

NOAA Technical Memorandum NWS WR-155



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A RAININESS INDEX FOR THE ARIZONA MONSOON

Salt Lake City, Utah  
July 1980

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**U.S. DEPARTMENT OF  
COMMERCE**

/ National Oceanic and  
Atmospheric Administration

/ National Weather  
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John H. TenHarkel

National Weather Service Forecast Office  
Phoenix, Arizona  
July 1980

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Philip M. Klutznick, Secretary

NATIONAL OCEANIC AND  
ATMOSPHERIC ADMINISTRATION  
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National Weather  
Service  
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This Technical Memorandum has been reviewed and is approved for publication by Scientific Services Division, Western Region.

A handwritten signature in black ink, appearing to read "L. W. Snellman". The signature is written in a cursive style with a long, sweeping tail that extends to the right.

L. W. Snellman, Chief  
Scientific Services Division  
Western Region Headquarters  
Salt Lake City, Utah

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## I. ABSTRACT

A raininess index is derived for Arizona for each summer day from 1897 through 1979. Mean values for each season and each date are tabulated, graphed and compared to other measures of monsoon activity. Column (date) means are used to derive a normal curve for the Arizona Monsoon. Some individual seasons are then compared to the normal curve.

## II. BACKGROUND

Arizona's summer rainy season has been called a "Monsoon" because it coincides with a seasonal shift of the winds aloft (from west to southeast). Although rainfall is lighter and much less frequent than that of the Asian Monsoon, it is seasonal, and it does depend on a seasonal wind shift. The name "Arizona Monsoon" has been used locally for many years and will be used here.

Most attempts to document the Arizona Monsoon have employed data from a few individual stations having a long period of record. Time-frequency graphs from such records show great day to day and station to station variability in rainfall. They give an impression of randomness in both a spatial and temporal sense.

The experience of the author in operational forecasting at Phoenix is that there are large systematic variations in raininess, from one day to another, and also for periods of a week or more. However, attempts to understand and anticipate these changes have had little success.

Before such changes can be studied, they must be documented. An index of rainfall coverage is needed, which is not subject to chance occurrence at fixed locations, and which can be averaged over a long period of record.

Bryson and Lowry (1955) devised a raininess index that used all available rain reports including those from unpaid "cooperative" observers, about 200 at the time. A two-day running mean was taken to reduce second-day error, caused when some observers took their readings on the following day (morning). Reiter (1957) employed a similar index. These authors tabulated their index for only the first part (onset) of the rainy season, and for only a 30-year period of record.

The following tabulation is for the entire summer, June 1 through September 30, from 1897 to 1979 (see appendix).

## III. DATA

Daily substation rainfall from the Arizona Section of "U.S. Climatological

Data" (or it's equivalent) were used to find a raininess index for each day. The index, hereafter, called the "Monsoon Index" or "M.I.", is defined as:

$$\text{M.I. (D)} = \frac{100 \times R}{N}$$

where N is the number of reporting stations having a complete record for the month and R is the number of stations reporting .01 inch or more of rain on a given day (D).

Values of M.I. were tabulated without any attempt to correct for second-day error. This type of error is discussed later.

The tabulation starts with 1897, the first year for which daily rainfall was included in the climatic data. At that time, there were 41 stations. There are now nearly 200.

The areal distribution of climatic stations has not changed very much. Since 1897, there has been a concentration of stations in the central and southeast sections. This roughly coincides with the region of maximum summer rainfall.

Figure 1 shows the distribution of stations in July 1979. Stations included in the tabulation are marked with a large black dot. The area that normally receives more than two inches of rain in July is shaded, the areas with over four inches are darkly shaded.

About one quarter of the state's area averages more than two inches of rain in July; and over one half (111 out of 188) of the reporting stations are within this area. Thus, the M.I. is weighted toward the area that normally has the most rainfall.

There is a close relationship between rainfall amount and areal coverage - for those years for which an average statewide rainfall was computed, the correlation between it and the average Monsoon Index is near 0.90 (slightly less in September).

#### IV. TABLES

The M.I. is tabulated by month; each row represents a year, each column a date. The average and standard deviation for each row (year) are shown on the right, and to the right of the September table, the seasonal average and standard deviation are shown. These are for the entire 122 days of the summer.

Rounded (Integer) averages for the columns are shown below (after 1979) for each day. These averages, along with standard deviation, and moment coefficients of skewness and kurtosis, are tabulated separately, in single precision (6-place) accuracy. (See Appendix.)

#### V. ANALYSIS

Daily (column) means are plotted in Figure 2. A normal curve was hand-fitted to the data points, then a polynomial fit was attempted. The equation:



$$M.I. = 28.34 + 0.02 x - 0.016 x_5 D^2 + 0.000085 x D^3 + 0.000003 x D^4 - 0.00000027 x D^5$$

explains 95.68% of the variance in M.I. Here, D is the day number, zero on August 1.

Figure 3 shows the individual season (Row) means for each year since 1897, and Figure 4 shows the monthly means for July, for comparison. Note the relatively small standard deviation, especially for the season totals.

Figures 5-7 compare individual seasons to the handfitted normal curve. The year 1900 (Figure 5) was very dry, the year 1931 (Figure 6) was very wet. The most recent year, 1979, is shown in Figure 7. Note the very high peak in early August, (August 12), a day of extensive flash flooding. Yet, the season was overall a very dry one.

## VI. DISCUSSION

Much can be learned simply by visual inspection of the tables. Note that rainy periods of several days do occur in August, supposedly a wet month. There have been many "breaks" in the monsoon similar to those of August 1976 and 1977, which caused much comment and speculation about a "failure" of the monsoon.

Very high peaks (over 80% coverage) are more common after the end of July, and especially in September, when frontal type precipitation and also hurricanes sometimes occur.

Skewness of the daily samples is very large in June, and again in September, because of the high frequency of dry days (M.I.=0). Kurtosis, a measure of the "peak-ness" of a distribution, also is high. This is typical of an arid climate, which Arizona's certainly is, most of the time.

Near the peak monsoon period, late July, skewness approaches zero and kurtosis nears the value 3, approaching the values of a normal distribution. This is not characteristic of aridity.

## VII. OTHER MEASURE OF MONSOON ACTIVITY

In recent years hourly ARTC radar maps have been composited for 12-hour periods, 0000-1200 GMT and 1200-0000 GMT, daily. These composite maps can be used to estimate how much of a geographic area has been subjected to rainfall, assuming all areas covered by a radar echo at least once in the 12-hour period had rain.

Unfortunately, until recently, no one had been keeping a record of these charts. They were collected at WSFO Phoenix for the summer of 1979, and rainfall coverage estimated using a template.

This gives us a fair estimate (subject to uneven radar coverage and infrequent reports) of the actual areal coverage of rainfall, with which we can try to correct the Monsoon Index for its "wrong day" error.

The following model was tested, using stepwise linear regression:

$$\text{adjusted M.I.} \cong \text{Radar Coverage (\%)} = B_0 + B_1 \times \text{M.I. (today)} + B_2 \times \text{M.I. (next day)} + B_3 \times \text{M.I. (yesterday)} + B_4 \times \text{M.I. (second day)}.$$

at the 5% confidence level, the only variables selected were the M.I. for "today" and "tomorrow", with the latter value having the greatest weight. The equation:

$$\text{Radar Coverage} = .184 + .296 \times \text{M.I. (today)} + .68 \times \text{M.I. (tomorrow)}$$

explained 86.2% of the variance in radar coverage.

An attempt was then made to screen in other predictors for individual stations having a record extending back to 1897. Parameters that would be available for use since that year include dewpoint, maximum and minimum temperature, rainfall and sky cover. The resulting equation:

$$\text{R.C.} = .254 \times \text{M.I. today} + .644 \times \text{M.I. tomorrow} + 1.45 \times [1/3 (\text{Sky cover PHX} + \text{Sky cover TUS} + \text{Sky cover INW})] - 0.16 \times (\text{PHX dewpoint at 000Z})$$

explained 88.04% of the variance in R.C. (Radar Coverage).

All of the single station variables were strongly dependent on Radar Coverage. It is likely that much of the unexplained variance in radar coverage is caused by incomplete radar coverage, and by too infrequent radar observations. Also, no attempt was made to "weight" the radar data toward the east central and southeast parts of Arizona, where the Monsoon Index is weighted.

Even so, the technique looks promising and another attempt will be made as soon as two or three more years of radar data are collected. If it is possible to reduce the variance by 90% or more, one could then eliminate most of the "second-day" observational error for the entire period of record (since 1897).

#### VIII. COMMENTS, SUGGESTIONS FOR RESEARCH

The monsoon rains in Arizona change character from great variability at start and finish to dependability near their peak. In addition, the rains are well known to be associated with southeast winds aloft. This implies the main cause of the monsoon is a seasonal shift in the mean circulation, which is subject to interruption early and late in summer.

One may speculate that these interruptions are caused by small scale waves, travelling in the westerlies, or in the easterlies, or both; or they may be caused by large-scale shifts in the latitude of the westerlies, or the east-west axis of the subtropical high.

Another (wetting) mechanism was postulated by Hales ("Surges of Maritime Tropical Air Northward Over the Gulf of California, 1971"). This "Gulf Surge" has proven easy to spot once it starts, but almost impossible to forecast.

In any case, too little is known about the circulation in the region south of Arizona. It obviously plays a vital role in the monsoon since the moisture bearing winds blow from the south or southeast.

So far, the only mean-circulation maps available are those prepared by Sadler (1975); 300 mb and 200-mb 10-year means. The monsoon peak coincides with the establishment of a 200-mb anticyclone over northwest Mexico, and the farthest northward retreat of the westerly jet. It also coincides with the maximum northward displacement of the northeast Trades. (See "The Upper Tropospheric Circulation Over the Global Tropics" Part 1, Page 9, upper right graph).

Similar mean charts should be prepared for the lower troposphere, in particular, for the surface - 600-mb layer analyzed by the National Hurricane Center since 1968. Composite maps should be prepared for several cases of peak monsoon activity, and also for several cases of abnormally low activity, to find out what circulation patterns are associated with these abnormalities.

Individual case studies can be made using NHC 200-mb and SFC-600-mb analyses, both available on micro-film from the Hurricane Center. The Monsoon Index records could be used to spot abnormalities to be investigated.

The index tables themselves can be studied in more detail. Has there been any significant change in the Monsoon over the 83-year period? What is the frequency of dry days, or days with more than 50% coverage, in July, or August? What is the probability of a sequence of, say, 3 dry days in a row, or more than one "wet" day in a week?

These are all ideas that should have been explored locally (at Phoenix) in the course of operational forecasting; but have not been, because of a lack of time and resources. Hopefully, more time and resources will become available, but meanwhile it is hoped that the historical data will be of use to others.

The index tables were printed and statistics generated using a TRS-80 micro-computer. The data are stored on a 5-inch mini-disc.

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  - (B) U.S. Department of Agriculture, Weather Bureau, "Climatological Report, Arizona Section", June-Sept. Vol. 1906-1913.
  - (C) U.S. Weather Service, "Climatological Data, National Summary", Vol. 18-83, No. 6-9 (June-Sept. 1914-1979).

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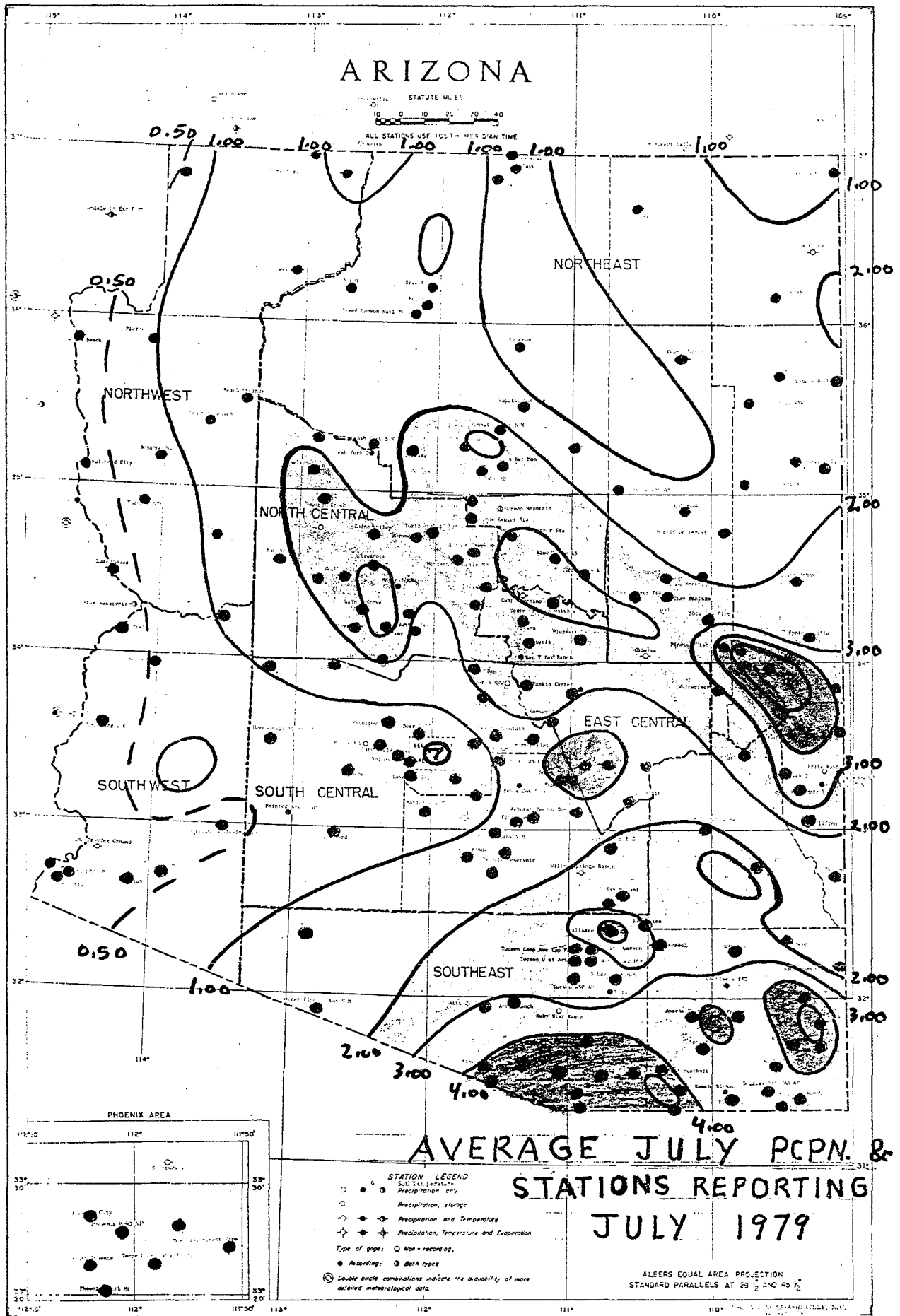


FIGURE 1

# AVERAGE DAILY MONSOON INDEX JUNE 1 - SEPT 30

— HAND FITTED NORMAL CURVE  
- - - POLYNOMIAL FIT

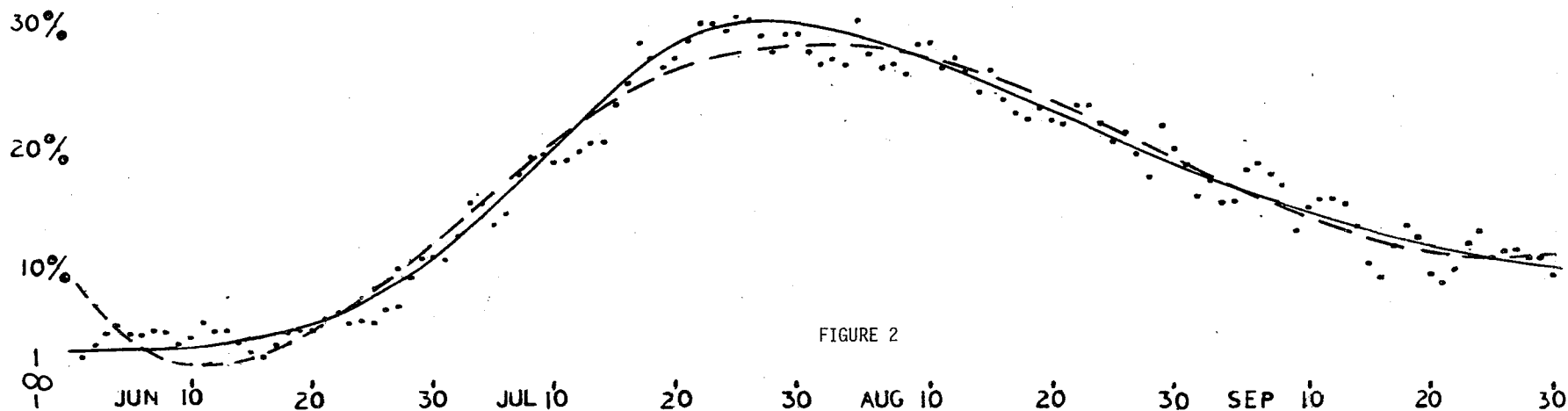
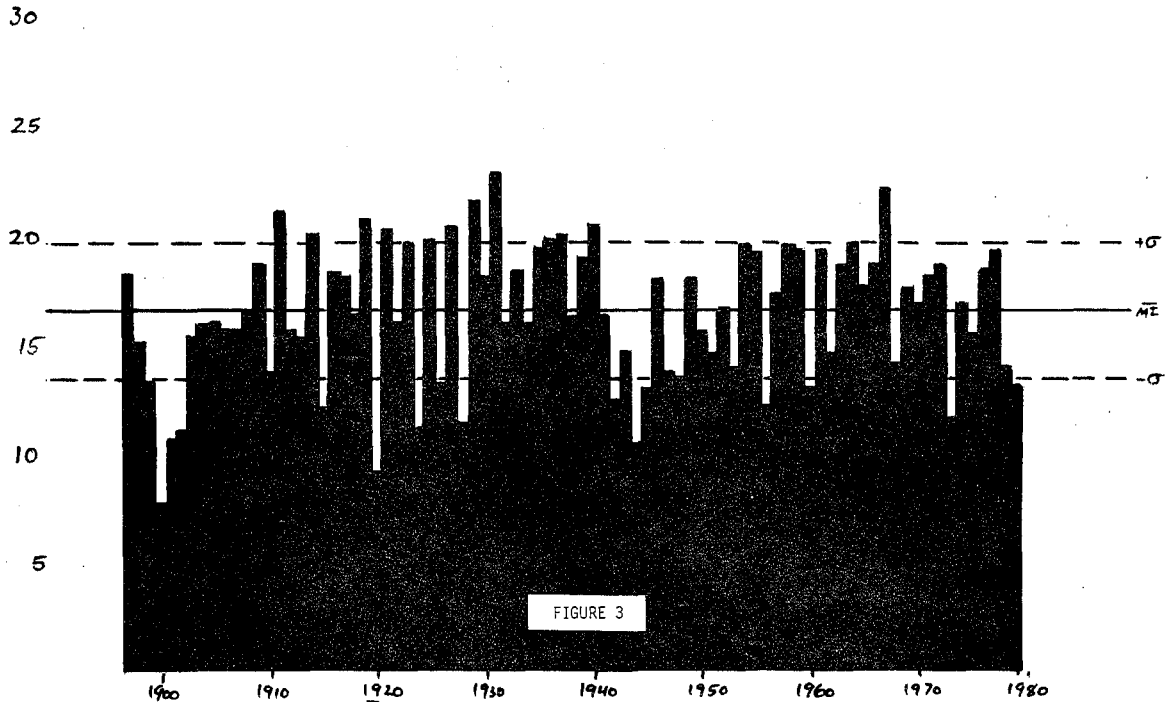


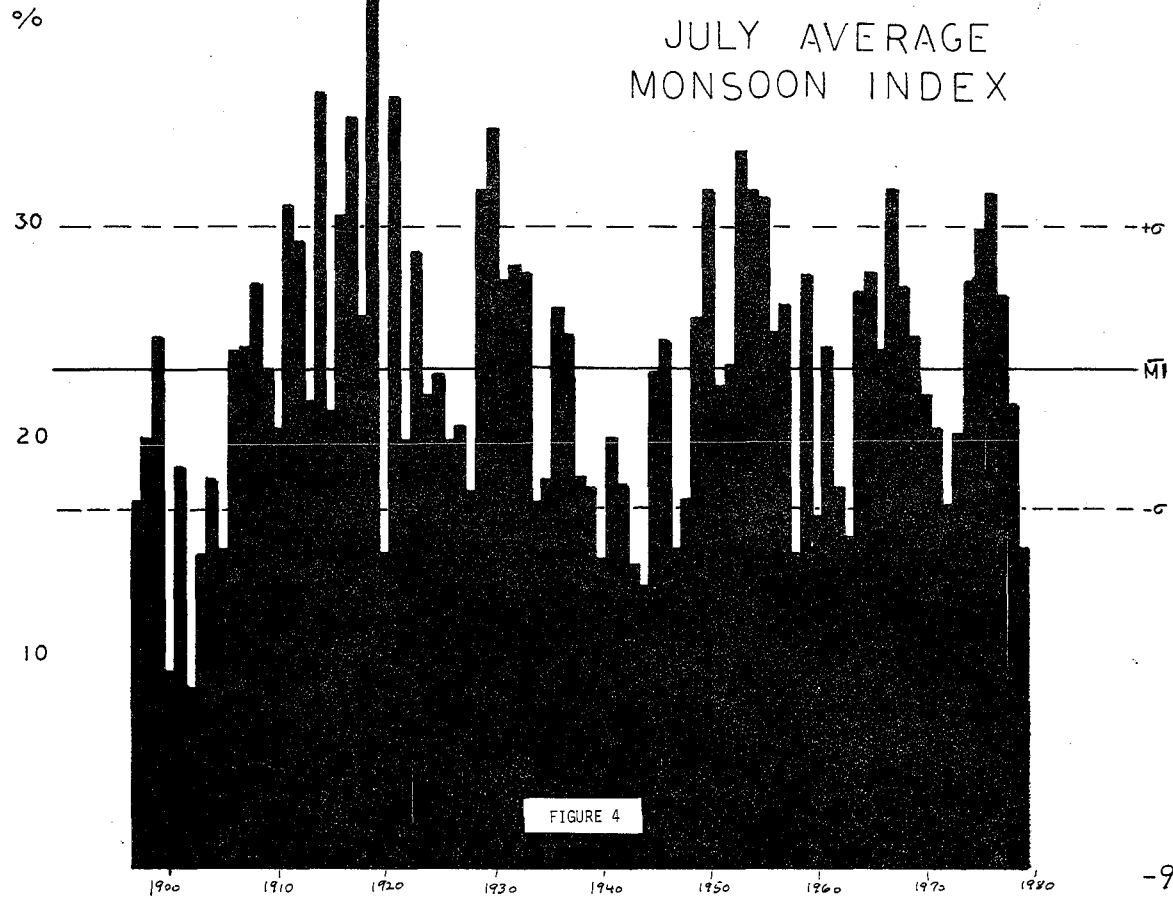
FIGURE 2

90

# SEASONAL AVERAGE MONSOON INDEX



# JULY AVERAGE MONSOON INDEX



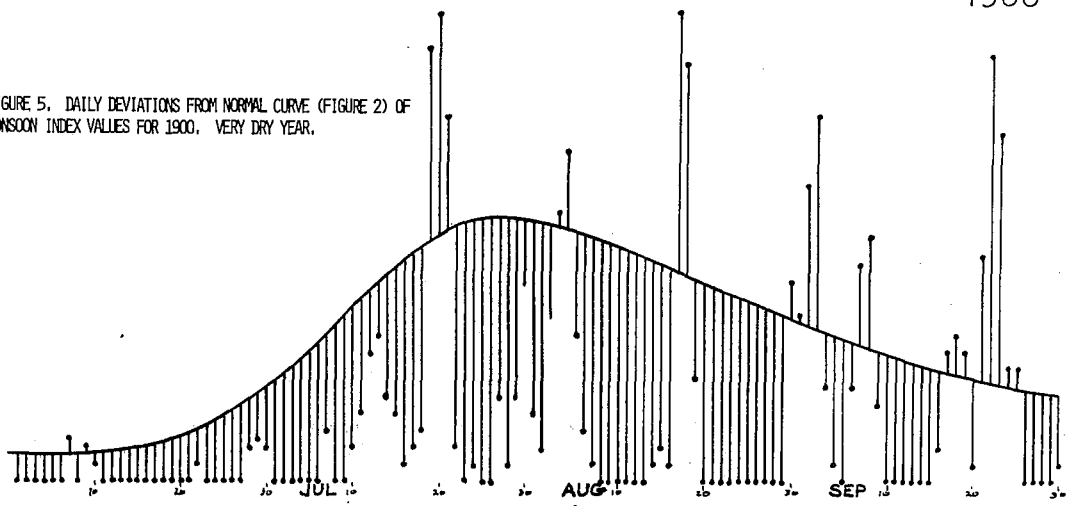
%

1900

50

FIGURE 5. DAILY DEVIATIONS FROM NORMAL CURVE (FIGURE 2) OF MONSOON INDEX VALUES FOR 1900. VERY DRY YEAR.

30



%

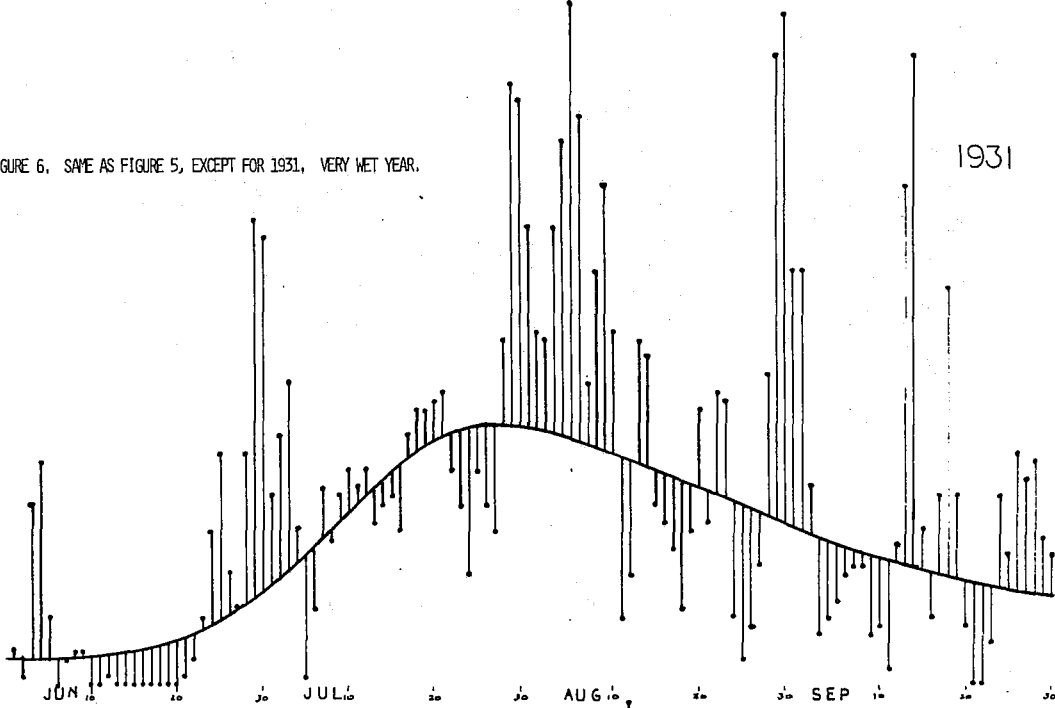
7

FIGURE 6. SAME AS FIGURE 5, EXCEPT FOR 1931, VERY WET YEAR.

1931

5

3



%

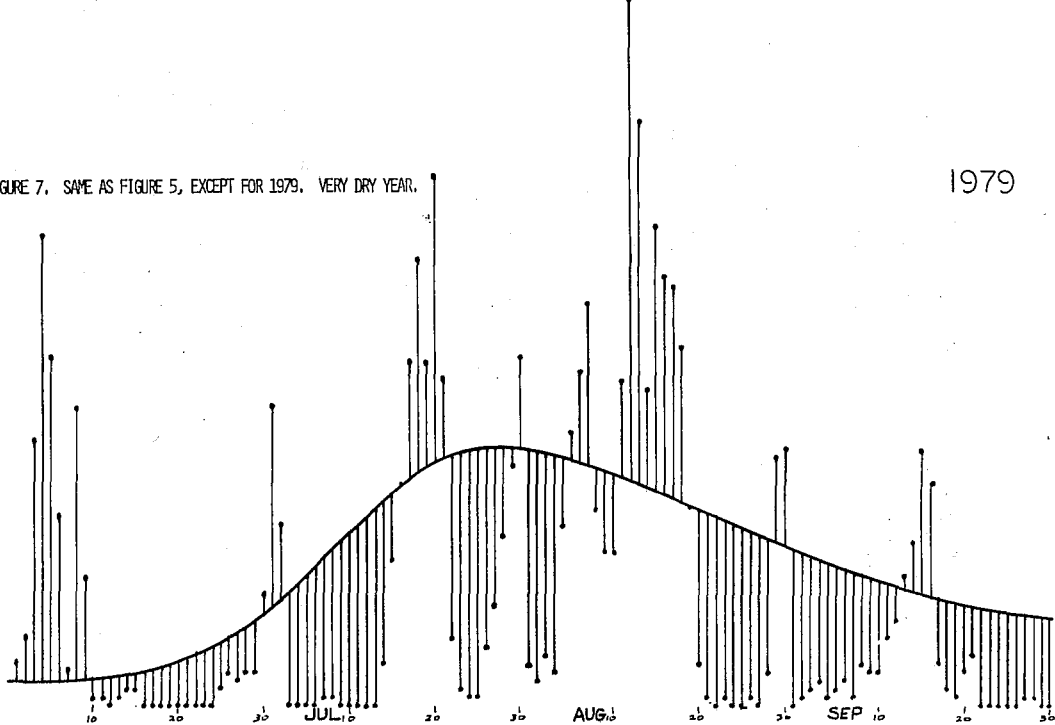
70

FIGURE 7. SAME AS FIGURE 5, EXCEPT FOR 1979, VERY DRY YEAR.

1979

50

30





X. APPENDIX - 1897-1979 DATA TABULATIONS

1. DAILY MONSOON INDEX VALUES BY MONTH (JUNE THROUGH SEPTEMBER).
2. MEANS, STANDARD DEVIATIONS, SKEWNESS AND KURTOSIS OF DAILY MONSOON INDEX DATA.









MEAN	S.D.	DEVIATION	SKENNESS	KURTOSIS
2.53012	8.04308	4.71937	26.7165	AUG 2
3.6506	10.6956	3.88229	18.3122	AUG 3
4.59036	10.1224	3.99397	16.4114	AUG 4
5.08434	11.5569	2.90281	10.8771	AUG 5
4.42169	9.51779	3.09366	13.9462	AUG 6
4.39759	9.6493	3.50144	18.1259	AUG 7
4.72108	11.5867	3.92948	21.7498	AUG 8
4.62651	11.6428	3.2038	13.112	AUG 9
3.6288	8.31358	2.745	10.1136	AUG 10
4.0241	9.19023	3.19023	13.2939	AUG 11
5.14958	10.9394	3.14858	13.7236	AUG 12
4.63855	10.7665	2.97152	11.7406	AUG 13
4.75904	12.6082	3.95199	19.9873	AUG 14
3.68675	8.61922	2.79149	10.4707	AUG 15
3.68413	7.65413	4.14928	21.8245	AUG 16
2.62651	6.55504	3.98478	14.837	AUG 17
3.50602	8.23048	3.21427	14.0304	AUG 18
4.53012	11.5445	3.51082	16.5436	AUG 19
4.8128	10.1827	2.74003	10.2504	AUG 20
5.77108	12.1237	2.55176	8.61475	AUG 21
6.15663	12.1188	2.57041	9.45394	AUG 22
5.22822	9.73837	2.76717	11.8137	AUG 23
5.2711	10.4056	3.51277	18.52287	AUG 24
6.4064	12.0619	2.7205	10.4781	AUG 25
6.7813	13.4762	2.67426	9.48693	AUG 26
7.06024	15.4765	2.94631	5.6303	AUG 27
10.747	15.5323	1.75125	5.6303	AUG 28
10.8916	15.3	1.61613	4.88972	AUG 29
12.506	15.0172	2.88877	9.49857	AUG 30
12.506	16.049	1.50185	4.50047	SEP 1
15.2289	17.1054	1.29144	4.47579	SEP 2
15.1446	17.0731	1.60288	3.12393	SEP 3
13.3614	15.656	1.46917	4.50057	SEP 4
14.4217	16.9478	1.18343	4.18943	SEP 5
17.3888	17.3837	1.82114	2.74212	SEP 6
18.712	18.7185	1.3312	3.26028	SEP 7
19.3253	17.5899	1.97505	3.40238	SEP 8
19.3253	17.5899	1.97505	3.40238	SEP 9
18.5365	15.1452	1.59036	15.9036	SEP 10
18.5365	15.1452	1.59036	15.9036	SEP 11
18.0876	16.0876	1.56386	13.012	SEP 12
15.6627	20.6429	15.6627	15.6627	SEP 13
13.3494	17.3494	13.3494	13.3494	SEP 14
13.3494	17.3494	13.3494	13.3494	SEP 15
12.5206	14.5206	12.5206	12.5206	SEP 16
11.8022	16.8022	11.8022	11.8022	SEP 17
13.5783	18.5783	13.5783	13.5783	SEP 18
13.5783	18.5783	13.5783	13.5783	SEP 19
12.5301	14.5301	12.5301	12.5301	SEP 20
13.8424	16.8424	13.8424	13.8424	SEP 21
13.8424	16.8424	13.8424	13.8424	SEP 22
13.8424	16.8424	13.8424	13.8424	SEP 23
11.488	18.1488	11.488	11.488	SEP 24
13.0723	13.0723	13.0723	13.0723	SEP 25
18.8916	18.8916	18.8916	18.8916	SEP 26
11.1887	18.1887	11.1887	11.1887	SEP 27
10.9227	18.10936	10.9227	10.9227	SEP 28
10.9227	18.10936	10.9227	10.9227	SEP 29
9.37349	16.9036	10.9036	9.37349	SEP 30
18.3442	18.3442	18.3442	18.3442	AUG 1
2.53012	8.04308	4.71937	26.7165	AUG 2
3.6506	10.6956	3.88229	18.3122	AUG 3
4.59036	10.1224	3.99397	16.4114	AUG 4
5.08434	11.5569	2.90281	10.8771	AUG 5
4.42169	9.51779	3.09366	13.9462	AUG 6
4.72108	11.5867	3.92948	21.7498	AUG 7
4.62651	11.6428	3.2038	13.112	AUG 8
3.6288	8.31358	2.745	10.1136	AUG 9
4.0241	9.19023	3.19023	13.2939	AUG 10
5.14958	10.9394	3.14858	13.7236	AUG 11
4.63855	10.7665	2.97152	11.7406	AUG 12
4.75904	12.6082	3.95199	19.9873	AUG 13
3.68675	8.61922	2.79149	10.4707	AUG 14
3.68413	7.65413	4.14928	21.8245	AUG 15
2.62651	6.55504	3.98478	14.837	AUG 16
3.50602	8.23048	3.21427	14.0304	AUG 17
4.53012	11.5445	3.51082	16.5436	AUG 18
4.8128	10.1827	2.74003	10.2504	AUG 19
5.77108	12.1237	2.55176	8.61475	AUG 20
6.15663	12.1188	2.57041	9.45394	AUG 21
5.22822	9.73837	2.76717	11.8137	AUG 22
5.2711	10.4056	3.51277	18.52287	AUG 23
6.4064	12.0619	2.7205	10.4781	AUG 24
6.7813	13.4762	2.67426	9.48693	AUG 25
7.06024	15.4765	2.94631	5.6303	AUG 26
10.747	15.5323	1.75125	5.6303	AUG 27
10.8916	15.3	1.61613	4.88972	AUG 28
12.506	15.0172	2.88877	9.49857	AUG 29
12.506	16.049	1.50185	4.50047	AUG 30
15.2289	17.1054	1.29144	4.47579	SEP 1
15.1446	17.0731	1.60288	3.12393	SEP 2
13.3614	15.656	1.46917	4.50057	SEP 3
14.4217	16.9478	1.18343	4.18943	SEP 4
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13.3494	17.3494	13.3494	13.3494	SEP 13
13.3494	17.3494	13.3494	13.3494	SEP 14
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12.5206	14.5206	12.5206	12.5206	SEP 16
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18.8916	18.8916	18.8916	18.8916	SEP 26
11.1887	18.1887	11.1887	11.1887	SEP 27
10.9227	18.10936	10.9227	10.9227	SEP 28
10.9227	18.10936	10.9227	10.9227	SEP 29
9.37349	16.9036	10.9036	9.37349	SEP 30

MEANS, STANDARD DEVIATIONS, SKENNESS AND KURTOSIS OF DAILY MONSOON INDEX DATA.

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