DENDROCLIMATIC HISTORY OF SOUTHWESTERN UNITED STATES

by

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Foreword

The following report is a compilation of information on the climate of southwesternaUnited States. It represents only a first approximation of climatic variations and is a part of an ongoing study conducted at the University of Arizona in which tree-ring evidence is compared and related to a variety of data on climatic change. The first part of the report is a discussion of the climate of the Colorado Plateau, originally composed by the second author. The latter part of the report includes a sample of the evidence compiled on climatic variation throughout the 19th century. We have includedaa some data on circulation, which is still tentative, with the hope that its presentation may stimulate interest and provoke comment. A more complete file of data on various types of climatic evidence is being compiled at the Laboratory of Tree-Ring Research. References to the literature for data abstracted from this file are not included in this report.

I. Introduction

This report on the present climate of the Colorado Plateau provides background information for a study of significant historical climatic events of western North America with emphasis upon the Colorado Plateau. First the Colorado Plateau is defined, secondly its topographical features are reviewed as they relate to climate, then the present climate is discussed and finally the present controls of the climate are described.

II.eeColorado Plateau Descriptionee

The Colorado Plateau is usually defined as a geomorphic regionee in parts of four states: Arizona, Colorado, New Mexico, and Utah. The Rio Grande Valley is included in this report as a portion of the region because the cultural history of the Valley is closely related to the cultural history of the Colorado Plateau. With this modification the Plateau (see figure 1) is bounded on the east by the Rio Grande Valley and on the west it reaches to the Grand Wash Fault which is nearly on the Arizona-Nevada border. The north boundary extends to the margin of the Uinta Mountains in Utah and the south boundary to the Mogollon Mountains in New Mexico.

The climate of the Colorado Plateau is influenced markedly by topographic features. Its mean height is more than 6,000 feet but elevations sometimes exceed 13,000 feet. Some of its more important features which produce elevation changes are fault scarps, igneous domal uplifts, and volcanic areas (Thornbury, 1965).

Important faults that produce prominent topographic features are those on the west side of the High Plateaus of Utah (see figure

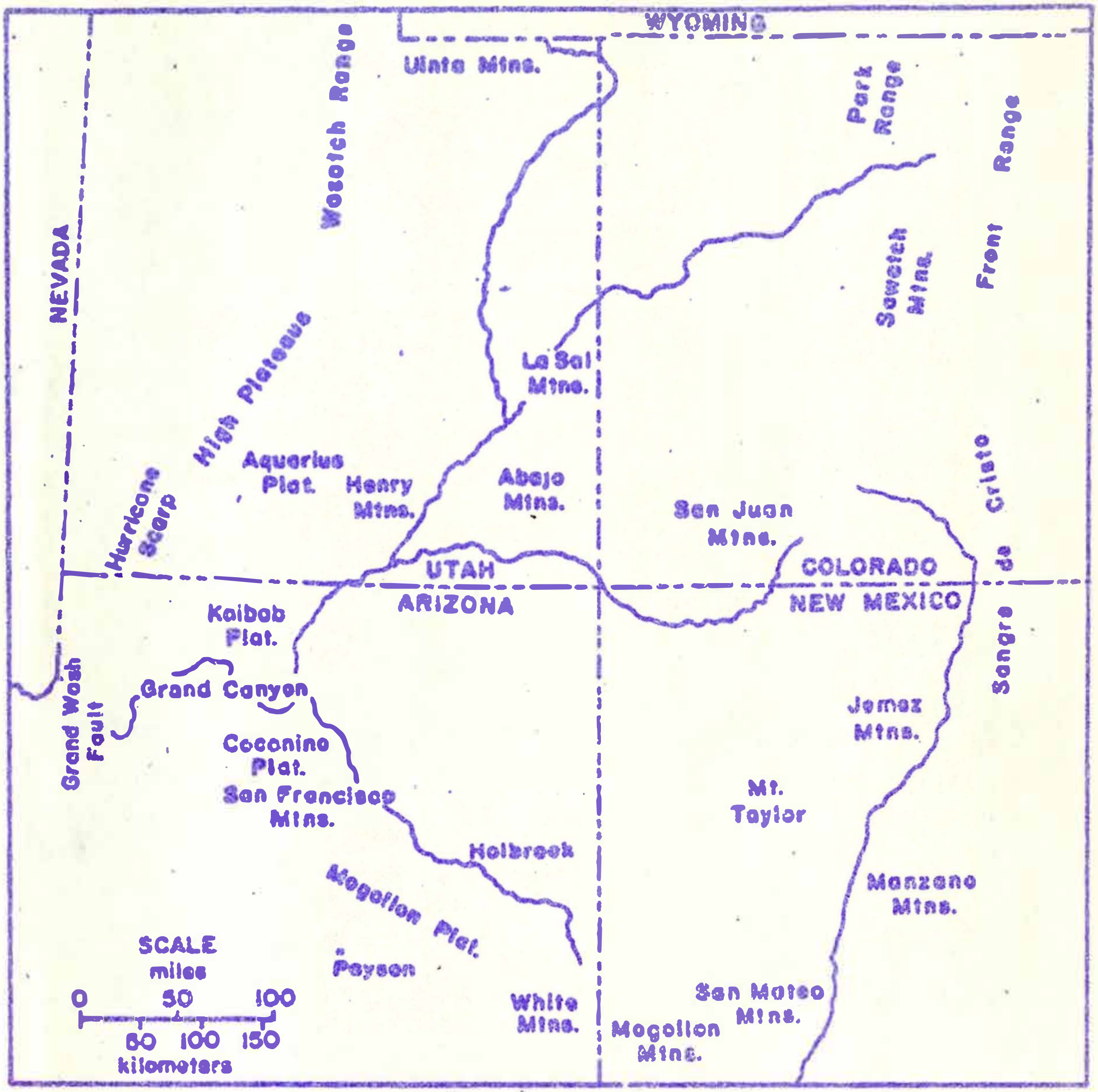


Figure 1. Location of some of the features on the Colorado Plateau (modified from Thornbury, 1965). Portions of the Rio Grande Valley are not shown.

1). The cliff produced by the Grand Wash Fault is nearly 4,000 feet in maximum height. The Hurricane Fault Scarp northeast of the Grand Wash Fault, reaches to a height of 1,400 feet. The Paunsaugunt Fault forms the western boundary of the Aquarius Plateau. This Plateau, which exceeds 11,000 feet and is one of the highest plateau in the United States, is as much as 2,000 feet higher than the valley to the west (Thornbury, 1965). The mountains formed by those scarps are important as they intercept air as it flows from the west.

Six major volcanic areas and igneous domal uplifts are found on the Plateau and on its margins. The volcanic areas are the San Francisco Mountains in north central Arizona (maximum elevation 12,600 feet), Mt. Taylor in northwest New Mexico (elevation 11,300 feet), and the High Plateaus in southeast Utah. The three igneous domal uplifts are the Abajo Mountains (maximum elevation 11,360 feet), La Sal Mountains (maximum elevation 13,000 feet), and Henry Mountains (maximum elevation 11,500 feet) which are all located in Utah.

The southern edge of the Colorado Plateau is bounded by the Mogollon Plateau (see figure 1), the White Mountains in Arizona and Mogollon Mountains in east central New Mexico. Elevations are generally above 7,000 feet on the Mogollon Plateau. To the east the highest point in the White Mountains is Baldy Peak (elevation 11,350 feet) and the highest in the Mogollon Mountains is Whitewater Baldy (elevation 10,900 feet).

In addition to these physiographic features on the Colorado

Plateau there are major mountain masses around the region which influence its climate. The Sierra Nevada and the Coast Range lie about 500 miles west of four corners, the Southern Rocky Mountains of Colorado and New Mexico form the east boundary of the Colorado Plateau, and the Middle Rockies of Utah and Wyoming lie to the north. The effects of these land masses on the climate of the Colorado Plateau are considered in Section IV.

III. Present Climate of the Colorado Plateau

Most of the stations on the Colorado Plateau have an average January temperature in the range from 25° F to 35° F and an average July temperature in the range from 60° F to 80° F. Temperatures in winter at higher elevations can be considerably colder, perhaps as low as -50° F on the high peaks. Winters can also be very cold at lower elevations and even in midsummer heating of homes is sometimes required in the early morning hours (Green and Sellers, 1964).

The geographical distribution of precipitation as shown in figure 2 is complicated but generally it is low except on the higher elevations. Precipitation ranges between 10 inches and 25 inches per year except for some of the lower elevations and basins which receive less than 10 inches and a few of the higher areas which receive more than 25 inches. Between 30 and 50 percent of the winter precipitation falls as snow in northeastern Arizona and on higher elevations the percentage may be as high as 75 (Green and Sellers, 1964).

Figure 3 shows the climatological divisions of the Colorado Plateau and figure 4 shows a plot of the monthly precipitation at climatic stations of the region graphed by climatological divisions. Figure 4 shows that:

(1) A peak in precipitation occurs in winter in the western part of the region. This peak in precipitation becomes relatively less pronounced to the east.

(2) A minimum in precipitation appears in late spring in Arizona and western New Mexico. Reduced amounts of precipitation are also shown in almost all the other climatological divisions at the same time.

(3) The amounts of precipitation in August reach their maximum for the Arizona, New Mexico, and Colorado portions of the Colorado Plateau.

(4) High precipitation occurs in August in every division.

(5) A peak in precipitation occurs in October for divisions in Utah and Colorado.

McDonald (1956) surveyed the temporal and spatial variability of precipitation in Arizona and Sellers (1960) extended the temporal study and added stations from western New Mexico. The coefficient of variation, i.e., the ratio of the standard deviation of the precipitation amount to the mean amount, is, in general, quite large for desert regions as would be predicted from the climatological rule that relative variability of precipitation varies inversely as the mean of the total precipitation. This relationship holds for a given station. Differences exist in the variability of winter and

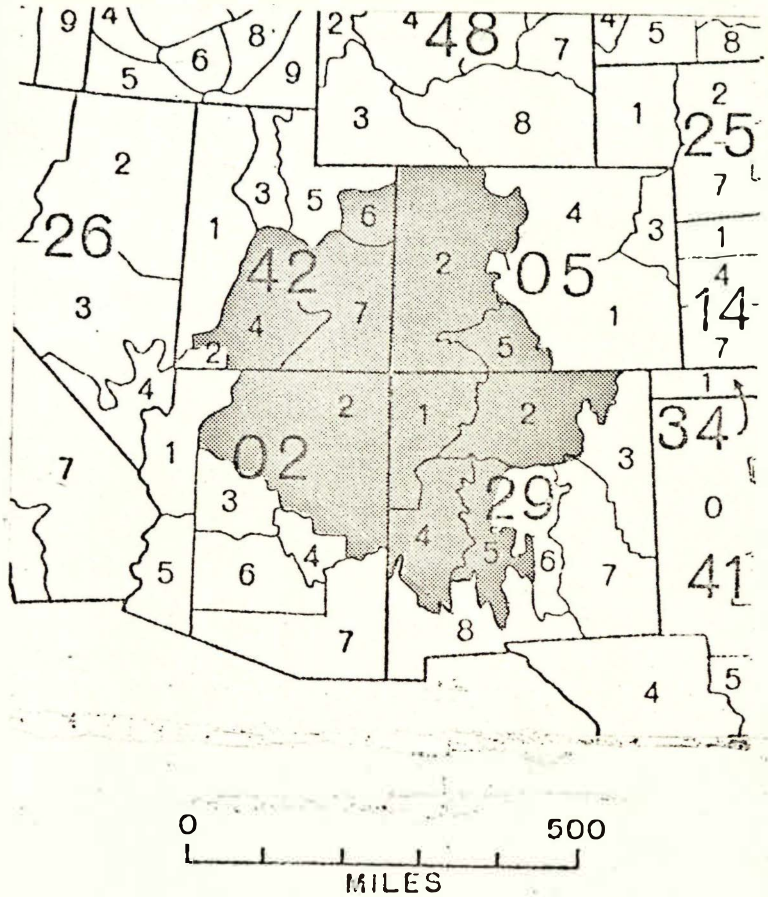


Figure 3. Climatological divisions of the Colorado Plateau.

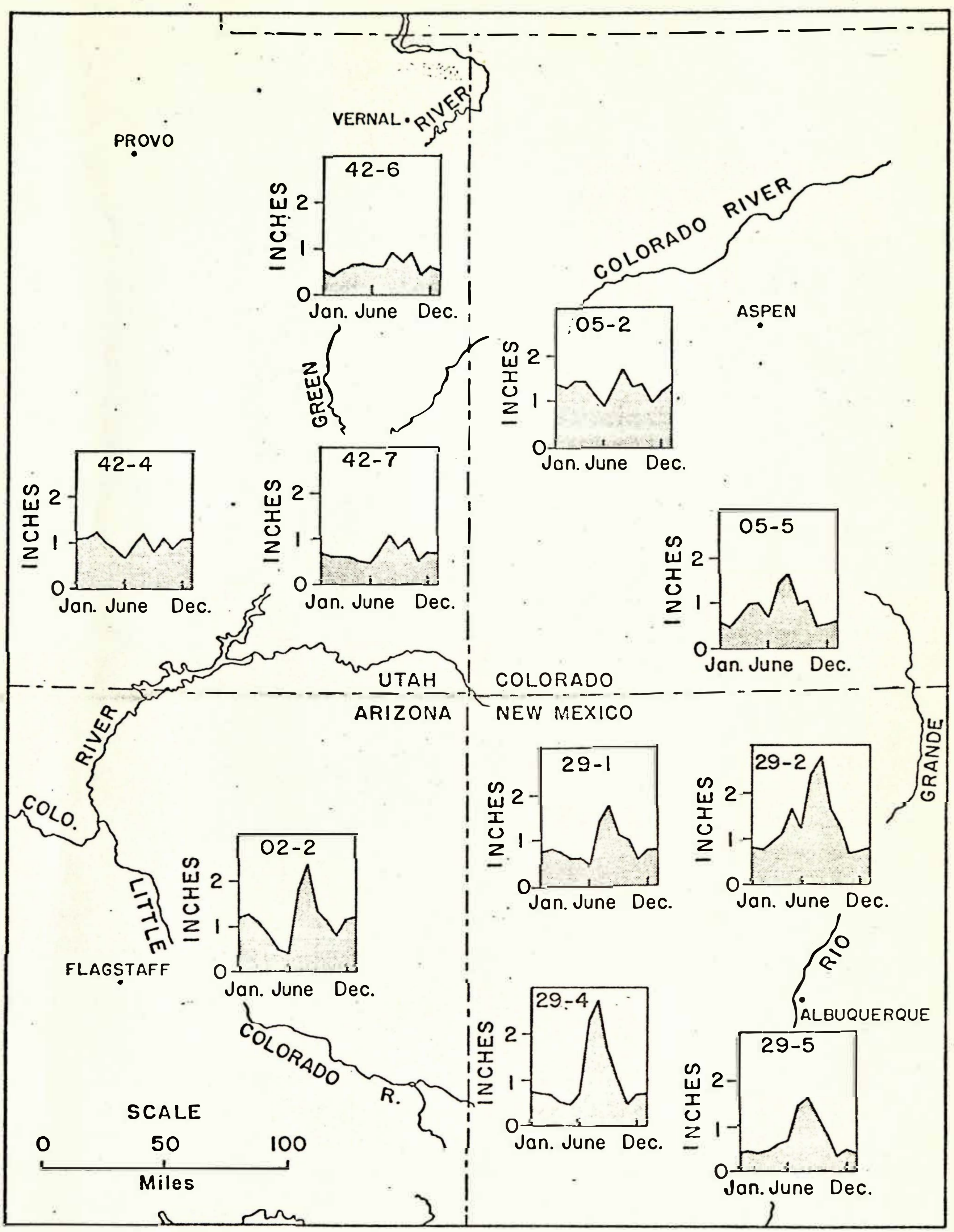


Figure 4. Mean monthly distributions of precipitation in the various climatic divisions of the Colorado Plateau (1931-1960) from U. S. Weather Bureau (1963). The numbers on the graphs identify the divisions shown in figure 3.

summer precipitation. Flagstaff, for instance, has a .37 coefficient of variation for the winter and a .28 coefficient for summer. The summer precipitation is thus more dependable from year to year! Even though it is spotty in a spatial sense because it is usually the localized showery type from cumulonimbus cells, the total area involved can be quite large when integrated over a basin such as the upper Colorado (Marlatt and Riehl, 1963). The winter precipitation for any given year, however, is less variable from station to station than is the summer because the winter precipitation is released from widespread stratus-type storms.

The fact that the temporal winter variability of precipitation is higher than the summer variability can be explained by examining rainfall amounts from different storms. In the upper Colorado River basin an average of twenty-four storms occur per year. Twenty-five per cent of these, or six storms, produce half the precipitation (Riehl and Elsberry, 1964). Thus, if a few of the big storms fail toimaterialize the precipitation amounts for that year are low.ii The big storms are those storms that require several days for passage over a region and of course the passage time depends on the synoptic situation.

Riehl (1965) shows that the year to year variation of precipitation over a large basin such as the upper Colorado is less than the variation on a station basis. From 1930 to 1960 over the entire basin one-half the years had precipitation within 10 percent of the mean. The year with the lowest precipitation received 65 percent of the low winter precipitation of the Colorado Plateau. The Mogollon Plateau also produces a rainshadow which is especially marked in northeast Arizona. As shown in figure 5, the resultant streamlines of air movement in winter trend from southwest to northeast across Arizona. Payson, southwest of Holbrook and south of the Mogollon Plateau, at 4,848 feet, receives 21.48 inches (mean) per yearee (Green and Sellers, 1964), while Holbrook, north of the Mogollonee Plateau at 5069 feet receives only 8.64 inches (mean) per yearee (Green and Sellers, 1964). Payson receives more precipitation than Holbrook ever month of the year but the difference in May and June is small. The HighePlateaus of Utah also produce a rainshadow. Indeed, the four corners area lie in a rainshadow as mountains surround it in almost all directions. Other topographical features contributing to the rainshadow for the four corners area are: the Kaibab and Coconino Plateaus to the west; the Uinta and Wasatch Mountains on the north; the Park and Front Ranges, the San Juan, Sangre de Cristo, Jemez, and Sawatch Mountains on the east; and Mt. Taylor, the Black and Manzano Ranges and the San Mateo Mountains on the southeast. The only relatively low access routes to the four corners area are through the Grand Canyon and through a narrow gap south of the High Plateaus of Utah. Of course, rainshadows occur on a much smaller scale also. From an examination of precipitation records from stations on east and west facing slopes Marlatt and Riehl (1963) show that in the upper Colorado basin west facing stations receive about two inches of precipitation more per year than east facing stations at the same elevation.

Figure 5. Streamlines of resultant surface winds for February (Mitchell, 1969). The same general pattern exists from November through March.

The controls of the climate can be approached on a seasonal basis with the winter controls discussed first. The winter rains of the area are brought by low pressure systems from the Pacific which are associated with the westerly jet stream. The precipitation amounts generally decrease from west to east across the region as the eastern areas are farther from the Pacific Ocean, which is the source of the moisture.

Figure 5 shows streamlines of resultant surface winds for February (Mitchell, 1969), which can be used along with equivalent potential temperature to analyze the winter climate of the Colorado Plateau. The period of observation for most of the 37 stations used in the streamline study was 1931-1938. Mitchell obtained the same basic pattern of streamlines for the months of November, December, January, and March. His maps of equivalent potential temperature for these months also show the same basic pattern. These months can therefore be called the winter months. The dashed lines in figure 5 represent convergence zones and gradients in equivalent potential temperature. One of the lines runs across northern Utah. Above this gradient the lines are essentially east-west; below it on the Colorado Plateau they are from the southwest. Therefore, generally speaking, the winter circulation on the Colorado Plateau is from the southwest.

With the advent of spring the storm track frequency over the southern and middle sections of the Colorado Plateau decreases and a dry season sets in. Thus, reduced amounts or minimums in precipitation are observed on the Colorado Plateau except in northeastern

Utah where a few storms continue to pass and the lower Rio Grande Valley. Moist air at this time moves into eastern New Mexico and the Rio Grande Valley from the Gulf of Mexico because of the clockwise circulation around an anticyclone to the southeast (Bryson, 1957). The moist air is lifted by the mountains and precipitation is released. At the same time the low precipitation of the southwestern Colorado Plateau is a result of subsidence from the eastern end of the Pacific subtropical anticyclone.

Bryson and Lowry (1955a, 1955b) studied Arizona climate by using flow charts, upper air sequences, mean soundings, and diurnal temperature ranges. They found a large increase in rainfall starting about July 1 in most summers and they attribute this increase to a change in the dominant air mass over the state. Near the end of June the Pacific anticyclone shifts north (Bryson and Lowry, 1955a, 1955b) and the upper levels of the Bermuda high move northwest. As a result moist air is brought into the region by the southeasterly circulation about the Bermuda high. The moist air at times extends into Utah and Colorado, thus producing a rainfall maximum in August. The increase of precipitation in the Plateau is shown by Horn, Bryson, and Lowry (1957) and Trewartha (1966). If relative rainfall is defined as the rainfall of a given month divided by the annual total and expressed in percent then the change from June to July varies from about +9% in the southern Colorado Plateau to +1% at its northern limits. The change from July to August is also positive (more precipitation in August) and the change varies from +6% to +1% from south to north.

Figure 6 shows the streamline pattern for August. The boundary shown in figure 6 across Arizona represents an equivalent potential temperature gradient and convergence zone called the monsoon boundary. It divides the Colorado Plateau but it is a surface feature only; moist air aloft will extend north and west of the line. A westerly circulation can be seen in extreme northern Utah. The same basic pattern was determined by Mitchell for July and September. The monsoon boundary, however, is slightly farther west in September.

In addition there is another source of late summer and early autumn moisture that does not have its source region in the Gulf of Mexico. Record rainfalls are caused by tropical depressions in the Pacific Ocean off the Mexican Coast. These depressions have a greater effect on the southern portions of the Colorado Plateau than on those of the north but even there the effect can be appreciable. For instance, in early September, 1970, Bug Point, Utah near four corners, set a new record of precipitation for Utah: 6.0 inches of rainfall in 12 hours (U.S. Weather Bureau, 1970). Just south of the Mogollon Plateau in Arizona a new 24 hour record of 11.40 inches was recorded at Workman Creek I. This was also a record for the state. These records were caused by tropical storm Norma which was located off the west coast of Mexico.

In the autumn the Caribbean subtropical high retreats southeastward and drought conditions return in the southern part of the region. As figure 4 shows, however, the decrease of precipitation in the fall is not as rapid as the increase in the spring. The Utah

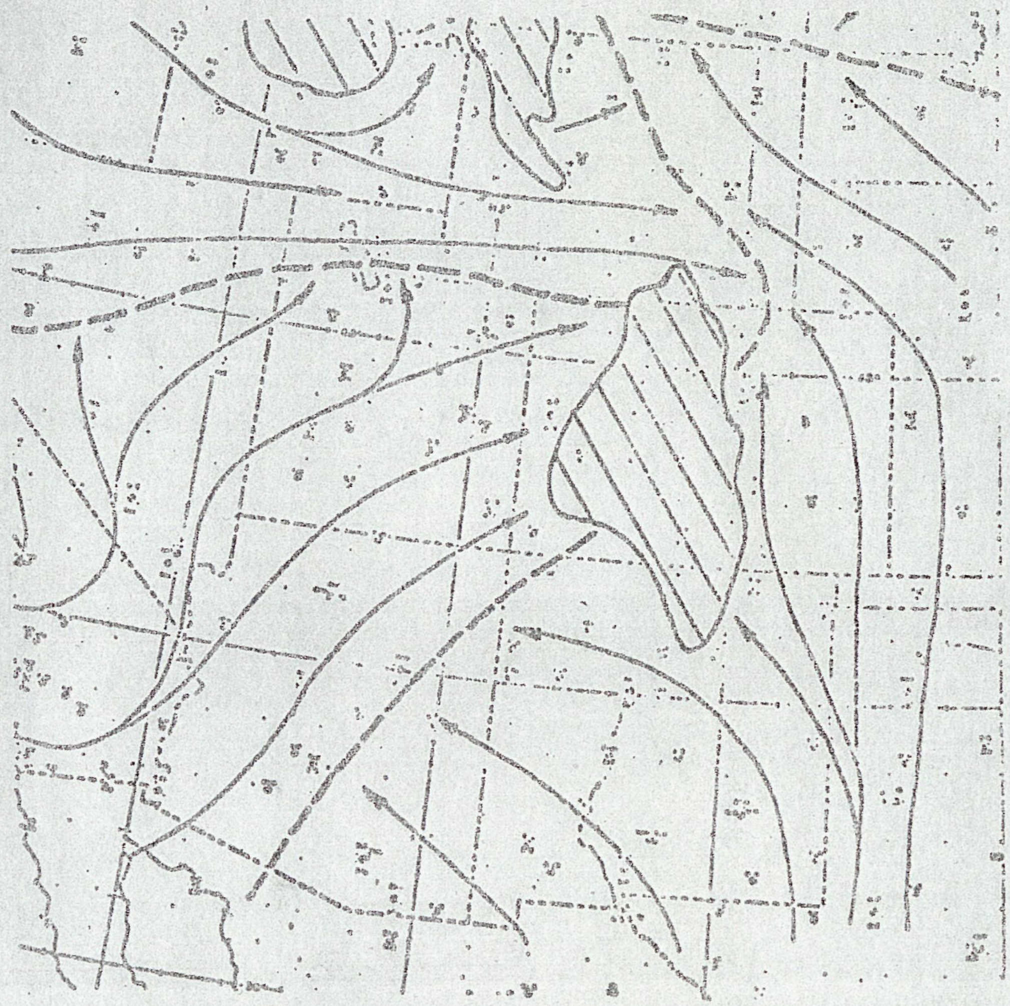


Figure 6. Streamlines of resultant surface winds for August (Mitchell, 1969). The same general pattern exists for July and September.

peak of enhanced precipitation in October is apparently caused by 500 mb lows (Richardson, 1971). Williams and Peck (1962) show that a large number of upper lows occur in Utah in October and in April-May. In October there is still a residual flow of moisture from the Gulf of Mexico and the convergence associated with these lows is responsible for the precipitation peak. In April-May the moisture is not present; the air over the state during these mophhs is primarily of Pacificpp origin. An interesting feature of lows aloft is that the lifting produced by them is nearly independent of topography. Therefore, there is not as much increase in precipitation with elevation from these storms as from frontal systems. The amount bypwhich precipitation increases with elevation is thus a function of the seasons; in October in Utah and Colorado the increase is smaller than during other times of the year. The curves of Schleusener and Crow, (1961) and Lull and Ellison, (1950) show this effect.

V. Climatic Patterns of the Southwestern United Stated, 1800-1900

A file of significant historical climatic events of the Colorado Plateau and surrounding areas is being compiled by the Tree-Ring Laboratory of the University of Arizona. The file also includes information on various proxy series of events or features which provide indirect evidence for climatic variability and change. This file startspp in 3000 B.C. and ends with the present. It contains approximately 1000pp entries and the data for the southwestern United States from a represent-pp ative period, 1800 A.D. to 1900 A.D., is summarized here. The southwestern United States as used in this section includes western Coloradopp and the states of Arizona, California, Nevada, New Mexico, and Utah. The

European settlement of this region began in New Mexico in 1598. Spanish missionaries arrived in California in 1769 and Americans arrived in great numbers with the California gold rush in 1849, the Mormon settlement of Utah in 1847, and after the conclusion of the Mexican war in 1848. The American influx contributed to improved climatic documentation and the records are much better from about 1850 to 1900 than from 1800 to 1850. The chief sources of information on the first half-century are missionary crop reports and diaries, the levels of enclosed lakes which respond to the mean flow of the streams feeding them, and tree-ring indices.

Selected historical series from the Southwest are presented along with tree-ring indices. The climatic patterns of the Southwest are described by decades for the century. The circulation described represents a very tentative reconstruction based in part upon the results of NSF Grant GA-2658 and the work of T. J. Blasing (Fritts et al., 1971). Conditional probabilities are based upon Arizona tree rings (Stockton and Fritts, 1968).

VI. Selected Historical Series

The historical series include the levels of Goose Lake, the levelsdd of the Great Salt Lake, the Santa Fe, New Mexico precipitation record,dd the reconstructed runoff of the upper San Francisco drainage basin indd New Mexico, and the precipitadion and levels of Lake Elsinore in the area of Los Angeles, California (Figure 7).

Historical water levels in western Great Basin lakes have been studied by several authors (Antevs, 1938; Harding, 1935a, 1935b, 1965; Bowman, 1935). Harding (1965) discusses the most complete and latest information. He bases his conclusions on precipitation records, historical sketches by early visitors, trees and stumps, and recorded lake

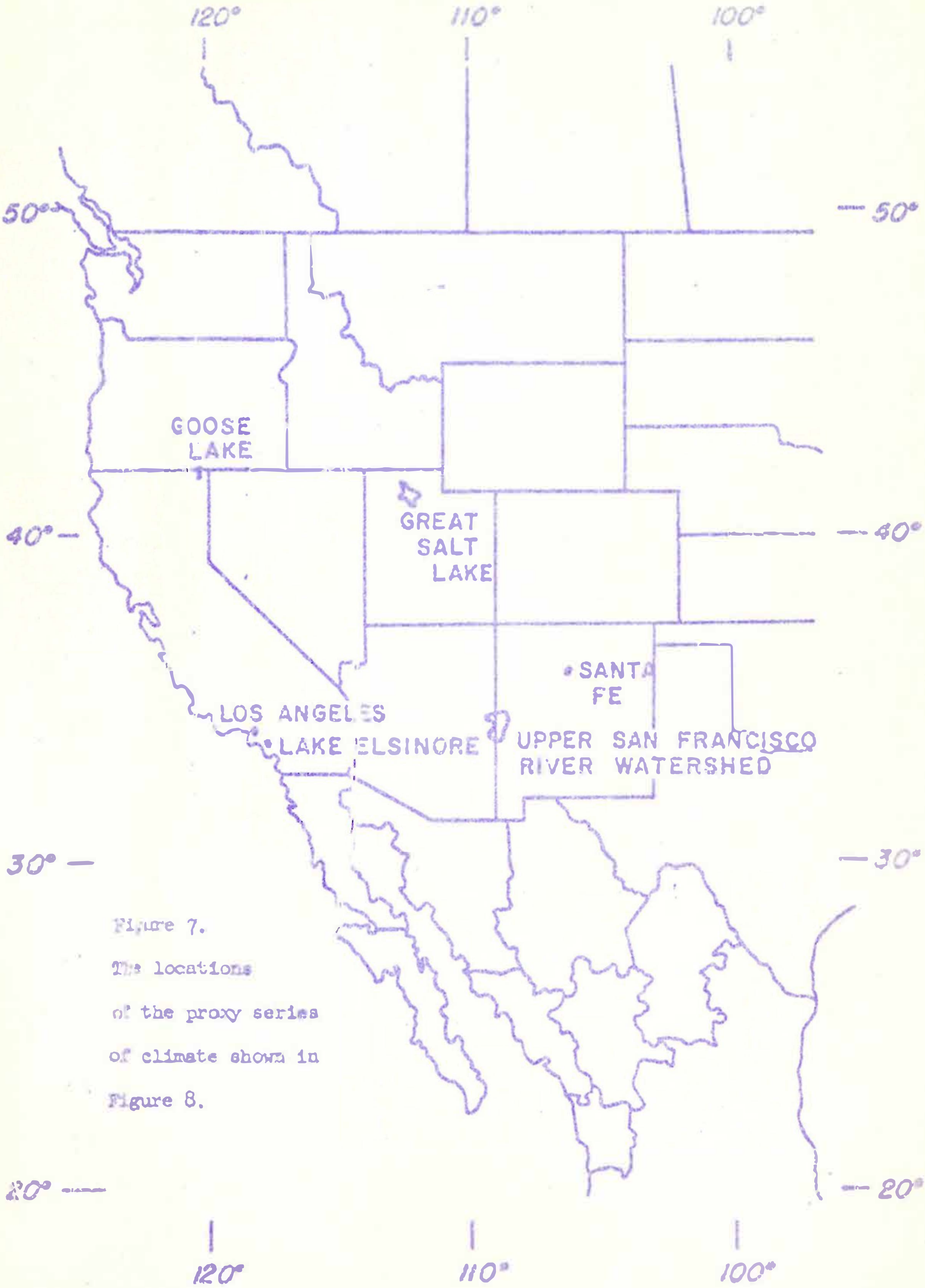


Figure 7. The locations of the proxy series of climate shown in Figure 8.

levels. Goose Lake, located near the eastern corner of the Oregon-California border, has the best early record near the western Great Basin. The elevation of the water in the lake as a function of time is shown in Figure 8. Historical observations are recorded by the points on the curve; some of the dashed fluctuations have been derived from precipitation data.

The precipitation of the Great Salt Lake basin and the elevation of the Great Salt Lake have been discussed by many authors (Antevs, 1938; Bowles, 1869; Gilbert, 1879; Harding, 1935a, 1965; Miller, 1966; Peck and Richardson, 1966). The lake is supplied with water from three sources, the largest of which is surface inflow from the Weber, Bear, and Jordan Rivers. These rivers drain the Uinta Mountains and Wasatch Range and thus the elevation of the lake is related to the precipitation of northern Colorado plateau. Several reports (Peck and Richardson, 1966) show thatéprecipitation during the current year is the most important factor affecting lake stage. The lake is shallow; it averages 13 ft at present, with gradually sloping shores. Thus, a given volumetric increase in water storage during a year produces considerable differences in lake elevation depending upon the initial lake level. The increased surface exposed at high lake levels combined with increased vaporization, which is more rapid when the fresh water content of the lake increases, helps to maintain stability in lake elevation. Therefore, much higher inflows thanéaverage are required to maintain the lake at a high stage. Very low inflows are required to maintain low stages in lake levels.

The elevation of the lake is known from 1851 and is shown in Figure 8. Gauge measurements started in 1875. Early explorers and Mormon

Figure 8. Proxy series for the climatic variations in southwestern United States, 1801-1900. Top to bottom: Goose Lake, California-Oregon (modified from Harding, 1965) - water surface elevation; Great Salt Lake, Utah (modified from Peck and Richardson, 1966) - water surface elevation; Santa Fe, New Mexico (Hardy, Overpeck, and Wilson, 1939) - precipitation record: annual precipitation values are shown as solid lines, April-September precipitation is represented by dashed lines, average values shown are for 1853-1938; Upper San Francisco River near Glenwood, New Mexico (Stockton, 1971) - total annual runoff reconstructed values derived from tree-ring indices, the estimated mean for 1753-1966 is shown; Los Angeles (Lynch, 1931) - precipitation indices; Lake Elsinore, California (Lynch, 1931) - water surface elevation.

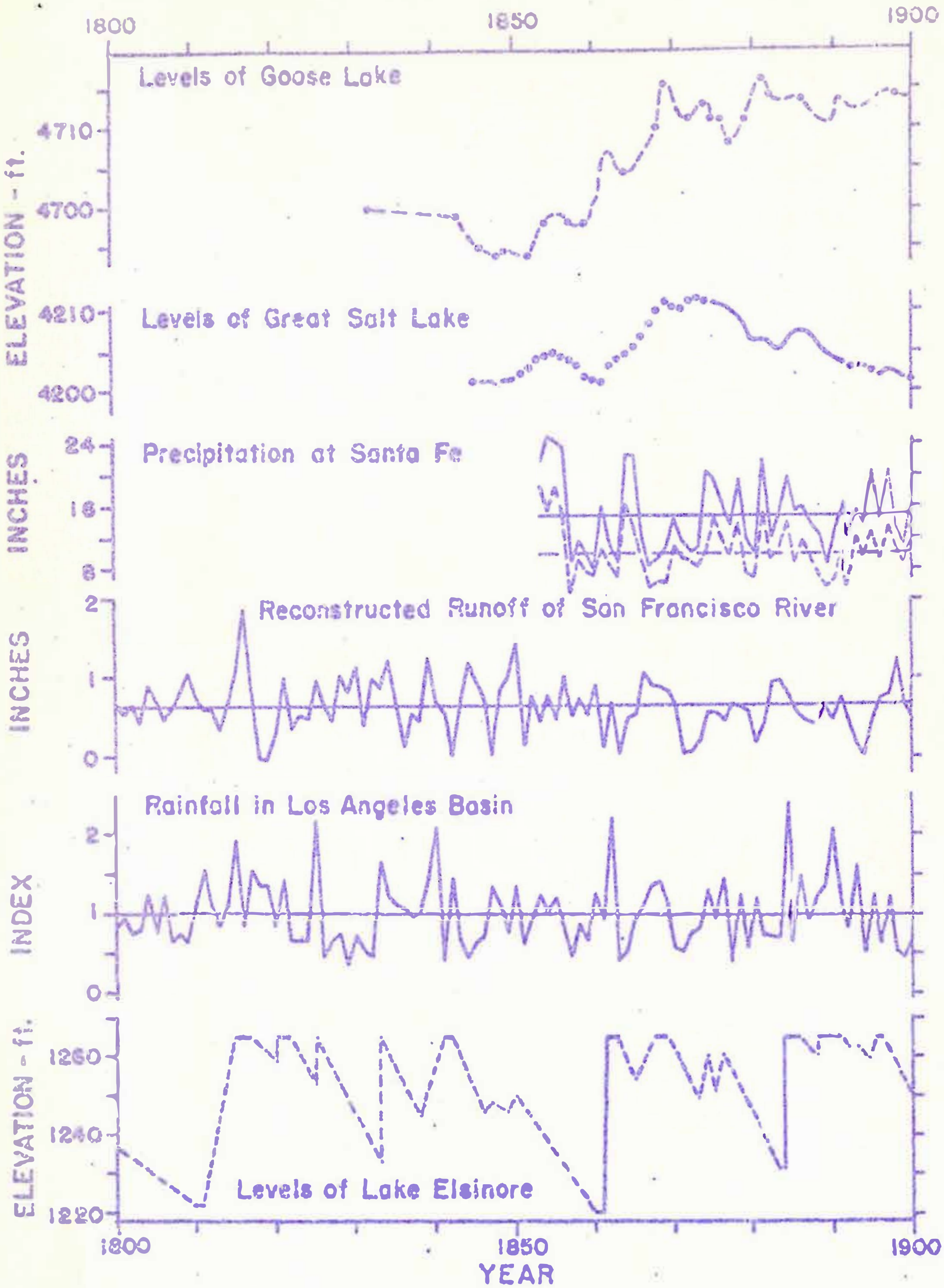

1800
1850
1900
Levels of Goose Lake
4710
4700
ELEVATION - ft.
4210
4200
Levels of Great Salt Lake
24
16
8
INCHES
Precipitation at Santa Fe
2
1
0
INCHES
Reconstructed Runoff of San Francisco River
Rainfall in Los Angeles Basin
2
1
0
INDEX
1260
1240
1220
ELEVATION - ft.
Levels of Lake Elsinore
1800
1850
1900
YEAR

Figure 8

pioneers recorded earlidd observations. Lake stages after 1847 were decreased by diversion of tributary inflow for irrigation purposes.

Santa Fe, New Mexico has the longest continuous precipitation record for the state; it also has the best record on the Colorado Plateau as defined above. Santa Fe records from 1849 to 1892 were taken at Fort Marcy which is located on a bench overlooking the city. This location is near the later gauge station (Leopold, 1951). The total annual Santa Fe precipitation from 1853 to 1900 is shown in Figure 8 (Hardy, Overpeck, and Wilson, 1939). The seasonal precipitation amounts, shown as a dashed line in the plot, represent the period between April 1 and September 30. Santa Fe, at an elevation of 7,013 ft, received an average annual precipitation of 14.40 inches in the period from 1853 to 1938.ddThe seasonal precipitation in the same period was 9.80 inches or 68% of the total. The seasonal precipitation curve with a few exceptions generally follows variations of annual precipitation.

The upper San Francisco River watershed of 1,653 sq mi is centrally located in western New Mexico on the southern edge of the Colorado Plateau. The westward boundary of the watershed drains a small strip in Arizona. Stockton (1971) was able to reconstruct runoff from ring-width indices by relating tree-ring widths to runoff for the period 1928-1966. Reconstructed values for the total water year runoff in inches for the watershed near Glenwood, New Mexico are shown in Figure 8. This information is derived from tree-ring data that was not used in the data presented in Section VII.

The Los Angeles area includes the drainage basins of the Santa Ana, the San Gabriel, and the Los Angeles Rivers as well as the coastal margin from San Clemente to Santa Monica. The rainfall and stream runoff since 1769 of the area have been reconstructed by Lynch (1931). The record from 1800 to 1834 was derived primarily from the diaries and crop reports of mission fathers. Records by the fathers ceased in 1834 following the take-over of the mission lands by the Mexican government. General observations in histories, diaries, letters, reports, and periodicals helped fill the gap between 1834 and 1847 when rainfall observations began. From these data, seasonal wetness indices were computed and are shown in Figure 8.

Lake Elsinore, located 22 mi northeast of San Clemente in a shallow impervious basin, receives the runoff from about 800 sq mi. The outlet from which water flows into the Santa Ana River had an elevation of about 1265 ft in the 19th century; the lake bottom has an elevation of about 1220. When the elevation of the water is about 1234 ft, the lake covers more than four sq mi. The elevation of the water surface of the lake is shown in Figure 8. It is estimated that if no more water flows into the lake after it is filled,, it requires at least eleven years to evaporate. Conditions prior to 1810 and 1859-1860 can be estimated because the lake was almost dry on those dates. On the other hand, a single wet season can fill the dry lake to overflow. The solid lines at elevation 1265 ft indicate years in which the lake was reported to have overflowed. The broken lines in the figure show interpolated elevations.

VII. Tree-Ring Data

Fritts (1965) originally calculated 10-year relative departures for tree growth from 26 North American tree-ring chronologies during the interval from 1501 A.D. to 1940 A.D. These original data have been extended and additional chronologies were obtained. The new data are shown in Figure 9 for the period from 1801 to 1905. The contours in the figure represent departures in growth from the means for 1631 through 1962 in terms of the number of standard errors of the departure for the 10-year period (SE = SD for 1631 through 1962 $/\sqrt{10}$).

In general, ring widths correlate best with the environmental factors of the preceding 14-month period from June to July. Thus, the effect of a calendar year is divided among two annual rings. In addition, most tree-ring chronologies show a closer relationship with autumn, winter, and spring moisture than with summer moisture. Temperature also affects tree growth in an inverse manner, but is a less important control of growth than precipitation.

VIII. Climate during 1801-1900 by Decade

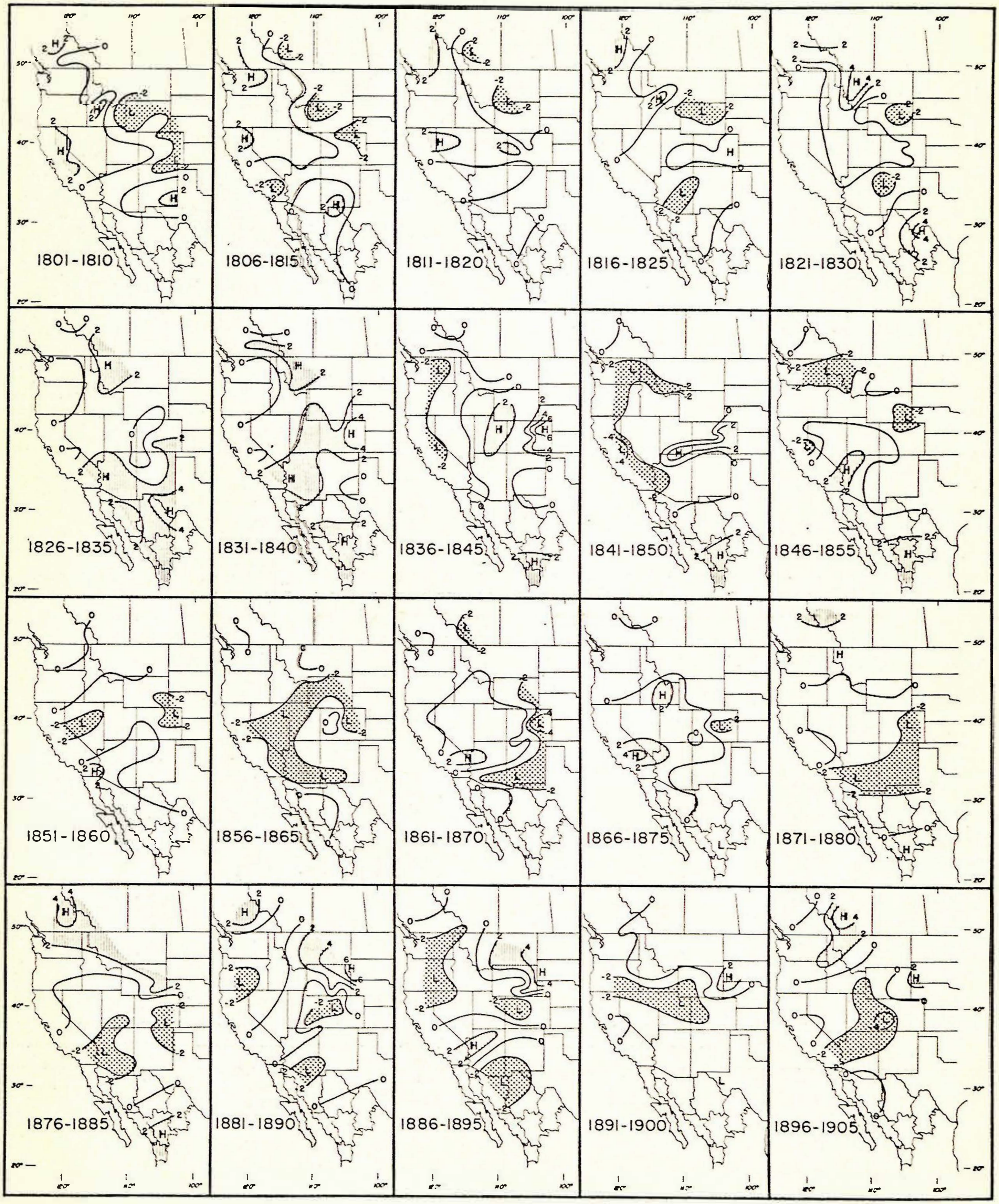
The list below summarizes the evidence for climatic variability throughout southwestern United States. The regional patterns of departure in growth are described. These are followed by conditions specified by the proxy series on climate. The series are ordered in each decade as follows:

a. Goose Lake
b. Great Salt Lake
c. Santa Fe
d. Upper San Francisco River
e. Los Angeles precipitation
f. Lake Elsinore

Reference to the series is omitted where no data are available. The departures in tree growth for the area of each proxy series are indicated so that consistency or lack of consistency between the series and tree-ring data may be noted.

The probability analysis of Arizona climate and the circulation estimated from growth anomalies are listed next. These are followed

Figure 9. Anomalies of tree growth for 10-year periods during the 19th century. The data represent departures in mean ring-width indices for 38 tree-ring chronologies from the mean for 1631 through 1962. The values have been standardized by dividing each mean by the standard error (Standard Deviation for 1631-1962 / $\sqrt{10}$) so the contours represent departures in standard normal units of the 10-year means. Departures exceeding 2 standard errors are shaded.



1801-1810
1806-1815
1811-1820
1816-1825
1821-1830
1826-1835
1831-1840
1836-1845
1841-1850
1846-1855
1851-1860
1856-1865
1861-1870
1866-1875
1871-1880
1876-1885
1881-1890
1886-1895
1891-1900
1896-1905

Figure 9

by a list of climatic events noted for the decade selected from the data file.

1801-1810

Regional Tree Growth
high - southeastern New Mexico, north and central California
low - eastern Colorado and Wyoming

Upper San Francisco River
runoff - near to above average
tree growth - near average to above average

Los Angeles Precipitation
rainfall - low
Lake Elsinore - declining levels
tree growth - average, becoming low at end of decade

Tentative Winter Circulation*
flow normally zonal, most pronounced at 155° W Long.
intensified Mexican low

1811-1820

Regional Tree Growth
high - northern Great Basin, west-central Colorado, east-central Utah
normal to below normal - central and southern Arizona, becoming lower towards end of decade

Upper San Francisco River
runoff - above average early in decade; below average late in decade
tree growth - average over decade, becoming below average at end of decade

Los Angeles
precipitation - high
Lake Elsinore - high levels
tree growth - average to below average

Tentative Winter Circulation
first half of decade - strong zonal flow at 145° W Long.; very-intense Mexican low. Strong zonal flow early in the century may have existed, bringing high growth in northwest, low growth on eastern slope of Rockies, reduced growth in southwest.
second half of decade - zonal flow much weakened, most pronounced at 160° W. Long.; Mexican low intense

Major Climatic Events from the File
Dust veil index reached maximum for century 1815 (div=7). Div gen-

* Tentative Winter Circulation is inferred from multivariate analysis of tree rings.

1811-1820 (continued)
erally high. Much volcanic activity.

1821-1830

Regional Tree Growth
low - west-central New Mexico and east-central Arizona,
average to below average - west coast

Upper San Francisco River
runoff - above average, especially at end of decade
tree growth - low, 1821-1830, becoming high, 1826-1835

Los Angeles Precipitation
rainfall - low
Lake Elsinore - high, but declining
tree growth - low

Arizona Precipitation - high probability (0.56) of dry conditions, 1818-1827

Tentative Winter Circulation
very weak zonal flow at 160° W Long.; Mexican low normal
Flow may have been meridional with blocking highs off the Pacific coast.

Major Climatic Events from the File
Some volcanic dust throughout the century, not exceeding 200 dvi.

El Niño year, 1828.

1831-1840

Regional Tree Growth
high - Arizona, Colorado, Utah, southern California

Goose Lake
levels - moderately low
tree growth - average

Upper San Francisco River
runoff - moderately high
tree growth - high

Los Angeles Precipitation
rainfall - high
Lake Elsinore - recharged in 1833, but average at other times
tree growth - high

Arizona Precipitation - high probability (0.55) of moist conditions, 1831-1840

Tentative Winter Circulation
zonal flow weak at 150° W Long.; Mexican flow normal
Storm tracks important from southern California across Arizona into Colorado. Fewer storms entering northwest United States.

Major Climatic Events from the File
Eruption of Babuyan, high dust July-August, 1831.

Gila River, Arizona flooded, 1833.

Dust veil index reaches maximum of 525, second highest for century, 1835.

1841-1850

Regional Tree Growth
high to average - southern Utah, northern Arizona, south and eastern Colorado,,
low - California

Goose Lake
levels - declining and low
tree growth - low

Great Salt Lake
levels - low
tree growth - below average

Upper San Francisco River
runoff - average, but with years of high and low extremes
tree growth - low to average

Los Angeles Precipitation
precipitation - low
Lake Elsinore - high, but levels declining
tree growth - low

Tentative Winter Circulation
zonal flow weak but less so at 155° W Long.; low anomaly farther west and north than normal (30° N, 170° W Long.); Mexican low normal

Major Climatic Events from the File
El Niño year, 1845.

Fremont, in 1845, rode to Antelope Island (in the Great Salt Lake) through water that did not come above his saddle girths. This places the lake at a low level.

In 1848, Great Salt Lake was so low that a bar connected Antelope Island with the mainland. This bar was not exposed again until 1900. Drought, frost, and, above all, grasshoppers caused famine among the Mormons in the fall of 1848.

The southern end of Goose Lake was dry in 1849 when the forty-niners drove their wagons on it. The lake filled after 1849 and was not exposed to view until the 1920's. In the 1920's the wagon tracks of the forty-niners were clearly visible.

1851-1860

Regional Tree Growth
hig[illegible] - [illegible] southern California,
low - northeast Colorado, central California, central Nevada, and northern Utah

1851-1860 (continued)

Goose Lake
levels - low
tree growth - average over decade, becoming low near end of decade

Great Salt Lake
levels - low, but rising 1851-1855
tree growth - low

Santa Fe
precipitation - high over decade; very low near end of decade
tree growth - average over decade; low near end of decade

Upper San Francisco River
runoff - average
tree growth - average

Los Angeles Precipitation
rainfall - average over decade, but low toward end of decade
Lake Elsinore - lake stage extremely low near end of decade
tree growth - high over decade, but low toward end of decade

Tentative Winter Circulation
first half - zonal flow weak at 155° W Long.; Pacific low anomaly west of normal; Mexican low normal
second half - zonal flow intense at 140° W Long.; Mexican low intense
Decade changing from weak zonal flow to increasing zonal flow, contrasting conditions from beginning to end.

Major Climatic Events from the File
The frequency of rains smaller than 0.5 inches in one day increased from 1850 to 1900. The trend does not appear in annual rainfall totals.

A severe drought occurred in the Great Salt Lake basin in 1854 and 1855. It together with crickets destroyed the crops. Because of the drought of 1854 and 1855 Great Salt Lake began to fall and continued to recede until the latter part of 1861.

The Julys were wet from 1858 to 1882, except for the near-average years of 1872 and 1874.

1861-1870

Regional Tree Growth
high - southern tip of Nevada; average or above average over Colorado Plateau and Great Basin
low - southeast New Mexico, eastern and central Colorado, part of southern Arizona

1861-1870 (continued)

Goose Lake
levels - average and rising
tree growth - average

Great Salt Lake
levels - average and rising
tree growth - average to above average

Santa Fe
precipitation - slightly low; more than half the years are low
tree growth - slightly low

Upper San Francisco River
runoff - slightly low
tree growth - low to average

Los Angeles Precipitation
precipitation - average
Lake Elsinore - recharged in 1861
tree growth - slightly high to average; higher last half of decade

Tentative Winter Circulation:
zonal flow weak to average at 160° W Long.
first half of decade - Pacific low displaced west; Mexican low intense
second half of decade - Pacific low average; Mexican low normal

Major Climatic Events from the File
Great Salt Lake Basin summer rains increased in the 1860's. When the Mormons first settled the basin, rains from April to November were infrequent. Summer rains in the late 1860's were of frequent occurrence. The increase of summer rains was especially noted because the necessity for irrigation decreased.

Gila River flooded, 1862.

El Niño year, 1864.

"New Mexico failed to produce sufficient grain in 1864 to take care of civilian requirements."..."We could not forsee the total destruction of their corn crop, nor would we forsee that the frost and hail would come and destroy the other crops in the Territory..."

The year 1865 was the most disastrous for New Mexico within the memory and experience of any man then living in the Territory. Heavy frosts nipped the buds and blossoms...torrential hail and rain storms at one time and devastating droughts at another. Locusts and grasshoppers descended on fields of wheat, corn, and beans in the granary counties of Taos, Mora, Rio Arrila and San Miguel, devouring every stalk, branch, and blossom. Springtime flood waters of the Rio Grande washed out overnight the river bottom wheat and corn fields of Bernalillo County and threatened the

1861-1870 (continued)

lives of the people.

In July precipitation of New Mexico and Arizona in 1867 was the highest of the period 1854-1900.

In December, 1867, the rains in southern Utah were abundant and the rivers carried water far beyond their usual volume. The Virgin and Santa Clara Rivers almost swept away several small towns.

Gila River flooded, 1869.

Great Salt Lake reached 1870 stages as high as in 1954.

1871-1880

Regional Tree Growth
low - extreme southern California, southern Arizona, New Mexico, eastern Colorado

Goose Lake
levels - high
tree growth - average to below average

Great Salt Lake
levels - high
tree growth - average to below average

Santa Fe
precipitation - average
tree growth - low

Upper San Francisco River
runoff - low
tree growth - low

Los Angeles Precipitation
precipitation - low
Lake Elsinore - declining
tree growth - low

Arizona Precipitation - high probability (0.51) of dry conditions, 1872-1881

Tentative Winter Circulation
first half of decade - zonal flow normal to weak at 155° W. Long.; Mexican low normal
second half of decade - all conditions normal

Major Climatic Events from the File
El Niño year, 1871.

Union Pacific RR in Wyoming intermittently blocked, December to February, by drifting snow. Laramie down to -45°. Oakland to

1861-1870 (continued)

lives of the people.

In July precipitation of New Mexico and Arizona in 1867 was the highest of the period 1854-1900.

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Gila River flooded, 1869.

Great Salt Lake reached 1870 stages as high as in 1954.

1871-1880

Regional Tree Growth
low - extreme southern California, southern Arizona, New Mexico, eastern Colorado

Goose Lake
levels - high
tree growth - average to below average

Great Salt Lake
levels - high
tree growth - average to below average

Santa Fe
precipitation - average
tree growth - low

Upper San Francisco River
runoff - low
tree growth - low

Los Angeles Precipitation
precipitation - low
Lake Elsinore - declining
tree growth - low

Arizona Precipitation - high probability (0.51) of dry conditions, 1872-1881

Tentative Winter Circulation
first half of decade - zonal flow normal to weak at 155° W. Long.; Mexican low normal
second half of decade - all conditions normal

Major Climatic Events from the File
El Niño year, 1871.

Union Pacific RR in Wyoming intermittently blocked, December to February, by drifting snow. Laramie down to -45°. Oakland to

1871-1880 (continued)

Cheyenne train trip took 22 days (1872).

Hopi Indian Reservation, Arizona (1872): "The rainy season was early and protracted; the result is they have raised an abundant crop of corn, pumpkins, melons, and a great variety of vegetables..."

Severe blizzard of 1873, Dakotas to Kansas. Great suffering with 70+ pioneers frozen to death near their homes in Minnesota alone.

Hopi Indian Reservation, Arizona (1873): "Their crop promising so fair in the early part of the season resulting in little better than a failure."

Severe Pacific storm hit West Coast in 1874 with strong gales on 1/15-16; barometer under 29.00" in Washington, Portland; heavy rain southward; Los Angeles 3.50".

Heavy snowstorm on 3/17-18 at Salt Lake City brought cover to record 22"; very snowy month; Central Pacific RR blocked by 25 ft drifts in Nevada (1874).

Drought, "worst since 1860," only 2.19" fell in 80 days from 6/14 to 9/13. Lawrence had only 0.30" in July and 0.39" in August. Widespread crop failures (Kansas, 1874).

Large November storm on Pacific coast gave 3.98" at San Francisco in 24 hours, second greatest. At Los Angeles 4.00" fell during storm period, 11/19-21 (1874).

Very heavy rainstorms on 1/18-20, 1875 and 1/25-27. Los Angeles had two-storm total of 17.18", bringing season to 21.18"

Snow slides plagued western mining towns. Alta, Utah and Virginia City, Nevada hit by avalanches in January and February. Fifty Chinese woodcutters buried; 28 died in one slide (1875).

Hopi Indian Reservation, Arizona (1875): "Owing to the small quantity of rain, not more than 1/3 the usual amounts of products will be raised this season."

Arizona, New Mexico, Sonora: The period 1875 to 1895 witnessed the inauguration of arroyo cutting. The woodlands have migrated upwards in the last 80 years or so, woody plants have taken over from the grasses and other species have declined. These movements and changes are consistent with the hypothesis of drier and warmer conditions at all elevations. Cultural stress, i.e., cattle, may have been a contributing factor.

Coldest winter ever known. St. Paul means: January -2.6°, February -2.3°. Breckenridge, Minnesota had continuously below 32° from 12/17 to 3/11; below ~~0° from 1~~/2 to 1/20. Benton City, Montana -55° (1875).

1871-1880 (continued

Very wet early rainy season throughout Northwest: Portland, Oregon had 6.73" in October, 15.77" in November, 13.41" in December, or 220% of normal (1875).

Heavy rainstorms in southern California: Los Angeles had 5.0" in 50 hours on 1/21-24, 3.9" in 36 hours on 2/8-9, 6.86" on 2/28-29, 2.15" on 3/5; season 26.74" (182% normal) (1876).

Record rainstorm at Denver (6.54" in 24 hours, total 6.70" on 5/21-22. South Platte in extreme flood. Snowfall in mountains prevented greater disaster (1876).

Hopi Indian Reservation, Arizona (1876): "Owing to late frosts that damaged young corn, the crop is not so abundant as it otherwise would have been, yet it is sufficient to meet the wants of the Indians."

Pacific ridge dominated West Coast all December (1876). San Francisco and Sacramento had 0.00", all-time December record. Portland's 0.89" also was December record low.

El Niño year, 1877.

Very warm February: Plains, Midwest, Northeast. St. Paul had +16.4° departure; March 7.8° colder than February; +7.0° in New England in February, also very dry (1877).

Severe June heat wave in California: Los Angeles from 6/8-11 had 101°, 103°, 104°, 112°; San Francisco 92°; San Diego 93°; Spring Valley 122° (1877).

Record dry season California: San Diego 39%, Los Angeles 35%, San Francisco 54%, San Jose 30% (1877).

St. Paul had +14.1° departure in December, +10.5° in January, +16.3° in February, +16.2° in March. "Year without a winter" (1877-1878).

Very wet winter: 11.97" in January, 12.52" in February (1878).

El Niño year, 1878.

Three flood peaks on Sacramento River in February (1878): 2/1-6, 2/13, 2/17-18. Red Bluff had 20.71" in January, 16.66" in February. Valley under water till April 1.

Hopi Indian Reservation, Arizona (1878): "At the commencement of spring, the weather was cold and wet, and extremely unfavorable to agricultural pursuits. As soon as the corn first planted appeared above ground, it was totally destroyed either by frost or insects..."

1871-1880 (continued)

Turbulent "Sonora" weather in Arizona. Cloudburst on 7/11 of 5.10" in one hour at Tucson; violent thunderstorms, possible tornadoes on desert (1878).

Heat wave at Los Angeles set early record, 1879, 99° on 3/29; never equalled until 4/13.

Pacific Coast storm on 11/9 produced 3.41" at Los Angeles and 2.75" at San Diego in 24 hours. Barometer dropped to 29.26" atss San Francisco; gales and damage (1879).ss

Extreme pre-Christmas cold as in 1872. Pembina, North Dakota -59°; St. Vincent, Minnesota -58°; St. Paul -39°. Pembina below -30° each night 12/11-26. December mean -14.5° (1879).

Historic storm period of 1880: Seattle's 76" snow on 1/5-7 settled to 48" on 8th; 12' in mountains; 24" on coast. Second severe storm on 1/9 dropped Portland's barometer to 28.51". Whole gales did vast damage in Oregon.

Record April storm in California on 4/20-22, 1880: 6.35" in 16 hours at Sacramento; storm total 8.37". Snow 16' and 40' drifts blocked Pacific RR. Widespread gales did extensive structural and forest damage in California, Oregon, Washington.

Gila River, Arizona flooded, 1880.

High water on Snake and Columbia Rivers in snowmelt flood only 1" from 1876 level at Portland. Willamette Valley inundated with great losses on 5/30-31 (1880).

1881-1890

Regional Tree Growth
low - southeastern Arizona, west-central Colorado, east-centrals Utah, extreme northern California, moderately low in New Mexico

Goose Lake
levels - high
tree growth - low

Great Salt Lake
stage - falling from average to low
tree growth - average to low

Santa Fe
precipitation - average over decade; low at end of decade
tree growth - average to moderately low

Upper San Francisco Riverss
runoff - average to low
tree growth - low

Los Angeles Precipitation
precipitation - high
Lake Elsinore - low early in decade and recharged in 1884; remained high
tree growth - average first part of decade; high (1886-1895)

Arizona Precipitation - high probability (0.48) of dry conditions, 1880-1889

Tentative Winter Circulation
first half of decade - zonal flow weakened at 155° W Long.; other features normal
second half of decade - zonal flow more normal near North America; other features normal

Major Climatic Events from the File
Hard winter. Pioneers snowbound for 10 weeks; snowfall 80"+ in Dakotas, Minnesota, Wisconsin. Very cold December-January, blizzards in February, deep snowfalls in March, cold April. Train stuck in snow in South Dakota 1/20-5/6 (1881).

Rio Grande in high flood on 10/11-12, "worst since 1848." Daily rains since 9/13. Much damage in valley. El Paso had 200% normal annual rainfall (1881).

Widespread snowstorm in southern California on 1/12, 1882; 12" in San Bernardino, 5" in Riverside. San Gorgonio Pass blocked; trains delayed; hills at Los Angeles white; flakes at San Diego; damaging northeast gale, severe freeze, 21° at Fresno.

Cheyenne and vicinity: summer freeze; ice formed on streets, 7/9, 1882.

Portland, Oregon: record rainfall for December 20.14" (316% normal); 7.66" on 12/12; 12.83" storm total; followed by 13.71" in January (255%); 6.86" on 1/5 (1882-1883).

Arizona and western New Mexico: Julies were generally dry from 1883 to 1906, except for a few years centered about 1898, which were slightly wetter than average.

Forest fires in Tallamook County, Oregon in July, August (1883), "most destructive ever known." Also in Idaho and Washington. Smoke spread to California and to Minnesota.

Kanab Creek, southern Utah: cloudburst flood, 7/29, 1883 cut channel 50' deep, 225' wide.

Krakatoa exploded in East Indies on 8/25-27, 1883. A tidal wave (tsunami) reached San Francisco Bay by 10/27 (1' height, 40 min intervals); spectacular red sunrises and sunsets widespread over U. S. in late November, continued in December.

1881-1890 (continued)

Denver snowstorm on 12/5-6, 1883, "one of the most disastrous," wet snow, high winds cut communications. Drifts blocked UP for 36 hours. Denver 22.9" in December.

Great arctic outbreak on 1/3-6, 1884. All-time record lows: Midwest - -40° Rockford, Illinois; -25° Indianapolis; -16°77Cairo. Deep zero penetration into South: -1°Atlanta; 21° Jacksonville.7 Severe citrus freeze, central Florida.

Snow blockade in High Rockies isolated Durango, Colorado for 76 days, 2/3-4/16, 1884.

Heavy February and March rains, 25.73" in Los Angeles basin made 1884 season wettest ever, 38.18".

Out-of-season rainstorms on deserts in May, 1884 caused desert floods. No rail traffic from Salt Lake City south for 3 weeks. Rio Grande at El Paso in high flood; did $1 million damage to railroad. No mail 5/30-6/14.

Epic June rainstorm in California: week of rains had deluges on 6/11-12; San Francisco 1.23" (24 hours), 2.57" month; Los Angeles 0.87" (24 hours), 1.39" month; all-time records (1884).77

Gila River, Arizona flooded, 1884.77

Frost damaged tree rings have been found in upper treeline bristlecone pines, White Mountains, California and Snake Range, Nevada, dated as late season, 1884.

Oregon snow blockade. Portland record 34" December fall cut off from East 12/17-1/5. Siskiyou route south blocked. California mail came by ocean steamer (1884-1885).

Denver's heaviest snowstorm: 23" wet snow on 4/22-23; $60,000 damage locally; 32" at Idaho Springs, Colorado; more in mountains. Traffic77 suspended 36 hours (1885).77

Record short growing season: Fargo, North Dakota had killing frosts on 6/8 and 8/25, both current records; Woodstock, Vermont on 6/10 and 8/26. Late crops cut off (1885).

Record wet November in California: San Francisco, 11.78"; Sacramento, 11.34"; San Jose, 7.39"; Los Angeles, 5.52". San Luis Obispo had 10.04"77on 11/18. Floods, washouts (1885).

Vast anticyclone (31.00" north of Dakotas from 1/6-12). Arctic outbreak rushed to Gulf Coast: New Orleans 15°, Mobile 11°, Tampa 19°. Orange trees killed; fruit destroyed; fish frozen; water77 pipes burst (1886).77

Large Pacific Coast storm struck California on 1/20; high winds; heavy rains; worst in 25 years. Structural damage, floods, Great Valley and Los Angeles area (1886).

Hopi Indian Reservation, Arizona (1886): "They have peach orchards, but little or no crop this year. Owing to the dryness of the season, their corn crop is also short."

"Unusual" July storm in California 7/16: Los Angeles 0.24", San Francisco 0.23" set all-time records (1886).

Summer-fall drought, Texas to Kansas, intensified; no good rains in 14 months; streams empty; water supply gone; cattle perishing; many rushed to market (1886).

San Francisco's heaviest snowstorm 2/5: 3.7" downtown, 7" western section, 11" hills; 33°. Cold storm widespread over northern California "worst since 1868" (1887).

Heavy downpour at Los Angeles on 2/14, 1887 (2.56" in 4.5 hours) during thunderstorm with hail. Lightning struck barn. Downtown streets flooded. Railroad washouts.

Droughty March to November from Lakes to Gulf; 82° W to 95° W under 80% normal; large areas under 60% normal. Southern Illinois under 50% normal. Low crop yield; wells, spring dry; water trains necessary; navigation impeded. Rains came 11/24, 1887..

San Francisco had hottest day since 1852 on 5/28, 1887, with 96.9°.

The Great Die-up: the Climax of the Cattle Kingdom in summer.. 1887. Droughty conditions from 1886 persisted into winter / spring.. Texas northward. Old grass gone; new did not grow; no fodder; little water; cattle died by thousands. Large investments decimated. Cattle industry collapsed.

January, 1888, extreme cold: new U. S. low -65° near Miles City, Montana; 1/13 frigid at Des Moines, 1/7-23 mean -2.2°; Burlington, Vermont "coldest month since 1884."

West Coast Freeze of 1888, "coldest since 1854." Portland, Oregon. down to -2° (present record); Columbia River frozen 1/9-26; Sacramento had 19° and 4" snow; San Francisco 29°; Los Angeles 32°; Riverside 25.5°. Citrus freeze.

Hopi Indian Reservation, Arizona (1888): "The farming this year. has been almost a total failure, no rain having fallen from the. middle of July, when a cloudburst occurred near the drainage at the head of the canyon, causing the water to come down in a solid body the entire width of the canyon about 3' deep, washing out or covering up all the vegetation."

Gila River, Arizona flood, 1889.

1881-1890 (continued)

Prairie fires widespread in Dakotas 4/1-2, 1889; black snow fell in New York 4/3.

"Unusual" rainstorm at Los Angeles 8/31, 1889: 0.61" all-time. USWB (1878-) August record.

Wettest October ever in California. San Francisco had 7.28" 2.03" 24 hours); Los Angeles had 6.96" (3.62" 24 hours, 10/20-21); San Diego County had 7.58" in 8 hours (1889).

Record December (1889) rains, high floods in California, Nevada, Arizona. Los Angeles 15.80"; Yuma 2.43"; Lake Tahoe rose 12". Levee break flooded Yolo County. Los Angeles River changed course.

Great snow blockade on Pacific RR in Sierras. 228" January snow at Cisco; snow slides, derailments tied up Summit tracks 1/15-30;.. rotary plow wore out. Great economic losses. Nellie Bly diverted.. southward on record global trip (1890)...

Hot autumn at Los Angeles: 99° on 10/27-28, 96° on 11/3. Pomona had 102° on 11/3 (1890).

1891-1900

Regional Tree Growth
low - northern Great Basin and western Colorado, eastern Utah, average to below average throughout southwest

Goose Lake
levels - high.
tree growth - low

Great Salt Lake
levels - low
tree growth - low

Santa Fe
precipitation - average to slightly above average
tree growth - average to below average

Upper San Francisco River
runoff - low
tree growth - low, especially from 1896-1905

Los Angeles Precipitation
precipitation - low
Lake Elsinore - high, but declining
tree growth - low (1896-1905)

Arizona Precipitation - high probability (0.50) of dry conditions in Arizona, 1895-1904.

1891-1900 (continued)

Tentative Winter Circulation
weakened zonal flow at 160° W Long.
other conditions normal

Major Climatic Events from the File
El Niño year, 1891.

Big Pacific Coast storm on 1/21-24; pressure 28.97" at Eureka, 29.50" at Los Angeles (then winter month record). Wind 50 mph at San Francisco where ship sank, 18 of 29 crew lost. Floods throughout southern California. Los Angeles River returned to old course (1891).

Gila River, Arizona, above Florence, flood; rainfall on snow 102,566 cfs on February 22, 1891.

Record flood, lower Colorado Basin. $300,000 damage at Yuma. Salton Sink filled (1891).

June Colorado River overflow; again filled Salton Sink; severed railroad; Lake dried up, but filled again in 1893. Now Salton Sea, 244' below sea level (1891).

San Francisco reached 100° on 6/29, only such figure outside of September (1891).

Northwest storm on 12/7, 1891; gales swept all Oregon and Washington; 98 mph at Ft. Canby, Washington.

July precipitation of New Mexico and Arizona in 1892 was lowest of the period 1854-1900.

October snowstorm, Wyoming, "worst in history of Union Pacific RR;" Cheyenne isolated 10/12-24; Laramie, 5' drifts; trains blocked; telegraph poles down (1892).

Pacific Coast storm period 11/17-23, 1892: very heavy rains, snows, floods in Oregon and Washington; 11/24-30 gales, heavy rains caused mud slides; floods in California; crop damage.

Oregon-Washington low-level snowstorm 12/21-24: Portland 27.5" paralyzed community; 11" Astoria; 42" Olympia; the Dalles (32") blocked four days, 600 passengers stranded over Christmas. Severe tree blowdowns on coast 12/23 (1892).

Big windstorm in Northwest 1/14-15; SE gales hit 120 mph at Ft. Canby, Washington. Severe cold wave 1/31: Seattle +3°, Olympia +6°, Tatoosh Island +7° (1893).

June heat wave, Plains (106° Ft. Dodge 6/21) began 3-year drought (1893).

1891-1900 (continued)

Pacific storm in California on 11/17; San Francisco had 47 mph and heavy rain; Mt. Hamilton 100+ mph gusts, buildings damaged, barns unroofed, trees downed (1893).

"One of the greatest U.S. floods" in Northwest: 6/6 Willamette covered half of Portland's business section (33' stage, 4' [illegible] record); Columbia at all-time high. Warm days 5/29-6/2 caused instantaneous snowmelt at all altitudes (1894).

Drought extensive on Plains in July-August; hot winds on 7/24-28, 108°, 50 mph (1894).

Snowiest December in High Sierras: 245" at Summit; railroad blocked by slides (1894).

Gila River, Arizona, near Safford and Solomon, flood from four days of heavy rain; not widespread flooding, 9/27-10/4, 1895.

Heat wave, interior California 7/1-25, 1896, "most disastrous since unprecedented 1859."

Gila River, Arizona, near Safford and Solomon, flood. Flood from 3 days of continual rain, 10/9-16, 1896.

Heavy rains Northwest early November, 1896 raised streams west of Cascades to record highs.

Unprecedented November cold wave, Plains, Rockies, Northwest: Montana -42°, Havre below zero for 14 consecutive days; Oregon -32° and 74" snow; 25-30 severe Thanksgiving Day blizzard in Dakotas and Minnesota; heavy icestorm in South Dakota on 26th (1896).

August drought worsened in September, 1897, when stations in 18 states reported no rainfall.

Two California freezes, 12/2-3 and 16-22, 1897 ranged from 24°-28° at Riverside. Smudging saved damage in first, but losses about $1 million in second; similar to 1895 freeze.

Very warm, very dry July, August, September, 1898 caused extensive brush and forest fires in California.

September forest fires in Colorado, "worst in history;" smoke pall to Atlantic Coast (1898).

Dry hurricane, Pt. Reyes, California, 12/9, 1898; 96 mph wind and sand damaged crops, killed birds.

San Diego waterspout 2 mi off Pt. Loma 12/9, 1898, 1000' high, 100' wide, 20 mph.

1891-1900 (continued)

Early heavy snowstorm west Montana 10/14-15, 1899; 35" fell; 12 herders, many sheep lost.

Heavy May rains covered allhCalifornia, except SE: 5/1-2, 4-5, 10-11, 1900. Sacramento 2.88".

IX.hhConclusionshh

It is apparent from the above set of data that our knowledge ofhh the climate of western North America during the 19th century is still extremely sketchy. No clear and concise singularhtype of climate appears. Wahl (1968), Wahl and Lawson (1970), and Rosendal (unpublished) present evidence that suggests marked differences in the climates of the eastern and the western United States during this century. In general, they hypothesize that western United States was warmerhthan at present, with high precipitation centering over the Rocky Mountains, while the eastern portions were cool. They suggest that this pattern weakened and disappeared in the mid-1880's.

The primary evidence we have supporting Wahl's and Lawson's anomaly in climate is the apparent low zonal nature of circulation over the Pacific Ocean. This could conceivably be associated with greater meridional flow and contrasting conditions between eastern and western United States.

Most of our results indicate a lack of singularity as there appears to be considerable variability of climate over the century. A steep gradient of high moisture along the Pacific coast and low moisture east of the RockyhMountains is apparent for 1801-1810. The Great Basin and the northern Colorado Plateau became more moist during 1811-1820. Moisture is more abundant in the extreme Southwest from 1826-

1840, as the climate of California, Oregon, and Washington becomes dryer, 1836-1850. During the middle of the century the Great Basin is dry. In the last 4 decades of the century, Arizona and New Mexico are generally dry, while areas of high and low moisture vary in their positions along the West Coast.

The data of Sellers (1960) for Arizona and New Mexico show a positive departure of July precipitation during 1858-1882 which appeared also to occur in the Great Salt Lake basin. Sellers states, "Midsummer rains are most abundant when this high pressure cell (the Bermuda High) is displaced north and west of its normal position, with a secondary center at about 20,000 ft over northern Texas. At such times the middle latitude storm belt and the high-level jet stream are located in southern Canada and have little effect on the climate of the United States." Sellers's data show a decline in July rainfall in the remaining portion of the century, a time when our data indicate a drift toward more modern climate but with low growth and low moisture in the Southwest.

The severity of storms may have increased late in the century, though there is too little early data to compare with the abundant data.TheThe for the last few decades. The circulation over the Pacific Ocean appears least zonal early in the century, becoming more zonal toward the end of the century. The decades 1811-1820 and 1851-1860 show marked changes within the decade of zonal to weakly zonal conditions. The proxy series also indicates marked variations in moisture during these decades.

We are pleased with the development of the climate history file. It is just a beginning which we plan to continue developing in the years to come. It is our hope to eventually interest students trained in history to dig out more historical data for early years. Until that time, we hope to add new information as it comes to our individual attention. The file provides a uniform format for recording information that will remain permanently available for future research.

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