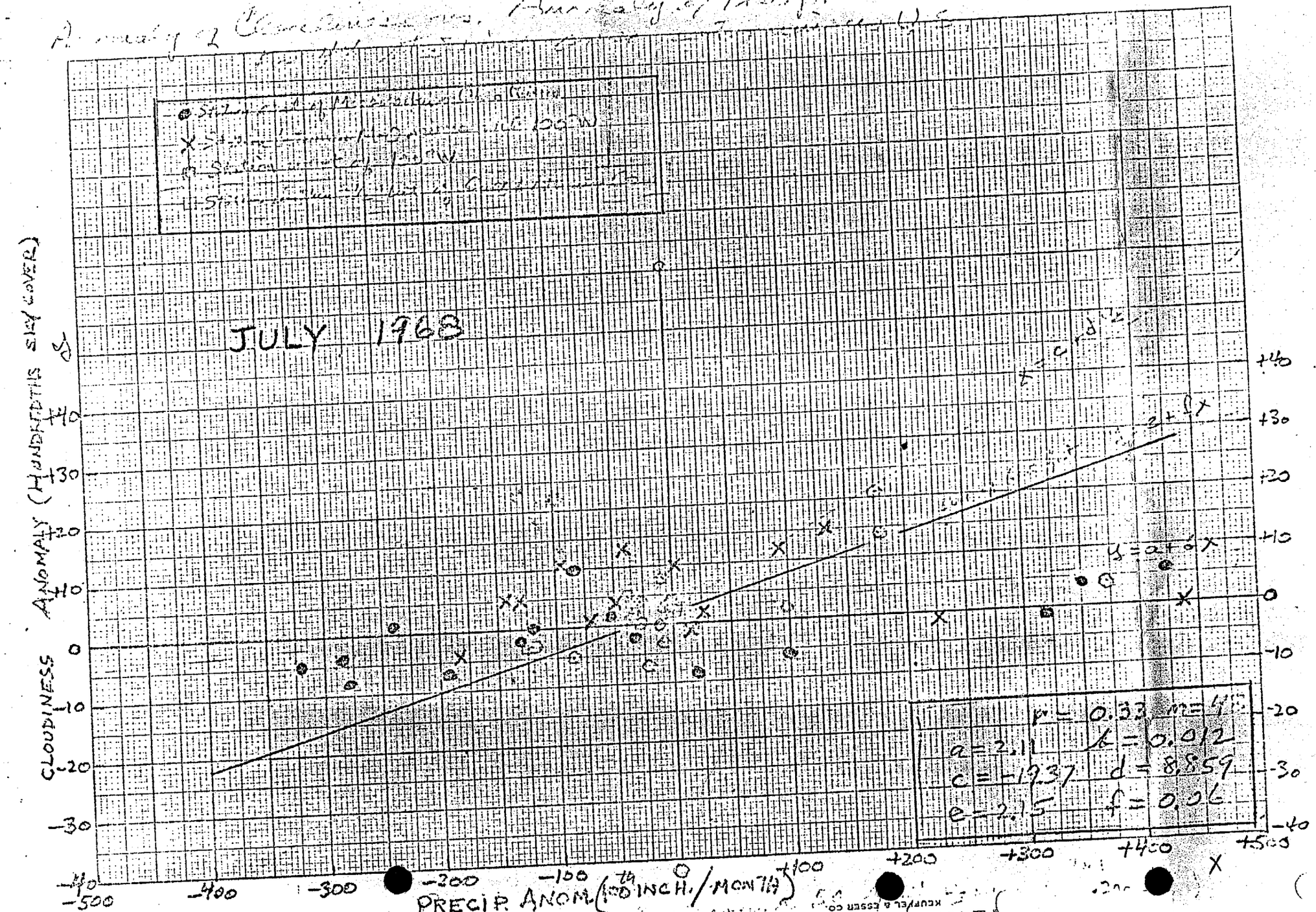

JANUARY 1968
CLOUDINESS ANOMALY (TOTAL SKY COVER)
PRECIPITATION ANOMALY
r = 0.55
a = 1.948
c = -7.7
e = 2.37
m = 48
b = 0.0420
d = 6.465
f = 0.101
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
-500
-400
-300
-200
-100
0
+100
+200
+300
+400

FIG. 1


JULY 1968
CLOUDINESS ANOMALY (TENTHS SKY COVER)
PRECIP. ANOM. (100th INCH/MONTH)
+40
+30
+20
+10
0
-10
-20
-30
-40
-500
-400
-300
-200
-100
+100
+200
+300
+400
+500
y = a + bx
y = c + dx
r = 0.33
n = 4
a = 2.11
b = 0.012
c = -1.37
d = 8.859
e = 2.15
f = 0.06

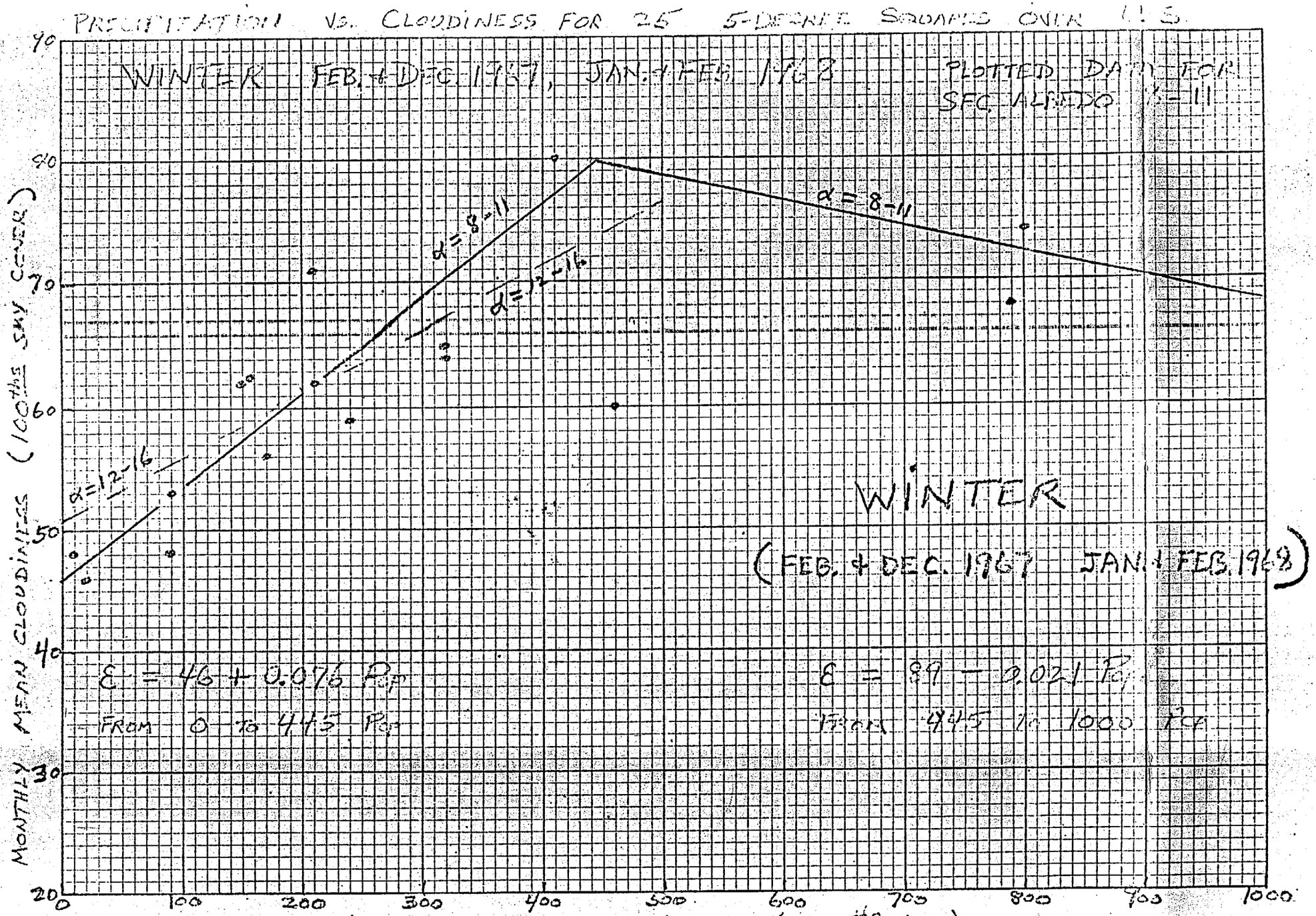

PRECIPITATION VS. CLOUDINESS FOR 25 5-DEGREE SQUARES OVER U.S.
WINTER FEB. + DEC. 1967, JAN. + FEB. 1968
PLOTTED DATA FOR SFC. ALBEDO 8-11
α = 8-11
α = 8-11
α = 12-16
α = 12-16
WINTER
(FEB. + DEC. 1967 JAN. + FEB. 1968)
ε = 46 + 0.076 P_cp
FROM 0 TO 445 P_cp
ε = 89 − 0.021 P_cp
FROM 445 TO 1000 P_cp
MONTHLY MEAN CLOUDINESS (100ths SKY COVER)
MONTHLY TOTAL PRECIPITATION (100ths INCH)
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700
800
900
1000

Fig. 3

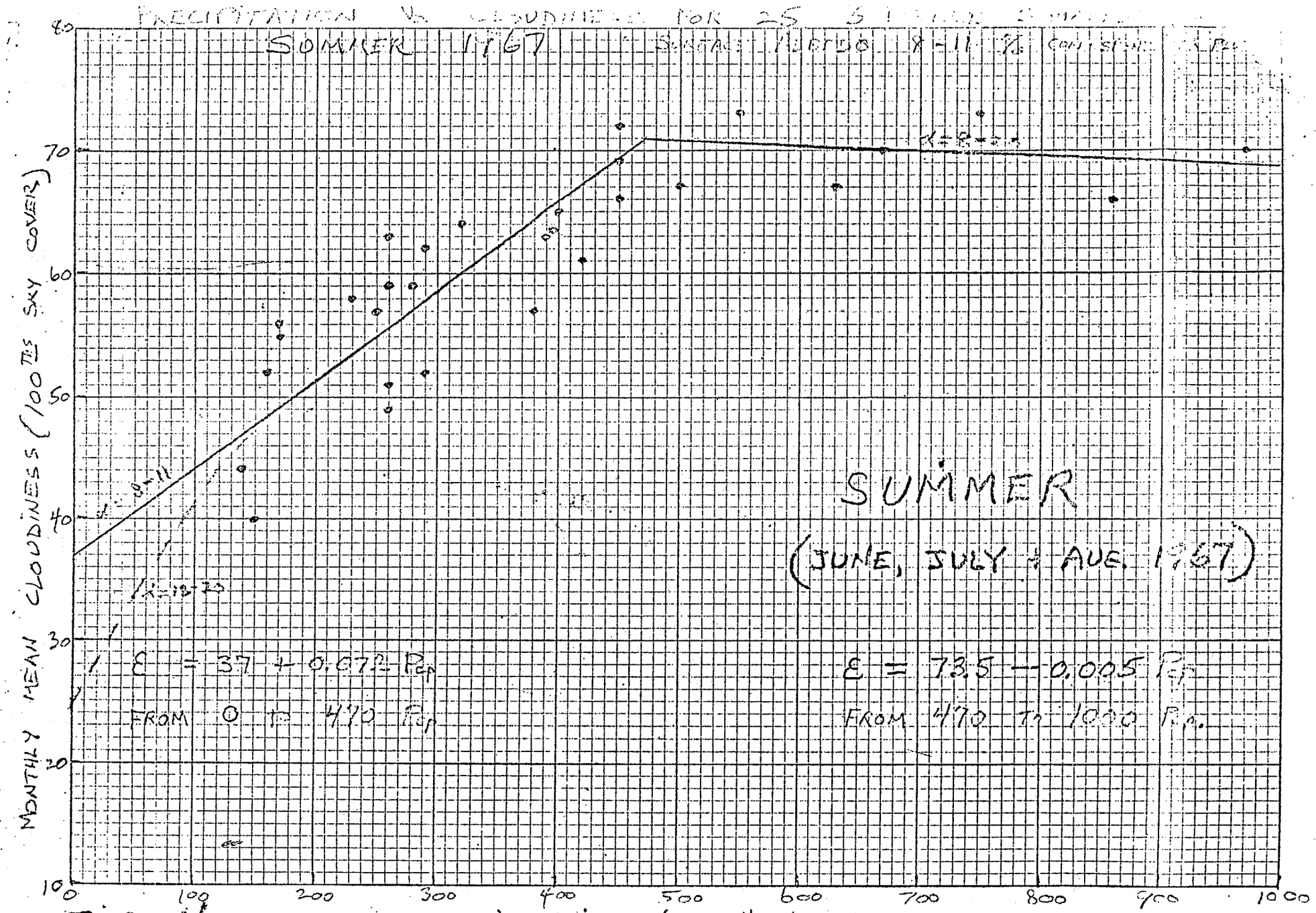

PRECIPITATION VS CLOUDINESS FOR 25 STATIONS
SUMMER 1967
SUMMER
(JUNE, JULY + AUG. 1967)
E = 37 + 0.072 Pp
FROM 0 TO 470 Pp
E = 73.5 − 0.005 Pp
FROM 470 TO 1000 Pp
MONTHLY MEAN CLOUDINESS (100ths SKY COVER)
MONTHLY PRECIPITATION (100ths INCH)
0
100
200
300
400
500
600
700
800
900
1000
10
20
30
40
50
60
70
80

FIG. 4

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MONTHLY-MEAN OPAQUE CLOUDINESS RELATED TO PRECIPITATION

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[Supplement to the author's NMC Office Note 48, "Relation Between Monthly-Mean Cloudiness and Precipitation," December 1970]

Introduction:

As a logical outgrowth of a previous study relating monthly-mean total cloudiness to precipitation (Clapp, 1970), it was decided to make a similar study of the relation of opaque cloudiness to precipitation. Since, by definition, opaque cloudiness includes only the thicker clouds which do not transmit any direct solar radiation (i. e. through which the solar disc cannot be seen) it was supposed that mean opaque cloudiness ought to be better related to precipitation than total cloudiness, and better related to the general circulation as well.

It was found that the particular measure of opaque cloudiness used in this study (explained below) did not satisfy the first supposition. Therefore opaque cloudiness is not recommended as a replacement for total cloudiness in its relation to precipitation. Nevertheless, the results will be summarized since they are of interest in confirming the previous study.

Definition of Opaque Cloudiness

Opaque cloudiness, as used in this study, is defined as 100 minus the percentage of maximum possible sunshine received at the ground at any locality during a given month. It is obtained from data of instruments which record the total minutes of sunshine during each day. Since the instruments can respond to cloudiness only in the direction of the sun, some question might be raised as to the representativeness of the derived opaque cloudiness, especially in winter and at high latitudes.

However, it is felt that the randomness of cloud distributions, together with the use of data summed over entire months, might result in fair estimates of the true opaque cloudiness.

It should be noted that subjective estimates of opaque (as well as total) cloudiness are made by observers at some of the first-order weather stations, but apparently no summaries of these data are available. On the other hand, the monthly percentage of possible sunshine is published, for stations having sunshine recorders, in the same tables with the mean total cloudiness (ESSA, 1968).

Results and Conclusions:

As in the previous study, anomalies of cloudiness and precipitation (departures from climatological averages) were computed for many stations over the conterminous United States and for the months of January and July, 1968. However, because of the large variability in the length of record used in determining the climatological values of cloudiness and possible sunshine, only those stations were chosen which have 19 or more years of record for both of these parameters. Of the 50 stations chosen, about 80% were different from the 48 stations selected previously. Therefore to some extent the present results may be taken as an independent check of the previous ones.

As before, linear correlation coefficients were computed relating the two selected parameters, and the two regression lines as well as the

line of best fit, defined in the previous study, were determined. In this brief summary, the only parameters listed in the tables are the correlation coefficient (r), the number of cases (n) and the coefficients of the line of best fit

$$y = e + fx$$

where y is the estimated cloudiness (in hundredths sky cover) and x is the precipitation (hundredths of inch).

Table 1 summarizes the results of relating total cloudiness and precipitation, and provides a comparison with the previous study. It indicates that the addition of new stations with consistent lengths of record does not change the relationship significantly.

Table 2 summarizes the relationship between opaque cloudiness (as defined above) and precipitation, but only for the 50 cases used in this study. The result for January is almost the same as when total cloudiness is used (Table 1, line 1) although the correlation coefficient is somewhat lower; but in July the relationship breaks down completely, and a small <u>negative</u> correlation is found. It is not easy to explain this unexpected result, but it may be related to the fact that in summer a large fraction of the precipitation falls from cumulonimbus clouds, which increase in thickness as they increase in intensity; but the more intense cells tend to be widely separated. This suggestion is supported to some extent by the previous finding (see Clapp, 1970; esp. Figs. 3 and 4) that

as total precipitation increases beyond about 4-1/2 inches for the month, there is a tendency for the mean monthly cloudiness to decrease somewhat.

In any case, this finding suggests that little is to be gained by further studies relating opaque cloudiness to precipitation.

References

Clapp, P. F., Relation between monthly mean cloudiness and precipitation. NMC Office Note 48, December 1970, 11 pp.

ESSA (Environmental Science Services Administration) Local Climatological Data, Annual Summary, 1968.

Tables

Table 1: Anomaly of monthly-mean total cloudiness (100ths sky cover) related to precipitation (100ths of inch) for "n" stations in the conterminous U. S. and for January and July, 1968. The two samples have 50 stations (this study) ~~and 48 stations (this study)~~ and 48 stations (previous one) with 20% of them in common. "r" is the linear correlation coefficient, and the coefficients of the line of best fit are the intercepts "e", in 100ths sky cover, and the slope, "f", in 100ths sky cover per hundredth inch.

Month 1968	n	r	e	f
January	50	+0.55	+2.98	+0.07
January	48	+0.55	+2.37	+0.10
July	50	+0.30	+1.90	+0.06
July	48	+0.33	+2.15	+0.06

Table 2: Anomaly of monthly-mean opaque cloudiness related to precipitation for 50 stations in conterminous U. S. See Table 1 for definition of symbols.

Month 1968	n	r	e	f
January	50	+0.50	+2.31	+0.10
July	50	-0.04	+3.78	-0.37