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PROJECT FILE

FINAL REPORT

SUBMITTED TO THE NATIONAL SCIENCE FOUNDATION

by

University of Arizona

Long-term Spatial and Temporal Drought Frequency Analysis in Western United States Utilizing Tree Rings

Grant - DES 74-24163

January 1, 1975 to June 30, 1976

Principal Investigator

Charles W. Stockton
Laboratory of Tree-Ring Research
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Tucson, Arizona 85721

ESTABLISHED 1885

THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA

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The main purpose of this project has been to increase our understanding of drought history of the western United States through the use of tree rings. Accordingly, we reconstructed the Palmer Drought Severity Index (PDSI) in the western United States back to A.D. 1700 from 40 tree-ring series. In addition, we studied the joint occurrence of drought in the western United States and sea surface temperatures (SST) anomalies in the eastern North Pacific. To derive a long term SST record we reconstructed SST off Baja California from tree-ring records in Mexico and the southwestern United States. From a comparison of the SST reconstruction with the PDSI reconstruction we found that anomalously cold SST in spring and early summer appears to be related to large scale spring and summer drought in western United States.

I. RECONSTRUCTION OF PALMER DROUGHT SEVERITY INDEX

Grouping of Climatological Divisions

The primary data used for examination of drought is the Palmer Drought Severity Index (PDSI) as described by Palmer (1965). The data used was obtained from the National Climatic

Data Center in Asheville and included values of the PDSI for each of the climatic divisions in the United States for the period 1931-1970. However, for our purposes we analyzed only that data for the area west of the Mississippi River.

The study area, shown in Figure 1, comprises approximately the contiguous states west of the Mississippi River. The number of climatological divisions (204) within this area was large enough to warrant spatial averaging of PDSI in order to simplify subsequent computations and mapping. Since our interest lay mainly with large-scale patterns, the loss of small-scale resolution was not expected to be a problem.

The 204 climatological divisions within the study area were combined to form 40 regions. To avoid the combining of divisions with greatly differing rainfall regimes into any one region, the rainfall classification scheme of Trewartha (1961) was used as a guideline in forming the regions. Trewartha delineated different rainfall regimes in the United States based on the seasonal distribution and the annual amount of rainfall. Adherence to Trewartha's scheme precluded the formation of regions from equal numbers of divisions; the number of divisions in a region varies from two to nine. All regions except five contain more than three divisions. The regions are outlined by the solid black lines in Figure 1.

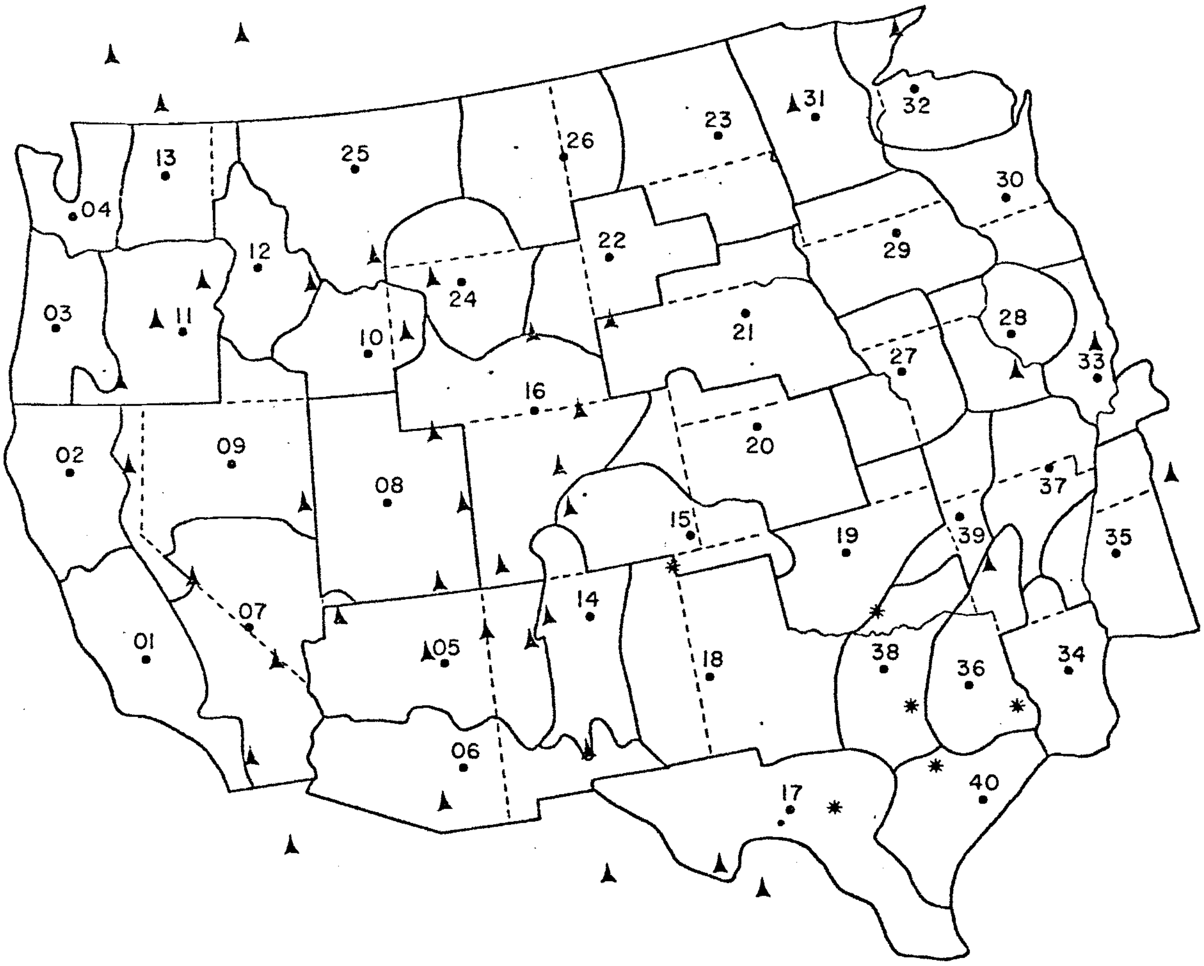


Figure 1. The study area. Solid lines: Regional boundaries. Triangles: tree-ring sites. Black dots: approximate geographical centers of regions. The numbers identify the regions. Asterisks: recently collected tree-ring sites not included in the initial reconstruction.

Mapping of the Palmer Drought Severity Index

The arithmetic mean of the PDSI values for all divisions within a given region was assumed to be the best estimate of the PDSI for that region. The regional PDSI was computed in this manner for each month of the period January 1931 to December 1970, and the results were computer plotted onto 480 outline maps of the study area. The maps in which we had special interest were then hand contoured for additional analysis.

The maps of the four driest Julys (1934, 1936, 1954, 1956) for the period 1931-1970 are shown in Figures 2a-2d; dryness was measured by the number of regions with PDSI $\leq$ -4.0. These maps indicate the following:

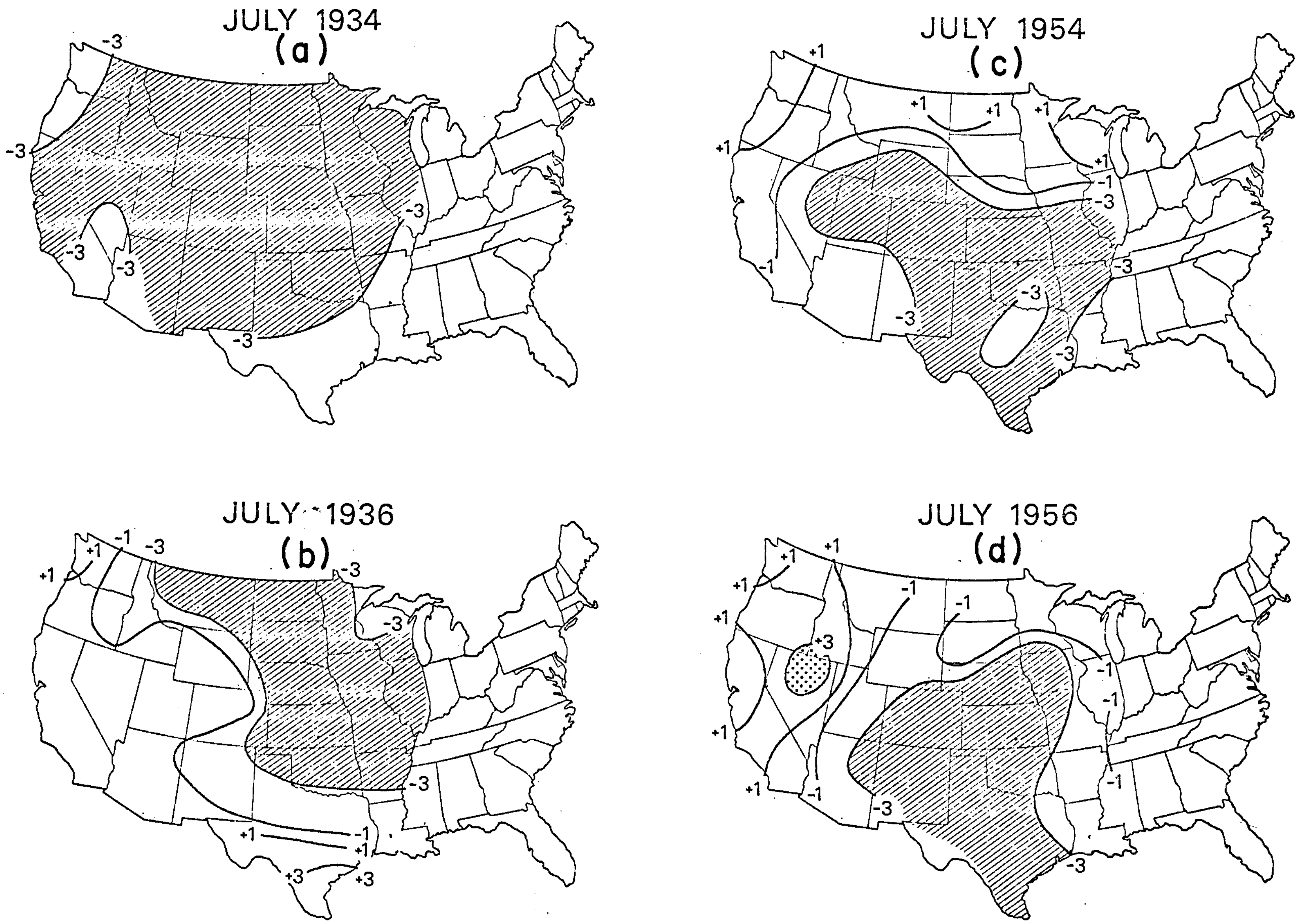
1. The 1934 drought was by far the most extreme of the four droughts.
2. The particular area affected differed greatly among the four droughts.
3. The droughts of the thirties were centered in the North, those of the fifties were centered in the South.

Not surprisingly, the only area of severe drought (PDSI $\leq$ -3.0 in common among the four droughts was the heart of the "dust bowl" of the southern Great Plains (Figure 2e).

Method of Reconstruction of PDSI

A. Eigenvector analysis of PDSI and tree-ring indices

Because it is computed from an autoregressive-type relation-



Figures a- d. The four driest Julys (1934, 1936, 1954, 1956) in the period 1931-70 as indicated by regionally averaged Palmer Drought Severity Index (PDSI). The measure of dryness used was the number of regions with PDSI ≤ -3.0.

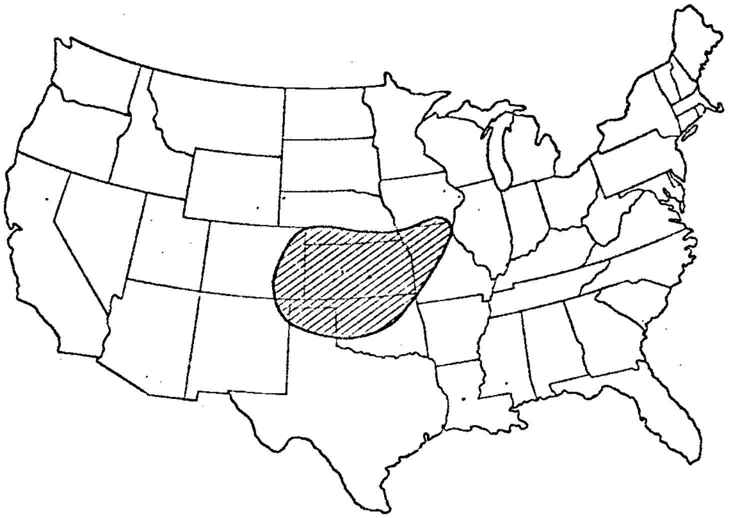


Figure 2e. The area of severe drought (PDSI $\leq$ -3.0) in common among the four driest Julys (1934,1936, 1954, 1956) of the 1931-1970 period.

ship, the Palmer Index reflects the moisture condition of several preceding months in addition to those of the current month. This serial correlation presents some problems in grouping of months for averaging. For this reason we decided in our initial effort to reconstruct a single month's PDSI rather than a time-averaged (for example, seasonal) value.

The month we have chosen for our initial reconstruction is July. A given tree species may be most responsive to climatic variations in one season while a second species responds more to variations in another season. Also, variations in response patterns occur even within the same species from one site to the next. Since our grid of tree-ring sites was composed of several species scattered over a wide geographic area, the decision as to which month's PDSI would be best reflected by the tree rings was necessarily somewhat arbitrary. July was chosen for the following reasons:

1. Annual tree growth as reflected in the ring widths is often nearly complete by the end of July.
2. The July PDSI reflects to some degree the moisture conditions of the prior spring; these conditions are relatively important to most species of trees.
3. Major droughts occurring during the period 1931-1970 tended to peak in intensity in July or August.
4. July PDSI is of special interest from an agricultural point of view.

Eigenvectors of PDSI were computed from the 40 observations of July PDSI (1931-1970) in the 40 regions. The percent variance explained by each of the first ten eigenvectors is shown in Table 1. The analysis indicated that the forty original spatial patterns of PDSI could be represented quite well by only the first five eigenvectors (75% variance explained).

TABLE 1. Percent variance explained, PDSI eigenvectors.

EIGENVECTOR	% VARIANCE
1	37.9
2	16.9
3	11.2
4	5.2
5	4.6
6	3.7
7	3.1
8	2.4
9	2.1
10	2.0
	89.1

Eigenvector analysis was also performed on the 264 year record (1700-1964) of tree ring indices at the 40 sites shown in Figure 1.

The results are summarized in Table 2. The ten most important eigenvectors accounted for about 64% of the total variance.

TABLE 2. Percent variance explained, tree-ring eigenvectors.

EIGENVECTOR	% VARIANCE
1	23.0
2	9.6
3	5.6
4	5.4
5	4.4
6	3.8
7	3.4
8	3.1
9	3.0
10	2.9
	64.2

Selection of Eigenvectors

The tree-ring record overlapped the PDSI record for the years 1931-1963, and these years defined the calibration period for the reconstruction. Each year was represented by amplitudes of 40 PDSI eigenvectors and amplitudes of 40 tree-ring eigenvectors. The approach to reconstructing consisted of deriving relationships to predict PDSI amplitudes from tree-ring amplitudes.

The paucity of observations (32) necessitated the reduction of the number of variables; only those eigenvectors felt to be most important could be included in the analysis. The reduction of variables was effected as follows:

1. All except the first 10 eigenvectors in each data set were omitted because of the small amount of variance they explained and their probable physical nonrelevancy.

2. A correlation matrix was computed of the amplitudes of the first 10 PDSI eigenvectors and the amplitudes of the first 10 tree-ring eigenvectors, current and lagged by one year.

3. Tree ring eigenvectors whose amplitudes would be used as variables were chosen on the basis of a high correlation with one of the first 10 drought eigenvectors.

Correlations with tree-ring amplitudes were small for all but the first five PDSI eigenvectors. The list of eigenvectors whose amplitudes were chosen to be variables is given in Table 3.

TABLE 3. Variance accounted for by eigenvectors chosen for canonical analysis.

PDSI EIGENVECTORS	% VARIANCE	TREE RING EIGENVECTORS	% VARIANCE
1	37.9	1	23.0
2	16.9	2	9.6
3	11.2	8	3.1
4	5.2	7	3.4
5	4.6	9	3.0
	75.8	10	2.9
			45.0

Canonical analysis was used to derive a matrix of coefficients to predict amplitudes of the five PDSI eigenvectors from the amplitudes of the six tree-ring eigenvectors. The resulting prediction explained approximately 64% of the variance of the PDSI eigenvector amplitudes during the calibration period.

The same coefficient matrix was then applied to the 1700-1962 tree-ring eigenvector amplitudes; in this manner the amplitudes of the PDSI eigenvectors were reconstructed back to 1700. Reconstructed values of PDSI were then obtained by multiplying the matrix of predicted PDSI amplitudes by the matrix of PDSI eigenvectors.

Results of the Reconstruction of PDSI

A. Reconstruction of the calibration period

Good agreement of the predicted values with the actual values in the calibration period is a necessary, though not a sufficient condition for valid reconstruction of past conditions. Accordingly, our first step was to check the accuracy of the reconstructions for the period 1931-1962.

For each July from 1931-1962, the number of regions in each of nine drought categories was tabulated; this was done for both the predicted and the actual data. The time series of the number of regions wetter than normal (PDSI $\geq + 1.0$) and the number of divisions drier than normal (PDSI $\leq$ -1.0) is shown in Figure 3. In general, the agreement of the predicted with the actual was good, with the predictions tending to be conservative (more regions reconstructed to have been normal than actually were). Of course, since only the first five PDSI eigenvectors were used in the reconstruction, those few years when minor eigenvectors were dominant were poorly predicted; such was the case with 1952 and 1962.

B. Results of the reconstruction

A time series (1700-1962) of the number of regions with PDSI $\geq$+ 1.0 vs. the number of regions with PDSI $\leq$ -1.0 is shown in graph-form in Figure 4. The graph is clearly skewed towards the positive side for most of the long term record, suggesting that the period 1931-1962 used for calibration was relatively dry (the terms wet and dry, used here to describe the Palmer Index, refer to the combined effect of temperature and precipitation).

In order to isolate droughts and wet periods that were extensive in both space and time, three-year-moving-sums were calculated of the number of regions with PDSI $\geq$+ 2.0 and the number of regions with PDSI $\leq$ -2.0. The resulting five wettest and five driest periods and their corresponding moving-sums are listed in Table 4. Maps for the wettest period prior to 1931 (1914, 1915, and 1916) and for the driest period prior to 1931 (1846, 1847, and

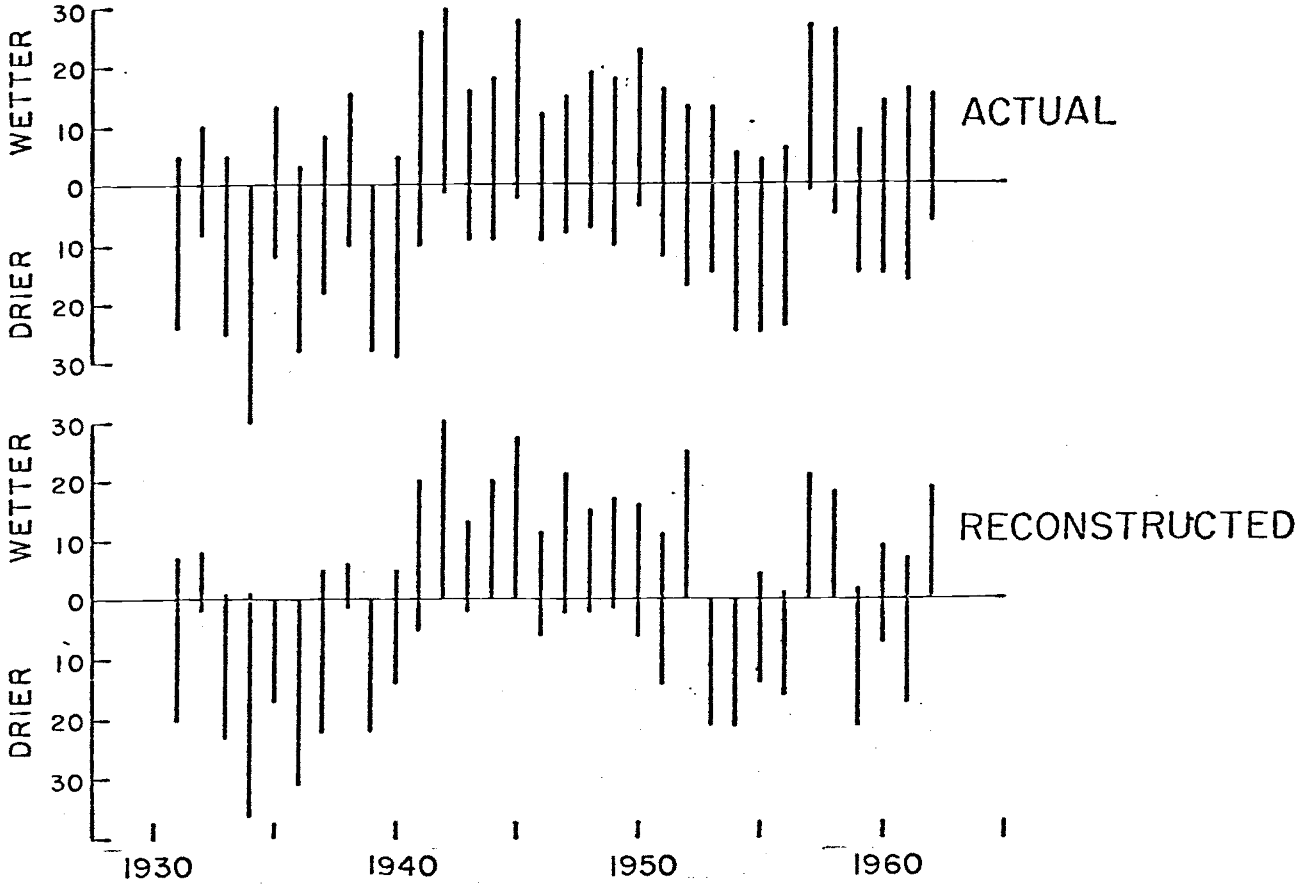


Figure 3. Number of regions drier than normal, number of regions wetter than normal; reconstructed and actual for the calibration period. Normal = (-1.0 < PDSI < +1.0).

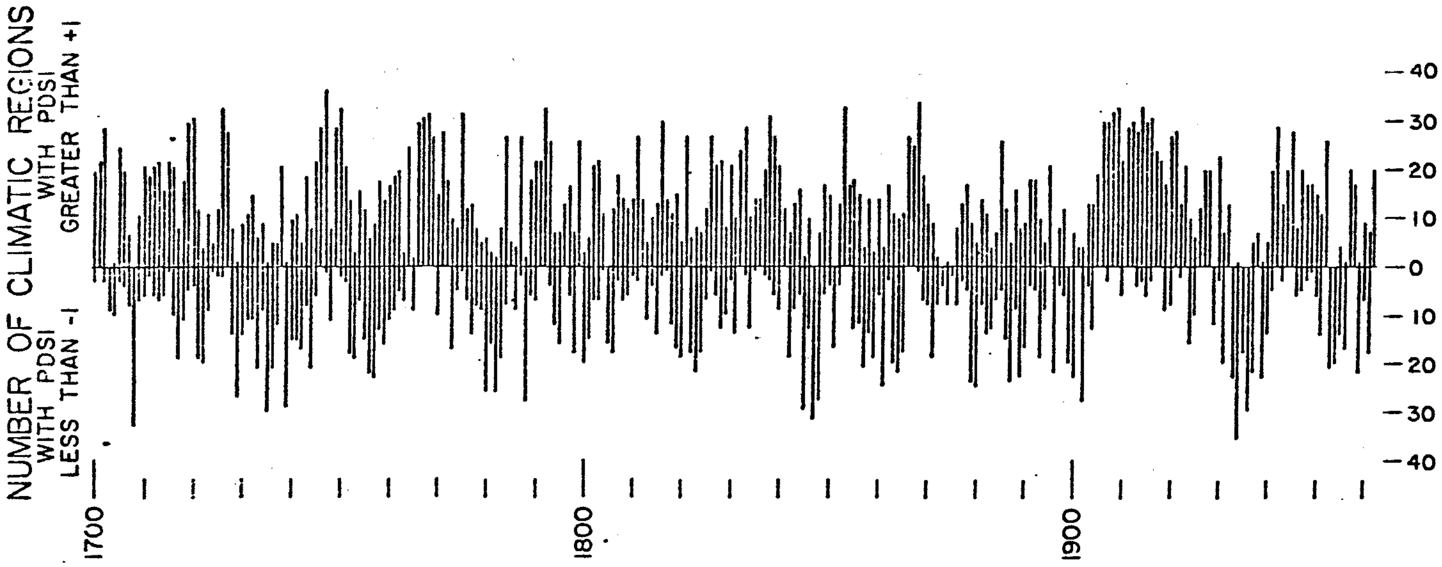


Figure 4. Number of regions reconstructed drier than normal and number of regions reconstructed wetter than normal, 1700-1962.

1848) are shown in Figure 5.

TABLE 4. Wettest and driest three year periods.

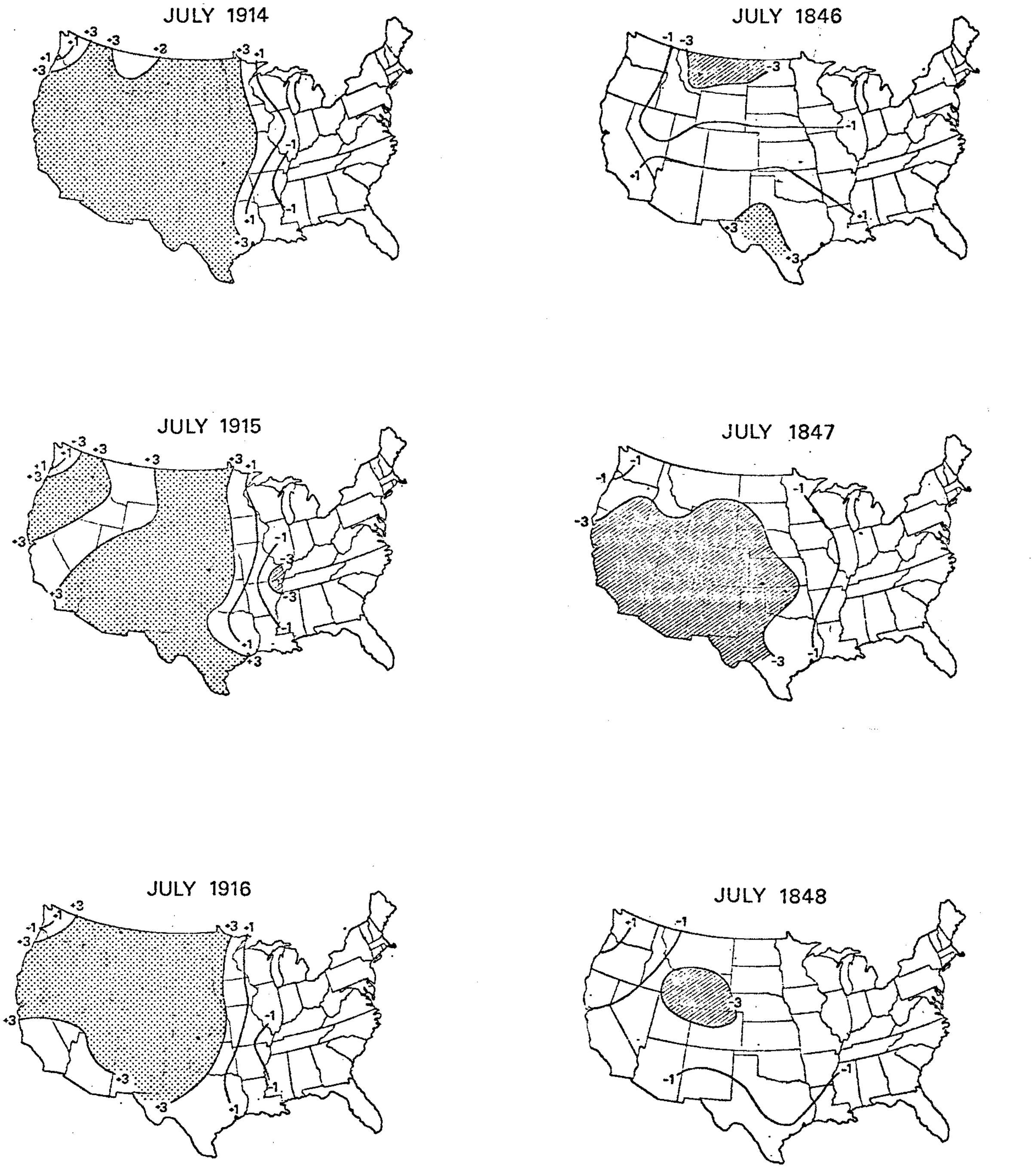
WET		DRY	
YEAR	SUM	YEAR	SUM
1916	87	1936	61
1909	83	1847	49
1913	70	1865	45
1747	69	1757	42
1840	63	1736	40

Year = year ending 3-year period

Sum = $n = \sum_{i=J1}^{J2} N_i$, where N_i is the number of regions in the moderate or worse PSDI category in year i. J1 first year of 3 year period; J2 = third year of 3 year period.

The driest single July in our reconstruction was 1934. Comparison of the 1934 reconstruction with that of the second driest July, 1757 (Figure 6), emphasizes the relative magnitude of the 1934 drought. In 1934, 19 regions were in the extreme drought category (PDSI $\leq$ -4.0); in 1757 only 10 regions were in extreme drought.

In 1907, the wettest single July of the reconstruction, 18 regions were in the extremely wet category (PDSI $\leq$ +4.0). This


JULY 1914

JULY 1846

JULY 1915

JULY 1847

JULY 1916

JULY 1848

Figure 5. The wettest (1914, 1915, 1916) and driest (1846, 1847, 1848) consecutive three-year periods of the reconstruction. Degree of wetness or dryness was measured by three-year moving sums of number of regions with PDSI ≥ +3.0 or numbers of regions with PDSI ≤ -3.0.

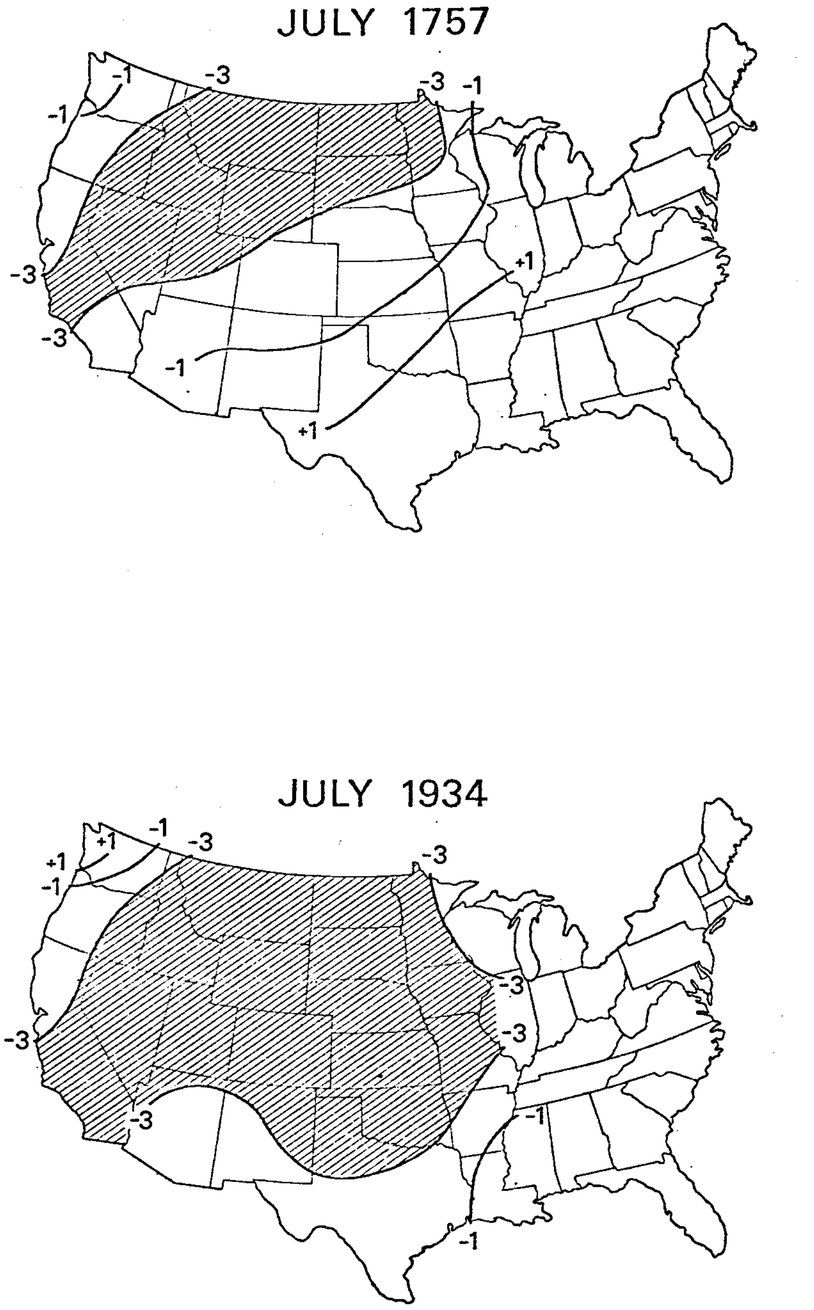


Figure 6. The driest (1934) and second driest (1757) single years reconstructed. Degree of dryness was measured by number of regions with PDSI ≤ -3.0.

compares with 12 regions in the extremely wet category in 1942, the wettest July of the calibration period. In all, eight years were reconstructed wetter than 1942.

The relative wetness of the long term record shown in Figure 4 was more pronounced in some areas than in others. The number of years with PDSI ≤ -1.0 and the number with PDSI $\leq +1.0$ were tabulated separately for each region. These numbers, expressed as a percentage of the long term record (263 years), are plotted on the map in Figure 7 . Wet years outnumbered dry years over the study area as a whole (in all except five regions), but the imbalance was greatest over the southern Great Plains.

Two factors qualify the results shown in Figure 7. First, an isolated dry year that is sandwiched between years favorable to tree growth is not necessarily reflected by a narrow ring width; tree growth in a dry year can be augmented through the use of nutrients stored during a preceding wet year. This effect could lead to an overestimation of the frequency of wet years in our initial reconstruction. Also, the tree-ring grid available at the beginning of the study did not include any sites in the southern Great Plains, the area in which the reconstructed wetness was most prominent. The addition of tree-ring records from sites in Oklahoma and Texas (some tree-ring records from these states are now being analyzed) could significantly alter our results.

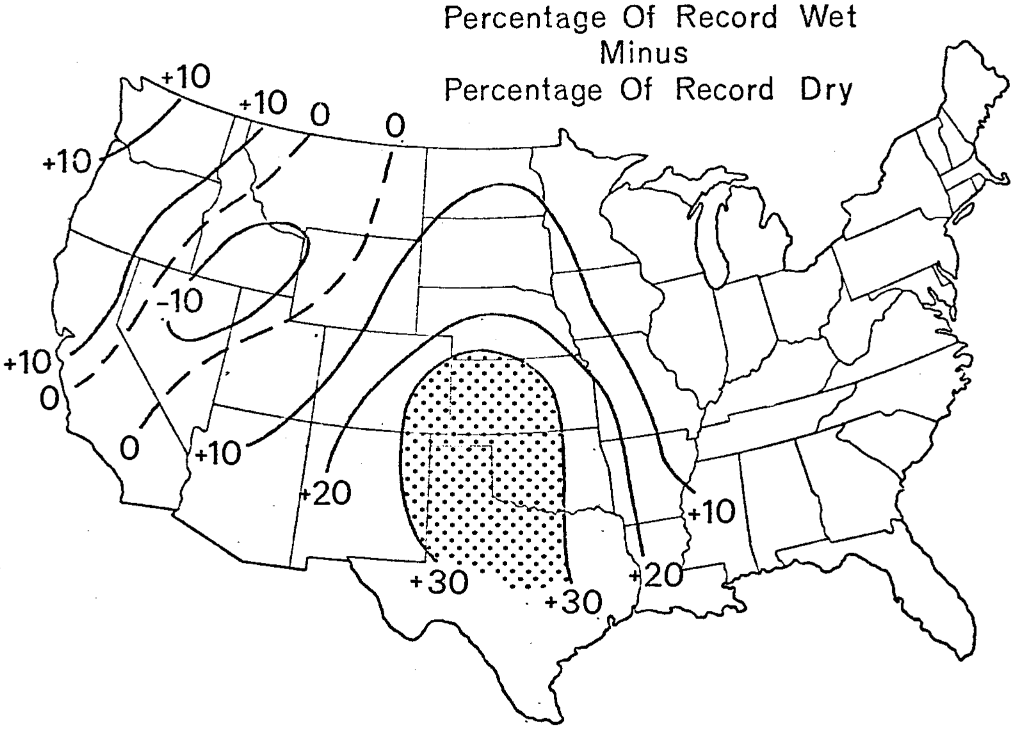


Figure 7 . Percentage of the 1700-1962 record reconstructed wetter than normal minus percentage of the 1700-1962 record reconstructed drier than normal. Normal = (-1.0 < PDSI < +1.0). Stippled area: difference is greater than 30 percent.

In summary, the initial reconstructions of July Palmer Drought Severity Index imply the following:

1. The frequency of wet (or cool) years was greater in the years prior to the calibration period (1931-1962) than in the calibration period.
2. In the current century, we have experienced a year--1934--as dry as any other single year in the preceding two centuries, and a year--1907--as wet as any other single year in the preceding two centuries.
3. The southern Great Plains was considerably wetter in the past than in the period 1931-1962; this result is tentative.

Independent Check of Tree-Ring Reconstructions

The approach to verifying our results, especially in the Great Plains where we do not have any tree-ring data, has been to compute the Palmer Drought Severity Index record for climatic stations where longer records exist. (We have during the first year developed the necessary computer software to do this). We then average the PDSI series for appropriate stations for comparison with our regional reconstructed series. In addition, we utilize tree-ring records not included in our calibration grid to qualitatively illustrate whether or not our reconstructions are reasonable.

The data available for evaluation of the reconstructed drought values consist of a limited number of continuous temperature and precipitation station records extending back into the nineteenth century. From meteorological observations, Palmer Index values were computed for the following stations: Williston, North Dakota; Miles City, Montana; Lincoln, North Platte, and Omaha, Nebraska; Denver, Ft. Collins, Pueblo, and Las Animas, Colorado; Dodge City, Kansas; and Albuquerque, New Mexico. These were averaged in groups of stations comparable spatially to the regions used in the reconstructions. The station average drought values were found to be good approximations of the regional values in the period 1931-70. Thus it was possible to evaluate the reconstruction for approximately the period 1890-1930. In Figure 8, plots of averaged station PDSI are compared with plots of reconstructed regional PDSI for two regions in the Great Plains.

From Figure 8 several conclusions can be drawn. First it is evident that reconstructions for individual years might be in considerable error. On the other hand, the general trends of the reconstructions seem to be quite good, with the exception of the period 1905-20. Our reconstructions apparently are best interpretated in terms of average moisture conditions prevailing over periods of three or more years. Thus, while further work must be done, the basic premise that Great Plains climate can be reconstructed from tree rings seems to be borne out.

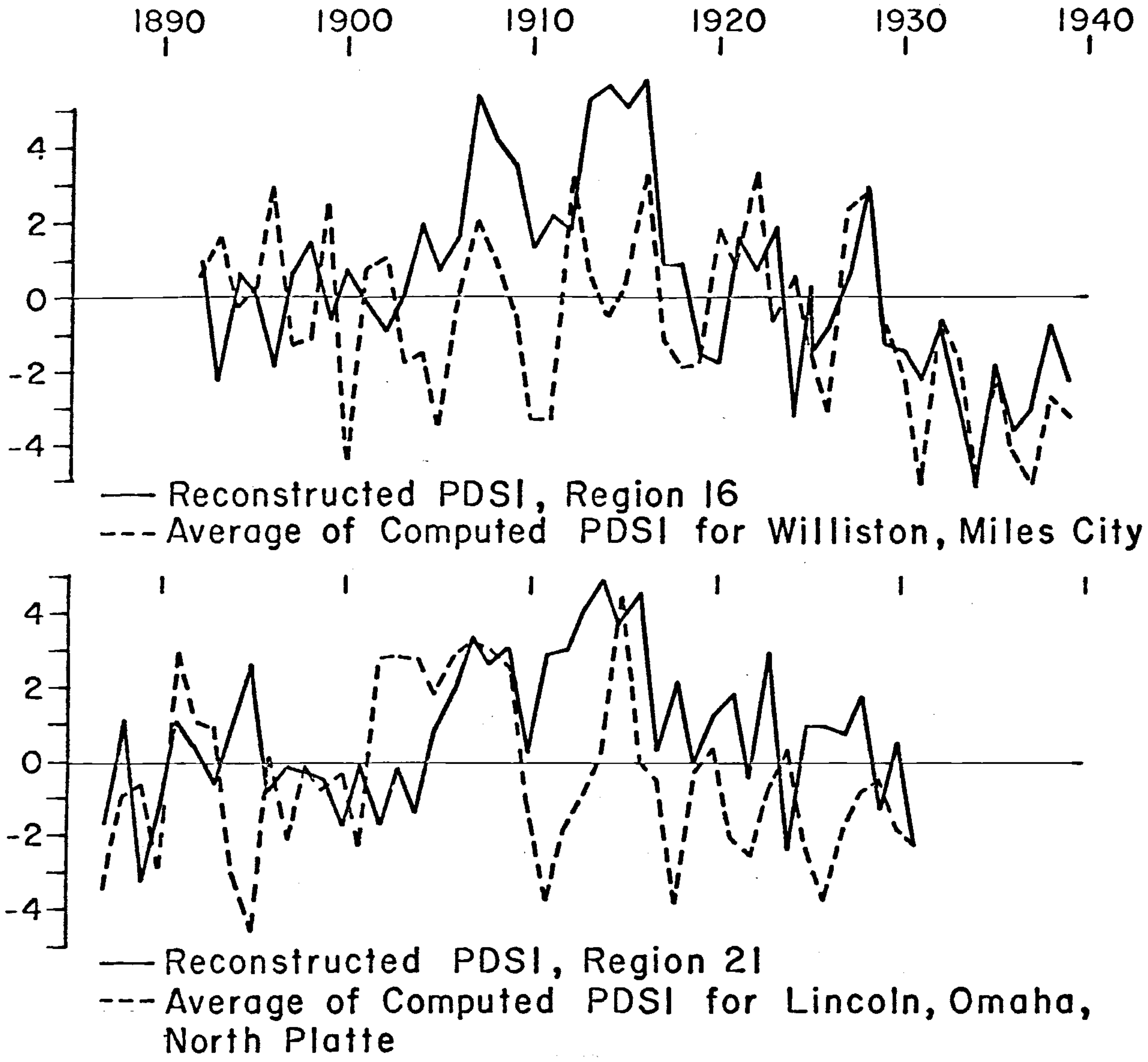


Figure 8. Comparison of tree-ring reconstructed Palmer Drought Severity Index series for selected regions with independently calculated series from the same region.

II. RECONSTRUCTION OF SEA-SURFACE TEMPERATURE

Linkage between Large Scale Continental Drought and Sea Surface Temperature Anomalies in the Eastern North Pacific

A growing collection of data has indicated that broad scale sea surface temperature (SST) anomalies in the North Pacific are associated with major changes in the atmospheric circulation across the North Pacific and North America (Namias, 1974, Bjerknes, 1969, and Allison et al, 1972). For example the occurrence of drought in the central Great Plains is believed to be controlled, in part, by the distribution of SST anomalies across the eastern North Pacific (Allison et al, 1972). A preliminary study by Douglas (1973a) has shown that year-to-year variations in SST off western Mexico do exert controls on the distribution of seasonal precipitation across the southwestern sector of the United States. Anomalously cool SST fields are associated with drought, while anomously warm SST fields are usually associated with above normal precipitation. The temporal occurrence and probably the intensity of droughts in the western United States are ultimately linked to broad scale changes in the distribution of sea surface temperatures across the Pacific Ocean.

In order to clarify the relationship between large scale droughts in the western United States and major SST changes in the North Pacific, we have attempted to reconstruct SST data for the eastern North Pacific, as well as Palmer drought indices for the western United States. By comparing the reconstructed drought index with the reconstructed SST we can determine whether widespread droughts in the western United States coincided with periods of anomalous SST in the eastern North Pacific. In addition we can analyze possible north south shifts in droughts as they may be controlled by north-south shifts in the pools of anomalously cold water off western North America.

The oceanic area having the longest record of SST is the coastal shipping route from Los Angeles southeastwards towards the Panama Canal. Average monthly SST data for the offshore region from 22°N to 33°N (Figure 10) is virtually complete for the periods 1924-1940, and 1949-1972 (41 years). Average monthly SST data for one degree squares within this region have been provided for our use by Dr. Richard Wert of Scripps Institution of Oceanography (NORPAC). In addition, data from Namias (personal communication, 1974) indicates that the SST in this near continent region is positively correlated with SST along the entire west coast of North America, and negatively correlated with SST in the central North Pacific (Figure 9). This tendency for anomalously cold SST along the west coast of North America to be associated with above normal SST in the central North Pacific, allows us to draw conclusions about North Pacific SST distributions and possible atmospheric flow during drought periods based upon the near shore SST.

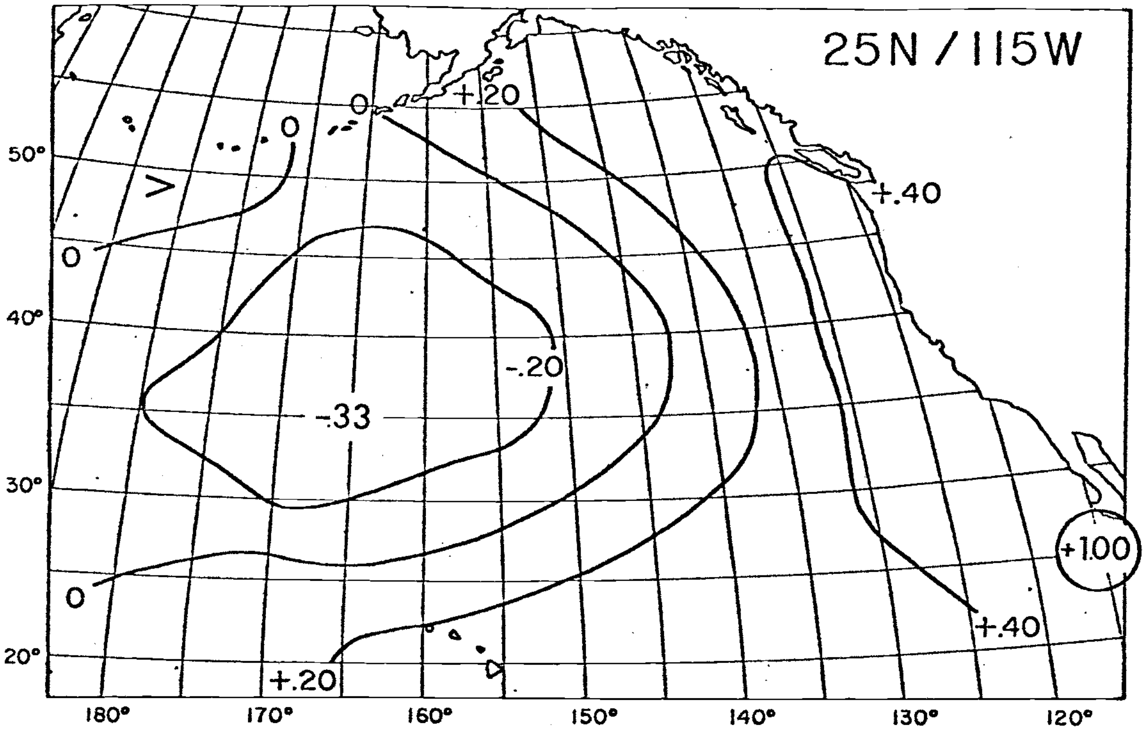


Figure 9. Correlation between SST off central Baja California with the rest of the North Pacific east of 180° w.

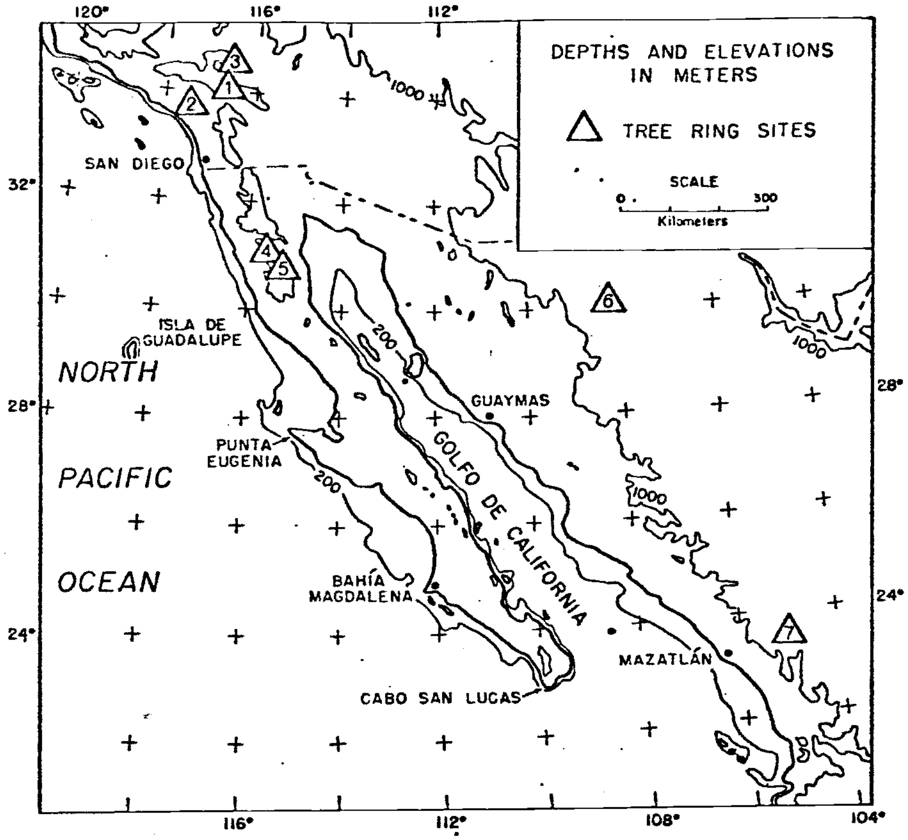


Figure 10. Location of tree-ring sites along the border of the eastern North Pacific Ocean.

Douglas (1973b) indicated that a high degree of relationship exists between annual tree growth and seasonalized SST data. This relationship occurs because variations in SST off California can greatly effect the climate downstream from the eastern North Pacific. Ultimately these effects of anomalous SST on the climate are then recorded in the growth of trees (Douglas, 1973b). The high degree of relationship between tree growth and season SST values is observed because tree growth represents an integration of weather information over some period of time longer than a month. Major SST anomalies do affect the weather across North America for months at a time. It was found by Douglas (1973b) that the following combination of months or "oceanic SST seasons" were highly correlated with tree growth: Winter, November through February; Spring, March through June; and Summer, July through October.

Method of Reconstruction and Results

A multiple linear regression (MLR) analysis was run between tree-ring data from seven sites and seasonalized SST data for twelve one-degree squares from 22° N to 33° N. The seven tree-ring sites are indicated in Figure 10, and the 12 one-degree squares are shown by dots in Figure 11. The regression equations

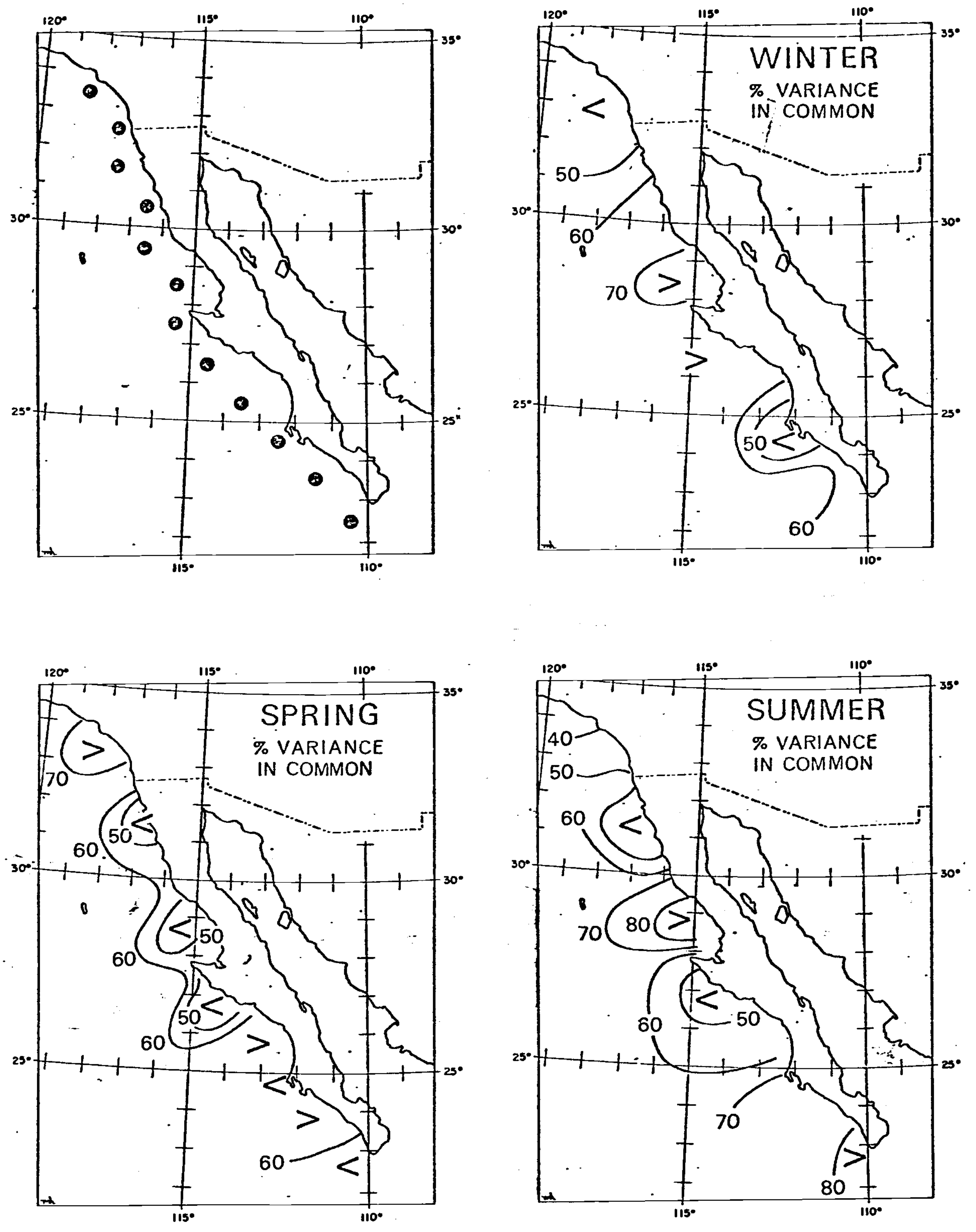


Figure 11. Map in the upper left shows the 1° square used in the analysis. The other three maps show the percent variance in common between the seasonal SST data and the tree-ring data.

estimate a dependent variable, say x_1 (SST), from independent variables x_2, x_3 . . . (the tree-ring data). In the case of the seven tree-ring chronologies, the number of independent variables can vary, but the regression equation has the form $x_1 = b_1 + b_2x_2 + b_3x_3$ . . . where b_1, b_2, b_3 . . . are constants. Since there is a tendency for carryover of climatic information into successive ring widths, the tree-ring data were rearranged so that each tree-ring data station was represented by ring widths at time t-1, t, t+1, t+2.

Sea surface temperature reconstruction equations were then chosen from the MLR analyses with all equations significant at the 95% level. The percent variance explained by each seasonal equation at each one degree square is given in Figure 11. On the average the equations account for about 60% of the variance in common between the SST data and the tree-ring data during the calibration period (1924-1940, 1949-1963). At some squares the summer equations account for 80% of the variance in common.

It is interesting to note that a very high degree of relationship exists between tree growth and summer SST off southern Baja California (Figure 11). This is a critical area for analyses since it is the boundary region between cool California current water from the north and very warm North Pacific Equatorial water from the southeast (including Gulf of California water). Major shifts in the boundary between these two water mases can result in major SST anomalies south of 25°N from July to December. The shifts in this boundary are ultimately related to major shifts in the low-level air flow across the eastern North Pacific. In the upper levels a subtropical jet normally lies across the area in the winter and spring, and the strength of the jet and its associated cloudiness might be affected by the underlying SST fields.

Results

The SST reconstruction equations which were selected for each season at each square were then run using the tree-ring data for the seven sites, 1671-1963. The reconstructed seasonalized SST data (1671-1963) for four of the 12 one-degree squares are given in Figures 12, 13, and 14. From the reconstructed SST data sets we have examined anomaly periods in which the reconstructed SST data at each square were greater than one standard deviation. The most important anomalies prior to the reconstruction period are shown for each season in Figure 15.

The coldest spring period indicated is for 1844-1847. This was associated with a major drought in the western United States (based on historical data and our Palmer Drought reconstructions, Figures 4 and 5). In contrast, the warmest spring period was for 1867-1869, and this was associated with above-normal precipitation in western United States (Figure 4). Another wet period is associated with war winter SST from 1748-1751 (Figures 4 and 13).

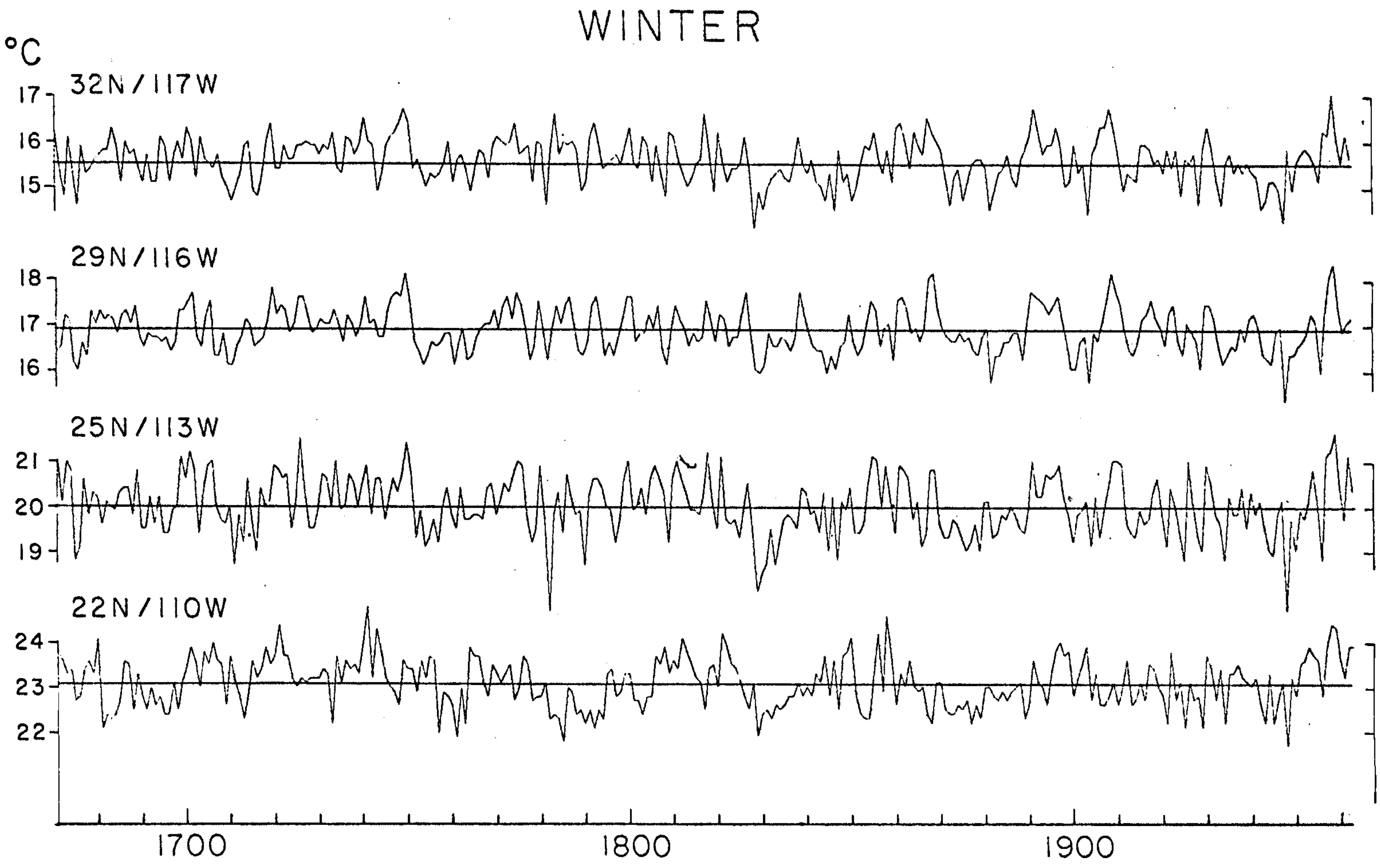


Figure 12. Plots of reconstructed SST for the winter, 1671-1963.

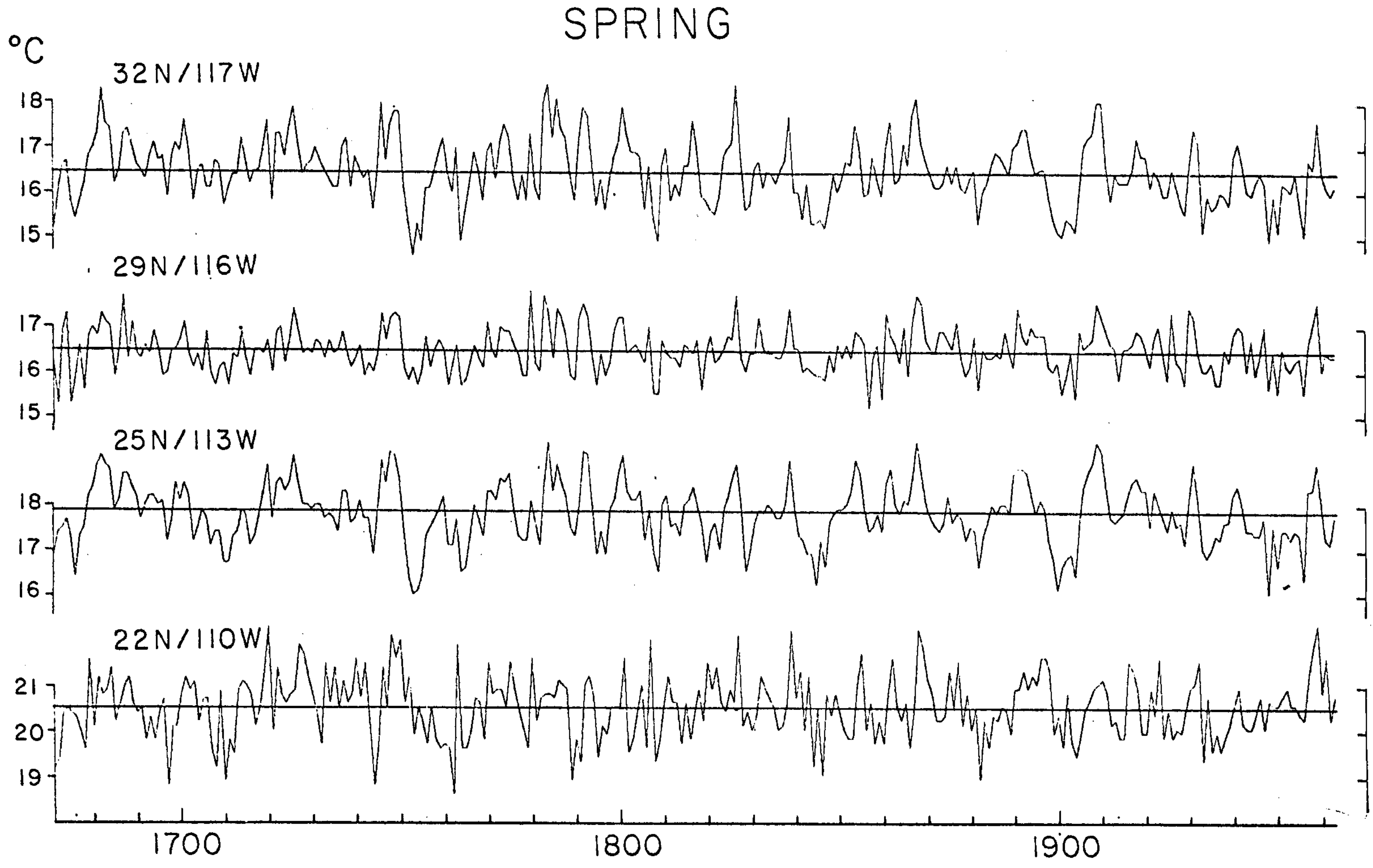


Figure 13. Plots of reconstructed SST for the spring, 1671-1963.

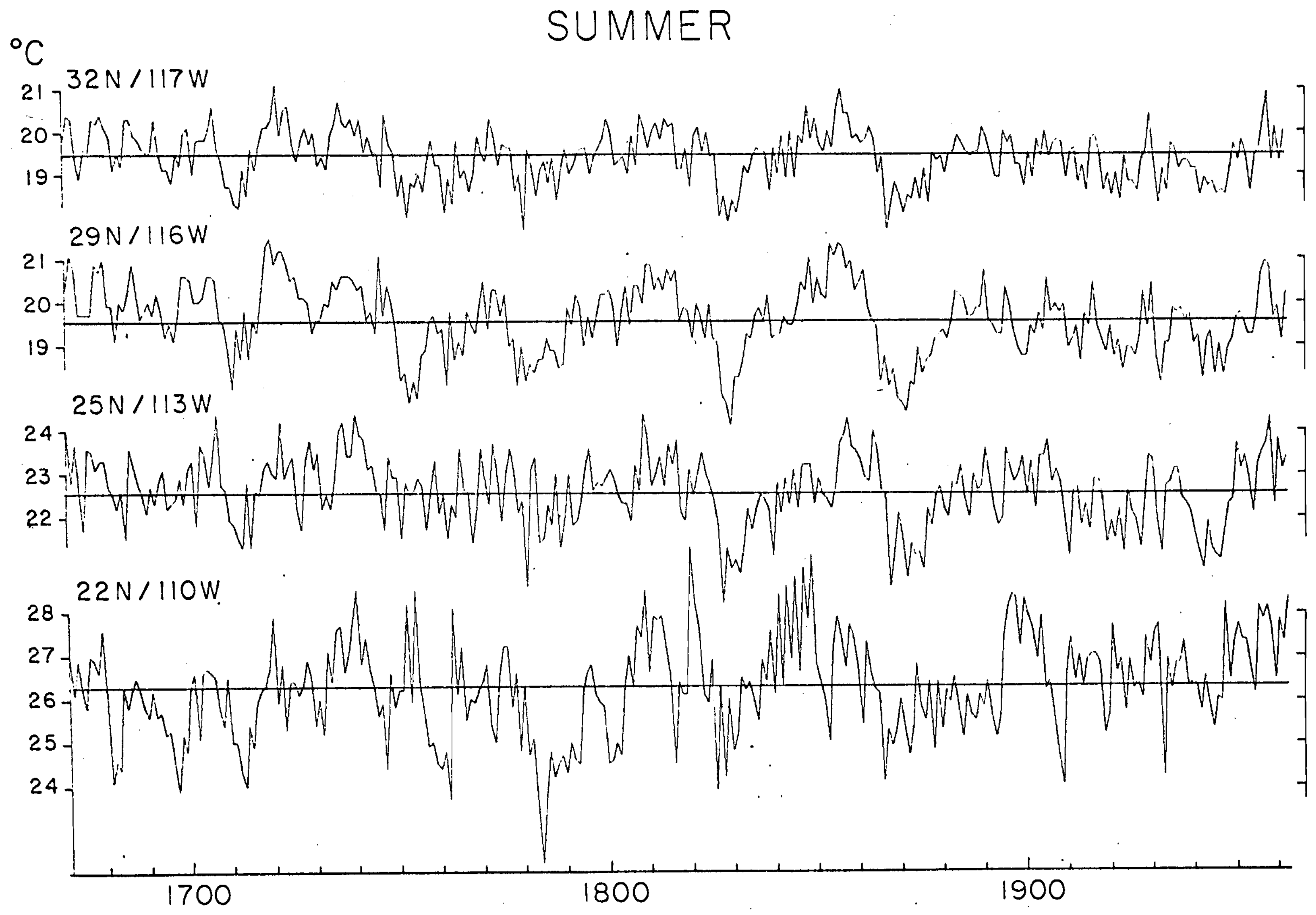


Figure 14. Plots of reconstructed SST for the summer, 1671-1963.

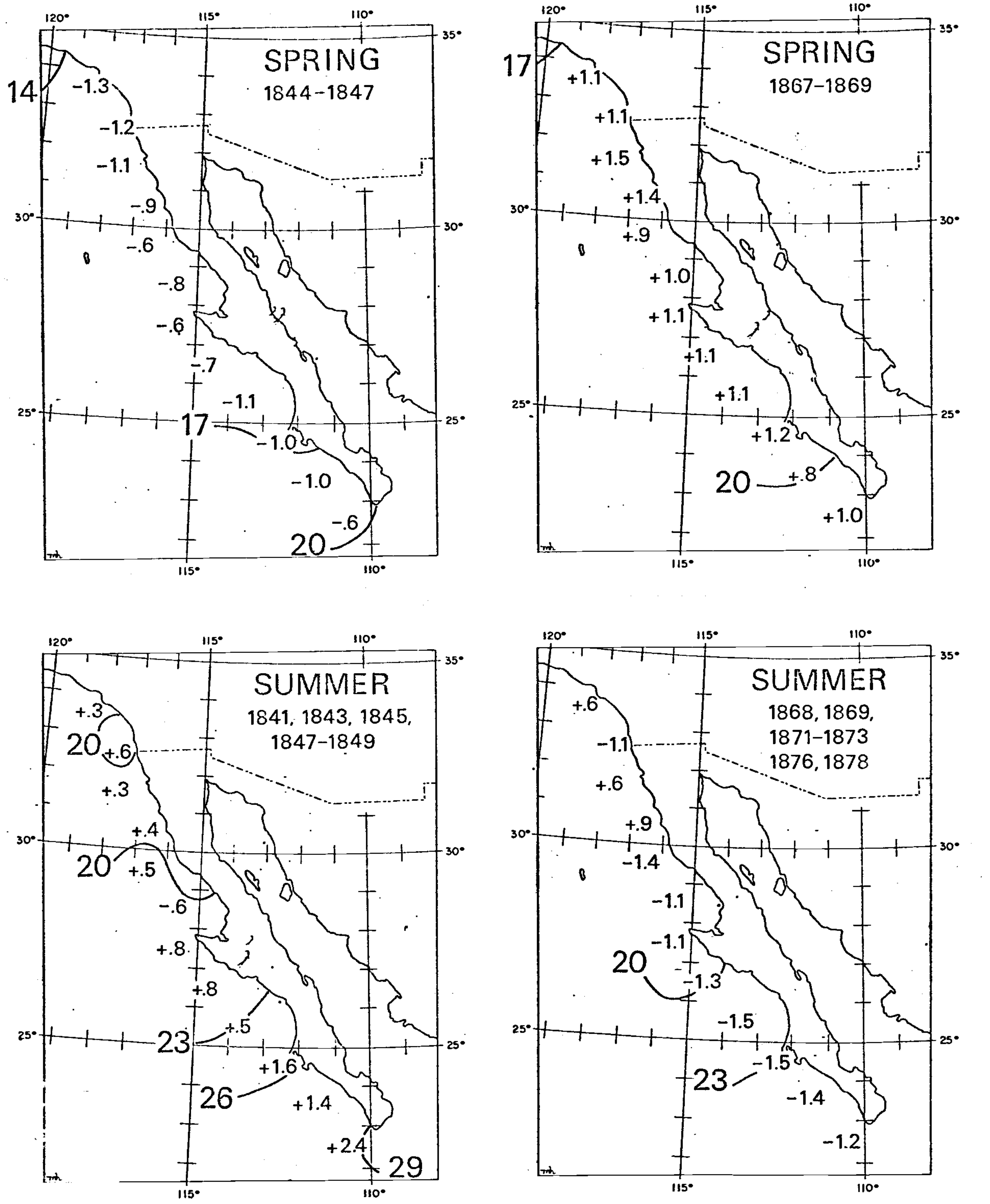


Figure 15. Major spring and summer SST anomalies which occurred during the period 1671-1963.

A comparison of Figures 12, 13, and 14 with Figure 4 shows that major drought periods were associated with cold eastern North Pacific SST during the spring, and that wet periods were associated with warm SST in the winter and spring. A relationship between summer SST and drought is not apparent, except when pools of cold water that were developed in the summer peristed into the fall, winter and spring (e.g., mid 1950's).

A major warm period is indicated for the summers of 1841-1859 (Figure 14). In the 1840's the summer SST pattern indicates probable en situ heating off Northern Baja California as well as a northward advection of warm water from the tropics to off southern Baja California. Fish collections in the 1850's indicated that during this ". . . the fish fauna at San Diego seems to have been more nearly tropical than it now is . . ." (Hubbs 1948, p. 479). Our reconstructions of warm summer SST are therefore in agreement with these historical findings of Hubbs. If such a major long term change in SST were to occur again, one would expect that the fisheries of the west coast would be greatly affected--either having to shift fishing efforts and canning operations to another region or having to fish for other fish species. It is interesting to note that the warm summer anomalies of the mid 1800's did not, however, tend to persist into the winter and spring. In fact, as noted above, the springs of 1844-1847 were anomalously cold. Such a wide range in SST between spring and summer is more characteristic of the eastern North Pacific near the southern tip of Baja California or in the Gulf of California. This oceanic regime of large seasonal changes in SST apparently expanded northwestward from southern Baja California in the mid 1800's.

In contrast to this southern Baja California regime, small season-to-season changes in SST are characteristic of the central California Coast. During the winter months, relatively warm water from off-shore is advected towards the coast by southwesterly winds on the southeast side of the aleutian low. Then, in the summer, relatively cool water is found near the coast when persistent northerly winds on the east side of the North Pacific high induce coastal upwelling and a southward flow of cool water. According to our SST reconstructions this type of regime was apparently displaced southwards from 1750-1800 (Figures 12, 13, and 14). During this time our reconstructions show a cooler-than-normal ocean in the summer and a warmer-than-normal ocean in the winter. This type of regime would greatly effect the atmospheric flow across North America--displacing storm tracks farther south than normal. Such a regime occurred during the early 1940's and it was associated with wet conditions in the western United States. The fisheries of the west coast would also be greatly affected by this type of oceanic regime.

Our reconstructions of seasonal SST data seem to agree with a number of proxy series: air temperature data from San Diego, spotty SST measurements in the eastern North Pacific 1900-1923, and with biological data that can be used to infer SST anomalies (Hubbs, 1948).

Permanent Equipment Purchased

We have not purchased any permanent equipment on this project.

Students Supported by Grant

A list of those students who have received financial support from the project are listed in Table 5. Art Douglas completed his dissertation in May, 1976. The dissertation title is "Past Air-Sea Interactions on the Eastern North Pacific Ocean as Revealed by Tree-Ring Data" and a copy is included with this report. David is in the early stages of dissertation research; he will probably be using results of this study in his dissertation. Stephen Caldwell has used computer software developed as part of this project to compute Palmer Drought Severity indices for individual stations of extraordinary length. These have been used for testing of the reconstructed series.

During the grant period, Christopher Rawson has completed the requirements for a Bachelor of Science Degree in Biosciences. Art Douglas completed requirements for the Ph.D. in Geosciences in May, 1976.

TABLE 5. List of Students Employed on Project and Area of Specialization

Name	Status	Education	Area of Research
Arthur Douglas	Ph.D.	B.A. Biology, Paleobiology, M.S. Geosciences	Sea surface temperatures, Atmospheric Teleconnection
David M. Meko	Ph.D.	B.S. Meteorology M.S. Atmospheric Sciences	Drought Frequency Analysis and Relation to Atmospheric Circulation: to be applied towards dissertation
Stephen Caldwell	Master's Candidate (Geography)	B.A. Geography	Drought Frequency Analysis in Central Great Plains, Verification of Tree-ring reconstructions
Edward Cook	Master's Candidate (Geosciences)	B.S. Wildlife Management	Field Collection of Tree-ring data and Laboratory analysis
Christopher Rawson	Graduate Student (Mathematics)	B.S. Biosciences	Tree-ring data grid and computer processing
Ricardo Casillas	Undergraduate (Liberal Arts)		Climatic data collection
Sherry Cooper	Undergraduate (Business and Public Administration)		Clerical and Administrative Assistant

Publications

In April 1975, Stephen Caldwell presented a paper entitled "Teleconnections of Drought Indices on the Central Great Plain" before the Geography Section of the Arizona Academy of Science and the abstract was published. Charles W. Stockton presented the results of our research to date at the AAAS Symposium on Climate in the United States since 1776, in Boston on February 23, 1976. The title was "A Two Hundred Year History of Drought Occurrence in Western United States as Inferred from Tree Rings." In addition, these results were the subject of an article entitled "A Long-Term History of Drought Occurrence in Western United States as Inferred from Tree Rings" published in Weatherwise, Volume 28, Number 6, December 1975, pages 244-249. Another paper is presently in preparation dealing with the relationship of the results of this study with solar variation. This paper, to be co-authored with J. Murray Mitchell, will be submitted to Science hopefully as early as August, 1976.

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