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NATIONAL SCIENCE FOUNDATION
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FINAL PROJECT REPORT
ATM-8319848

CLIMATIC REGIMES OF THE PACIFIC SECTOR AND ADJACENT CONTINENTS SINCE 1600: A SYNOPTIC DESCRIPTION AND COMPARISON OF INDEPENDENT CLIMATE PROXY RECORDS

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FINAL PROJECT REPORT

PART I - PROJECT IDENTIFICATION INFORMATION

Laboratory of Tree-Ring Research	Climate Dynamics	ATM-8319848
University of Arizona **Tucson, Arizona 85721**	From 6/15/84 To 5/30/87	Amount **$285,450**

Climatic Regimes of the Pacific Sector and Adjacent Continents Since 1600: A Synoptic Description and Comparison of Independent Climate Proxy Records

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PART II - SUMMARY OF COMPLETED PROJECT (FOR PUBLIC USE)

A variety of dendroclimatic techniques were examined and tested and then used to reconstruct spatial variations of sea-level pressure, temperature and precipitation for North America and the North Pacific from 1602 through 1963. The best reconstructions were described and evaluated. They were used to study climatic phenomena such as large-scale temperature variations over North America, the Southern Oscillation, the impact of explosive volcanic eruptions on the spatial variations of temperature in North America and sea-land interactions in the western North Pacific. A variety of other accurately dated proxy climate records were also studied. There were 154 series of temperature variations and 152 series of precipitation variations selected for statistical analysis. Time-periods of marked climatic anomalies and change were noted and these data were described in terms of the likely changes in the western Northern Hemisphere since 1601.

PART III - TECHNICAL INFORMATION (FOR PROGRAM MANAGEMENT USES)

1. ITEM

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2. Principal Investigator/Project Director Name (Typed)

Harold C. Fritts

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3. Principal Investigator/Project Director Signature | 4. Date

PART III - TECHNICAL INFORMATION (FOR PROGRAM MANAGEMENT USES)

1. a. ABSTRACTS OF THESES.

Cook, Edward R. 1985. A time-series analysis approach to tree-ring standardization. Ph.D. Dissertation, School of Renewable Natural Resources, University of Arizona, Tucson.

The problem of tree-ring standardization is examined in this study from the point-of-view of standardizing closed-canopy forest ringwidth series. The problem is defined in terms of the high level of uncertainty in differentiating climatic fluctuations from those fluctuations in the ringwidths caused by competitive interactions between trees and stand disturbances. The solution to the standardization problem must directly address and minimize this uncertainty in an objective way. A review of the literature reveals that no standardization procedure has satisfactorily solved this problem.

A biological model for a tree-ring standardization method is developed through the decomposition of a theoretical ringwidth series using a linear aggregate model. Five general classes of variance are defined for the model and the likely properties of each class is described. By this process, it is found that one class of non-climatic variance that is frequently responsible for standardization problems could be objectively minimized in theory. This is the variance caused by endogenous stand disturbances which create fluctuations in ringwidth series that are non-synchronous or out-of-phase when viewed across trees in a stand. Since out-of-phase fluctuations cannot be logically related to the common climatic signal affecting all trees in the stand, the proposed standardization method should remove only that variance regarded as unique to individual trees and simultaneously preserve all common variance resolvable from the age trend.

A time series model based on the autoregressive process is proposed as a means of minimizing the timewise influence of endogenous disturbances in a detrended ringwidth series. The properties of autoregressive and moving average processes are described, and it is shown how each process can be re-expressed in terms of the other one. This dual property leads to the relationship between autoregressive modelling and predictive deconvolution which facilitates the understanding of the autoregressive modelling procedure. Specific estimation techniques are described for applying autoregressive modelling to the tree-ring standardization problem and for reducing the influence of disturbance-caused outliers in the mean-value function. The final chronology developed by this overall methodology is called the ARSTND chronology.

A stochastic method of detrending based on smoothing splines is tested and adopted as part of the ARSTND methodology. The theoretical signal and noise variance properties of tree-ring series are derived based on an internal additive noise model which may be autoregressive in form. Signal-to-noise ratio (SNR) properties of this general model indicate that autoregressive modelling and prewhitening of detrended ringwidth indices will result in a higher SNR if and only if autocorrelated noise is present in the series. An empirical estimate of the level of autocorrelated noise in tree-ring series is derived. This enables the verification of the general SNR theory and the error variance reduction property of the ARSTND methodology.

The ARSTND methodology is tested using ringwidth data from stands not exhibiting any clear non-synchronous disturbance effects. The final chronologies developed by traditional means or by ARSTND are statistically indistinguishable. This indicates that ARSTND is unbiased as a chronology development tool. The need for additional "rewhitening" of the residual mean-value function is discovered in processing the bald cypress data. In addition, it is found that the autoregressive model should be rather robust when that assumed model is incorrect for the tree-ring series being processed.

Cropper, John P. 1985. Tree-ring response functions. An evaluation by means of simulations. Ph.D. Dissertation, Department of Geosciences, University of Arizona, Tucson.

The problem of determining the response of tree-ring width growth to monthly climate is examined in this study. The objective is to document which of the available regression methods are best suited to deciphering the complex link between tree-growth variation and climate.

Tree-ring response function analysis is used to determine which instrumental climatic variables are best associated with tree-ring width variability. Ideally such a determination would be accomplished, or verified, through detailed physiological monitoring of trees in their natural environment. A statistical approach is required because such biological studies on mature trees are currently too time consuming to perform.

The use of lagged climatic data to duplicate a biological, rather than a calendar, year has resulted in an increase in the degree of intercorrelation (multicollinearity) of the independent climate variables. The presence of multicollinearity can greatly affect the sign and magnitude of estimated regression coefficients.

Using series of known response, the effectiveness of five different regression methods were objectively assessed in this study. The results from each of the 2000 regressions were compared to the known regression weights and a measure of relative efficiency computed. The results indicate that ridge regression analysis is, on average, four times more efficient (average relative efficiency of 4.57) than unbiased multiple linear regression at producing good coefficient estimates. The results from principal components regression are slight improvements over those from multiple linear regression with an average relative efficiency of 1.45.

Rose, Martin R. (In preparation.) The Reconstruction of
Paleoclimatic Variability in the Southeastern Colorado
Plateau Region: the Past 1,000 Years. Ph.D. dissertation
to be submitted to the Department of Geosciences, University
of Arizona, Tucson.

The feasibility of using tree-ring data to reconstruct paleoclimatic conditions in western North America during the past 300 - 500 years has been repeatedly demonstrated. Recently, millennia long expanded tree-ring chronologies for locations in the Southwest have been constructed from living-tree chronologies merged with series composed of specimens recovered from nearby archaeological and historical contexts. Auto and cross-spectral analyses and Box - Jenkins ARMA modeling techniques insure the merging process incorporates pairs of chronologies with similar time and frequency domain characteristics. Eight expanded chronologies from northwestern New Mexico and southwestern Colorado covering the past 1,000 years are used.

Linear transfer functions are used to establish the nature of covariation between eigenvector amplitude series of tree-ring indices, as independent variables, with annual and seasonal temperature, precipitation, and the Palmer Drought Severity Index (PDSI), as dependent variables. Transfer functions are developed for a calibration period from 1916 to 1970. Instrumental climatic data predating the calibration period are employed to verify the climatic values predicted from application of the transfer function to the eigenvector amplitude series.

Transfer functions are also developed for years randomly selected from the total climatic record length, and verified against the remaining years. Results of these two procedures are compared and discussed. Reconstructions that fail the verification process are eliminated from further consideration.

The best verification results are achieved for the PDSI, followed by some of the precipitation variables. Most of the temperature variables exhibit poor verification. Long term reconstructions (1,000 years) are produced for variables passing the battery of verification tests. The long term reconstructions provide longer records for elucidating the descriptive statistical characteristics and time and frequency domain qualities of past climate in the southwestern United States.

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1. b. PUBLICATIONS RESULTING FROM GRANTS ATM-8115754 AND ATM-8310848.

1. Fritts, H. C. 1982. An overview of dendroclimatic techniques, procedures, and prospects. In: *Climate from Tree Rings*, M. K. Hughes, P. M. Kelly, J. R. Pilcher and V. C. LaMarche, Jr., eds. Cambridge University Press.

2. Fritts, H. C. 1982. The climate-growth response. In: *Climate from Tree Rings*, M. K. Hughes, P. M. Kelly, J. R. Pilcher and V. C. LaMarche, Jr., eds. Cambridge University Press.

3. Fritts, H. C. 1983. Tree-ring dating and reconstructed variations in Central Plains climate. *Transactions of the Nebraska Academy of Sciences*, XI (Special Issue):37-41.

4. Fritts, H. C. 1984. Discussion (of "Physical limitations of water resources" by John Bredehoeft). In: *Water Scarcity: Impact on Western Agriculture*, E. A. Engelbert and A. F. Scheuring, eds. University of California Press, Berkeley.

5. Fritts, H. C. 1986. Historical changes in forest response to climatic variations and other factors deduced from tree rings. In: "Climate Change", *Effects of Changes in Stratospheric Ozone and Global Climate* Vol. 3, J. G. Titus, ed. U. S. Environmental Protection Agency, Washington, D. C.

6. Fritts, H. C. 1987. Tree-ring analysis (dendroclimatology). In: "The Encyclopedia of Climatology", J. E. Oliver, ed., in *The Encyclopedia of Earth Sciences*, R. W. Fairbridge, ed. Van Nostrand Reinhold Company, New York.

7. Fritts, H. C. (In press.) Reconstructing Large-Scale Climatic Patterns from Tree-Ring Data: A Diagnostic Study. Submitted to the University of Arizona Press, Tucson.

8. Fritts, H. C. and J. M. Lough. 1985. An estimate of average annual temperature variations for North America, 1602 to 1961. *Climatic Change* 7:203-24.

9. Gordon, G. A., J. M. Lough, H. C. Fritts and P. M. Kelly. 1985. Comparison of sea-level pressure reconstructions from western North American tree rings with a proxy record of winter severity in Japan. *Journal of Climate and Applied Meteorology* 24:1219-24.

10. Lough, J. M. and H. C. Fritts. 1985. The Southern Oscillation and tree rings: 1602 to 1961. *Journal of Climate and Applied Meteorology* 24:952-66.

11. Lough, J. M. and H. C. Fritts. (In press.) An assessment of the possible effects of volcanic eruptions on North American climate using tree-ring data, 1602 to 1900 A.D. <u>Climatic Change</u>.

12. Lough, J. M., H. C. Fritts and Wu X. 1987. Relationships between the climates of China and North America over the past four centuries: a comparison of proxy records. In: <u>The Climate of China and Global Climate. Proceedings of the Beijing International Symposium on Climate Oct. 30 - Nov. 3, 1984, Beijing, China</u>, Ye Duzheng, Fu Congbin, Chao Jiping and M. Yoshino, eds. China Ocean Press, Beijing and Springer-Verlag, Berlin.

13. Wu X. and J. M. Lough. 1987. Estimating North Pacific summer sea-level pressure back to 1600 using proxy climate records from China and North America. <u>Advances in Atmospheric Sciences</u> 4(1):74-84, Beijing, China.

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1. e. TECHNICAL DESCRIPTION OF PROJECT AND RESULTS.

1. Introduction

Tree-ring width variations, historical documents and lake varves are all potential sources of proxy climate data which can provide accurately dated, annually or seasonally resolved information for the past few centuries. As outlined in the original proposal, the aim of this research is not only to finish the examination of spatial climatic reconstructions carried forward from project ATM-8115754, but also to assemble and compare the results of independently derived high resolution proxy climate records for the North Pacific/North American sector since 1600 A.D. All but the last project is either published or has been submitted. The results of the independently derived data are summarized in ten Technical Notes. (The last one, Technical Note 50, is still in draft form because of the large numbers of figures that are required.) Several manuscripts on these independent data are under preparation.

2. Results

I) Completion of Climatic Analyses

Application of the current generation of dendroclimatic reconstructions for the North Pacific and North America to the study of particular climatic phenomena has been completed. This has included the following applications:

a) Southern Oscillation

The reconstructions of sea-level pressure, temperature and precipitation from western North American tree-ring chronologies were shown to contain the same teleconnection patterns known from the instrumental climate record to be associated with variations of the Southern Oscillation (SO). This result is important as it suggests that dendroclimatic reconstructions can be used to study mid- to high-frequency sources of climatic variation. Statistically verified reconstructions of seasonal SO index values were also developed back to 1600 A.D. using the prewhitened 65 western North American chronologies. A paper describing these results entitled "The Southern Oscillation and tree rings: 1600 to 1961" was published in 1985 in the *Journal of Climate and Applied Meteorology* (see Publication 10, attached).

b) Large-scale temperature variations

Average reconstructed annual temperature for 77 stations in the United States and southwestern Canada were compared to the average instrumental Northern Hemisphere air temperatures (Jones *et al.*, 1982) as well as other data sets reported to reflect temperatures at a given location (LaMarche and Stockton, 1974;

Manley, 1974, Groveman and Landsberg, 1979; Jacoby and Cook, 1981). Periods of agreement and disagreement between the different series were identified. A paper describing these results entitled "An estimate of average annual temperature variations for North America, 1602 to 1961" was published in 1985 in Climatic Change (see Publication 8, attached).

c) Chinese rainfall

Variations of drought and flood in China, derived from historical information for the period 1470 to 1979 (Academy of Meteorological Sciences, 1981) were shown to be statistically related to variations of the instrumental North Pacific sea-level pressure field. Similar linkages were demonstrated to occur in the independent tree-ring derived reconstructions of sea-level pressure back to 1602 A.D. Monte Carlo simulations (Livezey and Chen, 1983) of our procedures demonstrated that the overall significance of the instrumental and reconstructed teleconnection patterns exceeds the levels expected by chance at the 95 percent confidence level. A paper coauthored by Lough, Fritts and Wu entitled "Relationships between the climates of China and North America over the past four centuries: a comparison of proxy records" has been submitted for a symposium volume (see Publication 12, attached).

d) Sea-level pressure reconstructions from Chinese and North American sources.

The successful comparisons between the documentary sources of climatic information from China and the dendroclimatic reconstructions from western North America encouraged us to attempt to reconstruct summer sea-level pressure over the western North Pacific using both proxy data sources as predictors. In this study we demonstrate that better models, in terms of significant calibration and verification statistics, were obtained when both western North American tree-ring chronologies and Chinese documentary rainfall indices were used as predictors of sea-level pressure than when either proxy data set was used alone. This result is important as it demonstrates the potential of combining different proxy data sources to derive estimates of past climate. A paper, coauthored with Wu Xiangding, entitled "Estimating North Pacific summer sea-level pressure back to 1600 using proxy climate records from China and North America" has been published in the Chinese journal Advances in Atmospheric Sciences (see Publication 13, attached).

e) Lake Suwa

The historically recorded freeze dates of Lake Suwa, Japan (Arakawa, 1954) are a good indication of winter severity (Tanaka and Yoshino, 1982). Early and late freeze dates, corresponding to severe and mild winters, respectively, have been shown to be associated with two distinct instrumental sea-level pressure patterns (teleconnections) over the North Pacific. Reconstructed sea-level pressures averaged for severe winters prior to 1683 show a pattern of anomalies similar to that of the instrumental data. The pattern associated with mild winters is not, however, well reproduced in the reconstructed sea-level pressure field. This study is important as it first helps to establish the reliability of some of the large-scale features of our sea-level pressure reconstructions and second, the study demonstrates how different types of proxy climate information from different regions can be compared by first establishing teleconnections from the instrumental data base. A paper coauthored with G. A. Gordon and P. M. Kelly entitled "Comparison of sea-level pressure reconstructions for western North American tree rings with a proxy record of winter severity in Japan" was published in 1985 in the Journal of Climate and Applied Meteorology (see Publication 9, attached).

f) Effects of volcanic eruptions on North American climate

Seasonal and annual temperature reconstructions derived from western North American semi-arid site tree-ring chronologies have been used to examine the spatial response of North American climate to volcanic eruptions within the period 1602 to 1900 A.D. Low-latitude eruptions appear to give the strongest response. Cooling of the annual average temperatures in the central and eastern United States is reconstructed to follow volcanic eruptions with warming in the western states. The magnitude and spatial extent of the cooling and warming varies seasonally. The cooling in the east is most marked in summer and the warming in the west is strongest and most extensive in winter. Four independent temperature/proxy temperature series within the area of the temperature reconstructions support this pattern of response. Three independent series lying outside the area suggest that the temperature spatial response may extend to the north beyond the area covered by the tree-ring reconstructions. This study illustrates how proxy climate records can be used to identify the source of some of the spatial and temporal variability of climate for periods during which the instrumental record is unavailable. The study also demonstrates how independent sources of proxy climate information can be used to verify various climate responses and to clarify the extent of the reconstructed patterns. A paper entitled "An assessment of the possible effects of volcanic eruptions on North American climate using tree-ring data, 1602 to 1900 A.D." has been accepted for Climatic Change (see Publication 11, attached).

II) Synthesis of Proxy Climate Records Since 1600 A.D.

The objective of this research has been to develop a more detailed description of the major climatic regimes that have prevailed in the North Pacific and North American sector since 1600 A.D.

a) Assembling and storage of data

Various proxy climate and climatic data sets have been collected for the Western Hemisphere for the period since 1600

A.D. Emphasis has been placed on assembling time series which are accurately dated, resolve climate at seasonal or annual time scales and for which a clear climatic response has been identified. The types of data assembled include reconstructions of climatic variables, e.g. from tree rings; indices of climatic variables developed from documentary or historical sources; proxy climatic series which have been shown to be primarily related to a particular climatic variable, e.g. upper tree-line tree-ring chronologies and lake varves; and early instrumental climatic records.

These data sets are stored on magnetic tape and descriptive information about each data set is stored on disc (referred to as the Climatic Data Index). In addition to climatic time series, references to individual climatic events, e.g. a very severe winter, have also been collected (referred to as the Climatic Event Index). The primary source of information for the Climatic Event Index was the Climate History File compiled by the Tree-Ring Laboratory and the University of Wisconsin (Thompson, 1984). This index is also stored on disc. Descriptions of the development of these two indices together with complete listings and bibliographies of sources are contained in two Technical Notes, numbers 41 and 42, attached. Various characteristics of each of the climate/proxy climate series analyzed, e.g. mean, standard deviation, autocorrelation, extremes, and significant spectral peaks, have also been summarized in Technical Note 43 (attached).

b) Comparisons of proxy records

We have continued to compare the climatic information contained in independent proxy records. Independent proxy climate records have also been used to verify large-scale patterns of change associated with particular phenomena such as volcanoes (see Publication 11).

i) Eastern North Pacific sea surface temperatures

Douglas (1976; 1980) developed reconstructions of winter, spring and summer sea surface temperatures (SSTs) for twelve areas in the eastern North Pacific from seven tree-ring chronologies in southwestern North America. These reconstructions cover the period 1671 to 1963. We have applied the methodology developed in previous studies (for example, Gordon et al., 1985, attached) to compare the instrumental and reconstructed SSTs to spatial grids of instrumental and reconstructed sea-level pressure, temperature and precipitation. We first established from the instrumental records that significant linkages exist between the variables being compared. We then examined the reconstructed records of the same variables for evidence of the same linkages.

In this study we found that instrumental winter and spring SSTs in the eastern North Pacific are significantly correlated with instrumental sea-level pressure, temperature and precipitation patterns. Instrumental summer SSTs do not show a strong relationship with the other climatic variables. The patterns of correlations identified from the instrumental records for winter and spring SSTs were also found to be present in the reconstructed data, with the exception of winter SSTs and winter precipitation. The winter and spring SSTs are also shown to be significantly negatively correlated with both instrumental (Wright, 1975) and reconstructed values (Lough and Fritts, 1985) of the Southern Oscillation index. Higher SSTs in the eastern North Pacific are associated with low Southern Oscillation index values. This study provides further verification of the major reconstructed features of the sea-level pressure and temperature fields as well as the Southern Oscillation index developed from the 65 western North American chronology grid. An internal report describing this study has been prepared (see Technical Note 44, attached).

ii) Regional comparisons

We have completed comparisons of different climate/proxy climate series for the following:

1) Seven temperature and seven precipitation series in the eastern United States.

2) Nineteen precipitation series in the southwestern United States.

3) Nine precipitation series in the midwest United States.

4) Nine temperature and four precipitation series in Alaska/Northwest America.

5) Seventeen temperature series in the Hudson Bay/N.E. Canada region.

The aim of these regional studies was to determine, through correlation analysis, the degree of similarity between independent climate/proxy climate series representative of the same climate variable and region. To do this we first established the "regional representativeness" of each series. As stated by Pittock (1982, p. 63): "a time series or proxy climate data from one tree or one site or even instrumental data from one location, may have little or highly qualified general significance." We, therefore, correlated each series, with the instrumental records of either temperature at 77 stations or precipitation at 96 stations in the United States and southwestern Canada. For each series analyzed, a map of the correlation coefficients was produced, with coefficients significant at the 95 percent confidence level flagged. This allowed one to determine the extent to which each series was related to climatic conditions of the region and, therefore, the likelihood that it should have some common information with other series from that region.

An example of this analysis is presented in Figure 1 which shows the correlations between annual instrumental precipitation at 96 stations in the United States and southwestern Canada and the annual precipitation index for San Bernardino (Lynch, 1931), the reconstruction of annual average precipitation for California (Fritts and Gordon, 1982) and the reconstruction of annual river runoff at Bright Angel Creek, Arizona (Stockton, 1975). It is apparent that the San Bernardino precipitation index and the Bright Angel Creek runoff reconstruction show significant and high correlations with annual instrumental precipitation in the vicinity of the respective sites. The reconstruction of California annual precipitation shows lower correlations, though still significant, with annual precipitation, and the center is displaced towards northern California. Reference to the procedures used to develop this reconstruction (Fritts and Gordon, 1982) indicates that the stations used to develop the statewide average are predominantly from northern California.

Having established the extent to which each series in a region is representative of that region, the different series were compared by correlating the original data, the data smoothed with a low-pass digital filter emphasizing low-frequency variance (LaMarche and Fritts, 1972), the residual series (i.e. original series minus filtered series) which emphasizes high-frequency variance, and correlations for non-overlapping 30-year subperiods. The latter analysis helped to establish the stability through time of any significant linkages identified. It is apparent from these studies that two independent series may be significantly correlated over the common length of record but the degree of agreement for any 30-year subperiod may be low, insignificant or even reverse sign.

These regional studies have been described in internal Technical Notes. A manuscript describing the major findings will be prepared for submission to a professional journal.

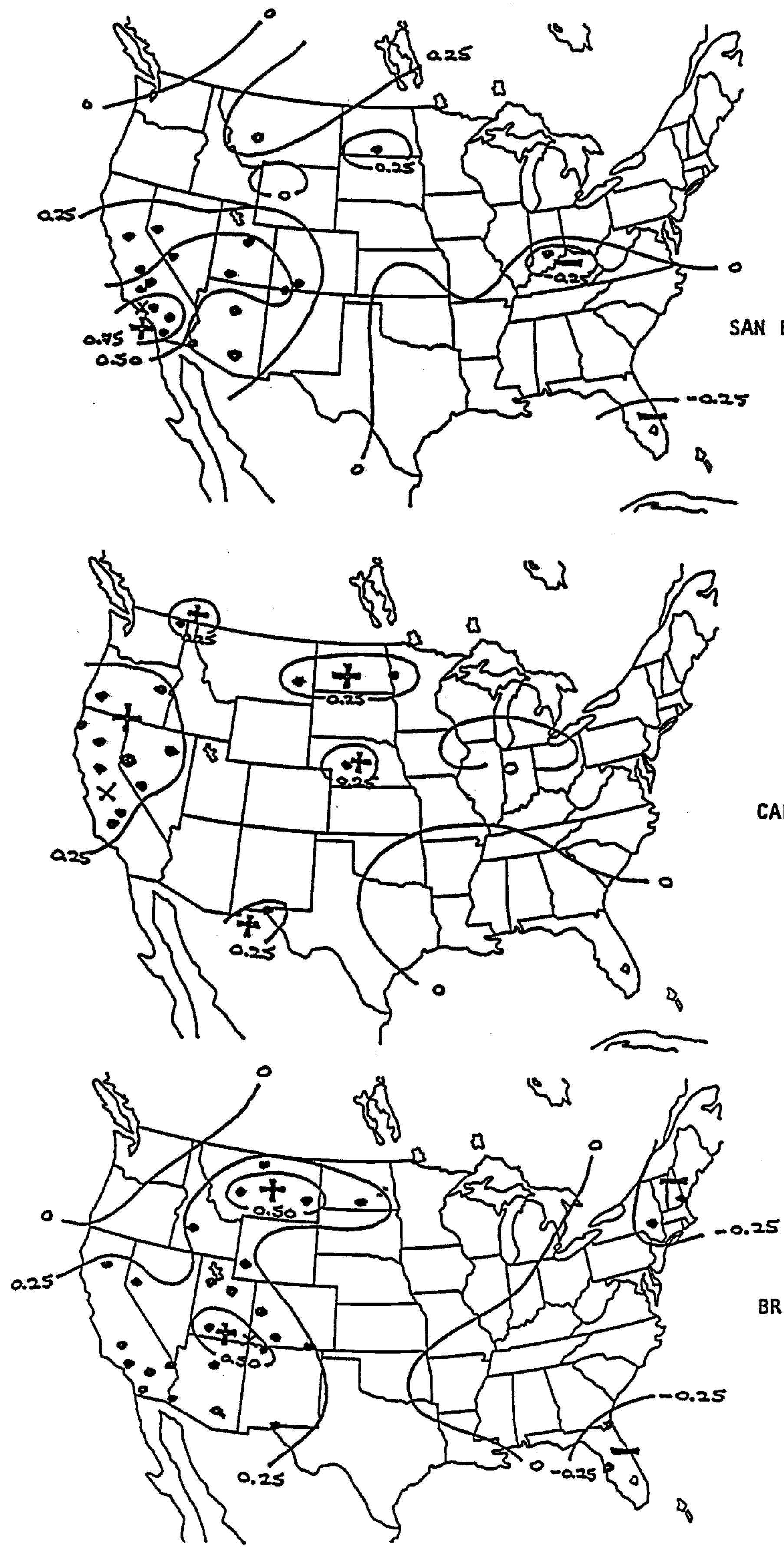
c) Identification of major climatic regimes since 1600 A.D.

The assembled climate/proxy climate records have been examined together for evidence of similarities in times of extreme climate and times of changing climate for the period 1600 to 1960. The series were first divided into two groups according to whether the particular series related to temperature or precipitation. A total of 154 temperature series and 152 precipitation series were analyzed for features that were in common to a large number of the series. This was accomplished by the following statistical analyses:

1) The long-term mean of each series was calculated and then the average departures from the mean were calculated for each decade (1601 to 1610, 1611 to 1620, etc). The mean of each decade was then tested for a significant difference from the long-term mean using Cramer's test (Mitchell _et al_., 1966, page 63). Decades for which the average value was significantly different from the long-term mean at the 95 percent confidence level were then noted, together with the sign of the departure.

Figure 1: Example of analyses to establish "regional representativeness" of proxy climate series. Correlation coefficients between annual instrumental precipitation at 96 stations in the United States and southwestern Canada and a) San Bernardino annual precipitation index (CD18), b) reconstructed annual precipitation for California (CD79) and c) reconstructed annual river runoff for Bright Angel Creek, Arizona (CD80). Period = 1901 to 1960 except for CD18, 1901 to 1930.

SOUTHWEST U.S. PRECIPITATION : CORRELATIONS



SAN BERNARDINO CD18

CALIFORNIA CD79

BRIGHT ANGEL CD80

Figure 1

2) Overlapping, 30-year means (i.e. 1601-1630, 1602-1631, etc) were calculated and the differences between successive, non-overlapping, 30-year periods were then determined. These differences were tested for significant at the 95 percent confidence level using Student's t-test (Mitchell <u>et al</u>., 1966, page 63). Thus the mean for the period 1601-1630 was subtracted from the mean for 1631-1660; 1602-1631 was subtracted from the mean for 1631-1661, etc. The year dividing two 30-year periods of maximum, significant change (as measured by the magnitude of the t-value) in the mean, and the sign of the change, were then identified. These years of maximum change were stored by the decade in which the year of change occurred.

3) A similar procedure was used to identify maximum significant changes in 30-year variances. The variance was first calculated for each overlapping 30-year period and the change in variance between successive, non-overlapping 30-year subperiods was determined. The significance of the change in variance, at the 95 percent confidence level, was then determined using the F-test (Mitchell <u>et al</u>., 1966, page 68). The year dividing two 30-year periods of maximum, significant change in the variance (as measured by the magnitude of the F-value), and the sign of the change were then identified.

An example of the results obtained is given in Table 1 for the Yukon Territory tree-ring chronology, responsive to summer temperatures, from Jacoby and Cook (1981). From this we can identify 16 decades (out of a total of 36) which were significantly different from the long-term (1601 to 1960) mean. These include four decades with negative departures, inferred cooler summer temperatures, in the mid-19th century, and four decades with positive departures, inferred warmer summer temperatures, in the 20th century. The change in the 30-year means are at maximum six times in the 1602-1960 period. Thus, in 1640 there was a maximum significant increase in the mean of 1640-1699 compared to the mean of 1610-1639. Similarly, in 1685 there was a maximum significant decrease in the mean of 1685-1741 compared to the mean in 1655-1684. There are ten times of maximum significant change in 30-year variances. Thus, 1633+ indicates an increase in variance between the two periods, 1603-1632 and 1633-1662.

The information presented in Table 1 was calculated for each of the 154 temperature and 152 precipitation series. Summary tables were then produced for each variable and season. Tables 2, 3 and 4 show these summarized results for decade departures, changes in 30-year means and changes in 30-year variances, respectively. These tables show, for each variable and season, the percentages of the total number of series present per decade which showed significant values. Taking summer temperatures, for example, 29 series were analyzed for the decade 1601-1610, of which 11 (i.e. 38%) had a decade average significantly different from the long-term mean. For 1621-1630, 16 of the 30 series analyzed (i.e. 53%) had a decade average significantly different from the long-term mean (Table 2).

Table 1: Yukon Territory chronology (Jacoby & Cook, 1981) - a) decades significantly different from the long-term mean, b) maximum significant change in 30-year mean and c) maximum significant change in 30-year variance.

Decade	(a) Decade Significant	(b) Change in 30-yr mean	(c) Change in 30-yr variance
1601-1610	-	\	\
1611-1620		\	\
1621-1630	-		
1631-1640	-	1640+	1633+
1641-1650			
1651-1660			
1661-1690			
1671-1680			
1681-1690		1685-	
1691-1700	-		1700+
1701-1710	-		
1711-1720	-		
1721-1730		1723+	
1731-1740			1738-
1741-1750			
1751-1760			
1761-1770		1770+	
1771-1780	+		1773-
1781-1790			
1791-1800			
1801-1810	+		1803+
1811-1820		1811-	
1821-1830			
1831-1840	-		1834-
1841-1850	-		
1851-1860	-		1857-
1861-1870	-		
1871-1880			
1881-1890			1887+
1891-1900			
1901-1910			
1911-1920			1912+
1921-1930	+	1923+	
1931-1940	+		1937-
1941-1950	+		
1951-1960	+	\	\

Note: a) Only the sign of the departure of the decade mean from the overall mean is given. For b) and c) the first year of the 30-year subperiod for which the maximum significant change in the mean or variance, and the direction of the change, is given.

Table 2: Percentages of total number of series with decade averages significantly different from the long-term mean: all series (/ indicates less than 50% of series present; * indicates more than 50% of series significant; underlined values indicate less than 10% of series significant).

	TEMPERATURE					PRECIPITATION				
Decade	WI	SP	SU	AU	ANN	WI	SP	SU	AU	ANN
1601-1610	56*	7	38	/	40	16	33	0	77*	/
1611-1620	25	80*	41	/	53*	11	72*	45	92*	/
1621-1630	31	53*	53*	/	73*	32	33	25	54*	/
1631-1640	31	0	37	/	27	26	22	60*	85*	/
1641-1650	63*	13	57*	/	27	11	22	55*	85*	/
1651-1660	6	60*	32	/	33	0	0	20	23	/
1661-1670	44	60*	26	/	53*	37	56*	40	8	/
1671-1680	11	72*	53*	50*	56*	8	13	56*	61*	12
1681-1690	42	44	34	47	61*	8	22	24	0	23
1691-1700	37	0	19	0	17	42	9	4	0	13
1701-1710	37	11	27	12	26	13	13	19	0	19
1711-1720	5	0	24	0	0	0	0	4	0	0
1721-1730	5	11	21	5	0	4	4	7	17	13
1731-1740	0	11	29	0	5	4	9	7	11	23
1741-1750	40	15	29	20	15	12	13	17	16	16
1751-1760	15	25	11	10	20	12	25	24	0	24
1761-1770	10	40	22	5	30	12	21	7	5	14
1771-1780	45	25	32	40	50*	40	4	21	53*	22
1781-1790	20	10	15	5	20	12	4	0	5	3
1791-1800	0	40	35	20	35	4	25	17	5	22
1801-1810	30	14	37	0	45	12	4	14	16	13
1811-1820	24	41	45	14	33	4	8	10	16	13
1821-1830	21	28	36	8	25	20	8	31	11	21
1831-1840	42	44	41	28	58*	36	71*	55*	16	57*
1841-1850	56*	12	45	31	32	15	14	19	62*	21
1851-1860	17	13	20	4	13	4	31	0	0	20
1861-1870	23	61*	28	9	48	9	50*	26	6	36
1871-1880	5	26	39	39	19	9	36	37	0	22
1881-1890	59*	52*	18	26	52*	30	18	4	47	14
1891-1900	5	35	27	0	19	0	0	15	24	5
1901-1910	14	17	50*	22	14	0	0	4	18	16
1911-1920	45	35	41	9	52*	57*	9	33	12	38
1921-1930	52*	10	33	15	45	0	14	19	13	14
1931-1940	43	14	68*	60*	79	23	5	42	0	28
1941-1950	38	33	39	10	37	36	43	0	0	28
1951-1960	43	19	51*	5	42	14	14	31	63*	31
Total # Series	26	27	48	27	26	28	27	32	22	43

Table 3: Percentages of total number of series with maximum significant change in 30-year means per decade: all series (/ indicates less than 50% of series present; * indicates more than 50% of series significant; underlined values indicate less than 10% significant).

	TEMPERATURE					PRECIPITATION				
Decade	WI	SP	SU	AU	ANN	WI	SP	SU	AU	ANN
1601-1610	/	/	/	/	/	/	/	/	/	/
1611-1620	/	/	/	/	/	/	/	/	/	/
1621-1630	/	/	/	/	/	/	/	/	/	/
1631-1640	38	53*	62*	71*	33	32	39	60*	0	/
1641-1650	25	13	14	0	7	32	33	5	0	/
1651-1660	0	40	33	43	33	21	22	15	77*	/
1661-1670	25	13	23	29	40	0	33	5	23	/
1671-1680	6	33	13	0	27	32	11	0	0	/
1681-1690	56*	47	35	29	20	26	17	60*	15	/
1691-1700	11	29	26	44	44	13	13	16	11	16
1701-1710	5	44	13	18	11	38	17	8	6	3
1711-1720	58*	11	25	0	28	8	13	28	72*	30
1721-1730	11	17	19	0	16	21	35	20	6	23
1731-1740	5	28	9	18	26	4	26	22	28	16
1741-1750	16	33	53*	0	32	29	9	22	50*	16
1751-1760	16	47	32	5	5	4	39	25	17	16
1761-1770	15	25	11	55*	50*	20	8	21	21	13
1771-1780	55*	25	37	0	35	32	13	24	5	16
1781-1790	10	35	5	5	15	8	13	10	16	6
1791-1800	25	20	34	50*	50*	24	8	21	58*	19
1801-1810	30	15	27	15	5	20	25	14	16	14
1811-1820	40	10	15	10	35	0	54*	14	0	14
1821-1830	15	67*	22	43	55*	44	25	38	63*	33
1831-1840	15	0	32	5	10	4	4	7	0	3
1841-1850	25	33	19	43	37	10	58*	33	14	34
1851-1860	20	48	38	14	26	10	26	33	0	19
1861-1870	10	5	23	0	5	5	0	8	0	0
1871-1880	48	45	12	9	60*	32	38	35	13	29
1881-1890	5	39	36	17	19	9	33	15	75*	17
1891-1900	9	17	11	22	24	0	0	23	13	14
1901-1910	38	14	17	15	15	68*	48	23	25	40
1911-1920	33	38	32	45	74*	9	5	42	25	13
1921-1930	14	19	29	5	11	5	0	8	6	3
1931-1940	0	5	24	0	16	50*	10	19	13	41
1941-1950	/	/	/	/	/	/	/	/	/	/
1951-1960	/	/	/	/	/	/	/	/	/	/
Total # Series	26	27	48	27	26	28	27	32	22	43

Table 4: Percentages of total number of series with maximum significant change in 30-year variances per decade: all series (/ indicates less than 50% of series present; * indicates more than 50% of series significant; underlined values indicate less than 10% significant).

	TEMPERATURE					PRECIPITATION				
Decade	WI	SP	SU	AU	ANN	WI	SP	SU	AU	ANN
1601-1610	/	/	/	/	/	/	/	/	/	/
1611-1620	/	/	/	/	/	/	/	/	/	/
1621-1630	/	/	/	/	/	/	/	/	/	/
1631-1640	38	53*	41	21	47	21	17	5	0	/
1641-1650	25	27	13	64*	27	26	22	65*	85*	/
1651-1660	31	27	43	0	13	5	33	0	8	/
1661-1670	19	40	23	21	7	5	6	15	0	/
1671-1680	6	53*	13	0	7	11	11	5	77	/
1681-1690	6	20	32	0	20	0	50*	25	0	/
1691-1700	28	6	23	0	28	13	13	12	11	20
1701-1710	26	6	25	12	22	21	0	8	11	3
1711-1720	16	11	16	24	17	33	57*	24	28	40
1721-1730	11	16	34	6	21	17	9	24	0	16
1731-1740	32	5	24	12	5	8	17	11	11	6
1741-1750	11	16	29	0	16	54*	30	22	22	35
1751-1760	5	21	12	0	5	4	4	14	0	10
1761-1770	35	15	11	50*	40	8	17	14	5	9
1771-1780	20	15	31	20	20	44	42	14	16	28
1781-1790	10	10	24	0	10	8	21	14	47	14
1791-1800	35	25	18	10	20	20	0	10	11	8
1801-1810	15	40	27	30	40	20	25	14	11	19
1811-1820	45	45	42	25	30	28	8	28	37	28
1821-1830	5	0	18	14	5	32	13	17	42	25
1831-1840	25	14	27	10	20	12	21	10	0	19
1841-1850	35	10	23	38	37	5	11	17	0	0
1851-1860	10	38	17	10	21	10	0	4	64*	19
1861-1870	10	9	14	18	25	36	19	19	6	12
1871-1880	29	23	14	5	25	5	38	15	0	6
1881-1890	0	26	34	17	24	5	10	23	6	14
1891-1900	18	17	27	17	33	32	24	31	31	17
1901-1910	5	38	19	10	5	14	24	15	0	20
1911-1920	19	14	39	20	47	41	5	38	0	9
1921-1930	5	5	24	10	0	32	10	15	6	9
1931-1940	5	5	27	5	5	14	5	12	0	9
1941-1950	/	/	/	/	/	/	/	/	/	/
1951-1960	/	/	/	/	/	/	/	/	/	/
Total # Series	26	27	48	27	26	28	27	32	22	43

Table 3 indicates that within the decade 1631-40, 18 of the 29 series analyzed (i.e. 62%) recorded a maximum significant change in 30-year means. Table 4 shows that 12 of the 29 series (i.e. 41%) recorded a maximum significant change in 30-year variances. The percentages of significant change in the means and variances for all temperature and precipitation series are plotted in Figures 2a-2c.

The results of this study can be summarized as follows:

1) From Table 2 and Figure 2a it is apparent that there are certain decades, within the period 1601 to 1960, when a considerable number of the series examined show significant departures from the long-term mean. Some departures are positive and some are negative so long-term variability rather than a particular mean pattern in climate is indicated. There are also decades when very few of the series show significant departures from the long-term mean. Thus, there is some consensus among the different series regarding changing patterns in the variations in climate (as measured by decadal departures from the long-term mean) in the Western Hemisphere over the time period considered.

The 17th century was characterized by several extreme decades. This was followed by a period of few extremes (i.e. a period most representative of long-term mean conditions) which lasted from the early 18th century through to the early 19th century. The number of extreme decades then started to increase again into the 20th century. For temperature alone, the most extreme decades are 1621-1630 and 1931-1940 and the least extreme, 1711-1720. For precipitation alone, the most extreme decades are 1611-1620 and 1831-1840 and the least extreme, 1711-1720. For both temperature and precipitation the most extreme decades are 1611-1620, 1621-1630 and 1831-1840 and the least extreme, again 1711-1720.

2) From Table 3 and Figure 2b it is evident that there is less agreement among the different series regarding maximum significant changes in 30-year means than the timing of extreme decades. Certain features are, however, apparent. When all temperature and precipitation series are considered together, the five decades with the maximum number of significant changes in 30-year means are, in order: 1931-1940 (42%), 1681-1690 (38%), 1841-1850 and 1901-1910 (34%) and 1631-1640 (33%). Thus, within the Western Hemisphere during the period since 1600 A.D., the most marked change in climate has been that which has occurred in the 20th century.

3) Changes in variance (Table 4 and Figure 2c) also show less agreement among the different series. For all temperature and precipitation series, the decades with the maximum number of significant changes in 30-year variances are in order: 1641-1650 (42%), 1671-1680 (35%), 1771-1780 (33%), 1681-1690 and 1931-1940 (32%) and 1811-1820 (30%). The majority of the significant series show a decrease in variance for these decades apart from 1811-1820 and 1931-1940, when the majority indicate an increase in variance.

Figure 2: For all temperature and precipitation series, percentages of total number of series with a) decade averages significantly different from the long-term mean, b) maximum significant change in 30-year means per decade and c) maximum significant change in 30-year variances per decade.

FIGURE 2a : PERCENTAGES OF TOTAL NUMBER OF SERIES WITH DECADE AVERAGES SIGNIFICANTLY DIFFERENT FROM THE LONG-TERM MEAN - ALL SERIES : TEMP. AND PPT

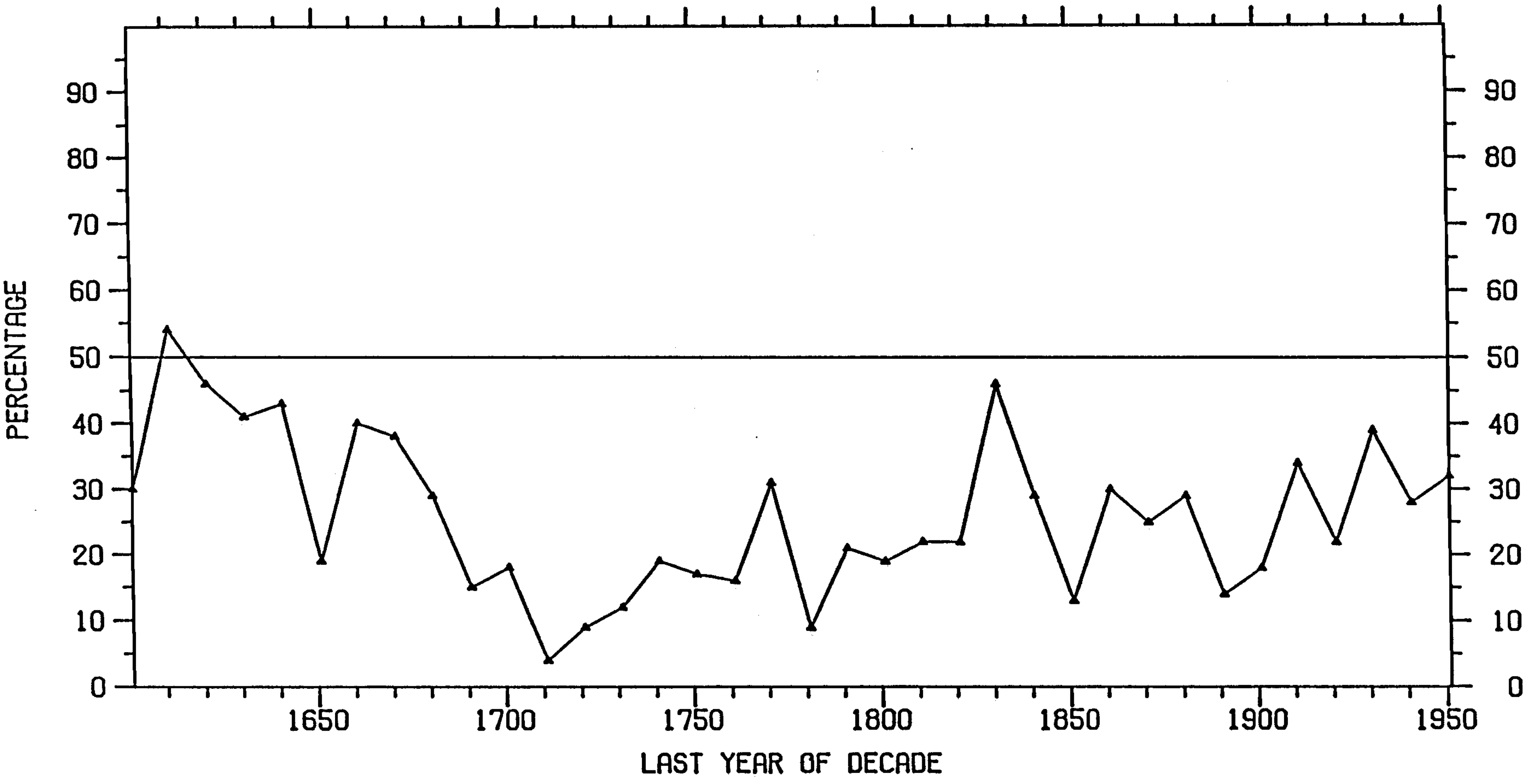


FIGURE 2b : PERCENTAGES OF TOTAL NUMBER OF SERIES WITH FIRST YEAR OF MAXIMUM SIGNIFICANT CHANGE IN 30-YEAR MEANS PER DECADE - ALL SERIES : TEMP. AND PPTN

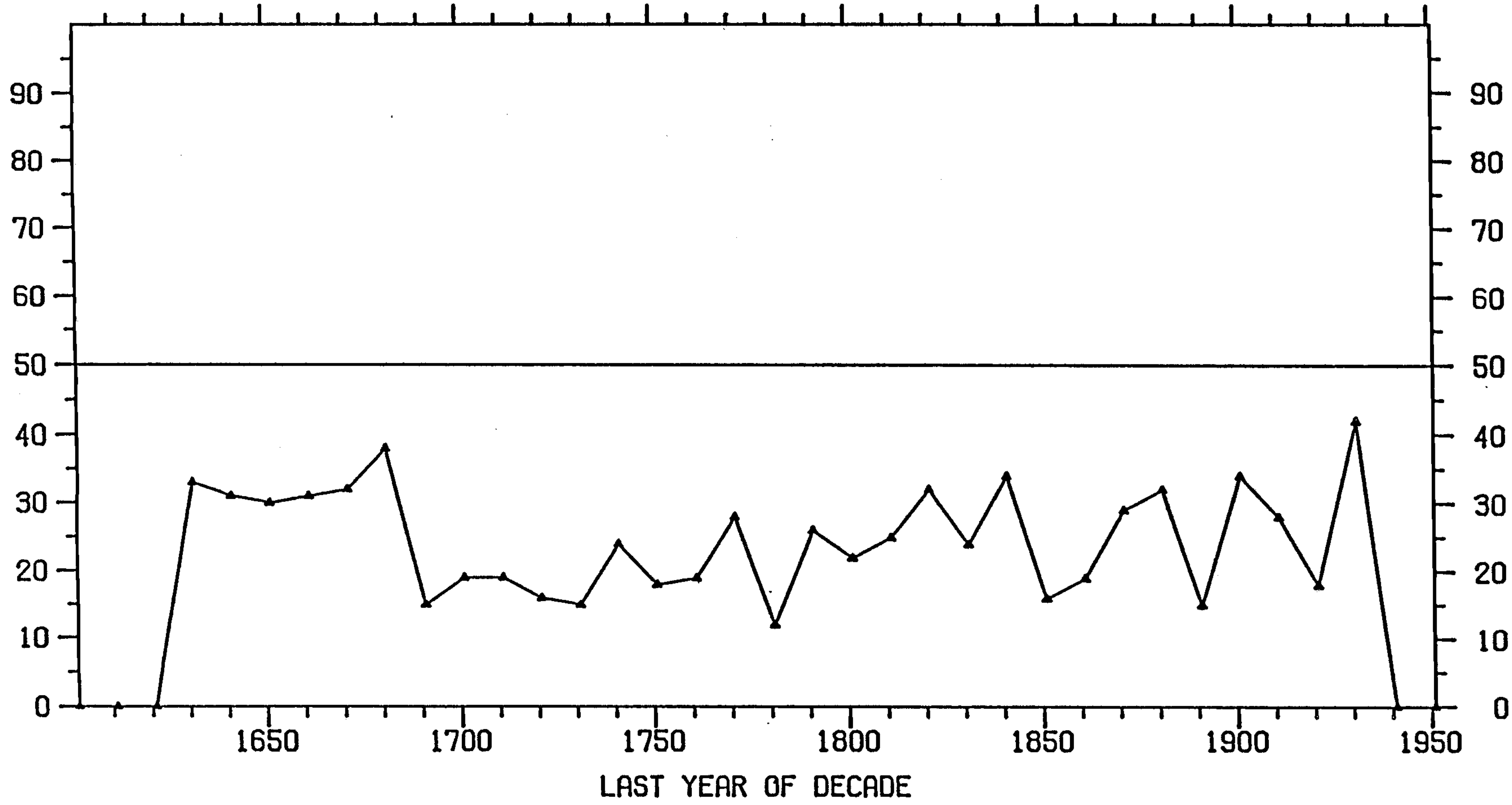
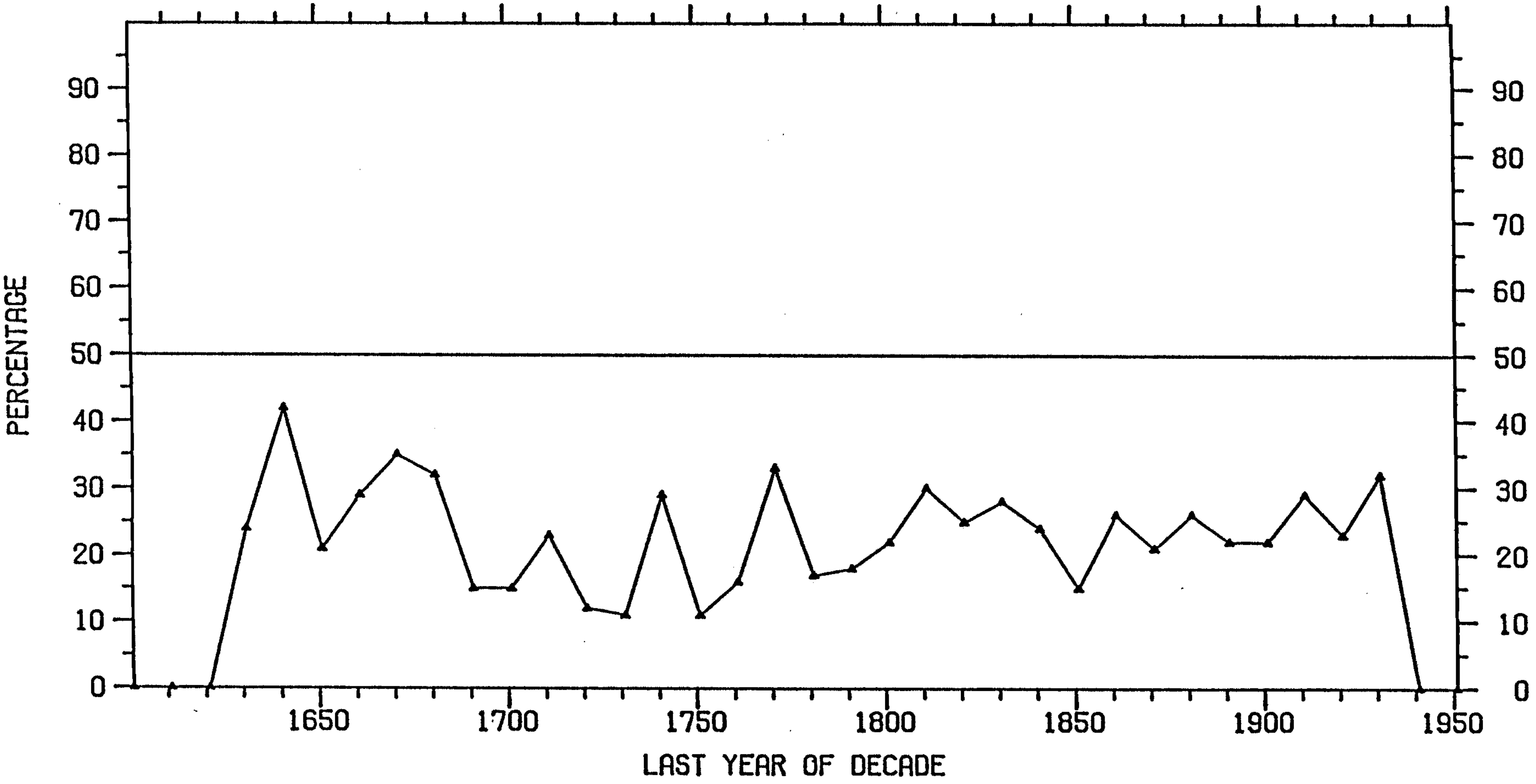


FIGURE 2c : PERCENTAGES OF TOTAL NUMBER OF SERIES WITH FIRST YEAR OF MAXIMUM SIGNIFICANT CHANGE IN 30-YEAR VARIANCES PER DECADE - ALL SERIES : TEMP. AND PPTN



4) The results of this study are being summarized in a manuscript entitled "Climatic Regimes of the Western Hemisphere since 1600 A.D.: an Examination of the Evidence from Climate/Proxy Climate Series" (Technical Note 50). This will include maps of the spatial patterns of reconstructed climate for the extreme decades as well as of the differences in climate between periods separated by maximum significant changes. Figure 3 shows an example of this for reconstructed annual sea-level pressure, temperature and precipitation for the nine major periods of change identified from the average reconstructed annual temperature series at 77 stations in the United States and southwestern Canada (Fritts and Lough, 1985).

Figure 3: a and b. Climatic variations associated with the most marked and significant changes in 30-year mean temperature. The average reconstructed departures from the 1901-1970 means are shown in the first two rows of (a) as maps for 1602-1636 and 1637-1666. The differences between these two maps are shown in the third map labeled 1637. The last two rows of maps in (a) and those in (b) are the difference maps obtained for the remainder of the 1602-1970 period.

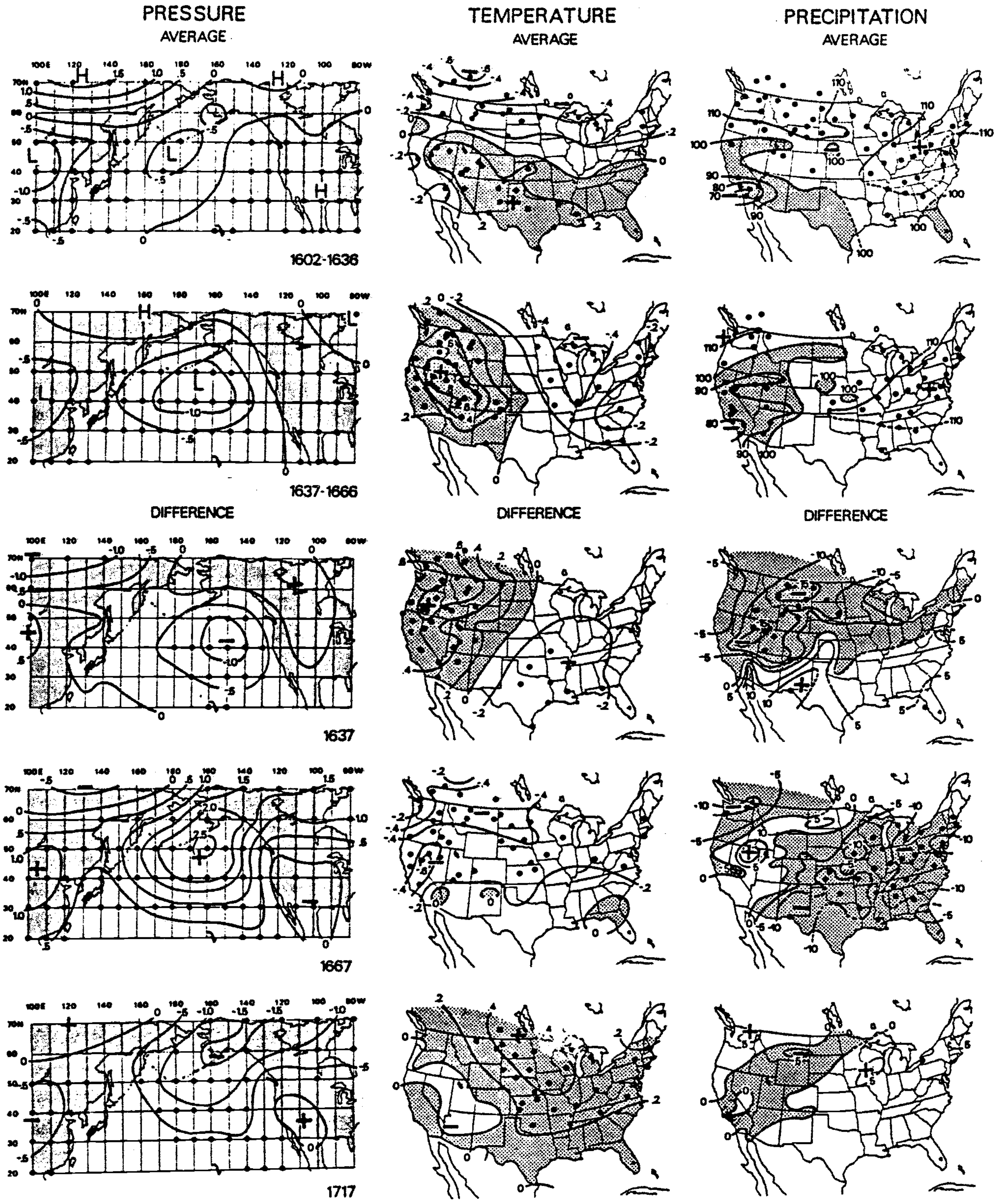

PRESSURE
AVERAGE
TEMPERATURE
AVERAGE
PRECIPITATION
AVERAGE
1602-1636
1637-1666
DIFFERENCE
DIFFERENCE
DIFFERENCE
1637
1667
1717

Figure 3

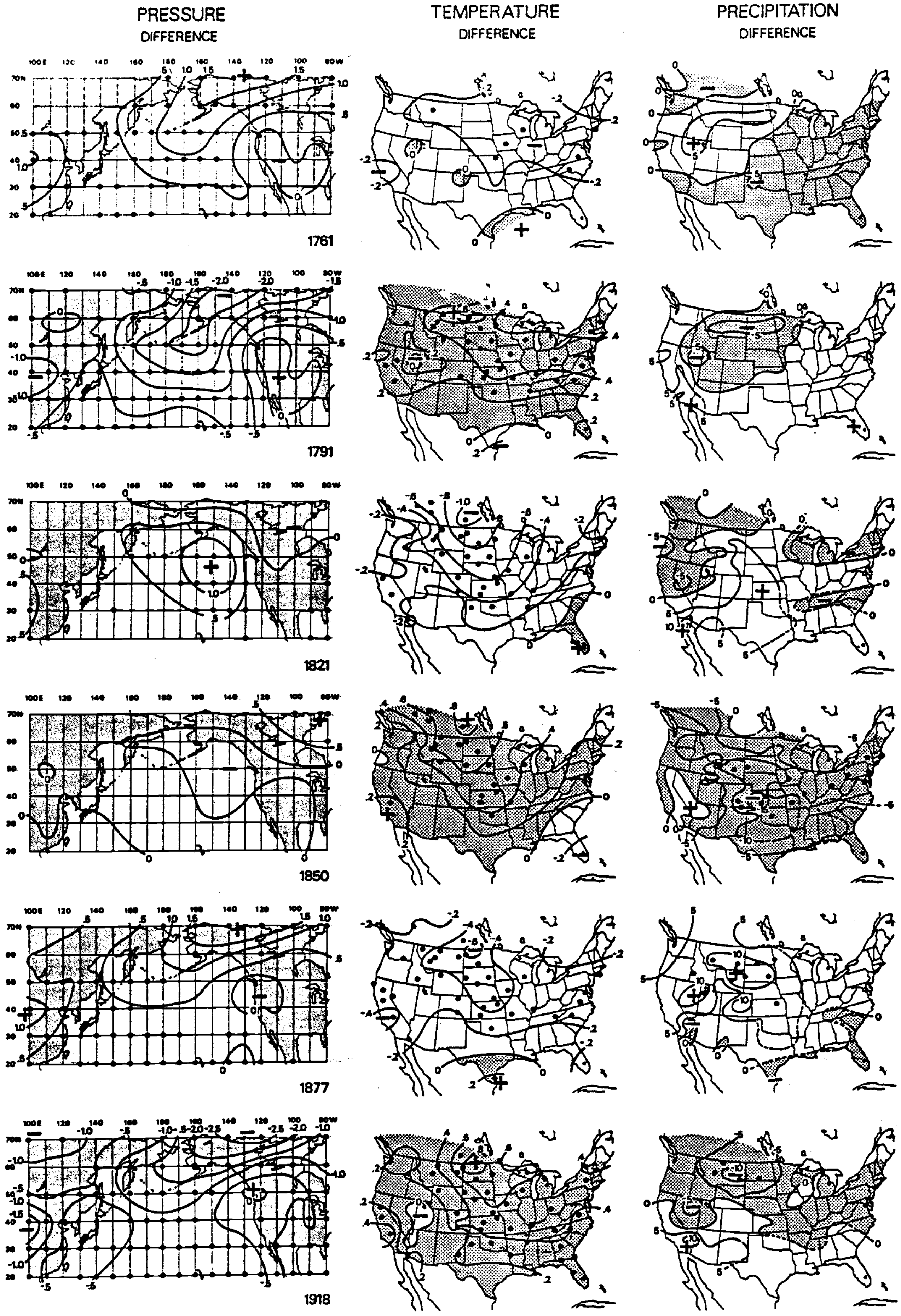


Figure 3 continued

The following part of this section is a report on the International Tree-Ring Data Bank that was supported in part by this grant.

THE INTERNATIONAL TREE-RING DATA BANK

The International Tree-Ring Data Bank (ITRDB) is a professional organization that provides secure storage and facilitates exchange of dendrochronological data around the world. It was originally formed as a first step in international cooperation with primary emphasis on dendroclimatology. The Data Bank holdings include 1) computerized records of dated tree-ring width and wood density measurements used to develop tree-ring chronologies, 2) the standardized site chronologies which are the summary data most commonly used to answer a variety of environmental and climatic questions, and 3) site information and associated chronology statistics. The ITRDB is housed at but operates independently from the Laboratory of Tree-Ring Research at the University of Arizona, Tucson.

The original purpose of the ITRDB was to offer a permanent location for the storage of well-dated dendroclimatic data. This would insure that data are protected from loss when laboratories move or dissolve or when scientists move to other projects or retire. In addition, a single computerized database was necessary to simplify data exchange problems. In 1986 an agreement was made between Soviet scientists, the director of the Laboratory of Tree-ring Research, and the ITRDB to begin entering data from the U.S.S.R. and to provide data required for Soviet investigations.

Membership consists of individual and institutional contributors of tree-ring data. For a number of years the ITRDB was officially open only to members. During last year the ITRDB was opened to all professions. It is administered by an international board selected from its membership, under the guidance of a Director, currently Harold C. Fritts. Daily business and computer operations are handled by a manager and programmer, and an editor is responsible for the ITRDB Newsletter and other communications among members.

Potential contributors to the ITRDB are supplied with standard site information forms which are available in English, French, German, and Russian. Each contribution that is received is checked for consistency to insure the quality of the data. The data are stored using software developed by the ITRDB and Tree-Ring Laboratory personnel and the UPDATE facility available on the Cyber 175 computer. Backup tapes are stored in three separate safe locations.

A new data retrieval system has been developed to extract basic ring measurements, chronologies, and site information. A manual for internal use outlines the routine data processing operations, including data entry, checking, alteration and retrieval. The data processing system consists of two parts, one for handling ring measurements and chronologies derived from them, and the other for maintaining site information.

Since the tree-ring measurements and chronologies are stored on tape, manipulation of these data sets uses the University of Arizona's Cyber mainframe computer. The site information and related data have recently been moved from the mainframe to an IBM PC-AT environment operating under DOS 3. The DBASE III+ database program is used to manage the site information data, and specific application programs have been written in the DBASE programming language. Prior to moving the site information to the IBM PC, an extensive check was made between the computerized information and the information originally provided by the investigator. All apparent discrepancies were rectified and at present the data are in the best possible shape.

The ITRDB resumed publication of the newsletter after a hiatus of six years, with Vol. 4, No. 1 published in Spring 1985. Since the previous Newsletter was published in 1978, 166 new sets of tree-ring and chronology data from ten countries had been added to the ITRDB holdings. These represent sites in Argentina, Australia, Canada, Chile, France, Ireland, New Zealand, South Africa, the United Kingdom and the U.S.A. The count of holdings in the spring of 1985 included 490 replicated data sets from 27 countries. Each holding represents data from a particular species from a specific geographical region. There were 98 site contributions from Europe and Great Britain; 33 from South America; 74 from New Zealand and Australia; one each from South Africa and the U.S.S.R.; and 283 from Canada, Mexico and the United States. The summary chronologies are included for about 85% of the entries. Nearly sixty species are represented and the longest record spans 1164 years.

Additional chronologies have been added to the ITRDB since the publication of the last newsletter and others are currently being processed. Thirty six sites in Washington and Oregon contributed by Lisa Graumlich and Linda Brubaker (University of Washington, College of Forest Resources) have been added, along with three sites from Japan contributed by Yasushi Kojo (Department of Anthropology, University of Arizona), and three densitometric sites in Maine from Laura Conkey (Department of Geography, Dartmouth University). The 28 chronologies from the California - Oregon collection project were contributed by Holmes and Fritts. Thus, seventy chronologies have been added in the past year alone to bring the total ITRDB holdings to 560. Currently being processed are 12 densitometric series from the Pyrenees (Spain and France) submitted by Otto Braker and Fritz Schweingruber, EAFV, Birmensdorf, Switzerland; 47 sites from Dave Stahle, University of Arkansas; and 66 chronologies from Ed Cook and Gordon Jacoby at Lamont-Doherty Geological Observatory of Columbia University.

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1. f. UNPUBLISHED TECHNICAL NOTES

This section contains unpublished technical reports which were based on research that was funded by NSF grants ATM-8115754 and ATM-8319848. Those marked with an asterisk (*) are attached.

Cropper, J. 1982. Independent Pressure Reconstructions for 20 Grid Points in the North Pacific Region from Arctic Tree-Ring Eigenvectors. Technical Note Number 23, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Lough, J. M. 1983. The Southern Oscillation and North American Climate, 1602 to 1962. Technical Note No. 24, Laboratory of Tree-Ring Research, University of Arizona, Tucson. (Subsequently published in Journal of Climate and Applied Meteorology 24:952-66:1985. See Publication 10.)

Lough, J. M. 1983. Twenty-Two Year Cycles in Instrumented Sea-Level Pressure and Temperature Records: Are They Evident in Dendroclimatic Reconstructions? Technical Note No. 29, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Lough, J. M. 1984. The Documentary Record of Drought and Flood in China: A Comparison with Dendroclimatic Reconstructions from Western North America. Technical Note Number 31, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Lough, J. M. 1984. Program Instructions and Computer Output Related to Climatic Causes (ATM 8115754) and Climatic Regimes (ATM 8319848) Projects: 1982 to 1986. Technical Note Number 35, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Lough, J. M. 1985. Application of Tree-Ring Reconstructions to Examine the Possible Impact of Explosive Volcanic Eruptions on North American Climate Since 1602. Technical Note Number 36, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

*Lough, J. M. 1986. Description of Climate Data Sets Assembled for Climatic Regimes Project. Technical Note Number 41, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

*Lough, J. M. 1986. Climatic Data and Climatic Event Indexes and Bibliographies. Climatic Regimes Project. Technical Note Number 42, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

*Lough, J. M. 1986. Time Series Characteristics of Climate/Proxy Climate Series Analyzed in Climate Regimes Project. Technical Note Number 43, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

*Lough, J. M. 1986. Reconstructed Sea Surface Temperatures of the Eastern North Pacific: Comparisons with Other Dendroclimatic Reconstructions. Technical Note Number 44, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

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Lough, J. M. 1986. Comparisons of Climate/Proxy Climate Series. II: Precipitation in the Southwestern United States. Technical Note Number 46, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Lough, J. M. 1986. Comparisons of Climate/Proxy Climate Series. III: Precipitation in the Midwest United States. Technical Note Number 47, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Lough, J. M. 1986. Comparisons of Climate/Proxy Climate Series. IV: Temperature and Precipitation in Alaska and Northwestern America. Technical Note Number 48, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Lough, J. M. 1986. Comparisons of Climate/Proxy Climate Series. V: Temperature in the Hudson Bay/N.E. Canada Region. Technical Note Number 49, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Lough, J. M. 1986. Climatic Regimes of the Western Hemisphere Since 1600 A.D.: an Examination of the Evidence from Climate/Proxy Climate Series. Technical Note Number 50, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Rapp, J. G. 1986. Technical Considerations for Simulation and Modeling. Technical Note Number 40, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Rose, M. R. 1983. Time Domain Characteristics of Tree-Ring Chronologies and Eigenvector Amplitude Series from Western North America. Technical Note Number 25, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Rose, M. R. 1984. Time Domain Characteristics of Selected Southern Hemisphere Tree-Ring Chronologies. Technical Note 26, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Rose, M. R. 1984. Verification of Southwestern U. S. Dendroclimatic Reconstructions. Technical Note Number 37, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Sowell, R. and J. M. Lough. 1984. Spectral Analysis of Time Series by Program SPECTRA. Technical Note Number 27, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

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Wu, X. and J. M. Lough. 1985. Estimating North Pacific Summer Sea-Level Pressure Back to 1600 Using Proxy Climate Records from China and North America. Technical Note Number 38, Laboratory of Tree-Ring Research, University of Arizona, Tucson. (Subsequently published in Advances in Atmospheric Sciences 4(1):74-84:1987. See Publication 13.)

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LaMarche, V. C., Jr. and C. W. Stockton. 1974. Chronologies from temperature-sensitive bristlecone pines at upper treeline in western United States. *Tree-Ring Bulletin* 34:21-45.

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