MONTHLY WEATHER REVIEW

VOLUME 95, NUMBER 8

AUGUST 1967

FURTHER STUDIES OF DROUGHT OVER NORTHEASTERN UNITED STATES

JEROME NAMIAS

Extended Forecast Division, Weather Bureau, ESSA,[1] Washington, D.C.

ABSTRACT

Following a study of large-scale atmospheric and oceanic interactions associated with the recent Northeast drought, smaller-scale manifestations of this drought are studied with the help of records from New York Central Park Observatory. The long-period records of this Observatory (since 1869) are then studied statistically in relation to dry periods. Among the most interesting facts brought out is a long-period downward trend in precipitation beginning sometime in the early 1930's or perhaps late 1920's. This appears to be related to general circulation aberrations of the same kind found in the earlier study of the recent (5-yr.) drought. However, an attempt to demonstrate a long-period air-sea interaction similar to the earlier-described short-period interaction failed—perhaps because of inadequacies in sea-surface temperature data.

Finally, nationwide precipitation patterns accompanying dryness in the Northeast are determined from 59 yr. of precipitation data. These patterns throw considerable light on the scale and nature of the precipitation-inhibiting processes as a function of season.

1. LOCAL MANIFESTATIONS OF THE DROUGHT AT NEW YORK CITY

In a recent paper [5] it was shown that the drought of 1962–65 in the Northeast affected a large area and that it was associated with aberrations in large-scale prevailing wind patterns (long waves) in the westerlies. The areal extent of the drought has been carefully documented by Palmer [7], Barksdale et al. [1], and others. It might be valuable, in addition, to examine in this paper the records of an individual station located in the core of the drought area, particularly the records of a station which has a good exposure and length of record. New York Central Park Observatory satisfies these criteria; its excellent observations were begun in 1869 [11].

In the following treatment, monthly means of various meteorological parameters for the period 1961–66[2] are plotted in such a way that it is easy to compare values between months of the same or of different years as well as to compare values with averages for the period 1931–60 (hereafter called the normals).

Figure 1 shows such a plot for the relative humidity observed at 1:00 p.m. local time, perhaps the most repre-

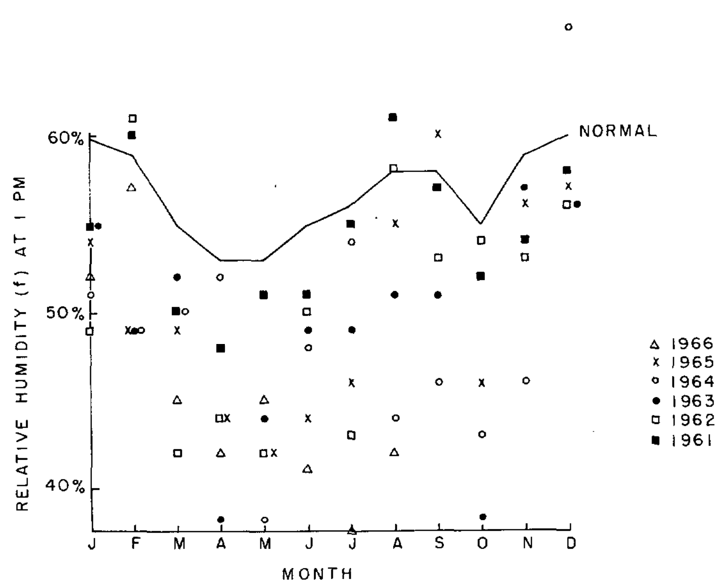

FIGURE 1.—Monthly mean 1:00 p.m. relative humidities at New York Central Park Observatory during the recent 5-yr. drought compared with normal.

[1] Most of this research was carried on while the author was on leave as Visiting Scientist at the Department of Meteorology and Oceanography of New York University.

[2] Throughout August 1966. Substantial rains began in September.

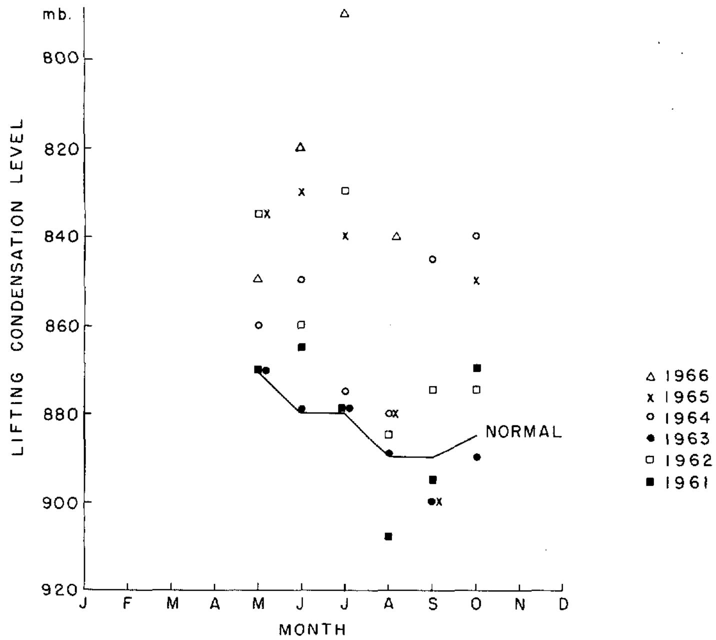

FIGURE 2.—Monthly mean lifting condensation levels at New York during the warmer halves of the drought years compared with normal.

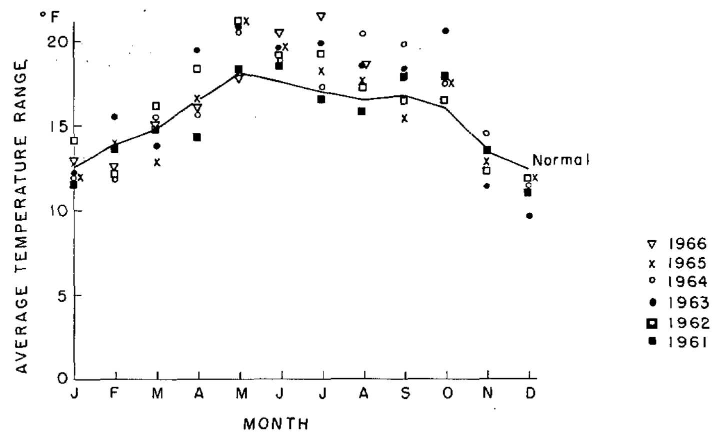

FIGURE 3.—Average monthly mean temperature range for New York during the recent 5-yr. drought compared with normal.

sentative of the friction layer of the four-times-daily observations of relative humidity listed in climatological records. It is at once clear that the mean monthly relative humidities, particularly from 1962 to August 1966, were prevailingly below normal, especially during the warmer months. This deficit is consistent with the humidity deficits up to the 700-mb. level brought to light in the analysis of aerological soundings at Washington, D.C. for the 4 yr. 1962–65 [5].

These low mean relative humidities are largely responsible for higher-than-normal lifting condensation levels for the warmer months May to October (fig. 2). Higher-than-normal condensation levels make it more difficult than normal for processes which induce mechanical or convective upward motions to bring about rain. Moreover, if the condensation level is reached, the deeper layer of dry air from surface to cloud base causes more than normal evaporation of the rainfall. These rain-inhibiting factors apparently reached a peak in July 1966, when the mean lifting condensation level was above the 800-mb. level and the month's total precipitation was only 1.25 in.

Figure 3 shows the average monthly temperature range (mean maximum minus mean minimum) for the drought period compared with the normally observed range. It is clear that during the warmer half of the year a greater-than-normal range of temperature was observed. This may be accounted for by the dry air cited earlier. At times—as in the summer of 1966—the increased range was due to high *maximum* temperatures produced by the combination of warm air advection, subsidence, and reduced cloudiness. In other years—such as 1965—the increased range was due instead to depressed *minimum* temperatures produced by cold air advection, dryness, and enhanced outgoing nocturnal radiation. As in the case of the high condensation levels, we see a tendency of the drought in New York to produce atmospheric responses characteristic of desert regions.

The average monthly precipitation yield per day, for days on which precipitation of ≥ 0.01 in. fell, is plotted in figure 4. It is the ratio (P/N) of the total monthly precipitation to the number of rainy (or snowy) days. Here again comparison with the normal brings out the fact that rainfall mechanisms, especially after 1962, were relatively inefficient during the drought period. Physical reasons for this lie in the dryness and stability factors discussed at some length in the earlier paper [5].

This precipitation-efficiency index, P/N, appears to be related in a roughly linear fashion to the mean monthly relative humidity (fig. 5). Higher precipitation yields go with higher mean relative humidities—despite the fact that all the parameters were derived from monthly mean values. The normal May-October mean humidities and precipitation-efficiency ratios (broken lines) bring into sharp focus the abnormal dryness of the 5-yr. period.

2. LONG-PERIOD TREND IN NEW YORK PRECIPITATION

Dr. Jerome Spar has drawn my attention to a plot of annual precipitation at Central Park Observatory since 1869. This graph, reproduced in figure 6, suggests a long-period decline beginning sometime during the decade 1927–37. Spar fitted a linear trend line to the annual values from 1927 to 1965 and found that the slope, or rate of precipitation decreases per year, amounted to almost 0.3 in.

This fascinating graph immediately raises numerous questions whose answers must be sought in any study in depth of the drought in the Northeast:

Does a long-period trend of this nature appear in other areas of the Northeast? If not, what are the reasons for this isolated circumstance? If so, what are the factors responsible for it?

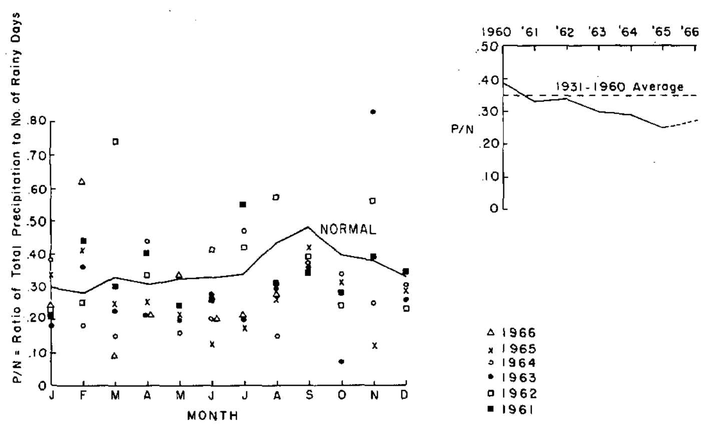

FIGURE 4.—Ratio (P/N) of total monthly precipitation to number of days on which measurable precipitation fell during the month at New York, and normal P/N. (Inset.) Annual mean values of P/N and 1931–60 average.

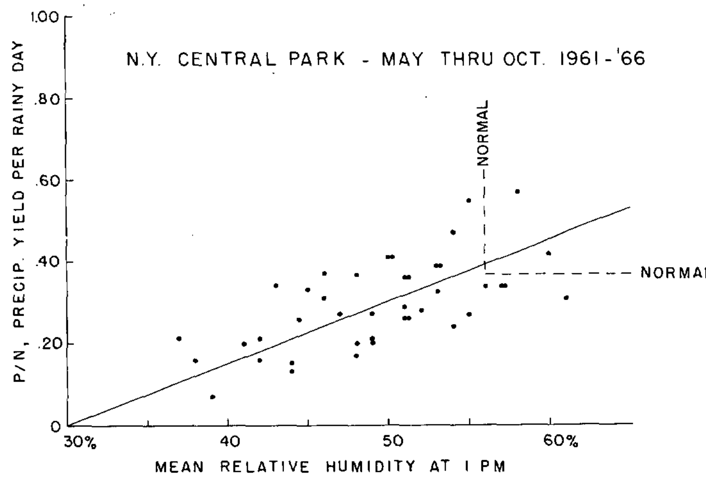

FIGURE 5.—Relationship of mean 1:00 p.m. monthly relative humidity to P/N at New York during warmer half-years of 1961–66.

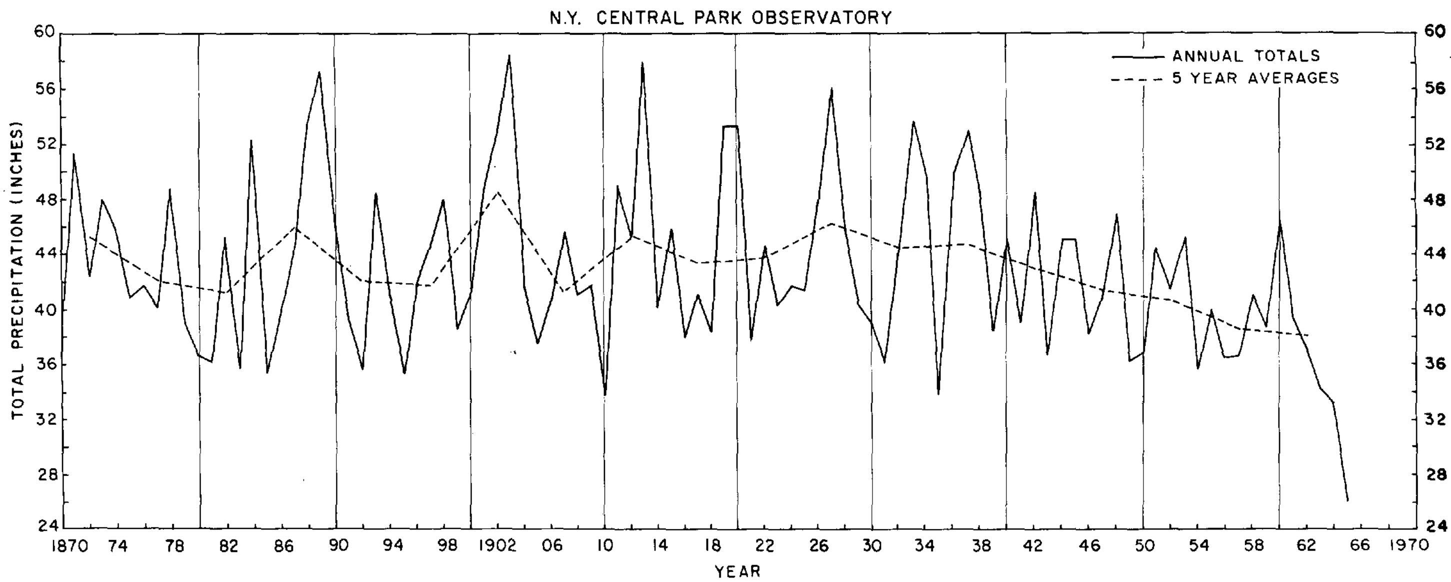

FIGURE 6.—Annual totals of precipitation at New York Central Park Observatory and 5-yr. non-overlapping means (broken lines).

Is the recent 5-yr. drought an amplified part of this longer-period decline? What relationship, if any, does the long-period decline have to the regional atmospheric circulation and large-scale air-sea interactions?

The above questions might yield to systematic research, on which a beginning is being made. The records of monthly precipitation from about 200 stations over the Northeast are being assembled, processed, and analyzed by Professor Spar. Other phases of the research will to some extent depend upon this analysis.

In the meantime, the Central Park Observatory record has been subjected to further study and an attempt made to relate the long-period trend of precipitation to prevailing mid-tropospheric wind currents. A discussion of this work follows.

First, precipitation amounts were plotted by seasons (winter=December, January, and February, etc.) for each year since 1927. These plots (not reproduced) show that the long-period trend was largely ascribable to spring, summer, and fall, but not winter. This tendency of drought to be confined to non-winter months also appears to have been true during the recent 5-yr. drought [5].

Second, a plot was made for the entire year and also for the warmer half-year (May through October) of the precipitation efficiency index P/N (see above). These graphs (the annual in fig. 7, May-October in fig. 8), also show a long-period decline. The slope of the annual P/N trend (1927–65) is −0.19. Thus, there is some suggestion that since the late 1920's or 1930's there has been a decline in both the total precipitation and in the yield per day,

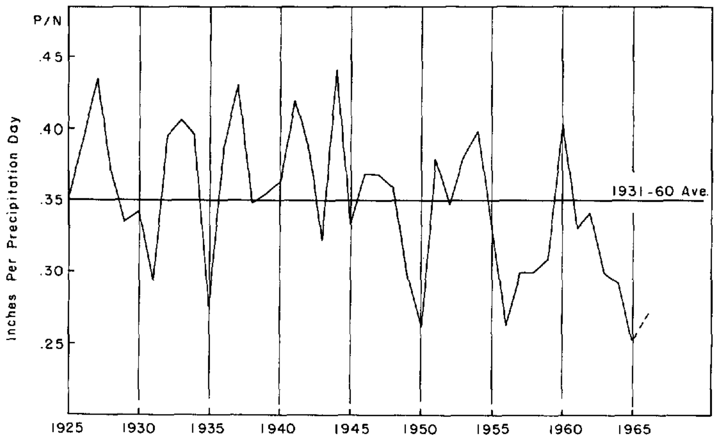

FIGURE 7.—Ratios of total annual precipitation to number of days with measurable precipitation at New York.

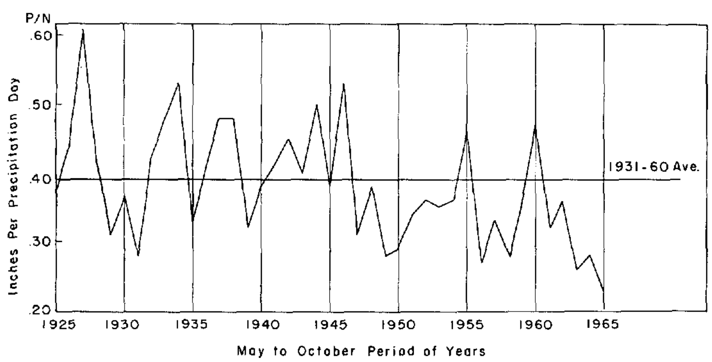

FIGURE 8.—Same as figure 7, but for May to October period.

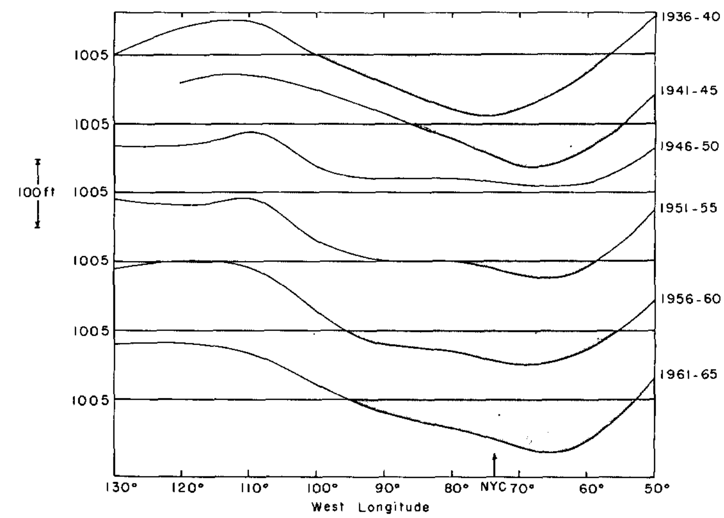

FIGURE 9.—Five-year mean, 700-mb. height profiles along 40°N. Shaded area is roughly proportional to depth of trough and delineates area below 10,050 ft.

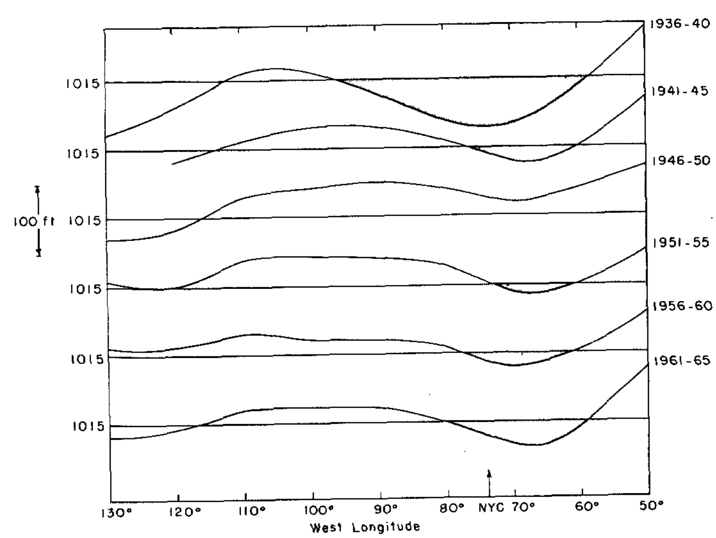

FIGURE 10.—Same as figure 9, but for May through October and with shading for areas below 10,150 ft.

with perhaps the strongest effect in the warmer six months of the year. There does not appear to have been a corresponding decline in frequency of precipitation, except during the recent 5-yr. drought. Further evidence for the reality of the long-period trend is suggested by certain changes in the regional upper-level wind circulation.

In order to see if there were substantial variations in the regional circulation during the period of declining precipitation, available monthly-mean 700-mb. charts were averaged for 5-yr. periods beginning in 1936 and ending with 1965. These 5-yr. period mean charts are on file at New York University and will not be reproduced here, although some of their more significant features relating to New York's precipitation will be displayed. One of these features is the 700-mb. height profile along latitude 40° N., which runs just south of New York City (40°47′ N.) (fig. 9). The most striking aspect of the time sequence of profiles is the increase in depth of the trough off the Atlantic seaboard (east of New York City) in the later 5-yr. periods compared to the earlier periods. These changes would essentially strengthen the prevailing northerly component of the the mid-tropospheric wind at New York, implying drier air masses and subsidence leading to vertical stabilization. These are precipitation-inhibiting mechanisms. The profiles also suggest that increased cyclonic and cyclogenetic activity has been taking place in later years off the Atlantic seaboard. These large-scale changes may account for some of the observed decline in precipitation at New York from an average of about 45 in. a year in 1936–40 to about 38 in. a year in 1961–65 (see broken curve of 5-yr. averages in fig. 6).

A similar series of profiles for the May to October period of each of the 5-yr. periods is shown in figure 10. The same shifts of prevailing trough position and intensity as in the annual curves again appear, and these shifts have similar rain-inhibiting effects even though the rainfall mechanisms of the warm half of the year are more convective in character than those of the cold half.

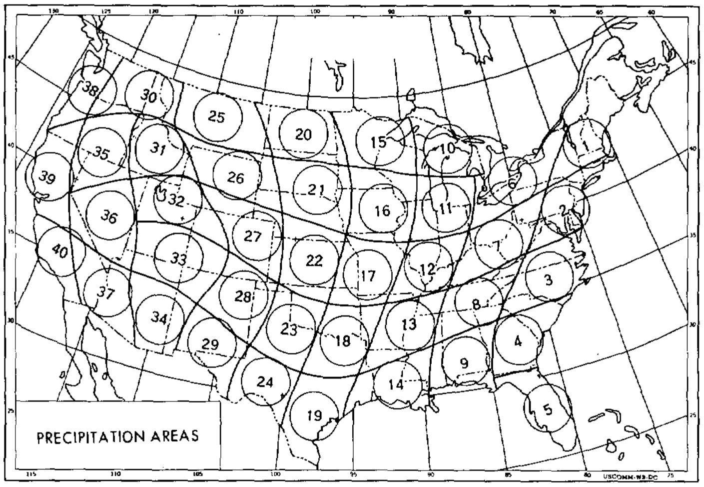

FIGURE 11.—Grid of 40 equal-area circles at which 5-day precipitation index was measured. Circles are located near the center of climatologically homogeneous areas delineated by the solid lines (from Klein [2]).

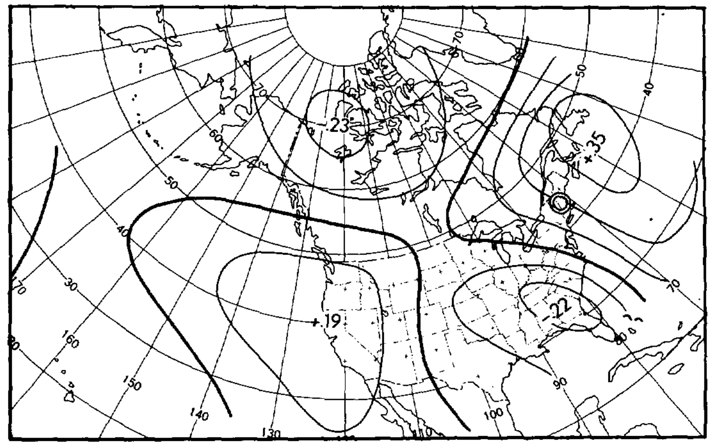

FIGURE 12.—Field of simple linear correlation between 5-day precipitation index in starred circle and simultaneous 5-day mean, 700-mb. height anomaly, for winter cases (from Klein [2]).

TABLE 1.—*Regression Equations. Five-day precipitation index specified from 700-mb. height departure from normal at the points indicated in brackets*

CIRCLE NO. 1

Winter F_1=3.60+.013[40°N., 60°W.]−.027[40°N., 90°W.]+.012[50°N., 60°W.]−.011[70°N., 120°W.]
Spring F_1=3.61−.037[40°N., 90°W.]+.031[40°N., 60°W.]+.010[60°N., 50°W.]
Summer F_1=3.72−.056[40°N., 90°W.]+.025[50°N., 60°W.]−.031[40°N., 130°W.]+.043[30°N., 90°W.]
Fall F_1=3.76−.012[40°N., 90°W.]+.042[30°N., 70°W.]+.016[50°N., 60°W.]−.035[40°N., 80°W.]

CIRCLE NO. 2

Winter F_2=3.40+.027[40°N., 70°W.]−.044[40°N., 90°W.]+.019[50°N., 80°W.]
Spring F_2=3.76−.010[40°N., 90°W.]+.067[40°N., 70°W.]−.099[40°N., 80°W.]−.031[30°N., 120°W.]+.025[50°N., 80°W.]+.040[30°N., 80°W.]
Summer F_2=3.48−.063[40°N., 90°W.]+.024[60°N., 120°W.]+.022[50°N., 60°W.]
Fall F_2=3.65−.090[40°N., 80°W.]+.064[40°N., 70°W.]−.041[30°N., 110°W.]−.012[60°N., 140°W.]

Another more elaborate way of demonstrating the reality of a precipitation-inhibiting mechanism as a manifestation of the regional large-scale circulation is by utilizing the extensive work of Klein [2] in specifying precipitation from 700-mb. contour patterns. By use of a statistical screening technique, Klein related precipitation in 40 climatologically homogeneous areas of the United States (circles 230 mi. in diameter as shown in fig. 11) to the 700-mb. height field on a 10°×10° grid of points covering North America and portions of the adjacent oceans (from 50°W. to 180°W.). For this purpose he used 5-day means of 700-mb. height and 5-day totals of precipitation over a 10-yr. period, broken down by season. The net result was a set of multiple regression equations, one for each area for each season, from which a precipitation index could be computed from the contemporary 700-mb. height distribution. The number of terms (generally three or four) used in these equations is sufficient so that additional terms do not appreciably improve the specification.

Klein's equations for circles No. 1 and No. 2 (see fig. 11) are given in table 1.

Klein's data were worked up for 5-day means. Yet since the large-scale features of the circulation which enhance or inhibit precipitation are similar for means of 5 days, a month, or a season, the results can be employed here. For example, Klein's formula for winter precipitation at circle No. 1, central New England, shows that the two most important terms are the heights at 40°N., 60°W. and 40°N., 90°W. The physical interpretation is that precipitation at circle No. 1 depends partly on the strength of the trough to the west and the ridge to the east—measures of the meridional flow related to large-scale convergence and divergence, source of moisture, etc. (fig. 12).

In order to see if a long-period trend has occurred in Klein's specifications, 700-mb. heights at the first two points listed in his equations were tabulated for 5-yr. means ending with the period 1961–65. An algebraic difference of the two values was then computed for each season and this result was plotted for each season for circles No. 1 and No. 2. The results for circle No. 1 are shown in figure 13, where the 5-yr. averages for the entire year and for the non-winter months are shown, as well as the 5-yr. average precipitation at New York. The downward trend of this precipitation index in spring, fall, and (except the last 5 yr.) in summer is clear, as is the long-

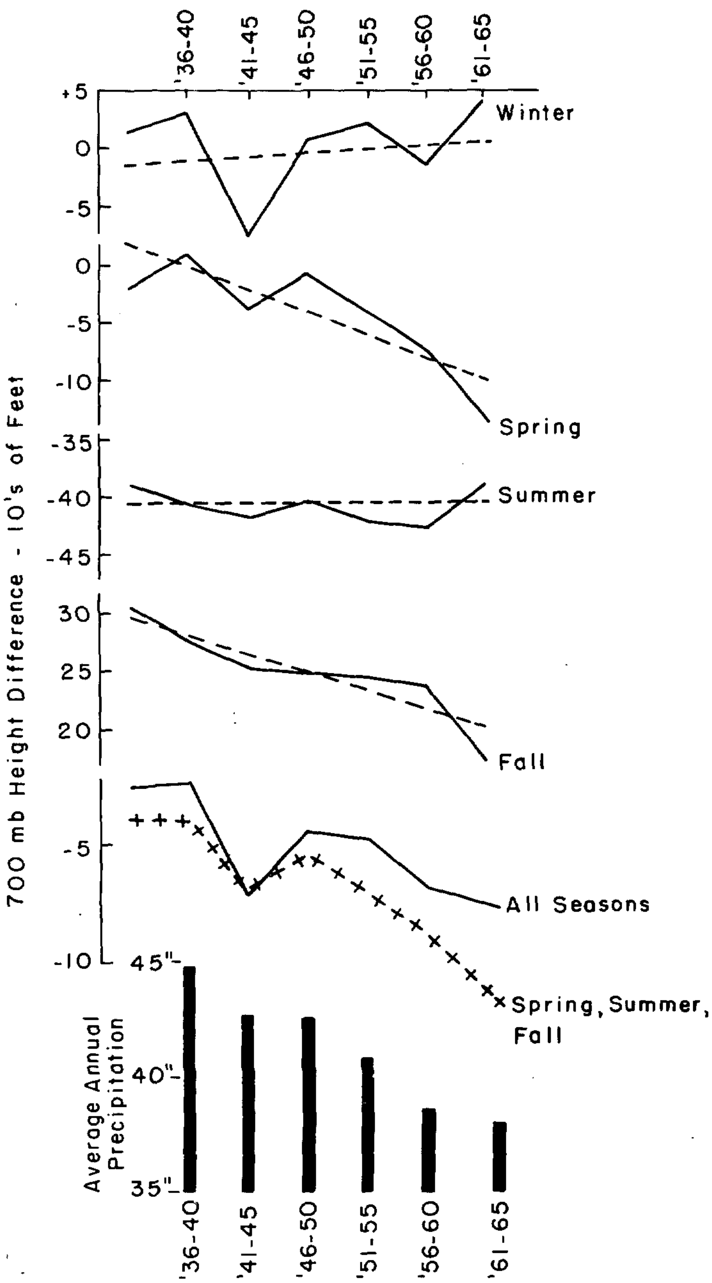

FIGURE 13.—700-mb. height difference determined from first two terms of Klein's [2] precipitation specification equations. Values are plotted so that higher precipitation amounts would be expected with higher positive (or lower negative) ordinate numbers. Broken straight lines fitted to ungrouped seasonal data by least squares. New York average annual precipitation for corresponding 5-yr. periods (base of figure).

period trend of the annual mean and the non-winter mean. Once again, it appears that a large-scale precipitation-inhibiting circulation has tended to develop over the Northeast during the past 25 years. An analysis for circle No. 2 shows similar results to those of circle No. 1, although the long-period trend is not as pronounced.

3. SOME CHARACTERISTICS OF NEW YORK'S MONTHLY PRECIPITATION TOTALS SINCE 1869

A number of climatological aspects of the monthly precipitation amounts observed at New York Central Park Observatory have been published [11]. Since the Central Park record extends back to 1869, it furnishes a base of further studies reported here.

In the first place, one may ask how the monthly values are distributed as to sign of departure from the record (1869–1965) mean. A simple tabulation of the number of months of above and below the record mean is given below:

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Ann.*
No. Above	42	43	39	39	46	40	47	41	37	40	46½	44	42
No. Below	55	54	58	58	51	57	50	56	60	57	50½	53	55

Thus, for every month there were more cases of negative departures from the record mean than positive departures. This skewness of the distribution, while not unexpected for monthly values, is also present in the annual precipitation (last column of above table). The reason for it is that the non-linear rainfall-producing processes have theoretical upper limits of duration and intensity much higher than average observed values, while zero is obviously the lower limit. For instance, the months of greatest discrepancy between the number of wet months and dry months (defined in terms of sign of departure from normal) in the above tabulation are April and September. The former is associated with heavy convective rains and springtime instability, and the latter with heavy rains, also convective in character, connected with tropical disturbances. Because of the skewness it is more meaningful to deal with the number of positive or negative departures from the rainfall *median* than from the rainfall mean.

We might ask how long spells of below or above the monthly median rainfall usually last. This was determined for New York's Central Park record and the results are summarized in figure 14. These data may be used for general planning.

Finally, a tabulation was made of the spells of three or more years with below median or above median precipitation, the results of which are given below.

Wet	*Dry*
1871–74	1879–81
1887–90	1916–18
1896–98	1929–31
1901–04	1954–59
1911–13	1961–65
1926–28	
1932–34	
1936–38	

No simple pattern emerges from these data, certainly not in the form of cycles.

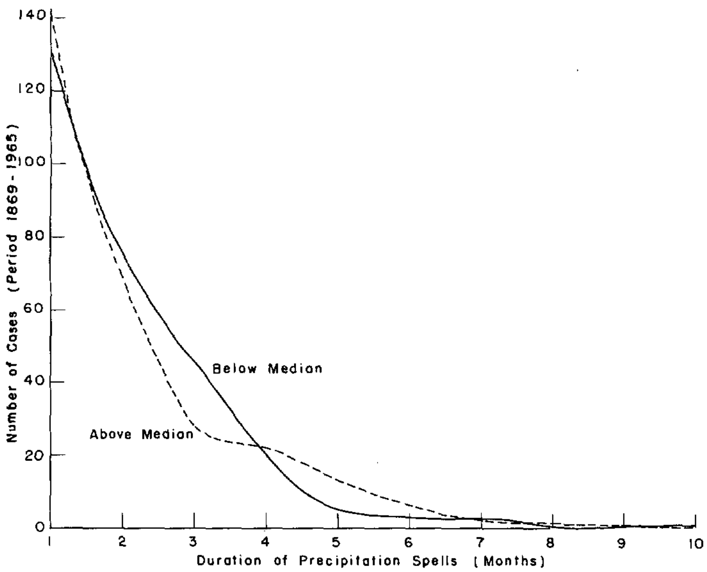

FIGURE 14.—Duration of spells of above and below median precipitation at New York determined from record 1869–1965.

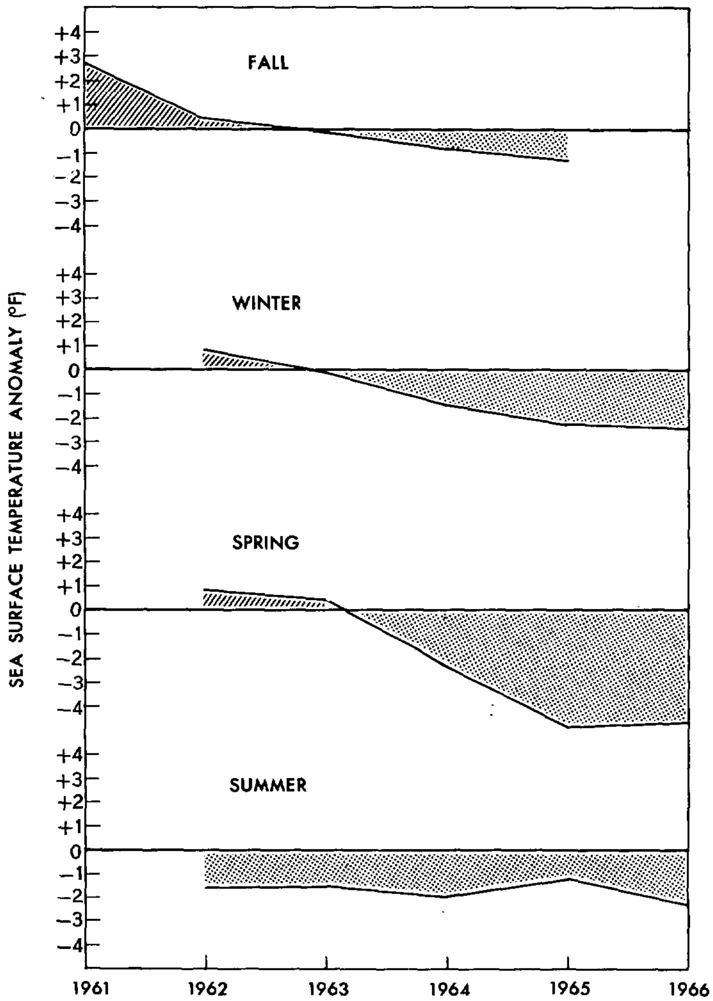

FIGURE 15.—Average seasonal departures from normal of sea-surface temperatures (°F.) along Atlantic shelf.

4. FURTHER STUDIES RELATING SEA-SURFACE TEMPERATURES OFF THE ATLANTIC SEABOARD TO THE DROUGHT IN THE NORTHEAST

In an earlier paper [5] on the drought in the Northeast I attempted to show that abnormally cold surface water along the Atlantic shelf from winter into early summer during the period 1962–65 played an important role in stabilizing the drought pattern—and also that the drought, in turn, played a role in maintaining the cold water. This kind of cooperation appears to be a rather common mode of large-scale interaction between air and sea.

In the report cited above, monthly mean departures from normal of sea-surface temperature in a circle 3° of latitude in diameter, centered at 37.5°N., 72.5°W., were shown in a graph running from 1960 to 1965. It was pointed out that the decline in water temperatures during the drought period was quite general along the Atlantic shelf and not restricted to this 3° circle. To strengthen this contention, I have computed the seasonal mean temperature anomalies for four such circular areas, centered at 42.5°N., 67.5°W.; 40°N., 70°W.; 37.5°N., 72.5°W.; and 35°N., 75°W.; these reasonably represent the average temperature anomalies of the water along the Atlantic shelf (fig. 15). All available ship observations were used. The general decline and the low values during the first half of the year, especially during the last few exceptionally dry years, are clear.

Numerous attempts were made to find if a simple relationship exists between coastal precipitation and offshore water temperatures. This research was cut short by the impossibility of obtaining reliable ocean surface temperatures. The only available open ocean data appeared to be those adapted by Riehl [8] from MacDonald's [3] atlas. These data, given for 5° squares, were used for the two squares 35°–40° N., 70°–75° W., and 40°–45° W., 65°–70° W. and compared to State-wide averages of seasonal precipitation for New Jersey and for southern New England for spring and summer. The precipitation was expressed in tertiles—light, moderate, heavy—according to season. It was hoped that contemporaneous associations between seasonal precipitation and off-shore ocean temperatures might show up in a contingency table, so the ocean temperature anomalies for these two squares were also broken down into the tertiles warm, moderate, and cold. The results of this investigation were entirely negative. Although one might draw the conclusion that no significant and lasting relationship exists between the off-shore sea-surface temperature and the precipitation in New Jersey or southern New England, we must bear in mind the following points:

1. Riehl adjusted MacDonald's data by smoothing techniques, designed to eliminate irregular values. But irregular values are an important component of the precipitation record.

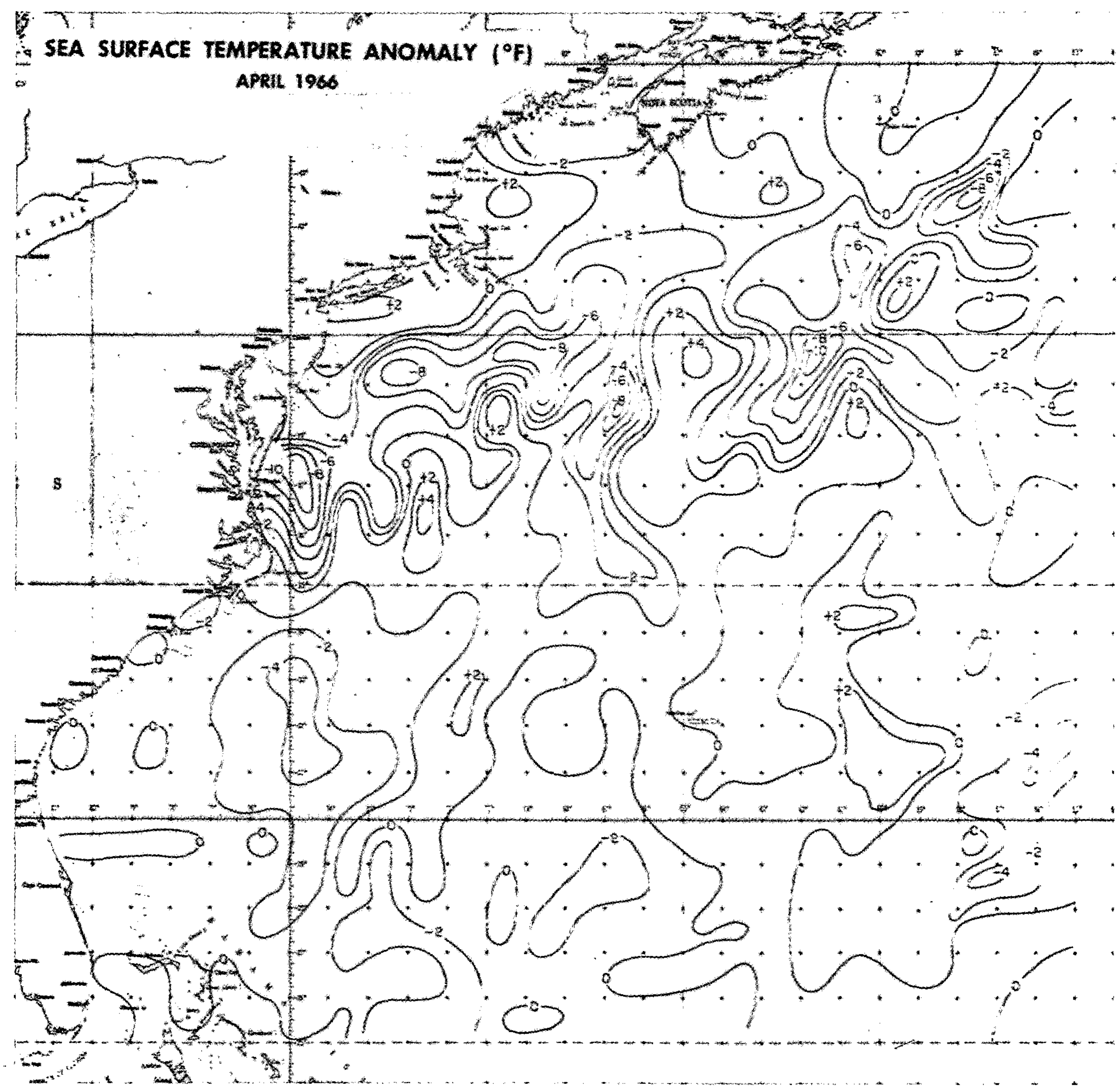

FIGURE 16.—Sea-surface temperature anomaly (°F.) for April 1966 (from [8]).

2. The data have been stratified in a manner too simple to illuminate a complex relationship.

3. The data were obtained for rather large (5°) squares in some areas where inhomogeneous water masses were observed.

In an attempt to surmount the possible inadequacies of Riehl's data, sea-surface temperatures at coastal points were studied to see if a correlation existed between them and open ocean temperatures along the Atlantic shelf over the last 6 yr., when values of both were available and reasonably correct. Had such a correlation been found, it would have been possible to reconstruct a long-period record of open ocean temperatures from regression equations developed from these correlations.

Unfortunately, no correlation was found. In-shore temperature anomalies for Atlantic City, Boston, and Portland plotted against those at 40° N., 70° W.; 42.5° N., 62.5° W.; and 37.5° N., 72.5° W., showed no relationship when broken down by season or otherwise.

This lack of correlation, probably not surprising to oceanographers, reflects the great complexity of water temperature patterns under varying conditions at in-shore locations. Figure 16, the U.S. Naval Oceanographic Office [10] sea-surface temperature anomaly chart for April 1966, presents a good example of why such a simple correlation fails. The spring cold water pool along the shelf was present, but just off the coasts of southern New England and New Jersey water temperatures were *above* normal.

5. NATIONWIDE PRECIPITATION PATTERNS ASSOCIATED WITH DROUGHT IN THE NORTHEAST

DETERMINING SPATIAL COHERENCE IN PRECIPITATION

Since drought is a large-scale phenomenon, spatial coherence of precipitation deficiencies over adjacent areas is to be expected. The nature of this coherence may be illuminated by a series of State-wide average monthly precipitation records [12]. Average values for States (or groups of a few small States, as in the case of southern New England) were obtained by weighting the precipitation totals for several stations according to area. These data were used by I. Enger and the author [4] in studies designed for predicting seasonal precipitation.

The series extends from 1899 to 1957. Seasonal totals were computed for each of 43 areas [3] and these arrayed so that equally frequent classes (tertiles) of light, moderate, or heavy were determined for each season. Because of round-off error and perhaps other errors, the percentage distribution of light, moderate, or heavy classes did not always come out equal.[4] However, in almost 90 percent of the cases the frequency of light, moderate, or heavy cases lay between 31 percent and 36 percent and the deviation from exact equal probability of occurrence is probably of little or no consequence for this use of the data.

Let us examine first the large-scale patterns of precipitation likely to occur over the United States when individual States of the Northeast drought area are dry. An example of one of the patterns is given in figure 17, where the percent probabilities of occurrence of light, moderate, and heavy winter precipitation are given when southern New England's winter precipitation is light. From this figure it is clear that when southern New England has a winter of light precipitation, adjacent and even fairly remote States as far away as the Central Plains also tend to have light precipitation, and there is a marked reduction in the frequency of "heavy" precipitation. Charts such as figure 18 were constructed for conditions of light precipitation in New Jersey, New York, Pennsylvania, Maryland, and southern New England.

Because the spatial coherence showed up in the frequency of both extreme categories, light and heavy, it was decided to plot charts showing the percentage of light minus the percentage of heavy cases when the key State was light. Theoretically, the range of values on such a chart should lie between +100 in the key State and −100 in a State in which the precipitation is in complete opposition to the key State—for example, always heavy when the key State is light.

CHARACTERISTIC NATIONWIDE PRECIPITATION PATTERNS ASSOCIATED WITH DRYNESS OVER THE NORTHEAST

The nationwide precipitation patterns associated with dryness in each of the five northeastern key areas and for

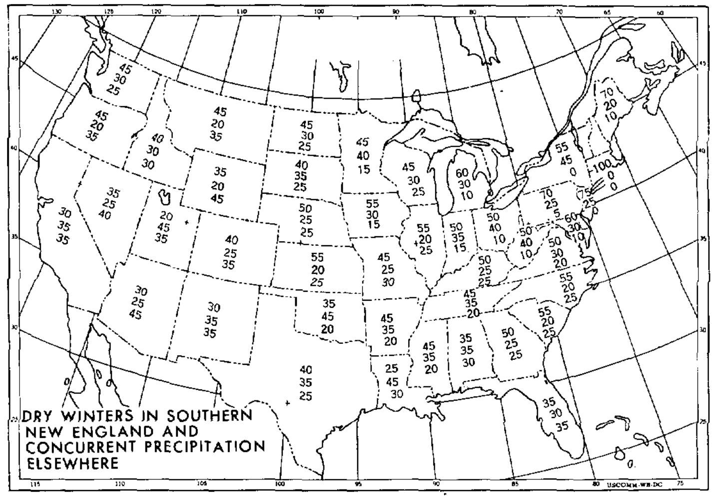

Figure 17.—Percent probability of light (top number), moderate (middle), or heavy (bottom) precipitation in winter when southern New England has light precipitation. State averages.

each of the four seasons are illustrated in figures 18A to T. At once it is clear that the scale of the phenomena producing deficient precipitation over any of the five key areas tends to be largest in winter and smallest in summer. For example, in winter a moderately strong tendency (25 percent or greater) to more light and less heavy than the climatologically probable extends from the Atlantic Coast to the Continental Divide, while in spring the western boundary of this area moves to the western Great Lakes, and in summer to the eastern Lakes.

A numerical measure of the areal extent of the coherence in the eastern United States can be determined by using a planimeter on the charts of figure 18. Specifically, the area enclosed by the 25 percent line (the eastern shaded area) was measured for each season and for each target State (fig. 19). The graphs indicate that, with the exception of Pennsylvania, the area dominated by relative dryness is about twice as large in winter as in summer. Spring and fall are intermediate, the former being the larger. Of course, these numerical values are very rough measures, not only because of the arbitrary choice of the 25 percent line as a boundary, but also because the eastern boundaries of deficient precipitation extend to unknown distances off the Eastern Seaboard.

The reduced coherent area in the warmer seasons reflects the fact that the long waves in the westerlies are shorter then than in the winter, and that precipitation-producing processes are of smaller scale. In the warm season smaller-scale activity involves not only cyclones and their associated upper-level short waves, but also mesoscale and convective shower systems.

As the scale of precipitation induced by long waves diminishes, there is a tendency for some areas to become wet when the key States are dry. This tendency is especially pronounced in summer for the western half of the country, and in spring for the Far West. It suggests that when a prevailing upper-level trough is off the Atlantic

[3] Northern New England included Maine, New Hampshire, and Vermont; southern New England, Massachusetts, Connecticut, and Rhode Island; Maryland included Delaware. Otherwise, each State of the contiguous United States was used.

[4] In very dry areas the tertile system breaks down.

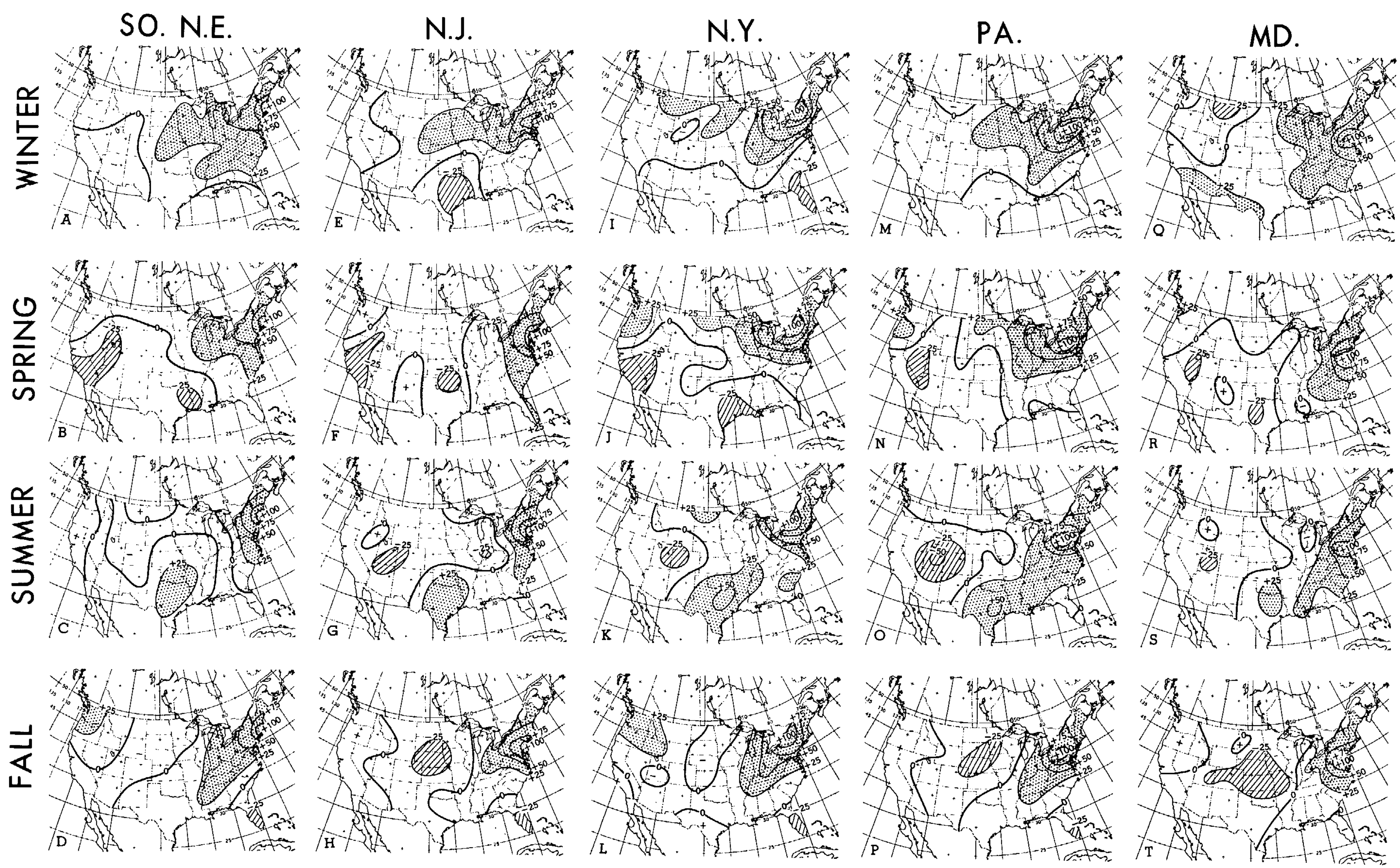

FIGURE 18.—(A–T) Charts showing national pattern of percent "light" minus percent "heavy" seasonal precipitation, given "light" precipitation at one of five key States. Positive coherence with key State indicated by values from 0 to 100 percent and negative coherence (opposition) by values from 0 to −100 percent. Shading represents values greater than ±25 percent.

Seaboard in spring, leading to dry weather over the Northeast, another trough frequently dominates the western Plateau, causing more intense frontal activity and convective showers there. In the summertime, however, it is uncommon to observe quasi-stationary troughs over the western Plateau [9], and precipitation there comes from a moist tongue which enters the United States from Mexico and flows around the upper-level anticyclone that is generally centered over the Southern Plains [13]. When the continental anticyclone is strongly developed, it produces dryness and frequently drought below it [4]. This circumstance is usually accompanied by a prevailing northwesterly flow over the northeastern States, which—because of subsidence and dryness—produces only light precipitation there. These considerations make possible an explanation of the complex patterns shown in the summer charts of figure 18. In all except the one on which Maryland is the key State, dryness in the Southern Plains and dryness in the Northeast are separated by a zone of less likely dryness, which extends from an area of heavier precipitation probability in the Far West. This tendency to heavier (or less light) precipitation is suggestive of the anticyclonic moist tongues frequently found in summer on isentropic charts. As these moist tongues move around the periphery of the upper-level anticyclone they usually lead to clusters of showers and thunderstorms which may be traced into the Ohio and Tennessee Valleys and often even into the Southeast [6]. Thus under these special types of circulation, the coherence pattern of dryness extending from the Northeast is interrupted. On the other hand, as the westerlies shift southward in the fall, and the upper-level continental anticyclone weakens or disappears, the moist tongue does not usually continue its anticyclonic flow, and the interruption ceases.

Another interesting area of dryness shows up in the Pacific Northwest in fall with the relative wetness in the central United States and dryness in the Northeast. These probabilities imply a flow pattern of upper-level ridges flanking a trough over the Western Plains. This situation is not uncommon when the Great Basin High occupies the northeastern Basin and a quasi-stationary anticyclone dominates the eastern third of the Nation.

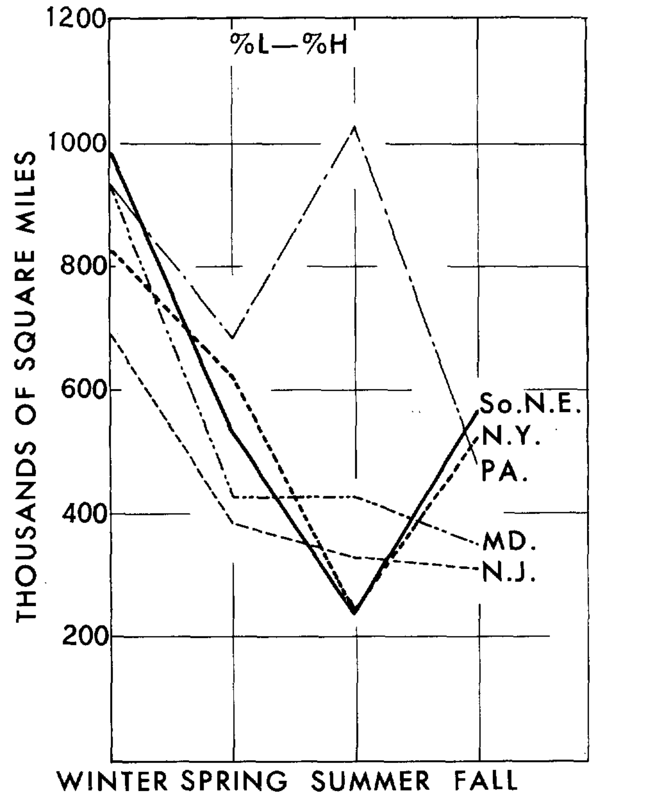

FIGURE 19.—Eastern shaded area encompassed by the 25 percent line in charts of figure 18. Area is a rough measure of the scale of the seasonal precipitation-inhibiting mechanisms.

6. SUMMARY

The local manifestations of the recent 5-yr. drought in the Northeast as revealed by monthly climatological records taken at Central Park Observatory in New York include (1) prevailing surface relative humidities lower than normal, (2) condensation levels in the warm half of the year higher than normal, (3) temperature range during the warm half of the year greater than normal, and (4) precipitation yield per storm less than normal.

Precipitation records since 1869 indicate a downward trend of almost 0.3 in. per yr. beginning in the decade 1927–37. The decline and a concurrent decline in the average precipitation yield per storm are consistent with a tendency for increased upper-level trough activity off the Atlantic Seaboard and with other features of upper-level flow patterns that imply suppression of precipitation in portions of the drought area. Unfortunately, attempts to relate the long-period decline in precipitation to sea-surface temperature anomalies have been stymied—perhaps because of inadequacies in the sea-surface data.

By the nature of precipitation statistics, runs of months below normal have been more frequent than runs above normal. However, when the median rather than the normal is used as a reference, spells below the median are slightly more frequent than spells above it, up to a duration of 3 mo., but less frequent for longer durations.

Geographic patterns of seasonal precipitation associated with dryness in the Northeast, worked up from 59 yr. of data, imply the existence of precipitation-inhibiting phenomena of a scale embracing about half the Nation in winter and one-fourth the Nation in summer. These scales appear to be associated with prevailing long waves in the westerlies and their associated air masses, fronts, cyclones, and convective systems. Therefore dryness in the East is often associated with wetness in the West. Geographic patterns of summer precipitation accompanying dryness in the Northeast strongly suggest dominant influence by the upper-level anticyclone in the Southern Plains. The evidence is the dryness of the Southern Plains and the broad anticyclonic tongue of relative wetness emerging from the far Southwest and penetrating the north central United States and the Midwest. This pattern is peculiar to summer, for in other seasons the continental upper-lever anticylcone is never present sufficiently long or frequently to show up in seasonal means.

ACKNOWLEDGMENTS

I wish to express gratitude to the following individuals who assisted in this work: At New York University, Mr. Kuoo Nan Liou and Mr. Peter Ronberg (computations and programing) and Mrs. Lillian Bloom (typing); in the Extended Forecast Division of the Weather Bureau, Messrs. Russell Jones and Robert H Gelhard for programing; Miss Myrtle Wagner for charting; Mr. Philip F. Clapp and Dr. Donald Gilman for suggestions leading to improvement of the manuscript, and Mrs. Rosita Elwell for typing.

REFERENCES

1. H. C. Barksdale, D. O'Bryan, and W. J. Schneider, *Effect of Drought on Water Resources in the Northeast,* Department of the Interior, U.S. Geological Survey, Mar. 1966.
2. W. H. Klein, "Application of Synoptic Climatology and Short-Range Numerical Prediction to Five-Day Forecasting," *Research Paper* No. 46, U.S. Weather Bureau, June 1965, 109 pp.
3. W. F. MacDonald, *Atlas of Climatic Charts of the Oceans,* U.S. Weather Bureau, 1938, 130 pp.
4. J. Namias, "Factors in the Initiation, Perpetuation, and Termination of Drought," International Union of Geodesy and Geophysics, Association of Scientific Hydrology, Publication No. 51 (Proceedings of the General Assembly, Helsinki), 1960, pp. 81–94.
5. J. Namias, "Nature and Possible Causes of the Northeastern United States Drought During 1962–65," *Monthly Weather Review,* vol. 94, No. 9, Sept. 1966, pp. 543–554.
6. J. Namias, "Thunderstorm Forecasting With the Aid of Isentropic Charts," *Bulletin of the American Meteorological Society,* vol. 19, No. 1, Jan. 1938, pp. 1–14.
7. W. C. Palmer, "The Northeast Drought Situation"—a running commentary and set of charts on the state of the drought in terms of an index of severity, appearing frequently in the *Weekly Weather and Crop Bulletin, National Summary,* Environmental Data Service, ESSA, 1965 to 1967.
8. H. Riehl, "Sea-Surface Temperature of the North Atlantic, 1887–1936," University of Chicago, Department of Meteorology, Research Report under Contract No. N6ori-02036, Project NR 082–120, ONR, Jan. 1956.
9. L. P. Stark, "Positions of Monthly Mean Troughs and Ridges in the Northern Hemisphere, 1949–1963," *Monthly Weather Review,* vol. 93, No. 11, Nov. 1965, pp. 705–720.
10. U.S. Naval Oceanographic Office, *Monthly Summary, the Gulf Stream,* vol. 1, No. 4, Apr. 1966.
11. U.S. Weather Bureau, "Climatic Guide for New York City, New York, and Nearby Areas," *Climatography of the United States,* No. 40–26, Washington, D.C., Nov. 1958, 61 pp.
12. U.S. Weather Bureau, *Climatological Data* by States and Sections (state-wide mean monthly temperature tabulations published for each State), up to 1957.
13. H. Wexler and J. Namias, "Monthly Isentropic Charts and Their Relation to Departure of Summer Rainfall," *Transactions, American Geophysical Union,* vol. 19, 1938, pp. 164–170.

[Received April 13, 1967; revised May 24, 1967]