**Title**

# Significant Changes to Twentieth-Century Temperature and Precipitation in the Sierra Nevada near Lake Tahoe: The Possible Anthropogenic Effect



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# Significant Changes to Twentieth-Century Temperature and Precipitation in the Sierra Nevada near Lake Tahoe: The Possible Anthropogenic Effect

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**Abstract.** A study of the weather records from six stations in the Sierra Nevada at and near Lake Tahoe, plus one station in the Diablo range of central California, reveals the following:

1. Since 1915, the date of the first major autumnal snowstorm has become progressively later at Tahoe City by 0.24 days/year (d/yr).

2. The change in the snowfall date results from an increase in the air temperature ($T$) at Tahoe City between 1909 and 2004, during the months of September through December, of $\overline{T'}_{max} = +0.011$ °C/yr, $\overline{T'}_{min} = +0.020$ °C/yr, $\overline{T'}_{mean} = +0.016$ °C/yr. These values agree substantially with those published by Coats et al. (2006).

3. On average, the other five stations show a much smaller increase, amounting to $\overline{T'}_{max} = +0.001$ °C/yr, $\overline{T'}_{min} = +0.012$ °C/yr, $\overline{T'}_{mean} = +0.007$ °C/yr. This mean value agrees well with the increase of $\overline{T'}_{mean} = +0.007 - +0.008$ °C/yr for the North American continent due to global warming (Jones and Moberg, 2003; Karoly et al., 2003).

4. The rate of temperature increase at Tahoe City is thus greater than would be expected from global warming and reflects a change in the microclimate of the Tahoe Basin, possibly due to human activity.

5. No overall change in precipitation with time is observed at any of the seven stations. However, statistically significant increases in precipitation with time occur, in the month of November, at the three Sierran stations located west of the Sierra crest, as well as at Tahoe City east of the crest. These increases coincide with the onset of the first substantial precipitation at these stations in the fall, and could be the result of "cloud seeding" by atmospheric pollutants, the precipitation becoming greater with time as the amount of pollution increases, and diminishing in December after these pollutants are washed out of the atmosphere by the first rains or snows.

**Keywords:** global warming, anthropogenic, human-caused, environmental change, snowfall, rainfall, meteorology

## 1. Introduction

Several years ago the writer carried out an investigation of an archeological site in the Sierra Nevada Mountains west of Lake Tahoe (Walker, 2012). That study indicated that the skyline position of the rising sun was used by the Indians to determine the date by which to leave their summer encampments, high in the mountains, in order to avoid being trapped by the first major autumnal snowstorm. In the course of this investigation, it was therefore necessary to determine the average date of the first significant autumnal snowfall at the site. To this end, all available snowfall records from the five weather stations nearest to the site were analyzed. That analysis indicated that the dates of the first large snowfall (arbitrarily defined as that which produced snow lasting either $\geqslant 4^{d}$ or $\geqslant 10^{d}$ on the ground after the beginning of the storm) were, with one exception, constant with time since the snowfall records began (generally between about 1904 and 1915). However, at one station, Tahoe City, the dates of the first $\geqslant 4^{d}$ and $\geqslant 10^{d}$ snowfalls have become progressively later with time since the first snowfall records, which began in 1915. The amount of this change was found to be $+0.25 \pm 0.02$ d/yr and $+0.23 \pm 0.08$ d/yr for the first $\geqslant 4^{d}$ and $\geqslant 10^{d}$ snowfalls, respectively.

Such a variation might arise as a result of secular changes in either the temperature or the precipitation; the progressively later snowfall date could result if the amount of precipitation decreased with time, or if the temperature increased with time. Accordingly, an analysis was made of the temperature and precipitation records for six stations in the Sierras near the archeological site and a "control" site, Mount Hamilton, located away from the mass of the Sierra Nevada. These sites, together with their locations and elevations, are listed in Table I. The temperature and precipitation data for these sites were taken from the following sources:

1. For the years 1870–1890, Greely and Glassford (1891, pp. 64, 70, 97, 129, 152, 157–158, 178, 202–203).
2. For the period 1891–1896, *Monthly Review of the California Climate & Crop Service*, Vols. 1–10, J.A. Barwick, Sacramento: State Printing Office.
3. From 1897–2004, *Climatic Data: California*, Weather Bureau, U.S. Department of Commerce.
4. Copies of the original observer's monthly reports, obtained from U.S. National Oceanic and Atmospheric Administration (NOAA).

> These contain data—particularly snowfall records—not published in *Climatic Data: California*. However, owing to the loss of the original reports in the 1906 San Francisco earthquake fire, these data no longer exist for the years prior to 1904.

Study of these records indicated that the change in the snowfall dates at Tahoe City results not from a change in precipitation, but rather from a progressive increase in temperature, particularly in the values of the minimum daily temperature. Since the results of the archeological study have not yet been published, and in view of the current interest in the question of the temperature of Lake Tahoe (Coats et al., 2006), the analysis of the temperature and precipitation observations at these various stations is presented here.

## 2. Station Histories

The weather stations whose records were analyzed are listed in Table I and include Blue Canyon, Boca, Colfax, Mount Hamilton, Soda Springs, Tahoe City, and Truckee. The records from these stations provide an instructive illustration of the problems that may be encountered when one attempts to investigate the long-term changes in temperature or precipitation from observations at one particular site. These problems result from the fact that at many stations, the instrumentation and methods of recording have changed with time. In addition, the instruments have often been relocated one or more times, and the type of shelter used has changed. Thus, the history of the station must be studied before that station's observations can be used to search for small, long-term variations in temperature or precipitation. The histories of the stations utilized in this study are therefore summarized below. Except as noted, the information presented here has been taken from the station histories obtained from the archives of the National Climatic Data Center, NOAA, U.S. Dept. of Commerce.

### 2.1. Blue Canyon

This station began operation October 1, 1899, and has been moved twice. First located at the Southern Pacific Railway station, it was moved 183 m (600 ft) north and to an elevation 17 m (55 ft) higher, on December 12, 1927. Observations at this site continued until June 30, 1944. On April 15, 1945, the station was moved again to the Blue Canyon airport, 3.3 km (2.0 mi) northeast of the Southern Pacific station. The first two locations were in a canyon, the third on a ridge top, 178 m (585 ft) higher than the Southern Pacific station, where it

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Table I. Weather Stations Included in Study.

| Station[a] Name | Location No. | Elevation m | ft | Side of Sierra Crest | Interval Years[b] |
|---|---|---|---|---|---|
| Blue Canyon | 1[c] | 1431,1448 | 4695, 4750 | W | 1899–1943 |
| | 2 | 1610 | 5283 | W | 1945–2004 |
| Boca | 1 | 1668 | 5474 | E | 1870–1917 |
| | 2 | 1699 | 5575 | E | 1937–2004 |
| Colfax | 1 | 737 | 2418 | W | 1870–1975 |
| | 2 | 735 | 2410 | W | 1976–1996 |
| | 3 | 732 | 2400 | W | 1997–2004 |
| Mt. Hamilton | 1–3[d] | 1283 | 4209 | —[e] | 1898–2004 |
| Soda Springs | 1 | 2058 | 6752 | W | 1913–1968 |
| Tahoe City | 1 | 1899 | 6230 | E | 1909–1949 |
| | 2 | 1899 | 6230 | E | 1950–1970 |
| | 3 | 1899 | 6230 | E | 1971–2004 |
| Truckee | 1 | 1774 | 5819 | E | 1870–1919 |
| | 2[f] | 1823, 1835 | 5982, 6020 | E | 1933–1982 |
| | 3 | 1835 | 6020 | E | 1983–2004 |

[a] For detailed descriptions of stations and locations, see text, Section 2.

[b] Of station operation (to 2004); may differ from intervals with utilized observations.

[c] Three locations combined. See text, Section 2.

[d] Various locations at Lick Observatory, on the summit of Mt. Hamilton, Diablo Range. See text, Section 2.

[e] On summit of Mt. Hamilton, Diablo Range.

[f] Three locations combined. See text.

remains. Since the first two locations were fairly close together, and since the time interval at each was relatively short, they have been combined in the analyses and are labelled "Blue Canyon No. 1," or "location 1," in all subsequent discussion.

### 2.2. Boca

The station began operation in 1870. The location of the instruments from 1870–1887 is unknown, but is presumed to have been at the Southern Pacific Railway station. The instruments *were* located at the Southern Pacific Railway station, at an elevation of 1669 m (5475 ft), from January 1, 1888 to May 31, 1918. No temperature observations were made between 1905 and 1918. No observations of temperature or precipitation were made from 1918–1936. On December 1, 1936, the station was relocated 0.5 km (0.3 mi) south, to a site 27 m (90 ft) north of the U.S. Bureau of Reclamation office, and 244 m (800 ft) southeast of the Boca Dam, at an elevation of 1699 m (5575 ft). It was still at this location in 2004, with only minor shifts in the location of the rain gauge: 5m (15 ft) to the northwest on June 22, 1958, and then 6 m (20 ft) southeast on October 22, 1960.

At the weather stations operated by the Southern Pacific Railway, maximum and minimum, or self-recording, thermometers were not used until 1904 or 1905. Prior to that time, thermometer readings were taken each day at 7 AM, 2 PM, and 9 PM, PST. The 2 PM temperature was considered to be the daily maximum, and the lower of the 7 AM or 9 PM temperatures to be the daily minimum. The daily mean temperature was then calculated by averaging the three observations (Barwick, 1896, p. 101). Actually, the true maximum daily temperature was likely to have been higher than the 2 PM observation, and the true minimum daily temperature lower than the 7 AM or 9 PM observations, perhaps by several degrees. Thus, these values cannot be combined with observations made using maximum and minimum thermometers. The mean temperature calculated from the three observations may have been closer to the true value, but is still likely to differ significantly from that found by averaging the actual maximum and minimum values.

From 1936 until 2004, the daily temperatures were recorded using maximum and minimum thermometers, and the daily mean temperatures found by averaging the maximum and minimum temperatures for that day. Thus, there is the possibility of systematic differences between the daily temperatures observed before 1905 and those recorded after 1935.

### 2.3. Colfax

Observations at this station began on February 1, 1870. The instruments remained in essentially the same location—about 9 m (30 ft) south of the Southern Pacific Railway depot, at an elevation of 737 m (2418 ft)—until January 19, 1976, when the station was moved 122 m (400 ft) northwest, to a location in the city of Colfax at an elevation of 735 m (2410 ft). The instruments remained at this location until October 5, 1996, when they were again moved, this time 2.5 km (1.5 mi) north, elevation 732 m (2400 ft). They were still at this location in 2004. From 1870–1971, the observations were made by agents of the Southern Pacific Railway; after 1971, by private observers.

As discussed in Section 2.2, above, prior to 1905 the temperatures at Colfax were measured three times daily, at 7 AM, 2 PM, and 9 PM. Thus, the maximum, minimum, and mean temperatures observed before 1905 can not be reliably compared with those measured in 1905 and later.

### 2.4. Mount Hamilton

Initially, Mount Hamilton appeared to be an ideal "control" station, being well away from the mass of the Sierras, located on the top of a peak to minimize orographic effects, and having continuous temperature and precipitation records extending back to 1880. However, a detailed examination of the available records reveals that the weather instruments were moved several times, with, apparently, no overlap in observations at the different locations. Consequently, the measurements of both temperature and precipitation are affected by systematic differences between some of these locations.

Unfortunately, the information regarding the instrument locations and dates of movement is somewhat limited. As near as can be determined from the available records, the instruments have been located—and relocated—as follows:

As indicated above, the first weather observations were made in 1880. Until 1928, the observations were made by the Lick Observatory staff, using their own instruments and shelters; the official Weather Bureau station began operation only in 1929. There is no record of where the first observations, from 1880–1883, were made, or the type of instruments used. In 1884, construction of the Main Building of the observatory and of the Meridian Circle Building was completed (Holden, 1887, pp. 38, 43). At that point, maximum and minimum thermometers were installed within the double wall of the Meridian Circle Building, on its north side, 2.3 m (7 1/2 ft) above the ground (Weather Bureau Station Description, February 12, 1906), and the rain gauge was installed on the roof of the Main Building, above the main entrance, with its top at a height of 10 m (33 ft) above ground level (Holden, 1887, p. 81). At the time of the next Weather Bureau Station Description (May 21, 1919), the maximum and minimum thermometers had been relocated and were mounted in a “standard” instrument shelter at a height of about 1.5 m (5 ft) above ground level, the shelter being located 12 m (40 ft) west of the Meridian Circle Building and due north of the north end of the Main Building. The rain gauge was still located on the roof of the Main Building. By May 17, 1935, the time of the next Weather Bureau Station Description, the rain gauge had been moved from the roof to a location near the middle of the summit area, 6 m (21 ft) south of the Photographic Building, with its top about 1.5 m (5 ft) above ground level. The date of this move is not recorded. It seems likely, however, that the rain gauge was moved from the roof to this location in 1929, when the Weather Bureau took over the station (on July 1, 1929). In addition, by 1935 the instrument shelter had been moved to a point 11 m (35 ft) north of the Meridian Circle Building, the (Weather Bureau) thermometers being mounted about 1.4 m (4 1/2 ft) above ground. In 1936, this shelter was located about 12 m (40 ft) northeast of the Meridian Circle Building (Weather Bureau Station Description, May 7, 1936). The rain gauge had not been moved. However, by 1943 (Weather Bureau Station Description, September 13, 1943), the rain gauge had been moved to a point 1.5 m (5 ft) north of the instrument shelter. The instruments then remained in this location until December 19, 1956, when the rain gauge and instrument shelter were moved about 24 m (80 ft) south, to near the southeast corner of the Meridian Circle Building, and close to the southeast edge of the flat area on the top of the peak. They remained in this location until August 1, 1985, when the maximum and minimum thermometers were replaced by a thermistor-type sensor, which was installed on a mast at the east end of the Laboratory Building, where it has remained until the present. On March 24, 1995, the rain gauge was moved 21 m (70 ft) to the west-southwest because “the previous (location) resulted in excessively low precipitation amounts” (Cooperative Station Report, March 24, 1995). The rain gauge was still at this last location in 2004.

### 2.5. Soda Springs

The station opened on January 21, 1913, and was operated by the Southern Pacific Railway until May 31, 1918. The precise location of the instruments is unknown, but is presumed to have been at the Southern Pacific depot. Details of the instruments used are not known.

Apparently, only a few measurements of precipitation were made during this period. No observations were made from 1918–1930.

On March 16, 1930, observations were begun again, with the instruments located on a wooden platform near the Southern Pacific depot, and whose floor was 4.6 m (15 ft) above ground level. Maximum and minimum thermometers were used, the thermometers being mounted in a standard shelter, whose base was 99 cm (39 in) above the floor of the platform, or about 5.5 m (18 ft) above the ground level. Observations were made from this location until the station ceased operation in 1969, the only change being relocation of the rain gauge on August 9, 1940, from the platform to a steel tower, with the top of the gauge 6 m (20 ft) above ground level.

### 2.6. Tahoe City

The station began operation on September 1, 1903; the precise location is unknown, but is thought to have been near the north abutment of the Truckee River Dam. Only scattered observations were made until September 1, 1909, when the station was relocated to a point 91 m (300 ft) south-southeast of the dam, and about 91 m (300 ft) south of the Truckee River outlet channel. It was again relocated on August 22, 1950, by being moved 114 m (375 ft) to the east. This move placed the station about 183 m (600 ft) east-southeast of the dam, and 24 m (80 ft) west of the shoreline of Lake Tahoe. On September 15, 1971, the station was once more relocated, being moved 145 m (475 ft) to the north-northeast of its last location. This move placed the station on the north side of the Truckee River outlet, at a distance of about 7.6 m (25 ft) from the river channel and about 24 m (80 ft) west of the shoreline of the lake. It was still at this location in 2004. It was not moved to the Coast Guard Station, 3 km (1.8 mi) to the northeast, in 1950, as reported by Coats et al. (2006).

Starting in 1909, maximum and minimum thermometers were employed at all locations, housed in standard Weather Bureau shelters whose floors were 1.5 m (5 ft) above ground level; the tops of the rain gauges were in each case 1.7 m (5 1/2 ft) above the ground.

### 2.7. Truckee

The station began operation on January 1, 1870. Until April 30, 1920, the station was operated by the Southern Pacific Railway. From about 1904–1920, the weather instruments were located at the Southern Pacific depot, at an elevation of 1774 m (5819 ft). While the exact location of the instruments from 1870–1904 is unknown, it is likely that they were situated at the depot during that interval as well. Prior to 1904, the temperature was recorded three times a day, at 7 AM, 2 PM, and 9 PM, PST, as at Boca and Colfax; by September 1904, maximum and minimum thermometers were in use. Thus, as at Boca and Colfax, there is the possibility of systematic differences between the temperatures recorded before and after 1904. At the Southern Pacific depot, the bottom of the standard Weather Bureau instrument shelter was 1.3 m (4.4 ft), and the top of the standard rain gauge was 1.8 m (6 ft), above ground level.

The station was closed and no weather records were kept from 1920–1931. On June 15, 1931, the station was re-established and relocated 0.7 km (0.4 mi) west-southwest of the Southern Pacific depot, at the U.S. Forest Service office on West Main Street in Truckee, elevation 1774 m (5820 ft). The bottom of the instrument shelter was 1.2 m (4 ft), and the top of the rain gauge 0.9 m (3 ft), above ground level.

On July 1, 1933, the station was relocated to the U.S. Forest Service, Truckee Ranger Station, 0.5 km (0.3 mi) north of the West Main Street location, at an elevation of 1823 m (5982 ft). (Note that while the station was relocated in 1933, temperature and precipitation records only began at this new location in 1935). At this location, the bottom of the instrument shelter was 0.8 m (2 1/2 ft), and the top of the rain gauge 0.9 m (3 ft), above ground level. On October 30, 1940, the instrument shelter was moved 91 m (300 ft) south, and the height of its base increased to 1.2 m (4 ft) above ground level; the location and height of the rain gauge remained unchanged. On July 17, 1959, the rain gauge was moved 13 m (42 ft) west. Its height at this new location was not recorded, but was probably still 0.9 m (3 ft). On November 1, 1959, the instrument shelter was moved 15 m (50 ft) to the northwest. Height of the shelter was not specified, but was probably 1.2 m (4 ft).

On May 25, 1983, the instrument shelter and rain gauge were moved to a location at the observer's residence, approximately 1.7 km (1 mi) northeast of the last location, and 2.1 km (1 1/4 mi) north-northeast of the Truckee post office, at an elevation of 1835 m (6020 ft). The heights of the instruments above ground level are not given, but are presumably the same as at the previous location. The instruments were still at this location in 2004.

In November, 1916, the observer noted on the monthly report sheet that the rain gauge had been stolen "some time ago," and that the precipitation recorded was therefore "only a guess." Apparently, the gauge was not replaced between November 1916 and April 30, 1920, when the station was closed; in 1920 the Station History states that "the rain gauge had previously been stolen and had not been recovered."

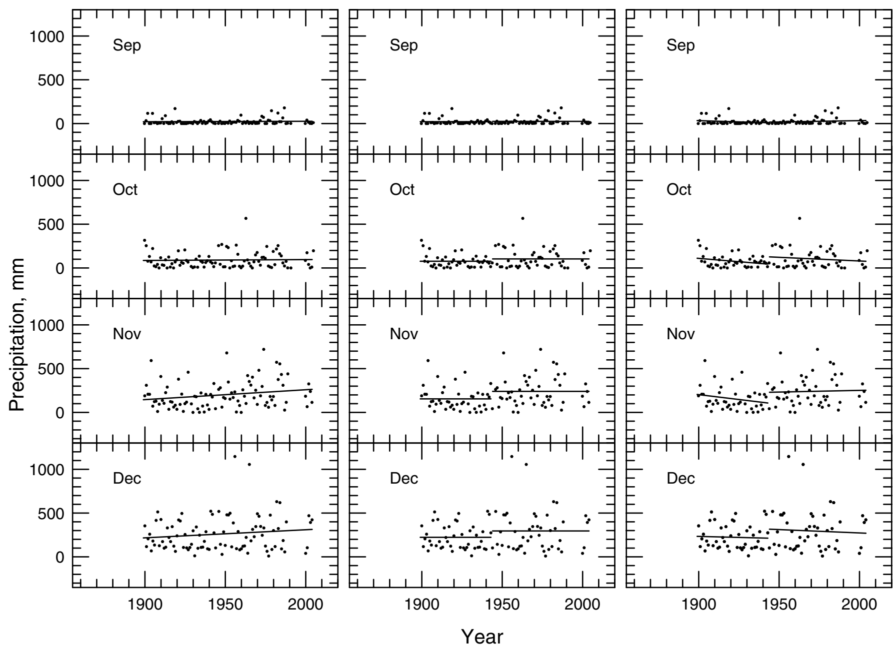


*Figure 1.* Monthly precipitation at Blue Canyon, 1899–2004, September (top) through December (bottom). Ordinate, precipitation in millimeters; abscissa, year. Left (a): Precipitation at locations 1 (1899–1944) and 2 (1945–2004). Lines are the regression lines for the entire interval. Middle (b): Precipitation at locations 1 and 2. Lines are the averages for each location. Right (c): Precipitation at locations 1 and 2. Lines are the regression lines for each location.

## 3. Precipitation

The precipitation records for the seven stations were analyzed to determine, for each of the four months, September–December, whether a secular change in precipitation with time has occurred. That analysis was complicated by the changes in the locations of the stations and rain gauges detailed in Section 2, above. Consequently, for each month, at each station, the average and least squares fit of the observations was calculated, first for the entire time span of the station and then for intervals between changes in instrumentation or location. These calculations are shown in Table II. The results for each station are discussed below.

### 3.1. Blue Canyon

The observations of precipitation ($P$) for the entire period from 1899–2004 are plotted in Figures 1a–c, and the numerical analyses of these data are summarized in Tables II and III. Figure 1a and Table II show that combining all of the observations, there is no evidence for a change in $P$ with time except in the month of November, when an increase in $P$ with time occurs. However, as discussed in Section 2.1, a major relocation of the station occurred in 1945. Analyzing the observations at each location separately, Tables II and III and Figures 1b, 1c, and 8 indicate that there are, in fact, significant differences in $P$ at the two locations. The nature of these differences is particularly well shown in Figure 8, which shows the variation of the average monthly precipitation ($\overline{P}$) with month at the various Sierran stations. In this figure, the curves represent the observations of $\overline{P}$ at Colfax from 1870–1944, scaled to fit the observations at the other stations. The observations at Colfax have been adopted as the standard for comparison with the other stations since this set of measures is the most precise, being based on the longest sequence of observations prior to 1945, with no change in the location of the rain gauge. Figure 8 shows that at Blue Canyon location 1, the increase of $\overline{P}$ with month matches (with proper scaling) that of the "standard" variation at Colfax within the statistical uncertainty. At location 2, the measures in September, October, and December fit this same standard curve, when the ordinates of the location 1 curve are multiplied by 1.302, while the precipitation in November ($\overline{P}_{Nov}$) lies significantly above this curve. These differences between locations 1 and 2 could, in principle, result either from the relocation of the weather instruments or to changes in $\overline{P}$ with time. Since, as will be discussed below, other stations show the same type of increase in $\overline{P}$ with month as is observed at Colfax from 1870–1944 and at Blue Canyon No. 1, but with no change in ordinate with time, it appears that $\overline{P}$ at Blue Canyon No. 2 is systematically greater than at Blue Canyon No. 1 by about 30 percent for the months of September, October, and December. The larger value of $\overline{P}_{Nov}$ at location 2 could be a peculiarity of Blue Canyon No. 2, or could reflect an increase in $\overline{P}_{Nov}$ with time. Since, as shown in Figure 8 and discussed below, three other Sierran stations (Colfax, Soda Springs and Tahoe City) show similar increases in $\overline{P}_{Nov}$ during the time period of the observations at Blue Canyon No. 2, but with no change in the location of the weather instruments, it would appear that the increase in $\overline{P}_{Nov}$ at Blue Canyon No. 2 does not result from a peculiarity of the weather pattern at that particular location, but represents a real increase in $\overline{P}_{Nov}$ with time.

From Table II we see that there is no indication of a change in $\overline{P}$ with time at location 1. However, at location 2, an increase in $\overline{P}$ with time of as much as $\overline{P'} = +1.524$ mm/yr could exist for the month of November, masked by the large dispersion in $\overline{P}$ at that location. An approximate value of $\overline{P'}_{Nov}$ can be derived from the data in Table II by taking the value of $\overline{P}_{Nov}$ at location 1, multiplying by 1.302 to

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Table II. Average Monthly Total Precipitation.

| Station, Location, Interval | Month | No. Years | Observed mm $\overline{P}$ | $\sigma_{\overline{P}}$ | Time Variation of $\overline{P}$ mm/yr $\overline{P'}$ | $\sigma_{\overline{P'}}$ | Student $t$ | $t_c$[a] |
|---|---|---|---|---|---|---|---|---|
| Blue Canyon | Sep | 96 | 23.2 | 3.8 | +0.05 | 0.13 | 0.38 | 1.66 |
| No. 1+2 | Oct | 95 | 91.1 | 9.7 | +0.10 | 0.33 | 0.30 | 1.66 |
| 1899–2004 | Nov | 93 | 199.9 | 16.3 | +1.13 | 0.56 | 2.02 | 1.66 |
| | Dec | 93 | 260.5 | 20.9 | +0.92 | 0.74 | 1.24 | 1.66 |
| Blue Canyon | Sep | 45 | 21.3 | 5.4 | –0.55 | 0.41 | 1.34 | 1.69 |
| No. 1 | Oct | 44 | 76.9 | 10.8 | –1.52 | 0.80 | 1.90 | 1.69 |
| 1899–1943 | Nov | 44 | 154.7 | 19.7 | –2.22 | 1.48 | 1.50 | 1.69 |
| | Dec | 45 | 223.1 | 21.0 | –0.47 | 1.63 | 0.28 | 1.69 |
| Blue Canyon | Sep | 51 | 24.8 | 5.4 | +0.30 | 0.33 | 0.91 | 1.68 |
| No. 2 | Oct | 51 | 103.4 | 15.3 | –0.84 | 0.93 | 0.90 | 1.68 |
| 1945–2004 | Nov | 49 | 240.5 | 24.2 | +0.39 | 1.53 | 0.25 | 1.68 |
| | Dec | 48 | 295.6 | 34.9 | –0.77 | 2.22 | 0.35 | 1.68 |
| Boca | Sep | 109 | 10.4 | 1.5 | +0.15 | 0.05 | 3.00 | 1.66 |
| No. 1+2 | Oct | 107 | 29.0 | 3.3 | +0.15 | 0.08 | 1.88 | 1.66 |
| 1870–2004 | Nov | 107 | 53.6 | 5.3 | +0.33 | 0.13 | 2.54 | 1.66 |
| | Dec | 108 | 89.9 | 8.1 | +0.05 | 0.20 | 0.25 | 1.66 |
| Boca | Sep | 44 | 3.8 | 1.0 | +0.15 | 0.08 | 1.88 | 1.68 |
| No. 1 | Oct | 42 | 19.3 | 4.1 | +0.20 | 0.28 | 0.71 | 1.68 |
| 1870–1917 | Nov | 43 | 33.8 | 6.4 | +0.08 | 0.46 | 0.17 | 1.68 |
| | Dec | 43 | 88.9 | 13.7 | +0.25 | 0.99 | 0.25 | 1.68 |
| Boca | Sep | 65 | 15.0 | 2.3 | +0.18 | 0.13 | 1.38 | 1.67 |
| No. 2 | Oct | 65 | 35.1 | 4.6 | –0.15 | 0.25 | 0.60 | 1.67 |
| 1937–2004 | Nov | 64 | 66.8 | 7.4 | –0.05 | 0.41 | 0.12 | 1.67 |
| | Dec | 65 | 90.7 | 10.2 | +0.20 | 0.53 | 0.38 | 1.67 |
| Colfax No. 1+2+3 | Sep | 131 | 16.3 | 2.3 | +0.18 | 0.08 | 2.25 | 1.66 |
| 1870–2004 | Oct | 131 | 63.5 | 6.1 | 0.00 | 0.18 | 0.00 | 1.66 |
| | Nov | 130 | 143.3 | 10.4 | +0.46 | 0.28 | 1.64 | 1.66 |
| | Dec | 131 | 198.4 | 12.7 | –0.08 | 0.36 | 0.22 | 1.66 |

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Table II—Continued

| Station, Location, Interval | Month | No. Years | Observed mm $\overline{P}$ | $\sigma_{\overline{P}}$ | Time Variation of $\overline{P}$ mm/yr $\overline{P'}$ | $\sigma_{\overline{P'}}$ | Student $t$ | $t_c$[a] |
|---|---|---|---|---|---|---|---|---|
| Colfax No. 1+2+3 | Sep | 98 | 18.8 | 3.6 | −0.10 | 0.13 | 0.77 | 1.66 |
| 1905–2004 | Oct | 98 | 61.7 | 7.1 | +0.20 | 0.25 | 0.80 | 1.66 |
| | Nov | 97 | 143.0 | 11.2 | +0.91 | 0.38 | 2.39 | 1.66 |
| | Dec | 98 | 191.8 | 14.0 | +0.20 | 0.48 | 0.42 | 1.66 |
| Colfax No. 1+2+3 | Sep | 59 | 17.5 | 3.6 | +0.19 | 0.20 | 0.95 | 1.67 |
| 1945–2004 | Oct | 59 | 69.1 | 10.9 | −0.41 | 0.62 | 0.66 | 1.67 |
| | Nov | 57 | 168.4 | 15.5 | −0.07 | 0.92 | 0.08 | 1.67 |
| | Dec | 58 | 197.1 | 19.8 | +0.06 | 1.18 | 0.05 | 1.67 |
| Colfax No. 1 | Sep | 34 | 16.3 | 4.8 | +0.91 | 0.41 | 2.22 | 1.70 |
| 1870–1907 | Oct | 30 | 69.3 | 12.7 | +1.50 | 1.07 | 1.40 | 1.70 |
| | Nov | 27 | 144.0 | 24.1 | +1.42 | 2.03 | 0.70 | 1.71 |
| | Dec | 29 | 218.2 | 28.7 | +1.30 | 2.51 | 0.52 | 1.70 |
| Colfax No. 1 | Sep | 72 | 15.2 | 3.2 | +0.01 | 0.15 | 0.07 | 1.67 |
| 1870–1944 | Oct | 72 | 58.9 | 6.9 | −0.04 | 0.32 | 0.12 | 1.67 |
| | Nov | 73 | 123.4 | 13.5 | −0.36 | 0.62 | 0.59 | 1.67 |
| | Dec | 73 | 199.4 | 16.5 | −0.62 | 0.76 | 0.82 | 1.67 |
| Colfax No. 1 | Sep | 102 | 14.0 | 2.5 | −0.03 | 0.08 | 0.38 | 1.66 |
| 1870–1975 | Oct | 102 | 64.8 | 7.4 | +0.23 | 0.25 | 0.92 | 1.66 |
| | Nov | 103 | 137.9 | 11.7 | +0.51 | 0.38 | 1.34 | 1.66 |
| | Dec | 103 | 200.7 | 14.2 | −0.13 | 0.46 | 0.28 | 1.66 |
| Colfax No. 1 | Sep | 68 | 13.0 | 2.8 | −0.15 | 0.15 | 1.00 | 1.67 |
| 1905–1975 | Oct | 69 | 62.7 | 9.1 | +0.69 | 0.46 | 1.50 | 1.67 |
| | Nov | 70 | 135.1 | 13.0 | +1.60 | 0.61 | 2.62 | 1.67 |
| | Dec | 70 | 192.5 | 16.0 | +0.51 | 0.79 | 0.65 | 1.67 |
| Colfax No. 2 | Sep | 21 | 29.7 | 8.1 | −1.88 | 1.24 | 1.52 | 1.73 |
| 1976–1996 (S) | Oct | 20 | 57.3 | 12.9 | −0.61 | 2.30 | 0.27 | 1.73 |
| 1976–1995 (O–D) | Nov | 19 | 163.3 | 30.1 | −1.91 | 5.63 | 0.34 | 1.74 |
| | Dec | 20 | 175.0 | 28.6 | +2.97 | 5.05 | 0.59 | 1.73 |

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Table II—Continued

| Station, Location, Interval | Month | No. Years | Observed mm $\overline{P}$ | Observed mm $\sigma_{\overline{P}}$ | Time Variation of $\overline{P}$ mm/yr $\overline{P'}$ | mm/yr $\sigma_{\overline{P'}}$ | Student $t$ | Student $t_c{}^a$ |
|---|---|---|---|---|---|---|---|---|
| Colfax No. 3 | Sep | 8 | 11.4 | 5.1 | −3.68 | 1.88 | 1.96 | 1.94 |
| 1997–2004 (S) | Oct | 9 | 62.7 | 17.7 | +1.10 | 7.30 | 0.15 | 1.90 |
| 1996–2004 (O–D) | Nov | 8 | 162.9 | 25.8 | −16.75 | 10.07 | 1.66 | 1.94 |
| | Dec | 8 | 226.1 | 74.3 | −16.90 | 34.34 | 0.49 | 1.94 |
| Mt. Hamilton | Sep | 102 | 8.1 | 1.8 | −0.03 | 0.05 | 0.40 | 1.66 |
| No. 1+2+3+4 | Oct | 105 | 32.0 | 3.3 | +0.03 | 0.10 | 0.30 | 1.66 |
| 1898–2004 | Nov | 102 | 72.9 | 5.3 | +0.18 | 0.18 | 1.00 | 1.66 |
| | Dec | 98 | 103.4 | 8.6 | −0.15 | 0.28 | 0.54 | 1.66 |
| Mt. Hamilton | Sep | 31 | 11.9 | 4.8 | +0.05 | 0.53 | 0.09 | 1.70 |
| No. 1 | Oct | 31 | 31.5 | 6.6 | −1.22 | 0.71 | 1.72 | 1.70 |
| 1898–1928 | Nov | 31 | 69.6 | 8.4 | −1.24 | 0.94 | 1.32 | 1.70 |
| | Dec | 31 | 108.5 | 11.9 | +1.12 | 1.35 | 0.83 | 1.70 |
| Mt. Hamilton | Sep | 26 | 24.9 | 10.7 | −0.05 | 0.13 | 0.38 | 1.71 |
| No. 2 | Oct | 26 | 32.5 | 6.1 | +0.53 | 0.79 | 0.67 | 1.71 |
| 1929–1956 | Nov | 26 | 65.3 | 12.2 | +2.16 | 1.47 | 1.47 | 1.71 |
| | Dec | 27 | 127.0 | 21.8 | +0.58 | 2.03 | 0.29 | 1.71 |
| Mt. Hamilton | Sep | 35 | 9.7 | 2.3 | +0.41 | 0.20 | 2.05 | 1.69 |
| No. 3 | Oct | 38 | 30.5 | 4.6 | +0.48 | 0.43 | 1.12 | 1.68 |
| 1957–1994 | Nov | 36 | 74.4 | 9.7 | +0.30 | 0.91 | 0.33 | 1.69 |
| | Dec | 31 | 69.6 | 9.7 | +0.56 | 0.89 | 0.63 | 1.70 |
| Mt. Hamilton | Sep | 10 | 4.8 | 1.8 | +0.91 | 0.53 | 1.72 | 1.86 |
| No. 4 | Oct | 10 | 36.8 | 14.5 | +2.95 | 5.23 | 0.56 | 1.86 |
| 1995–2004 | Nov | 9 | 95.2 | 16.5 | +0.10 | 6.83 | 0.01 | 1.90 |
| | Dec | 9 | 136.1 | 33.0 | +2.59 | 13.67 | 0.19 | 1.90 |
| Soda Springs | Sep | 40 | 15.7 | 2.3 | −0.18 | 0.15 | 1.20 | 1.68 |
| 1913–1969 | Oct | 41 | 81.8 | 13.5 | +1.37 | 0.86 | 1.59 | 1.68 |
| | Nov | 37 | 159.5 | 19.8 | +3.30 | 1.37 | 2.41 | 1.68 |
| | Dec | 35 | 228.6 | 31.8 | +3.61 | 2.79 | 1.29 | 1.68 |

Table II—Continued

| Station, Location, Interval | Month | No. Years | Observed mm $\overline{P}$ | $\sigma_{\overline{P}}$ | Time Variation of $\overline{P}$ mm/yr $\overline{P'}$ | $\sigma_{\overline{P'}}$ | Student $t$ | $t_c{}^a$ |
|---|---|---|---|---|---|---|---|---|
| Soda Springs | Sep | 36 | 15.0 | 2.3 | −0.13 | 0.20 | 0.65 | 1.69 |
| 1930–1969 | Oct | 36 | 88.9 | 14.7 | +1.02 | 1.30 | 0.78 | 1.69 |
| | Nov | 35 | 165.1 | 20.3 | +3.05 | 1.70 | 1.79 | 1.69 |
| | Dec | 35 | 228.6 | 31.8 | +3.61 | 2.79 | 1.29 | 1.69 |
| Tahoe City | Sep | 94 | 15.2 | 2.3 | +0.08 | 0.08 | 1.00 | 1.66 |
| No. 1+2+3 | Oct | 95 | 43.9 | 4.6 | +0.18 | 0.18 | 1.00 | 1.66 |
| 1909–2004 | Nov | 94 | 95.0 | 8.1 | +0.53 | 0.30 | 1.77 | 1.66 |
| | Dec | 93 | 131.8 | 10.7 | −0.05 | 0.38 | 0.13 | 1.66 |
| Tahoe City | Sep | 40 | 12.4 | 3.0 | −0.28 | 0.28 | 1.00 | 1.68 |
| No. 1 | Oct | 40 | 36.3 | 5.6 | +0.41 | 0.48 | 0.85 | 1.68 |
| 1909–1949 | Nov | 40 | 78.5 | 10.4 | +0.64 | 0.89 | 0.72 | 1.68 |
| | Dec | 40 | 129.5 | 13.7 | −0.30 | 1.19 | 0.25 | 1.68 |
| Tahoe City | Sep | 21 | 13.2 | 3.0 | +0.33 | 0.48 | 0.69 | 1.73 |
| No. 2 | Oct | 21 | 51.3 | 13.2 | −1.93 | 2.21 | 0.87 | 1.73 |
| 1950–1970 | Nov | 21 | 102.4 | 18.3 | +0.41 | 3.12 | 0.13 | 1.73 |
| | Dec | 20 | 150.6 | 29.7 | −4.14 | 4.93 | 0.84 | 1.73 |
| Tahoe City | Sep | 33 | 20.1 | 4.8 | −0.41 | 0.51 | 0.80 | 1.70 |
| No. 3 | Oct | 34 | 48.3 | 7.4 | −0.53 | 0.76 | 0.70 | 1.70 |
| 1971–2004 | Nov | 33 | 110.0 | 15.5 | −0.10 | 1.65 | 0.06 | 1.70 |
| | Dec | 33 | 123.2 | 18.0 | +1.70 | 1.88 | 0.90 | 1.70 |
| Tahoe City | Sep | 54 | 17.5 | 3.3 | +0.10 | 0.20 | 0.50 | 1.68 |
| No. 2+3 | Oct | 55 | 49.5 | 6.9 | −0.30 | 0.43 | 0.70 | 1.68 |
| 1950–2004 | Nov | 54 | 107.2 | 11.7 | +0.20 | 0.76 | 0.26 | 1.68 |
| | Dec | 53 | 133.6 | 15.7 | −0.56 | 0.99 | 0.57 | 1.68 |
| Truckee | Sep | 117 | 13.0 | 2.0 | +0.13 | 0.05 | 2.60 | 1.66 |
| No. 1+2+3 | Oct | 117 | 37.3 | 4.1 | +0.20 | 0.10 | 2.00 | 1.66 |
| 1870–2004 | Nov | 113 | 78.7 | 6.6 | +0.41 | 0.18 | 2.28 | 1.66 |
| All obs. | Dec | 116 | 121.9 | 10.2 | +0.36 | 0.25 | 1.44 | 1.66 |

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Table II—Continued

| Station, Location, Interval | Month | No. Years | Observed mm $\overline{P}$ | $\sigma_{\overline{P}}$ | Time Variation of $\overline{P}$ mm/yr $\overline{P'}$ | $\sigma_{\overline{P'}}$ | Student $t$ | $t_c$[a] |
|---|---|---|---|---|---|---|---|---|
| Truckee | Sep | 105 | 13.0 | 2.0 | +0.13 | 0.05 | 2.60 | 1.66 |
| No. 1+2+3 | Oct | 105 | 40.4 | 4.3 | +0.18 | 0.10 | 1.80 | 1.66 |
| 1870–1907 + | Nov | 102 | 83.8 | 7.1 | +0.36 | 0.18 | 2.00 | 1.66 |
| 1920–2004 | Dec | 104 | 125.7 | 10.7 | +0.23 | 0.25 | 0.92 | 1.66 |
| Truckee | Sep | 37 | 7.1 | 2.0 | +0.33 | 0.18 | 1.83 | 1.69 |
| No. 1 | Oct | 36 | 29.2 | 6.1 | +0.46 | 0.53 | 0.87 | 1.69 |
| 1870–1907 | Nov | 35 | 62.5 | 9.7 | +0.10 | 0.86 | 0.12 | 1.69 |
| | Dec | 37 | 106.2 | 16.3 | −0.91 | 1.47 | 0.62 | 1.69 |
| Truckee | Sep | 16 | 13.5 | 6.4 | −0.69 | 1.42 | 0.49 | 1.76 |
| No. 1 | Oct | 16 | 15.7 | 6.4 | −1.37 | 1.37 | 1.00 | 1.76 |
| 1904–1920 | Nov | 15 | 31.0 | 6.4 | −0.51 | 1.42 | 0.36 | 1.77 |
| | Dec | 16 | 97.3 | 20.3 | −2.64 | 4.52 | 0.58 | 1.76 |
| Truckee | Sep | 47 | 13.7 | 2.8 | +0.38 | 0.20 | 1.90 | 1.68 |
| No. 2 | Oct | 47 | 48.0 | 7.4 | +0.18 | 0.53 | 0.34 | 1.68 |
| 1935–1982 | Nov | 46 | 94.0 | 11.4 | +0.46 | 0.81 | 0.57 | 1.68 |
| | Dec | 46 | 146.0 | 17.5 | +0.10 | 1.07 | 0.09 | 1.68 |
| Truckee | Sep | 21 | 21.8 | 6.6 | −1.32 | 1.04 | 1.27 | 1.73 |
| No. 3 | Oct | 22 | 42.9 | 8.4 | −0.36 | 1.37 | 0.26 | 1.73 |
| 1983–2004 | Nov | 21 | 97.3 | 18.0 | −4.90 | 2.84 | 1.73 | 1.73 |
| | Dec | 21 | 115.3 | 22.9 | +3.35 | 3.78 | 0.89 | 1.73 |
| Truckee | Sep | 68 | 16.3 | 2.8 | +0.23 | 0.15 | 1.53 | 1.67 |
| No. 2+3 | Oct | 69 | 46.5 | 5.6 | −0.05 | 0.28 | 0.18 | 1.67 |
| 1935–2004 | Nov | 67 | 95.0 | 9.7 | +0.08 | 0.48 | 0.17 | 1.67 |
| | Dec | 67 | 136.4 | 14.0 | −0.51 | 0.71 | 0.72 | 1.67 |

[a] Critical value: 95 percent confidence level.

Table III. Precipitation Difference between Station Locations.

| Station, Location, Interval | Month | Precipitation Difference (mm) (2) −(1) $\Delta\overline{P}$ | $\sigma_{\Delta\overline{P}}$ | (3) −(2) $\Delta\overline{P}$ | $\sigma_{\Delta\overline{P}}$ | (4) −(3) $\Delta\overline{P}$ | $\sigma_{\Delta\overline{P}}$ |
|---|---|---|---|---|---|---|---|
| Blue Canyon | Sep | + 3.5 | 7.6 | — | — | — | — |
| 1) 1899–1943 | Oct | +26.5 | 18.7 | — | — | — | — |
| 2) 1945–2004 | Nov | +85.8 | 31.2 | — | — | — | — |
| | Dec | +72.5 | 40.7 | — | — | — | — |
| Boca | Sep | +11.2 | 2.5 | — | — | — | — |
| 1) 1870–1917 | Oct | +15.7 | 6.1 | — | — | — | — |
| 2) 1937–2004 | Nov | +33.0 | 9.7 | — | — | — | — |
| | Dec | + 1.8 | 17.0 | — | — | — | — |
| Colfax | Sep | +16.8 | 8.6 | −18.3 | 9.7 | — | — |
| 1) 1870–1975 | Oct | − 5.3 | 15.7 | + 5.3 | 23.9 | — | — |
| 2) 1976–1996 | Nov | +28.2 | 32.8 | − 5.6 | 41.9 | — | — |
| 3) 1997–2004 | Dec | −17.5 | 32.8 | +16.0 | 52.8 | — | — |
| Mount Hamilton | Sep | +13.0 | 11.7 | −15.2 | 10.9 | − 4.8 | 2.8 |
| 1) 1898–1928 | Oct | + 1.0 | 8.9 | − 2.0 | 7.6 | + 6.4 | 1.5 |
| 2) 1929–1956 | Nov | + 5.6 | 14.7 | + 9.1 | 15.5 | +20.8 | 19.0 |
| 3) 1957–1994 | Dec | +18.5 | 24.9 | −58.2 | 23.9 | +67.3 | 34.3 |
| 4) 1995–2004 | | | | | | | |
| Tahoe City | Sep | + 0.8 | 8.6 | + 6.9 | 5.6 | + 4.3[a] | 4.6[a] |
| 1) 1909–1949 | Oct | +15.0 | 14.2 | − 3.0 | 15.2 | +13.5[a] | 5.8[a] |
| 2) 1950–1970 | Nov | +23.9 | 21.1 | + 7.6 | 23.9 | +27.7[a] | 11.2[a] |
| 3) 1971–2004 | Dec | +21.1 | 32.8 | −27.4 | 34.8 | + 7.4[a] | 19.3[a] |
| 4) 1950–2004 | | | | | | | |
| Truckee | Sep | + 6.6 | 3.6 | + 8.1 | 7.1 | + 9.1[a] | 3.6[a] |
| 1) 1870–1907 | Oct | +18.8 | 9.7 | − 5.1 | 11.2 | +17.3[a] | 8.4[a] |
| 2) 1935–1982 | Nov | +31.5 | 15.0 | + 3.3 | 21.3 | +32.5[a] | 16.0[a] |
| 3) 1983–2004 | Dec | +39.9 | 23.9 | −30.7 | 28.7 | +30.2[a] | 21.3[a] |
| 4) 1935–2004 | | | | | | | |

[a] Interval (4) *minus* Interval (1).

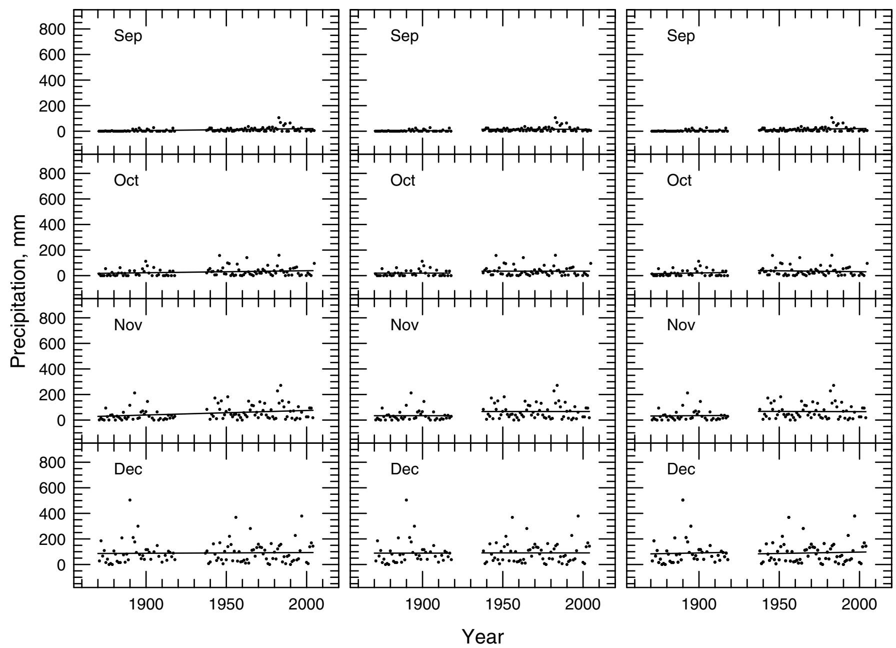


*Figure 2.* Monthly precipitation at Boca, 1870–2004. Ordinate, abscissa and layout as in Figure 1. Left (a): Precipitation at locations 1 (1870–1917) and 2 (1937–2004). Lines are the regression lines for the entire interval. Middle (b): Precipitation at locations 1 and 2. Lines are the averages for each location. Right (c): Precipitation at locations 1 and 2. Lines are the regression lines for each location.

correct for the systematic difference in $\overline{P}$ between locations 1 and 2, and subtracting this value from the observed value of $\overline{P}_{Nov}$ at location 2. The increase in $P_{Nov}$ at location 2 is then $\overline{P}_{Nov} = +62.7$ mm. Taking the time period to be the interval between the means of the intervals at locations 1 and 2 (50.0 yr), $\overline{P'}_{Nov} = +1.254$ mm/yr. Since there is no indication of an increase in $\overline{P}_{Nov}$ at location 1, that increase may have begun only in, or after, 1945, in which case $\overline{P'}_{Nov} = +2.164$ mm/yr.

### 3.2. Boca

Combining all of the observations from 1870–2004, Table II and Figure 2a show statistically significant increases in $P$ with time for the months of September, October, and November, but no significant change in December. However, as discussed in Section 2.2, the location of the weather instruments was changed in 1936, so that there is the possibility of a systematic difference between the values of $P$ measured before 1918 and after 1936.

Considering the observations at locations 1 and 2 separately, Table II and Figure 2c show that a statistically significant change in $P$ with time is observed only in September at location 1 (1870–1917), and this change is extremely small. No change in $P$ with time is observed in the longer and probably more reliable set of observations at location 2 (1937–2004). Significant differences in $\overline{P}$ between locations 1 and 2 are shown in Table III and Figure 2b, for the months of September and November and, with less certainty October, indicating the existence of a systematic difference in $P$ at the two locations. These results are substantiated by the plot of $\overline{P}$ against month, shown in Figure 8. In this figure, we see that within their statistical uncertainties, the measures at location 1 fit the standard curve of the variation of $\overline{P}$ with month defined by the observations at Colfax, 1870–1944, and scaled to give $\overline{P}$ = 76.2 mm in December, while those at location 2 fit this curve adjusted to give $\overline{P}$ = 101.6 mm in December, indicating that $\overline{P}$ at location 2 is systematically greater than at location 1 by about 33 percent; no statistically significant increase in $\overline{P}_{Nov}$ is detected at either location. Thus, at Boca, a small systematic difference in $P$ exists between locations 1 and 2, but no significant change in $P$ with time is detected.

### 3.3. Colfax

As indicated in Section 2.3, observations at this station were made at the same location from 1870–1975. The weather instruments were then relocated twice: in 1976 and again in 1996. As shown in Table III, analysis of the precipitation records for these three intervals reveals no statistically significant differences in $P$ between any of these locations although, owing to the short periods of time that observations were made at locations 2 and 3, the possibility of some small difference at one or both of these sites can not be ruled out.

Considering all of the observations from 1870–2004, Table II and Figure 3a show no significant change in precipitation with time except in the month of November, where an increase of $\overline{P'}_{Nov} = +0.46 \pm 0.28$ mm/yr occurs. For the shorter period from 1870–1975 when there was no change in instrument location, Table II shows no change in $\overline{P}$ with time except, once again, in November, when an increase of $\overline{P'}_{Nov} = +0.51 \pm 0.38$ mm/yr occurred, statistically significant at the 90 percent confidence level. Statistically significant increases in $\overline{P}$ with time in the month of November are also found for the intervals from 1905–1975 and 1905–2004, but not for 1870–1907, 1870-1944, and 1945–2004; the intervals with observations at locations 2 and 3 are too short to permit detection of a change in $\overline{P}_{Nov}$ with time at either of these sites. These

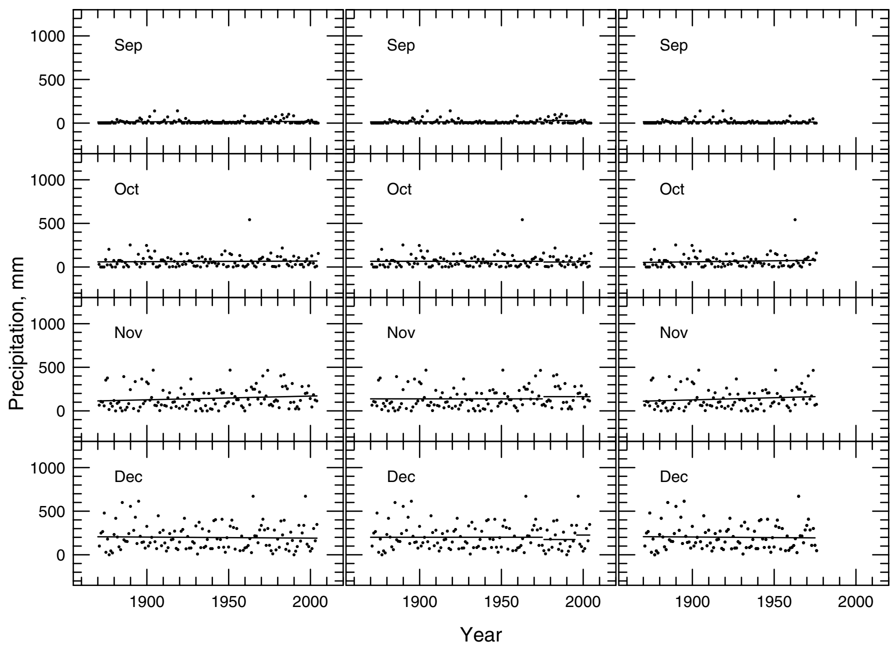


*Figure 3.* Monthly precipitation at Colfax, 1870–2004. Ordinate, abscissa and layout as in Figure 1. Left (a): Precipitation at locations 1 (1870–1975), 2 (1976–1995), and 3 (1996–2004). Lines are the regression lines for the entire interval. Middle (b): Precipitation at locations 1, 2, and 3. Lines are the averages for each location. Right (c): Precipitation at location 1 (1870–1975). Lines are the regression lines for this interval.

observations thus indicate that while $P$ has remained unchanged from 1870–2004 during the months of September, October and December, an increase in $\overline{P}_{Nov}$ has occurred sometime during that interval.

These conclusions are further confirmed by the plots of $P$ as a function of month in Figure 8, which shows the observations for the intervals 1870–1944 and 1945–2004. For both intervals, $\overline{P}$ increases smoothly from September–December, except for the month of November in the period 1945–2004, where an increased amount of precipitation occurs. Dividing the observations into overlapping 20-year intervals and calculating for each interval the excess precipitation in November ($E_{Nov}$), defined as $E_{Nov} = \overline{P}_{Nov}$ - $(\overline{P}_{Oct} + \overline{P}_{Dec})/2$, it appears that $E_{Nov}$ probably first appears sometime between 1930 and 1940, and has increased more or less linearly with time since that date.

As discussed earlier, since Colfax has the longest interval prior to 1945 with no change in instrument location, the curve representing the variation of $\overline{P}$ with month for 1870–1944 has been adopted as the

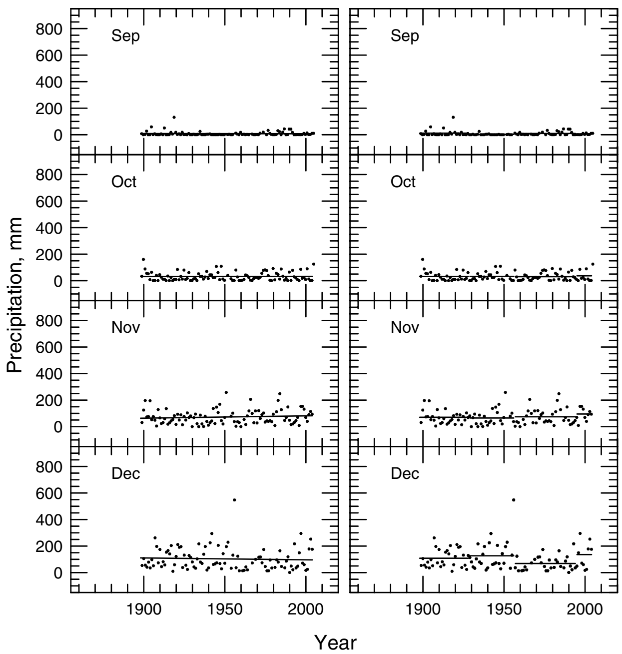


*Figure 4.* Monthly precipitation at Mount Hamilton, 1898–2004. Ordinate, abscissa and layout as in Figure 1. Left (a): Precipitation at locations 1 (1898–1928), 2 (1929–1956), 3 (1957–1994), and 4 (1995–2004). Lines are the regression lines for the entire interval. Right (b): Precipitation at locations 1, 2, 3, and 4. Lines are the averages for each location.

"standard" for comparison with the variation of $\overline{P}$ with month at the other stations.

### 3.4. Mount Hamilton

As discussed in Section 2.4, precipitation records began in 1880. However, only a few observations were made between 1880 and 1897. Consequently, only observations in the period 1898–2004 have been analyzed in the present study.

Considering all of the observations in this interval, we see from Table II and Figure 4a that no significant change in the amount of precipitation with time is detected. However, this result is rendered somewhat uncertain by the possibility of systematic differences in the amount of precipitation recorded as a result of differences in both the types and locations of the rain gauge, as detailed in Section 2.4. Owing to the sketchy documentation and short intervals of time that the rain gauge was situated at some of these locations, the observations from

1898–2004 have been divided into four groups in Tables II and III and Figure 9:

1. 1898–1928, when the rain gauge was of the Draper type and was mounted on the roof of the Main Building.

2. 1929–1956, when the gauge was located at different positions on the top of the peak near its center and northeast edge.

3. 1957–1994, when it was located near the southeast edge of the top of the peak.

4. 1995–2004, when the gauge was located 21 m (70 ft) to the west-southwest of its 1957–1994 position.

The final relocation was made because the weather observers had reported that the precipitation amounts measured near the southeast edge of the peak were systematically low, and this effect can be clearly seen in the observations for December in Figures 4 and 9, and Tables II and III. The reason for this difference is that during rain storms the accompanying winds are southerly in direction and sweep upwards along the southeast slope of the peak producing, for an observer standing along the southeast edge of the summit, the interesting phenomenon of rain falling *upwards*. In consequence, there is a narrow zone along the southeast edge of the peak where the amount of precipitation is abnormally low. The reason that the effect is seen only in December may be that the wind velocities are higher at this time; unfortunately, no wind velocity records are available.

Since demonstrably different rainfall was observed at this one location, the possibility of other smaller systematic effects can not be ruled out, even though none of statistical significance are revealed in Table III. Thus, we can only conclude that the observations at Mount Hamilton yield no conclusive evidence for a secular change in precipitation with time, but that there is the possibility that some small change could have occurred which is masked by the dispersion and possible systematic errors of the observations.

The same conclusions are indicated by the plot of $\overline{P}$ against month in Figure 9. This figure shows that except for the precipitation in December during the period 1957–1994, the variation of $\overline{P}$ with month matches the standard variation, at Colfax, 1870–1944, within the error bars. There is no conclusive evidence of an increase or excess of $\overline{P}_{Nov}$ and while the ordinates of the standard Colfax curves vary slightly between the four locations, these variations are too small to be statistically significant.

### 3.5. Soda Springs

Precipitation measures began in 1913. From 1913–1917, observations were made in four years in September, five years in October, two years in November, and none in December. No observations were made from 1918–1929. In 1930, measurement began once more and continued without interruption until 1969. As discussed in Section 2.5, the location of the rain gauge in 1913–1917 is unknown, but is presumed to have been the same as in 1930–1939. In August, 1940, the gauge was relocated from a wooden platform to an adjacent tower, with little change in position or height above the ground. Thus, it is unlikely that systematic differences exist between the 1913–1917, 1930–1939, and 1940–1969 observations, although this possibility should be kept in mind.

The observations from 1913–1969 are shown in Figure 5, where the lines are the regression lines for the entire data sets. Table II shows that a statistically significant increase in $\overline{P}$ with time occurred in November and, at the 93 percent confidence level, in October as well; the slope of the regression line in December is not statistically significant, and is based on observations from 1930 to 1965 only. Note that, as shown in Table II, the few observations from 1913–1917 fall along the regression lines defined by the observations from 1930–1969, as well as by the entire data sets, supporting the conclusion that the slope results from a secular change in $\overline{P}_{Nov}$ rather than a systematic difference due to relocation of the rain gauge.

Figure 8 shows that the variation of $\overline{P}$ with month lacks the curvature of the standard Colfax 1870-1944 variation, which may again indicate increased or excess $\overline{P}$ in October and November. Here, as the figure shows, the observations can be fitted to the standard curve within the error bars, so that the existence of enhanced precipitation in November—and possibly October—cannot be verified. However, the least squares solutions in Table II, discussed above, demonstrate that an increase in $\overline{P}_{Nov}$ and possibly $\overline{P}_{Oct}$with time has occurred at this station.

### 3.6. Tahoe City

As discussed in Section 2.6, the weather instruments at Tahoe City have been moved twice, although the distances involved were fairly small. Thus, there is the possibility of systematic differences between the amounts of precipitation recorded at these locations. However, as shown in Table III, analyzing the observations at each location separately, we find no evidence of such differences, so that the measurements at all three locations can be combined.

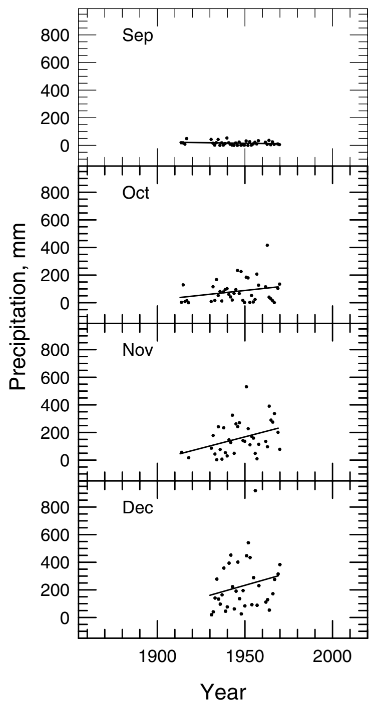


*Figure 5.* Monthly precipitation at Soda Springs, 1913–1969. Ordinate, abscissa and layout as in Figure 1. Lines are the regression lines for the entire interval.

Table II and Figure 6 show that the precipitation measures for the interval from 1909–2004 reveal no statistically significant variation of $\overline{P}$ with time except in the month of November, when $\overline{P'}_{Nov} = +0.54$ $\pm 0.30$ mm/yr. Whether changes in $\overline{P}_{Nov}$ with time occur during the shorter intervals at locations 1, 2, 3, and 2+3, listed in Table II, can not be determined owing to the large dispersion of the observations.

A somewhat clearer picture results from plotting $\overline{P}$ against month, in Figure 8. Here, the average monthly values of the precipitation are plotted for the intervals 1909–1949 and 1950–2004. It will be seen that, with only one exception, the observations from both intervals fall, within the error bars, along the (same) standard curve for the variation of $\overline{P}$ at Colfax, 1870–1944. The one exception is the value of $\overline{P}_{Nov}$ for the interval 1950–2004, which lies above the curve by about 2.5 $\sigma$. Calculating $\overline{P'}_{Nov}$ from the difference in $\overline{P}_{Nov}$ between the two intervals (as at Blue Canyon in Section 3.1, above), and taking the time interval between the two values of $\overline{P}$ to be that between the midpoints of the intervals, $\overline{P'}_{Nov} = +0.60$ mm/yr, similar to the value given above for the period 1909–2004. Since the value of $\overline{P'}_{Nov}$ for 1909–1949 falls along the (adjusted) standard curve for Colfax, it is possible that the

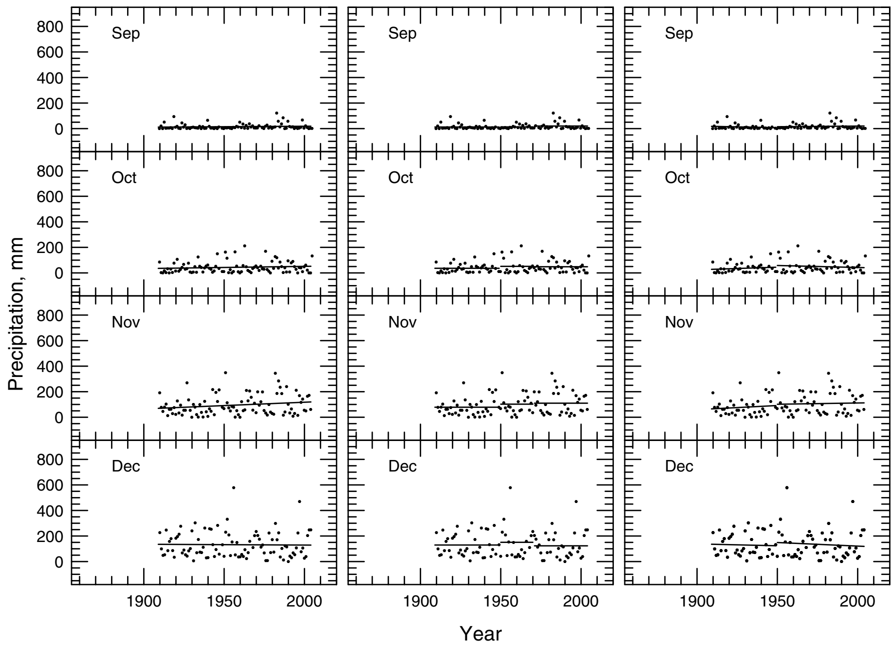


*Figure 6.* Monthly precipitation at Tahoe City, 1909–2004. Ordinate, abscissa and layout as in Figure 1. Left (a): Precipitation at locations 1 (1909–1949), 2 (1950–1970), and 3 (1971–2004). Lines are the regression lines for the entire interval. Middle (b): Precipitation at locations 1, 2, and 3. Lines are the averages for each location. Right (c): Precipitation at locations 1 and 2 + 3. Lines are the regression lines for the intervals 1909–1949 and 1950–2004.

increase in $\overline{P}_{Nov}$ began only around 1950, in which case $\overline{P'}_{Nov} = +1.06$ mm/yr. A further estimate of the date of the beginning of the increase in $\overline{P}_{Nov}$ can be derived by plotting $E_{Nov}$ against year (see Section 3.3, above). This plot suggests that the increase in $\overline{P}_{Nov}$ began around 1935–1940, as at Colfax, and has increased linearly with time since that date.

It appears, then, that there are no detectable systematic differences in $\overline{P}$ at the various Tahoe City weather instrument locations, and no evidence for a change in $\overline{P}$ with time except during the month of November, when—beginning around 1935–1940—an increase in $\overline{P}$ with time has occurred.

### 3.7. Truckee

Taking all of the observations from 1870–2004 together, Table II and Figure 7 indicate an increase in $P$ with time, that increase being statistically significant at the 95 percent confidence level in the months of September, October, and November, and at about the 92 percent

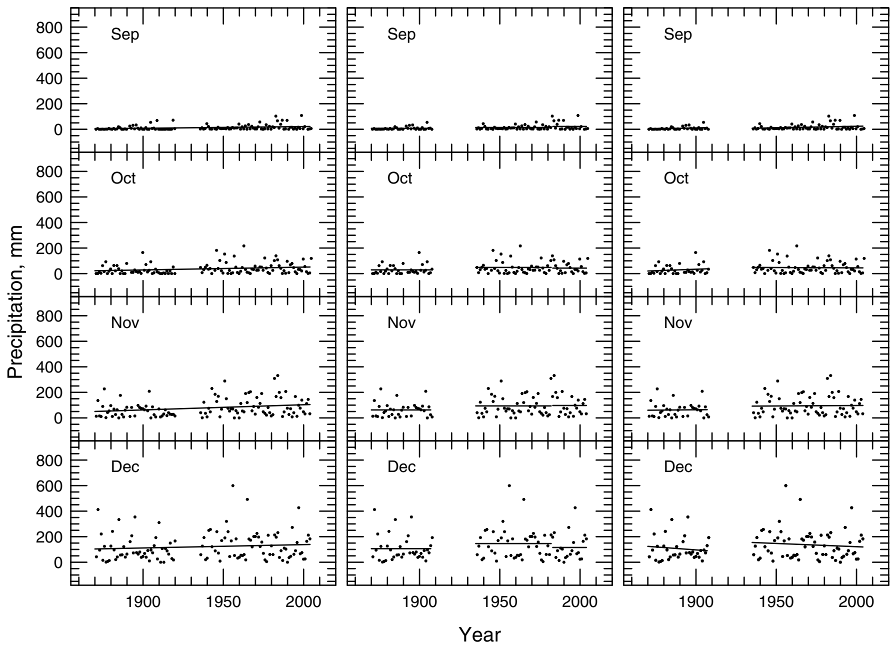


*Figure 7.* Monthly precipitation at Truckee, 1870–2004. Ordinate, abscissa and layout as in Figure 1. Left (a): Precipitation at locations 1, 2, and 3. All observations, 1870–2004. Lines are the regression lines for the entire interval. Middle (b): Precipitation at locations 1 (1870–1907), 2 (1935–1982), and 3 (1983–2004); observations at location 1 from 1908–1919 are omitted. Lines are the averages for each location. Right (c):Precipitation at locations 1 (1870–1907) and $2 + 3$ (1935–2004). Lines are the regression lines for each interval.

confidence level in December. However, as indicated in Section 2.7, the station was relocated in 1933, and again in 1983. Thus, the observed increase could result from systematic differences in $P$ at the three locations. In addition, the observations from about 1907–1919 are unreliable owing to theft of the rain gauge, and Table II and Figure 7 show that, in fact, the measures of $P$ during this interval do tend to be slightly smaller than those at location 1 from 1870–1907, and at locations 2 and 3. Excluding the observations from 1908–1919, Tables II and III show that significant increases in $P$ occur at locations 2 and 2+3, compared to location 1, in the months of September through November. No significant differences between locations 2 and 3 are detected, although this result is less certain owing to the shortness of the time intervals, particularly at location 3. Since Table II and Figure 7 show no significant change in $P$ with time at any of the three location separately, nor for location 2+3, it would appear that there has been no statistically significant change in $P$ with time at Truckee, and that the

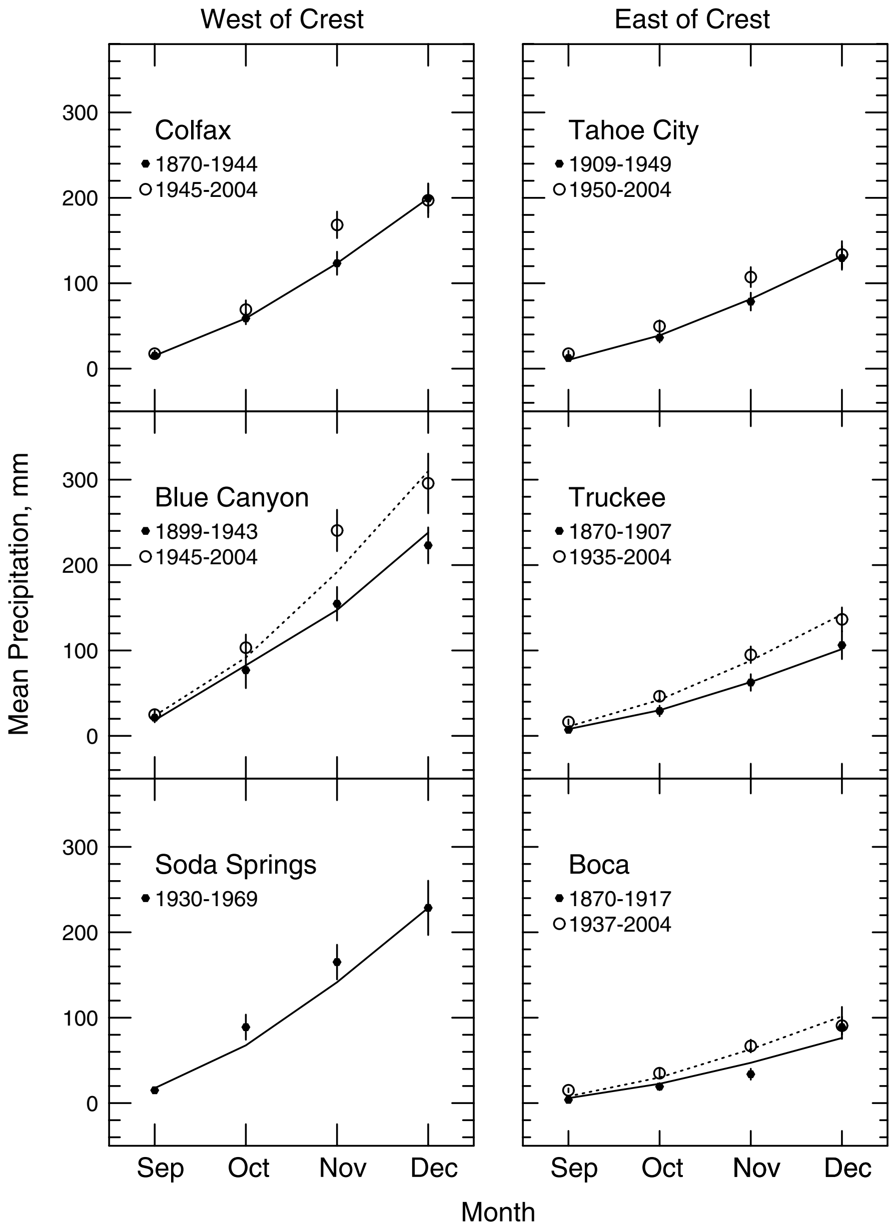


*Figure 8.* Average monthly precipitation at weather stations in the Sierra Nevada. Ordinate, precipitation in millimeters; abscissa, month. From top to bottom and left to right, the stations are shown in the order of their location from west to east across the Sierra Nevada range. Stations in the left-hand column are located west of the Sierra crest, stations in the right-hand column are situated east of the crest. At each station, measures in the first time interval are indicated by dots, those in the second by circles. Curves represent the observations at Colfax, 1870–1944, with ordinates scaled to fit the measures at the particular station and time interval. Vertical lines indicate the standard deviations of the measures.

apparent increase between 1870 and 2004 results from a systematically greater precipitation at locations 2 and 3 compared to location 1.

These conclusions appear to be borne out by the plot of $\overline{P}$ against month in Figure 8.In this figure, the observations at location 1 (1870–1907) and at location 2+3 (1935–2004) both fall along the adjusted curves of the monthly variation of $\overline{P}$ at Colfax, 1870–1944, corresponding to a systematically greater $\overline{P}$ at location 2+3 of 37.6 percent compared to location 1. There is no detectable increase in $\overline{P}$ with time at either location.

### 3.8. Discussion

As we have seen, the interpretation of the precipitation measures is complicated by the changes in instrument location that occurred at all of the stations, although allowing for these changes is facilitated by the fact that (with certain exceptions in November) the manner in which $P$ increases from September through December appears to be nearly identical at all of the stations studied. Allowing, insofar as possible, for the effects of relocation, we find no evidence for a *decrease* in precipitation with time at any of the stations. Thus, the progressively later date of the first major snowfall at Tahoe City can not be attributed to a decrease in precipitation with time.

No change in $P$ with time is detected at Mount Hamilton (Figure 9). However, there is evidence for an *increase* in precipitation with time, in the month of November only, at four of the Sierran stations, namely Blue Canyon, Colfax, Soda Springs and Tahoe City. The other two stations, Boca and Truckee, display no statistically significant increases in $\overline{P}$ with time. Table II shows that at each of these six stations, November is the first month in the fall with substantial precipitation, i.e., more than 50 percent of the maximum (December) monthly average precipitation at the station. Thus, there is the interesting possibility that the observed November increase results from "cloud seeding" by the particulate matter in the atmosphere. In each year, the effect will be greatest at the beginning of the fall precipitation, and will then decrease as the condensation nuclei are removed by that precipitation. The "cloud-seeding" effect will increase with time, as the level of atmospheric pollution increases.

Note also that the November increase is, on average, larger at those stations west of the Sierra crest than at those east of the crest. Calculating the weighted means of the November excesses, $E_N$ (defined as in Section 3.3, above), for the stations west and east of the crest for the most recent interval at each station shown in Figure 8, we have: $E_{N,w} = +3.10 \pm 0.52$ mm, $E_{N,e} = +0.31 \pm 0.14$ mm, and $\Delta E_{N,w-e} =$

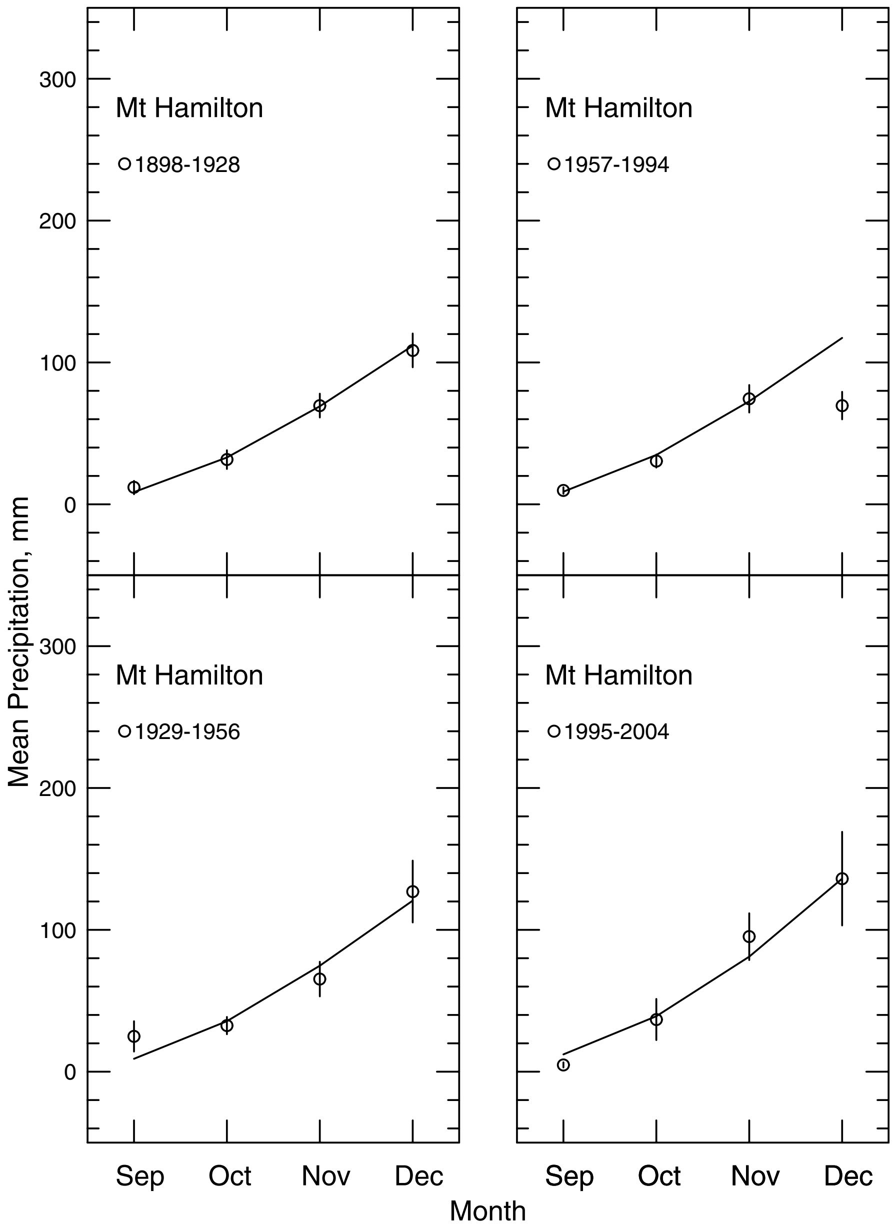


*Figure 9.* Average monthly precipitation at Mount Hamilton. Ordinates, abscissae, lines and curves as in Figure 8.

+2.79 ±0.54 mm. This difference is statistically significant even after allowance is made for the greater average November precipitation on the west side of the crest, compared to the east. Such a difference is consistent with the "cloud-seeding" hypothesis: "Cloud seeding" would be expected to be most effective where the moisture-laden clouds, arriving from the west, are first uplifted by the Sierras to produce precipitation. Further observations to investigate this phenomenon would clearly be of interest.

## 4. Temperature

The average daily maximum, minimum, and mean temperatures for the months of September, October, November, and December for each year at each of the seven stations were analyzed to determine whether changes with time occur. The average maximum, minimum, and mean temperatures and the slopes of the regression lines ($\overline{T'}$) were calculated for each month at each station. In addition, the weighted means of the four monthly values of $\overline{T'}$ were calculated, weighting each value by its mean square error; since it would be expected that a general warming or cooling trend would affect all four months similarly, combining them will result in a greater statistical accuracy for $\overline{T'}$ at each station. As with the precipitation, the analysis of the temperatures is complicated by the changes in location and type of instruments used at the various stations. Consequently, the above calculations were carried out, first for the entire time period of the observations at the station, and then for the intervals between changes in the location or type of instrument used. The results are given in Tables IV–VI. The temperatures observed at each station are discussed below.

### 4.1. Blue Canyon

As discussed in Section 2.1, the first two locations of this station were fairly close together and were utilized for relatively short periods of time. Consequently, the observations at these two locations have been considered together, and are labelled as "Blue Canyon No. 1" in Tables IV–VII.

As can be seen from Tables IV–VI and Figure 10, there are very significant differences between the average maximum, minimum and mean daily temperatures at locations 1 and 2, the maximum daily temperature being higher, and minimum daily temperature lower, at location 1 compared to location 2. There is no consistent evidence of a change in temperature with time at either location. Thus, the lines

Table IV. Average Daily Maximum Temperature.

| Station, Location, Interval | Month | No. Years | Observed °C $\overline{T}$ | Observed °C $\sigma_{\overline{T}}$ | Time Variation of $\overline{T}$ °C/yr $\overline{T'}$ | °C/yr $\sigma_{\overline{T'}}$ | Student $t$ | Student $t_c{}^a$ |
|---|---|---|---|---|---|---|---|---|
| Blue Canyon | Sep | 40 | 24.25 | 0.40 | +0.030 | 0.035 | 0.86 | 1.69 |
| No. 1 | Oct | 39 | 19.53 | 0.38 | –0.030 | 0.033 | 0.91 | 1.69 |
| 1904–1943[b] | Nov | 39 | 14.52 | 0.53 | +0.042 | 0.046 | 0.91 | 1.69 |
| | Dec | 40 | 10.30 | 0.58 | +0.006 | 0.051 | 0.12 | 1.69 |
| Blue Canyon | Sep | 48 | 22.24 | 0.31 | –0.011 | 0.019 | 0.58 | 1.68 |
| No. 2 | Oct | 48 | 17.03 | 0.37 | +0.001 | 0.024 | 0.04 | 1.68 |
| 1945–2004[b] | Nov | 46 | 10.43 | 0.43 | –0.065 | 0.027 | 2.41 | 1.68 |
| | Dec | 45 | 7.51 | 0.44 | –0.023 | 0.029 | 0.79 | 1.68 |
| Boca | Sep | 65 | 24.53 | 0.28 | +0.018 | 0.014 | 1.29 | 1.67 |
| No. 2 | Oct | 65 | 18.62 | 0.33 | +0.036 | 0.017 | 2.12 | 1.67 |
| 1937–2004[b] | Nov | 64 | 10.85 | 0.33 | +0.005 | 0.018 | 0.28 | 1.67 |
| | Dec | 65 | 6.10 | 0.30 | –0.011 | 0.016 | 0.69 | 1.67 |
| Colfax | Sep | 95 | 29.01 | 0.23 | +0.027 | 0.008 | 3.38 | 1.66 |
| Nos. 1+2+3 | Oct | 99 | 23.54 | 0.26 | +0.013 | 0.009 | 1.44 | 1.66 |
| 1905–2004[b] | Nov | 95 | 16.83 | 0.30 | –0.032 | 0.010 | 3.20 | 1.66 |
| | Dec | 99 | 12.78 | 0.27 | –0.002 | 0.009 | 0.22 | 1.66 |
| Colfax | Sep | 66 | 28.88 | 0.27 | +0.059 | 0.012 | 4.92 | 1.67 |
| No. 1 | Oct | 70 | 23.34 | 0.31 | +0.016 | 0.015 | 1.07 | 1.67 |
| 1905-1975[b] | Nov | 68 | 17.24 | 0.35 | –0.036 | 0.017 | 2.12 | 1.67 |
| | Dec | 71 | 12.79 | 0.33 | +0.003 | 0.017 | 0.18 | 1.67 |
| Colfax | Sep | 58 | 29.15 | 0.27 | +0.056 | 0.014 | 4.00 | 1.67 |
| No. 1 | Oct | 58 | 23.51 | 0.30 | +0.007 | 0.018 | 0.39 | 1.67 |
| 1917–1975 | Nov | 56 | 17.03 | 0.36 | –0.040 | 0.021 | 1.90 | 1.67 |
| | Dec | 59 | 13.12 | 0.33 | –0.034 | 0.019 | 1.79 | 1.67 |
| Colfax | Sep | 21 | 29.31 | 0.57 | +0.134 | 0.088 | 1.52 | 1.73 |
| No. 2 | Oct | 20 | 24.41 | 0.53 | +0.116 | 0.091 | 1.27 | 1.73 |
| 1976–1996 | Nov | 19 | 16.20 | 0.65 | –0.006 | 0.123 | 0.05 | 1.73 |
| | Dec | 20 | 13.36 | 0.54 | –0.086 | 0.094 | 0.91 | 1.73 |

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Table IV—Continued

| Station, Location, Interval | Month | No. Years | Observed °C $\overline{T}$ | Observed °C $\sigma_{\overline{T}}$ | Time Variation of $\overline{T}$ °C/yr $\overline{T'}$ | °C/yr $\sigma_{\overline{T'}}$ | Student $t$ | Student $t_c$[a] |
|---|---|---|---|---|---|---|---|---|
| Colfax | Sep | 8 | 29.53 | 0.73 | +0.612 | 0.240 | 2.55 | 1.94 |
| No. 3 | Oct | 9 | 23.14 | 0.90 | +0.419 | 0.339 | 1.24 | 1.90 |
| 1997–2004 | Nov | 8 | 14.85 | 0.72 | +0.167 | 0.331 | 0.50 | 1.94 |
| | Dec | 8 | 11.31 | 0.63 | –0.312 | 0.269 | 1.10 | 1.94 |
| Mt. Hamilton | Sep | 102 | 22.73 | 0.23 | +0.027 | 0.007 | 3.85 | 1.66 |
| Nos. 1+2+3 | Oct | 105 | 17.88 | 0.24 | +0.027 | 0.007 | 3.85 | 1.66 |
| 1898–2004 | Nov | 100 | 12.51 | 0.26 | 0.000 | 0.008 | 0.00 | 1.66 |
| | Dec | 101 | 9.38 | 0.24 | +0.009 | 0.008 | 1.12 | 1.66 |
| Mt. Hamilton | Sep | 21 | 20.69 | 0.42 | –0.049 | 0.070 | 0.70 | 1.73 |
| No. 1 | Oct | 21 | 16.54 | 0.51 | +0.087 | 0.084 | 1.04 | 1.73 |
| 1898–1918 | Nov | 20 | 11.67 | 0.43 | +0.006 | 0.075 | 0.08 | 1.73 |
| | Dec | 21 | 8.47 | 0.48 | –0.157 | 0.073 | 2.15 | 1.73 |
| Mt. Hamilton | Sep | 61 | 23.31 | 0.26 | +0.022 | 0.013 | 1.69 | 1.67 |
| No. 2 | Oct | 64 | 18.02 | 0.29 | +0.027 | 0.014 | 1.93 | 1.67 |
| 1919–1984[b] | Nov | 62 | 12.83 | 0.34 | –0.022 | 0.017 | 1.29 | 1.67 |
| | Dec | 61 | 9.74 | 0.31 | +0.015 | 0.016 | 0.94 | 1.67 |
| Mt. Hamilton | Sep | 20 | 23.11 | 0.52 | +0.131 | 0.088 | 1.49 | 1.73 |
| No. 3 | Oct | 20 | 18.87 | 0.56 | –0.066 | 0.098 | 0.67 | 1.73 |
| 1985–2004 | Nov | 18 | 12.34 | 0.63 | –0.157 | 0.118 | 1.33 | 1.75 |
| | Dec | 19 | 9.23 | 0.55 | +0.016 | 0.102 | 0.16 | 1.74 |
| Soda Springs | Sep | 36 | 20.37 | 0.31 | –0.017 | 0.028 | 0.61 | 1.69 |
| 1930–1969[b] | Oct | 36 | 14.73 | 0.42 | –0.002 | 0.038 | 0.05 | 1.69 |
| | Nov | 34 | 8.29 | 0.48 | –0.087 | 0.039 | 2.23 | 1.69 |
| | Dec | 35 | 4.73 | 0.37 | –0.048 | 0.032 | 1.50 | 1.69 |
| Tahoe City | Sep | 94 | 21.03 | 0.19 | +0.009 | 0.007 | 1.29 | 1.66 |
| Nos. 1+2+3 | Oct | 94 | 14.91 | 0.23 | +0.020 | 0.008 | 2.50 | 1.66 |
| 1909–2004[b] | Nov | 94 | 8.36 | 0.20 | +0.006 | 0.007 | 0.86 | 1.66 |
| | Dec | 93 | 4.49 | 0.19 | +0.014 | 0.007 | 2.00 | 1.66 |

Table IV—Continued

| Station, Location, Interval | Month | No. Years | Observed °C | | Time Variation of $\overline{T}$ °C/yr | | Student | |
|---|---|---|---|---|---|---|---|---|
| | | | $\overline{T}$ | $\sigma_{\overline{T}}$ | $\overline{T'}$ | $\sigma_{\overline{T'}}$ | $t$ | $t_c$[a] |
| Tahoe City | Sep | 40 | 21.07 | 0.28 | +0.033 | 0.024 | 1.38 | 1.69 |
| No. 1 | Oct | 40 | 14.48 | 0.32 | −0.017 | 0.028 | 0.61 | 1.69 |
| 1909–1949 | Nov | 40 | 8.23 | 0.29 | −0.057 | 0.023 | 2.48 | 1.69 |
| | Dec | 40 | 3.99 | 0.31 | −0.027 | 0.027 | 1.00 | 1.69 |
| Tahoe City | Sep | 21 | 20.34 | 0.29 | −0.006 | 0.049 | 0.12 | 1.73 |
| No. 2 | Oct | 20 | 14.37 | 0.39 | −0.025 | 0.065 | 0.38 | 1.73 |
| 1950–1970 | Nov | 21 | 7.92 | 0.32 | +0.034 | 0.054 | 0.63 | 1.73 |
| | Dec | 20 | 4.47 | 0.43 | −0.003 | 0.072 | 0.04 | 1.73 |
| Tahoe City | Sep | 33 | 21.43 | 0.37 | +0.049 | 0.038 | 1.29 | 1.70 |
| No. 3 | Oct | 34 | 15.74 | 0.43 | +0.077 | 0.043 | 1.79 | 1.70 |
| 1971–2004 | Nov | 33 | 8.80 | 0.38 | +0.045 | 0.041 | 1.10 | 1.70 |
| | Dec | 33 | 5.12 | 0.28 | −0.002 | 0.029 | 0.07 | 1.70 |
| Tahoe City | Sep | 73 | 21.23 | 0.22 | +0.010 | 0.007 | 1.43 | 1.67 |
| Nos. 1+3 | Oct | 74 | 15.06 | 0.27 | +0.021 | 0.008 | 2.62 | 1.67 |
| 1909–1949 + | Nov | 73 | 8.49 | 0.24 | +0.006 | 0.008 | 0.75 | 1.67 |
| 1971–2004 | Dec | 73 | 4.50 | 0.22 | +0.015 | 0.007 | 2.14 | 1.67 |
| Truckee | Sep | 84 | 23.44 | 0.28 | +0.010 | 0.010 | 1.00 | 1.66 |
| Nos. 1+2+3 | Oct | 83 | 17.23 | 0.40 | +0.013 | 0.013 | 1.00 | 1.66 |
| 1904–2004 | Nov | 81 | 9.46 | 0.37 | −0.029 | 0.012 | 2.42 | 1.66 |
| | Dec | 81 | 4.79 | 0.32 | −0.002 | 0.011 | 0.18 | 1.66 |
| Truckee | Sep | 16 | 22.59 | 0.81 | +0.257 | 0.167 | 1.54 | 1.76 |
| No. 1 | Oct | 16 | 17.09 | 1.42 | +0.382 | 0.302 | 1.26 | 1.76 |
| 1904–1919 | Nov | 15 | 11.58 | 1.22 | +0.083 | 0.269 | 0.31 | 1.77 |
| | Dec | 16 | 4.69 | 1.22 | +0.319 | 0.261 | 1.22 | 1.76 |
| Truckee | Sep | 47 | 23.66 | 0.31 | −0.033 | 0.022 | 1.50 | 1.68 |
| No. 2 | Oct | 45 | 16.93 | 0.44 | +0.016 | 0.032 | 0.50 | 1.68 |
| 1935–1982 | Nov | 45 | 9.11 | 0.37 | +0.006 | 0.027 | 0.22 | 1.68 |
| | Dec | 44 | 4.96 | 0.35 | −0.015 | 0.026 | 0.58 | 1.68 |

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Table IV—Continued

| Station, Location, Interval | Month | No. Years | Observed °C $\overline{T}$ | $\sigma_{\overline{T}}$ | Time Variation of $\overline{T}$ °C/yr $\overline{T'}$ | $\sigma_{\overline{T'}}$ | Student $t$ | $t_c$[a] |
|---|---|---|---|---|---|---|---|---|
| Truckee | Sep | 21 | 23.61 | 0.66 | +0.175 | 0.099 | 1.77 | 1.73 |
| No. 3 | Oct | 22 | 17.94 | 0.66 | +0.056 | 0.106 | 0.53 | 1.73 |
| 1983–2004 | Nov | 21 | 8.67 | 0.73 | +0.019 | 0.124 | 0.15 | 1.73 |
| | Dec | 21 | 4.50 | 0.35 | +0.025 | 0.059 | 0.42 | 1.73 |
| Truckee | Sep | 68 | 23.64 | 0.29 | −0.007 | 0.014 | 0.50 | 1.67 |
| Nos. 2+3 | Oct | 67 | 17.26 | 0.37 | +0.026 | 0.018 | 1.44 | 1.67 |
| 1935–2004[b] | Nov | 66 | 8.97 | 0.34 | −0.006 | 0.017 | 0.35 | 1.67 |
| | Dec | 65 | 4.81 | 0.26 | −0.013 | 0.013 | 1.00 | 1.67 |

[a] Critical value: 95 percent confidence level.

[b] Intervals when maximum/minimum thermometers were used and when these instruments were at the same location or at locations with no detectable systematic differences between them. Used in calculating final values of $\overline{T'}$ in Table 8.

shown in Figure 10 are the average temperatures for the particular locations and months.

As discussed in Section 2.1, location 1 was in a canyon, while location 2 is situated on a ridgetop. Thus, the higher maximum and lower minimum temperatures at location 1 most probably result from the trapping of daytime heat in the canyon and the down-slope drainage of cold air (cooled by contact with the cold ground surface), at night. This interpretation is supported by the differences between the monthly averages of the daily maximum and minimum temperatures for the various stations studied, listed in Table VII. This table shows that the temperature differences are rather similar at all of the stations except Blue Canyon No. 2 and Mount Hamilton. For these two stations, the differences are again rather similar, but both are significantly smaller than those at the other stations. Mount Hamilton is located in the Diablo range, near to the California coastline, and at night is usually

Table V. Average Daily Minimum Temperature (°C).

| Station, Location, Interval | Month | No. Years | Observed °C $\overline{T}$ | Observed °C $\sigma_{\overline{T}}$ | Time Variation of $\overline{T}$ °C/yr $\overline{T'}$ | °C/yr $\sigma_{\overline{T'}}$ | Student $t$ | Student $t_c$[a] |
|---|---|---|---|---|---|---|---|---|
| Blue Canyon | Sep | 39 | + 7.23 | 0.40 | +0.025 | 0.035 | 0.71 | 1.69 |
| No. 1 | Oct | 39 | + 4.43 | 0.32 | −0.013 | 0.027 | 0.48 | 1.69 |
| 1904–1943 | Nov | 39 | + 1.31 | 0.27 | −0.006 | 0.023 | 0.26 | 1.69 |
| | Dec | 40 | − 1.19 | 0.25 | +0.019 | 0.022 | 0.86 | 1.69 |
| Blue Canyon | Sep | 48 | +12.01 | 0.28 | +0.029 | 0.017 | 1.71 | 1.68 |
| No. 2 | Oct | 48 | + 7.79 | 0.32 | +0.041 | 0.020 | 2.05 | 1.68 |
| 1945–2004 | Nov | 46 | + 2.85 | 0.30 | −0.019 | 0.020 | 0.95 | 1.68 |
| | Dec | 45 | + 0.42 | 0.36 | +0.018 | 0.024 | 0.75 | 1.68 |
| Boca | Sep | 65 | − 1.11 | 0.19 | +0.008 | 0.010 | 0.80 | 1.67 |
| No. 2 | Oct | 65 | − 4.12 | 0.22 | −0.008 | 0.011 | 0.73 | 1.67 |
| 1937–2004 | Nov | 64 | − 6.98 | 0.24 | −0.004 | 0.013 | 0.31 | 1.67 |
| | Dec | 64 | −10.38 | 0.42 | +0.004 | 0.022 | 0.18 | 1.67 |
| Colfax | Sep | 94 | +13.01 | 0.21 | +0.010 | 0.007 | 1.43 | 1.66 |
| No. 1+2+3 | Oct | 99 | + 8.64 | 0.19 | +0.007 | 0.007 | 1.00 | 1.66 |
| 1905–2004 | Nov | 94 | + 4.26 | 0.18 | −0.006 | 0.007 | 0.86 | 1.66 |
| | Dec | 98 | + 1.79 | 0.19 | −0.002 | 0.007 | 0.29 | 1.66 |
| Colfax | Sep | 65 | +13.21 | 0.28 | +0.054 | 0.012 | 4.50 | 1.67 |
| No. 1 | Oct | 70 | + 8.68 | 0.24 | +0.030 | 0.012 | 2.50 | 1.67 |
| 1905–1975 | Nov | 67 | + 4.46 | 0.23 | +0.009 | 0.011 | 0.82 | 1.67 |
| | Dec | 70 | + 1.88 | 0.24 | +0.004 | 0.012 | 0.33 | 1.67 |
| Colfax | Sep | 21 | +12.51 | 0.31 | −0.051 | 0.050 | 1.02 | 1.73 |
| No. 2 | Oct | 20 | + 8.86 | 0.33 | −0.016 | 0.058 | 0.28 | 1.73 |
| 1976–1996 (S) | Nov | 19 | + 3.65 | 0.32 | −0.136 | 0.051 | 2.67 | 1.73 |
| 1976–1995 (O–D) | Dec | 20 | + 1.48 | 0.38 | −0.101 | 0.064 | 1.58 | 1.73 |
| Colfax | Sep | 8 | +12.78 | 0.36 | +0.192 | 0.151 | 1.27 | 1.94 |
| No. 3 | Oct | 9 | + 7.78 | 0.50 | +0.319 | 0.168 | 1.90 | 1.90 |
| 1997–2004 (S) | Nov | 8 | + 4.08 | 0.60 | −0.142 | 0.279 | 0.51 | 1.94 |
| 1996-2004 (O–D) | Dec | 8 | + 1.85 | 0.50 | +0.091 | 0.234 | 0.39 | 1.94 |

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Table V—Continued

| Station, Location, Interval | Month | No. Years | Observed °C | | Time Variation of $\overline{T}$ °C/yr | | Student | |
|---|---|---|---|---|---|---|---|---|
| | | | $\overline{T}$ | $\sigma_{\overline{T}}$ | $\overline{T'}$ | $\sigma_{\overline{T'}}$ | $t$ | $t_c$[a] |
| Mount Hamilton | Sep | 102 | +13.73 | 0.24 | +0.026 | 0.007 | 3.71 | 1.66 |
| No. 1+2+3 | Oct | 103 | + 9.83 | 0.23 | +0.022 | 0.007 | 3.14 | 1.66 |
| 1898–2004 | Nov | 100 | + 5.59 | 0.22 | –0.008 | 0.007 | 1.14 | 1.66 |
| | Dec | 101 | + 2.96 | 0.21 | –0.002 | 0.007 | 0.29 | 1.66 |
| Mount Hamilton | Sep | 21 | +12.88 | 0.43 | –0.048 | 0.073 | 0.66 | 1.73 |
| No. 1 | Oct | 21 | + 9.62 | 0.39 | +0.108 | 0.072 | 1.50 | 1.73 |
| 1898–1918 | Nov | 20 | + 5.86 | 0.42 | +0.017 | 0.067 | 0.25 | 1.73 |
| | Dec | 21 | + 2.98 | 0.31 | –0.117 | 0.066 | 1.77 | 1.73 |
| Mount Hamilton | Sep | 61 | +13.63 | 0.31 | +0.029 | 0.016 | 1.81 | 1.67 |
| No. 2 | Oct | 62 | + 9.41 | 0.29 | +0.025 | 0.014 | 1.79 | 1.67 |
| 1919–1984 | Nov | 62 | + 5.56 | 0.29 | –0.017 | 0.015 | 1.13 | 1.67 |
| | Dec | 62 | + 3.03 | 0.27 | +0.007 | 0.014 | 0.50 | 1.67 |
| Mount Hamilton | Sep | 20 | +14.91 | 0.59 | +0.198 | 0.094 | 2.11 | 1.73 |
| No. 3 | Oct | 20 | +11.37 | 0.48 | –0.027 | 0.086 | 0.31 | 1.73 |
| 1985–2004 | Nov | 18 | + 5.40 | 0.54 | –0.038 | 0.107 | 0.36 | 1.75 |
| | Dec | 19 | + 2.57 | 0.54 | +0.047 | 0.099 | 0.47 | 1.74 |
| Soda Springs | Sep | 36 | +3.16 | 0.23 | +0.033 | 0.020 | 1.65 | 1.69 |
| 1930–1965 | Oct | 36 | – 0.61 | 0.19 | +0.038 | 0.016 | 2.38 | 1.69 |
| | Nov | 34 | – 5.49 | 0.31 | +0.041 | 0.026 | 1.58 | 1.69 |
| | Dec | 35 | – 9.09 | 0.41 | +0.070 | 0.035 | 2.00 | 1.69 |
| Tahoe City | Sep | 94 | +3.56 | 0.14 | +0.025 | 0.004 | 6.25 | 1.66 |
| No. 1+2+3 | Oct | 95 | – 0.11 | 0.13 | +0.020 | 0.004 | 5.00 | 1.66 |
| 1909–2004 | Nov | 94 | – 3.28 | 0.15 | +0.016 | 0.005 | 3.20 | 1.66 |
| | Dec | 93 | – 6.49 | 0.21 | +0.016 | 0.007 | 2.29 | 1.66 |
| Tahoe City | Sep | 40 | +2.82 | 0.18 | +0.037 | 0.014 | 2.64 | 1.69 |
| No. 1 | Oct | 40 | – 0.71 | 0.19 | +0.041 | 0.015 | 2.73 | 1.69 |
| 1909-1949 | Nov | 40 | – 4.32 | 0.22 | +0.012 | 0.019 | 0.63 | 1.69 |
| | Dec | 40 | – 7.00 | 0.32 | +0.052 | 0.027 | 1.93 | 1.69 |

Table V—Continued

| Station, Location, Interval | Month | No. Years | Observed °C $\overline{T}$ | $\sigma_{\overline{T}}$ | Time Variation of $\overline{T}$ °C/yr $\overline{T'}$ | $\sigma_{\overline{T'}}$ | Student $t$ | $t_c$[a] |
|---|---|---|---|---|---|---|---|---|
| Tahoe City | Sep | 21 | + 4.06 | 0.29 | +0.041 | 0.048 | 0.85 | 1.73 |
| No. 2 | Oct | 21 | + 0.43 | 0.22 | +0.017 | 0.037 | 0.46 | 1.73 |
| 1950–1970 | Nov | 21 | − 2.95 | 0.27 | +0.071 | 0.043 | 1.65 | 1.73 |
| | Dec | 20 | − 5.74 | 0.38 | +0.059 | 0.064 | 0.92 | 1.73 |
| Tahoe City | Sep | 33 | + 4.14 | 0.22 | +0.039 | 0.022 | 1.77 | 1.70 |
| No. 3 | Oct | 34 | + 0.27 | 0.020 | +0.044 | 0.019 | 2.32 | 1.70 |
| 1971–2004 | Nov | 33 | − 3.52 | 0.23 | +0.032 | 0.024 | 1.33 | 1.70 |
| | Dec | 33 | − 6.32 | 0.34 | +0.046 | 0.036 | 1.28 | 1.70 |
| Tahoe City | Sep | 73 | + 3.42 | 0.16 | +0.024 | 0.004 | 6.00 | 1.67 |
| No. 1+3 | Oct | 74 | − 0.26 | 0.15 | +0.019 | 0.004 | 4.75 | 1.67 |
| 1909–1949 + | Nov | 73 | − 3.96 | 0.17 | +0.014 | 0.005 | 2.80 | 1.67 |
| 1971–2004 | Dec | 73 | − 6.69 | 0.24 | +0.016 | 0.008 | 2.00 | 1.67 |
| Truckee | Sep | 84 | + 2.13 | 0.22 | −0.007 | 0.007 | 1.00 | 1.66 |
| No.1+2+3 | Oct | 83 | − 1.36 | 0.22 | −0.011 | 0.007 | 1.57 | 1.66 |
| 1904–2004 | Nov | 81 | − 5.38 | 0.26 | −0.012 | 0.009 | 1.33 | 1.66 |
| | Dec | 82 | − 8.94 | 0.28 | −0.013 | 0.009 | 1.44 | 1.66 |
| Truckee | Sep | 16 | + 3.07 | 0.84 | −0.172 | 0.184 | 0.93 | 1.76 |
| No. 1 | Oct | 16 | − 0.79 | 0.93 | −0.287 | 0.193 | 1.49 | 1.76 |
| 1904-1919 | Nov | 15 | − 4.02 | 0.99 | −0.255 | 0.209 | 1.22 | 1.77 |
| | Dec | 16 | − 9.96 | 0.71 | +0.134 | 0.154 | 0.87 | 1.76 |
| Truckee | Sep | 47 | + 1.64 | 0.21 | +0.002 | 0.016 | 0.12 | 1.68 |
| No. 2 | Oct | 45 | − 1.98 | 0.21 | −0.013 | 0.015 | 0.87 | 1.68 |
| 1935–1982 | Nov | 45 | − 5.87 | 0.27 | +0.019 | 0.020 | 0.95 | 1.68 |
| | Dec | 45 | − 8.80 | 0.36 | −0.040 | 0.026 | 1.54 | 1.68 |
| Truckee | Sep | 21 | + 2.51 | 0.25 | −0.028 | 0.040 | 0.70 | 1.73 |
| No. 3 | Oct | 22 | − 1.53 | 0.23 | −0.060 | 0.036 | 1.67 | 1.73 |
| 1983–2004 | Nov | 21 | − 5.28 | 0.35 | +0.054 | 0.058 | 0.93 | 1.73 |
| | Dec | 21 | − 8.43 | 0.51 | +0.118 | 0.082 | 1.44 | 1.73 |

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Table V—Continued

| Station, Location, Interval | Month | No. Years | Observed °C $\overline{T}$ | $\sigma_{\overline{T}}$ | Time Variation of $\overline{T}$ °C/yr $\overline{T'}$ | $\sigma_{\overline{T'}}$ | Student $t$ | $t_c$[a] |
|---|---|---|---|---|---|---|---|---|
| Truckee | Sep | 68 | + 1.91 | 0.17 | +0.016 | 0.008 | 2.00 | 1.67 |
| No. 2+3 | Oct | 67 | − 1.83 | 0.16 | +0.002 | 0.008 | 0.25 | 1.67 |
| 1935–2004 | Nov | 66 | − 5.68 | 0.22 | +0.019 | 0.011 | 1.73 | 1.67 |
| | Dec | 66 | − 8.68 | 0.29 | −0.002 | 0.014 | 0.14 | 1.67 |

[a] Critical value: 95 percent confidence level.

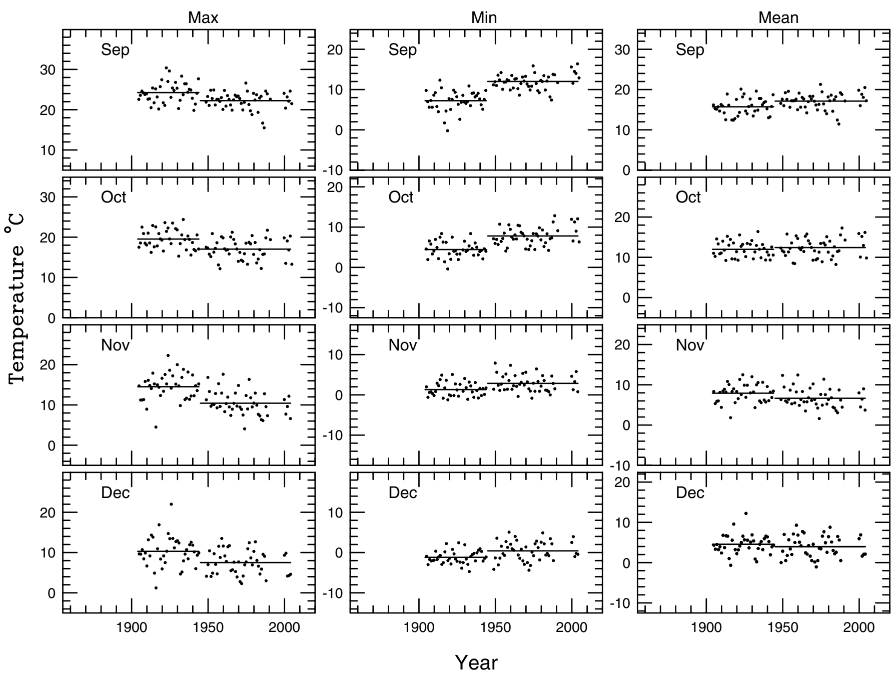


*Figure 10.* Monthly temperatures at Blue Canyon, 1904–2004, September (top) through December (bottom). Ordinate, temperature in degrees Celsius; abscissa, year. Left to right: maximum, minimum, and mean temperature. Lines are the average temperatures at locations 1 (1904–1944) and 2 (1945–2004).

above the top of the temperature inversion which marks the upper limit of the surface convective layer of the atmosphere. Being on the top of the highest peak in the Diablo range (1283 m, 4209 ft), this station is unaffected by local daytime heating and by nighttime down-slope air drainage. Typically, locations such as this, in the free air above the surface convection and away from air drainage problems, have a rather small diurnal temperature range, and a nearly constant temperature during the night. The similarity of the diurnal temperature ranges at Blue Canyon No. 2 and Mount Hamilton thus suggests that, unlike Blue Canyon No. 1 and the other Sierran stations, Blue Canyon No. 2, like Mount Hamilton, is situated in the free air above the surface convection layer and away from local heating and air drainage effects.

As indicated above, Tables IV–VII and Figure 10 show no consistent evidence for a change in $T$ with time. The tables indicate that while a few months show what appear to be statistically significant changes in $\overline{T}_{max}$, $\overline{T}_{min}$, or $\overline{T}_{mean}$ with time, these changes are in some cases increases and in others decreases, and the presumably more accurate four-month weighted means of these values, given in Table VIII, show no significant change with time. Thus, it appears that no statistically significant change in $T$ with time is detected at this station.

### 4.2. Boca

As discussed in Section 2.2, the station was relocated in 1936. No maximum and minimum temperatures were observed prior to 1937 and, in addition, the mean temperatures recorded before 1905 were derived from observations at 7 AM, 2PM, and 9PM, so that these temperatures may differ systematically from the mean temperatures recorded after 1936, which were derived by averaging the true daily maximum and minimum temperatures. Consequently, there is the possibility of a systematic difference between the values of the mean temperature from before 1905 and after 1936.

Considering all of the observations from 1870–2004, Table VI and Figure 11 show a statistically significant *decrease* in mean temperature with time in September. However, Tables IV–VI and Figure 12 demonstrate that the better set of observations from 1937–2004 reveals statistically significant *increases* of $\overline{T}_{max}$ with time in October, and $\overline{T}_{mean}$ in September and October, while no significant change was observed in $\overline{T}_{min}$ for any of the four months. As shown in Table VIII, combining the four months, no significant change in $\overline{T'}_{max}$ or $\overline{T'}_{min}$ occurs, while $\overline{T'}_{mean} = +0.009 \pm 0.004$ °C/yr, significant at about the 93 percent confidence level. On the other hand, taking the differences between the average mean temperatures from 1870–1904 at location 1,

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Table VI. Average Daily Mean Temperature.

| Station, Location, Interval | Month | No. Years | Observed °C $\overline{T}$ | $\sigma_{\overline{T}}$ | Time Variation of $\overline{T}$ °C/yr $\overline{T'}$ | $\sigma_{\overline{T'}}$ | Student $t$ | $t_c{}^a$ |
|---|---|---|---|---|---|---|---|---|
| Blue Canyon | Sep | 39 | +15.73 | 0.34 | +0.028 | 0.029 | 0.97 | 1.68 |
| No.1 | Oct | 39 | +11.98 | 0.31 | −0.021 | 0.027 | 0.78 | 1.68 |
| 1904–1943 | Nov | 39 | + 7.91 | 0.37 | +0.018 | 0.032 | 0.56 | 1.68 |
| | Dec | 40 | + 4.54 | 0.38 | +0.012 | 0.033 | 0.36 | 1.68 |
| Blue Canyon | Sep | 48 | +17.13 | 0.28 | +0.009 | 0.018 | 0.50 | 1.68 |
| No. 2 | Oct | 48 | +12.42 | 0.34 | +0.022 | 0.021 | 1.04 | 1.68 |
| 1945–2004 | Nov | 46 | + 6.65 | 0.36 | −0.042 | 0.023 | 1.83 | 1.68 |
| | Dec | 45 | + 3.97 | 0.39 | −0.002 | 0.026 | 0.08 | 1.68 |
| Boca | Sep | 99 | +12.06 | 0.21 | −0.011 | 0.005 | 2.20 | 1.66 |
| No. 1+2 | Oct | 97 | + 7.41 | 0.19 | −0.003 | 0.004 | 0.75 | 1.66 |
| 1870–2004 | Nov | 96 | + 2.06 | 0.21 | −0.003 | 0.005 | 0.60 | 1.66 |
| | Dec | 99 | − 2.07 | 0.25 | −0.002 | 0.006 | 0.33 | 1.66 |
| Boca | Sep | 34 | +12.71 | 0.52 | −0.076 | 0.033 | 2.30 | 1.69 |
| No. 1 | Oct | 31 | + 7.61 | 0.48 | −0.071 | 0.048 | 1.48 | 1.69 |
| 1870–1904 | Nov | 32 | + 2.29 | 0.49 | +0.020 | 0.049 | 0.41 | 1.69 |
| | Dec | 33 | − 2.07 | 0.43 | −0.049 | 0.043 | 1.14 | 1.69 |
| Boca | Sep | 65 | +11.72 | 0.16 | +0.013 | 0.08 | 1.62 | 1.67 |
| No. 2 | Oct | 65 | + 7.26 | 0.17 | +0.014 | 0.008 | 1.75 | 1.67 |
| 1937–2004 | Nov | 64 | + 1.94 | 0.19 | +0.001 | 0.011 | 0.09 | 1.67 |
| | Dec | 64 | − 2.11 | 0.31 | −0.004 | 0.017 | 0.24 | 1.67 |
| Colfax | Sep | 130 | +20.87 | 0.18 | +0.010 | 0.004 | 2.50 | 1.66 |
| No. 1+2+3 | Oct | 132 | +15.95 | 0.17 | +0.009 | 0.004 | 2.25 | 1.66 |
| 1870–2004 | Nov | 127 | +10.63 | 0.17 | −0.009 | 0.004 | 2.25 | 1.66 |
| | Dec | 131 | + 7.49 | 0.17 | −0.003 | 0.007 | 0.21 | 1.66 |
| Colfax | Sep | 96 | +20.95 | 0.20 | +0.021 | 0.007 | 3.00 | 1.66 |
| No.1+2+3 | Oct | 99 | +16.10 | 0.20 | +0.011 | 0.007 | 1.57 | 1.66 |
| 1905–2004 | Nov | 94 | +10.57 | 0.20 | −0.019 | 0.007 | 2.71 | 1.66 |
| | Dec | 98 | + 7.28 | 0.21 | −0.002 | 0.007 | 0.29 | 1.66 |

Table VI—Continued

| Station, Location, Interval | Month | No. Years | Observed °C | | Time Variation of $\overline{T}$ °C/yr | | Student | |
|---|---|---|---|---|---|---|---|---|
| | | | $\overline{T}$ | $\sigma_{\overline{T}}$ | $\overline{T'}$ | $\sigma_{\overline{T'}}$ | $t$ | $t_c$[a] |
| Colfax | Sep | 34 | +20.63 | 0.37 | −0.059 | 0.036 | 1.64 | 1.69 |
| No. 1 | Oct | 33 | +15.51 | 0.36 | −0.006 | 0.036 | 0.17 | 1.69 |
| 1870–1904 | Nov | 33 | +10.81 | 0.31 | +0.013 | 0.030 | 0.43 | 1.69 |
| | Dec | 33 | + 8.09 | 0.29 | −0.023 | 0.029 | 0.79 | 1.69 |
| Colfax | Sep | 67 | +20.95 | 0.25 | +0.059 | 0.010 | 5.90 | 1.67 |
| No. 1 | Oct | 70 | +16.02 | 0.24 | +0.023 | 0.012 | 1.92 | 1.67 |
| 1905–1975 | Nov | 67 | +10.88 | 0.24 | −0.013 | 0.012 | 1.08 | 1.67 |
| | Dec | 70 | + 7.32 | 0.26 | +0.004 | 0.013 | 0.31 | 1.67 |
| Colfax | Sep | 21 | +20.88 | 0.41 | +0.041 | 0.068 | 0.60 | 1.73 |
| No. 2 | Oct | 20 | +16.64 | 0.41 | +0.050 | 0.072 | 0.69 | 1.73 |
| 1976–1996 (S) | Nov | 19 | + 9.42 | 0.42 | −0.072 | 0.078 | 0.92 | 1.73 |
| 1976–1995 (O–D) | Dec | 20 | + 7.43 | 0.37 | −0.093 | 0.062 | 1.50 | 1.73 |
| Colfax | Sep | 8 | +21.17 | 0.52 | +0.405 | 0.180 | 2.25 | 1.94 |
| No. 3 | Oct | 9 | +15.47 | 0.68 | +0.371 | 0.244 | 1.52 | 1.90 |
| 1997–2004 (S) | Nov | 8 | + 9.47 | 0.60 | +0.015 | 0.282 | 0.05 | 1.94 |
| 1996–2004 (O–D) | Dec | 8 | + 6.59 | 0.34 | −0.112 | 0.155 | 0.72 | 1.94 |
| Mount Hamilton | Sep | 102 | +18.24 | 0.23 | +0.027 | 0.007 | 3.86 | 1.66 |
| No. 1+2+3 | Oct | 103 | +13.87 | 0.23 | +0.024 | 0.007 | 3.43 | 1.66 |
| 1898–2004 | Nov | 100 | + 9.07 | 0.23 | −0.003 | 0.008 | 0.38 | 1.66 |
| | Dec | 101 | + 6.17 | 0.22 | +0.004 | 0.007 | 0.57 | 1.66 |
| Mount Hamilton | Sep | 21 | +16.77 | 0.42 | −0.049 | 0.071 | 0.69 | 1.73 |
| No. 1 | Oct | 21 | +13.08 | 0.46 | +0.096 | 0.076 | 1.26 | 1.73 |
| 1898–1918 | Nov | 20 | + 8.76 | 0.41 | +0.012 | 0.070 | 0.17 | 1.73 |
| | Dec | 21 | + 5.73 | 0.44 | −0.135 | 0.069 | 1.96 | 1.73 |
| Mount Hamilton | Sep | 61 | +18.49 | 0.28 | +0.026 | 0.014 | 1.86 | 1.67 |
| No. 2 | Oct | 62 | +13.73 | 0.29 | +0.027 | 0.014 | 1.93 | 1.67 |
| 1919–1984 | Nov | 62 | + 9.22 | 0.32 | −0.019 | 0.016 | 1.19 | 1.67 |
| | Dec | 61 | + 6.40 | 0.28 | +0.013 | 0.015 | 0.87 | 1.67 |

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Table VI—Continued

| Station, Location, Interval | Month | No. Years | Observed °C $\overline{T}$ | $\sigma_{\overline{T}}$ | Time Variation of $\overline{T}$ °C/yr $\overline{T'}$ | $\sigma_{\overline{T'}}$ | Student $t$ | $t_c$[a] |
|---|---|---|---|---|---|---|---|---|
| Mount Hamilton | Sep | 20 | +19.06 | 0.54 | +0.171 | 0.087 | 1.97 | 1.73 |
| No. 3 | Oct | 20 | +15.14 | 0.51 | −0.046 | 0.091 | 0.51 | 1.73 |
| 1985–2004 | Nov | 18 | + 8.91 | 0.58 | −0.092 | 0.112 | 0.82 | 1.76 |
| | Dec | 19 | + 5.91 | 0.52 | +0.030 | 0.096 | 0.31 | 1.74 |
| Soda Springs | Sep | 36 | +11.77 | 0.24 | +0.009 | 0.022 | 0.41 | 1.69 |
| 1930–1969 | Oct | 36 | +12.72 | 0.27 | +0.018 | 0.024 | 0.75 | 1.69 |
| | Nov | 34 | +1.41 | 0.32 | −0.022 | 0.027 | 0.81 | 1.69 |
| | Dec | 35 | −2.17 | 0.34 | +0.012 | 0.031 | 0.39 | 1.69 |
| Tahoe City | Sep | 94 | +12.30 | 0.13 | +0.017 | 0.004 | 4.25 | 1.66 |
| No. 1+2+3 | Oct | 94 | +7.39 | 0.16 | +0.020 | 0.006 | 3.33 | 1.66 |
| 1909–2004 | Nov | 94 | +2.32 | 0.15 | +0.011 | 0.006 | 1.83 | 1.66 |
| | Dec | 93 | −0.99 | 0.18 | +0.016 | 0.007 | 2.29 | 1.66 |
| Tahoe City | Sep | 40 | +11.94 | 0.19 | +0.035 | 0.016 | 2.19 | 1.69 |
| No. 1 | Oct | 40 | +6.89 | 0.21 | +0.012 | 0.018 | 0.67 | 1.69 |
| 1909–1949 | Nov | 40 | +1.96 | 0.21 | −0.022 | 0.018 | 1.22 | 1.69 |
| | Dec | 40 | −1.51 | 0.29 | +0.013 | 0.026 | 0.50 | 1.69 |
| Tahoe City | Sep | 21 | +12.20 | 0.26 | +0.019 | 0.044 | 0.43 | 1.73 |
| No. 2 | Oct | 20 | +7.36 | 0.27 | −0.008 | 0.046 | 0.17 | 1.73 |
| 1950–1970 | Nov | 21 | +2.49 | 0.27 | +0.053 | 0.043 | 1.23 | 1.73 |
| | Dec | 20 | −0.63 | 0.37 | −0.028 | 0.063 | 0.44 | 1.73 |
| Tahoe City | Sep | 33 | +12.79 | 0.24 | +0.044 | 0.024 | 1.83 | 1.70 |
| No. 3 | Oct | 34 | +8.02 | 0.29 | +0.061 | 0.028 | 2.18 | 1.70 |
| 1971–2004 | Nov | 33 | +2.65 | 0.28 | +0.039 | 0.029 | 1.34 | 1.70 |
| | Dec | 33 | −0.59 | 0.27 | +0.022 | 0.029 | 0.76 | 1.70 |
| Tahoe City | Sep | 73 | +12.33 | 0.16 | +0.017 | 0.004 | 4.25 | 1.67 |
| No. 1+3 | Oct | 74 | +7.41 | 0.19 | +0.021 | 0.006 | 3.50 | 1.67 |
| 1909–1949 + | Nov | 73 | +2.27 | 0.18 | +0.011 | 0.006 | 1.83 | 1.67 |
| 1971–2004 | Dec | 73 | −1.09 | 0.21 | +0.016 | 0.007 | 2.29 | 1.67 |

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Table VI—Continued

| Station, Location, Interval | Month | No. Years | Observed °C | | Time Variation of $\overline{T}$ °C/yr | | Student | |
|---|---|---|---|---|---|---|---|---|
| | | | $\overline{T}$ | $\sigma_{\overline{T}}$ | $\overline{T'}$ | $\sigma_{\overline{T'}}$ | $t$ | $t_c{}^a$ |
| Truckee | Sep | 116 | +12.80 | 0.18 | –0.001 | 0.004 | 0.25 | 1.66 |
| No. 1+2+3 | Oct | 114 | +7.63 | 0.21 | +0.006 | 0.005 | 1.20 | 1.66 |
| 1870–2004 | Nov | 112 | +2.22 | 0.22 | –0.012 | 0.005 | 2.40 | 1.66 |
| | Dec | 114 | –1.93 | 0.22 | –0.001 | 0.006 | 0.17 | 1.66 |
| Truckee | Sep | 84 | +12.79 | 0.19 | +0.002 | 0.007 | 0.29 | 1.66 |
| No. 1+2+3 | Oct | 83 | +7.81 | 0.26 | +0.001 | 0.009 | 0.11 | 1.66 |
| 1904–2004 | Nov | 81 | +2.04 | 0.26 | –0.020 | 0.009 | 2.22 | 1.66 |
| | Dec | 81 | –2.06 | 0.25 | +0.006 | 0.009 | 0.67 | 1.66 |
| Truckee | Sep | 33 | +12.88 | 0.39 | —— | —— | —— | —— |
| No. 1 | Oct | 32 | + 7.22 | 0.34 | —— | —— | —— | —— |
| 1870–1904 | Nov | 32 | + 2.79 | 0.37 | —— | —— | —— | —— |
| | Dec | 34 | – 1.64 | 0.42 | —— | —— | —— | —— |
| Truckee | Sep | 48 | +12.83 | 0.34 | –0.029 | 0.024 | 1.21 | 1.68 |
| No. 1 | Oct | 47 | + 7.50 | 0.41 | +0.035 | 0.028 | 1.25 | 1.68 |
| 1870–1919 | Nov | 46 | + 3.05 | 0.40 | +0.053 | 0.027 | 1.96 | 1.68 |
| | Dec | 49 | – 1.95 | 0.40 | –0.004 | 0.028 | 0.14 | 1.68 |
| Truckee | Sep | 16 | +12.82 | 0.68 | +0.043 | 0.153 | 0.28 | 1.76 |
| No. 1 | Oct | 16 | + 8.18 | 0.99 | +0.038 | 0.223 | 0.17 | 1.76 |
| 1904-1919 | Nov | 15 | + 3.78 | 0.96 | –0.084 | 0.212 | 0.40 | 1.77 |
| | Dec | 16 | – 2.64 | 0.83 | +0.226 | 0.178 | 1.27 | 1.76 |
| Truckee | Sep | 47 | +12.66 | 0.20 | –0.016 | 0.014 | 1.14 | 1.68 |
| No. 2 | Oct | 45 | + 7.48 | 0.26 | +0.002 | 0.019 | 0.11 | 1.68 |
| 1935–1982 | Nov | 45 | + 1.63 | 0.24 | +0.012 | 0.018 | 0.67 | 1.68 |
| | Dec | 44 | – 1.89 | 0.31 | –0.028 | 0.022 | 1.27 | 1.68 |
| Truckee | Sep | 21 | +13.07 | 0.37 | +0.074 | 0.058 | 1.28 | 1.73 |
| No. 3 | Oct | 22 | + 8.20 | 0.39 | –0.002 | 0.063 | 0.03 | 1.73 |
| 1983–2004 | Nov | 21 | + 1.70 | 0.44 | +0.037 | 0.073 | 0.51 | 1.73 |
| | Dec | 21 | – 1.96 | 0.36 | +0.073 | 0.058 | 1.26 | 1.73 |

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Table VI—Continued

| Station, Location, Interval | Month | No. Years | Observed °C $\overline{T}$ | Observed °C $\sigma_{\overline{T}}$ | Time Variation of $\overline{T}$ °C/yr $\overline{T'}$ | Time Variation of $\overline{T}$ °C/yr $\sigma_{\overline{T'}}$ | Student $t$ | Student $t_c$[a] |
|---|---|---|---|---|---|---|---|---|
| Truckee | Sep | 68 | +12.78 | 0.18 | +0.005 | 0.009 | 0.56 | 1.67 |
| No. 2+3 | Oct | 67 | + 7.72 | 0.22 | +0.014 | 0.011 | 1.27 | 1.67 |
| 1935–2004 | Nov | 66 | + 1.65 | 0.22 | +0.007 | 0.011 | 0.64 | 1.67 |
| | Dec | 65 | − 1.92 | 0.24 | −0.008 | 0.012 | 0.67 | 1.67 |

[a] Critical value: 95 percent confidence level.

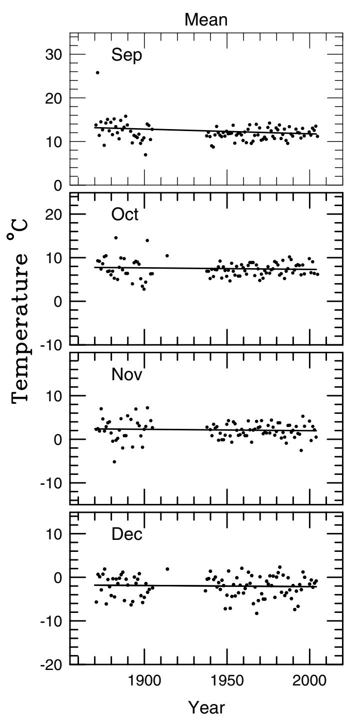


*Figure 11.* Monthly mean temperature at Boca, 1870–2004, September (top) through December (bottom). Ordinate, temperature in degrees Celsius; abscissa, year. Lines are the regression lines for the entire interval.

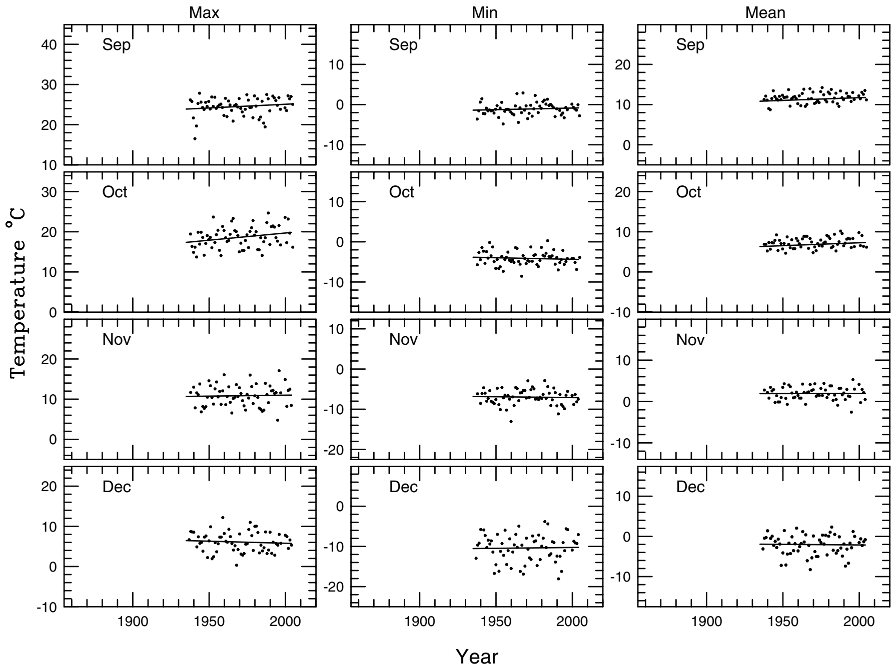


*Figure 12.* Monthly temperatures at Boca, 1935–2004. Ordinate, abscissa and layout as in Figure 10. Lines are the regression lines for the interval 1935–2004.

and from 1937–2004 at location 2, we have $\Delta\overline{T}_{mean(2-1)} = -0.98 \pm 1.01$ °C (September), $-0.36 \pm 0.39$ °C (October), $-0.35 \pm 0.37$ °C (November), and $-0.06 \pm 0.45$ °C (December). Combining the four months, $\Delta\overline{T}_{mean(2-1)} = -0.43 \pm 0.19$ °C, so that the difference is statistically significant at the 92 percent confidence level.

It would appear, then, that there is almost certainly both a small systematic difference between the mean temperatures at Boca locations 1 and 2, and a slight increase in mean temperature with time at location 2.

## 4.3. Colfax

Combining all observations from 1870–2004, we find, as can be seen from Table VI and Figure 13, statistically significant increases in $\overline{T}_{mean}$ with time in September and October, a significant decrease in November, and no significant change in December. However, the daily mean temperatures recorded before 1905 were derived from observations at 7 AM, 2 PM, and 9PM, while beginning in 1905 they were calculated by averaging the true daily maximum and minimum temperatures

.

Table VII. Average Daily Temperature Range ($\overline{R}$).

| Station | Interval[a] | $\overline{R} = (\overline{T}_{max} - \overline{T}_{min})$ °C | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sep | | Oct | | Nov | | Dec | |
| | | $\overline{R}$ | $\sigma_{\overline{R}}$ | $\overline{R}$ | $\sigma_{\overline{R}}$ | $\overline{R}$ | $\sigma_{\overline{R}}$ | $\overline{R}$ | $\sigma_{\overline{R}}$ |
| Blue Canyon 1 | 1904–1943 | 17.02 | 0.57 | 15.10 | 0.50 | 13.21 | 0.59 | 11.49 | 0.64 |
| Blue Canyon 2 | 1945–2004 | 10.23 | 0.41 | 9.24 | 0.49 | 7.58 | 0.52 | 7.09 | 0.58 |
| Boca | 1937–2004 | 25.63 | 0.34 | 22.73 | 0.40 | 17.83 | 0.41 | 16.48 | 0.51 |
| Colfax 1 | 1905–1975 | 15.67 | 0.39 | 14.66 | 0.38 | 12.78 | 0.42 | 10.91 | 0.41 |
| Mt. Hamilton 2 | 1919–1984 | 9.68 | 0.40 | 8.61 | 0.41 | 7.27 | 0.45 | 6.71 | 0.41 |
| Soda Springs | 1930–1969 | 17.21 | 0.39 | 15.34 | 0.47 | 13.78 | 0.57 | 13.82 | 0.55 |
| Tahoe City 1 | 1909–1949 | 18.25 | 0.33 | 15.19 | 0.37 | 12.55 | 0.36 | 10.99 | 0.49 |
| Tahoe City 2 | 1950–1970 | 16.28 | 0.41 | 13.94 | 0.45 | 10.87 | 0.42 | 10.21 | 0.92 |
| Tahoe City 3 | 1971–2004 | 17.29 | 0.43 | 15.47 | 0.43 | 12.32 | 0.44 | 11.44 | 1.28 |
| Truckee 2+3 | 1935–2004 | 21.74 | 0.34 | 19.09 | 0.41 | 14.66 | 0.40 | 13.49 | 0.39 |

[a] Intervals when temperatures were measured using maximum/minimum thermometers, and when these instruments remained in the same locations, except at Truckee, where measures from two locations have been combined. See text.

read from maximum and minimum thermometers. Thus, there is the possibility of a systematic difference in $\overline{T}_{mean}$ before and after 1905.

In addition, as discussed in Section 2.3, the station has been relocated twice, in 1976 and 1996. Calculating the monthly averages $\overline{T}_{max}$, $\overline{T}_{min}$, and $\overline{T}_{mean}$ for the intervals 1905–1975 (location 1), 1976–1994 (location 2), and 1995–2004 (location 3), we find no statistically significant differences in any of these temperatures between locations 1 and 2, although owing to the fairly large standard deviations at location 2 (due primarily to the shorter time interval at that site), differences of 1 °C or less could be present. Likewise, no systematic difference in temperature between locations 1 and 3 is found, although the period of time at location 3 is too short to permit detection of differences less than about 2 °C.

Since there remains the possibility of at least some small systematic difference between the three locations, the maximum, minimum, and mean temperatures have been analyzed not only for the entire period from 1905–2004, but also for the intervals before and after 1976 and 1996. The results of these calculations are shown in Tables IV–VI. The Tables and Figure 14 show that for the interval 1905–2004,

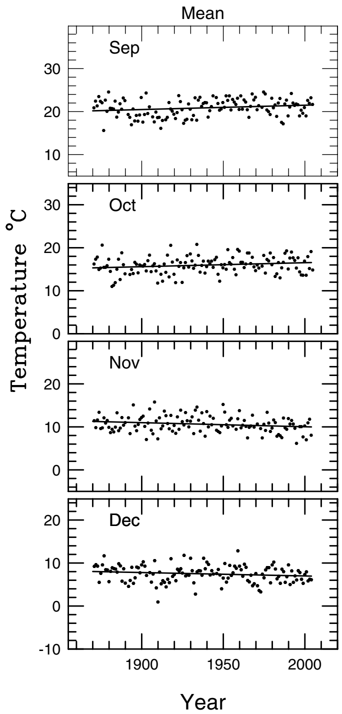


*Figure 13.* Monthly mean temperatures at Colfax, 1870–2004. Ordinate, abscissa and layout as in Figure 11. Lines are the regression lines for the entire interval.

$\overline{T}_{max}$ increased significantly with time in September, but decreased significantly in November, with no significant change in October and December, while $\overline{T}_{min}$ showed no significant change, and $\overline{T}_{mean}$ increased significantly in September and November. Similar results are found for the most homogeneous set of observations, from 1905–1975 when the maximum and minimum thermometers were installed at the same location. Here, a significant increase in $\overline{T}_{max}$ occurred in September and a significant decrease in November, while $\overline{T}_{min}$ and $\overline{T}_{mean}$ showed significant increases in September and October. For both intervals, combining all four months, no significant change with time is detected for any of the temperatures, maximum, minimum, or mean. This is shown for the interval 1905–1975 in Table VIII.

The observations at Colfax thus indicate that no statistically significant difference in temperature can be detected between the various instrument locations, and no statistically significant change with time in the maximum, minimum, or mean daily temperature has occurred since at least 1905.

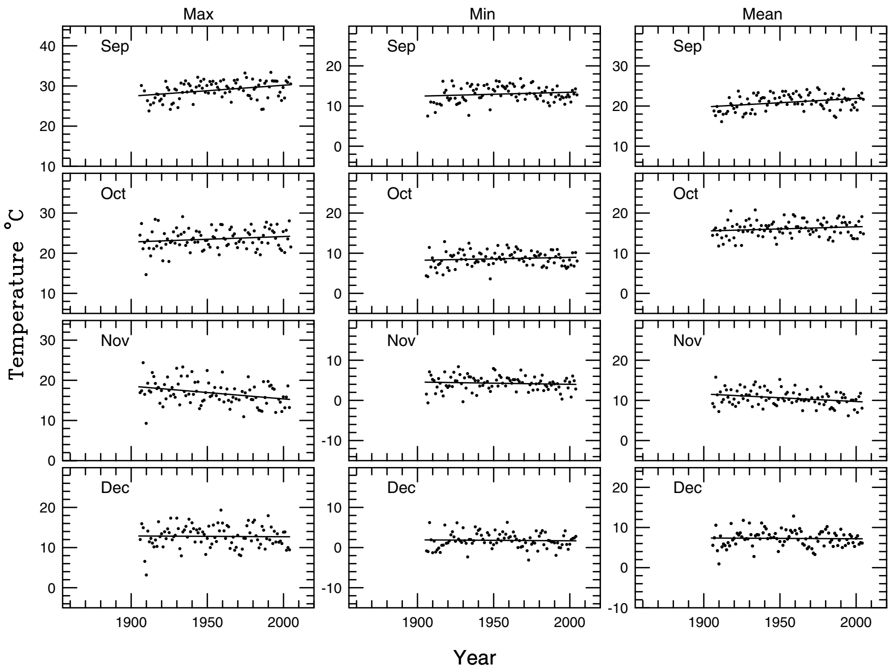


*Figure 14.* Monthly temperatures at Colfax, 1905–2004. Ordinate, abscissa and layout as in Figure 10. Lines are the regression lines for the entire interval.

## 4.4. Mount Hamilton

Observations of the average daily maximum, minimum, and mean temperatures for each of the four months are plotted in Figure 15. As can be seen from the figure and Tables IV–VI, taking all of the observations together the measurements would indicate a statistically significant, and indeed pronounced, increase in the maximum, minimum, and mean temperatures with time in September and October. However, these trends vanish when we analyze the observations from the various instrument locations separately. For that analysis, the observations were divided into three parts: No. 1, 1898–1918, when the thermometers were located within the double wall of the Meridian Circle Building; No. 2, 1919–1985, when they were located in standard instrument shelters at various ground-level locations on the top of the peak as described in Section 2.4; No. 3, 1985–2004, when the maximum and minimum thermometers were replaced by a thermistor-type sensor located at a height of 10.7 m (35 ft) above the ground level of the top of the peak.

The figure and tables show that a significant difference exists between the maximum temperatures measured at locations 1 and 2. This temperature difference is greatest in September, less in October, and

.

Table VIII. Time Variation of Temperature at Each Station, September through December (°C/yr).

| Station, Location | Interval[a] | Maximum[b] | | Minimum[b] | | Mean[b] | |
|---|---|---|---|---|---|---|---|
| | | $\overline{T'}_w$ | $\sigma_{\overline{T'}_w}$ | $\overline{T'}_w$ | $\sigma_{\overline{T'}_w}$ | $\overline{T'}_w$ | $\sigma_{\overline{T'}_w}$ |
| Blue Canyon No. 1 | 1904–1943 | +0.007 | 0.017 | +0.006 | 0.009 | +0.007 | 0.012 |
| Blue Canyon No. 2 | 1945–2004 | −0.021 | 0.013 | +0.018 | 0.013 | −0.001 | 0.013 |
| Boca No. 2 | 1937–2004 | +0.012 | 0.010 | 0.000 | 0.004 | +0.009 | 0.004 |
| Colfax No. 1 | 1905–1975 | +0.021 | 0.020 | +0.023 | 0.011 | +0.022 | 0.016 |
| Mt. Hamilton No. 2 | 1919–1984 | +0.013 | 0.010 | +0.011 | 0.010 | +0.013 | 0.010 |
| Soda Springs | 1930–1969 | −0.035 | 0.017 | +0.040 | 0.006 | +0.006 | 0.008 |
| Tahoe City No. 1+2+3 | 1909–2004 | +0.011 | 0.003 | +0.020 | 0.002 | +0.016 | 0.002 |
| Tahoe City No. 3 | 1971–2004 | +0.034 | 0.007 | +0.040 | 0.003 | +0.042 | 0.008 |
| Truckee No. 2+3 | 1935–2004 | −0.003 | 0.008 | +0.009 | 0.004 | +0.004 | 0.003 |

[a] Intervals when maximum/minimum thermometers were used and when these instruments were located at one location, or at locations with no detectable systematic differences in temperature between them, except at Tahoe City; see text.

[b] Values given are the weighted means of the monthly values in Tables IV–VI, the weights being the values of the standard deviations for each month.

not statistically significant in November and December. It is clear that the effect of having the thermometers in the double wall of the Meridian Circle Building was to prevent the daytime (maximum) temperature from rising to ambient, the depression of the maximum being greatest in September when the maximum temperature and the diurnal temperature range (maximum to minimum) was greatest, as shown in Tables IV–VII. The nighttime (minimum) temperatures were statistically the same at the two locations, probably due to the fact that a slot in the roof and walls of the building was opened at night for observations of stars with the Meridian Circle.

No statistically significant temperature differences are detected between locations 2 and 3. However, owing to the short interval (19 years) with the instruments at location 3, the dispersion of the observations is too great to permit detection of small systematic differences.

For security, therefore, we consider only the observations at location 2, from 1918–1984. Tables IV–VI show that for this interval, statistically significant increases with time in the maximum, minimum, and mean temperatures occurred in September and October. However, Ta-

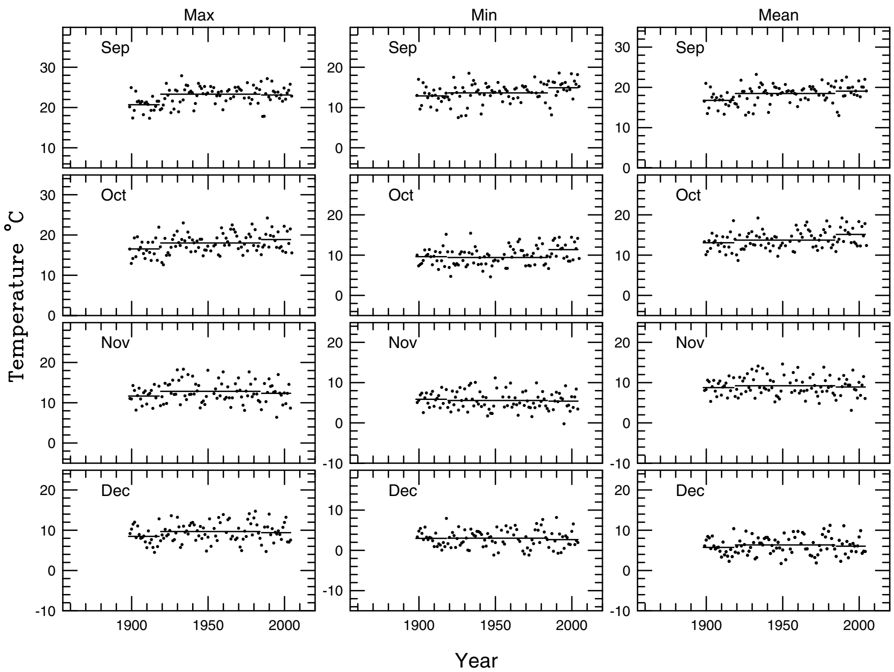


*Figure 15.* Monthly temperatures at Mount Hamilton, 1898–2004. Ordinate, abscissa and layout as in Figure 10. Lines are the averages at locations 1 (1898–1918), 2 (1919–1984), and 3 (1985–2004).

ble VIII shows that combining all four months, no significant change with time is found for any of these three temperatures.

## 4.5. Soda Springs

While the temperature measurements at this station were all made at the same location and using the same type of instruments, the interval covered, 1930–1969, is rather short, so that the results may be somewhat less reliable than those of the other stations. The observations are shown in Figure 16. The analysis, summarized in Tables IV–VI, indicates a significant decrease in maximum temperature with time in November and a possible decrease in December, but significant increases with time in minimum temperature in September, October, December, and possibly November. The mean temperature shows no significant change with time in any of the four months. Combining all four months, Table VIII shows that no significant variation with time occurs for the maximum and mean temperatures, while a significant increase in minimum temperature with time is indicated.

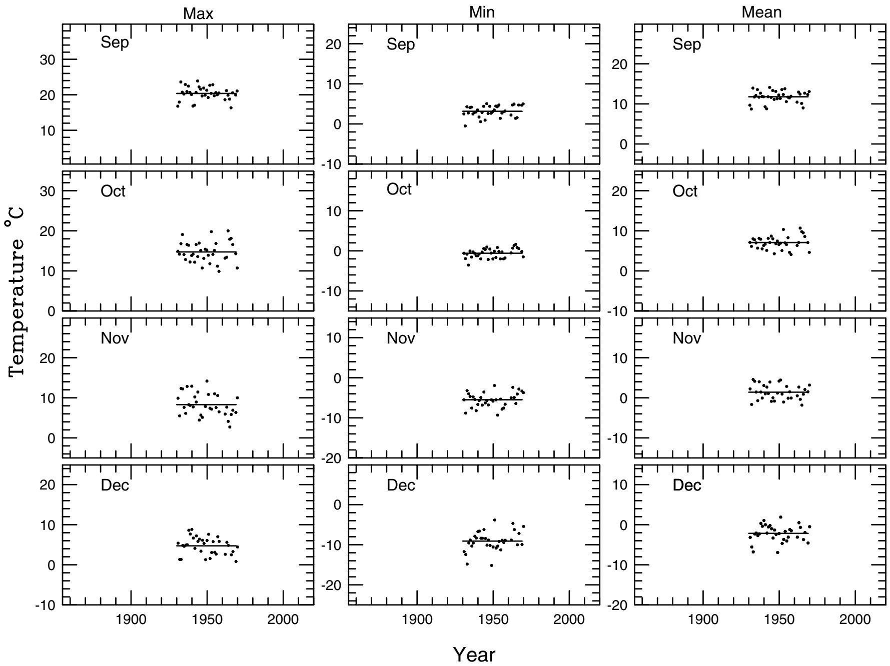


*Figure 16.* Monthly temperatures at Soda Springs, 1930–1969. Ordinate, abscissa and layout as in Figure 10. Lines are the averages of the temperatures.

### 4.6. Tahoe City

As shown in Figures 17 and 18 and Tables IV–VI, the measurements at Tahoe City provide very clear evidence of an increase in temperature with time. Figure 17 shows the maximum, minimum, and mean daily temperatures for the interval from 1909–2004, with lines indicating the least squares fits to the observations. These figures and tables demonstrate that significant increases in $\overline{T}_{max}$ occurred for the months of October and December, while no variation was observed in September or November. Combining all four months, an increase in $\overline{T}_{max}$ with time of $\overline{T'}_{max}$ = +0.011 ±0.003 °C/yr is found. The minimum temperatures show an even larger increase with time in all four months, where $\overline{T'}_{min}$ = +0.020 ±0.002 °C/yr. The mean temperatures also show significant increases with time in each month and in the combined four months, where $\overline{T'}_{mean}$ = +0.016 ±0.002 °C/yr. These values agree well with those found by Coats et al. (2006) (as measured on their Figure 8) of: $\overline{T'}_{max}$ = +0.007 °C/yr, $\overline{T'}_{min}$ = +0.023 °C/yr, and $\overline{T'}_{mean}$ = +0.014 °C/yr, based on temperatures for the entire year and covering the interval from 1916–2002.

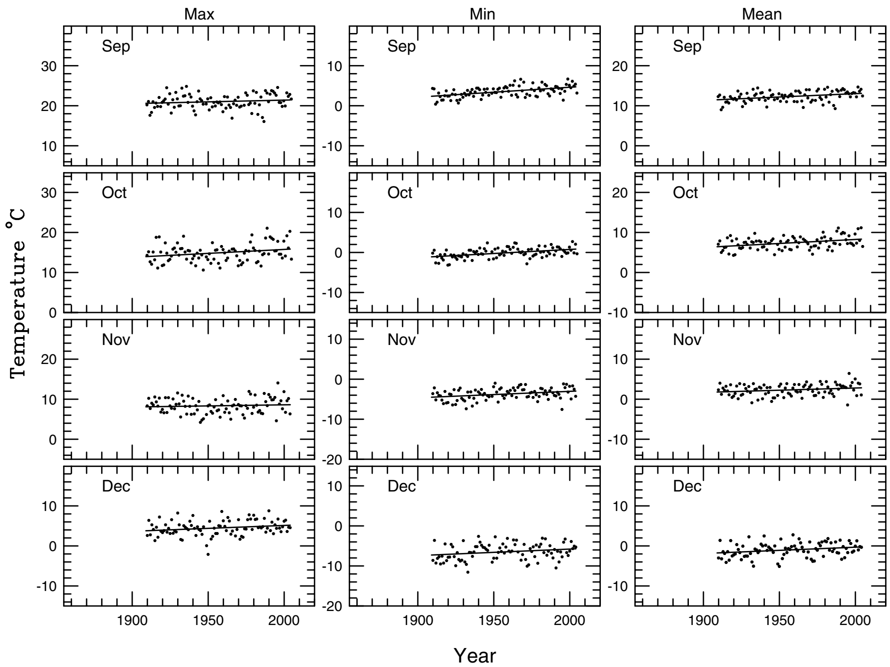


*Figure 17.* Monthly temperatures at Tahoe City, 1909–2004. Ordinate, abscissa and layout as in Figure 10. Lines are the regression lines for the entire interval.

However, as discussed in Section 2.6, the weather instruments were relocated in 1950 and again in 1971. Thus, there is the possibility of systematic differences between the temperatures recorded before and after these dates and, in fact, it appears that the measures at location 2, from 1950–1970, do differ from those made at locations 1 and 3. This difference can be seen in Tables IV–VII and Figure 18, where the temperature data have been divided into the intervals 1909–1949, 1950–1970, and 1971–2004. Figure 18 shows the average daily maximum, minimum, and mean temperature for each of these intervals.

From the figure and Table VII, we see that while there is no significant difference between the daily temperature ranges ($R = T_{max} - T_{min}$) for each month at locations 1 and 3, those at location 2 are consistently smaller, the weighted mean difference for the four months being $\Delta\overline{R}$ (locations 1+3 minus location 2) = +1.45 ±0.14 °C. Plotting the monthly average maximum, minimum, and mean daily temperatures at locations 1–3 as a function of time, we find that the temperatures at locations 1 and 3 fall along, or close to, the regression lines for each month for the entire data set (1909–2004). However, at location 2, while the mean temperatures fall along the regression lines, the maximum temperatures lie below, and the minimum temperatures

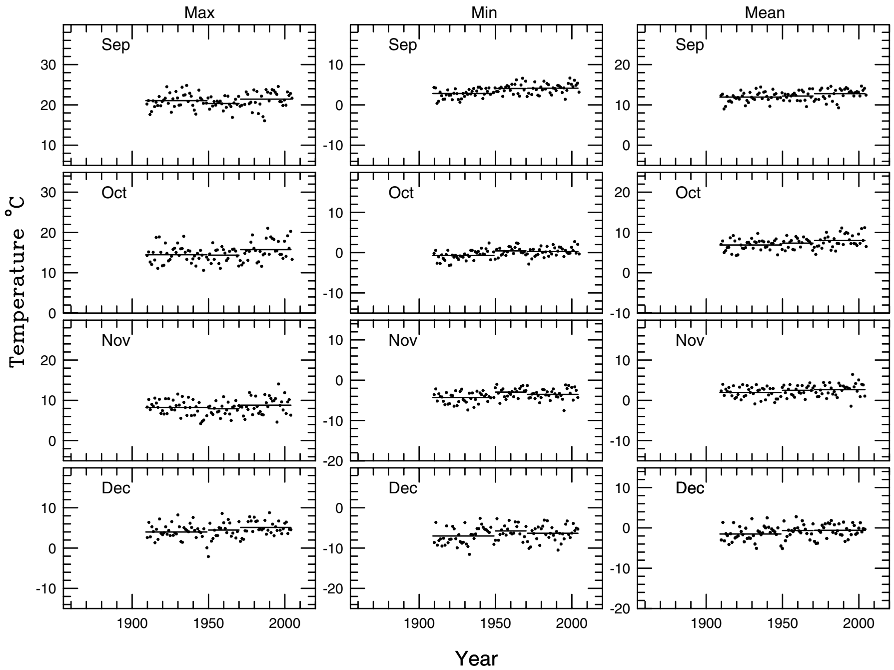


*Figure 18.* Monthly temperatures at Tahoe City (1909–2004). Ordinate, abscissa and layout as in Figure 10. Lines are the averages at locations 1 (1909–1949), 2 (1950–1970), and 3 (1971–2004).

above, these lines. Thus at location 2, the maximum temperatures are too low and the minimum temperatures too high, compared to the other two locations, but there is no systematic difference in the mean temperatures.

Owing to the fact that the observations at location 2 are situated almost exactly half way in time between those at locations 1 and 3, these systematic differences at location 2 have little effect on the calculated values of $\overline{T'}$ for the period from 1909–2004. This can be seen in Tables IV–VI, where the rates of temperature increase for this period have been calculated both with and without the observations from 1950–1970 at location 2. The systematic difference at location 2 could, however, affect calculations of $T'$ for other time intervals.

Combining all four months and comparing location 3 with the complete data set (1909–2004), we find differences in the rate of temperature increase (location 3 minus complete data set) of: $\Delta\overline{T'}_{max} = +0.023 \pm 0.007$ °C/yr, $\Delta\overline{T'}_{min} = +0.020 \pm 0.004$ °C/yr, and $\Delta\overline{T'}_{mean} = +0.026 \pm 0.008$ °C/yr. Thus, there is some indication of an increase in $\overline{T'}$ since about 1970, although these results are somewhat suspect owing to the shortness of the time interval at location 3.

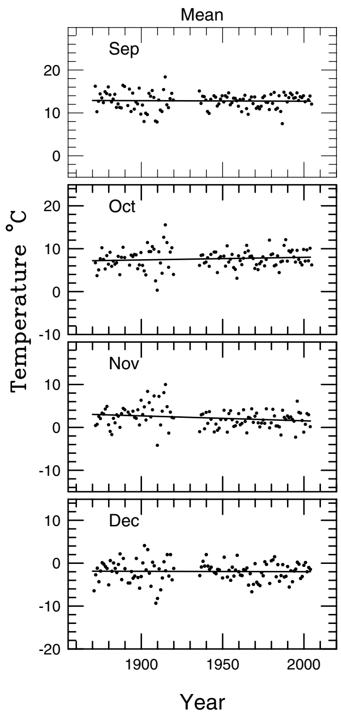


*Figure 19.* Monthly mean temperatures at Truckee, 1870–2004. Ordinate, abscissa and layout as in Figure 11. Lines are the regression lines for the entire interval.

## 4.7. Truckee

As discussed in Section 2.7, the station has been relocated twice, in 1935 and 1983. In addition, prior to 1904 no maximum and minimum temperature observations were made, the reported daily mean temperatures being calculated from the thermometer readings at 9AM, 2PM, and 9PM. Thus, there is the possibility of systematic differences between temperature measurements made before and after each of these critical dates.

Analyzing all of the observations of mean temperature from 1870–2004, Table V and Figure 19 indicate no significant change in $T_{mean}$ with time; the lines in Figure 19 are the regression lines. The observations of $\overline{T}_{max}$, $\overline{T}_{min}$, and $\overline{T}_{mean}$ from 1904–2004 are shown in Tables IV–VI and Figure 20. The lines in Figure 20 are once again the regression lines for the entire interval. It will be seen that the tables and figure again indicate no statistically significant change in temperature with time except for a *decrease* with time in $T_{max}$ and $T_{mean}$ in the month of November. The observations from the three instrument locations have also been analyzed separately, and the results are shown

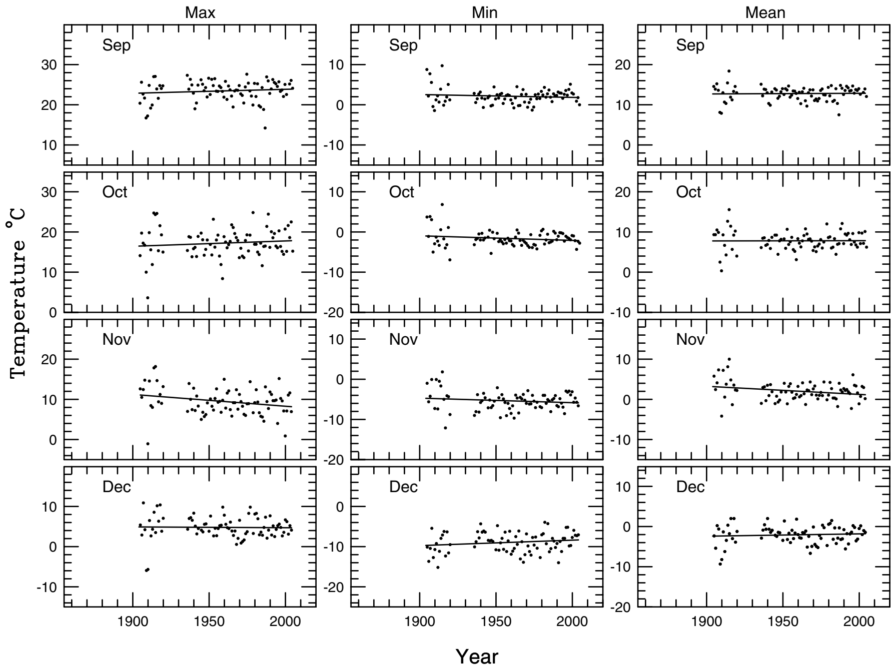


*Figure 20.* Monthly temperatures at Truckee, 1904–2004. Ordinate, abscissa and layout as in Figure 10. Lines are the regression lines for the entire interval.

in Tables IV–VI and Figure 21. The lines in Figure 21 are the averages of the temperatures at each of the three locations. As can be seen, the dispersions in the measurements from 1904–1919 at location 1 are much greater than those at locations 2 and 3, so that even though differences in $\overline{T}_{max}$, $\overline{T}_{min}$, and $\overline{T}_{mean}$ before and after 1920 exist, these differences are not statistically significant. Likewise, no significant differences are found between locations 2 and 3, and Table VII shows that the average daily temperature ranges are also not significantly different at any of the three locations. Combining the values of $\overline{T'}$ for all four months at locations 2+3, we find, as shown in Table VIII, that no significant variation in temperature with time is detected in the interval from 1935–2004.

### 4.8. Discussion

Analyzing the temperature observations from all of the stations for those time intervals when maximum/minimum thermometers were used and when the instruments were installed at the same location or at locations where no systematic differences in temperature between them

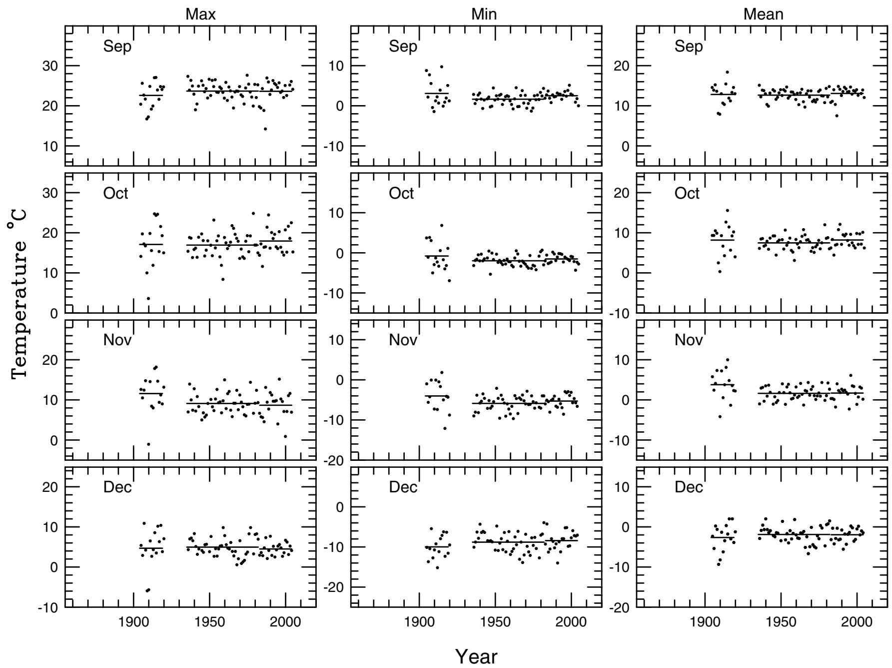


*Figure 21.* Monthly temperatures at Truckee, 1904–2004. Ordinate, abscissa and layout as in Figure 10. Lines are the average temperatures at locations 1 (1904–1919), 2 (1935–1982), and 3 (1983–2004).

have been detected (indicated by $^a$ in Tables IV–VI, and listed in Table VIII), we find:

1. Tahoe City shows a consistent and statistically significant increase in maximum, minimum, and mean temperature with time in each of the four months, and in the four months combined.

2. At all of the other stations, no consistent evidence for a change of temperature with time is found, either for the individual months or for the four months combined.

It will be noted from Tables IV–VI that the mean square errors of a single observation are appreciably smaller at Tahoe City than at the other stations. This difference may be due to the stabilizing effect of the water in Lake Tahoe, which may prevent the air temperatures near the lake from undergoing as large day-to-day fluctuations in $T_{max}$, $T_{min}$, and $T_{mean}$ as elsewhere. Thus, while some of the non-Tahoe stations show slight indications of increases in temperature with time, these increases, if real, are masked by the larger dispersions of the observations at these locations.

Since a very significant increase in temperature has occurred at Tahoe City and not at the other Sierran stations, it seems clear that the retardation of the snowfall dates at Tahoe City results from the warming of the air at that location.

Further smoothing of the non-Tahoe observations of $\overline{T'}$ can be achieved by combining the weighted mean values for all four months at each of these stations, listed in Table VIII, into final mean values for all of the non-Tahoe stations, where the values of $\overline{T'}$ at each station are weighted according to the standard deviations of the values of $\overline{T'}$ at that station. (Note that in forming these final means, Blue Canyon location 1 and location 2 have been counted as two separate stations while at Tahoe City, the observations for 1909–2004 were used). The results are shown in Table IX. This table lists these final mean values for the non-Tahoe stations together with the values of $\overline{T'}$ for Tahoe City measured both by Coats et al. (2006) and in the present investigation and, for comparison, values of the increase in mean temperature due to global warming (Jones and Moberg, 2003; Karoly et al., 2003).

Table IX shows that:

1. The rate of increase in $\overline{T}_{mean}$ at Tahoe City is significantly larger than the value expected due to global warming.
2. A smaller increase in $\overline{T}_{mean}$ is observed for the non-Tahoe stations studied in the present investigation, and this increase agrees quite well with the increase due to global warming published by Jones and Moberg (2003) and by Karoly et al. (2003).

It would appear, therefore, that all of the non-Tahoe stations studied here have experienced the general global warming, although the effect is not clearly visible at any one particular station owing to the sizes of the dispersion in the observations of the temperatures at these locations. Furthermore, it is clear that the conclusion of Coats et al. (2006), attributing the observed temperature increase at Tahoe City entirely to global warming, is not correct. Instead, the present study shows that this increase results from a combination of global warming and local heating due to a change in the microclimate of the Tahoe basin. Most likely, that change has resulted from human activity in the basin, including the paving of surface areas, the burning of wood and fossil fuels, and the generation of dust and aerosols.

The present study confirms the finding by Coats et al. (2006) that the warming at Tahoe City is greatest for the minimum (nighttime) temperatures. This effect is ascribed to increasing turbidity in the lower atmosphere, which reduces the incident short-wave solar radiation during the day, while preventing the escape of long-wave radiation at night (Kukla and Karl, 1993).

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Table IX. Variation of Temperature with Time (°C/yr).

| Location | $\overline{T'}_{max}$ | $\sigma_{\overline{T'}_{max}}$ | $\overline{T'}_{min}$ | $\sigma_{\overline{T'}_{min}}$ | $\overline{T'}_{mean}$ | $\sigma_{\overline{T'}_{mean}}$ |
|---|---|---|---|---|---|---|
| Tahoe City[a] | +0.007[b] | —— | +0.023[b] | —— | +0.015[b] | —— |
| Tahoe City[c] | +0.011 | 0.003 | +0.020 | 0.002 | +0.016 | 0.001 |
| Non-Tahoe Stations[d] | +0.001 | 0.006 | +0.012 | 0.006 | +0.007 | 0.002 |
| N. A. Continent[e] | —— | —— | —— | —— | +0.008 | —— |
| N. Hemisphere[f] | —— | —— | —— | —— | +0.006 | —— |
| N. Hemisphere[g] | —— | —— | —— | —— | +0.005 | —— |
| N. A. Continent[h] | —— | —— | —— | —— | +0.007[i] | 0.001[i] |

[a] Observations covering entire year, 1914–2002 (Coats et al., 2006).

[b] Measured on Coats et al. (2006: Figure 8).

[c] Observations in Sep–Dec, 1909–2004, from Table VIII, this study.

[d] Observations in Sep–Dec. Stations and intervals as in Table VIII, this study, weighted mean of observations in Table VIII for the seven stations, excluding Tahoe City.

[e] Observations covering entire year, 1901–2000. "Continent" is area: latitude 15°–60°N, longitude 50°–140°W (Jones and Moberg, 2003).

[f] Observations covering entire year, 1901–2000. "Hemisphere" is land plus sea (Jones and Moberg, 2003).

[g] Observations in Sep–Nov, 1901–1999. "Hemisphere" is land plus sea (Jones and Moberg, 2003).

[h] Observations covering entire year, 1900–1999. "Continent" is area: latitude 30°–65°N, longitude 40°–165°W (Karoly et al., 2003).

[i] Measured on Karoly et al. (2003: Figs 2c and 3).

## 5. Conclusions

A study by the writer (Walker, 2012) has demonstrated that the date of the first major autumnal snowfall at Tahoe City has become progressively later, at a rate of about 0.24 d/yr, since the first observations in 1915. This change is not observed at the other weather stations in the vicinity. Such a retardation could result either from a decrease with time in the amount of precipitation, or an increase in the temperature.

Analysis of the weather records for Tahoe City and five nearby weather stations, plus a "control" station at Mount Hamilton, for the months of September–December reveals that the progressively later snowfall dates do not result from a decrease in the amount of precipitation. No significant decrease in precipitation is observed at any of the stations. However, statistically significant *increases* in precipitation with time are observed, in the month of November, at four of the Sierran stations: Blue Canyon, Colfax, Soda Springs, and Tahoe City. Three of these stations, Blue Canyon, Colfax, and Soda Springs, are located west of the Sierra crest. Averaging separately the stations east and west of the crest, the November increase is significantly larger on the western side of the crest than on the eastern. November is the first month in the fall with substantial precipitation. Thus, the increase in precipitation with time in November may be due to "cloud seeding" by the particulate material in the atmosphere which acts as condensation nuclei. The process is most effective west of the Sierra crest where the moisture content of the arriving storm clouds is highest. The amount of precipitation produced increases with time as the quantity of particulate material grows due to the ever-increasing atmospheric pollution. After November, the effect diminishes as this material is washed out of the atmosphere by the precipitation.

Analysis of the temperature data for the various stations shows that the increasingly later snowfall dates at Tahoe City result from an increase in the temperature with time at Tahoe City, and presumably throughout the Tahoe basin, amounting to: $\overline{T'}_{max} = +0.011$ °C/yr, $\overline{T'}_{min} = +0.020$ °C/yr, and $\overline{T'}_{mean} = +0.016$ °C/yr. Combining observations at all of the other stations studied, a smaller temperature increase is detected, amounting to: $\overline{T'}_{max} = +0.001$ °C/yr, $\overline{T'}_{min} = +0.012$ °C/yr, and $\overline{T'}_{mean} = +0.007$ °C/yr. This value of $\overline{T'}_{mean}$ agrees with the values of $\overline{T'}_{mean} = +0.007 \pm 0.004$ °C/yr (Karoly et al., 2003) and +0.008 °C/yr (Jones and Moberg, 2003), due to global warming, and indicates the detection of the effects of global warming at these sites. The rate of warming at Tahoe City is about twice as large as that due to global warming, and this excess is clearly a local phenomenon, presumably the result of human activity in the Tahoe basin.

The present investigation illustrates the difficulties that may be encountered in measuring small, long-term changes in temperature or precipitation at a particular location. Even where the weather station has not been affected by urban growth, systematic errors may exist owing to changes in the locations and/or types of instruments used. The observations discussed here illustrate the need for overlap measurements at the old and new sites, or with the old and new instruments, when changes are made.

## 6. Acknowledgements

I am greatly indebted to Dr. Arnold Klemola for carrying out the calculations of $\overline{P}$, $\overline{P'}$, $\overline{T}$, and $\overline{T'}$, and their associated errors, in Tables II, IV–VI, as well as preparing all of the illustrations.

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