AFCRL-69-0003

CLIMATIC NORMALS AS PREDICTORS
Part 5: Conclusion

by

ARNOLD COURT
PROFESSOR of CLIMATOLOGY
SAN FERNANDO VALLEY STATE COLLEGE

15 DECEMBER 1968

FINAL REPORT
DECEMBER 1965 - DECEMBER 1968
CONTRACT AF19 (628)-5716

PROJECT NO. 8624 TASK NO. 862402

WORK UNIT NO. 86240201

REPORT NO. 68-82-5

Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.

SAN FERNANDO VALLEY STATE COLLEGE FOUNDATION
NORTHRIDGE
(Los Angeles)
Calif. 91324

AD 687138

CONTRACT MONITOR: IVER A. LUND
Aerospace Instrumentation Laboratory

MAY 20 1969

prepared for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS
01730

Reproduced by the
CLEARINGHOUSE
for Federal Scientific & Technical
Information Springfield Va. 22151

19

AFCRL-69-0003

C L I M A T I C N O R M A L S A S P R E D I C T O R S

PART 5: CONCLUSION

BY

ARNOLD COURT
Professor of Climatology
San Fernando Valley State College
Northridge (Los Angeles) Calif., 91324

Final Report
December 1965 - December 1968

Contract AF 19(628)-5716

Project No. 8624 Task No. 862402
Work Unit No. 86240201

15 December 1968

Contract Monitor: Iver A. Lund
Aerospace Instrumentation Laboratory

Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.

Prepared for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS 01730

Climatic Normals as Predictors, Part 5: Conclusion

F I N A L R E P O R T

ABSTRACT

Methods of previous Reports, concerned with the number of antecedent years for which the mean value of a climatic element offers the minimum variance estimator of the next year's value, are extended to similar predictions more than one year ahead. For predicting a value m years beyond the end of the averaging period, the best average is found to be based on a period m years shorter than for predicting the next year's value. Apparently each climatic record has an average period of maximum homogeneity, whose length must be equalled, for optimum prediction, by the interval from the start of the averaging period to the end of the predicted one. Climatic normals for 15-year periods, rather than 30 years as at present, are recommended, with recomputation every 5 years. Medians of values over 15 years are suggested as even better predictors than means. Finally, 7 years is suggested as a suitable period for the definition of climate.

Climatic Normals as Predictors, Part 5: Conclusion

F I N A L R E P O R T

1. Introduction

Prediction, rather than description, is the primary purpose of weather observations, whether assembled for synoptic analysis or tabulated into climatic summaries. While the avowed intent of a climatic summary may be to "describe" climate, any description of past conditions is of little value unless persistence is assumed. The overwhelming use of climatic statistics is for the estimation of future conditions: the clothes needed for a trip, the size of the furnace for a new building, the crops that can be introduced into a region, the most advantageous route for an airplane, and so on.

In summarizing their statistics, however, few climatologists consider the uses to which the results will be put. They follow faithfully the 19th century criteria for characterising climate, although granting grudgingly the fallacy of the concomitant concept of climatic constancy. Climatology is far more persistent than is climate.

Climatic "normals," cornerstones of climatology, are senescent survivors of the pervasive proposition of permanency. Until the last century, hills were everlasting, biologic species had not changed since Creation, and "climate" was the fixed value about which weather conditions varied randomly. The accepted characteristics of a species were averages of many measurements of individual eagles or eels or elephants, and the "true" climate was the average of weather observations for many years, the more the better.

With the slow acceptance, in this century, of the reality of climatic changes and fluctuations, the 19th century description of a place's climate by the average of all available observations, regardless of when made, has been replaced by a rigid recipe: the mean of observations during a period of 30 consecutive years, beginning in 1901, 1931, 1961, etc. A period of 30 years, rather than 10 or 25 or 50, apparently was chosen

(by the International Meteorological Organization in 1937) as the shortest period for which an average would be meaningful or stable. The variance of the average of k independent observations from a normally-distributed population is 1/k times the variance of the individual observations, so the standard error of a 30-year mean would be $30^{-1/2} = 0.18$ times the standard error of each observation.

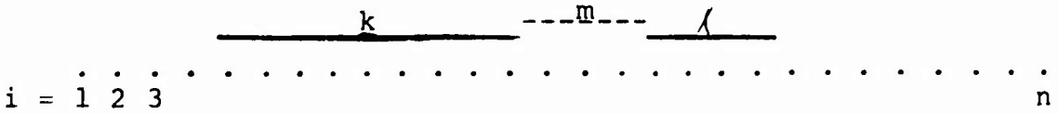
The presumed precision of a climatic quantity, however, has much less intrinsic importance than the expected error with which it forecasts future phenomena. For what period should a climatic "normal" be computed so as to approximate most closely coming conditions? This question, little investigated previously, is discussed in the present Report, the result of almost three years of study.

Various aspects of this question have been discussed in four previous Scientific Reports. SR 1 examined, in greater detail than here, the history and definition of climatic normals, and summarized and compared five previous studies, in the U.S., England, and Russia, on the number of years for which the average offered the best estimate of the following year's temperature, precipitation, or streamflow. SR 2 extended these analyses, in greater detail, to monthly temperature and precipitation at 7 U.S. stations, verifying the findings of previous authors that, in general, means based on anything more than 10 years were about equal in predictive precision. SR 3 showed that the next year's value was slightly closer, on the average, to the <u>median</u> of the antecedent values than to their mean. SR 4 verified the results of the previous authors, and of SR 2, for a variety of U.S. and foreign records of temperature, precipitation, rainy days, and sunshine percentage.

The present Report offers the somewhat surprising results of seeking the period for which the mean (or median) estimates most closely a value more than one year beyond the end of the period. It also presents the conclusions of the entire study, quite different from those anticipated when it began. An appendix contains translations of two Russian papers, already discussed in SR 1.

2. Methodology

Throughout this study, the primary interest has been in defining the number of years, k* ("k-star"), over which a moving average gives the "best" estimator of an average for the ℓ years beginning in the k + mth year:



In all except one of the previous studies, and in SR 2 and SR 4, the criterion of "best" was taken to be minimum variance. The desired k* was the value minimizing

$$S^2_{k\ell m} = \frac{1}{n-k-\ell-m+2} \sum_{i=1}^{n-k-\ell-m+2} \left[\frac{1}{\ell} \sum_{j=m}^{m+\ell-1} x_{i+j+k-1} - \frac{1}{k} \sum_{j=0}^{k-1} x_{i+j} \right]^2$$

One previous study used mean absolute error, obtained by taking the absolute value, rather than the square, of the difference, and here designated as $Q_{k\ell m}$. This criterion was also applied in SR 2, and used in SR 3 for comparison with the mean absolute difference between the median of the antecedent years and the next year's observation; in this study this quantity is designated as $D_{k\ell m}$.

In all previous studies, except for portions of two, and in SR 2, SR 3, and SR 4, the k-year means (or medians) were compared only to the next (k + 1st) value, i.e. both ℓ and m were one. (Actually, m = 1 means that no intervening observation is omitted.) As mentioned in SR 2, and given in detail in SR 3, the FORTRAN IV program developed for the present study computes $S^2_{k\ell m}$, $Q_{k\ell m}$, and $D_{k\ell m}$ for ℓ = 1 with m = 1,2,3, ...,10, and for ℓ = 10 with m = 1. Complete results were printed out in a table in which successive lines give $S^2_{k\ell m}$ for k = 1,2,3,...,50 or $Q_{k\ell m}$ or $D_{k\ell m}$ for k = 1,3,5,..., 49. Successive columns are for m = 1,2,3,...,10 with ℓ = 1; the final column gives values for ℓ = 10 and m = 1, for

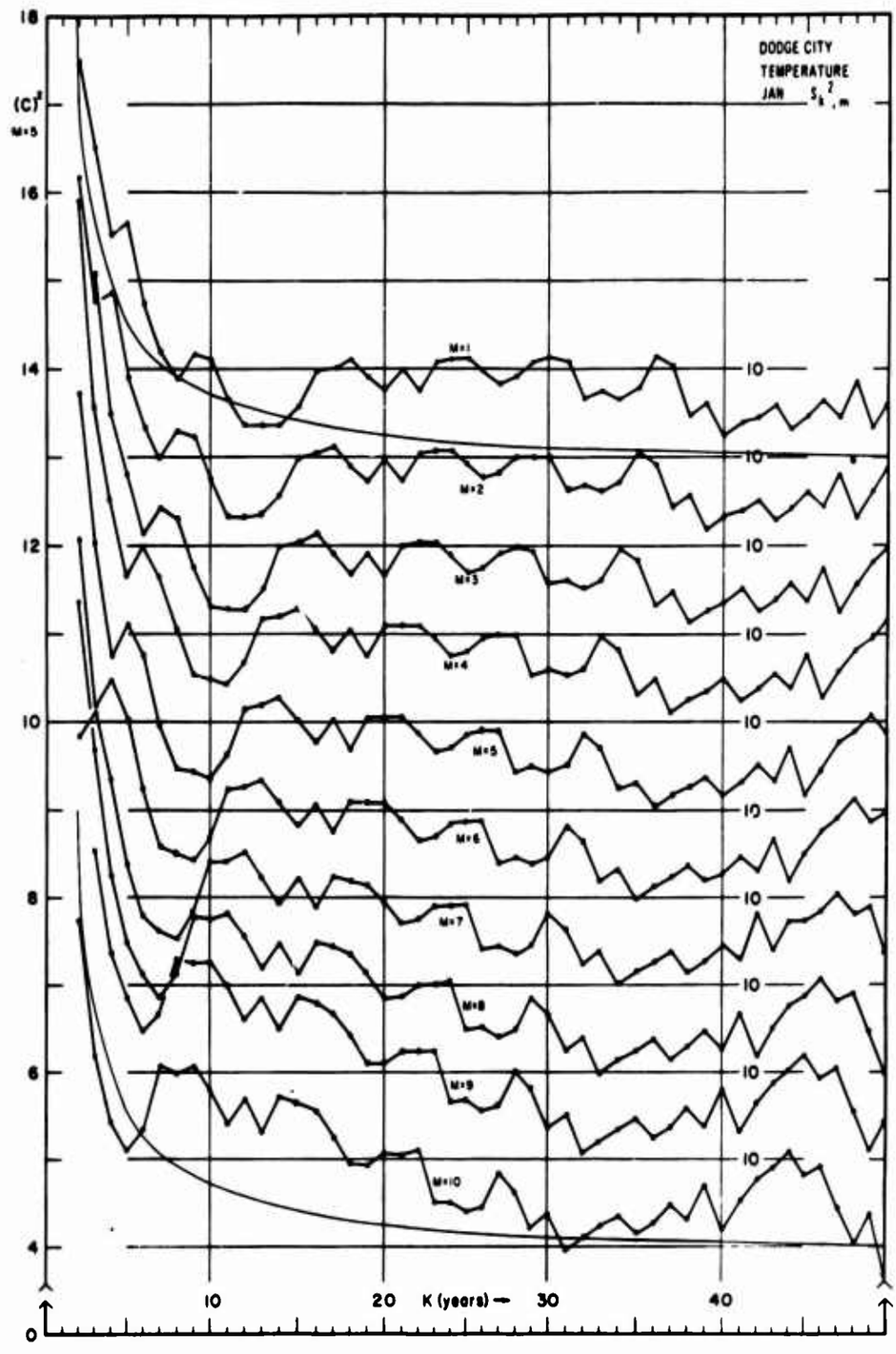


Figure 1. $S^2_{k/m}$ as a function of k for m = 1,2,...,10, for January temperatures at Dodge City, Kansas, 1874-1960

predicting the mean over the 10 years immediately following the k years. The complete program, with examples of the printout, is given in SR 3.

For each variable in each month at each station, therefore, six full pages of printout were received, with the input data on a seventh page. The many figures of SR 2 and SR 4 summarize the results of only the first columns of the tables.

Representation similar to those of SR 2 and SR 4, but for all 10 values of m , is offered in Figure 1, for January temperatures (1874-1960) at Dodge City, Kansas. Shown are curves of $S^2_{k/m}$ as a function of k , separately for each m . The topmost curve is the January curve of Figure 1B in SR 2. Below it, for increasing lags, m , are the corresponding curves, each displaced downward by one unit. Each curve varies generally between 8 and 12 deg^2, around a line labelled "10". The ordinate is labelled for the topmost curve, and is interrupted near the bottom so that all curves could be shown on a single sheet. The bottom curve, for m = 10 , represents the extrapolation variance when a k-year mean is used to predict the January temperature 10 years after the end of the k-year period.

3. Discussion

The most unexpected, and most significant, result of the entire study is shown clearly in Figure 1, and would be just as clear in a similar figure for any of the other computations. The curves are very similar in shape, but for each additional year of extrapolation, they shift one year to the left, toward smaller values of k . In this example, k* is 40 years for prediction one year ahead, 39 years for two years ahead, and so on to 31 years for predicting the temperature 10 years ahead.

This behavior was apparent on almost all the printout sheets, on which the minimum value of $S^2_{k/m}$ in each column, which identified its k*, was marked by an asterisk, as shown in the tables in SR 3. These asterisks "marched uphill" on most of the tables. In addition, secondary minima behaved similarly, as shown by the first major dip in the curves of

Figure 1, which begins at k = 12-14 for m = 1 and regresses to k = 5 for m = 10.

To represent the behavior of $S^2_{k/m}$ as both k and m vary, with $/ = 1$, isopleths of the values on the computer printout sheets were drawn on overlays. Examples are shown in Figure 2, for annual precipitation and temperature at Dodge City. On each diagram, dots mark the value of k* for each m. The isopleths indicate the values of $S^2_{k/m}$, in deg^2 for temperature and cm^2 for precipitation.

In the left-hand diagram, for precipitation, two general troughs of minimum values are shown, both trending upward, to decreasing values of k with increasing m. Most k* dots fall in the lower trough, but three occur in the upper one. In the right-hand diagram, for temperature, the isopleth pattern is less marked, but the k* dots trend generally upward until, at m = 8, they drop to a second trough and then resume the upward march.

Similar diagrams for annual temperature and precipitation at the other six stations are shown in Figures 3 and 4. On both, the general trend of the patterns is toward smaller values of k as m increases, and the k* dots show the same trend, unexpected and at first quite mystifying. Only at Lynchburg, for both elements, is the pattern at all unclear, but it still is not markedly different from the others.

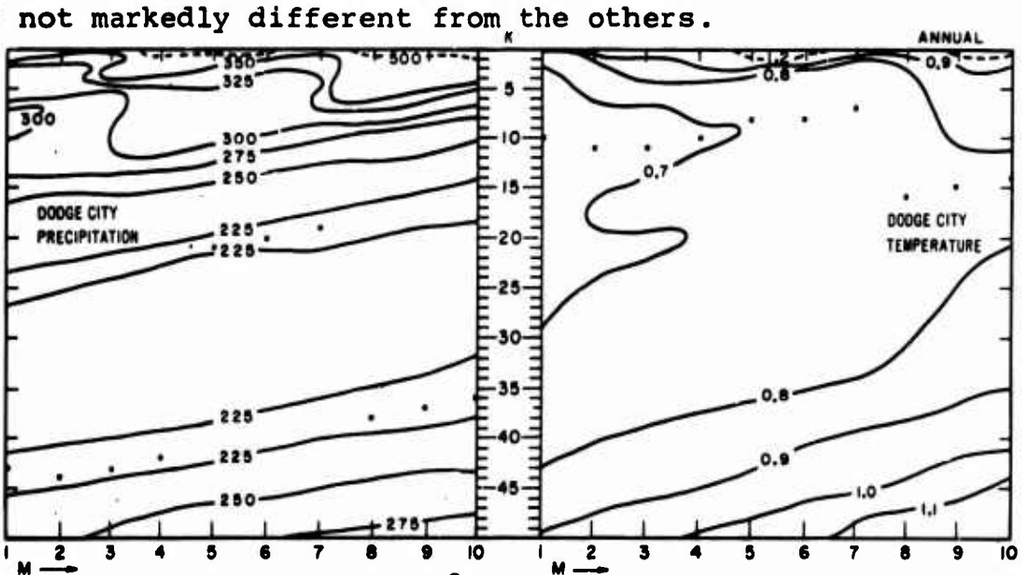


Figure 2. Isopleths of $S^2_{k/m}$ for annual precipitation and temperature at Dodge City, Kansas, 1874-1960.

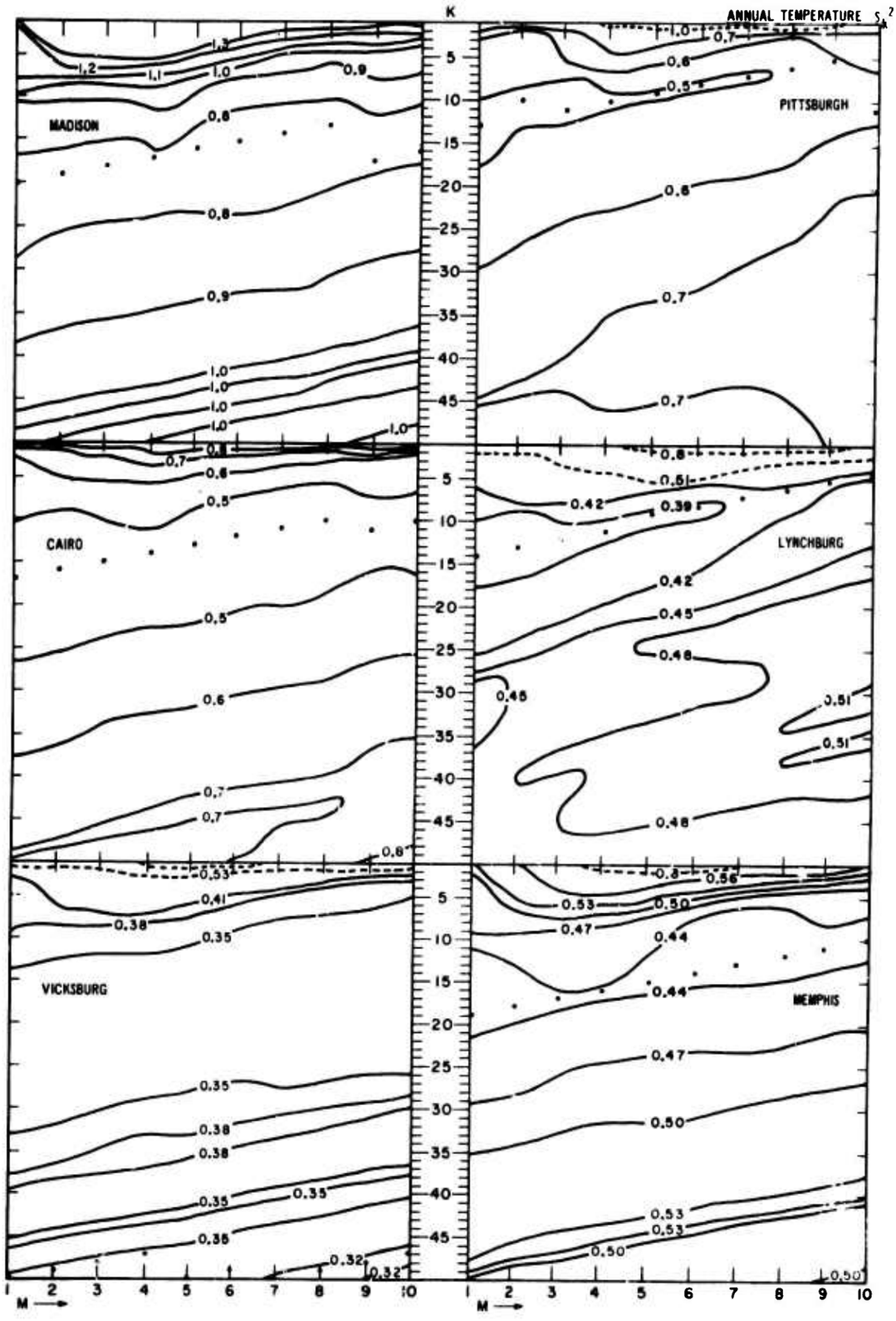


Figure 3. Iospleths of $S_{k\ell}^2$ for annual temperature at seven U. S. stations

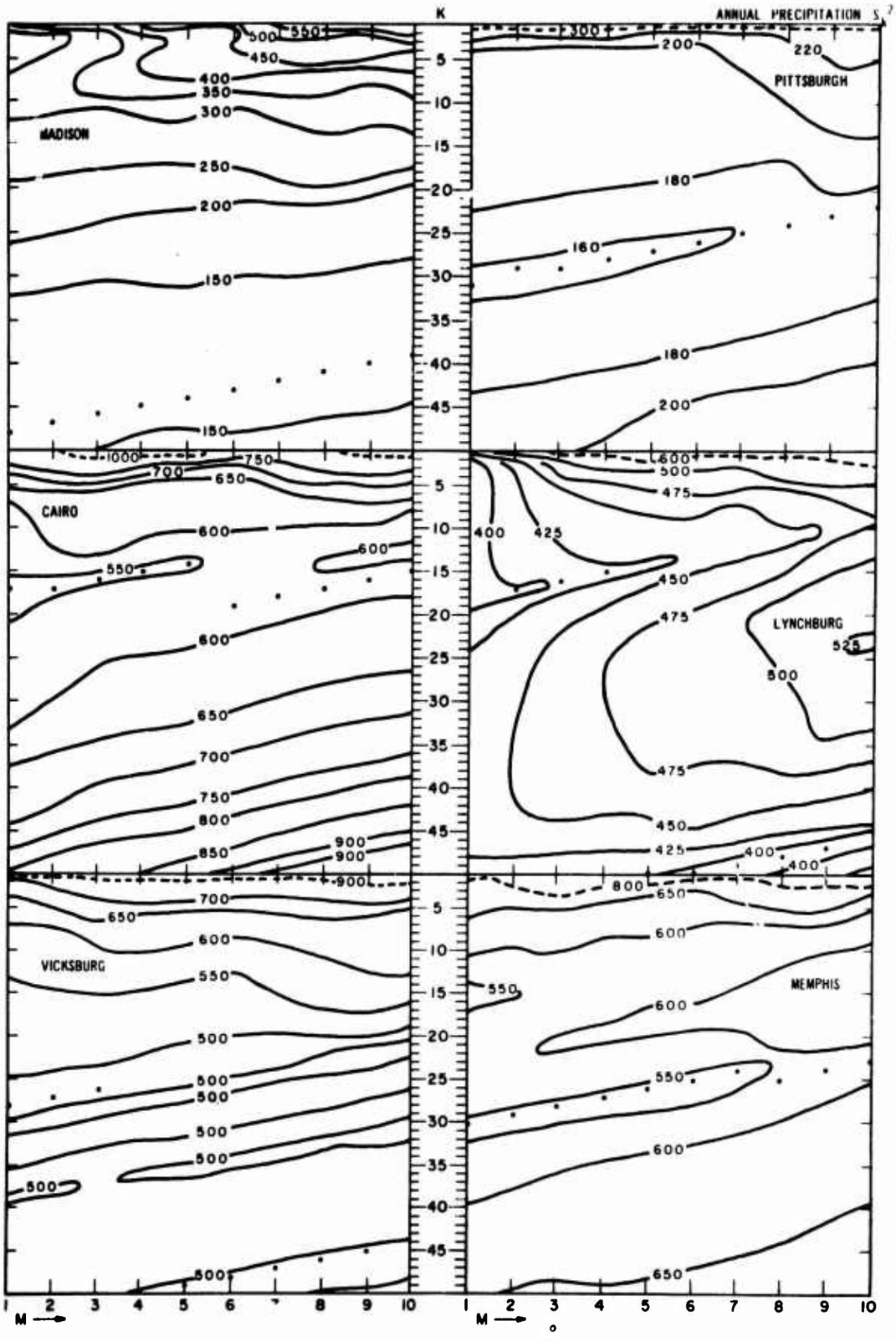


Figure 4. Iospleths of $S_{k\ell}^2$ for annual precipitation at seven U. S. Stations

unexpected and at first quite mystifying. Only at Lynchburg, for both elements, is the pattern at all unclear, but it still is not markedly different from the others.

The monthly diagrams (Figures 5 to 10 for temperature, 11 to 16 for precipitation) show this same characteristic. It also appears on the printout sheets for all the other places and elements considered in SR 2 and SR 4. Although the actual value of k^* may vary markedly from month to month and element to element, it is usually one year less for each additional year of extrapolation.

4. Explanation

Why should the temperature, precipitation, or sunshine in the year after next be estimated best by the mean (or median) of an antecedent period one year shorter than that appropriate for next year's value? The exact opposite relation had been conjectured at the start of the study: the original hypothesis was that the optimum length of antecedent record would be directly proportional to the length to which it would be extrapolated. If next year's value was best estimated by the mean (or median) of the preceding 20 years, a value 10 years ahead was assumed to require a somewhat longer antecedent period. This conjecture was incontrovertably refuted by many computations, a few of which are summarized diagrammatically in the figures included here.

Any valid explanation of this inherent characteristic of climatic series must be also compatible with concurrent conclusions of this study. As developed in SR 2 and SR 4, these are generally that, for prediction purposes, each climatic element behaves differently in each month at each station, but may have some regional resemblances in some months. The erratic behavior of S^2, Q, and D represents the inherent variability of weather and climate, and is not the result of observational practices.

No significant serial correlation has been found for annual or monthly values of climatic elements. However, smoothing such correlations by a Fourier transform into a power spectrum

shows supposed significant spectral spikes. For example, in the Woodstock data, presented in SR 4, Landsberg, Mitchell, and Crutcher (Mon. Wea. Rev. 87:283-298, 1959) found that "Spectral peaks in temperature, of periods near 2 years and greater than 50 years, both achieve high levels of statistical significance."

Spectrum analysis, however, can apply only to the past record, and no procedures are available to establish the persistence into the future of any apparently significant peaks. When long series of observations are divided into segments, each sufficiently long for spectrum analysis, results often differ for the various segments. Similar differences were found for extrapolation variance in the two halves of the long temperature series at Hohenpeissenberg, Basel, and Geneva (SR 4). Hence the results of any spectrum analysis of climatic data cannot validly be extended to the future.

Nevertheless, some light serial dependence may be present in climatic elements. If they were completely random, s_k^2 would decrease generally according to $1 + 1/k$. Many s_k^2 curves, however, wander up and down, in a manner similar to curves for random normal variables biased in mean or in variance (SR 1).

Essentially, monthly and annual means of climatic elements behave like a stochastic process which is non-stationary in mean and variance. Alternatively, the observations may be considered as drawn from two or more different populations, each with constant mean and variance, but with the mixing ratio variable in time. This hypothesis has been considered, in various ways, by many investigators.

Climatic records can be described, and hence considered to be explained by either of these models, or even both. But such explanation has the same limitation as any other analytic description of climate: it does not lead to useful prediction. No procedures are available for estimating future values of means, variances, or mixing ratios. In the present study, efforts were made to use each of these models, but were abandoned when this inherent non-predictability became apparent.

5. Conclusion

Whatever the probabilistic nature of climatic elements, any long series of their monthly and annual values has an average period of maximum homogeneity or minimum variability of h years. In such a record, therefore, the average difference between means over two disjoint intervals, of k and ℓ years, separated by m years, is least when

$$k + m + \ell = h - 1 .$$

This average interval of maximum homogeneity is $h = k^*_{1,1} + 1$ when $k^*_{1,1}$ is the length of antecedent period for which the mean provides the minimum variance estimator of the $k + 1$st value, i. e. with $\ell = m = 1$. As the extrapolation interval, m , increases, the corresponding $k^*_{\ell m}$ must decrease. As the prediction interval, ℓ , increases, $k^*_{\ell m}$ also decreases.

This explanation is the only rational conclusion that can be drawn from the evidence, in previous Sections of this Report, that k^* decreases directly as m increases. But it does not provide a clear solution to the basic problem being investigated. The length of the period of maximum homogeneity, h , apparently depends entirely on the particular record for which it is computed. Changing the number of observations, n , by a single year can result in a drastic change in h . It is no more constant than any other basic or derived aspect of climate.

The number of years, $k^*_{1,1}$, for which the mean is closest to the next year's value has been determined, in previous Reports, for the specific periods over which the elements were studied at two dozen stations around the world. The length, n , of these periods ranged from 57 years for sunshine percentage at 9 stations to 206 years for temperature at Basel (SR 4).

For these periods, elements, months, and stations, values of $k^*_{1,1}$ vary generally from less than 10 to more than 50 years. But $k^*_{1,1}$ can change markedly if a different, shorter, or longer period of years, n , is used, and certainly changes from month to month and element to element. No valid average

value can be obtained for $k^*_{1,1}$. Furthermore for prediction m years ahead, as shown in previous Sections of this Report, generally $k^*_{m,1} = k^*_{1,1} - m$. Since a climatic average is used to estimate not only next year's value but values two or more years ahead, a climatic "normal" should be based on some average k^* , perhaps that for m = 5.

Although no average best value for such a k^* can be established, the variations in $k^*_{1,1}$ show that, on the whole, for all elements at all stations in all months, prediction one year ahead is just as good from an antecedent 10 or 15 year mean as from one based on a longer period. Because many stations have short records, the number of stations for which normals can be computed will increase with a decrease in the length of the period on which the normal is to be based.

The obvious conclusion of this study, therefore, is that 30 years is far too long to form the basis for a useful climatic normal. Instead, normals should be based on no more than 15 years, and recomputed every five years.

Routine collection, computation, and publication of such values would require two or three years, so that their general use would be for prediction three to eight years beyond the end of the averaging period. For such use these "normals" would be, on the whole, closer to the values which will actually occur than would be the present 30-year normals, from which departures are zealously computed and analyzed, often with consternation.

Even better than 15-year averages would be the medians of 15-year values, as amply demonstrated by William Slusser in SR 3. Medians are somewhat better than means for predicting elements with symmetrical distributions, such as temperature, in which theoretically mean and median coincide. They are far better than means for elements with skewed distributions, such as precipitation and windspeed. Despite long agitation, however, conservative climatology may not yet be ready to abandon the inefficient mean in favor of the simple median.

Finally, these considerations require reassessment of other climatic computational concepts, and indeed of the basic definition of climate. Many climatic problems require only

one value per year, rather than means or medians. Extreme value analysis, to determine return periods, is not considered valid unless based on at least 30 years. If climate is as inherently nonstationary as is indicated by the present investigation, how valid are these estimates?

Climate itself, once considered to be constant and now defined in terms of some time interval, often taken as 30 to 50 years, may require closer definition. Apparently it changes even during 30 years, and so no more than 15 years are recommended here for computation of normals. Even this may be too long for a basic definition, yet "climate" means something more than the conditions during a single year, or even two. Perhaps the alternation of seven years of plenteousness and seven years of dearth, which afflicted Egypt just as Joseph had foretold from the Pharoah's dream (Genesis 41), is characteristic: seven years may be a suitable period for defining climate, and even for normals.

7. Acknowledgements

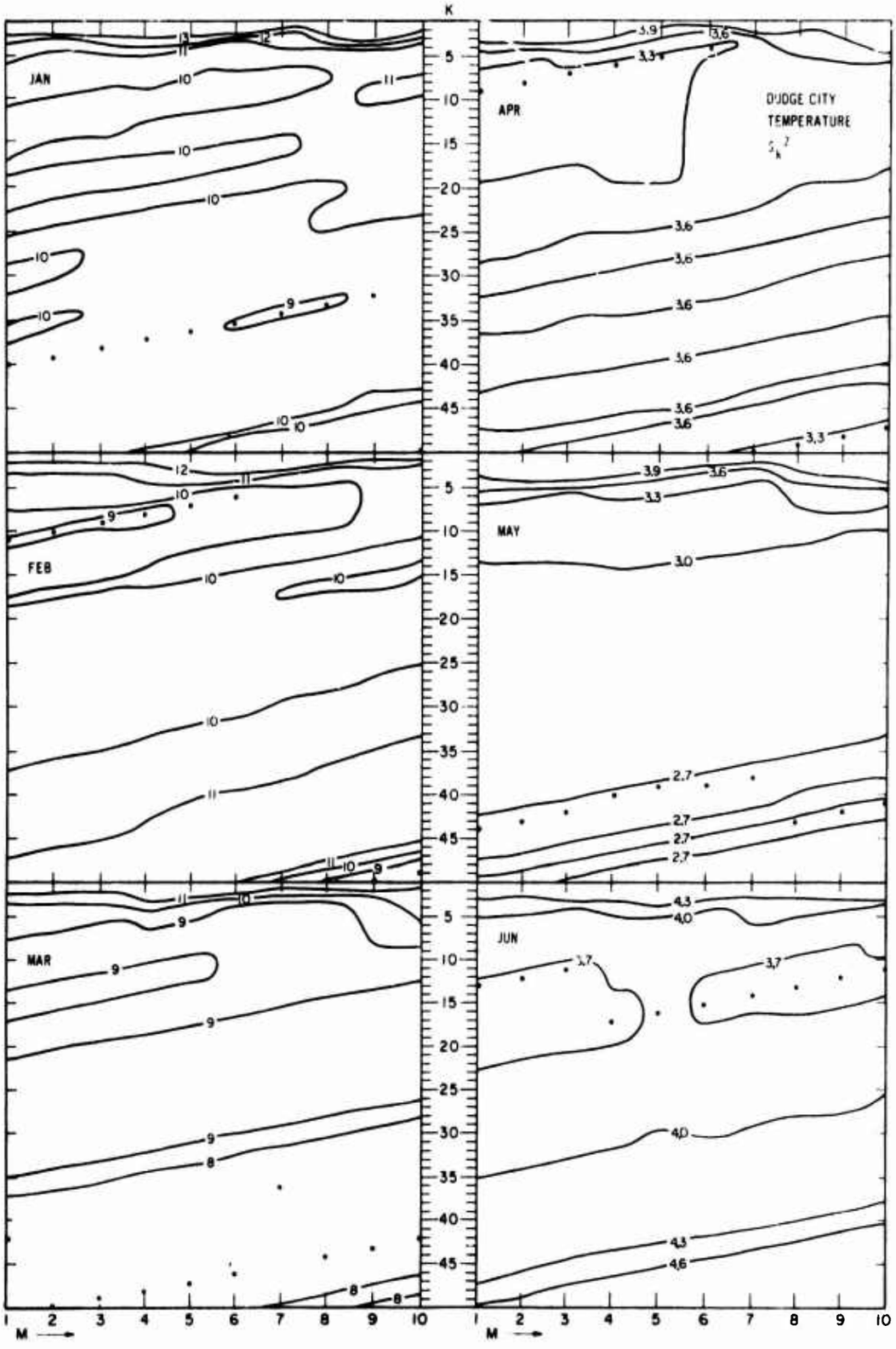
Most of the tedious labor for this study was done or directed by William Slusser, whose master's thesis forms SR 3. He revised and extended the basic computer program, introducing many useful innovations. He helped design and execute the various graphic presentations, and supervised their drafting by an assortment of graduate students. One of them, Ward Koutnik, used some data tabulations, assembled at the outset of the investigation but found to be unsuited for the analysis procedure eventually adopted, in his master's thesis, of which a summary has been published: "Newhall Winds of the San Fernando Valley," Weatherwise 21 : 186 - 189, 202 (Oct. 1968).

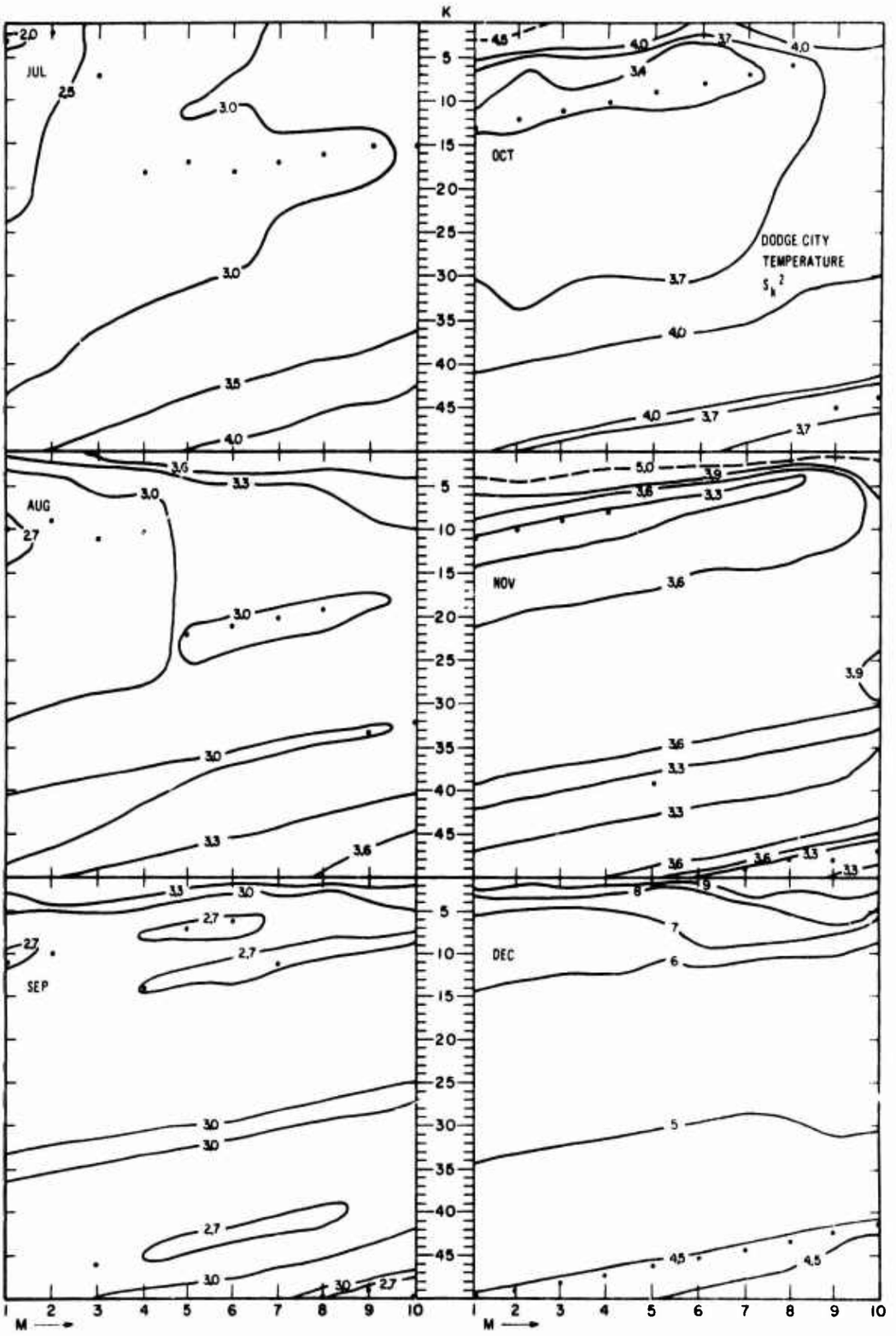
Probabilistic models of climate elements (mentioned in Section 4) were investigated in detail, with the assistance of Dr. Alfredo Baños, assistant professor of mathematics at San Fernando Valley State College and a consultant to the project. Non-linear decrease of serial correlation, with increasing lag, was studied extensively, but without useful results. Dr. Baños also aided in the interpretation of the statistical

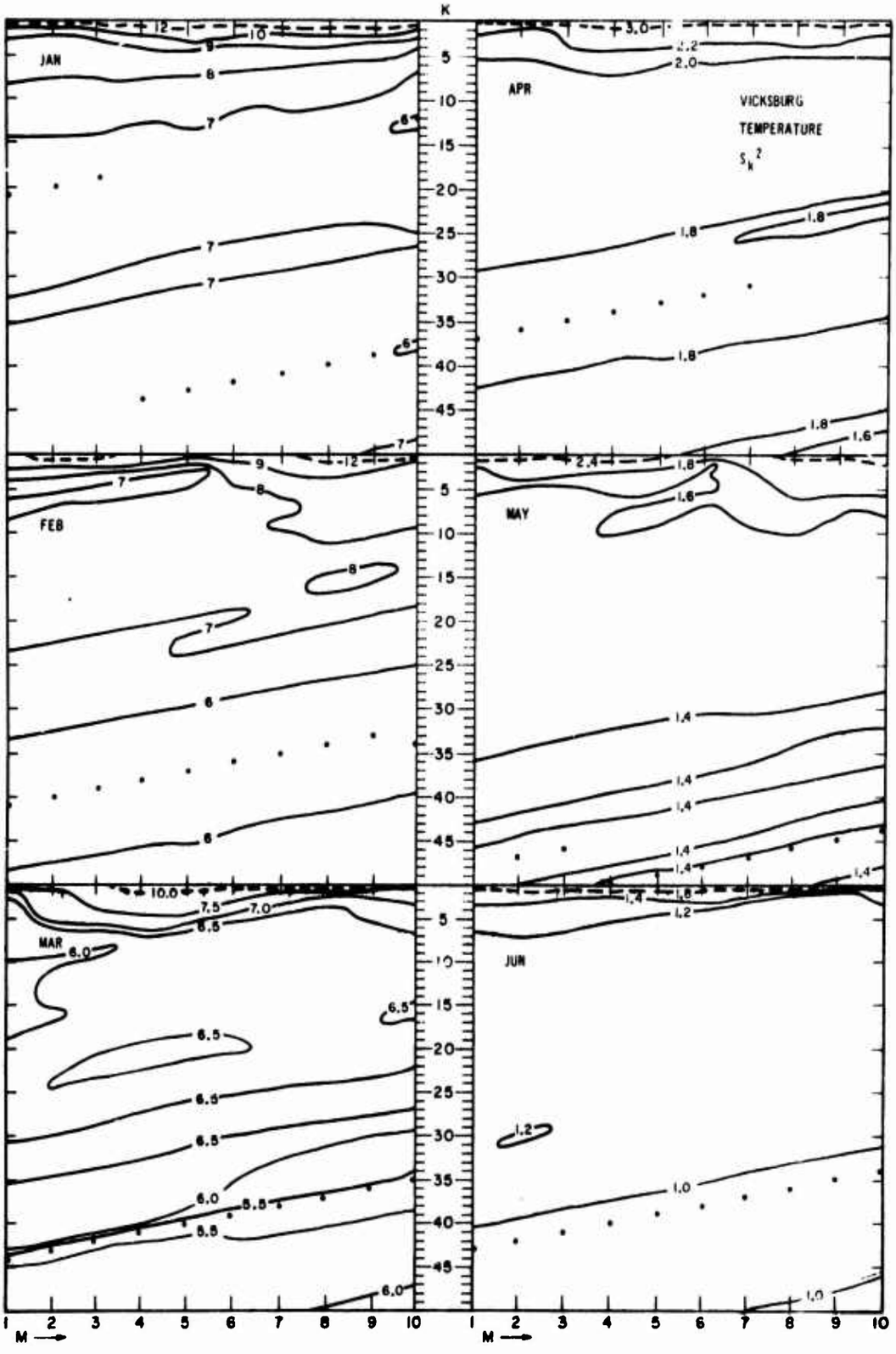
procedures reported by Rubinshtein in the second of the two Appendix papers, both of which were translated by Mr. George S. Mitchell, also a consultant.

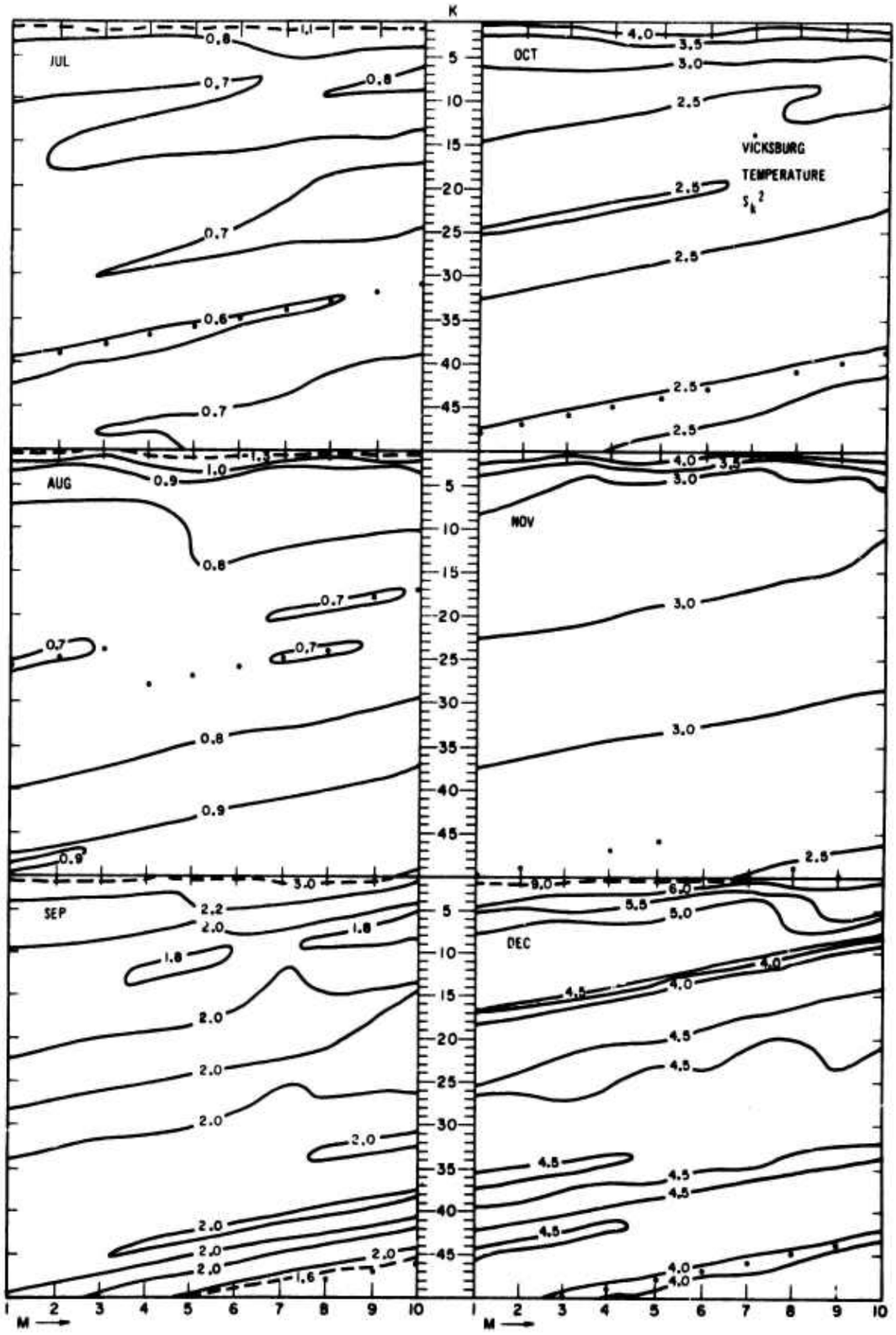
As unexpected results were developed in the course of the investigation, the principal investigator sought opportunities to discuss them with colleagues around the country. To this end, seminars were offered at the Air Force Cambridge Research Laboratories, the University of Oklahoma, the Weather Bureau's Central Regional Headquarters in Kansas City, the University of California at Los Angeles, and the Santa Barbara-Ventura chapter of the American Meteorological Society. A paper entitled "Climatic Normals are Inefficient" was presented at the A.M.S. Conference and Workshop on Applied Climatology in Asheville, N.C., on 31 October 1968. Some of the material of that paper has been used in this Report, which also has benefited from discussions with colleagues, too numerous to mention, at Asheville and elsewhere.

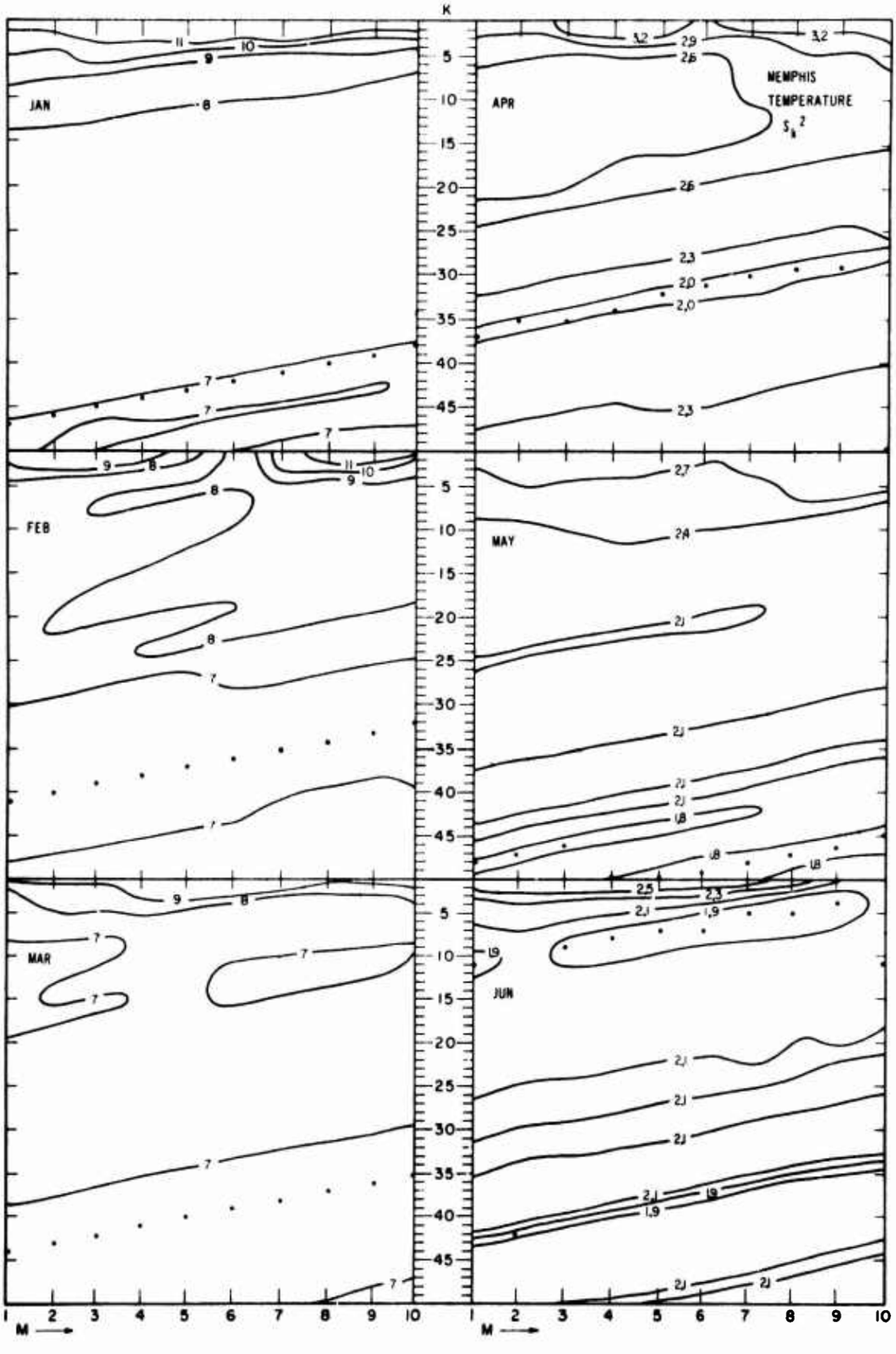
Figures 5 through 18 present, by isopleths, $S^2_{k\ell m}$ for $\ell = 1$ as a function of k and m, for monthly temperature and precipitation at 7 U.S. stations, already studied in detail in SR 2. The charts have been discussed in Section 3.

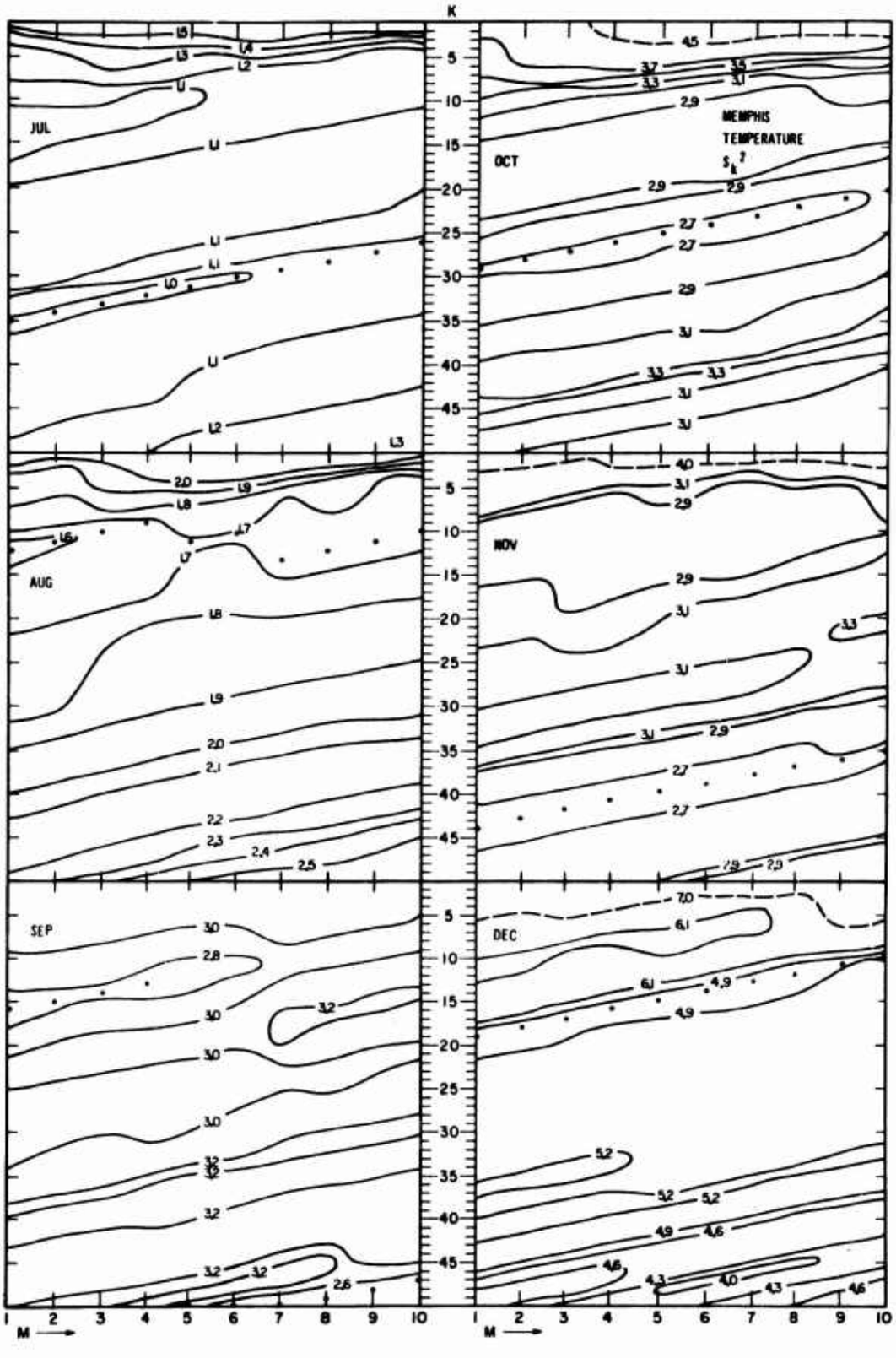

K
JAN
FEB
MAR
APR
MAY
JUN
DODGE CITY
TEMPERATURE
M
M

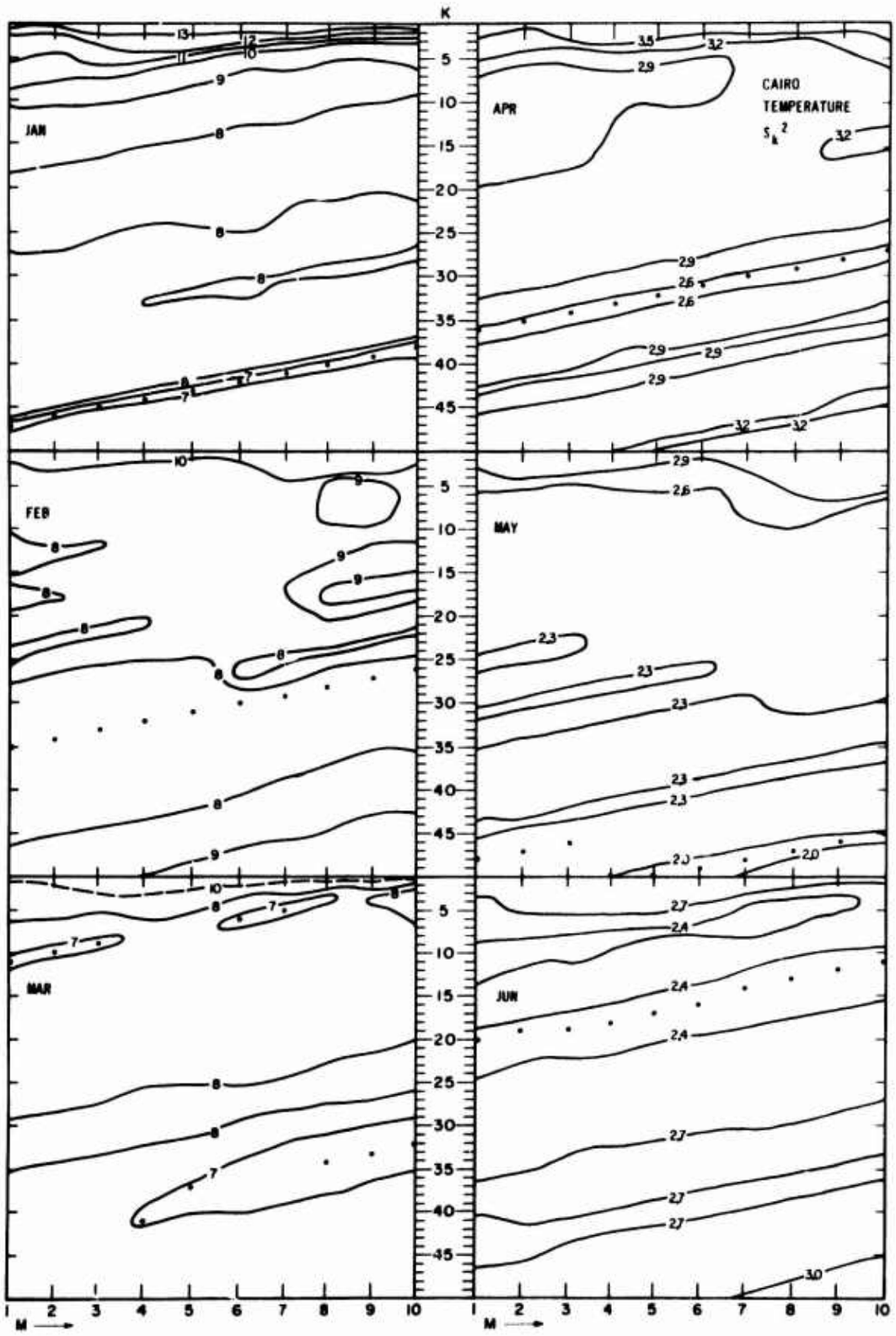

K
JUL
AUG
SEP
OCT
NOV
DEC
DODGE CITY
TEMPERATURE
S_k^2
M
M

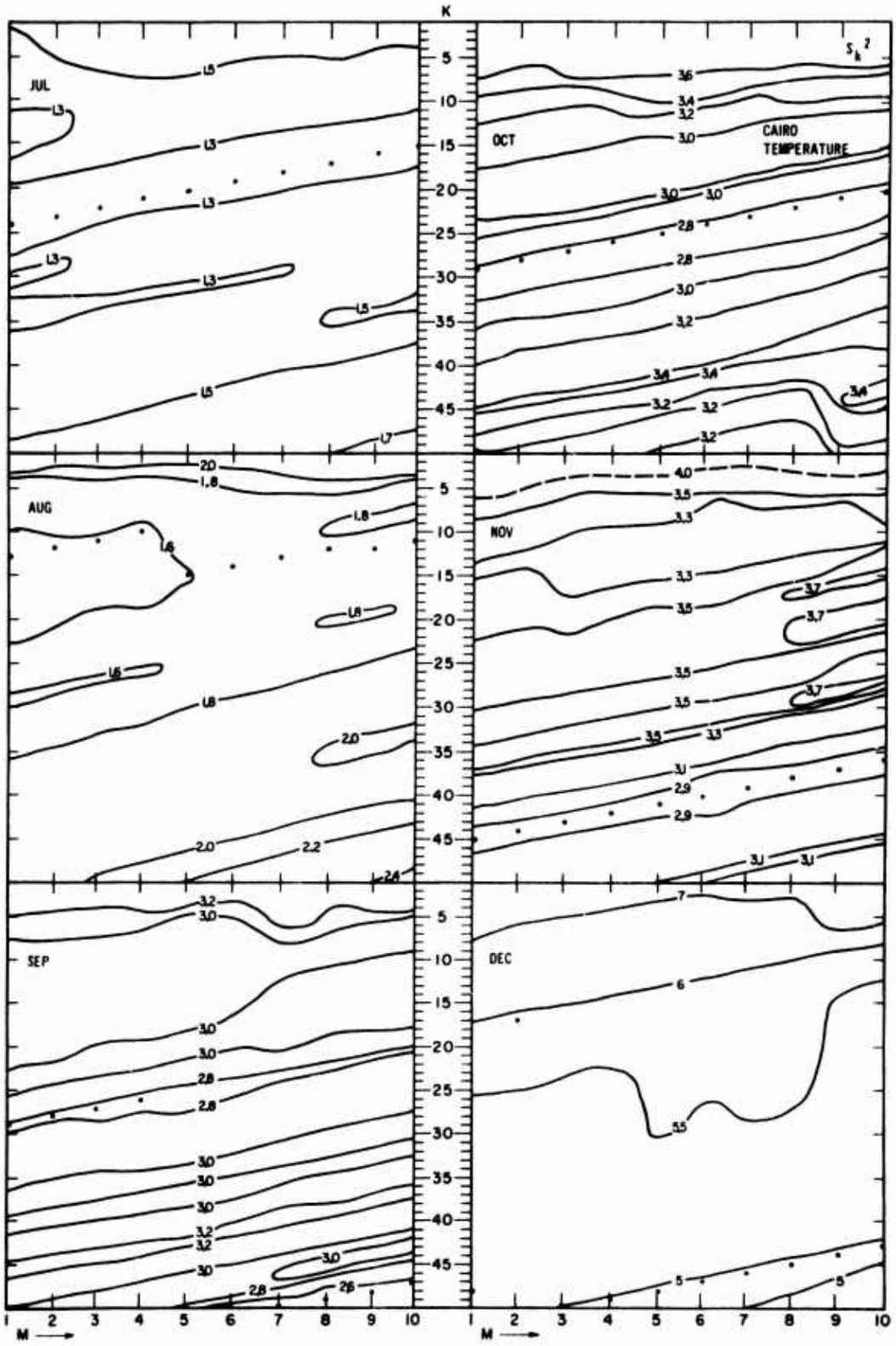

K
JAN
APR
VICKSBURG
TEMPERATURE
S_k^2
FEB
MAY
MAR
JUN
M
M

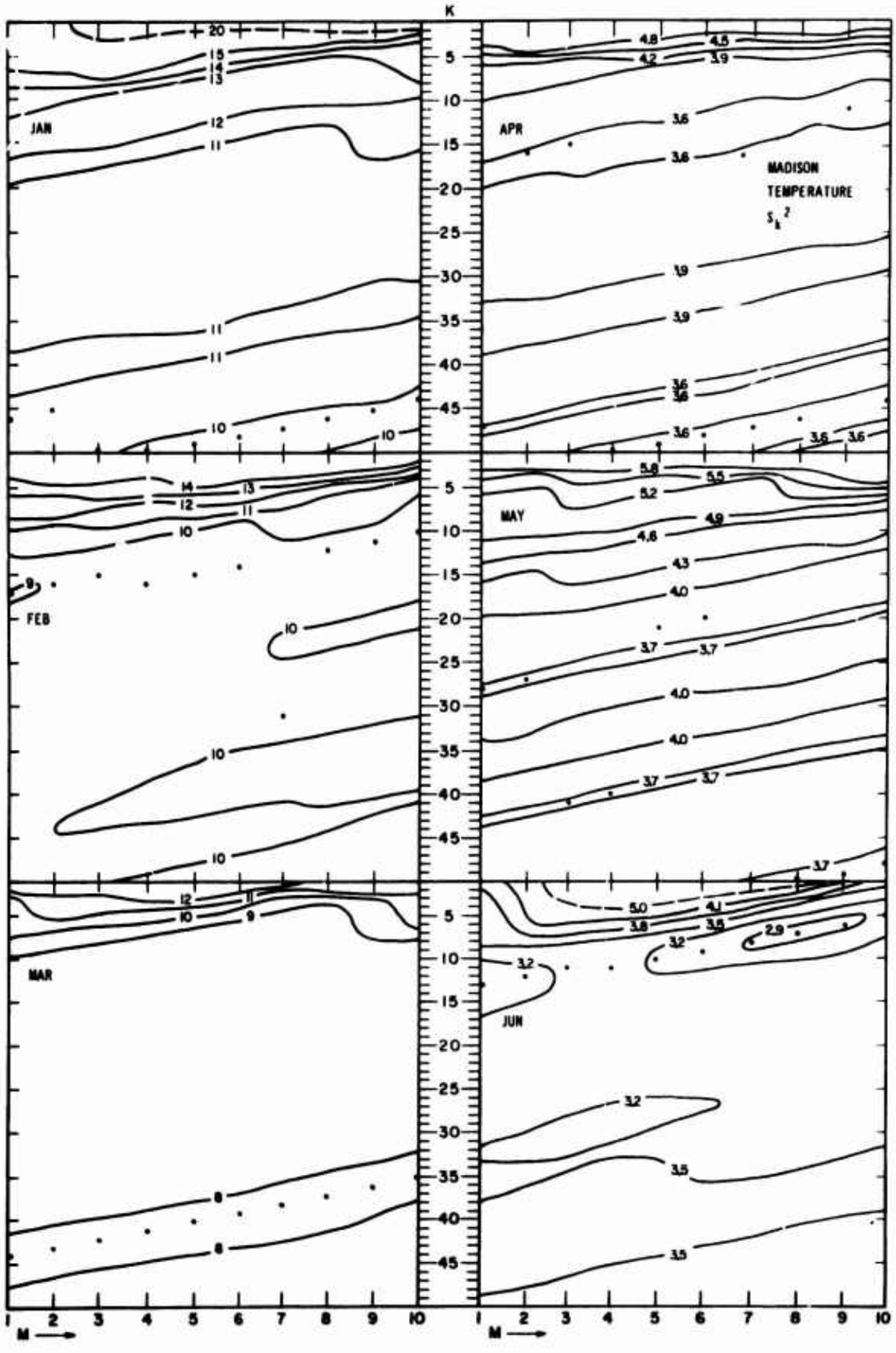

K
JUL
AUG
SEP
OCT
NOV
DEC
VICKSBURG
TEMPERATURE
S_k^2
M
M

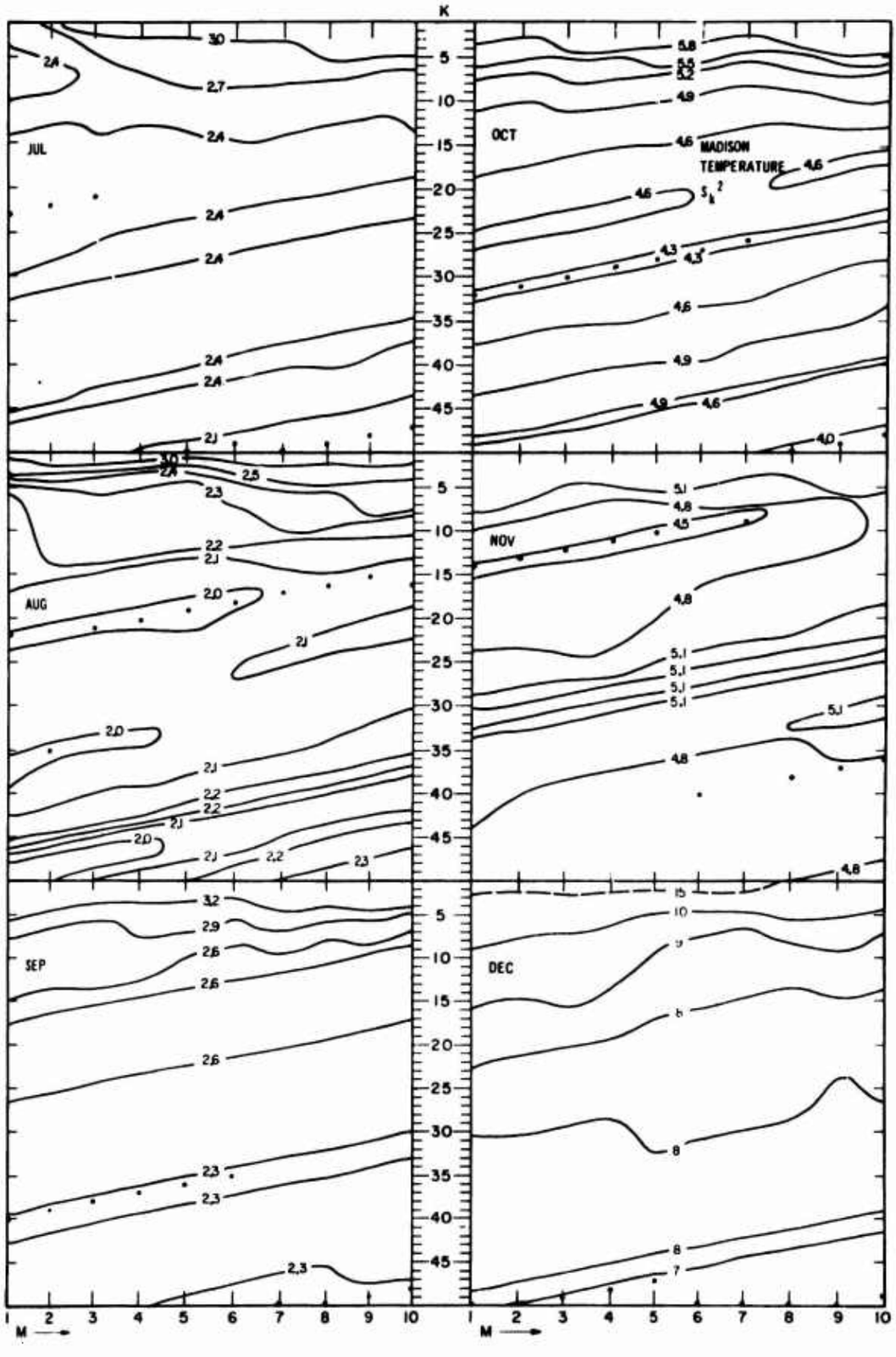

K
JAN
FEB
MAR
APR
MAY
JUN
MEMPHIS
TEMPERATURE
M
M

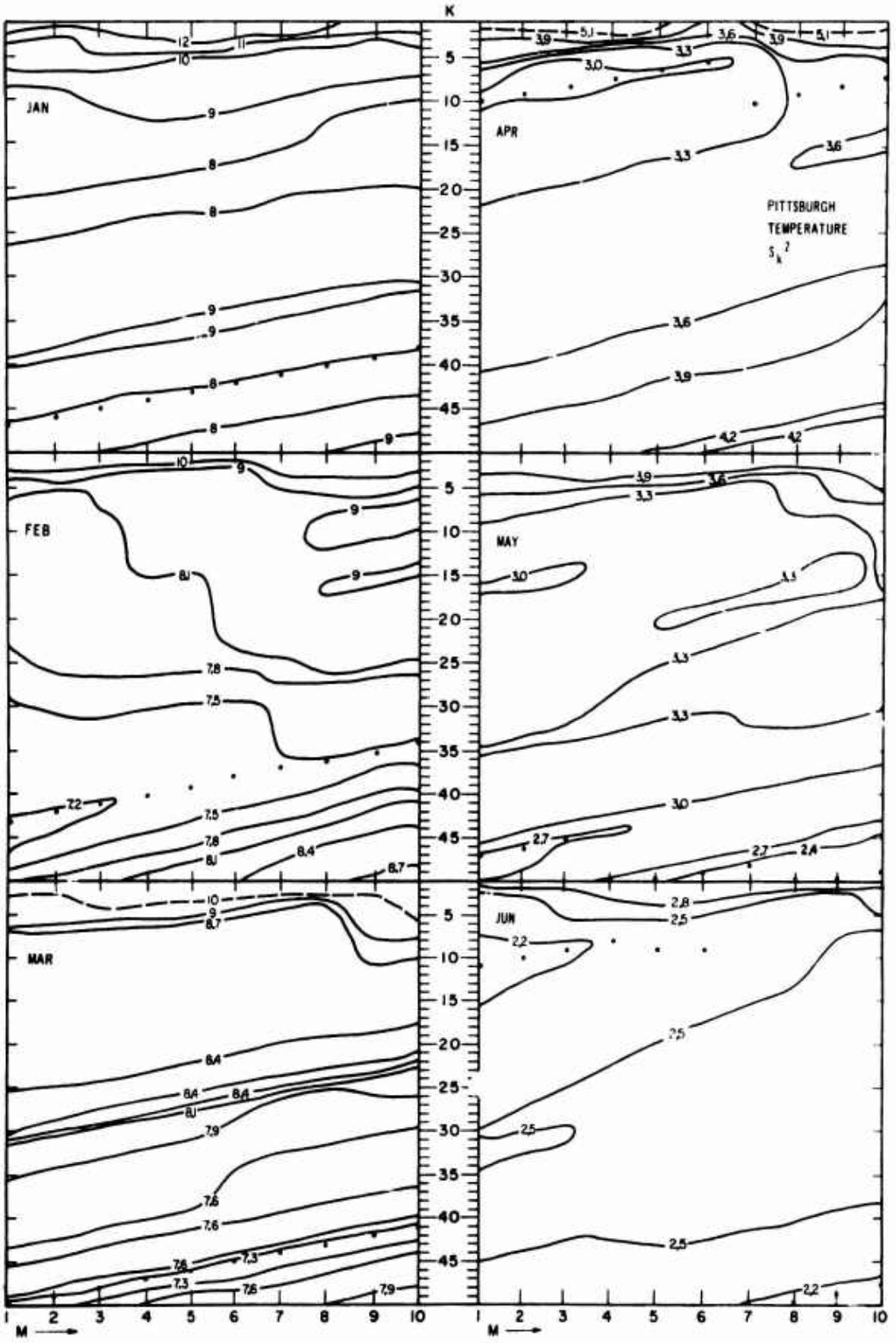

K
JUL
AUG
SEP
OCT
NOV
DEC
MEMPHIS
TEMPERATURE
M
M

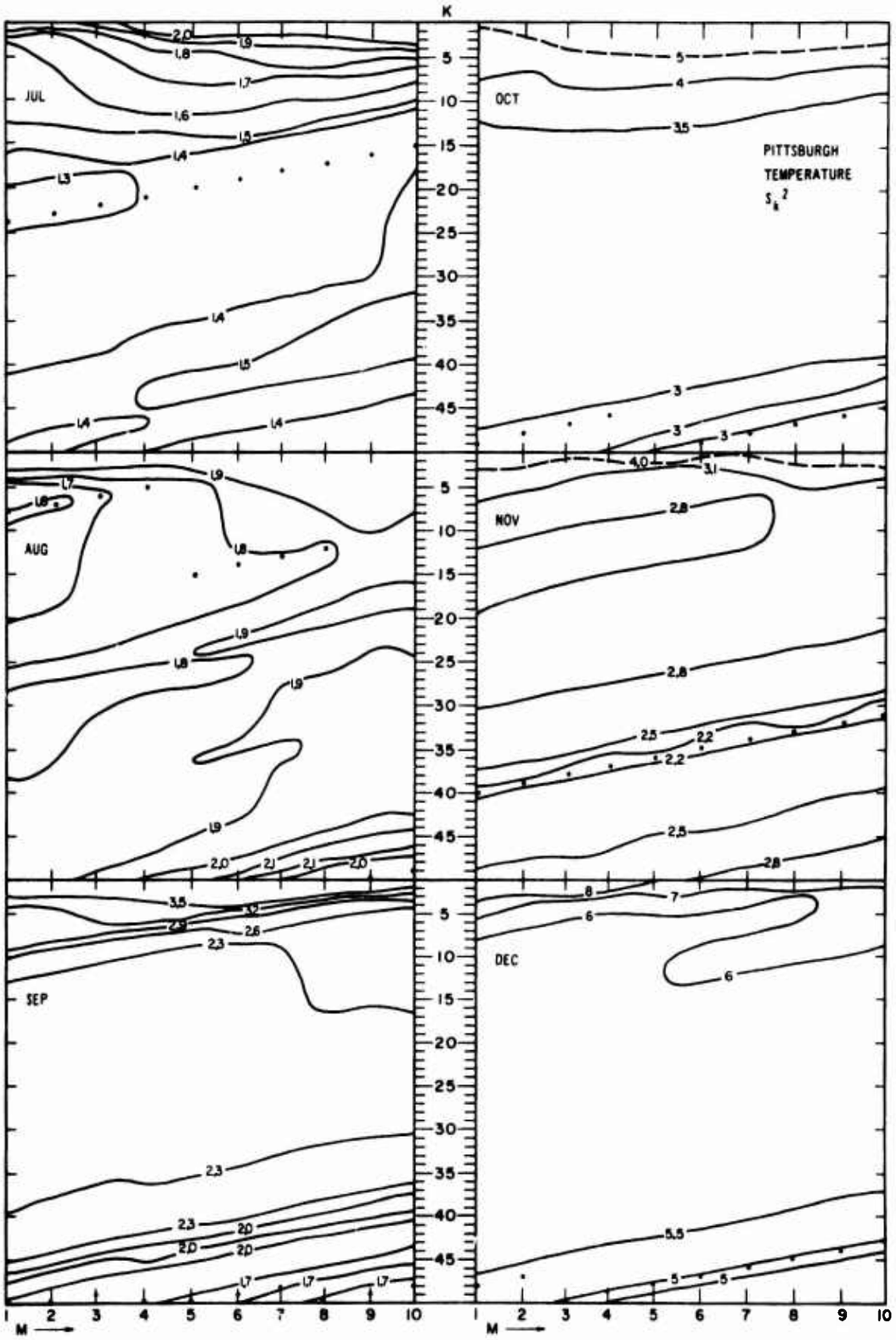

K
JAN
FEB
MAR
APR
MAY
JUN
CAIRO
TEMPERATURE
M
M

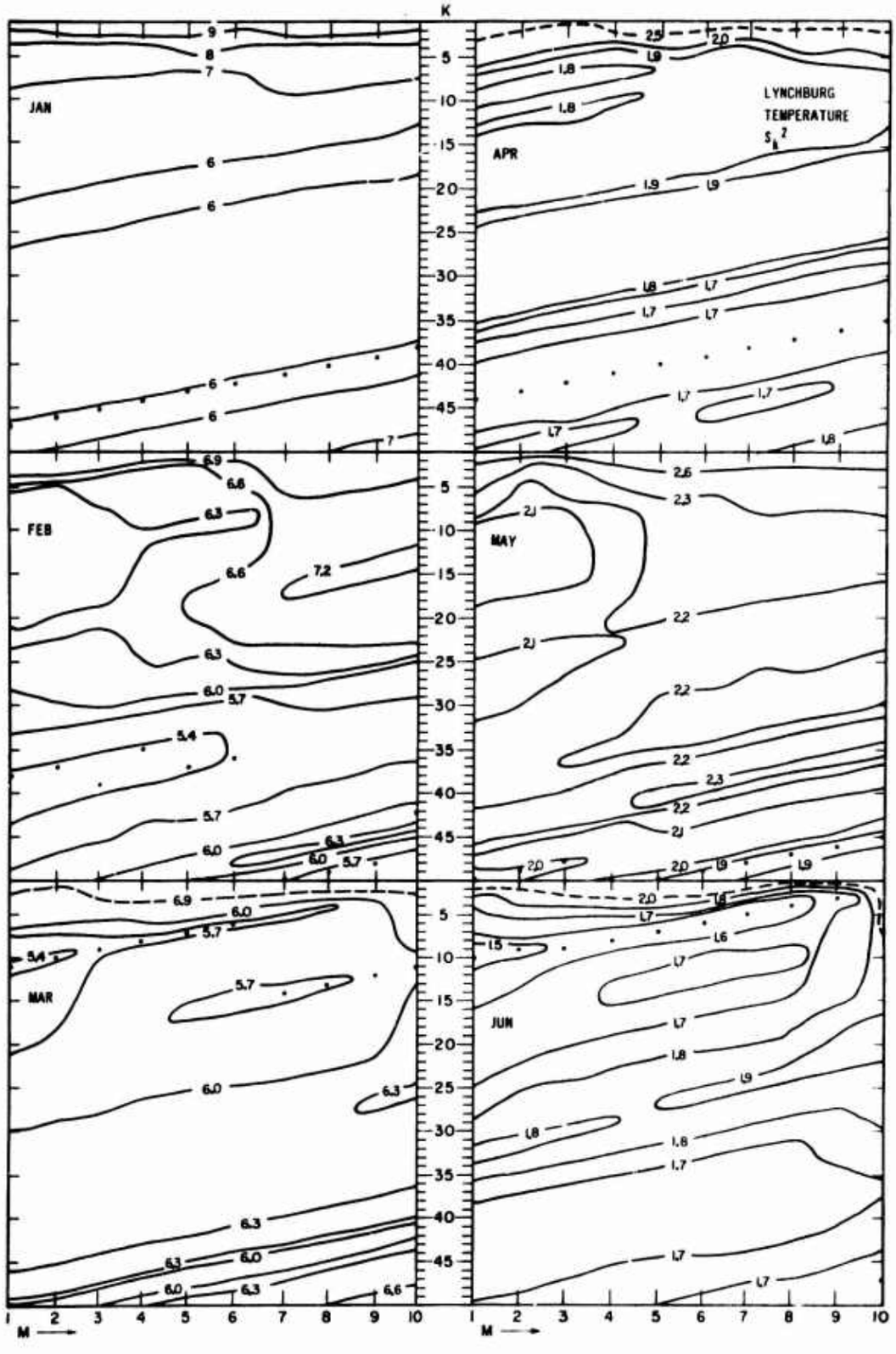

K
JUL
AUG
SEP
OCT
NOV
DEC
CAIRO
TEMPERATURE
M
M

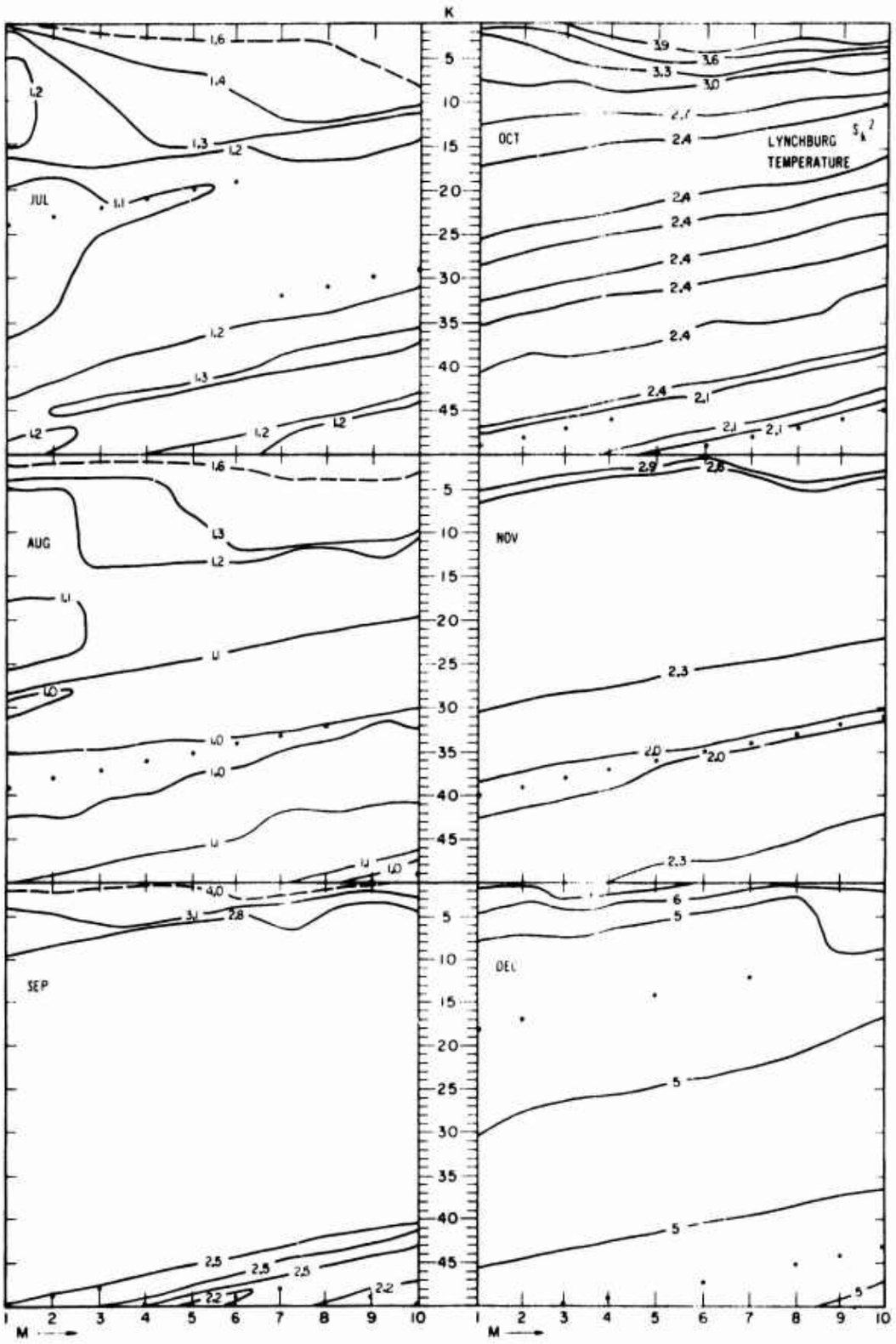

K
JAN
FEB
MAR
APR
MAY
JUN
MADISON
TEMPERATURE
M
M

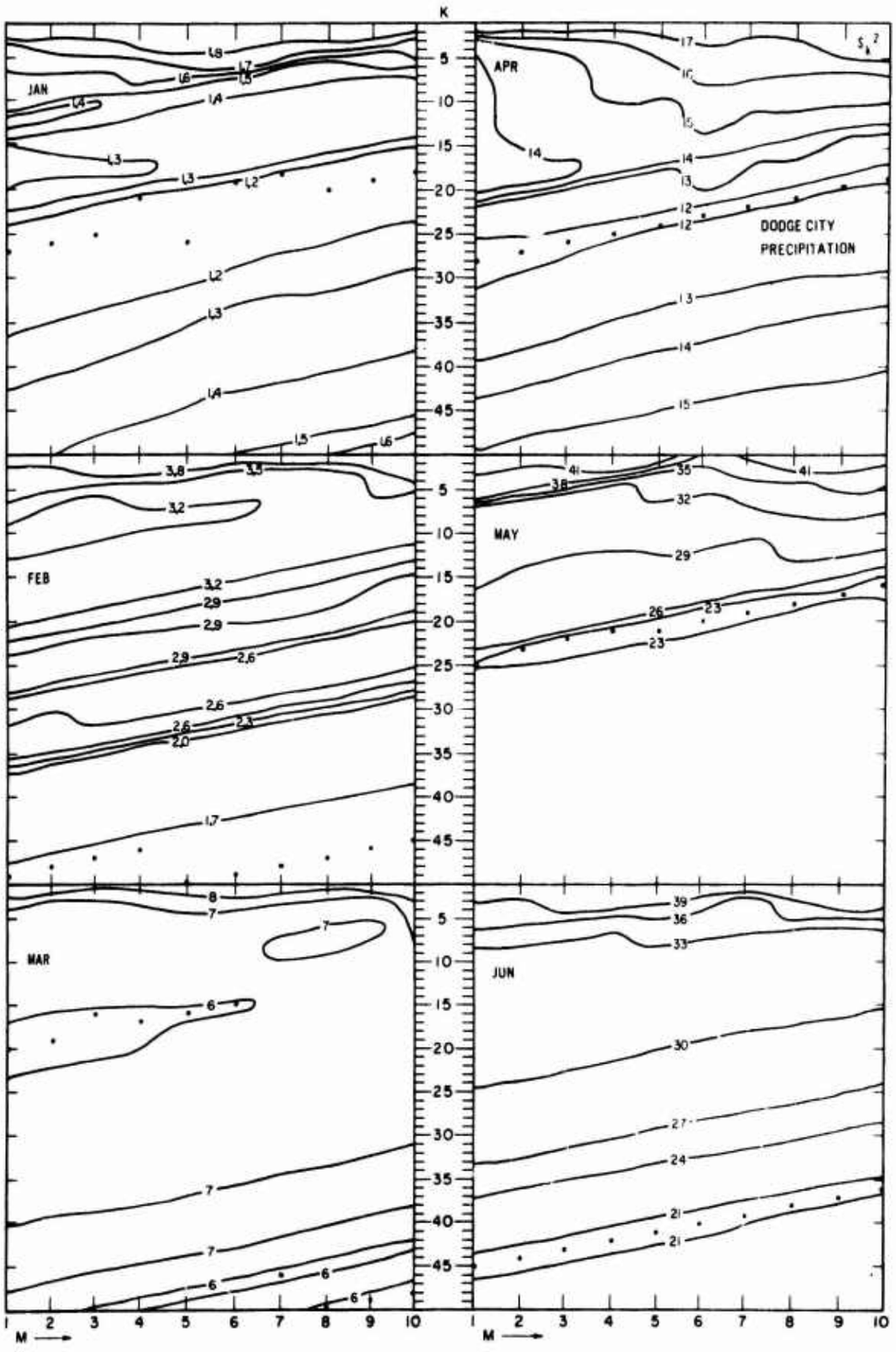

K
JUL
AUG
SEP
OCT
NOV
DEC
MADISON
TEMPERATURE
M
M

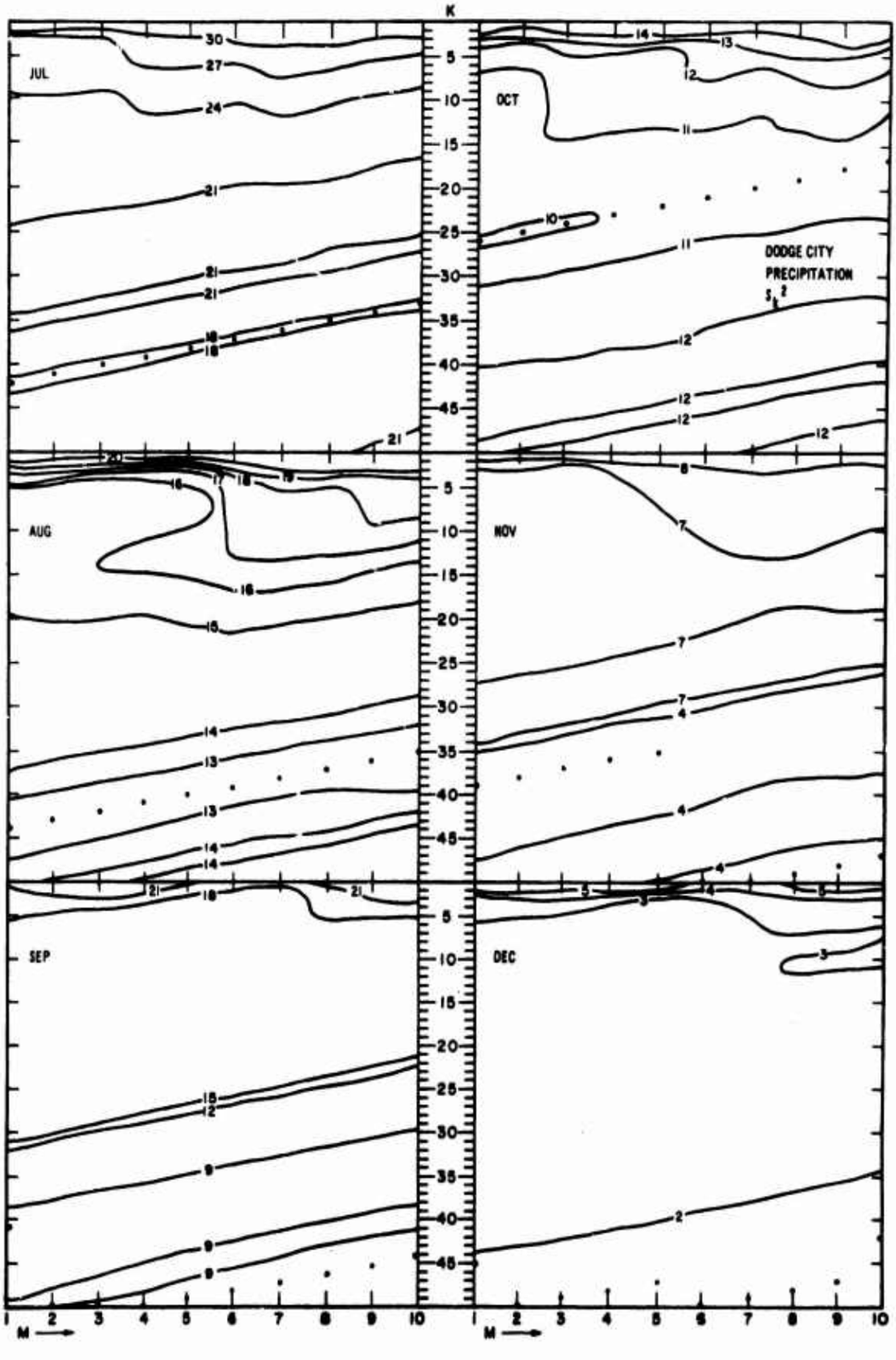

K
JAN
FEB
MAR
APR
MAY
JUN
PITTSBURGH
TEMPERATURE
M
M

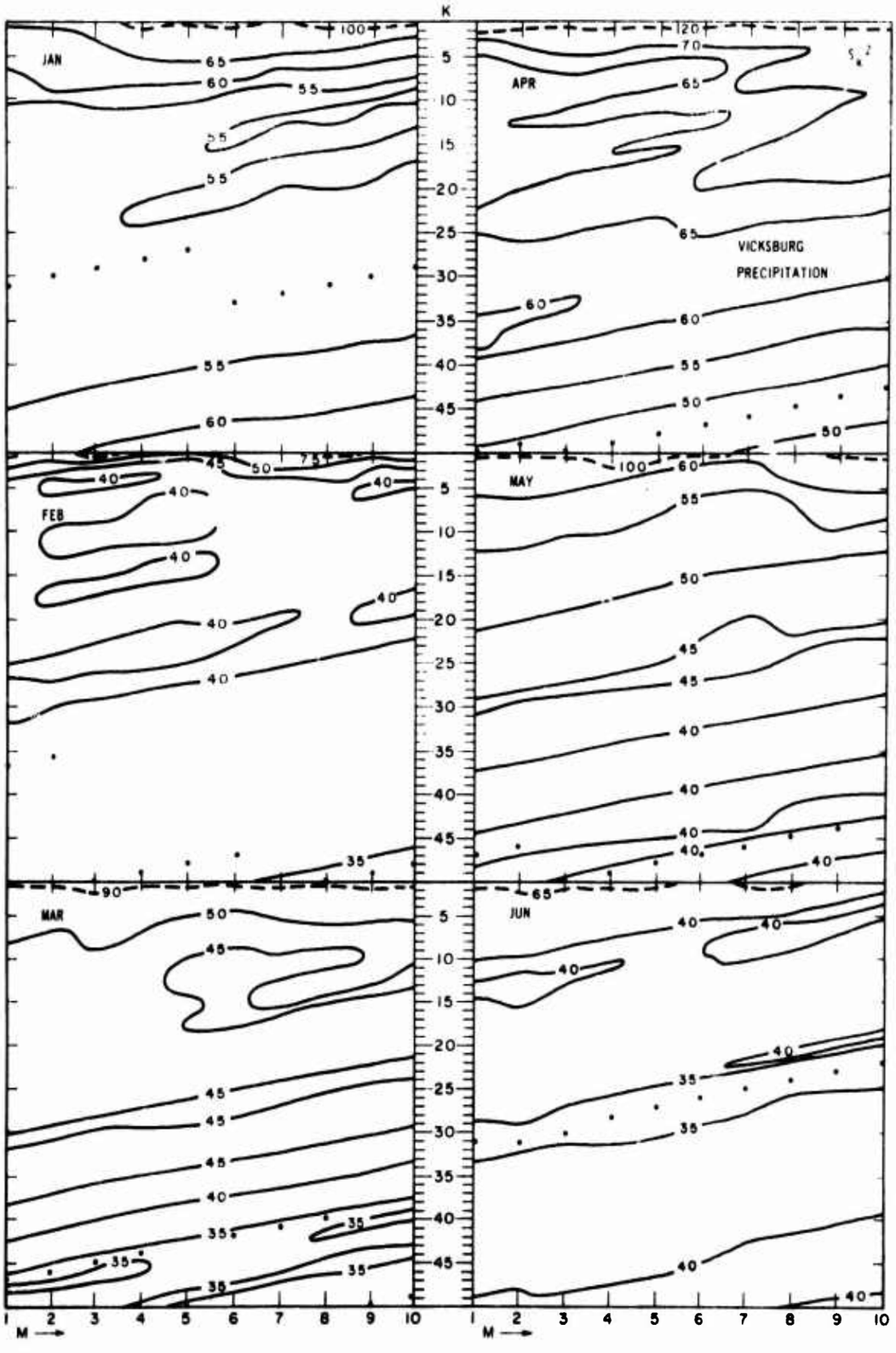

K
JUL
AUG
SEP
OCT
NOV
DEC
PITTSBURGH
TEMPERATURE
S_k^2
M
M

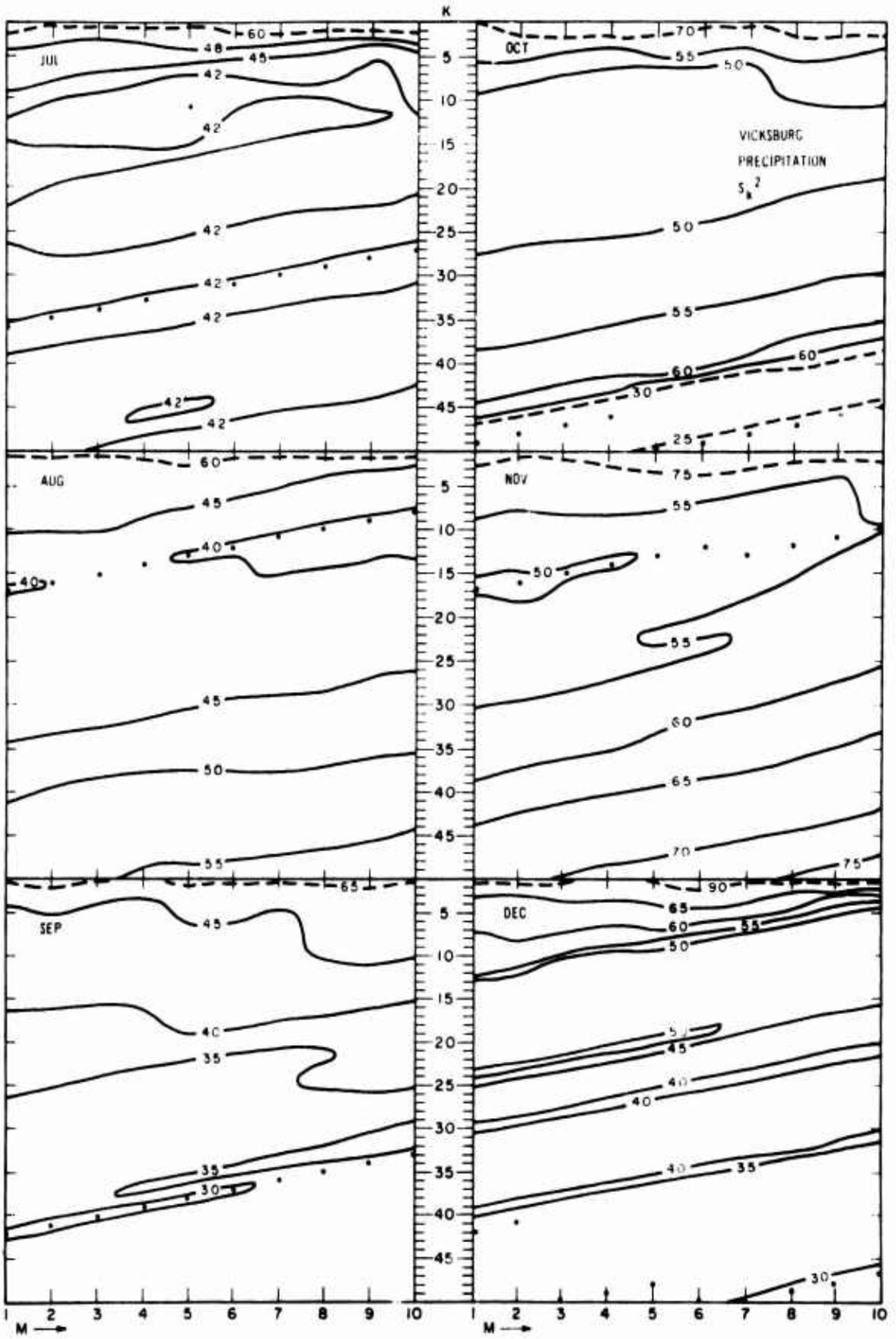

K
JAN
FEB
MAR
APR
MAY
JUN
LYNCHBURG
TEMPERATURE
M
M

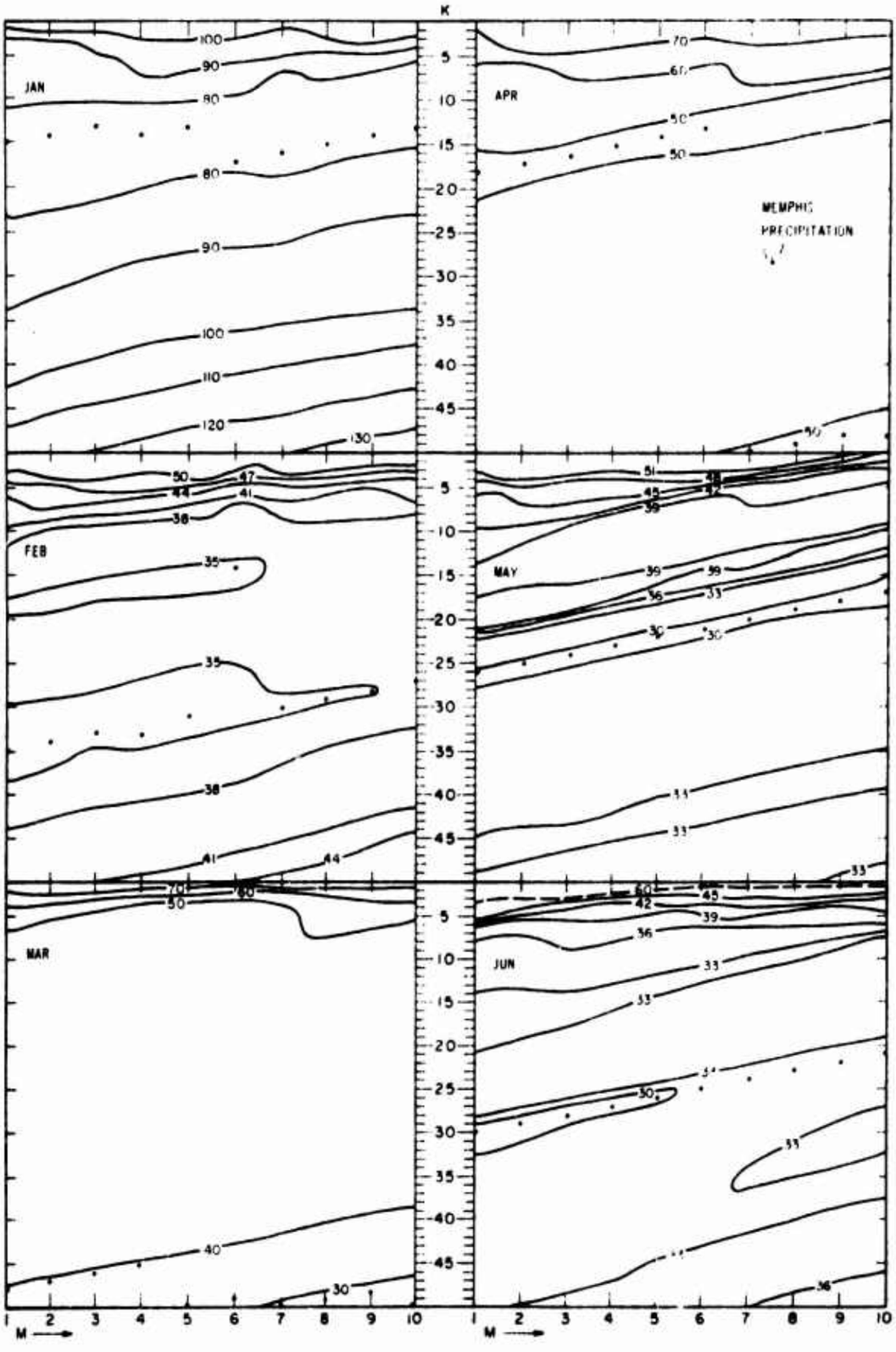

K
JUL
AUG
SEP
OCT
NOV
DEC
LYNCHBURG
TEMPERATURE
M
M

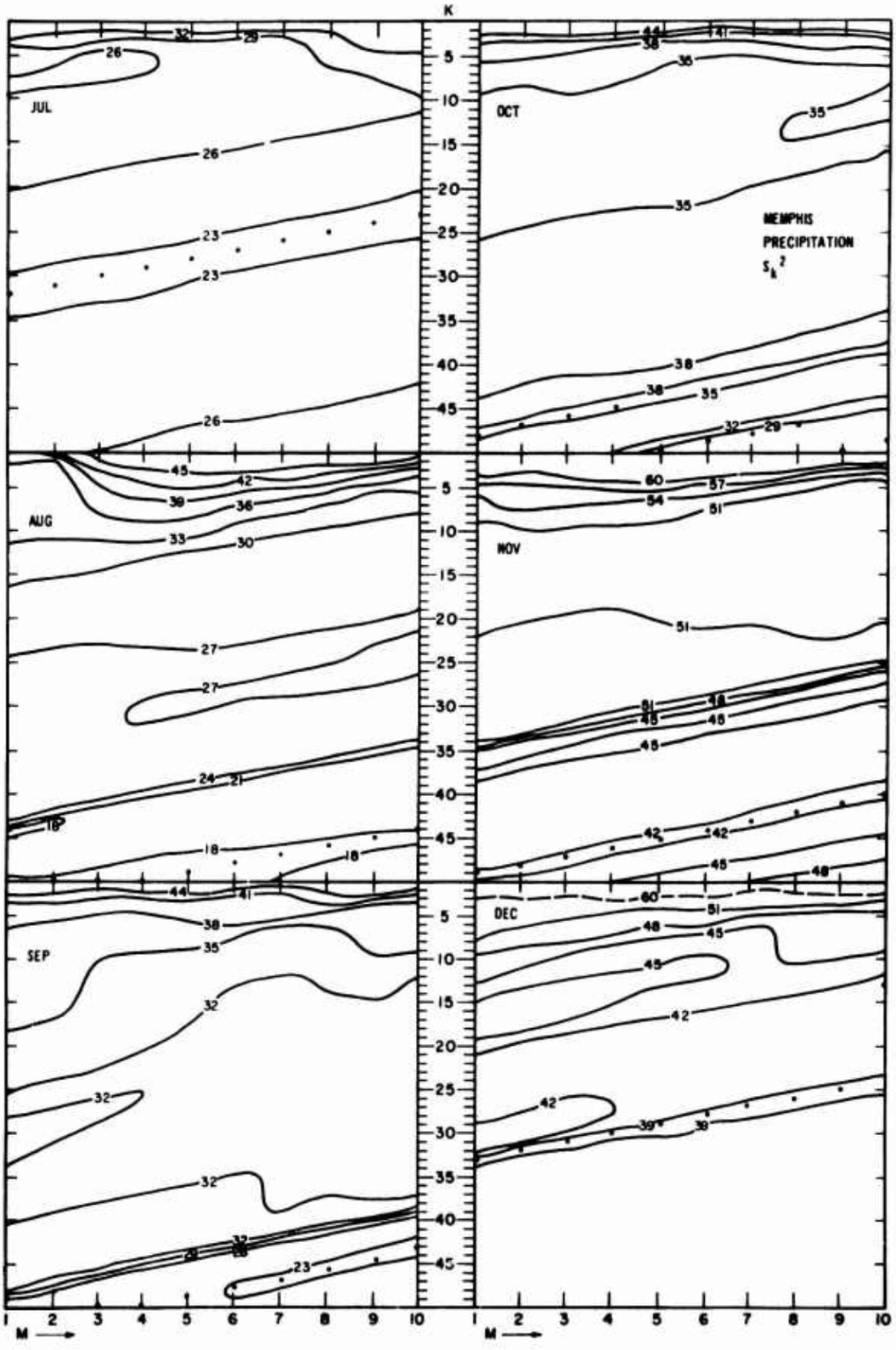

K
JAN
APR
DODGE CITY
PRECIPITATION
FEB
MAY
MAR
JUN
M
M

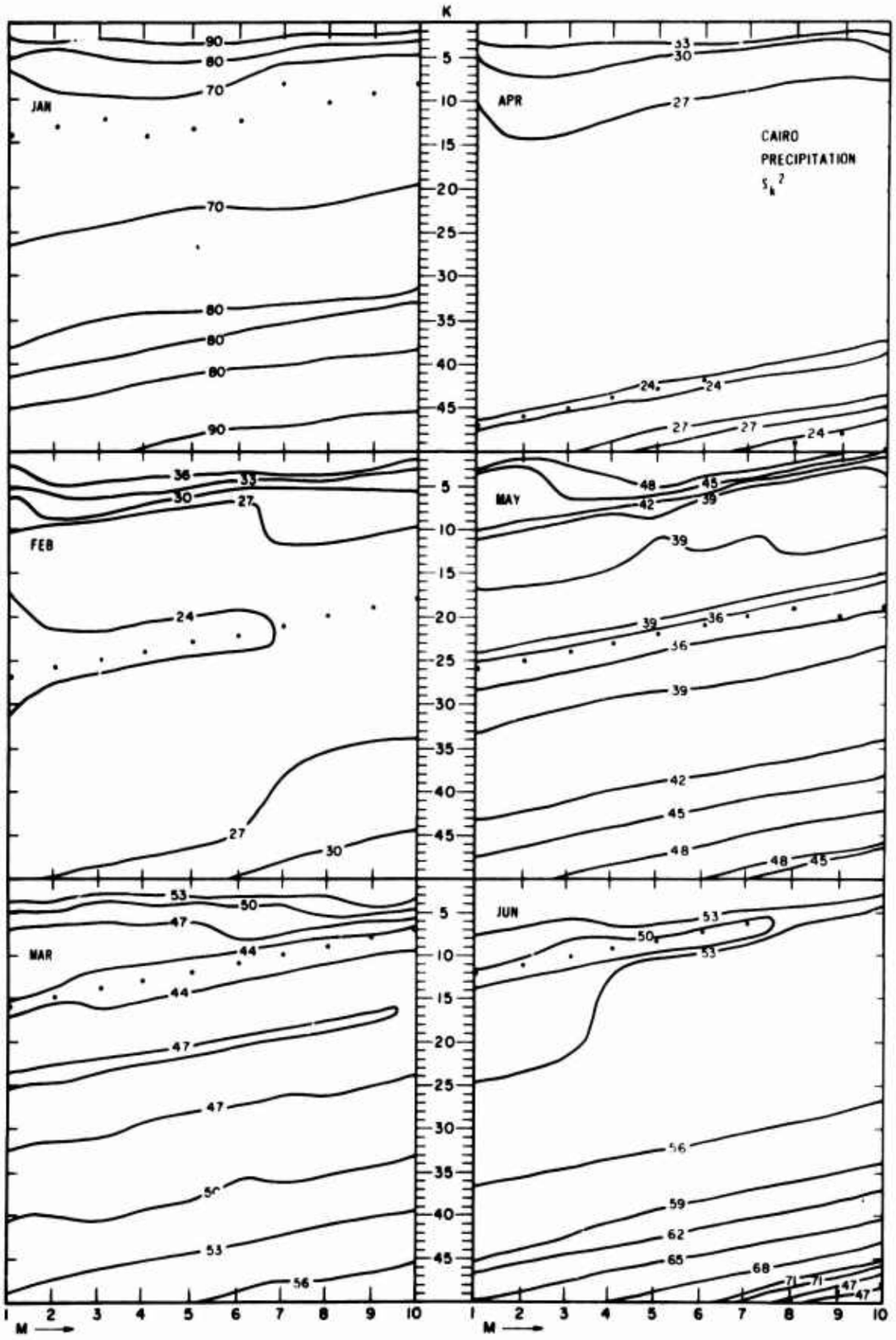

K
JUL
AUG
SEP
OCT
NOV
DEC
DODGE CITY
PRECIPITATION
M
M

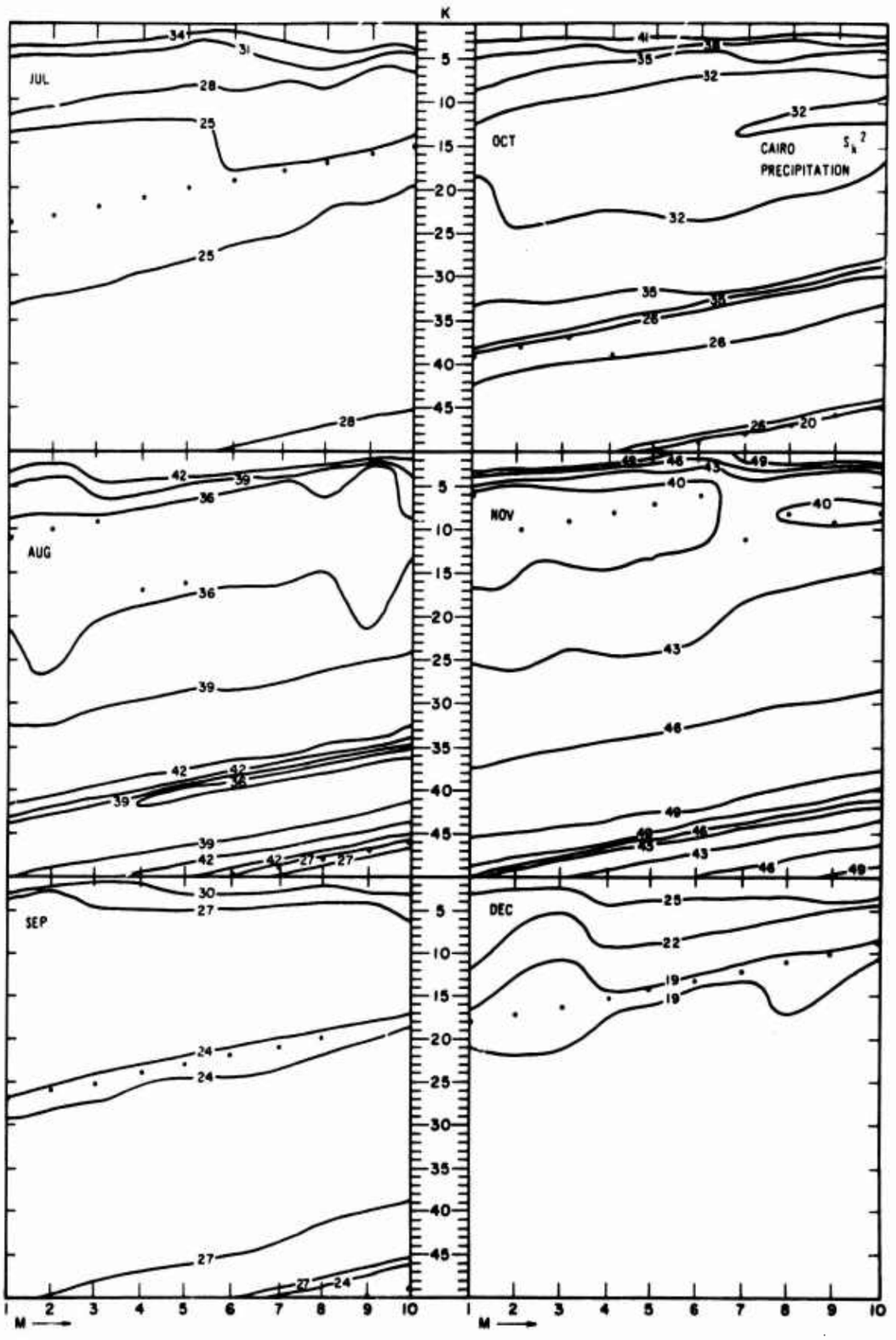

K
JAN
APR
FEB
MAY
MAR
JUN
VICKSBURG
PRECIPITATION
M
M

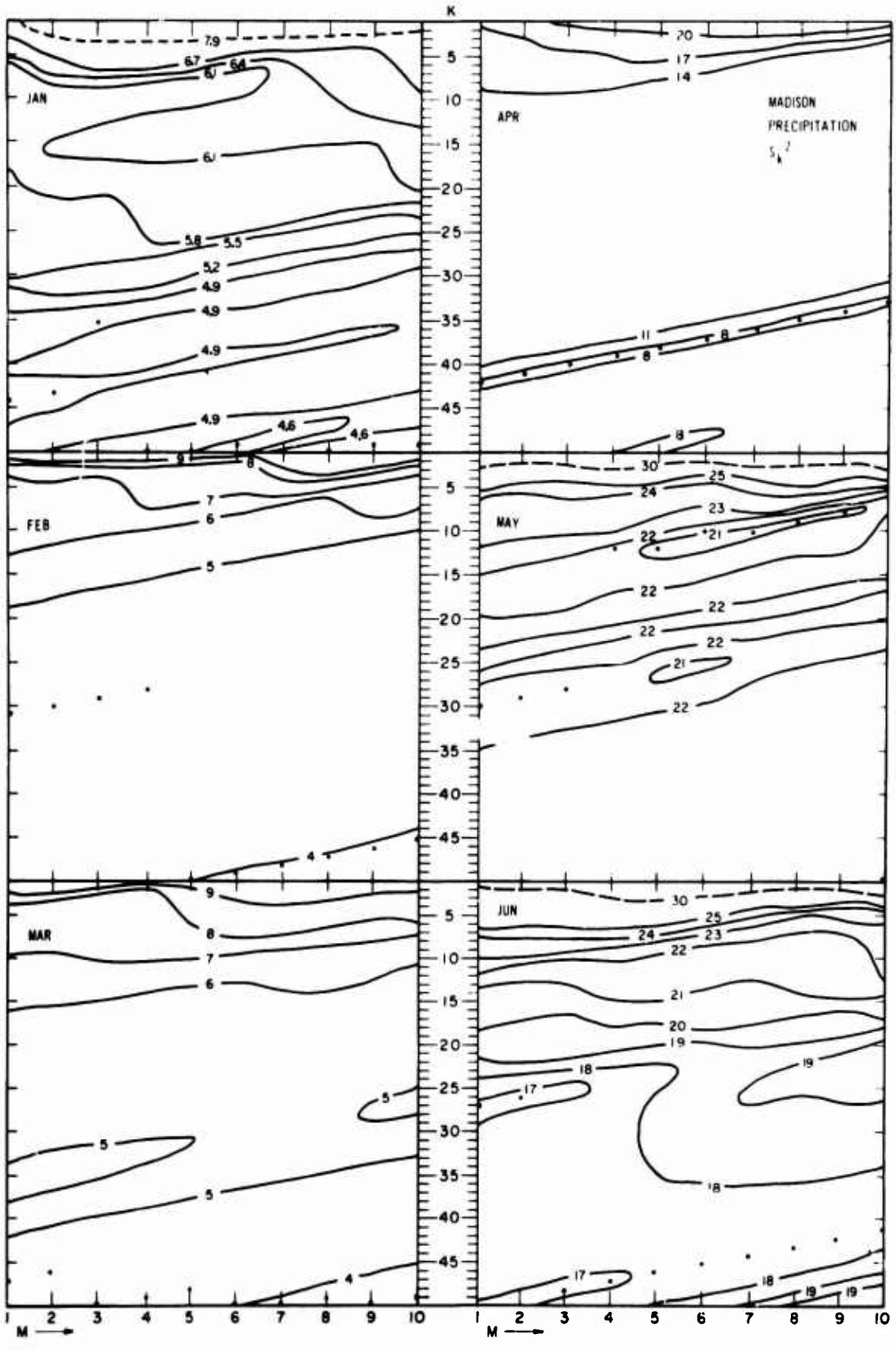

K
JUL
AUG
SEP
OCT
NOV
DEC
VICKSBURG
PRECIPITATION
S_k^2
M
M

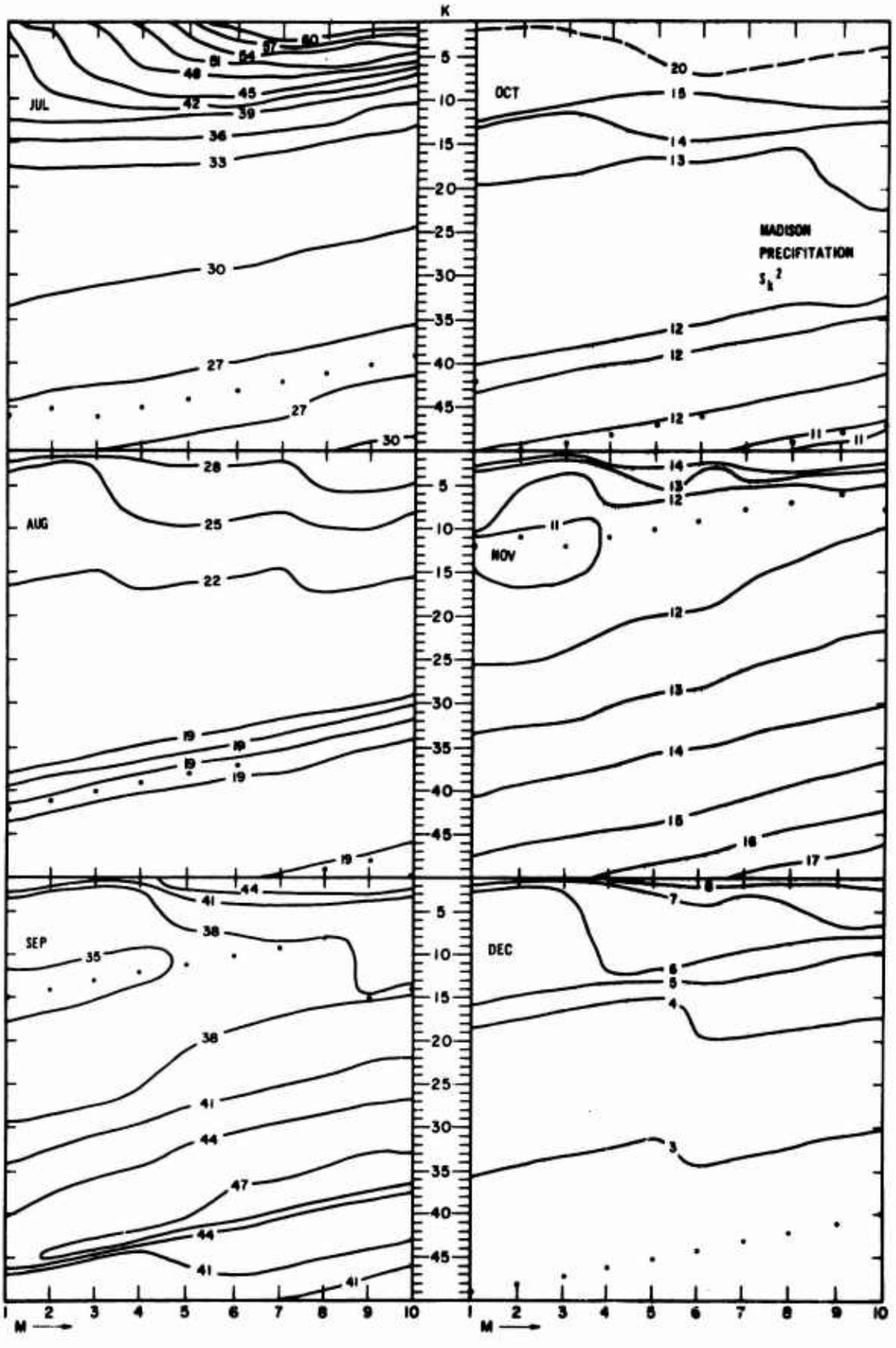

K
JAN
APR
MEMPHIS
PRECIPITATION
FEB
MAY
MAR
JUN
M
M

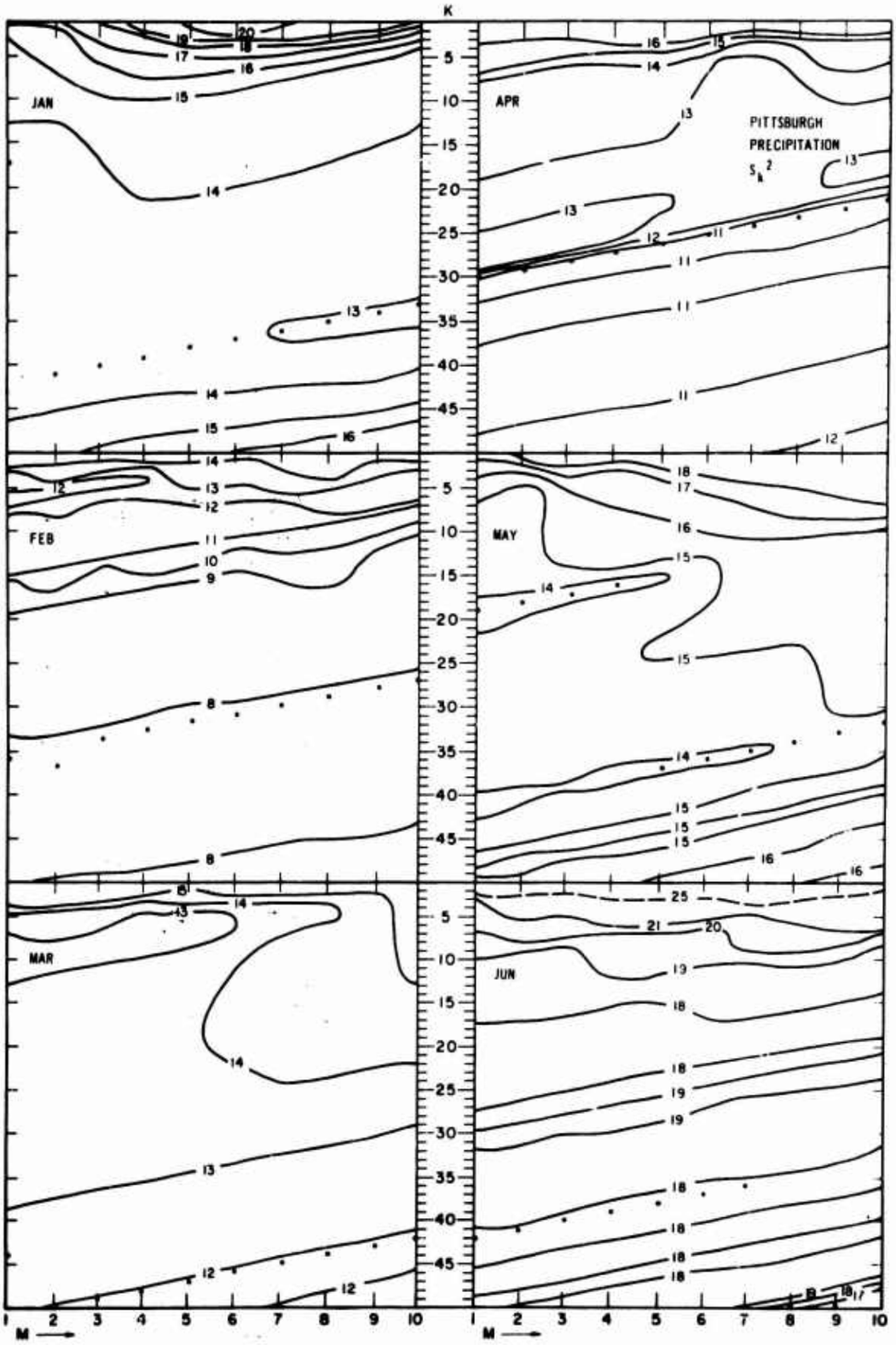

K
JUL
AUG
SEP
OCT
NOV
DEC
MEMPHIS
PRECIPITATION
S_k^2
M
M

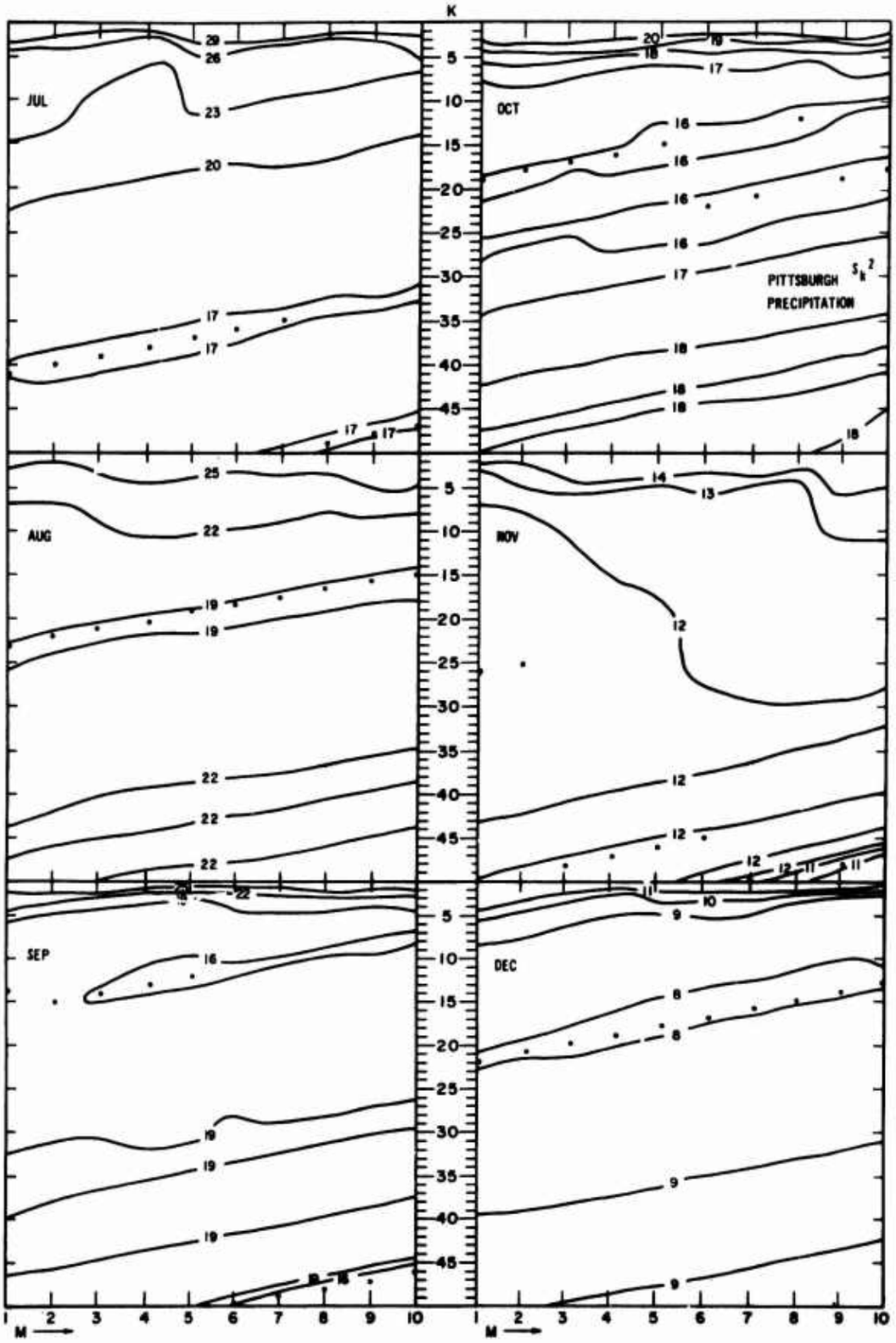

K
JAN
FEB
MAR
APR
MAY
JUN
CAIRO
PRECIPITATION
M
M

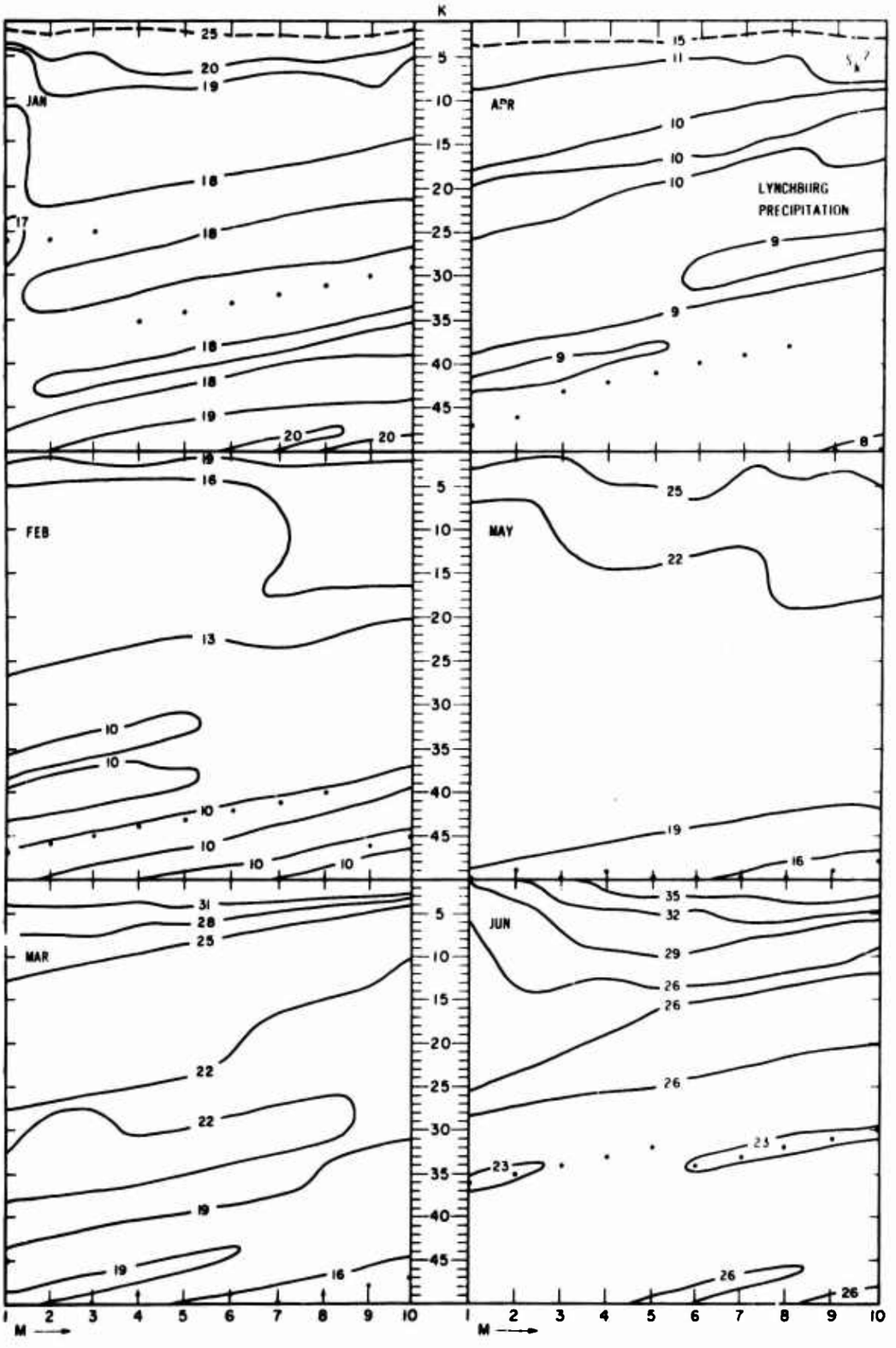

K
JUL
AUG
SEP
OCT
NOV
DEC
CAIRO
PRECIPITATION
M
M

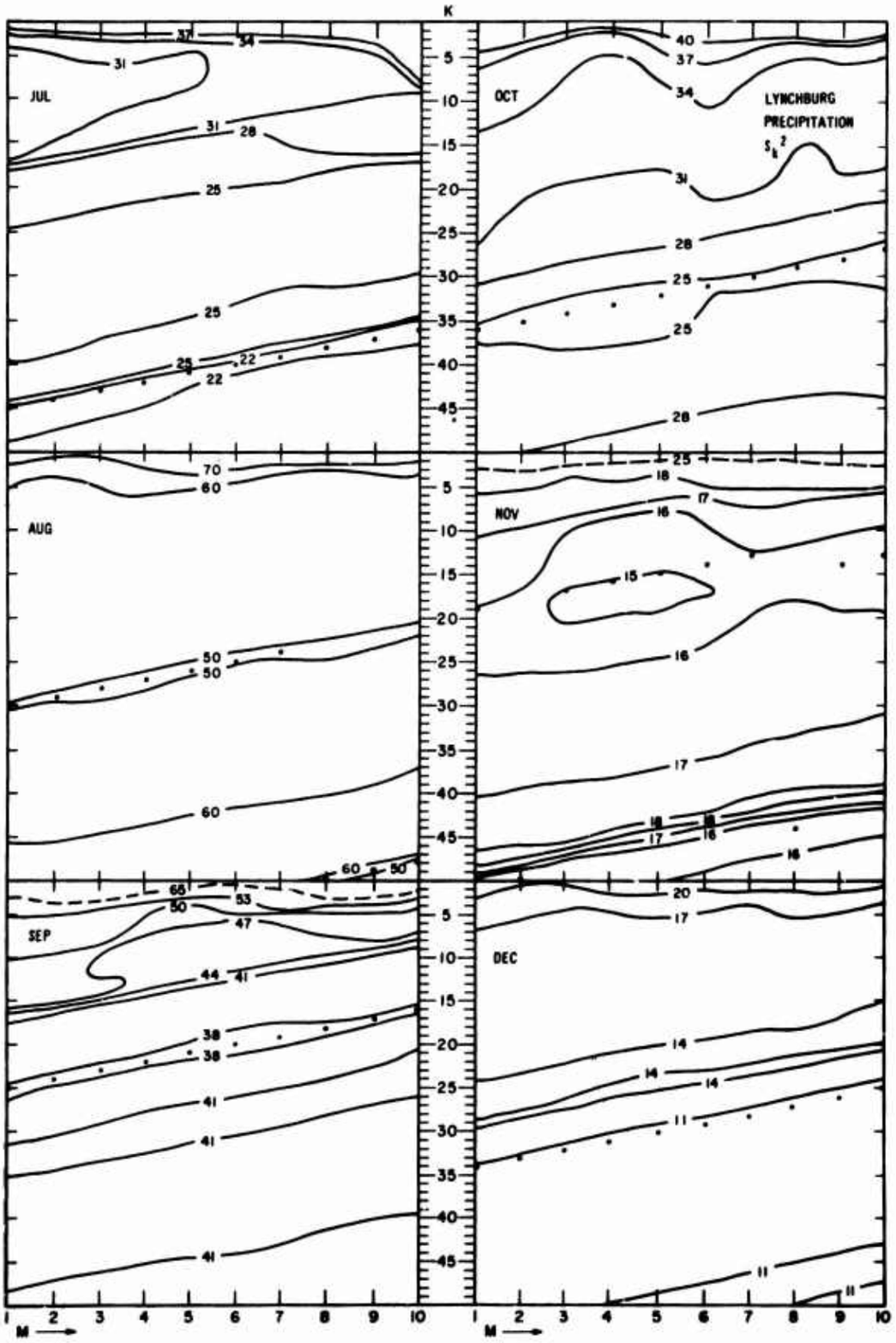

K
JAN
FEB
MAR
APR
MAY
JUN
MADISON
PRECIPITATION
M
M


K
JUL
AUG
SEP
OCT
NOV
DEC
MADISON
PRECIPITATION
S_k^2
M
M


K
JAN
FEB
MAR
APR
MAY
JUN
PITTSBURGH
PRECIPITATION
S_k^2
M
M


K
JUL
AUG
SEP
OCT
NOV
DEC
PITTSBURGH S_k^2
PRECIPITATION
M
M


K
JAN
FEB
MAR
APR
MAY
JUN
LYNCHBURG
PRECIPITATION
M
M


K
JUL
AUG
SEP
OCT
NOV
DEC
LYNCHBURG
PRECIPITATION
S_k^2
M
M

К ВОПРОСУ ОБ ОПТИМАЛЬНОЙ ДЛИТЕЛЬНОСТИ ПЕРИОДА ОСРЕДНЕНИЯ ПРИ КЛИМАТОЛОГИЧЕСКИХ ИССЛЕДОВАНИЯХ.

О. А. ДРОЗДОВ, В. В. ОРЛОВА, Ц. А. ШВЕР

Glavnaia Geofizisheskaia Observatoriia, Leningrad

Trudy no. 181, 1965 Pp. 14 - 45 .

Translated by George S. Mitchell, Consultant, as:

THE OPTIMAL LENGTH OF PERIOD FOR CLIMATIC AVERAGES

by O. A. DROZDOV, V. V. ORLOV, and TS. A. SHVER.

Edited by Arnold Court, Principal Investigator

Contract AF 19(628)-5716 Project No. 8624 Task No. 862402

THE OPTIMAL LENGTH OF PERIOD FOR CLIMATIC AVERAGES

by O. A. DROZDOV, V. V. ORLOV, and TS. A. SHVER.

Abstract: For the pressing problem of selecting the length of period for climatic averaging, a new empirical method of verifying the degree of stability of climatic series is proposed, exemplified by observational series on air temperature and atmospheric precipitation.

1. Problem

The optimal length of series to be averaged in climatological processing has not yet been determined. Some climatologists advocate the longest possible series for which the stipulation of comparability in time and space is maintained [1, 2, 3]. Others recommend relatively shorter periods, for reasons limited primarily to technical aspects, for example to the assumption that the actual accuracy of the observations is small and is attained with a comparatively short length of observations.

On the other hand, more rigorous procedures, especially the method of sequential analysis, both in the USSR and abroad, [6, 10], point out the need for much longer periods, of the order of 70 years, to assure a much greater stability of the averaging. This is natural because the coherence of meteorological series, as a rule, results in smaller variance than in a series made up of purely random terms.

Other approaches to this problem have also been taken, both in the USSR and abroad. Abroad, [6, 9], to extrapolate values for the next year or two, a 15 to 20 year period was found optimal.

2. Russian Findings.

In the USSR this problem has been posed in a more general form: extrapolating means to the next 15 to 20 years, or at 5-year intervals beyond the period of averaging. A major consideration is that 5 to 10 years are required for processing the original data and publishing them (in the past up to 20 years have been spent) and each tabulation is used for more than 10 years.

Concerning precipitation, Sharov and Shver [3] showed that the improvement in accuracy from lengthening the period is small, but 50-year averages offer better extrapolation than averages of shorter series.

From temperature data of 9 stations (Leningrad, Salekhod, Yeniseysk, Yakutsk, Barnaul, Nerchinskii Zavo- Vladivostok, Tbilisi, Kazalinsk) for January, February, April, July and October, V. V. Orlov has found that monthly temperatures, averaged for 10 years, usually showed smaller differences from preceding 50-year averages than from preceding 10- or 25-year averages. Only half as often were the differences larger than for the shorter antecedent periods. For the 9 stations, the divergence between the average temperatures for 25 and 50 years and the subsequent 5, 10 and 15 years is 0.1 deg less than for 10-year averages, and during winter the decrease reaches even 0.3 deg (Table 2).

Significantly, a substantial increase in accuracy from using a 50-year average temperature is obtained even for January, when the secular variation of temperature is most sharply expressed. Obviously, this is associated with the large aperiodic random fluctuations of air temperature from year to year during this month. Only in April, when the variability of the temperature from year to year is smallest, does the extrapolation of the mean appear to be more accurate when computed from a shorter antecedent period (on the order of 30 years).

3. Varying Criteria

The average for 30-year periods, which are the basis of the climatic norms of the World Meteorological Organization (1901-1930 and 1931-1960), however, are without scientific foundation. In extrapolating a norm, the optimal length of the averaging period depends on the length of the period for which the extrapolation is made, and may vary depending on the purpose for which the mean is used.

The period used to describe climatic characteristics for practical purposes must vary with each objective, as for example, for biological purposes [Davitaya]. To investigate field crops, data for specific years may be required; to determine natural vegetation, periods of an order of decades or even centuries must be considered; to study the formation of soils the climate over many centuries or even millenia must be taken into account. Here, too, not only the averages but also other climatic characteristics are needed.

The various objectives cited by Davitaya involve extremely different periods of time, hence the requirements for the descriptive climatic norms must vary substantially. Obviously, requirements must differ even in designing industrial products intended for different lengths of service. Consequently, no single optimal period of averaging can be suitable in all fields, unless the average of a series of meteorological values tends toward some kind of limit as the averaging period increases. Whether such a limit exists, in principle, is not altogether clear.

Thus for periods so long that the composition and properties of the atmosphere may change substantially--the geographic, astronomical and astrophysical conditions of the geological past--constancy of climate at a given place on the earth's surface cannot be assumed, although certain astronomical factors vary quasi-periodically. Even over shorter periods, since the end of the latest glaciation, important changes occurred in climate in which, of course, some rhythmic oscillations of varying length prevailed.

In addition, consideration must be given to any absolutely aperiodic variation whose origin has not been established. In the assumed cyclical oscillations of a tidal character [9], as well as those of astrophysical and of auto-oscillatory character in the atmosphere-hydrosphere system (continental and sea ice), the average lengths of complete cycles are of varying order (1850 years, hundreds of years, several hundreds of years, 11, 8, 5½, 2 years, and others less substantiated). Consequently, the stability of climatic norms over a long period is doubtful, inasmuch as the variations of a climatic regime are not only multicyclic but obviously cannot be reduced entirely to cyclic recurrence: in general, any series of climatic indices will be divergent.

4. Estimating Stability .

The degree of stability of a climatic series may be verified empirically. The theory of series with damping constraints [4] assumes that the process of averaging excludes short cycles, and thus increases the stability of the averages. Moreover, if a climatic series diverges, then any increase in the period of averaging beyond a specific length not only does not increase the stability, but conversely will contribute to the recession of the averages from present-day conditions.

The insufficient length of instrumental observations does not permit distinguishing an overextended cycle from an irreversible change in climate. The limited development of the theory of climatic oscillations does not provide a solution of this problem by taking into account general regularities; it must be approached empirically by comparing the variabilities with a different averaging [6].

Of the different variants of such an approach, of interest here is the successive averaging for various long periods beginning with the most recent year. Use of such a series is rather natural because climatologists, for a number of reasons, tend to use observations up to recent years; the years thereafter will be considered subsequent, except for periods of interruption in the observations. The question, "What year completes the period of the averaging?" always arises.

By investigating the damping of oscillations of averages for successively increasing periods, the following problems may be solved:

1. Whether an average tends to any type of limit, or, at least for the period of observations available at our disposal and beginning with such a number of years of observations, whether the average becomes practically constant and does not depend on the length of the period.
2. Whether the averages show symptomatic variations. If the meteorological homogeneity of the series has been established, such a variation may indicate (a) the presence of "ultrasecular" (more than 100 years--Tr.) oscillations with a period equalling the very large actual number of years of observations, or

(b) a change in the meteorological regime at the station as the result of an unobserved inhomogeneity, or (c) an actual rapid change in the meteorological regime in a given region (for example, the creation of a new reservoir or the drying up of a lake like the Caspian Sea).

5. Results

To examine the problem, monthly temperature and precipitation data, each for six stations, were studied: temperature for January, April, July and October, and precipitation for the warmer (April-October) and colder (November-March) seasons, and also for individual months (five stations for January and July; one station for August and April). Results are summarized in Tables 3 and 4, and given in detail in the Appendix. [Omitted]

In most cases, the mean temperature became relatively constant as the series was lengthened, and was independent of the period. The latter result was obtained when the series became longer than 50 and sometimes only when longer than 80 years. In certain cases a further lengthening of a temperature series is useless, because the temperature gradually diverges from values characteristic for present-day epochs. Such, for example, are the results of averaging January and April temperatures.

Dry years at the beginning of the second quarter of the 19th century are strongly reflected in the average value, even when computed for years including recent years of the 20th century. This is especially characteristic for Barnaul and Leningrad, for which series are long enough to investigate the dry period. How frequently such long dry periods develop has not yet been determined, and whether they consequently must be considered is not now clear.

Table 1. Number of cases, by months, in which increasing the period of averaging decreased (-), increased (+), or did not change (0) the difference between that average and that for the following ten years.

Month	50 years vs. 10 years			50 years vs. 25 years		
	-	+	0	-	+	0
JAN	8	1	0	6	1	2
FEB	8	0	1	6	1	2
APR	4	4	1	1	5	3
JUL	4	2	3	2	3	4
OCT	5	2	2	5	4	0
J+F+O	29	9	7	20	14	11
TOTAL	21	3	3	17	6	4

Table 2. Average difference between mean temperature for 10, 25, and 50-year periods and mean temperatures of following 5, 10 and 15 year-periods.

Month	for next 5 yrs			for next 10 yrs			for next 15 yrs		
	10	25	50	10	25	50	10	25	50
JAN+FEB	1,4	1,1	1,1	1,2	1,1	1,1	1,2	1,0	1,0
MARCH	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4
JULY	1,3	1,3	1,1	1,3	1,3	1,2	1,3	1,3	1,2
OCT	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3
TOTAL	2,1	2,1	2,0	2,1	2,0	2,0	2,1	2,0	2,0

In this study, the optimal averaging period to yield the best stability of the monthly averages, especially for temperature, was found to be of the order of 50-80 years, beginning with recent years. For precipitation, the length of the series is the same, although as yet how to handle the pronounced negative precipitation anomalies during the 1830's and 1840's is not clear. If this phenomenon is cyclic in character, the optimal length must be increased to 150 years or even more. If similar anomalies are extremely rare, the period of averaging might be less than 150 years but not including the anomalous years.

The lack of sufficiently long series of instrumental observations prevents solution of the problem as stated originally. Clearly the existing series of observations of precipitation amounts are not long enough for their averages to achieve stability; attempts of some authors [5] to estimate precipitation normals by extending shorter series are without firm foundation.

Table 3. Air temperature (degrees).

Year	January		February		April		July		October	
	No. years	mean	No. years	mean	No. years	mean	No. years	mean	No. years	mean
				Leningrad						
1960	1	—10,0	1	—9,6	1	3,8	1	20,1	1	2,6
1959	2	—7,0	2	—6,6	2	4,2	2	19,6	2	3,3
1958	3	—7,2	3	—5,3	3	3,6	3	18,5	3	4,3
1957	4	—6,2	4	—4,8	4	3,4	4	18,8	4	4,7
1956	5	—6,8	5	—6,6	5	2,8	5	18,0	5	4,7
1955	6	—6,7	6	—6,8	6	2,2	6	17,9	6	5,1
1954	7	—7,0	7	—7,6	7	2,2	7	18,0	7	5,2
1953	8	—7,0	8	—8,1	8	2,6	8	18,0	8	5,4
1952	9	—6,5	9	—7,8	9	2,8	9	17,9	9	5,1
1951	10	—6,7	10	—7,7	10	3,0	10	17,7	10	5,2
1950	11	—7,3	11	—7,6	11	3,4	11	17,5	11	5,2
1949	12	—6,9	12	—7,2	12	3,5	12	17,5	12	5,3
1948	13	—7,0	13	—7,4	13	3,5	13	17,5	13	5,3
1947	14	—7,1	14	—7,9	14	3,5	14	17,4	14	5,2
1946	15	—7,0	15	—8,0	15	3,6	15	17,5	15	5,0
1945	16	—6,9	16	—7,8	16	3,5	16	17,6	16	4,8
1944	17	—6,7	17	—7,7	17	3,3	17	17,7	17	5,0
1943	18	—7,0	18	—7,5	18	3,4	18	17,7	18	5,1
1942	19	—7,6	19	—7,7	19	3,3	19	17,6	19	5,2
1941	20	—8,0	20	—7,8	20	3,1	20	17,8	20	5,0
1940	21	—8,3	21	—8,0	21	3,1	21	17,8	21	5,0
1939	22	—8,2	22	—7,8	22	3,0	22	17,9	22	4,9
1938	23	—8,2	23	—7,6	23	3,0	23	18,0	23	4,9
1937	24	—8,1	24	—7,6	24	3,1	24	18,0	24	5,0
1936	25	—8,0	25	—7,7	25	3,2	25	18,1	25	4,9
1935	26	— 8,0	26	—7,6	26	3,2	26	18,0	26	5,0
1934	27	—7,8	27	—7,5	27	3,2	27	18,1	27	5,1
1933	28	—7,8	28	—7,5	28	3,2	28	18,2	28	5,1
1932	29	—7,7	29	—7,6	29	3,3	29	18,2	29	5,1
1931	30	—7,6	30	—7,7	30	3,2	30	18,2	30	5,1
1930	31	—7,4	31	—7,6	31	3,3	31	18,2	31	5,1
1929	32	—7,5	32	—7,9	32	3,1	32	18,2	32	5,2
1928	33	—7,5	33	—7,9	33	3,1	33	18,1	33	5,2
1927	34	—7,5	34	—7,9	34	3,1	34	18,2	34	5,1
1926	35	—7,7	35	—7,9	35	3,0	35	18,2	35	5,0
1925	36	—7,6	36	—7,7	36	3,1	36	18,2	36	5,0
1924	37	—7,6	37	—7,7	37	3,0	37	18,2	37	5,0
1923	38	—7,5	38	—7,8	38	3,0	38	18,2	38	5,0
1922	39	—7,5	39	—7,9	39	3,0	39	18,1	39	5,0
1921	40	—7,4	40	—7,9	40	3,1	40	18,1	40	4,9
1920	41	—7,6	41	—7,8	41	3,2	41	18,1	41	4,9
1919	42	—7,5	42	—7,9	42	3,2	42	18,2	42	4,9
1918	43	—7,6	43	—7,9	43	3,2	43	18,1	43	4,9
1917	44	—7,7	44	—8,0	44	3,2	44	18,1	44	5,0
1916	45	—7,6	45	—7,9	45	3,2	45	18,1	45	4,9
1915	46	—7,6	46	—7,9	46	3,2	46	18,1	46	4,9
1914	47	—7,7	47	—7,8	47	3,2	47	18,2	47	4,8
1913	48	—7,6	48	—7,8	48	3,3	48	18,2	48	4,8
1912	49	—7,7	49	—7,8	49	3,2	49	18,2	49	4,7
1911	50	—7,7	50	—7,9	50	3,2	50	18,2	50	4,7
1910	51	—7,6	51	—7,8	51	3,2	51	18,1	51	4,7
1909	52	—7,6	52	—7,8	52	3,2	52	18,1	52	4,8
1908	53	—7,6	53	—7,9	53	3,2	53	18,1	53	4,8
1907	54	—7,7	54	—7,8	54	3,2	54	18,1	54	4,8
1906	55	—7,6	55	—7,8	55	3,2	55	18,1	55	4,8
1905	56	—7,6	56	—7,7	56	3,2	56	18,1	56	4,8
1904	57	—7,6	57	—7,7	57	3,2	57	18,0	57	4,9
1903	58	—7,6	58	—7,6	58	3,3	58	18,0	58	4,8
1902	59	—7,0	59	—7,6	59	3,2	59	17,9	59	4,7
1901	60	—7,5	60	—7,7	60	3,2	60	17,9	60	4,8
1900	61	—7,5	61	—7,7	61	3,2	61	17,9	61	4,8
1899	62	—7,5	62	—7,7	62	3,1	62	17,9	62	4,8

Table 3. Air temperature (degrees). Concluded.

Year	January		February		April		July		October	
	No. years	mean	No. years	mean	No. years	mean	No. years	mean	No. years	mean
1898	63	—7,5	63	—7,7	63	3,1	63	17,9	63	4,8
1897	64	—7,5	64	—7,7	64	3,2	64	17,9	64	4,8
1896	65	—7,5	65	—7,7	65	3,1	65	17,9	65	4,8
1895	66	—7,5	66	—7,8	66	3,1	66	17,9	66	4,9
1894	67	—7,5	67	—7,8	67	3,2	67	17,9	67	4,8
1893	68	—7,6	68	—7,9	68	3,1	68	17,9	68	4,8
1892	69	—7,6	69	—7,9	69	3,1	69	17,9	69	4,8
1891	70	—7,6	70	—7,8	70	3,1	70	17,9	70	4,8
1890	71	—7,6	71	—7,8	71	3,1	71	17,8	71	4,8
1889	72	—7,6	72	—7,9	72	3,1	72	17,8	72	4,9
1888	73	—7,7	73	—7,9	73	3,1	73	17,8	73	4,8
1887	74	—7,6	74	—7,9	74	3,1	74	17,8	74	4,8
1886	75	—7,7	75	—7,9	75	3,1	75	17,8	75	4,8
1885	76	—7,6	76	—7,8	76	3,1	76	17,8	76	4,8
1884	77	—7,6	77	—7,8	77	3,1	77	17,8	77	4,8
1883	78	—7,7	78	—7,8	78	3,1	78	17,8	78	4,8
1882	79	—7,6	79	—7,8	79	3,1	79	17,8	79	4,8
1881	80	—7,7	80	—7,8	80	3,0	80	17,8	80	4,8
1880	81	—7,7	81	—7,8	81	3,0	81	17,8	81	4,8
1879	82	—7,7	82	—7,8	82	3,0	82	17,8	82	4,7
1878	83	—7,7	83	—7,7	83	3,0	83	17,8	83	4,8
1877	84	—7,8	84	—7,8	84	2,9	84	17,7	84	4,8
1876	85	—7,8	85	—7,8	85	3,0	85	17,7	85	4,7
1875	86	—7,9	86	—7,8	86	2,9	86	17,7	86	4,7
1874	87	—7,8	87	—7,8	87	2,9	87	17,9	87	4,8
1873	88	—7,8	88	—7,8	88	2,9	88	17,9	88	4,8
1872	89	—7,7	89	—7,8	89	2,9	89	17,8	89	4,8
1871	90	—7,8	90	—7,9	90	2,8	90	17,7	90	4,8
1870	91	—7,7	91	—8,0	91	2,8	91	17,7	91	4,8
1869	92	—7,8	92	—7,9	92	2,8	92	17,7	92	4,8
1868	93	—7,8	93	—8,0	93	2,8	93	17,8	93	4,8
1867	94	—7,9	94	—8,0	94	2,8	94	17,7	94	4,8
1866	95	—7,8	95	—8,0	95	2,8	95	17,7	95	4,8
1865	96	—7,8	96	—8,0	96	2,8	96	17,8	96	4,8
1864	97	—7,8	97	—8,0	97	2,8	97	17,8	97	4,7
1863	98	—7,7	98	—8,0	98	2,8	98	17,7	98	4,8
1862	99	—7,8	99	—8,0	99	2,8	99	17,7	99	4,8
1861	100	—7,9	100	—8,0	100	2,7	100	17,8	100	4,8
1860	101	—7,9	101	—8,0	101	2,8	101	17,8	101	4,8
1859	102	—7,8	102	—8,0	102	2,8	102	17,7	102	4,8
1858	103	—7,8	103	—8,0	103	2,7	103	17,8	103	4,8
1857	104	—7,8	104	—7,9	104	2,7	104	17,7	104	4,8
1856	105	—7,8	105	—7,9	105	2,7	105	17,7	105	4,8
1855	106	—7,8	106	—8,0	106	2,7	106	17,8	106	4,8
1854	107	—7,9	107	—8,0	107	2,7	107	17,8	107	4,8
1853	108	—7,8	108	—8,0	108	2,7	108	17,8	108	4,8
1852	109	7,8	109	—8,0	109	2,6	109	17,7	109	4,8
1851	110	—7,8	110	—8,0	110	2,6	110	17,8	110	4,8
1850	111	—7,9	111	—8,0	111	2,6	111	17,8	111	4,8
1849	112	—7,9	112	—8,0	112	2,5	112	17,7	112	4,8
1848	113	—8,0	113	—8,0	113	2,6	113	17,7	113	4,8
1847	114	—8,0	114	—8,0	114	2,5	114	17,7	114	4,8
1846	115	—8,0	115	—8,0	115	2,5	115	17,7	115	4,8
1845	116	—7,9	116	—8,1	116	2,5	116	17,7	116	4,8
1844	117	—8,0	117	—8,2	117	2,5	117	17,7	117	4,8
1843	118	—7,9	118	—8,1	118	2,5	118	17,7	118	4,8
1842	119	—7,9	119	—8,1	119	2,4	119	17,7	119	4,8
1841	120	—7,9	120	—8,1	120	2,5	120	17,7	120	4,8
1840	121	—7,9	121	—8,1	121	2,4	121	17,7	121	4,8
1839	122	—7,9	122	—8,1	122	2,4	122	17,7	122	4,8
1838	123	—8,0	123	—8,2	123	2,4	123	17,7	123	4,7
1837	124	—8,0	124	—8,1	124	2,4	124	17,6	124	4,7
1836	125	—8,0	125	—8,1	125	2,4	125	17,6	125	4,7
1835	126	—8,0	126	—8,1	126	2,4	126	17,6	126	4,7

Table 4. Precipitation amounts (mm).

Year	January		July		Cold period		Warm period	
	No. of years	mean	No. of years	mean	No. of years	mean	No. of years	mean
			Leningrad					
1960	1	60	1	70	1	175	1	331
1959	2	68	2	56	2	182	2	375
1958	3	59	3	65	3	189	3	407
1957	4	58	4	59	4	196	4	423
1956	5	53	5	61	5	199	5	403
1955	6	55	6	59	6	206	6	378
1954	7	50	7	72	7	198	7	388
1953	8	44	8	74	8	197	8	394
1952	9	45	9	71	9	199	9	403
1951	10	44	10	76	10	200	10	395
1950	11	41	11	72	11	200	11	385
1949	12	40	12	69	12	183	12	382
1948	13	42	13	66	13	196	13	420
1947	14	40	14	70	14	191	14	392
1946	15	38	15	69	15	198	15	388
1945	16	38	16	69	16	196	16	392
1944	17	38	17	66	17	183	17	386
1943	18	37	18	67	18	181	18	396
1942	19	36	19	67	19	176	19	388
1941	20	36	20	65	20	176	20	380
1940	21	35	21	65	21	176	21	380
1939	22	36	22	67	22	176	22	375
1938	23	36	23	66	23	176	23	376
1937	24	35	24	68	24	176	24	374
1936	25	36	25	69	25	175	25	373
1935	26	35	26	69	26	176	26	386
1934	27	35	27	70	27	175	27	386
1933	28	34	28	70	28	175	28	391
1932	29	34	29	69	29	175	29	391
1931	30	35	30	69	30	175	30	395
1930	31	35	31	68	31	175	31	395
1929	32	34	32	69	32	176	32	395
1928	33	34	33	70	33	176	33	400
1927	34	34	34	69	34	176	34	400
1926	35	33	35	67	35	176	35	403
1925	36	33	36	68	36	176	36	404
1924	37	33	37	66	37	178	37	404
1923	38	33	38	65	38	178	38	404
1922	39	33	39	66	39	177	39	406
1921	40	33	40	67	40	177	40	408
1920	41	33	41	67	41	177	41	407
1919	42	32	42	65	42	177	42	405
1918	43	33	43	65	43	177	43	405
1917	44	33	44	65	44	178	44	403
1916	45	33	45	64	45	178	45	401
1915	46	33	46	63	46	180	46	403
1914	47	33	47	63	47	182	47	401
1913	48	33	48	62	48	180	48	399
1912	49	33	49	61	49	180	49	399
1911	50	32	50	61	50	182	50	399
1910	51	33	51	61	51	183	51	396
1909	52	32	52	61	52	182	52	394
1908	53	35	53	61	53	180	53	394
1907	54	31	54	61	54	179	54	394
1906	55	31	55	62	55	179	55	394
1905	56	31	56	62	56	180	56	391
1904	57	31	57	62	57	180	57	394
1903	58	31	58	61	58	180	58	395
1902	59	31	59	61	59	182	59	394
1901	60	31	60	61	60	183	60	391
1900	61	31	61	61	61	182	61	391
1899	62	32	62	60	62	186	62	391

Table 4. Precipitation amounts (mm). Concluded.

Year	January		July		Cold period		Warm period	
	No. of years	mean	No. of years	mean	No. of years	mean	No. of years	mean
1898	63	32	63	60	63	186	63	390
1897	64	32	64	60	64	186	64	390
1896	65	32	65	60	65	186	65	390
1895	66	32	66	60	66	187	66	390
1894	67	32	67	61	67	187	67	390
1893	68	32	68	61	68	187	68	391
1892	69	31	69	61	69	187	69	392
1891	70	31	70	61	70	187	70	392
1890	71	31	71	61	71	186	71	392
1889	72	31	72	61	72	185	72	391
1888	73	31	73	61	73	184	73	390
1887	74	30	74	61	74	184	74	390
1886	75	30	75	61	75	183	75	391
1885	76	30	76	62	76	182	76	391
1884	77	31	77	62	77	181	77	390
1883	78	30	78	63	78	180	78	390
1882	79	30	79	63	79	179	79	391
1881	80	30	80	63	80	178	80	391
1880	81	30	81	64	81	180	81	390
1879	82	30	82	64	82	178	82	391
1878	83	30	83	65	83	177	83	392
1877	84	30	84	65	84	177	84	392
1876	85	30	85	65	85	175	85	391
1875	86	30	86	65	86	174	86	391
1874	87	29	87	65	87	174	87	389
1873	88	30	88	65	88	174	88	389
1872	89	30	89	65	89	174	89	389
1871	90	30	90	65	90	174	90	389
1870	91	30	91	65	91	174	91	389
1869	92	29	92	65	92	174	92	389
1868	93	29	93	65	93	174	93	389
1867	94	30	94	65	94	174	94	389
1866	95	30	95	65	95	174	95	389
1865	96	30	96	65	96	175	96	389
1864	97	30	97	65	97	175	97	389
1863	98	30	98	65	96	175	98	390
1862	99	30	99	65	99	174	99	390
1861	100	30	100	65	100	173	100	389
1860	101	29	101	65	101	172	101	388
1859	102	29	102	65	102	172	102	387
1858	103	29	103	65	103	171	103	385
1857	104	29	104	64	104	171	104	384
1856	105	29	105	64	105	170	105	384
1855	106	28	106	64	106	170	106	383
1854	107	28	107	63	107	168	107	380
1853	108	28	108	63	108	168	108	380
1852	109	28	109	63	109	168	109	377
1851	110	28	110	63	110	168	110	377
1850	111	28	111	62	111	168	111	377
1849	112	28	112	62	112	168	112	376
1848	113	28	113	63	113	167	113	376
1847	114	28	114	62	114	167	114	376
1846	115	28	115	63	115	166	115	376
1845	116	28	116	63	116	166	116	376
1844	117	28	117	64	117	166	117	376
1843	118	28	118	64	118	166	118	376
1842	119	28	119	64	119	166	119	376
1841	120	28	120	64	120	165	120	376
1840	121	28	121	64	121	164	121	374
1839	122	28	122	64	122	164	122	374
1838	123	28	123	64	123	164	123	374
1837	124	28	124	65	124	164	124	374
1836	125	27	125	65			125	374
1835			126	65				

REFERENCES :

ЛИТЕРАТУРА

1. Алисов, Б. П., Дроздов, О. А., Рубинштейн, Е. С. : Курс климатологии, ч. I и II, Гидрометеоиздат, Л., 1952.

Alisov, B. P.; Drozdov, O. A.; Rubinshtein, E. S.: Course in Climatology, part I and II; Gidrometeoizdat, Leningrad, 1952.

2. Дроздов, О. А.: Основы методов климатологической обработки Изд. Л Г У, 1956.

Drozdov, O. A.: Basic Methods in Climatological Operations. Publisher: Leningrad State University, 1956.

3. Дроздов, О. А., Шарова, В. Я., Швер, Ц. А.: К вопросу вычисления среднего многолетнего количества осадков. Труды ГГО, вып. 148, 1963.

Drozdov, O. A., Sharova, V. Ya., Shver, Ts. A.: Computing Long-period Precipitation Averages; Trudy Glavnia Geofisischikaya Obs., vol. 148, 1963.

4. Келлер, Л. В.: Распространение предельных теорий вероятностей на интегралы и средние значения функции сплошного аргумента. Труды ГГО, вып. 4, 1935.

Keller, L. V.: Distibution of Limit Theory of Probability on Integrals and the Average Significance of Functions Compact Arguments; Trudy Glavnia Geofisischikaya Obs., vol. 4, 1935.

5. Сапожникова, С. А.: О климатических нормах. Метеорология и гидрология, №2, 1963.

Sapozhnikova, S. A. : On Climatological Normals; Meteorology and Hydrology, No. 2, 1963

6. Швер, Ц. А.: Применение метода последовательных изменений и интегрально разностных крывых для вычисления норм осадков. Труды ГГО, вып. 162, 1964.

Shver, Ts. A.: Application of a Method of Sequential Changes & Integral-difference Curves for Computing Precipitation Rates; Trudy Glavnia Geofisischikaya Obs., vol. 162, 1964.

7. Шнитников, А. В.: Изменчивость климатического увлажнения на материке Евразии. Зап. ВГО, новая сер., № 15, 1957.

Shnitnikov, A. V.: Climatic Variability in Moisture on the Eurasian Continent; Proc. V. Geofisischikaya Obs., new series, No. 15, 1957.

8. Beaumont, R. T. : A Criterion for selection of length of period to a moving arithmetic mean for hydrologic data. Transactions Amer. Geophys. Union, vol. 38, no. 2, April, 1957.

9. Enger, J.: Optimum length of period for climatological estimates of temperature. J. Geophys. Research, vol. 64, No. 7, July 1959.

10. Esio, R. : Applicazioni dell'analisi sequenziale a problemi di climatologia. Geofis. e meteorolo. No. 1-2, 5-8, 9, 1961.

К ВОПРОСУ О ПЕРИОДЕ ОСРЕДНЕНИЯ В КЛИМАТОЛОГИИ

Е. С. РУБИНШТЕЙН

Glavnaia Geofizicheskaia Observatoriia, Leningrad

Trudy no. 181, 1965. Pp. 46 - 55 .

Translated by George S. Mitchell, consultant, as:

THE PROBLEM OF AVERAGING PERIOD IN CLIMATOLOGY

by E. S. RUBINSHTEIN

Edited by Arnold Court, Principal Investigator

Contract AF 19(628)-5716 Project No. 8624 Task No. 862402

THE PROBLEM OF AVERAGING PERIOD IN CLIMATOLOGY, BY E. S. RUBINSHTEIN

ABSTRACT: The problem of length of period required for obtaining consistent climatic mean values is examined. The change in climate occurring over a greater part of the world renders the 30-year period to have no scientific basis.

1. Introduction

The length of period to be used in computing climatic averages is a problem that has long awaited solution.

The great lack of comparability between similar studies covering just one country, as well as between studies of different countries, impedes the development of climatic theory and the solution of practical problems.

This problem should be solved formally on an international scale, but at each of the three sessions of the [W. M. O.] Climatology Commission, at numerous conferences of regional organizations, in working groups, and in a number of periodicals published in different countries, the solution usually adopted has been subject to criticism. Its practical use frequently gives unsatisfactory results, because the 30-year period for averaging climatic values has insufficient scientific basis.

Undoubtedly, the problem of what period must be selected as "standard" for computing climatic "norms" for the entire world has many difficulties, but they are surmountable and a reasonable answer can be found. The difficulties arise from the differences in climates in various parts of the world, and from the variety of purposes for which many-year averages are computed.

Climates in the USSR vary from the Arctic in the north to subtropic in the south, from marine along sea coasts to severely continental in the interior, and from plains to high mountains. The density of the network of meteorological stations, and the length of the series of observations, differ in different parts of the USSR.

For these reasons, Soviet climatologists have become increasingly more interested in the problem of the most rational selection of a period to yield stable and mutually comparable average values of the meteorological elements. In addition, Soviet scientists have dealt with the entire world and the Northern Hemisphere. All these works have provided extensive experience in methods of climatological processing of observations over the entire world--and in particular on the problem of the most rational selection of the period for obtaining stable average values of the meteorological elements. The following considerations are inferences from this experience.

2. Requirements

Many-year averages of meteorological elements are used for the most diverse purposes, but all may be divided into two categories.

In some cases, the absolute values of the meteorological elements are not so important as the differences or relations between them at individual stations, or over individual portions of the area under study. Thus, for example, questions arise concerning differences in air temperature between city and surrounding areas, between coastal and interior stations, and between valley and slope stations. To solve such problems, a long period of observations is not required, but during too short a record, the relations may not be the same in different seasons or under different types of atmospheric circulation. A 10-year period has been found sufficient provided the series is homogeneous.

In another category of problems, great absolute accuracy of the average average values of the meteorological elements has been found essential through extensive contact between climatologists and specialists in pertinent branches of science and practical work. These problems include designing modern grandiose constructions (dams, canals), predicting long-period levels of enclosed seas and lakes, establishing the connection between climate and landscape (relief), investigating climatic changes, et cetera.

How can one scientifically determine the length of a series necessary for obtaining stable averages of climatic elements? The very nature of the fields of different meteorological elements precludes stability in time (from year to year). Therefore, the length of the series which will assure stable mean values is not the same for different elements.

In addition, climatic changes in one form or another, embracing the entire world, are now well-known. These changes complicate the problem and its solution even more--rational selections of the period for which climatic averages must be computed will differ, depending on whether these variations are rhythmic (oscillations) or tend in one direction (rise in air temperature, decrease in precipitation amount, etc.)

3. Temperatures

The problem of the observational period necessary for obtaining stable average monthly air temperatures will be discussed first. Numerous works of scientists in many countries have defined the nature of air temperature variations with time, and the regions in which they occur. The vast amount of material on the problem of temperature change published in recent years [1, 2] is too well known to require discussion here. These data provide the objective basis for a further consideration of the problem of the period necessary for obtaining stable averages.

The magnitude of the differences between temperatures in individual 10-year periods is shown by the following examples. At Salekhard the average temperature for November, 1885-1894, was -19.2 C but for 1934-1943 it was -10.5 C; the southern regions of the USSR differ only a little from this. At Kazalinsk the average January temperature, 1886-1895, was -14.8 C but during 1909-1918 only -7.9 C. At Barnaul during the 1940s temperatures on the average were 5 deg higher than at the end of the 19th century.

Such differences sometimes are attributed to the growth of cities, but a number of works both by Soviet and foreign scientists show that this is not the chief cause of the instability in 10-year averages. This follows from analysis of individual months (adjacent months should show analogous increases in averages) and also from comparison of moving averages for corresponding months at neighboring stations, one urban, one rural. Nowhere have temperatures in the city and in nearby open locations been found to be so large.

The well established changes in temperature with time has led to the conclusion that the mean monthly temperatures over a 30-year period are unstable. For corroboration, Table 1 presents the differences between average monthly temperatures for two 30-year periods, 1931-1960 and 1901-1930, at 7 stations in different portions of the USSR.

TABLE 1. DIFFERENCES BETWEEN MEAN MONTHLY TEMPERATURES, 1931-1960 and 1901-1930

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Leningrad	-0.3	-0.3	-0.6	0.1	0.1	0.7	0.6	1.3	0.5	0.6	0.4	1.0
Kiev	-0.8	0.0	-0.6	0.1	0.3	0.8	1.3	1.2	0.9	0.1	0.2	0.4
Sverdlovsk	0.7	0.3	-0.3	0.6	0.7	0.6	0.5	1.1	0.4	1.0	-0.9	0.5
Salekhard	2.3	-0.5	-0.1	1.9	1.4	0.9	0.1	0.4	0.3	0.9	2.0	0.2
Turukhansk	1.6	1.0	0.6	2.0	1.2	1.4	-0.1	-0.5	0.7	1.0	-0.8	2.5
Kazalinsk	-1.2	0.8	0.3	0.7	-0.2	-0.4	-0.6	0.0	0.4	0.2	-1.3	-0.6
Barnaul	-0.7	-0.4	0.6	1.3	0.2	0.1	0.2	0.1	0.3	1.4	-1.9	-1.2

At each station in some months the differences between temperatures in the consecutive 30-year periods exceed 1 degree and some are around 2 degrees (Salekhard in January, April and November; Turukhansk in April and December; Barnaul in November). In most months the period 1931-1960 was warmer than the 1901-1930 period, but in certain regions cooling appeared in winter (Leningrad, Kiev, Kazalinsk, Barnaul).

A change in sign of the differences during adjacent months results from a change in the character of the annual march of temperature during the second 30-year period compared with the first; sometimes the month with the lowest temperature changed. Thus, during 1901-1930 at Salekhard the January and February temperatures are -24.4 C and -21.8 C respectively and during 1931-1960 -22.1 C and -22.3 C. January and February temperatures at Kazalinsk were identical during the first period (-10.0 C), but were -11.3 C and -9.1 C in 1931-1960.

Thus, at Salekhard the January and February temperatures were characteristic of a continental climate during 1901-1930, but of a marine climate in 1931-1960; at Kazalinsk the relation was reversed. At Barnaul the drop in temperature from October to November during 1901-1930 was 8.8 deg. but during 1931-1960 it was 12.1 deg.

4. Inadequacy of 30-year Period

Clearly, a 30-year series of observations cannot yield stable average monthly temperatures in the temperate zone, and especially in the polar zone where the change in climate is great. A 30-year period cannot be used as the "standard" for comparison. With which of the two 30-year series should temperatures of current years be compared to provide departures from the "norm"? At first glance, the second period seems more natural, but no scientific basis exists for this choice.

Many scientists believe that the warming period has ended and a cooling has begun. Actually the nature of a climatic change is much more complex; in some regions the warming continues while in others it has terminated. This is very evident from the variation of the moving averages presented by Polozova and Rubinshtein [2]. It also is evident from Table 1, which shows, for example, the oscillations in temperature at Salekhard and at Kazalinsk to be in opposite phase in January, February and November.

In addition, even where the 1931-1960 temperatures are, on the average, higher than during 1901-1930, sharp differences may be observed between monthly temperatures of consecutive years in both periods. For example, the January temperature at Leningrad in 1925 was -0.5 C while in 1926 it was -12.9 C; in 1929 it was -10.3 C but in 1930 only -0.9 C; in 1949 it was -2.2 C while in 1950 it was -13.9 C; the December temperature was -1.3 C in 1954 but -14.0 C in 1955. In a region with very pronounced warming, temperatures from one year to the next may vary greatly; for example, the mean April temperature at Salekhard was -4.5 C in 1955 but -14.5 C in 1956.

Another inconsistency arises in using 30-year periods, 1901-1930 or 1931-1960, as standards. In many countries, including the USSR, maps have been constructed of the departures of temperatures from the many-years average for each month of the year. These maps are widely used in scientific work, and also considered by synoptic meteorologists in search of analogs. Departures from the many-year averages are published also in "Monthly Climatic Data for the World".

Prior to 1960, the standard period was 1901-1930, but beginning in 1961 the 1931-1960 period has been used. If, for example, at some station the January temperatures were identical in 1960 and 1961, use of different "norms" caused departures from normal to be different, and sometimes even of opposite sign.

5. Deficiencies of Short Periods

Use of means for a recent brief period is defended by some writers on the assumption that temperatures of the most recent years will be closer to the 30-year period just ended; this hypothesis has no scientific foundation. Examples presented previously show large differences in the monthly temperatures from one year to the next.

Other advocates of short series of observations cite the conclusions of Beaumont [5] and Enger [6]; these works offer an obvious ambiguity. As is evident from the very title of the work, Beaumont used moving averages to select objectively the period for averaging precipitation amounts to predict for the subsequent year. Analogous work for air temperature led Enger to the conclusion that moving averages for 15 up to 20 years are most suitable for predicting temperature during the subsequent years. But moving averages cannot be used as a "standard", either for a climatic atlas or as a "norm" for calculating departures for individual years.

Steinhauser [7] also pointed out the unsuitability of the 30-year means as a "standard". Absolutely correctly, he asserted that certain 30-year means vary so that they may be used better as indices of climatic fluctuation rather than as the bases for climatic maps. The same result is shown in Mitchell's report at the Rome symposium in October 1961, comparing means for the two 30-year periods, 1891-1920 and 1921-1950.

6. Advantages of 50 to 80 Years

How can a rational conclusion be reached from the assumptions that have been made? The 10-year moving averages of monthly temperatures show an oscillatory character in the change of temperature; evidently several rhythms are superposed over each other, and consequently the distances between corresponding phases of the resultant curve are variable. The most stable monthly average temperatures can be obtained only from a very long series of observations.

TABLE 2. DIFFERENCES BETWEEN MEAN MONTHLY TEMPERATURES 1881-1960 AND 1881-1935

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Leningrad	-0.2	0.1	-0.1	0.1	0.0	0.3	0.1	0.3	0.1	0.1	0.1	0.2
Kiev	0.0	0.1	0.0	0.2	-0.1	0.4	0.3	0.4	0.2	-0.2	0.1	0.2
Salekhard	0.6	-0.6	-0.5	1.0	0.5	0.9	0.1	0.3	0.2	0.2	0.8	0.4
Kazalinsk	0.5	0.5	0.0	0.2	0.0	-0.1	-0.2	0.0	0.1	0.0	-0.2	0.0
Barnaul	0.0	0.1	0.3	0.6	0.3	0.0	0.1	0.0	0.1	0.3	-0.2	-0.1

Addition of the last 25 years to the 55-year mean 1881-1935 (Table 2) in most cases changes the many-years' average only by 0.1 to 0.3 deg., but in regions of more pronounced climatic change the many-year average temperature during certain months varied even as much as 0.8 to 1.0 deg. (Salekhard, April, June and November).

Thus, the average monthly temperature for a period of 50 to 80 years may be taken as the "standard" with which to compare data for individual years. Only such averages are suitable for constructing climatic maps, although for individual regions with a pronounced climatic change even these long-period averages may be insufficiently stable in individual months. Only climatic data obtained from long periods of observations should be considered in constructing huge projects designed for a prolonged existence (dams, canals, et cetera).

7. Extrapolations of Short Series

However, stations with a long and also homogenous series of observation are too few to provide climatic data for research and practical purposes. In the opinion of some, this is the chief obstacle to using the 50-80 year averages as the "norm". This objection would be valid if calculation of the many-years averages were restricted to simple arithmetical computation. But modern climatology has developed a theory of extending short series of observations to a long period, by differences for air temperature and humidity, by ratio for precipitation.

The method of extending short series of observations to a long period has been widely applied for many years by Soviet climatologists, for studies of the Soviet Union and of other countries. Undoubtedly, the long periods to which data of individual countries will be reduced cannot be identical over the entire world. Nevertheless, means for 50 to 80 year periods will be more comparable with each other than averages for a common but brief period, as Drozdov [3], has demonstrated.

(Editor's Note: The following discussion has been translated faithfully, with slight changes in notation--from n and N to m and n, and with subscripts rather than superscripts in parentheses. However, the basic inconsistencies in the original presentation cannot be removed, and the original paper [3] is unavailable. Apparently the quantities in Eq. (1) are not actual variances, but estimates of precision; Eq. (2) cannot be derived by standard statistical methods, so the validity of the result is not established.)

Data for two stations, X and Y, for n and m<n years, respectively, are considered. The variance of the difference between the m-year averages at each of the two stations may be compared with the variance of the difference between the n-year average at X and the m-year average at Y. If the first variance is less than the second, data for the two stations can be compared more adequately from the two m-year series than by using n years at X and m years at Y:

$$\sigma^2 \left(\bar{x}_m - \bar{y}_m \right) < \sigma^2 \left(\bar{x}_m - \bar{y}_n \right), \qquad (1)$$

where $\bar{x}_m$ and $\bar{y}_m$ are the average values of the meteorological element in question at stations X and Y for the m years, and $\bar{x}_n$ the average for the entire n years. This condition may be rewritten in terms of r_m, the correlation coefficient between temperatures at stations X and Y during the m years, and of σ_x and σ_y, the corresponding standard deviations, as

$$\frac{1}{m}\sigma_x^2 + \frac{1}{m}\sigma_y^2 - \frac{2}{m}\sigma_x\sigma_y r_m < \frac{1}{n}\sigma_x^2 + \frac{1}{m}\sigma_y^2 - 2r_m\sqrt{\frac{m}{n}}\,\sigma_x\sigma_y \Big/ \sqrt{m\,n} \qquad (2)$$

Hence $r_m > \sigma_x' / 2\,\sigma_y'$ is the condition under which extension of a short series of observations to a longer period by the difference method gives a more accurate value than one computed directly. Thus, at distances between stations at which extension to a long series is impossible, a long series of observations is more comparable to a shorter one than would be two short synchronous series.

Extension of a short series to a long period improves the accuracy of the many-year average value when the correlation between temperatures at the stations under comparison satisfies

$$r\,(x,y) > \sigma_x' / 2\,\sigma_y' \qquad (3)$$

When $\sigma_x' = \sigma_y'$, which often occurs in lowland areas, the condition for the feasibility of extrapolation becomes $r\,(x,y) > 0.5$. Isocorrelation lines [1], [4] indicate $r = 0.5$ at distances of hundreds of kilometers between stations, depending on season. If $\sigma_x' \neq \sigma_y'$, which occurs in comparing coastal with continental stations, or mountain with plains stations, etc., the critical value of r depends strongly on the ratio σ_x' / σ_y'.

The above discussion shows that computation of the average monthly and annual temperatures for long but not identical periods in different countries is entirely possible. Such data will be more comparable with each other and more stable than those for synchronous but shorter periods.

8. Other Elements

For further comparison of "norms" for different periods and for other meteorological elements, the conclusions obtained from study of the actual data will be discussed only briefly. The principles on which the conclusions are based are the same as for many-year averages of air temperature.

Atmospheric pressure for individual 10-year periods in the USSR may vary greatly: by as much as 1.3 mb at Leningrad in February, for example, and by 4 to 5 mb at Barnaul and Kazalinsk in January. Differences between atmospheric pressure in November 1931-1960 and 1901-1930 at Leningrad, Moscow and Sverdlovsk are at least 4 mb (Table 3). Large pressure differences are observed also in other months (Leningrad: August; Barnaul: January; Sverdlovsk: January, February, June). The inadequacy of a 30-year period for providing stable averages of pressure is perfectly obvious. Extrapolation of a short series of observations to a long period improves the accuracy of the average monthly pressure values in the temperate zone, even over distances of the order of 500 km. An obvious expedient is to use the same base period as for the air temperature.

Precipitation amounts show great variability with time (from year to year), as well as a rapid decrease in continuity of pattern between stations as the distance between them increases. Attaining stable monthly precipitation values is made much more difficult by the difference in instruments and exposures.

TABLE 3. DIFFERENCES BETWEEN MEAN MONTHLY ATMOSPHERIC PRESSURES (mb) 1931-1960 and 1901-1930

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Leningrad	1.0	-0.9	1.1	-0.1	0.0	0.8	0.6	2.3	-1.0	-0.9	4.5	1.6	1.0
Moscow	1.1	-1.8	0.0	0.2	1.7	1.0	1.0	1.5	-1.1	-1.2	3.9	0.5	0.3
Sverdlovsk	3.5	2.4	0.4	-0.2	0.3	2.4	0.4	1.8	0.2	-0.2	4.4	0.4	1.0
Kazalinsk	0.9	-1.2	-1.0	-0.1	-0.2	-0.3	-0.9	-0.6	-0.7	-0.8	1.3	1.1	-0.3
Barnaul	2.4	1.2	-0.6	-0.3	0.1	-0.1	-0.8	1.6	-0.5	-0.2	1.5	0.7	0.3

TABLE 4. PERCENTAGE RATIOS OF MONTHLY PRECIPITATION TOTALS (1931-1960) / (1901-1930)

	APR	MAY	JUN	JUL	AUG	SEP	OCT
Leningrad	96	82	89	131	95	99	109
Kiev	95	101	84	87	111	94	119
Barnaul	119	104	110	123	103	94	77
Irkutsk	105	96	128	115	124	118	112

Monthly ratios of precipitation for two 30-year periods (Table 4) demonstrate the inadequacy of a 30-year period for obtaining stable mean values of the precipitation. At Leningrad the ratios vary from 82% in May to 131% in July; the annual march of precipitation is distorted from that obtained over a longer period. Similarly, the difference between ratios of precipitation amounts at two stations during different 30-year periods shows that the July value at Kiev was 148% of that at Leningrad during 1901-1930 but only 98% during 1931-1960, etc. (Table 5)

Although a 30-year period is inadequate for obtaining stable average precipitation values, recommendations are much more difficult than for air temperature and atmospheric pressure. Extrapolation of short series to a long period is possible, and actually is realized, but it is not feasible everywhere because of the rapid decrease in the correlation coefficient with dis-

TABLE 5. RATIOS (%) OF PRECIPITATION TOTALS AT PAIRS OF STATIONS FOR TWO PERIODS

		APR	MAY	JUN	JUL	AUG	SEP	OCT
Kiev/ Leningrad	(1901-1930)	135	108	126	148	79	80	82
	(1931-1960)	134	133	120	98	93	77	90
Irkutsk/Barnaul	(1901-1930)	66	84	136	136	143	99	34
	(1931-1960)	59	77	157	128	172	124	50

tance between stations. Nevertheless, extrapolation by ratios should be recommended because the results are more accurate than the non-reduced if

$$r_{xy} \quad (k/2) \quad (\sigma_x / \sigma_y), \tag{4}$$

where k is the approximate selected coefficient. Average precipitation amounts must also be computed from possibly longer although non-synchronous averages.

Atmospheric humidity is characterized by small variations in time. In the USSR average values of absolute humidity computed for different 10-year periods may differ from each other by as much as 1 to 2 mb in summer, but by only 0.5 mb in winter. (Apparently this refers to vapor pressure, which is measured in millibars, and not to absolute humidity, which is measured in grams per cubic meter --Ed.) The 1300 hour relative humidity may differ by 5 to 10 percent, and the 24-hour average somewhat less, during different 10-year periods. Humidity data for 30 to 35 years are fairly stable; even in summer, absolute humidity (vapor pressure? -- Ed.) averages during different 30-year periods differ by around 0.5 mb, and average relative humidity at 1300 hours by 2 to 3 percent.

Reduction of short series of observations of vapor pressure to a longer period is feasible in lowland areas of the temperate zone for distances of 250 to 300 km and those of t e relative humidity in summer up to 200 km. In winter the humidity is so stable from year to year that even a 20 to 25 year series yields satisfactory accuracy. These recommendations for obtaining a stable average for humidity are based on data for the Soviet Union; additional studies on this topic are required for other climatic zones.

Conclusions

Analyses of series of meteorological observations of air temperature, atmospheric pressure, atmospheric precipitation, vapor pressure and relative humidity lead to the following recommendations:

1. In view of the great instability of average values of the meteorological elements (temperature, pressure, and precipitation) over a 30-year period, caused by variation in climate, neither 1901-1930 nor 1931-1960 should be assumed as standard on an international scale.

2. Average values of the meteorological elements which might be useful as "standards" for comparison of corresponding data, both in time and in different portions of the world, must be computed from long series of observations, on the scale of 50 to 80 years. These are not necessarily synchronous, because longer series are more comparable than shorter but synchronous series.

To compute such long-term averages the method of extrapolating short series of observations to a long period must be widely applied. The theory has been worked out in detail and verified in practice. In those few instances where such a reduction is not feasible (in countries with a poorly developed meteorological network), stations with longer periods, although still less than 50 years in length, should form the basis for extending shorter series at neighboring stations to a longer period. After some specified time (for example, 10 years) these means can be adjusted. Averages obtained in this manner may also be useful for constructing climatic charts and for computing departures from them for individual years, and for practical requirements generally.

To promote climatological studies pertaining to the entire world or the Northern Hemisphere, 10-year averages of air temperature and atmospheric pressure should be compiled and published, as well as maps of the distribution of these averages over the entire world. While such data may not be useful as "norms", they will be extremely valuable indices of the nature of the distribution of the meteorological element during the period, and of the extent and variation in its distribution from one 10-year period to another.

REFERENCES:

ЛИТЕРАТУРА

1. Rubinshtein, E. S. : Ob Izmenenii Klimata za Poslednie Desiatiletiia (Climatic Changes During the Last 10 Years) (From the Book) A. N. Voeykov i Sovremennye Problemy Klimatologii (A. N. Voeykov and Contemporary Problems in Climatology). Leningrad, Gidrometeoizdat, 1956.

I. Рубинштейн, Е.С. Об изменении климата за последние десятилетия. В кн. "А. И. Воейков и современные проблемы климатологии" . Гидрометеоиздат, М., 1958.

2. Polozova, L. G., and E. S. Rubinshtein: Sovremennoe Izmenenie Klimata (Contemporaneous Change in Climate). Izvestiia Akad. Nauk SSSR. Seriia Geografiia. No. 5, 1963.

2. Полозова, Л.Г., Рубинштейн, Е.С. Современное изменение климата. Изв. АН, СССР, сер. геогр., № 5, 1963.

3. Drozdov, O. A., and E. S. Rubinshtein: Itogi Izucheniia Klimata SSSR (Results of Studying the Climate of the USSR). Trudy Vsesoiuz. Nauch. Meteorolog. Soveshchaniia. Vol. 1. Leningrad, Gidrometeoizdat, 1962.

3. Дроздов, О. А.,Рубинштейн, Е. С. Итоги изучения климата СССР. Труды Всесоюз. науч. метеорол. совещания, т. I. Гидрометеоиздат, Л., 1962.

4. Rubinshtein, E. S. : Kolichestvennia Kharaktoristika Sviazi Mezhdu Temperaturoi Vozdukha Raznykh Chastei Sovetskogo Soiuza (The Quantitative Characteristics of the Relation Between the Air Temperature in Various Portions of the Soviet Union). Trudy Pervoi Nauchnoi Konferentsii po Obshchei Tsirkuliatsii Atmosfery. Moscow, Gidrometeoizdat, 1962.

4. Рубинштейн, Е. С. Количественная характеристика связи между температурой воздуха разных частей Советского Союза Труды первой научной конференции по общей циркуляции атмосферы. Гидрометеоиздат, М., 1962.

5. Beaumont, R. T. : A Criterion for selection of length of record for a moving arithmetic mean for hydrologic data. Transactions Amer. Geophys. Union, Vol. 38, No. 2, April 1957.

6. Enger, J. : Optimum Length of Record for Climatological Estimates of Temperature. Journal of Geophys. Res., Vol. 64, No. 7, July, 1959.

7. Steinhauser, F. : Sulle Oscillazioni Climatiche in Europa. Geofis. e Meteorol., 8, No. 5-6, 1960.

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

SAN FERNANDO VALLEY STATE COLLEGE FOUNDATION
Northridge, California 91324

2a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

2b. GROUP:

3. REPORT TITLE

CLIMATIC NORMALS AS PREDICTORS. PART 5: CONCLUSION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific Final December 1965 to December 1968

5. AUTHOR(S) (First name, middle initial, last name)

Arnold Court

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
15 December 1968	74	17

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
AF19(628)-5716	82-68-5
b. PROJECT, TASK, WORK UNIT NOS. 8624-02-01	
c. DOD ELEMENT 6240539F	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d. DOD SUBELEMENT 681000	AFCRL-69-0003

10. DISTRIBUTION STATEMENT

1-Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
TECH, OTHER	Air Force Cambridge Research Laboratories L. G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

Methods of previous Reports, concerned with the number of antecedent years for which the mean value of a climatic element offers the minimum variance estimator of the next year's value, are extended to similar predictions more than one year ahead. For predicting a value m years beyond the end of the averaging period, the best average is found to be based on a period m years shorter than for predicting the next year's value. Apparently each climatic record has an average period of maximum homogeneity, whose length must be equalled, for optimum prediction, by the interval from the start of the averaging period to the end of the predicted one. Climatic normals for 15-year periods, rather than 30 years as at present, are recommended, with recomputation every 5 years. Medians of values over 15 years are suggested as even better predictors than means. Finally, 7 years is suggested as a suitable period for the definition of climate.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
NORMALS, CLIMATIC						
PREDICTION, CLIMATIC						
OPTIMUM RECORD LENGTH						