NOTES AND CORRESPONDENCE

The Association between Mean Temperature and Interannual Variability

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ABSTRACT

There was no single relationship between mean temperature and the variability of temperature in the years 1876–1975 in Europe and North America, nor did the variability of precipitation in North America necessarily increase when the temperature decreased.

1. Introduction

There are two ideas about interannual variability which are often expressed as axioms, although, as far as we know, they have never been proven (see, e.g., Tyson, 1977, p. 111). The first is that increased variability is a consequence of cooling in the polar regions. The assumption is that when these regions cool, the temperature contrast between low and high latitudes increases, the circulation in the polar vortex therefore increases, and in an effort to warm the polar regions the waves in the vortex amplify. The result is frequent extremes of weather at the earth's surface.

The other notion is that cool periods of history are periods of enhanced instability of climate, characterized by extremes such as droughts, floods, excessively hot summers, and excessively cold winters.

Proponents of the former idea, who maintain that interannual variability has increased in recent decades, assume that the increased temperature contrast at the surface between the tropics and the arctic, owing to the cooling in the arctic and warming in the tropics between the 1940's and early 1970's (van Loon and Williams, 1976, Figs. 8 and 9), is representative of the troposphere. We have demonstrated that this assumption is not necessarily right: From 1949 to 1972, for instance, when the zonally averaged temperature difference at the surface between 20 and 80°N rose in winter by more than 2°C, the temperature difference between the same parallels hardly changed at 700 mb (van Loon and Williams, 1977, Fig. 6). Instead the temperature at 700 mb fell by 2°C at 45°N with little or no change at 20 and 80°N, so that the latitudinal temperature gradient increased south of 45°N while it decreased to the north. The steepening of the gradient south of 45°N was accompanied by a southward movement of storm tracks, and at the same time high pressure and lower temperatures at the surface became more frequent in the arctic, particularly on the Atlantic-Siberian side. *If* the climate became more variable during these 24 winters, it was not because of the cooling at the surface in the arctic; that cooling occurred in association with the circulation changes and was not a cause of them.

The other popular thought, that climate is more variable in cool periods, is easy to check as it implies an inverse association between the mean temperature and the variance of temperature and other elements. Our investigation does not support this contention but shows that there is no unique relation between temperature and interannual variability of temperature and precipitation.

2. Data and analysis

The temperature and precipitation data are from *World Weather Records*, and we have used such stations for which we had a complete 100-year record until 1975. The standard deviations were computed after the linear trend had been removed as our interest lies in the variability from year to year and not in the slow changes expressed by the long-term trend. The *F*-ratio by which we measure the statistical significance of the difference between the standard deviations of the two periods, 1876–1926 and 1925–1975, is the ratio of the higher to

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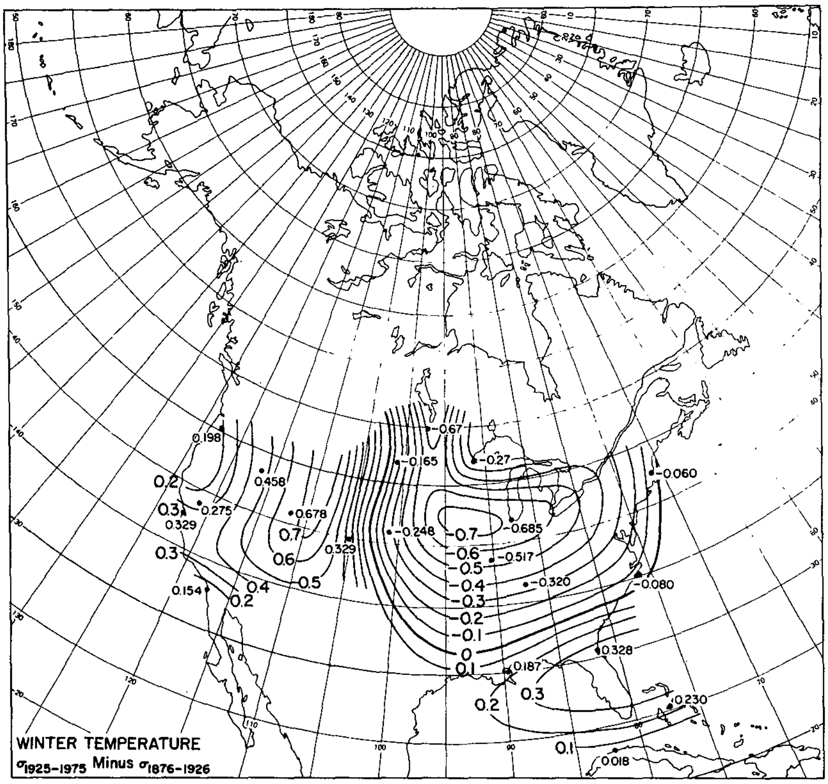

Fig. 1. The difference, 1925–1975 minus 1876–1926, of standard deviation of winter (DJF) temperature (°C).

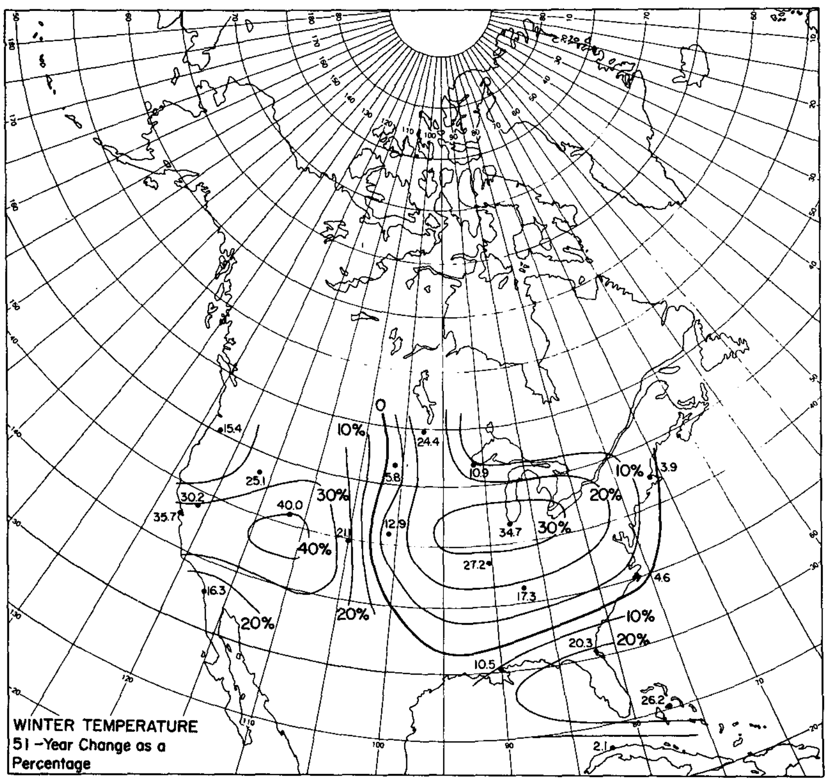

Fig. 2. The change in standard deviation of winter temperature, 1925–1975 minus 1876–1926, expressed as a percentage of the mean 51-year standard deviation.

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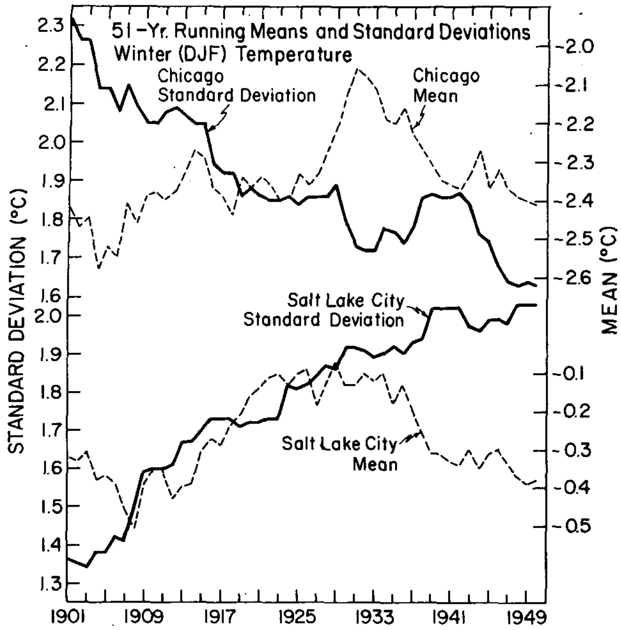

FIG. 3. Running 51-year values of standard deviations and means of winter temperature (°C) at Chicago and Salt Lake City.

the lower variance, σ^2. For 51-year periods the 95% confidence limit for the F-ratio is 1.60, and the 99% limit is 1.95.

3. The difference between 1876–1926 and 1925–1975

The differences between the 51-year standard deviations (SD) of winter (DJF) temperature, $\sigma_{1925-1975}$ minus $\sigma_{1876-1926}$, are not fortuitously distributed over the United States (Fig. 1), but form a large-scale pattern with decreasing variability in the Midwest and Northeast and increasing variability in the South and West. The F-ratios in Table 1 indicate that the change from the first 51-year period to the second is statistically significant. The amount by which the SD changed, expressed as a percentage of the average 51-year SD (Fig. 2), shows that the rise or drop in variability was substantial. The standard deviation at Salt Lake City

TABLE 1. F-ratios for the difference in variance between 1876–1926 and 1925–1975. $F=1.60$ for the 95% confidence limit and 1.95 for the 99% limit.

Winter temperature		Summer rainfall	
St. Louis	1.73	Jacksonville	2.20
Sacramento	1.84	North Platte	1.83
San Francisco	2.06	Salt Lake City	1.95
Chicago	2.02	Boise	1.97
Salt Lake City	2.25	Burlington, VT	2.56
Boise	1.66		
Winnipeg	1.63		
Nassau	1.69		

TABLE 2. Difference of standard deviations of temperature, 1925–1975 minus 1876–1926, and the F-ratio.

	Spring		Autumn	
	Difference of standard deviation	F-ratio	Difference of standard deviation	F-ratio
Bodö	−0.26	1.56	0.07	1.14
Haparanda	−0.28	1.45	0.31	1.52
Helsinki	−0.32	1.58	0.30	1.62
Aberdeen	0.13	1.40	−0.07	1.21
Valentia	0.01	1.04	−0.06	1.19
Godthaab	−0.08	1.13	0.34	1.91
Thorshavn	−0.03	1.09	−0.07	1.21
De Bilt	0.09	1.22	−0.10	1.26
Zürich	0.30	1.86	−0.17	1.43
Marseilles	0.06	1.18	−0.29	1.90
Madrid	0.03	1.05	−0.01	1.03
Lisboa	0.10	1.28	0.16	1.56
Sibiu	0.29	1.67	−0.36	1.79
Sulina	0.28	1.70	−0.18	1.31
Bucuresti	0.36	1.93	−0.25	1.48
Athinai	0.08	1.22	−0.13	1.33
Leningrad	−0.28	1.40	0.16	1.30
Jerusalem	0.33	1.87	0.09	1.22

rose from 1.36°C in the first period to 2.03°C in the second, and at Chicago it dropped from 2.32 to 1.63°C.

The variation of SD from one 51-year period to another near the centers of largest change in variability is shown in Fig. 3. The 51-year running standard deviations at Chicago and Salt Lake City plainly outline the opposing trends of variability in winter temperature and indicate that a SD for such a period is stable neither in space nor in time. The patterns of the SD in 1876–1926 and 1925–1975 are shown in Fig. 4. The prevalent traits are the same, as they depend on latitude and distance from the sea in the sense that variability should increase as one goes from sea to land and from lower to higher latitudes; but during 1925–1975, the pattern was farther from this ideal than in 1876–1926 because comparatively small values in the Midwest during the former period interrupted the expected poleward increase.

Differences between two periods which change sign from one region to another such as those in Fig. 1 are, of course, not limited to temperature in the United States in winter but are found everywhere in all seasons for both temperature and precipitation. Examples for spring and autumn in Europe are given in Table 2.

The dashed curves in Fig. 3 are the 51-year running means of winter temperature for the same periods as the SD. It is immediately seen that *there is no single connection between trend of temperature and the trend of its variability* because the means begin and end at nearly the same level whereas the SD in the one instance increases and in the other decreases from the beginning to the end of the period.

A simple test of the relationship between mean and

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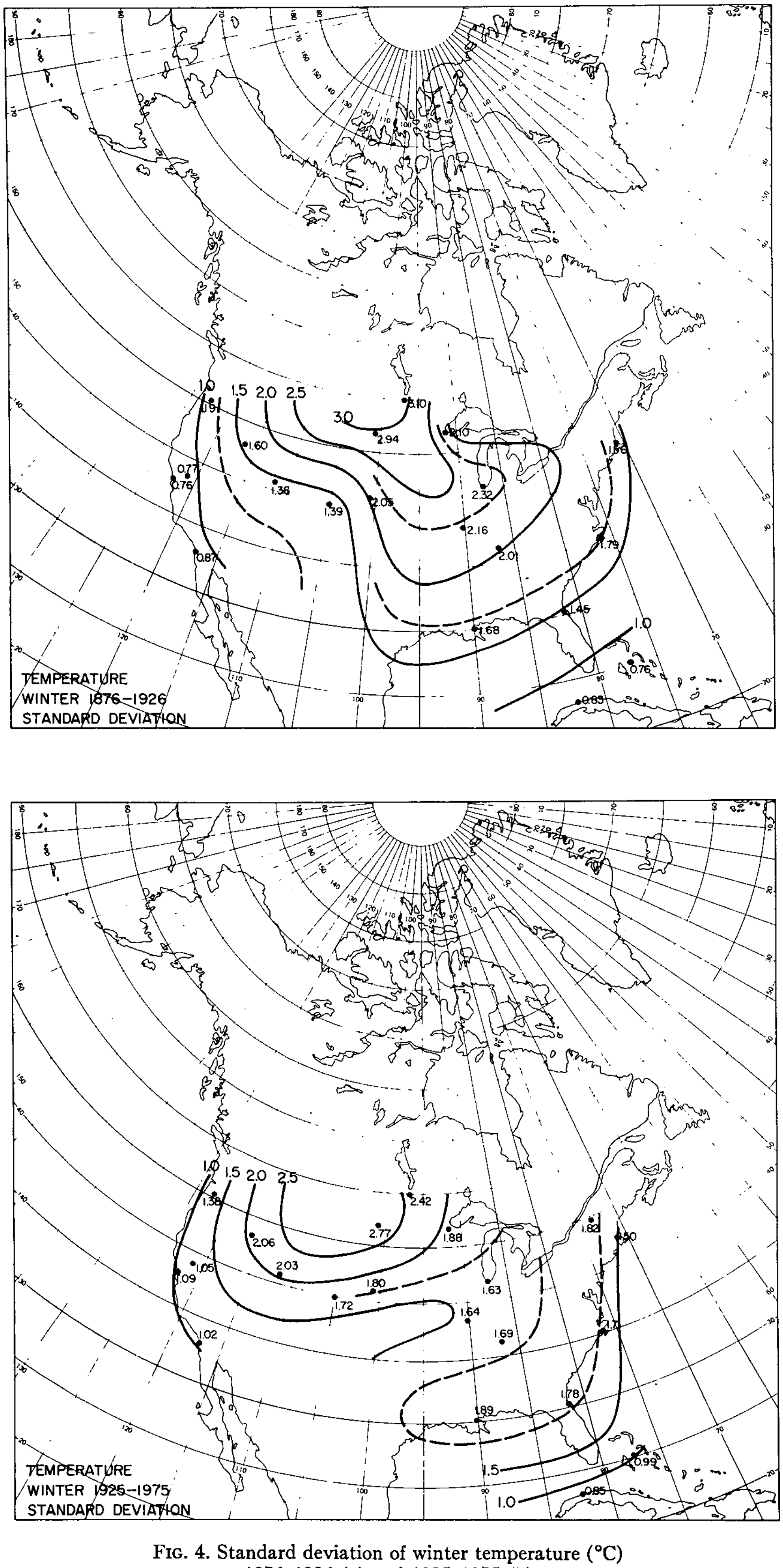

Fig. 4. Standard deviation of winter temperature (°C) 1876–1926 (a) and 1925–1975 (b).

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TABLE 3. Correlations between running 51-year standard deviations and means of temperature.

	Temperature			
	Winter	Spring	Summer	Fall
Jacksonville	0.44	0.89	0.85	−0.34
New Orleans	−0.27	0.28	0.07	−0.52
San Diego	0.80	0.35	0.61	0.61
Cape Hatteras	−0.59	0.27	0.91	−0.77
Nashville	−0.62	0.60	0.81	−0.37
St. Louis	−0.68	−0.35	0.69	−0.72
Denver	0.84	−0.58	0.24	0.68
Sacramento	0.32	0.83	−0.32	−0.38
San Francisco	0.21	0.30	0.93	−0.50
Blue Hill	0.21	−0.33	0.70	0.75
Chicago	−0.53	0.22	0.50	−0.16
North Platte	−0.76	−0.04	0.51	−0.68
Salt Lake City	0.34	0.74	0.24	−0.17
Burlington, VT	—	—	—	—
Boise	0.39	0.02	0.66	−0.85
Portland, OR	0.82	−0.41	0.28	−0.53
Duluth	0.05	−0.42	−0.16	−0.23
Bismarck	−0.02	−0.84	−0.18	−0.72
Winnipeg	−0.88	−0.75	0.07	−0.76
Nassau	−0.93	−0.36	0.93	−0.84
Havana	−0.17	0.72	0.82	0.67
Percent negative	50.0	45.0	15.0	80.0

standard deviation is the correlation between the running 51-year values of the means and the standard deviations. The correlation coefficients between these quantities are given in Table 3 for all seasons. The 51-year running values are not statistically independent so the degrees of freedom are few and no confidence limits will therefore be given. The correlation coefficients in this instance should be regarded as a tool which describes in a limited space the association between pairs of curves such as those in Figs. 3 and 5. If the idea were right that higher variability is associated with colder periods, the correlation coefficients should be negative, or negative coefficients should at least be more numerous than positive ones. In winter and spring there is about the same number of positive and negative correlation coefficients, in summer only 15% are negative, and a tendency for negative correlation is found in fall only. *It is therefore unlikely that the postulated association exists between cold periods and high variability of temperature.*

TABLE 4. Slopes of the linear trends of 51-year running standard deviations of precipitation (mm $year^{-1}$) and of 51-year running means of temperature (°C $year^{-1}$) for 1876–1975.

	Winter		Summer	
	Precipitation	Temperature	Precipitation	Temperature
Jacksonville	−0.03	0.01	1.04	0.01
New Orleans	−0.20	0.01	0.35	0.01
San Diego	−0.11	0.02	—	—
Cape Hatteras	0.01	0.01	0.65	0.01
Nashville	0.38	0.01	0.28	0.01
St. Louis	0.23	0.01	0.19	0.01
Denver	−0.14	0.02	0.09	0.02
Sacramento	0.24	0.00	—	—
San Francisco	−0.40	0.00	—	—
Blue Hill	0.27	0.02	0.51	0.02
Chicago	0.24	0.00	0.03	0.01
North Platte	−0.06	0.02	0.21	0.01
Salt Lake City	0.03	0.00	0.25	0.01
Boise	−0.16	0.00	−0.05	0.01
Portland, OR	0.27	0.02	0.03	0.02
Duluth	0.15	0.01	0.07	0.01
Bismarck	−0.03	0.03	−0.01	0.02
Winnipeg	−0.01	0.03	−0.05	0.01
Nassau	0.35	−0.02	0.06	−0.01
Havana	−0.16	0.00	−0.66	−0.01

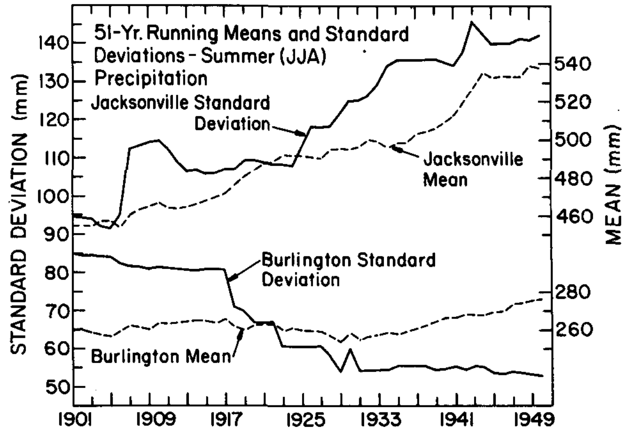

FIG. 5. Running 51-year values of standard deviations and means of summer (JJA) rainfall (mm) at Jacksonville and Burlington.

Does the variability of precipitation increase when the temperature goes down or decrease when the temperature rises? This question is answered by a comparison of the trends of temperature and the trends of SD of precipitation in Table 4. The association between the two elements, considering winter and summer together, is inclined neither toward being opposite nor toward being parallel.

On the map of the difference between 1876–1926 and 1925–1975 of precipitation SD in summer, which is not shown, the difference between the periods is particularly big at Jacksonville, FL, and Burlington, VT. The 51-year running values of the SD and mean of precipitation at these two places are given in Fig. 5. Note that the standard deviation at Jacksonville rises abruptly between the 51 years centered on 1906 and those centered on 1907. The rise was caused by heavy rains in one month, June 1932, when 592 mm fell at Jacksonville. Without this summer the SD centered on 1907 would have been 99.7 instead of 112.3 mm. The upward trend of the SD curve would have been steeper if 1932 were removed; for example, the SD centered on 1942 would drop only 9 mm and thus stay substantially above the values at the beginning of the curve. Just as in Fig. 1, Fig. 5 is an example of opposing trends of variability in the same season at places far from each other; at both

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stations the change from 1876–1926 to 1925–1975 was statistically significant beyond the 99% level (Table 1). Fig. 5 also demonstrates that in precipitation, too, there is no unique association between trend of mean and trend of variability.

4. Conclusion

There has been much speculation about whether year-to-year variability of climatic elements is related to the temperature level, either in such a way that cooling at the surface in the polar regions causes higher variability in temperate latitudes, or that cooling in general goes together with higher variability. With regard to the first idea we have earlier shown that the surface cooling in the arctic during the winters of recent decades accompanied a change in the circulation whereby the storm tracks moved southward in association with a southward extension of the major baroclinic zone in the troposphere at middle latitudes. If there was an increase of variability in temperate latitudes during these decades it would then not have been *caused* by the surface cooling in the arctic which itself was caused by the circulation change. The fact that changes in variability of the same sign occur on a large scale with regions of both increases and decreases of variability during the same period (Fig. 1), also does not support the idea that changes in variability in temperate latitudes are uniquely associated with temperature changes at the surface in high latitudes.

As for the postulated coincidence of cold periods and high variability of climatic elements, our investigation does not provide evidence for such a connection. Only in autumn did the correlation between mean temperature and variability of temperature show a bias toward negative values. During the rest of the year there was either no such bias or the correlation was more often positive than negative. The association between trend of precipitation variability and trend of temperature over North America was also not unique.

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