STATE OF DENDROCLIMATOLOGICAL INFORMATION AVAILABLE FROM NORTH AMERICA

85/03/15

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1.0 Introduction

High quality tree-ring records sensitive to climatic variations are now becoming available throughout temperate and subpolar areas of the world (Hughes, *et al.*, 1982). Such tree-ring chronologies can provide climatic information on time scales as short as one season to as long as a century. However, the reliability of such dendroclimatic data is maintained only by sampling high quality tree-ring materials, dating and processing them carefully, and subjecting only the best materials to rigorous dendroclimatic analysis (Fritts, 1976; Hughes *et al.*, 1982; Brubaker and Cook, 1984).

Most dendroclimatic reconstructions have been used to address a particular question in a local area or watershed where there are usable tree-ring and climate data. For example, Lisa Graumlich and Linda Brubaker, Department of Forestry, University of Washington are conducting the first basic research of this kind in Washington. They are reconstructing the annual temperature at Longmire with high-elevation tree-ring chronologies.

A grid of 65 North American tree-ring chronologies (Figure 1) from semi-arid sites has been calibrated with climatic data and the calibration used to reconstruct spatial variations of past temperature, precipitation, and pressure over a large sector of North America and the North Pacific (see Blasing and Fritts, 1976; Fritts *et al.*, 1979). Similar tree-ring grids are now being used to reconstruct climate in other areas of the world (e.g. Hughes et al., 1982; Briffa *et al.*, 1983). Data from particular tree-ring chronologies can be used to reconstruct climatic variations in specific nearby areas. It will be shown later that even the data from the large North American grid are likely to emphasize large-scale variations over hundreds of km rather than local variations that are unique to the individual stations used for calibration. Recently Cropper & Fritts (1984) used reconstructions from four climate stations of a large grid to estimate the temperature and precipitation of the Pasco Basin.

2.1 Tree-Ring Data

Special collecting, measuring, and analyzing techniques have been designed to help separate and remove the nonclimatic variations from the climatic information in tree-ring-width data (Fritts, 1976; Hughes *et al.*, 1982). Such techniques were applied in the selection of 65 high quality arid-site western North American tree-ring chronologies. The chronologies were selected on the basis of the greatest number of trees sampled, the statistical characteristics of the data, the longest records, and the spatial distribution of the sampled tree sites (Fritts and Shatz, 1975). All chronologies in the 65-site array spanned the period from 1600 to 1963, but were best replicated after 1700, and had a geographical coverage extending from the North Pacific coastal states to the Black Hills of North Dakota and from the Canadian Rocky mountains to Durango, Mexico (Figure 1).

Kutzbach and Guetter (1980) studied calibration and verification of climatic grids of varying densities and size to estimate climate over different regions. The density of the 65-chronology grid is about seven sites per million square kilometers (Cropper and Fritts, 1982), which is nearly three times the "high-density" network of 2.5 sites per million square kilometers, considered by Kutzbach and Guetter to be adequate for evaluating large-scale spatial variations in climate. They used high-density grids of instrumental data confined to restricted longitudinal sectors such as western North America to estimate climatic information over a wider area such as the entire North American continent and found that the results were sometimes comparable in quality to those obtained from lower-density grids spread over the entire region they were estimating.

It was also noted by Fritts and Lough (1985) that the large-scale atmospheric circulation anomalies over the North Pacific and North America which influence the growth of the trees tend to move from west to east (Bryson and Hare, 1974) and influence surface temperature and precipitation in regions well beyond the area of the tree-ring grid. The results of Kutzbach and Guetter (1980) support these observations and help to justify the use of the 65 tree-ring chronologies to reconstruct climatic variations beyond the boundaries of the tree-ring grid, which in this case is confined to western North America.

The tree-ring predictors consisted of two sets of the first 15 principal components (PCs) of the 65 chronologies: the first, with, and the second, without, first-order autocorrelations removed. These accounted for 69 percent and 67 percent, respectively, of the total tree-ring variance over the period 1600 to 1963. Thus 31 percent and 33 percent of the smallest scale variations in growth represented by the last 50 PCs was not used in the analysis.

2.2 Climatic Data

These 15 or so PCs of tree growth were calibrated with the larger PCs of seasonal surface temperature at 77 stations and precipitation at 96 stations in the United States and southwestern Canada using the relationships during the 1901 to 1961 period. They were also calibrated with the larger PCs of seasonal sea-level pressure at 96 grid points between 100E and 80W/20 to 70N over the period 1899 to 1961. (The grid points are located at 10-degree latitude intervals and 10-degree longitude intervals between 20 and 50N and 20-degree intervals at 60 and 70N.) Two additional sets of temperature and precipitation data which cover only western North America were calibrated but the results were disregarded because they were not so accurate as those from the 77 and 96 stations.

2.1 Calibration and Verification

Calibration models were varied to include different numbers of PCs of climate and growth arranged at different leads or lags. A model included one or two pairs of the 15 tree-ring PC sets with and without autocorrelation removed for a lead of one year preceding climate to a lag of one year following climate (Fritts *et al.*, 1979). Several models were considered in an attempt to assess which autoregressive and moving-average (lag and leading) relationships gave the best reconstructed relationships as well as the most reasonable model structure in terms of the climate/tree-growth system (Fritts et al., 1979). Stepwise canonical regression, modified from Blasing (1978) (also see Fritts et al., 1979; Lofgren and Hunt, 1982), was used to calibrate PCs of growth with PCs of climate. This stepwise analysis reduced the large number of predictor PCs (15 or 30) to a smaller number of from one to seven canonical variates. A transfer function was obtained and applied to the tree-ring PCs to reconstruct seasonal temperature and precipitation at each station and sea-level pressure at each grid point back to 1602.

The instrumental record of temperature and precipitation prior to 1901 (the independent data) was used to verify each reconstruction (Gordon, 1982). In winter, for example, 54 stations had seven or more years of data prior to 1901, the number of years which we considered to be the minimum needed for statistical testing. Eight stations had more than 30 years of independent observations. The amount of independent data available for the other seasons varied only slightly from these numbers.

Insufficient independent data were available prior to 1899 for comparable verification of the sea-level pressure models so a split calibration/verification technique was used. The data from 1901-1960 were divided into six different 10-year subperiods. A given model was calibrated six times over the remaining 52 years and reconstructions were obtained for the ten independent years of each subperiod. The six 10-year subperiods were later combined to obtain a continuous 60-year series of independent estimates which then were tested against the instrumental record (Gordon, 1982). In addition, the calibration and verification tests were applied to the PCs of sea-level pressure rather than the gridded data because the latter might be expected to include a high amount of spatial correlation (Livezey and Chen, 1983) and would complicate the interpretation.

Objective statistical tests to verify that the reconstructions are reliable were made with the climatic data independent of the calibration period used to develop the transfer function. These verification tests could be made only at those climatic stations with independent data. When two or more out of a possible five verification tests performed consistently better than expected by chance (at the 95 percent confidence level) a station reconstruction was considered to be verified. A positive reduction of error indicated that there was useful information in the reconstruction (Gordon and Leduc, 1981). Only models in which the number of stations with significant statistics exceeded the 95 percent confidence level were retained for further study.

3.2 Averaging Procedures

The statistics were used to rank the models and select those which gave the optimum results. The collective statistics for the optimum models were all well above the 95 percent confidence level. The reconstructions from a number of those models with the greatest differences in structure were grouped into twos and threes and their results averaged. The calibration and verification statistics were recalculated and the combinations of two or three with the best verification and calibration statistics were then selected as the optimum seasonal result.

In the case of pressure, those model structures with the best calibration and verification statistics were recalibrated using the instrumental data over the entire calibration period to obtain the final transfer function and reconstructions. This procedure verified the general form of the model for pressure but not the actual sea-level pressure reconstructions (Gordon, 1982).

The increase in reliability of the final averaged series was measured by comparing the calibration and verification statistics derived from the combined reconstruction to the average of the statistics derived from the individual models. The statistics of the selected final combinations were always an improvement over the average statistics for the individual sets. The combined models appeared to reduce the noise (error) while retaining the signal of climate that was common in the individual reconstructions.

The combined reconstructions for the seasons as well as the instrumental record were merged into annual estimates (December through November). The calibration and verification statistics were recalculated using the annual values of both the reconstructions and instrumental data. It is interesting to note here that our attempts to calibrate the tree-ring data directly with annual climatic data failed because no more than one or two canonical variates usually were significant.

One biological explanation for this result is that the factors limiting to growth varied according to the season considered. Low temperatures, for example, might be limiting in winter while high temperatures, if associated with drought, might be limiting in summer. This positive association between ring width and climate in winter would counteract the negative association in summer so that the statistical relationship with annually averaged temperatures would be too weak to give significant calibration and verification statistics. However, when seasonal data rather than annual data were calibrated, the inverse response to temperatures in summer would be converted to a temperature estimate that could be averaged with the estimates from other seasons to obtain a more reliable annual reconstruction. This procedure resulted in a marked improvement in both the calibration and verification statistics which became progressively better as the original seasonal calibrations were averaged into the combined models and then averaged again to form the annual estimates (Table I).

As an example of the improvement at different levels of averaging, the best performing models for seasonal temperature and seasonal sea-level pressure had calibrated variances averaged over all seasons and stations in the reconstructed grid of 30.1 percent and 28.6 percent, respectively (Fritts and Lough, 1985). The reconstructions from the best two or three models within seasons were averaged and the square of the correlation coefficient between the average estimate and the instrumental record calculated. Averaged for the four seasons these statistics indicated a variance in common of 36.2 percent and 35.5 percent, respectively. When the seasonal estimates were averaged to form annual values, the variance in common rose to 47.7 percent and 48.4 percent, respectively. Except for the percent reduction of error for autumn temperature, the verification statistics for all annual combinations were higher than those for the seasonal data.

The percentage variance calibrated in these annual values varied among the stations or grid points (Figure 2). For annual temperature, between 28 percent and 66 percent of the station variance was calibrated and for annual sea-level pressure between 24 percent and 76 percent of the grid-point variance was calibrated. The reduction of error pooled over all stations or grid points was 0.127 for annual temperature and 0.167 for annual pressure with 75 percent and 60 percent of the stations and grid points, respectively, having reduction of errors greater than zero, values which indicate some skill in the estimates (Figure 2). The number of other verification tests that passed significance testing averaged 50 percent and 44 percent, respectively.

As might be expected, the temperature reconstructions were weakest around the periphery of the grid and in the eastern United States (Figure 2) which were the areas furthest removed from the tree sites. Although some groups of temperature stations located at sizeable distances downwind from (east of) the tree sites had significant statistics, the relationship generally weakened with increasing separation distance and especially with increasing proximity to the maritime influences of the Atlantic Ocean and Gulf of Mexico. Large areas over the central portions of the pressure grid which were upwind from (west of) the tree sites had more than two significant verification tests pass or had positive reduction of error statistics. These, as well as a variety of other results (Gordon et al. in press; Lough, 1983; 1984), repeatedly demonstrate that the final chosen models performed adequately over the independent as well as the dependent period, and their averaged results appear to contain meaningful information on past variations in climate over a wide spatial grid.

The improvement in statistics indicated that the errors of the reconstructions were further reduced by combining several grid points or station estimates into regional averages or by smoothing the data temporally by using an 8-year, 50-percent low-pass digital filter to enhance the low frequencies (LaMarche and Fritts, 1972; Fritts, 1976). This result may reflect the fact that only the larger PCs of tree growth and climate were used in the canonical analysis, so that the large-scale regional patterns of climate were calibrated at the expense of precision at the individual grid points or stations.

4.1 The Pasco Basin Tree Ring Data and their Analysis

Cropper and Fritts (1984) evaluated the existing climatic reconstructions for the Pasco Basin in Washington. They also attempted to improve upon the existing reconstructions using a new set of ten chronologies representing tree-ring-width collections obtained by Linda Brubaker, Lisa Graumlich and Terry Mazany, which are now on deposit in the International Tree-Ring Data Bank. These new chronologies all ended after the growing season of 1975 or later so that it was possible to extend the analysis 13 more years beyond the 65 chronology set which stopped in 1963.

The cross-dating of these new chronologies was checked by program COFECHA (Holmes, 1983) and they were standardized using the program ARSTAN developed by Edward R. Cook and modified by Richard L. Holmes (1984) to use both an exponential curve and then a rigid spline to detrend the data. Bivariate means are calculated and the differences in autoregression between the measured series are modeled and removed during the process of standardization only when this procedure leads to a reduced error variance.

These data were calibrated and verified with the mean seasonal temperature or mean seasonal precipitation from Baker, Spokane, Walla Walla, and Waterville. These data had much poorer verification statistics than the reconstructions derived from the larger 65-chronology grid. Failure to match the large-grid statistics eliminated these new reconstructions from further consideration.

4.2 The Pasco Basin Climate

Reconstructions from the earlier study using 77 temperature stations and 96 precipitation stations were available from Aberdeen, Baker Ranch, Kalispell, Kamloops and Roseburg. Only temperature reconstructions were available from Spokane, Vancouver and Walla Walla, while only precipitation was available from Colville, Lewiston, Port Angeles and Porthill. The nine temperature and precipitation reconstructions were combined to form Columbia Basin average series. In addition the temperature records were averaged from Baker, Spokane and Walla Walla to approximate the Pasco Basin values. There were 51 out of 150 verification statistics that were significantly different from random values and 22 out of 30 reduction of error statistics that were greater than zero (Cropper and Fritts, 1984).

The annual reconstructions for the Pasco Basin are shown in Figure 3 and the seasonal values are shown in Figure 4 and 5. The statistics from the 20th century are compared to the statistics reconstructed for the three prior centuries in Table 1.

The reconstructed temperature averaged over the year was generally warmer and more variable in the three prior centuries. The average annual value for 1602-1900 was only 0.17 degrees F warmer which is 22% of the standard deviation for annual temperature reconstructed in the 20th century. However the summer and autumn average values were reconstructed to have been somewhat cooler in the three prior centuries.

The reconstructed annual precipitation was on the average 0.32 inches higher in the prior three centuries while the standard deviation of the reconstructions was 29% higher. The precipitation reconstructed for spring and summer was 0.15 and 0.11 inches lower in the prior three centuries.

One can see from the figures that the seasonal reconstructions for both temperature and precipitation exhibit many differences from one another, but there are also overall patterns common among the seasons much like those found in the modern instrumental record. The 17th century began with generally cool and moist conditions and ended with relatively average conditions. A cold period noted in the instrumental record around 1915 was as severe as conditions reconstructed in the three prior centuries. Droughts were common in a number of time periods and sometimes were more persistent over time than droughts found in the 20th century.

5.1 Limitations of Current Work

In the following discussion the various limitations are itemized first, then remedies are suggested.

(1) The reconstructions used in the Pasco Climatic Reconstruction project (Cropper and Fritts, 1984) were based on 65 tree-ring chronologies which begin in 1600 or earlier and extend to 1963. Many of the chronologies are based on a small number of trees during the first half of the 17th century and the standard error is high (Fig. 6).

(2) The chronologies are also widely scattered over a large geographic area and were calibrated with an even larger grid of temperature and precipitation stations. The canonical regression used in the calibration related only the largest scale variations in tree growth to the very largest scale variations of climate. The above project (Cropper and Fritts, 1984) used the combined records of four individual station estimates closest to the Pasco Region. These reconstructions appear to contain about one half of the climatic variance of the Pasco region (although this value was not measured directly) which was probably dominated by the large-scale variations throughout the region. The remaining unexplained variance represents unassessed climatic variations,

especially those of a local nature as well as noise or error.

(3) There were probably climatic records closer to the Pasco Basin area which were not analyzed. This was largely because they were not readily available and finances of the project were limited. These data need to be examined to relate the mean values of the Pasco Basin to the reconstructions for the adjoining stations that were reconstructed for the same time period.

(4) The climatic analysis was limited in scope. It should include analysis of circulation features that are revealed in the pressure reconstructions and be more closely related to the climatic modeling effort.

(5) The filtered annual reconstructions for a region appear to be the most reliable reconstructions available at present. The statistics that represent century-long and regional averages can be used with a high degree of certainty because the averaging has reduced the noise in the individual station seasonal climatic estimates. As we consider smaller time or space scales such as the results for individual stations (the variance over the region), an annual or a seasonal value, the error or noise in the record attains much less acceptable levels and the reconstructions appear to be relatively inaccurate.

5.2 Possible Remedies

(1) A number of climatically sensitive tree core collections should be obtained from the mountains and plateaus around the study area. This could include up to 15 to 20 chronologies, two cores per tree and 25 to 40 trees per site. The ages of these

trees would be expected to range from 150 to 450 years. If temperature reconstruction is important, then high altitude species that may extend back 500 or more years, should be collected. This might represent ten additional sites. The reconstructions should then be recalibrated to include these new chronologies.

The recalibration need not be restricted to these 30 sites. They could still include the ten new chronologies studied by Cropper and Fritts (1984) and many if not all of the 65 chronologies that have been proven to be climatically sensitive.

(2) Calibration models should include analysis of the biological system as well as Auto Regressive Moving Average (ARMA) features of the tree-ring series. They also should include ridge regression analysis which is a possible replacement of response function analysis. Such an approach would provide the information needed to determine the best strategy of calibration. They would help answer the following questions: Should the climate of different seasons be calibrated separately? What seasons should be used for temperature and precipitation? Should the high and low frequencies in growth variation be calibrated separately? If so, what are the optimum models to use? Perhaps by separating these two frequency extremes, higher frequencies can be calibrated more effectively.

(3) The available climatic data should be examined and those series most useful to this study identified. These data should then be entered into the computer or purchased from NOAA in preparation for analysis. A lack of homogeneity of data needs to be identified and eliminated and missing values estimated.

(4) The relationships of these data to pressure anomalies over the North Pacific should also be studied and the reconstructions of these pressure data related to the anomalies of temperature and precipitation. Perhaps some relationships that become evident from this study will suggest ways of improving the climatic modeling.

REFERENCES

Blasing, T. J. 1978. Time series and multivariate analysis in paleoclimatology. In Time Series and Ecological Processes, H. H. Shugart, Jr., ed., pp. 212-26. SIAM-SIMS Conference Series, No. 5. Society for Industrial and Applied Mathematics, Philadelphia.

Blasing, T. J. and H. C. Fritts. 1976. Reconstructing past climatic anomalies in the North Pacific and western North America from tree-ring data. Quaternary Research 6(4): 563-79.

Briffa, K. R., P. D. Jones, T. M. L. Wigley, J. R. Pilcher and M. G. L. Baillie. 1983. Climate reconstruction from tree rings: Part 1. Basic methodology and preliminary results for England. Climatology 3:233-42.

Brubaker, L. B. and E. R. Cook. 1984. Tree-Ring Studies of Holocene Environments, Late Quaternary Environments of the United States, Vol. 2: The Holocene, H. E. Wright, Jr., ed., pp. 222-235, University of Minnesota Press, Minneapolis.

Bryson, R. A. and F. K. Hare, eds. 1974. Climates of North America, World Survey of Climatology, Vol. 11. Elsevier. Amsterdam.

Cook, E. R. and R. L. Holmes. Program Arstan Users Manual. December 1984. Lamont-Doherty Geological Observatory, University of Columbia, Palisades, N. Y. and Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ.

Cropper, J. P. and H. C. Fritts. 1982. Density of tree-ring grids in western North America. Tree-Ring Bulletin 42: 3-9.

Cropper, J. P. and H. C. Fritts. 1984. A 360 year temperature and precipitation record for the Pasco Basin derived from tree-ring data. Final Report to Pacific Northwest Laboratories, Battelle Memorial Institute, Contract No. B-G5323-A-E.

Fritts, H. C. 1976. Tree Rings and Climate. Academic Press, London.

Fritts, H. C. and J. M. Lough. 1985. An estimate of average annual temperature variations for North America, 1602 to 1961. Climatic Change (in press).

Fritts, H. C. and D. J. Shatz. 1975. Selecting and characterizing tree-ring chronologies for dendroclimatic analysis. Tree-Ring Bulletin 35:31-40.

Fritts, H. C., G. R. Lofgren and G. A. Gordon. 1979. Variations in climate since 1602 as reconstructed from tree rings. Quaternary Research 12(1):18-46.

Gordon, G. A. 1982. Verification of dendroclimatic reconstructions. In Climate from tree rings M. K. Hughes, P. M. Kelly, J. R. Pilcher and V. C. LaMarche, Jr., eds. pp. 58-61. Cambridge University Press, Cambridge.

Gordon, G. A. and S. K. Leduc. 1981. Verification statistics for regression models. In Proceedings of Seventh Conference on Probability and Statistics in Atmospheric Sciences, pp. 129-33. November, 1981, Monterey, California.

Gordon, G. A., Lough, J. M., Fritts, H. C. and Kelly, P. M. In Press. Comparison of sea-level pressure reconstructions from western North American tree rings with a proxy record of winter severity in Japan, Journal of Climatology and Applied Meteorology. (Accepted).

Holmes, R. L. 1983. Computer-Assisted quality control in tree-ring dating and measuring. Tree-Ring Bulletin 43:69-78.

Hughes, M. K., P. M. Kelly, J. R. Pilcher and V. C. LaMarche, Jr., eds. 1982. Climate from Tree Rings. Cambridge University Press, Cambridge.

Kutzbach, J. E. and P. J. Guetter. 1980. On the design of paleoenvironmental data networks for estimating large-scale circulation patterns. Quaternary Research 14(2):169-87.

LaMarche, V. C., Jr. and H. C. Fritts. 1972. Tree-rings and sunspot numbers. Tree-Ring Bulletin 32:19-33.

Livezey, R. E. and W. Y. Chen. 1983. Statistical field significance and its determination by Monte Carlo techniques. Monthly Weather Review 111:46-59.

Lofgren, G. R. and J. H. Hunt. 1982. Transfer functions. In Climate from tree rings, M. K. Hughes, P. M. Kelly, J. R. Pilcher and V. C. LaMarche, eds., pp. 50-6. Cambridge University Press, Cambridge.

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, AZ.

Lough, J. M. 1984. The documentary record of drought and flood in China: a comparison with dendroclimatic reconstructions from western North America, Technical Note No. 31, Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ.

FIGURES

TABLE 1

Statistical comparison of the 20th century record with the reconstructed record for 1602-1900

MEAN

Variable	Instrumental 1901-1970	Reconstruction 1602-1900	(1901-1970) - (1602-1900)
TEMPERATURE (F)			
ANNUAL	49.485	49.657	-.172
Winter	31.399	32.018	-.619
Spring	52.208	52.530	-.322
Summer	70.298	70.245	0.053
Autumn	50.065	49.741	0.324
PRECIPITATION (inches)			
ANNUAL	13.730	14.051	-.321
Winter	4.145	4.212	-.067
Spring	4.991	4.841	0.150
Summer	1.180	1.067	0.113
Autumn	3.414	3.931	-.517

STANDARD DEVIATION

Variable	Reconstruction 1901-1961	Reconstruction 1602-1900	(1901-1961) / (1602-1900)
TEMPERATURE (F)			
ANNUAL	0.742	0.771	0.962
Winter	1.904	1.768	1.076
Spring	1.173	1.441	0.814
Summer	1.051	1.205	0.872
Autumn	0.436	0.600	0.727
PRECIPITATION (inches)			
ANNUAL	1.162	1.495	0.777
Winter	0.358	0.443	0.808
Spring	0.818	0.883	0.926
Summer	0.327	0.300	1.090
Autumn	0.643	1.035	0.621

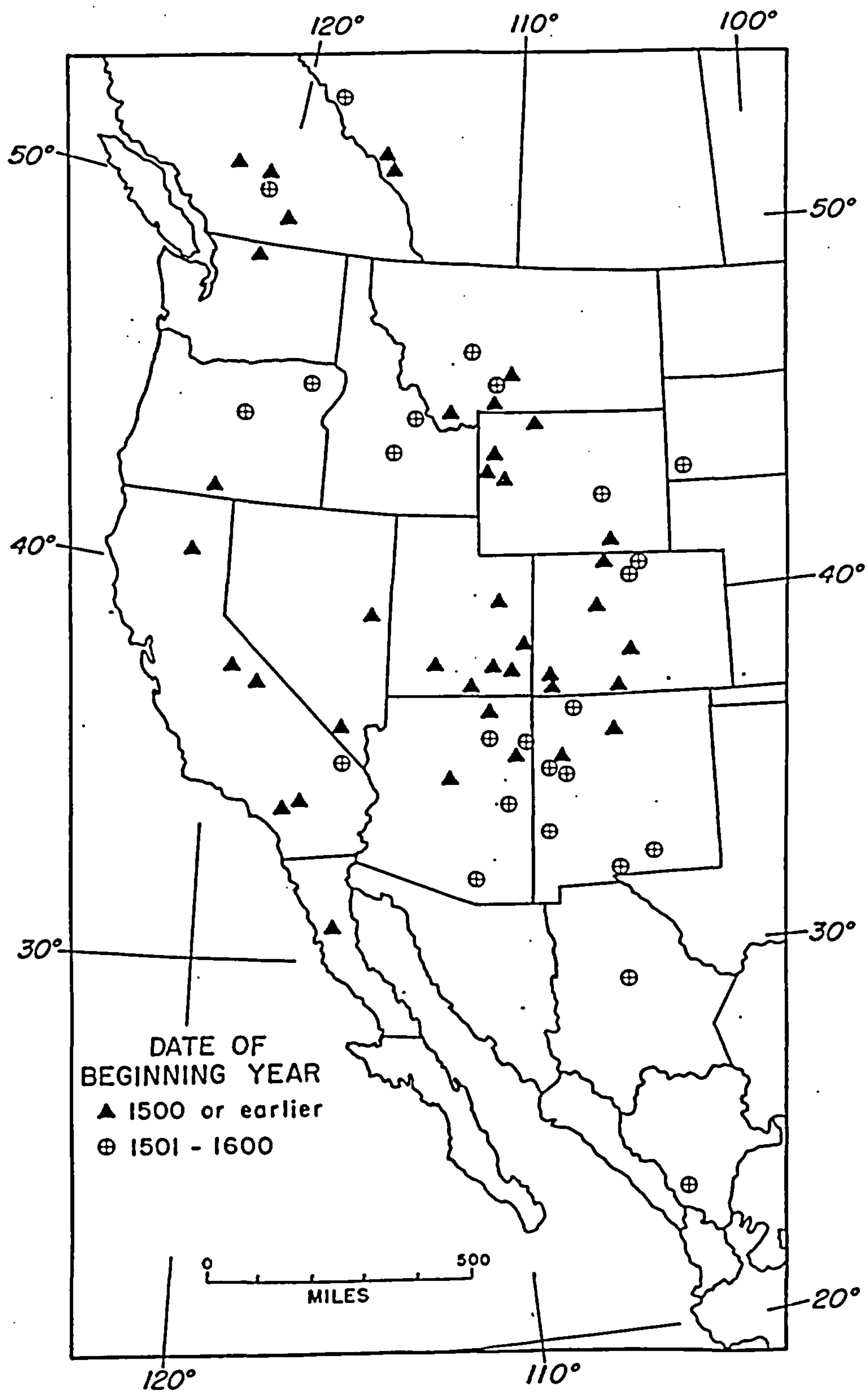

120°
110°
100°
50°
50°
40°
40°
30°
30°
20°
DATE OF
BEGINNING YEAR
1500 or earlier
1501 - 1600
0
500
MILES
120°
110°

Figure 1

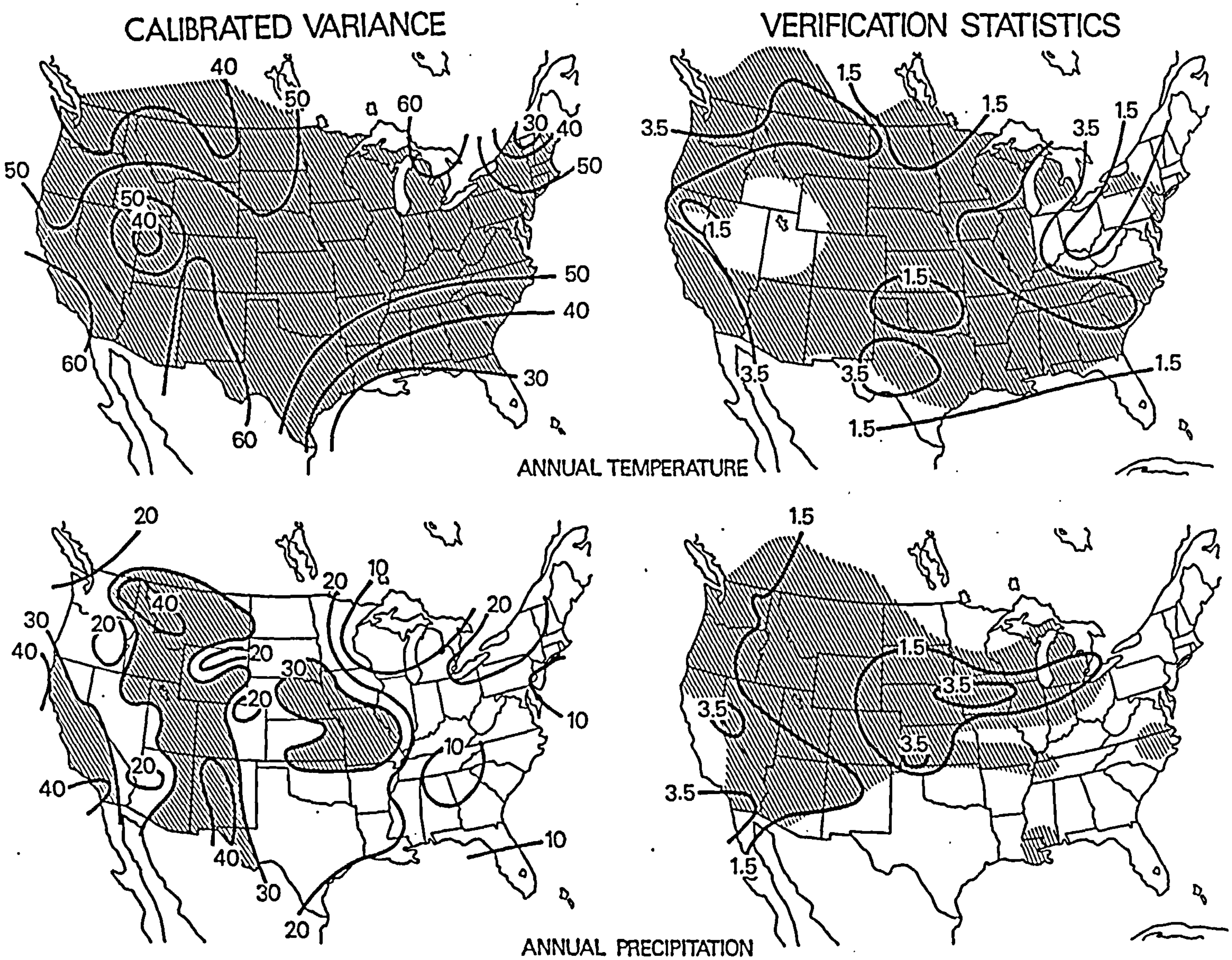
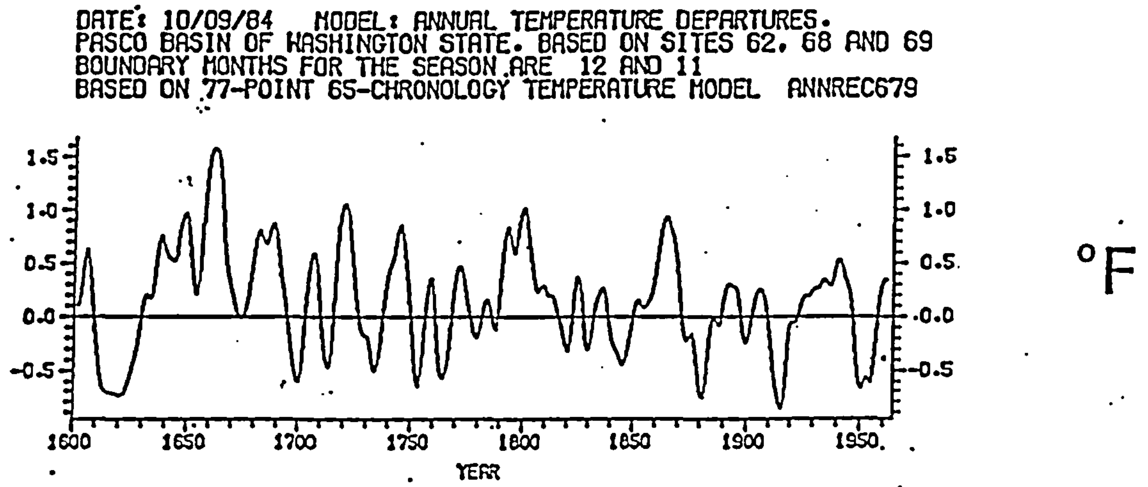

CALIBRATED VARIANCE
VERIFICATION STATISTICS
ANNUAL TEMPERATURE
ANNUAL PRECIPITATION

Figure 2


DATE: 10/09/84 MODEL: ANNUAL TEMPERATURE DEPARTURES.
PASCO BASIN OF WASHINGTON STATE. BASED ON SITES 62, 68 AND 69
BOUNDARY MONTHS FOR THE SEASON ARE 12 AND 11
BASED ON 77-POINT 65-CHRONOLOGY TEMPERATURE MODEL ANNREC679
1.5
1.0
0.5
0.0
-0.5
1600
1650
1700
1750
1800
1850
1900
1950
YEAR
°F

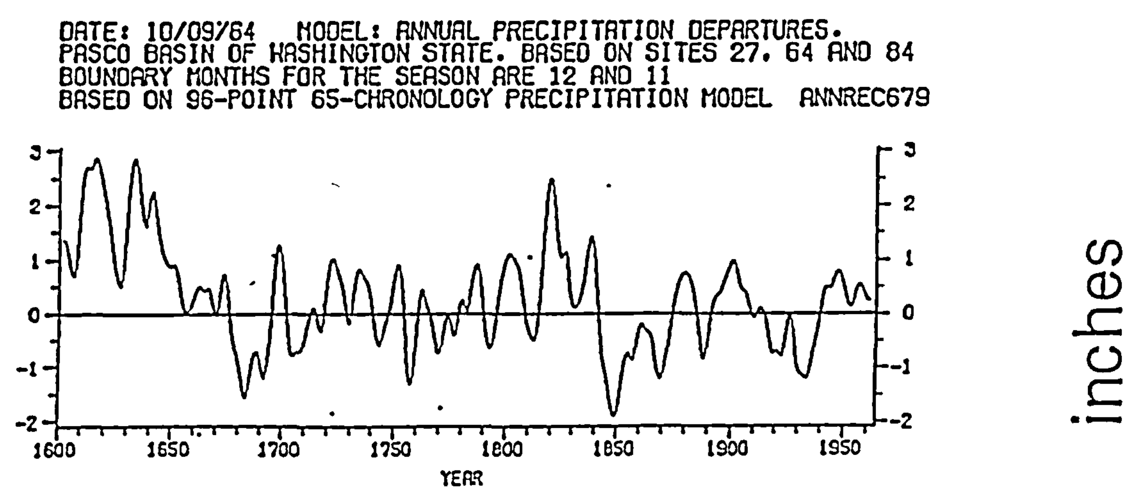
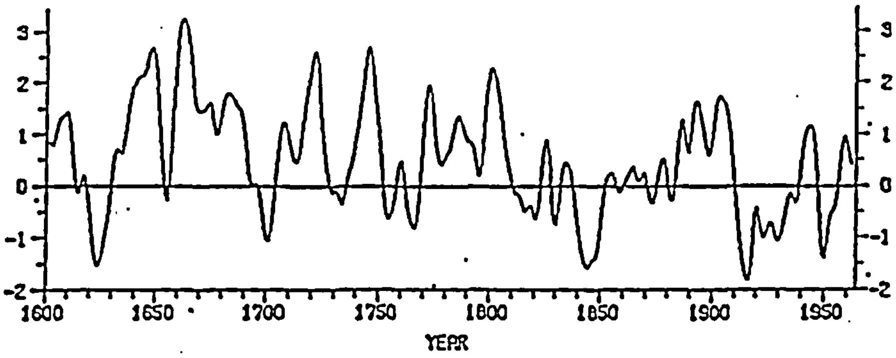
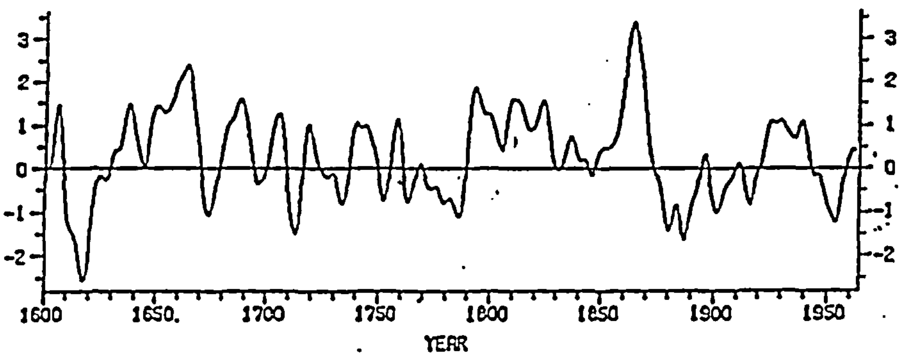

DATE: 10/09/84 MODEL: ANNUAL PRECIPITATION DEPARTURES.
PASCO BASIN OF WASHINGTON STATE. BASED ON SITES 27, 64 AND 84
BOUNDARY MONTHS FOR THE SEASON ARE 12 AND 11
BASED ON 96-POINT 65-CHRONOLOGY PRECIPITATION MODEL ANNREC679
3
2
1
0
-1
-2
1600
1650
1700
1750
1800
1850
1900
1950
YEAR
inches

Figure 3

DATE: 10/09/84   MODEL: WINTER TEMPERATURE DEPARTURES.
PASCO BASIN OF WASHINGTON STATE. BASED ON SITES 62, 68 AND 69
BOUNDARY MONTHS FOR THE SEASON ARE 12 AND 2
BASED ON 77-POINT 65-CHRONOLOGY TEMPERATURE MODEL 5TI16TIM

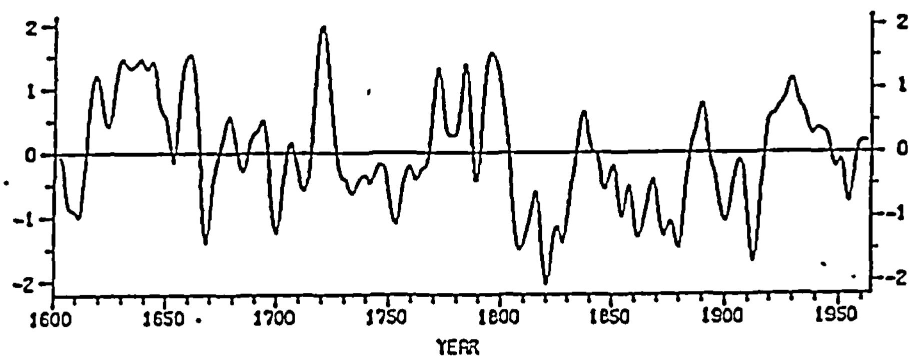


DATE: 10/09/84   MODEL: SPRING TEMPERATURE DEPARTURES.
PASCO BASIN OF WASHINGTON STATE. BASED ON SITES 62, 68 AND 69
BOUNDARY MONTHS FOR THE SEASON ARE 3 AND 6
BASED ON 77-POINT 65-CHRONOLOGY TEMPERATURE MODEL 16BM16I1M



°F

DATE: 10/09/84   MODEL: SUMMER TEMPERATURE DEPARTURES.
PASCO BASIN OF WASHINGTON STATE. BASED ON SITES 62, 68 AND 69
BOUNDARY MONTHS FOR THE SEASON ARE 7 AND 8
BASED ON 77-POINT 65-CHRONOLOGY TEMPERATURE MODEL 7IF9F8FMF



DATE: 10/09/84   MODEL: AUTUMN TEMPERATURE DEPARTURES.
PASCO BASIN OF WASHINGTON STATE. BASED ON SITES 62, 68 AND 69
BOUNDARY MONTHS FOR THE SEASON ARE 9 AND 11
BASED ON 77-POINT 65-CHRONOLOGY TEMPERATURE MODEL 18IM17FMF

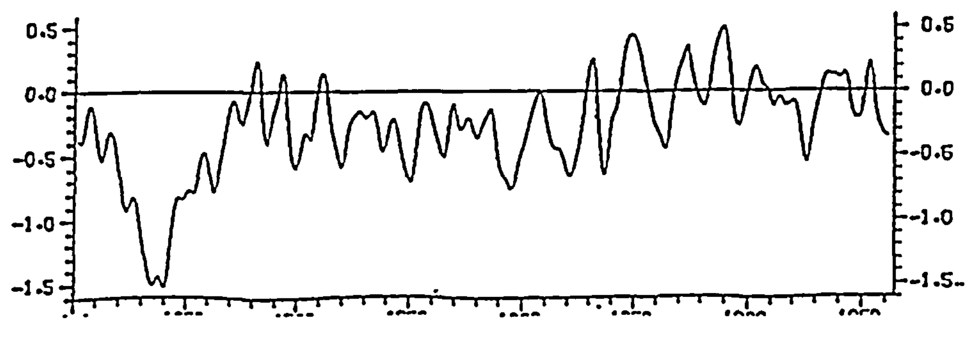
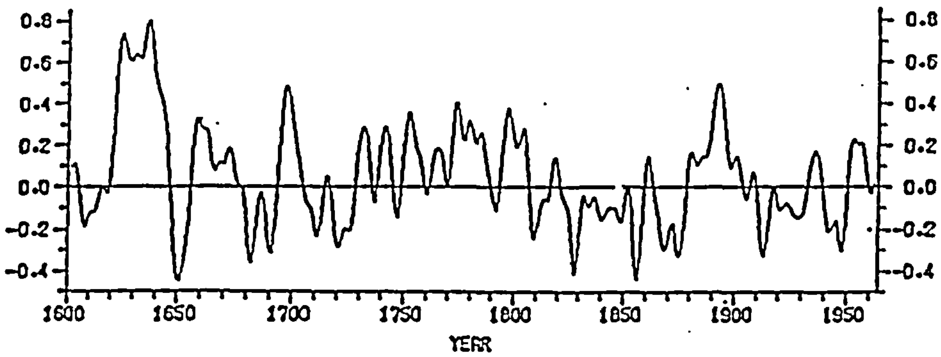
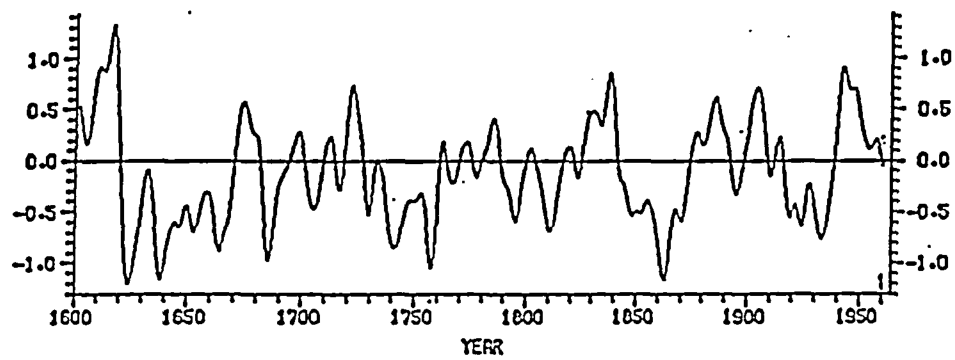


Figure 4

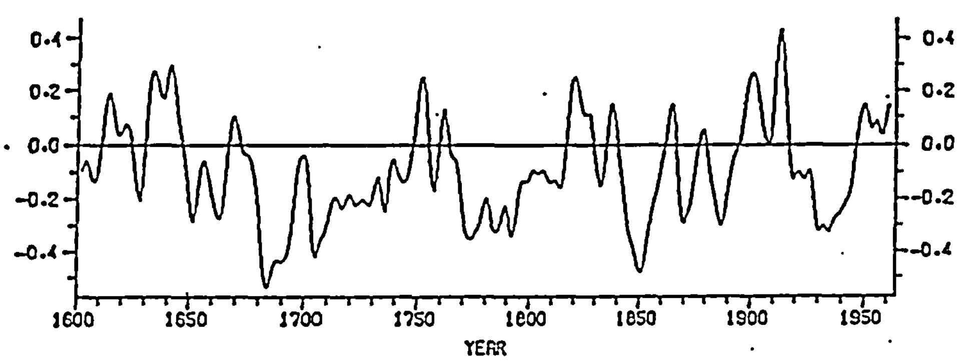
DATE: 10/09/84 MODEL: WINTER PRECIPITATION DEPARTURES.
PASCO BASIN OF WASHINGTON STATE. BASED ON SITES 27, 64 AND 84
BOUNDARY MONTHS FOR THE SEASON ARE 12 AND 2
BASED ON 96 POINT 65 CHRONOLOGY PRECIPITATION MODEL 5I6IM



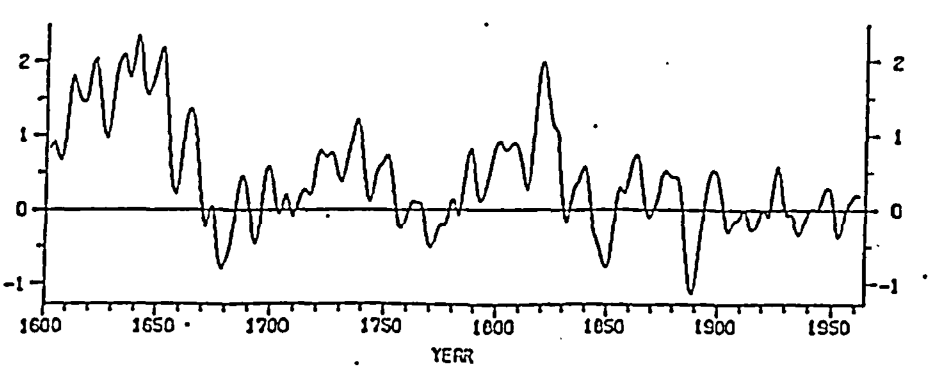
DATE: 10/09/84 MODEL: SPRING PRECIPITATION DEPARTURES.
PASCO BASIN OF WASHINGTON STATE. BASED ON SITES 27, 64 AND 84
BOUNDARY MONTHS FOR THE SEASON ARE 3 AND 6
BASED ON 96-POINT 65-CHRONOLOGY PRECIPITATION MODEL 10M8IF9IM



DATE: 10/09/84 MODEL: SUMMER PRECIPITATION DEPARTURES.
PASCO BASIN OF WASHINGTON STATE. BASED ON SITES 27, 64 AND 84
BOUNDARY MONTHS FOR THE SEASON ARE 7 AND 8
BASED ON 96-POINT 65-CHRONOLOGY PRECIPITATION MODEL 16F6FFF

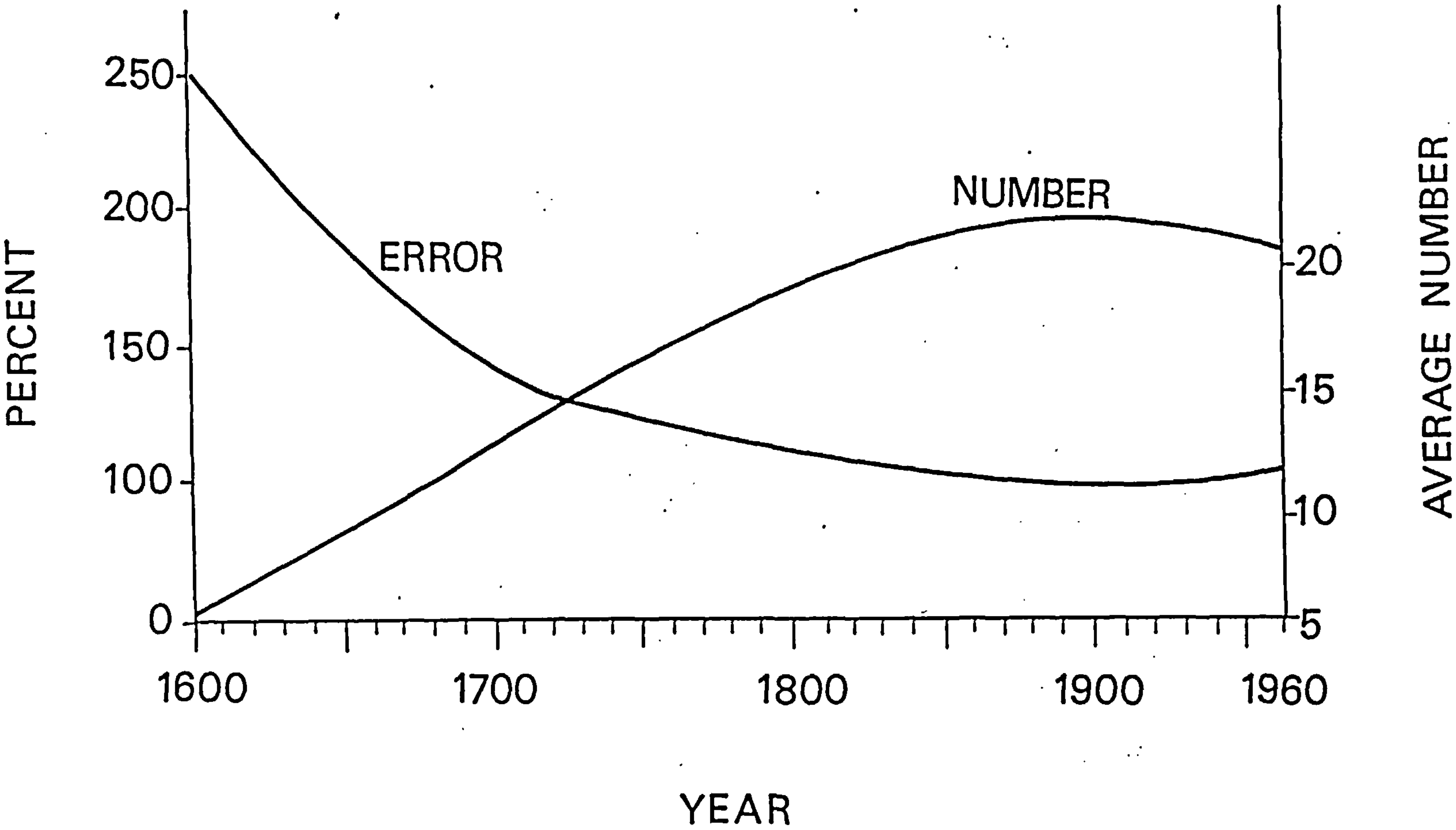


DATE: 10/09/84 MODEL: AUTUMN PRECIPITATION DEPARTURES.
PASCO BASIN OF WASHINGTON STATE. BASED ON SITES 27, 64 AND 84
BOUNDARY MONTHS FOR THE SEASON ARE 9 AND 11
BASED ON 96-POINT 65-CHRONOLOGY PRECIPITATION MODEL 3IMF3FMF



inches

Figure 5



PERCENT
250
200
150
100
0
ERROR
NUMBER
AVERAGE NUMBER
20
15
10
5
1600
1700
1800
1900
1960
YEAR

Figure 6