Secular change in the variability of temperature

(climate)

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ABSTRACT The mean temperatures for January, April, summer and October at New Haven, Connecticut, for 1781–1970 were analyzed for evidence of a secular change in several indices of variability. The January–July difference decreased significantly. Although the standard deviation (SD) of the summer temperature within decades decreased significantly, the SDs of January, April, and October did not, and none of the SDs were correlated with means. The SD about trends within decades was not correlated with the magnitude of the trends except in April. There was no significant trend in the January-to-January persistence during the 19 decades.

If climatic change is gradual and steady, humans have time to adapt their crops and husbandry to a new environment. If, on the other hand, the climate becomes a shifty one of quick, frequent, and large changes from month to month, food markets and then all human affairs become chaotic unless expectations are lowered to the worst of times. Thus concern about changing climate has come to rest on agriculture and then on changing variability of climate as much as or more than on changing averages (e.g., ref. 1). Accordingly, I have examined the long record of temperatures in New Haven, Connecticut, for changes in variability.

An expectation of more variable weather, distinct from a change to a new average weather, is evident in Schneider's (2) entitling a section of a book "Unusual weather may be increasing" and citing the cold winter of 1967–1968, followed by a hot summer. Climatologists in a conference felt that there was cause to believe—although it was far from certain—that climatic variability in the remaining years of this century would be even greater than during 1940–1970 (3). When, however, the National Defense University (4) sought an opinion about future climatic variability by asking a panel of climatologists whether they expected the standard deviation (SD) of precipitation to change, the University evoked no clear expectation of increased climatic variability and worried that the panelists "were unaccustomed to thinking about variability in terms of the standard deviation (for which, in any case, historical data are not generally available)."

The possibility of increased variability accompanying temperature changes was mentioned by Hare (3) in his conference report. Lamb (5) wrote that the variance of summer temperatures in Sweden tended to be highest when warm summers were frequent and the variance of winter temperatures in Western Europe tended to be greatest during periods of frequent cold winters. After analyzing about two centuries of temperatures in Stockholm, however, Wallen (6) wrote of a score of warm summers with variable temperatures, a period of summer temperatures near or below normal with increasing temperature and its variability, and a period of increasingly warm summers and variability. Thus, there is reason to look for an

association between mean and variability of temperature as well as to look for changing variability.

DATA

A register kept by Rev. Ezra Stiles, D.D., President of Yale College, shows the first temperatures observed in New Haven. "This register extends from the commencement of Dr. Stiles' presidency in June, 1778, until two days before his death, which occurred May 10, 1795. There is an interruption of the Journal from July 4, 1779 to January 22, 1780, caused by the invasion of New Haven by British troops, at which time President Stiles' thermometer was broken." (7). I began my analysis with 1781, after the British had surely departed, and replaced the 9 months missing after Stiles' death with the means for 1780–1872. The monthly means for 1781–1935 were published by Kirk (8). The means for 1936–1976 were taken from Weather Bureau records, or, for 12 months, the average of Groton and Bridgeport. Like Western Europe, New Haven was cool in the 19th century, warmed for four decades in the 20th century, and then cooled; summers changed little, and the changes were largely in the winter (9). During their long history the New Haven observations have been taken in several places, but always in the lowland near the harbor of a city of only 135,000 people today. Because the well-known trends of average temperatures around the North Atlantic are evident in the New Haven record, the effect of changing the thermometer exposure upon the mean have not been great, and the effect upon year-to-year variability was surely less.

METHODS

The difference between January and July means was used to indicate the annual range. Following Lamb (5), I analyzed January means; following Wallen (6), I analyzed the mean of June–August as "summer"; and, seeking an indication of the change of seasons, I analyzed the means of April and of October, the average times of last and first frost. SDs were usually calculated within 19 decades, beginning in 1781. Bartlett's (10) test for homogeneity of variances was used.

The trend of temperature within a decade and its slope b was estimated by linear regression. The sum of squares S^2 of deviations from the mean of the decade was divided into the sum attributed to the trend and the sum S_r^2 about the trend of slope b . The corresponding SDs were

$$SD = (S^2/9)^{1/2}$$

and

$$SD_r = [S^2(1 - r^2)/8]^{1/2} = (S_r^2/8)^{1/2},$$

in which r is the coefficient of correlation.

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Symbols: b , slope of trend within a decade; r , correlation coefficient; S^2 , sum of squares about mean; S_r^2 , sum of squares about trend; SD, standard deviation about mean; SD_r , standard deviation about trend.

If successive temperatures fluctuate at random, the expected variance S_d^2 of the difference between successive temperatures is twice the variance S^2 of the temperatures themselves. Accordingly,

$$R_a = SD\sqrt{2}/SD_d - 1$$

will be zero in a random series, positive if temperatures persist, and negative if successive temperatures tend to be alternatively high and low (11). I used R_a as an index of the temporal distribution of variability within a decade, calculating S_d^2 from the temperatures of year 2 minus year 1, year 3 minus year 2, . . . , year 11 minus year 10.

RESULTS

Annual Range. The difference between the January and July mean decreased at 0.0074°C per year from 1781 to 1970. Although this trend explained a negligible portion of the variation of annual differences, it explained a highly significant portion (45%) of the variation among decadal means of the January–July difference. The mean difference for 1961–1970 was the greatest in the 20th century.

SD, January. No secular trend was evident in the 19 SDs of January means in decades (Fig. 1). An attempt to fit a linear trend to the 19 SDs accounted for only 2% of their variation.

The effect of different starting dates upon the calculated SD was examined by calculating SDs for 18 decades beginning 1781, 1782, . . . , or 1790. The variance of each of the 10 sets of 18 SDs was estimated, and no evidence was found that the 10 variances of the 10 sets were not homogeneous.

Returning to the 19 decades beginning 1781, I related the SD within each decade to the mean temperature of the decade (Fig. 2). No relation was evident.

April. No trend was evident in the 19 SDs of April means in decades, and SD was not correlated with the decadal means.

Summer. A trend of -0.019°C per year was evident in the 19 SDs of summer means in decades (Fig. 3). The trend accounted for 24% of the variation in the SD. The effect of different starting dates upon the trend was examined by calculating the ten trends for decades beginning 1781, 1782, . . . , or 1790. The 10 trends accounted for 16–36% of the variability of the SD, confirming that the summer temperatures had grown less variable during the past 2 centuries.

No evidence was found of a relation between the SD and the means within decades.

FIG. 1. SD of January mean temperatures in New Haven within decades identified by the first year of the decade.

FIG. 2. SD of January mean temperatures in New Haven within decades as a function of the mean of the decade.

October. No secular trend was found in the 19 SDs of October means in decades, and the SD and the means within decades were not correlated significantly.

Trend within a Decade and the SD. I now turn from the secular trend during the 190 years to trends and their slopes b within single decades. For January, April, summer, and October there are 76 decades; trends accounted for a significant portion of the variation within 5 of the 76 decades, approximately the 1 in 20 expected for random changes in the temperatures between years.

The steepness of the slope $|b|$, up or down, accounted for a significant 21–43% of the variability of the 19 SDs for January, April, and October. There was no significant relation of SD to $|b|$ for summer.

When, however, the standard deviation SDs about the trends within decades were correlated with $|b|$, no significant relationship was found for January, summer, or October. For April, the relationship with $|b|$ accounted for a significant 22% of the variation in SD.

Persistence. Because the variances of the differences between successive January means within decades were approximately twice the variances of the January means themselves, the R_a varied from -0.3 to 0.3 without significant trend during the 19 decades.

The R_a for summer, which varied from -0.2 to 0.4 , was somewhat more interesting (Fig. 4). The R_a values for the three decades 1781–1820 were large, indicating little change between

FIG. 3. SD of summer mean temperatures in New Haven within decades identified by the first year of the decade. The line represents a secular decrease of 0.019°C per year.

FIG. 4. Index R_d of persistence for summer mean temperatures in New Haven within decades identified by the first year of the decade.

these successive warm summers. The three decades 1941–1970, on the other hand, include the decade when successive summers changed most and two decades of little change between successive summers. No trend in R_d was evident during the 19 decades.

DISCUSSION

After surveying climatological opinion about future weather, the National Defense University (4) concluded that additional efforts should be made to quantify “perceptions of past, current and future variability.” Thus, several indices, not just one, must be examined for clues to the “perception.”

A great difference between the temperatures of a winter and the following summer might be perceived as increased variability, as Schneider (2) did in the passage cited in my introduction. If so, the cold winters of 1961–1970 without accompanying cool summers were increased variability, and a continuation of the cooling of winters without cooling of summers would, by this index, be perceived as still further increased variability.

If, on the other hand, it is the variation of the temperatures of a season (for example, both warm and cold Januarys in a decade) that is perceived as climatic variability, then the SD within a decade is the obvious index. During the past 190 years, however, the SD has not been increasing. In fact, the SD of summer mean temperatures has tended downward (Fig. 3).

Parenthetically, I turn aside from the discussion of the perception of variability to discuss similarity between European and American temperatures and the relations between SD and means or trends. Wallen (6) called attention to decreased SD of summer temperatures in Stockholm during the first decades of the 19th century, but at the same time in New Haven the variability was great although the summers were cool. On both sides of the Atlantic variability was great in the middle and decreased at the end of the 19th century. On both shores the temperatures of the first summers of the 20th century were variable, were more uniform during 1911–1940, were variable in the 1940s, and have been more uniform since 1951.

In New Haven the SDs of the January or summer temperatures of decades were not related to the mean temperatures of the decades. When nine means and SDs of summer temperatures in Stockholm for 20 year periods beginning 1756, 1776, . . . , 1916 (6) were correlated, the coefficient was only an insignificant 0.33. Beginning the periods in 1766, 1786, . . . , 1926 did not produce a significant correlation. Thus the record does not suggest that a warmer or cooler climate will be a more variable one, a conclusion also reached by van Loon and Williams (12).

The correlation between the absolute value of a trend within a decade and the SD about the mean confirms the obvious increase in gross variability caused by a trend (6). With the possible exception of April, however, there is no evidence that the variation *about* the trend will be greater as the trend is steeper. Thus the record does not suggest that a change to another climatic mean will be accompanied by increased variability in addition to the change itself.

Now I return to the discussion of the perception of variability. If the regular alternating between warm and cool seasons (for example, warm, then cold, then warm, . . . , then cold Januarys in a decade) is perceived as climatic variability, then a negative R_d of persistence is an obvious index. The persistence of January and summer temperatures has not, however, decreased regularly during the past 190 years.

To foresee the future, a climatologist generally looks to history, expecting it will repeat. The recent trend to cooler winters, but not summers, suggests that the variability of temperatures within years will increase. Fortunately and generally, however, the long record of temperature in New Haven shows no trend toward increased indices of other sorts that would be perceived as increased climatic variability with accompanying disruption of our affairs.

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