Secular Trend of Surface Temperature at an Elevated Observatory in the Pyrenees

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ABSTRACT

Surface temperature was measured at the Pic du Midi de Bigorre, 2862 m MSL, from the foundation of the Observatory in 1878 until the closing of the meteorological station in 1984. After testing the homogeneity of the series with the annual mean temperatures in western Europe and in southwestern France, the period 1882–1970 was retained for trend analysis.

The mean annual temperature increased 0.83°C during the 89-yr period. This increase is the sum of a very significant increase in the daily minimum temperature (+2.11°C) and a decrease in the maximum temperature (−0.45°C). In consequence, the most dramatic change in the temperature regime was the difference between maximum and minimum; this decreased from 8.05°C in 1882 to 5.49°C in 1970. A mean increase is observed in all seasons, but, as for western Europe, it is stronger in spring and fall than in winter and summer.

Analysis of cloudiness data for the same period shows a 15% increase in annual mean cloudiness and also significant year-to-year correlations between cloudiness and the maximum and minimum temperatures. In consequence, the change in the temperature regime observed at the Pic du Midi since the end of last century is most probably the result of a climatic change involving an increase in cloud cover and, maybe, an increasing greenhouse effect.

1. Introduction

In general, the evidence of a global surface warming of about 0.5°C over the past 100 years is not questioned. This warming is consistent with the expected impact of increasing concentration of CO_2, but the cause is not proved beyond all possible doubt (Mitchell 1989). The recent sudden increase in the rate of warming (Tsonis and Elsner 1989) justifies the developing interest in the subject.

Many of the discussions concerning an enhanced greenhouse effect and climate change are based on compilations of mean surface air temperature for the Northern Hemisphere (Jones et al. 1986a; Vinnikov et al. 1990) and for the two hemispheres (Hansen and Lebedeff 1987). A number of recent studies use marine data, both surface air temperature and sea surface temperature for the two hemispheres (Folland et al. 1984; Jones et al. 1986b; Newell et al. 1989). The quality and coverage of the data have been discussed in detail; the most crucial problems are probably systematic errors in time series of data based on ship observations (Wright 1986) and the effect of urban warming at a great number of land stations. However, concerning this last point, Jones et al. (1989) concluded that urbanization is unlikely to account for a substantial proportion of the warming trend observed in the surface air temperature average for northern landmasses.

Instead of averaging surface air temperatures from many stations for which the data are more or less representative of regional climatic changes, we can use data from a few rural stations for which well-documented measurements are available. In this respect, we present and discuss a long series of data taken by professional meteorologists at an elevated astronomical observatory. Moreover, this type of data is the only one taken outside the planetary boundary layer before the instrumented air sounding period, and so it may give new insights on the temperature trend in the free atmosphere.

2. Description of the site and of the temperature measurements

The Pic du Midi de Bigorre (43°04′N, 0°09′E, 2862 m MSL) is an isolated peak of the Pyrenees situated about 10 kilometers north of the central part of the mountain range (Fig. 1). This exceptional situation led geophysicists of the past century to build on its summit an observatory devoted to the sciences of the atmosphere and the sky (Fig. 2).

The observatory was inaugurated in 1878. Since then a permanent group of scientists and technicians has been present on the site, among them a meteorologist in charge of a synoptic observing station. Due to a reduction in staff, the station was closed at the end of 1984. An automatic weather station is planned.

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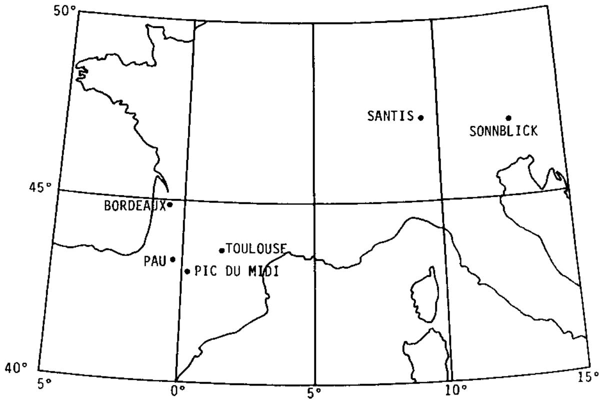

FIG. 1. Locations of the Pic du Midi and other weather stations cited in the text.

The climate of the Pic du Midi is alpine under maritime influence, since the Atlantic Ocean is only 160 km to the NNW, the prevailing wind direction. The mean annual precipitation is 925 mm, 60% of this amount falling from November through April (Table 1). The detailed temperature data will be presented below, but we note that the monthly average is less than 0°C from October through May (Table 1). As a consequence, the environment of the station, which consists of steeply sloped and rocky ground, is nearly always snow-covered during this period. The snow cover is never regular due to the strong winds generally observed at the station.

The set of temperature data, consisting of monthly averages of the daily maxima and minima, is complete for the period 1882–1984, with the exception of the war years of 1943 and 1944. For these two years, the maximum and minimum annual averages are available, but the monthly averages have been lost. In order to arrange continuous series for the statistical evaluation of the seasonal trends, seasonal means for 1943 and 1944 were generated from seasonal means at the nearest available long-term station (Pau-Ville, 58 km to the northwest) using equivalent normalized anomalies.

The complete set of data for the period 1882–1984, consisting of seasonal and annual averages of the maximum and minimum temperatures, is given in appendix A.

3. Data homogeneity

The first task when analyzing secular temperature trends at a station is to survey the major factors that may affect station homogeneity (Jones et al. 1986a).

Changes in station location and instrumentation. As in almost all the stations where temperature measurements were made for some 100 years, several changes

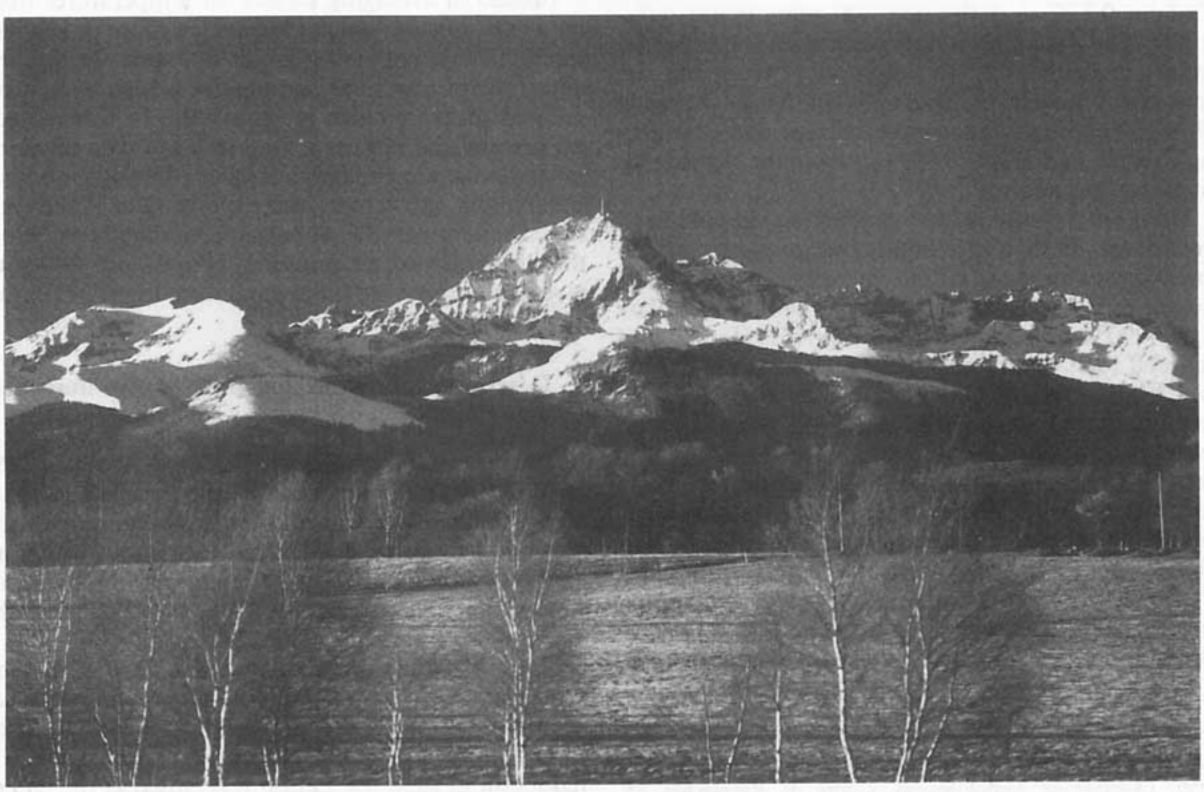

FIG. 2. A view of the Pic du Midi taken from Lannemezan, 28 km to the north.

TABLE 1. Monthly mean precipitation (1951–80) and mean temperature (1882–1970) at the Pic du Midi de Bigorre.

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Precipitation (mm)	106	82	86	86	66	59	53	62	63	67	89	107	925
Temperature (°C)	−7.5	−7.3	−5.6	−4.4	−1.1	3.8	6.8	7.0	4.0	−0.3	−4.2	−6.7	−1.29

in exposure and instrumentation occurred. From the foundation of the observatory until 1949, measurements were made on the eastern part of the terrace (Fig. 3), with different types of thermometer screens specially designed to avoid snowpacks. In 1950, the station was moved some meters above the terrace to a radio tower. Finally, a major change occurred in 1971 when the station was moved to the top of a new multipurpose building. Not only did this move increase the altitude of the screen from 2862 to 2880 m, but it brought the station nearer to the north ravine, with a strong NW wind ventilation.

Changes in observation times and methods of calculating monthly averages. There is no potential source of error concerning these points. The daily values of the minimum and maximum were always observed on minimum and maximum thermometers and then used to calculate the monthly averages; there is no "time of observation bias" (Karl et al. 1986) in the series, since the minimum and maximum thermometers were always read at 1200 and 1800 UTC, respectively (UTC is also LST as the Pic du Midi is nearly on the Greenwich meridian).

Changes in the environment around the station. There are several problems with the environment of the station at the Pic du Midi. First of all, instead of grass around the thermometer screen, there is snow or rock and cement. Another important complication is that, although the population remained very small during the period of measurements (5–30 people), new buildings sporadically appeared on the summit. Changes were slow from 1884 to 1970, with only the installation of a few astronomical turrets. In 1971, the construction of the large multipurpose building considerably modified the landscape, and the release of sensible heat around the station increased.

We first tested for data homogeneity by comparing the series of the Pic du Midi with a regional series. A series beginning in 1880 was established by Hansen and Lebedeff (1987) for western Europe. It consists of the temperature anomaly for an amalgam of 224 stations situated in a "box" of about 2500 × 2500 km (Hansen and Lebedeff's box 9), the Pic du Midi being in the southwestern corner of the box. The test used to check possible inhomogeneities in the Pic du Midi series is the bivariate test for the detection of a systematic change in the mean (Maronna and Yohai 1978). The test should ideally be applied to a serially independent sequence $\{x_i, y_i\}$ of n two-dimensional random vectors, each vector distributed bivariate normal.

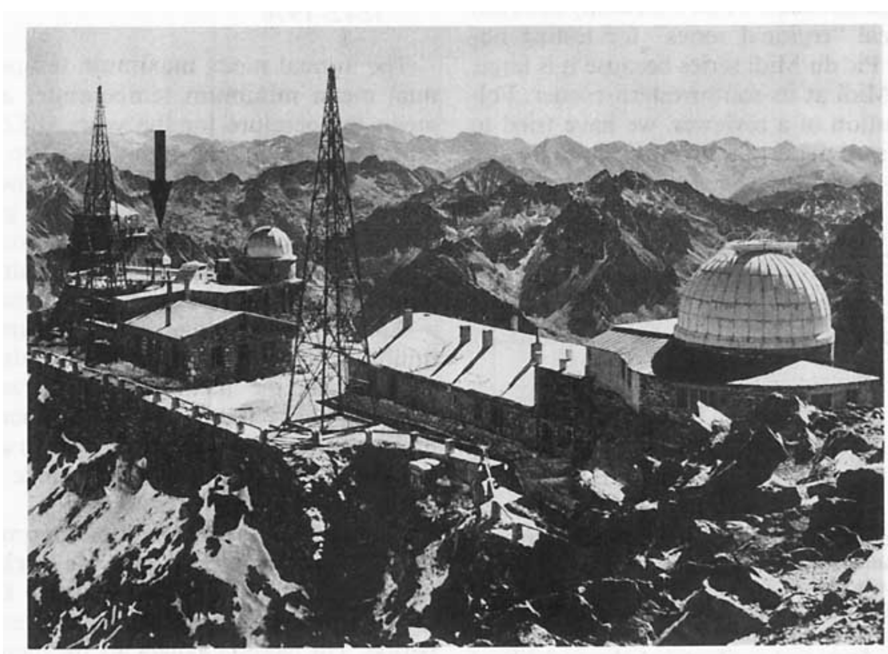

FIG. 3. The Observatory of the Pic du Midi in 1945, with the location of the weather station (photograph by Studio Alix).

It is also assumed that the sequence is stationary, with the exception of a possible shift in the mean in $\{y_i\}$. Use of the bivariate test was illustrated with the annual precipitation series by Potter (1981); results are excellent, even in cases where there are two or more shifts in the mean.

The step-by-step description of the procedure by which the bivariate test is applied is given in appendix B. The statistic T_0, used to test whether or not a relative shift in the mean has occurred, is the maximum value of T_i over all $i < n$ where T_i is a measure of the difference of the two series. All values of T_i are plotted in Fig. 4 for the series [box 9, Pic du Midi]. The 0.10, 0.05, and 0.01 critical values of T_0 for $n = 103$ are also plotted. The result of the test indicates a relative shift in mean after the year $i = 89$ (1970), with a significance level between 0.10 and 0.05. The test also gives the amount of change in the mean at the Pic du Midi after 1970: −0.58°C. No other change in means is observed on the curve of Fig. 4.

The bivariate test assumes serial independence and stationarity of the series $\{x_i\}$. The assumption of independence may not be strictly satisfied in the case of annual temperature series. However, like the case of annual precipitation series, it is probable that the serial dependence is not strong enough to substantially alter the conclusion of the test (Potter 1981). Similarly, the assumption of stationarity of the series $\{x_i\}$ is not completely satisfied since the Hansen–Lebedeff series likely contains a long-term trend. However, the test is probably insensitive to such a trend since it is present in both series $\{x_i\}$ and $\{y_i\}$, and the statistic T_i depends on the residuals of one regressed against the other.

The Hansen and Lebedeff's box 9 certainly does not constitute an ideal "regional series" for testing homogeneity of the Pic du Midi series because it is large, with the Pic du Midi at its southwestern corner. Following the suggestion of a reviewer, we have tried to combine several stations in southwest France in order

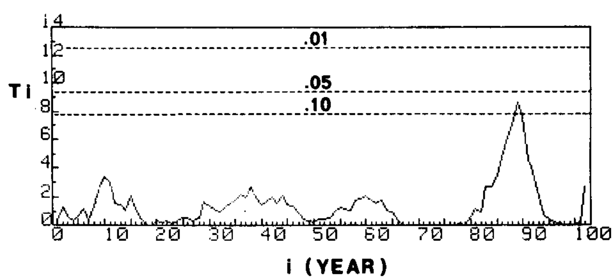

FIG. 4. Illustration of the bivariate test for detecting inhomogeneities in the Pic du Midi annual mean temperature series. The regional series used for comparison is an average of data from 224 stations in Western Europe. The test statistic, T_i, is plotted against the years of the period 1882–1984. Dashed lines on the figure indicate 0.10, 0.05, and 0.01 levels of statistical significance. A change significant at the 0.10 level is observed after year $i = 89$ (1970).

to construct a regional series for a smaller area. In this effort, we found the classical difficulties: the very few stations that operated during the first half of the period 1882–1984 slowly became embedded in urban areas, then stopped. We were obliged to construct two different series, one for the period 1901–53 and the other for the period 1946–84. For the period 1901–53, the regional series is constituted by the means of the annual mean temperatures at Bagnères de Bigorre (nearly at the foot of the Pic du Midi), Pau-Ville (58 km northwest of the Pic du Midi, see Fig. 1), and Bordeaux-Floirac (220 km to the north-northwest). For the period 1946–84, we have a good regional series with means of temperatures measured at airport weather stations: Bordeaux-Mérignac, Pau-Uzein, and Toulouse-Francazal (130 km to the northeast). The results of the bivariate test with these two series corroborates the preceding results: there is no relative shift in the mean observed at the Pic du Midi during the period 1901–53 (a very flat diagram of T_i, with a maximum value of 1.43), and there is a marked relative shift for the period 1946–84 after the year 1970, with a maximum value of 21.10 for T_i (with a statistical significance better than 0.01).

In conclusion, the only change that has had a significant effect on series homogeneity is the moving of the station to the top of the new building in 1971. Adjusting the data for the period 1971–84 would be a dangerous artifact for a study of long-term trends, so we decided to retain only the period 1882–1970 (89 years) for the analysis of surface temperature at the Pic du Midi.

4. Mean annual and seasonal trends for the period 1882–1970

The annual mean maximum temperature, the annual mean minimum temperature, and the annual mean temperature for the years 1882–1970 are repsented in Fig. 5. The trend lines are determined by regression analysis with time as the independent variable. Ordinates of the trend lines are given in Table 2 for the first and last years of the period.

Surprisingly, the maximum and minimum temperatures do not have a strong year-to-year correlation ($r = 0.33$) and their long-term trends are opposing: the minimum has increased by 2.11°C during the whole period, while the maximum has decreased by 0.45°C. These opposite trends lead to an increase of annual mean temperature by 0.83°C, and to a large and very significant decrease in the difference between maximum and minimum temperatures.

Table 3 gives the seasonal maximum and minimum temperature changes. Again, these changes are estimated from the differences between the ordinates of the trend lines for the first and last years of the whole period. The largest changes are the increase of the minimum temperature during the intermediate seasons

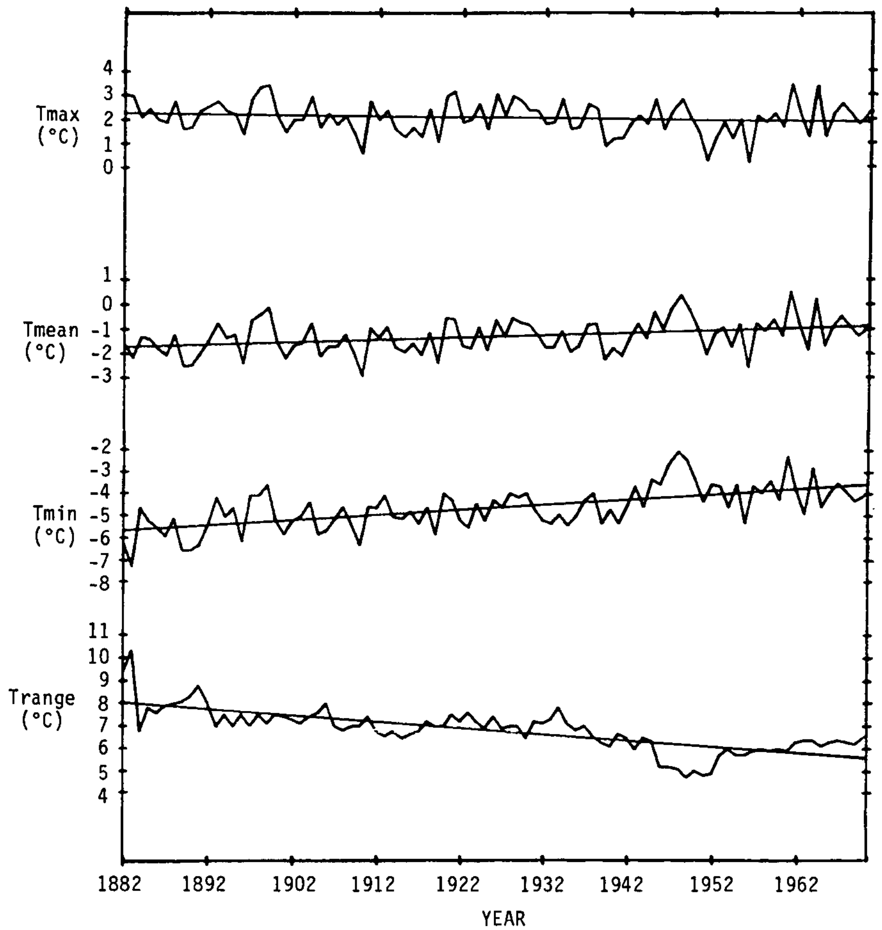

FIG. 5. Variation of annual temperature at the Pic du Midi during the period 1882–1970: original series and trend lines.

(spring and fall). For each of the four seasons, the minimum increase is significant at the 1% level, while the maximum decreases in December–February, March–May, and June–August are only significant at the 5% level. The maximum increase in September–November is not significant at the 10% level.

The comparison of the temperature trend in western Europe during the period 1882–1970 [+0.57°C in box 9 of Hansen and Lebedeff (1987)] with the trend at the Pic du Midi during the same period (+0.83°C) suggests that the warming in the free atmosphere may be larger than the warming near the surface. A comparison is possible with two other mountain stations in western Europe: Säntis (Switzerland), 47°15′N, 9°20′E, 2500 m MSL (Smithsonian Miscellaneous Collection) and Sonnblick (Austria), 47°03′N, 12°57′E, 3106 m MSL (Böhm 1986). The mean temperature increase is 0.90°C at Säntis (1882–1970) and 0.97°C at Sonnblick (1887–1970). The correlations between the Pic du Midi and Säntis, $r = 0.69$, and between the Pic du Midi and Sonnblick, $r = 0.67$, are better than the correlation between the Pic du Midi and box 9, $r = 0.35$, which may be a sign of data quality in high mountain stations (good ventilation of the

TABLE 2. Mean annual temperature changes (°C) at the Pic du Midi evaluated by linear trends during the period 1882–1970.

	Mean value 1882	Mean value 1970	Change	Change per 100 yr	Trend correlation
Maximum	2.32	1.87	−0.45	−0.51	0.24
Minimum	−5.73	−3.62	+2.11	+2.40	0.62
Mean	−1.70	−0.87	+0.83	+0.94	0.33
Max − min	8.05	5.49	−2.56	−2.91	0.77

APPENDIX A (*Continued*)

Year	D—J—F max	D—J—F min	M—A—M max	M—A—M min	J—J—A max	J—J—A min	S—O—N max	S—O—N min	Annual max	Annual min
1890	−4.1	−11.6	−0.5	−10.5	8.7	0.5	2.7	−4.8	1.7	−6.6
1891	−3.3	−11.2	−0.3	−10.6	8.9	−0.9	4.2	−3.0	2.4	−6.4
1892	−4.0	−11.3	1.4	−8.7	10.2	1.5	2.9	−3.4	2.6	−5.5
1893	−4.5	−11.5	3.2	−4.3	9.6	2.5	2.8	−3.4	2.8	−4.2
1894	−3.0	−10.9	0.4	−8.1	9.7	2.1	2.5	−3.7	2.4	−5.1
1895	−6.0	−12.8	0.0	−7.5	9.8	2.3	5.5	−0.8	2.3	−4.7
1896	−2.8	−10.1	0.1	−8.5	7.9	0.5	0.2	−6.5	1.3	−6.2
1897	−3.5	−10.0	1.0	−6.5	10.2	3.0	3.7	−2.8	2.9	−4.1
1898	−1.1	−8.1	−1.0	−8.9	11.2	3.1	4.4	−2.5	3.4	−4.1
1899	−2.4	−9.0	0.9	−6.8	10.0	2.0	5.5	−0.8	3.5	−3.6
1900	−3.2	−10.1	−1.1	−9.7	9.9	2.1	3.2	−3.5	2.2	−5.3
1901	−5.8	−12.9	−0.2	−8.6	10.0	2.7	2.0	−4.7	1.5	−5.9
1902	−3.5	−10.3	0.3	−7.9	9.3	1.7	1.9	−4.6	2.0	−5.3
1903	−3.0	−9.3	0.0	−8.6	8.8	1.2	2.3	−3.6	2.0	−5.1
1904	−4.0	−11.0	1.1	−6.8	11.3	3.4	3.7	−3.0	3.0	−4.4
1905	−3.5	−10.9	0.0	−7.8	9.7	1.8	0.5	−6.8	1.7	−5.9
1906	−6.6	−13.4	0.3	−9.0	11.2	2.7	4.3	−3.1	2.3	−5.7
1907	−4.5	−11.0	−0.2	−8.2	9.7	2.4	2.3	−3.9	1.8	−5.2
1908	−3.7	−10.1	−0.7	−8.4	8.5	1.5	4.7	−1.4	2.2	−4.6
1909	−4.9	−10.9	0.5	−7.4	7.4	0.2	2.9	−3.8	1.5	−5.5
1910	−4.9	−11.1	−1.3	−9.3	7.6	0.2	0.9	−5.2	0.6	−6.4
1911	−2.9	−9.4	−0.3	−8.8	10.8	2.7	3.6	−3.0	2.8	−4.6
1912	−1.4	−7.4	0.6	−6.8	7.7	0.3	1.2	−4.8	2.0	−4.7
1913	−3.3	−9.0	0.8	−6.6	9.2	1.8	3.0	−2.8	2.4	−4.1
1914	−4.8	−11.0	0.5	−6.7	7.9	0.6	2.8	−3.4	1.6	−5.1
1915	−6.1	−11.4	0.0	−7.2	9.9	2.5	1.2	−4.7	1.2	−5.2
1916	−3.9	−9.5	−0.5	−7.8	9.0	1.7	2.3	−3.9	1.7	−4.9
1917	−6.5	−12.4	−1.1	−8.5	9.6	2.1	3.2	−3.0	1.3	−5.4
1918	−2.3	−8.1	−0.1	−8.5	9.9	2.0	2.4	−4.0	2.5	−4.7
1919	−5.5	−11.1	−0.1	−8.2	9.7	1.5	0.4	−5.9	1.1	−5.9
1920	−2.4	−8.3	2.1	−5.1	9.5	1.3	2.8	−3.7	3.0	−4.0
1921	−2.8	−9.4	0.0	−8.6	10.5	2.5	5.1	−1.6	3.2	−4.3
1922	−4.1	−10.6	0.2	−7.4	9.6	1.5	1.9	−4.7	1.9	−5.3
1923	−5.6	−12.3	0.3	−8.0	10.8	2.1	2.4	−4.2	2.0	−5.6
1924	−4.6	−11.5	2.2	−5.8	9.8	2.4	3.3	−3.1	2.7	−4.5
1925	−3.0	−9.2	−1.8	−9.2	8.9	1.9	2.3	−4.6	1.6	−5.3
1926	−2.0	−8.9	0.9	−6.6	9.7	1.1	3.8	−2.8	3.1	−4.3
1927	−4.3	−10.8	1.0	−6.2	8.9	2.1	3.1	−4.0	2.2	−4.7
1928	−2.9	−9.4	−0.3	−7.3	12.1	4.2	3.2	−3.5	3.0	−4.0
1929	−4.1	−10.7	1.2	−6.2	10.3	2.8	3.8	−2.7	2.8	−4.2
1930	−4.5	−10.4	0.3	−7.1	9.6	3.3	4.3	−1.7	2.4	−4.0
1931	−5.3	−11.6	1.4	−6.1	10.2	2.2	3.1	−3.9	2.4	−4.8
1932	−2.5	−9.2	−0.9	−8.8	8.4	0.5	2.0	−3.7	1.8	−5.3
1933	−6.2	−12.2	1.5	−6.3	10.4	1.9	1.8	−4.8	1.9	−5.4
1934	−3.7	−9.8	1.2	−8.0	10.3	1.6	3.6	−3.9	2.8	−5.0
1935	−5.8	−12.5	−0.5	−8.0	10.3	2.8	2.4	−4.2	1.6	−5.5
1936	−2.9	−9.1	−0.5	−7.0	8.8	1.1	1.2	−5.3	1.7	−5.1
1937	−3.6	−10.1	0.0	−7.6	11.4	3.6	2.9	−2.9	2.7	−4.3
1938	−4.7	−10.8	0.9	−6.3	10.2	3.1	3.7	−2.0	2.5	−4.0
1939	−4.0	−10.1	−3.3	−9.6	8.3	1.6	2.4	−3.3	0.9	−5.3
1940	−5.7	−10.5	0.3	−6.0	8.2	1.5	1.9	−4.1	1.2	−4.8
1941	−5.2	−11.0	−1.3	−8.2	8.6	1.5	2.7	−4.0	1.2	−5.0
1942	−6.3	−11.6	0.9	−6.0	9.3	2.4	3.2	−3.2	1.8	−4.6
1943*	−3.9	−11.3	1.2	−4.5	9.9	2.9	1.5	−1.7	2.2	−3.7
1944*	−5.0	−11.2	0.7	−7.3	9.9	3.1	1.4	−2.9	1.8	−4.6
1945	−4.6	−10.2	3.0	−4.3	10.0	2.4	3.3	−1.5	2.9	−3.4
1946	−4.8	−9.9	−1.4	−6.1	9.0	3.1	3.4	−1.1	1.6	−3.5
1947	−5.8	−10.5	1.1	−4.6	10.9	5.2	3.5	−0.9	2.4	−2.7
1948	−2.4	−7.4	0.2	−4.7	9.1	3.0	4.8	0.7	2.9	−2.1
1949	−3.3	−7.3	−0.8	−5.6	9.9	4.7	2.5	−1.7	2.1	−2.5
1950	−5.8	−10.2	−1.4	−6.1	10.5	4.9	2.5	−2.1	1.5	−3.4
1951	−5.0	−9.6	−3.0	−7.9	7.9	2.6	1.4	−2.5	0.3	−4.4
1952	−5.6	−10.1	−0.1	−4.1	9.6	3.9	0.8	−4.2	1.2	−3.6
1953	−4.5	−9.6	0.2	−5.9	7.9	2.3	4.1	−1.5	1.9	−3.7
1954	−5.4	−10.6	−1.3	−7.3	7.3	1.3	4.0	−2.3	1.2	−4.7

APPENDIX A (*Continued*)

Year	D—J—F max	D—J—F min	M—A—M max	M—A—M min	J—J—A max	J—J—A min	S—O—N max	S—O—N min	Annual max	Annual min
1955	−3.7	−8.5	1.0	−5.7	8.5	2.9	2.3	−3.0	2.0	−3.6
1956	−7.1	−12.4	−1.0	−6.5	7.2	1.3	1.6	−3.8	0.2	−5.4
1957	−3.5	−9.1	0.4	−5.8	7.9	2.2	3.8	−1.9	2.2	−3.6
1958	−3.2	−8.7	−1.6	−7.1	8.9	2.2	3.6	−2.2	1.9	−4.0
1959	−2.7	−8.9	−0.3	−6.0	9.1	2.7	3.1	−1.9	2.3	−3.5
1960	−4.3	−10.2	1.1	−5.7	8.7	2.7	1.1	−4.1	1.6	−4.3
1961	−1.7	−7.6	2.4	−3.8	9.9	3.5	3.2	−1.9	3.4	−2.4
1962	−4.1	−9.9	−1.2	−7.1	10.4	3.7	3.9	−2.1	2.3	−3.9
1963	−6.4	−12.2	−0.8	−7.6	8.4	2.0	4.0	−2.1	1.3	−5.0
1964	−2.1	−8.3	0.8	−5.3	10.4	3.6	4.6	−1.6	3.4	−2.9
1965	−4.4	−10.7	−0.5	−6.7	8.7	2.3	1.5	−3.6	1.3	−4.7
1966	−2.3	−8.3	0.4	−6.4	8.8	2.3	2.3	−3.4	2.3	−3.9
1967	−2.9	−9.4	−0.2	−6.6	9.8	3.4	3.9	−1.8	2.7	−3.6
1968	−4.3	−10.4	−0.3	−6.7	8.7	2.2	4.9	−0.9	2.3	−3.9
1969	−4.8	−11.1	−0.7	−6.2	8.8	2.1	3.7	−2.3	1.7	−4.4
1970	−5.1	−10.5	−1.8	−8.5	9.6	2.9	5.9	−0.6	2.2	−4.2
1971	−4.2	−8.9	−3.2	−8.0	7.6	2.2	2.2	−2.8	0.6	−4.4
1972	−5.2	−10.2	−3.6	−8.5	6.5	1.0	1.4	−3.3	0.2	−5.3
1973	−5.8	−11.1	−2.4	−7.8	8.0	2.9	3.1	−2.1	0.7	−4.5
1974	−3.0	−8.5	−2.7	−6.9	8.3	2.4	−1.0	−6.7	0.4	−4.9
1975	−3.2	−7.9	−3.8	−8.9	7.7	2.6	1.1	−3.9	0.4	−4.5
1976	−4.3	−8.8	−1.4	−6.1	7.1	2.4	0.1	−4.8	0.4	−4.3
1977	−3.7	−8.4	−1.3	−6.5	4.9	0.1	3.3	−1.8	0.8	−4.2
1978	−4.7	−10.0	−3.4	−8.5	7.1	1.9	4.2	−1.4	0.8	−4.5
1979	−4.6	−9.8	−3.5	−8.1	8.7	2.9	2.2	−2.9	0.7	−4.5
1980	−4.4	−9.9	−3.4	−8.7	7.9	2.3	3.3	−2.1	0.9	−4.6
1981	−4.9	−10.3	−1.3	−6.5	8.5	3.2	3.5	−1.2	1.5	−3.7
1982	−3.8	−8.5	−1.5	−7.0	9.2	3.6	3.3	−1.2	1.8	−3.3
1983	−2.4	−7.7	−3.2	−7.7	9.1	4.0	5.2	−0.2	2.2	−2.9
1984	−5.1	−10.5	−3.4	−8.5	7.9	2.7	1.6	−3.2	0.2	−4.9

* Seasonal averages for the years 1943 and 1944 are evaluations (see text).

APPENDIX B

Bivariate Test

The step-by-step description of the procedure by which the bivariate test is applied has been kindly supplied by Potter (1981).

Let $\{x'_j\}$ be regional series of length n and $\{y'_j\}$ be test series of length n.

Step 1. Standardize series:

$$\text{Let } \bar{X} = (1/n)\sum_{j=1}^{n} x'_j, \quad \bar{Y} = (1/n)\sum_{j=1}^{n} y'_j,$$

$$S_x = [(1/n)\sum_{j=1}^{n}(x'_j - \bar{X})^2]^{1/2}$$

$$S_y = [(1/n)\sum_{j=1}^{n}(y'_j - \bar{Y})^2]^{1/2},$$

$$x_j = (x'_j - \bar{X})/S_x, \quad y_j = (y'_j - \bar{Y})/S_y \quad \text{for all } j.$$

Step 2. Compute test statistics:

$$\text{Let } X_i = (1/i)\sum_{j=1}^{i} x_j,$$

$$y_i = (1/i)\sum_{j=1}^{i} y_j \quad \text{for all} \quad i < n,$$

$$S_{xy} = \sum_{j=1}^{n} x_j y_j,$$

$$F_i = n - [X_i^2 ni/(n-i)] \quad \text{for all} \quad i < n,$$

$$D_i = (S_{xy}X_i - nY_i)n/(n-i)F_i \quad \text{for all} \quad i < n,$$

$$T_i = i(n-i)D_i^2 F_i/(n^2 - S_{xy}^2) \quad \text{for all} \quad i < n,$$

$$T_0 = \max_{i<n}[T_i].$$

Also let i_0^* be the value of i for which T_i is a maximum.

Step 3. Conduct test:

Compare T_0 to the critical value for the appropriate n and the desired significance level [see Table 1 in Potter (1981)]. If T_0 exceeds the critical value, reject the null hypothesis. That is, assume that the mean of y has changed in the year after i_0^* by an amount equal to $D_{i_0}^* S_y$.

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