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CONCERNING NORMALS, SECULAR TRENDS AND CLIMATIC CHANGES.

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Is the climate changing? This question, so frequently asked, may be answered "Yes" or "No" with equal propriety, depending upon the particular point of view. Geological records leave no question whatever that very great changes of climate have occurred in the vast lapse of time covered by the geological ages of the past. On the other hand, no conclusive evidence can be found to prove that any material or notable *permanent* changes for the globe as a whole have occurred during the several thousand years of authentic human history. That is to say, no data are known which prove, nor have we any good reason to believe from all that *is* known, that the climate of the globe is systematically or permanently different at the present time from what it was 6,000 years ago.

Notwithstanding these unequivocal affirmative and negative answers to the question "Is the climate changing?" the present writer is inclined to believe that important long-time fluctuations of climatic conditions have occurred and that minor surgings of the seasons to and fro can and do take place and prevail over restricted regions for relatively long periods of time like 50 or 100 years.

Conservative climatologists do not, in principle, subscribe to these views, perhaps, and while marked fluctuations of several years' duration are admitted, nevertheless it is the common belief that a seeming systematic departure from normal of one kind is quite soon offset by a like departure of the opposite kind, and that the *normal* state is more or lesss steadily maintained. It is believed the evidence submitted in what follows will help to show that such views are more or less incorrect and will tend to justify the deep-seated conviction in the minds of a great many keen observers of mature years that weather conditions at the present time differ in material ways from corresponding conditions easily within their memory. Our fathers and grandfathers, and their foreparents, probably entertained like convictions, and while memory and personal impressions can not be accepted as safe guides to questions of facts of this character, it is probably wrong to assume that such generally prevalent convictions are fictions of the imagination and quite without foundation of fact. Indeed, it seems that exact statistical methods may disclose hitherto unsuspected changes in climatic conditions which the conventional methods of analysis do not reveal, and consequently there may be some foundation of fact in the ideas of the oldest inhabitants on the subject.

In order that the writer may not be misunderstood, however, it may be proper to state that the changes here recognized as possible are not permanent, but are simply marked abnormalities which trend steadily in one direction and for many years away from that unchanging constant thing we may call the absolute normal climate. It is a mistake also to suppose that all the major features of what we call the climate of a place can be comprised or experienced within such supposedly long periods of time as, say, 50 or 100 years. We must recognize, rather, that several hundred years of records will be required to really establish the essential characteristics of the climate of a given place and period.

These views are some of the conclusions reached by the writer in the course of a series of studies upon the subject of the "Laws of sequence of weather conditions."

Normals.—By universal practice and accord among meteorologists, the term *normal* as applied to climatic data is defined by the equation—

$$N=\frac{a_1+a_2+a_3+\ldots\ldots a_n}{n}=\frac{S}{n} \qquad (1)$$

in which S is the sum of a large number, n, of homogeneous observations, a_1, a_2, etc., of equal weight. Just what is meant by the expressions "a large number," "homogeneous and of equal weight" is pretty well understood though rather difficult to specify, nevertheless the significance of the terms will be briefly analyzed.

A large number.—No one has ever satisfactorily specified just what constitutes a "large number" within the meaning of the definition. It is obvious, however, that in climatology, at least, mere number of observations alone is not sufficient, but, rather, that *many years of time* must be embraced by the whole series of observations before it will fairly include all the essential climatic features and serve the purpose of fixing a true or absolute normal. On the other hand, many will regard a record of, say, 50 years as very long and will point to the insignificant change in the value of N which results when observations for several more years are added. These conflicting considerations impel the writer to favor some looseness in defining the word *normal*, so that the mean or average value of 30 or 40 years, for example, of good data could very properly be designated a "normal," reserving the expressions *true normal* or *absolute normal* to refer to the arithmetical mean of several hundred years of data. Insistence upon the rigorous definition simply operates to eliminate the familiar word *normal* from legitimate usage or, rather, popular usage will define the word as it pleases in spite of the *ipse dixit* of the professionals.

In this connection it must be recognized that in general a value of N becomes very nearly a constant when derived from 40 or 50 years of record. This is due entirely to arithmetical causes, and if we are to attach some kind of magic significance, as is generally done to the concept of *a true normal* we must at the same time place great importance upon very small changes in its value. The real truth is the "normal" is simply a ratio between two numbers, both of which increase steadily as the length of a series of observations increases, so that the ratio soon becomes to all intents and purposes a *constant* which undergoes small fluctuations but the chief useful purpose of which is to serve as a base number with reference to which climatic fluctuations and changes may be analyzed and examined. Any arbitrary number whose value is near the average of a fairly long record is just as useful and just as significant as the supposed magic or true normal, the exact value of which can never be accurately known, and even if known would be less convenient to employ than a simple base number of nearly the same value.

Homogeneous and of equal weight.—While the import of these terms is essentially different, they are so closely related as to permit them to be considered together in this brief analysis. Strict homogeneity and equality of weight are simply unattainable, especially in long meteorological records, either for a single locality or for some considerable unit area. Such records necessarily comprise many breaks, discontinuities, changes in instruments, locations, exposures, observers, and even in the stations and surface conditions themselves. The deepest and first concern of the climatologist and statistician is to secure at the outset of any investigation the highest approach he can to homogeneity and equality of weight in the data employed. At the best some faulty values remain and appear as abnormalities, false fluctuations, or seeming climatic changes which can not be satisfactorily eliminated and cause much uncertainty in conclusions and interpretations.

Accumulated sums of departures.—Recognizing from all that precedes that there is no magic significance to the concept *normal* and that a simple base number conveniently near the average of 30 or 40 years of data answers all practical purposes as a reference base, the question at once arises, what methods are best for analyzing and disclosing secular trends and climatic changes?

The chief purpose of this paper is to develop and present a method which has long been familiar to many in the Weather Bureau, but of which very little and unimportant use has been made.[1] It seems appropriate and convenient to designate the process *the method of accumulated sums of departures*. In 1886 the Weather Bureau began to compile in its original records the accumulated daily departures of temperature and precipitation since January 1 of each year, using the best normal or base values then available from not over 16 years of observations. This tabulation is being continued at the present time, but fails to serve any particularly useful purpose, because, first, the accumulation runs only for each calendar year separately, but a more serious complication arises because the normal or base number has changed from time to time. This latter makes it impossible to easily derive the accumulated sums for long periods of time. The writer has found by trial that these accumulated sums (abbreviation *A. S.*) are wonderfully significant of secular trends and climatic changes, as will be more fully shown in what immediately follows:

Theory of accumulated sums.—Some confusion will be avoided in presenting the elemental theory of *A. S.* if only *annual* values of data are first considered, because this does not require any consideration of the well-known seasonal or annual changes which are such striking features of temperature and to a less extent of other meteorological elements. Accordingly, let B be a true normal annual value or, more conveniently, any arbitrary unchanging simple number nearly equal to the average of 30 or 40 years of any climatic data. Any single yearly value of the data, a_1, for example, gives rise to the equation

$$a_1 - B = d_1$$

in which d_1 is the familiar departure from normal or base, and in like manner any long record may be transformed into or replaced by a series of values or departures d_1, d_2 - - - -, thus:

TABLE 1.—*Illustrating computation of accumulated sums for annual data.*

Date.	Data.	Base.	Departure.	$\frac{A.S.}{y}$	
....	$a_1 -$	$B =$	$\pm d_1$	d_1	
....	$a_2 -$	$B =$	$\pm d_2$	$d_1 + d_2$	
....	$a_3 -$	$B =$	$\pm d_3$	$(d_1 + d_2) + d_3$	
....	...	...	...	....	
....	$a_n -$	$B =$	$\pm d_n$	$\pm \Sigma d$	
	$\Sigma a -$	$nB =$	$\pm \Sigma d$		(2)

Now, the universal impression seems to prevail that if the value of the base number B is reasonably close to a true normal value, then the sum of the departures *A.S.* tends to be zero—that is, directing attention to the last column the values of y therein will never become very large nor ever long remain continuously of the same algebraic sign, but that the signs will change with comparative frequency and the magnitudes of y remain comparatively small. A very few trials by calculating y for reliable long records will show at once that the facts are very different from the impressions expressed above. Moreover, a diagram of the values of y in the above table, plotted against dates as abscissae, is most useful and instructive. Attention is invited to the following striking properties of the above table and diagram of y.

In the table above

(1) Any value of y in the table divided by the number of observations it comprises gives a quotient which, added to the base number B, is the normal or average value of the data for the length of the record up to that date.

(2) In a similar manner, dividing the algebraic difference between any two values of y in the table by the number of observations comprised, and adding the quotient algebraically to the base number gives the average value of the data over the period of record embraced.

The diagrams in some cases show prolonged and striking trends of the values of y away from the adopted base line, and it is plain from the properties designated (1) and (2) above that the slope of a straight line from the origin to any point on the curve gives the average value *of the departure over the period covered.* In like manner, the slope of a line between any two points of the diagram gives again the average value of the departure between the dates represented. A very little trial and use of this method of accumulated sums will show its striking superiority over customary methods for disclosing secular trends and many important characteristics of meteorological data.

It is often easy to pick out from the values of y as shown by either the table or the diagram of certain kinds of data, times when the secular trends have maximum, minimum or other significant values which are more or less steadily maintained for 50 or 100 years.

[1] While this article was in the hands of the printer, the writer's attention was called to the publication of diagrams of accumulated sums of departures of temperatures from normal by Dr. P. H. Dudley of the New York Central Lines in a leaflet entitled "Forcast for 1922–1923." This use appears to have started in 1921.

In the illustration utilizing *annual* values of any element, a constant unchanging value for the base number or normal suffices. However, whenever it becomes necessary to analyze daily, weekly, or other values affected by the annual period we must obviously employ the best daily, weekly, or other fixed normals available. In these cases it will rarely, or never, be necessary to extend the *A. S.* beyond the period of a single year or even of a season, so that exactitude in the daily or other values of the normal used may not be very consequential, nevertheless if comparisons are extended over many years and the analysis is carried out to important details, the base numbers or normals used must be homogeneous and uniform over the whole period.

It is plain in all cases where a changing value of the base number B is necessary, that equation (2) must be written [1]

$$\Sigma a - \Sigma B = \pm \Sigma d \qquad (3)$$

The broad utility of the method is in no sense limited either to meteorological data on the one hand or to the disclosure of striking cases of abnormal secular trends and the fixing of epochs of marked changes in climatic characteristics. Any body of statistical data running through a more or less continuous sequence is subject to critical analysis by this scheme. Furthermore, the method may be used with great success to check up the accuracy of doubtful and inconsistent records by comparisons with other known standard data or with group averages or data for considerable areas of a standard or representative character.

Finally, the method surpasses all others known to the writer for establishing secular trends accurately, both as to the length of time a given trend prevails and also the quantitative measurement of the trend.

As all statisticians recognize, the elimination of secular trends is the most important, if not the first necessary step in any serious study of periodic recurrences and the laws of sequence of natural and economic phenomena.

Applications to actual data.—Naturally one's interest is chiefly centered upon long records, and the results given below will serve to indicate some features of climatic changes not hitherto recognized, as well as show the general utility of the method.

New England furnishes some of the best and longest meteorological records available within the United States. Perhaps the oldest is the rainfall record begun in a summer of severe drouth in 1749 by Prof. Winthrop at Cambridge, Mass.

Annual values by this record are continuous from 1750 to 1774, inclusive. After a gap of two years values for 1777 and 1778 are available at Watertown. Five years later a record began at Andover, some 20 miles nearly northwest from Boston, and continued until the close of 1786, with occasional annual values thereafter. The year 1792 marks the beginning of two closely accordant records at Charlestown, very near Boston, and Stow, about 25 miles to the west, which ran unbroken until about 1804. A long gap of 13 years then follows before observations became finally continuous in the immediate vicinity of Boston with the records of Dr. Enoch Hale, 1818 to 1822, and of Jonathan P. Hall, 1823–1865, and maintained thereafter at many stations.

[1] *Note to computers.*—In forming the values of y in Table 2, an error made in any single value, either of a departure or the *A. S.* is carried forward in all following computations of y. It is, therefore, imperative to check the accuracy of both the departures and the computations of y. This is done at a single operation by direct computation of occasional values of Σd by the use of equation (2) or (3), as the case may require. In general, the sums of the observations must be computed in any case, and if done on a listing machine subtotals after each fifth or tenth item serve for rapidly checking the calculation of y as the work progresses.

Estimation of missing data.—For general purposes it seems possible to the writer to bridge the gaps in this long record and thus draw conclusions concerning precipitation in the vicinity of Boston for a period of 173 years, from 1750 to date. This is done in the following manner:

Only two assumptions can be made concerning missing data. In a general way, missing values must be *conformable* to or *nonconformable* with observed values for periods of time before and after the missing intervals. When no other *prima facie* evidence is available than the discontinuous record itself, no reasonable assumption can be made other than the one that the missing data averages about the same as the observed values before and after. For simplicity we may designate this the *rule of conformity.*

Let us see how this principle applies in the present case. We have—

	Inches.
Average annual precipitation for 25 years, 1750 to 1774	40.41
Average from broken record for 20 years at Andover, Watertown, and Stow, covering period 1777 to 1804	41.41
Average for 32 years from 1818 to 1849, a composite record of from 3 to 5 stations near Boston	40.40
General mean	40.78

In the face of these almost identical averages, why may we not confidently say the rainfall during the missing years must have averaged about 40 inches?

The greatest doubt arises with reference to the missing period of 13 years, from 1805 to 1818. By good fortune an excellent record begun at New Haven, Conn., in 1804, covers this whole period. From it we have—

	Inches.
Average annual precipitation at New Haven, 1805 to 1817	44.91

The Rodman record, begun at New Bedford, Mass., in 1814, also gives—

	Inches.
Average annual precipitation, 1814 to 1817	42.83

Finally, the Rodman record and the Boston record, from 1818 to 1849, give averages as follows:

	Inches.
Average annual rainfall New Bedford, 1818 to 1849, 32 years	44.84
New Haven, broken record 1818 to 1849, only 10 years	44.74
Boston for 1818 to 1849	41.01

From these results, by the familiar *rule of comparison*, Boston received less rain by 3.78 inches on the average than New Haven and New Bedford. This rate, deducted from the New Haven record during the missing years of the Boston record, gives $44.91 - 3.78 = 41.13$ inches. The practical identity of this amount with 40.74 inches, the amount of rain estimated by the *rule of conformity*, seems to leave no reasonable ground for opposing the use of the rule in a case like this to fix the average amount of rain which fell during the years observations were missing.

Probably few will reject the foregoing conclusions, but many will hesitate to follow the writer in the next bold attempt to approximate to the annual values for the individual missing years. We might, of course, fill the gaps by inserting the *average* value in each of the missing dates. This would preserve the average, but is obviously quite irrational. The following appears to be a better plan:

There are 77 actually observed values of annual precipitation in the 100 years from 1750 to 1849. Thus there are 23 years of record missing. These fall in four groups of 2, 3, 5, and 13 years, respectively. I wrote down the 77 observed values on bits of paper of exactly the same size and drew out 23 times in succession, returning the number and vigorously mixing up the papers before each drawing. The numbers drawn were entered successively in the gaps of the record.

	Inches.
Average of the 23 numbers drawn	40.01

Here, again, the close identity of this average to the number 40.74, indicated by the *rule of conformity*, allows very little ground for rejecting the *drawings* as fair approximations to the general rain for the missing years. The writer offers no defense here for this rather bold but still logical scheme for tentatively bridging over gaps in this valuable record for 173 years.

The individual values, of course, have no significance whatever, but they serve a useful purpose in forming a continuous series of departures in Table 2, which preserves the general average trend, and the sequel will show that the main final conclusions are in no way affected by the detailed values secured from the drawings. The only possible question involved is whether the *rule of conformity* is a safe guide.

While considering here the *rule of conformity* and the method of *drawings* outlined in the foregoing for supplying missing data in justifiable cases when no other evidence is available, it may be appropriate to remark that the process of drawing is very nearly equivalent to inserting, for the missing value, a most probable value inferred from the values which have been observed. Such a value is better than to insert the normal or average value in the case of missing data, or to follow a method commonly practiced, when one or two days are missing from a month's record, of using the average value for the month as that derived from the days on which observations were taken. This in effect affirms that the missing values were equal to the average of the observed values.

The grand average of all the observations, including the 23 values drawn from the cup is 41.78, and we use the convenient base number 41.8 for computing departures and the values of y as given in the table 2 and shown in the graph. Figure 1.

This diagram and the important facts disclosed by it are the real objectives of this study.

The conspicuous features which appear in diagrams of accumulated sums of departures are, first, the prolonged secular trends as shown by the straight lines O B, or A B and B C. Second, the points A, B, C seem to mark important epochs when climatic changes set in.

While Prof. Winthrop was prompted to begin his early record in 1749 because of a state of severe drought at the time, nevertheless, for the next 9 years the average rate of rain amounted to over 45 inches per year, attaining the point A on the diagram. How interesting and instructive it would be if we only had the complete record back, say, to 1700! It might then appear the point A really marked an epoch of climatic change, when the average rate of rainfall changed to a value of 40 iuches or less per year, as indicated by the dotted straight line A B, and that a higher rate had prevailed for many years prior thereto.

From the foregoing it appears that each reasonable assumption we make leads to the unequivocal conclusion *that the rainfall in the vicinity of Boston for 90 to 100 years prior to 1850 averaged 40 to 40.5 inches per year.* The years 1846 to 1849 seem to mark a climatic epoch in precipitation after which for a period of more than 50 years the rainfall averaged about 44.7 inches per annum.

The point C appears to mark the close of this epoch with the year 1903, and the 20 years of record thereafter seem to show the beginning of a new secular trend of rainfall at a diminished rate of about 40 inches per annum. Our present knowledge affords no safe ground either to conclude surely that 1903 is one of the climatic epochs like B, or that the average annual rainfall for the immediate vicinity of Boston is destined to be about 40 inches for a number of years in the future.

The features of this diagram have been discussed at some length because it illustrates the possibilities of the *method of accumulated sums to disclose and evaluate* secular trends accurately, and to fix the dates of what for lack of a better name we have designated epochs of climatic changes.

It is perfectly obvious, of course, that the use of straight lines and their intersections to define secular trends and to locate epochs of change are only crude approximations in lieu of some appropriate curved line whose character is as yet quite unknown.

In order to answer the obvious question, what do other records show? We have built up a different 173-year record by uniting the above Boston record up to 1804 with the long records available at New Haven, New Bedford, Providence, New York City, Albany, and other places which together furnish 10 almost uninterrupted records after 1849. While this record includes the three *groups of 2, 3, and 5 years interpolated by drawings, the* interpolation of 13 years and all others are wholly unnecessary. While Boston is represented in the group of 10 stations, only a single record is included, which of course has a weight of only one-tenth in the average annual values.

For the values of y from these data, see Figure 2. Although the data are necessarily identical in Figures 1 and 2 from 1750 to 1804, the two diagrams are otherwise mainly alike in major features, which goes far to prove the actual occurrence of an epoch of climatic change about 1849, when a low rate of annual precipitation of about 41 inches per year gave place to a wetter period for at least 50 years, with 45.4 inches per annum, or an increase of 10 per cent, in the annual rainfall. Furthermore, the feature C appears in both diagrams at 1903, as if another change to a future secular trend with diminished rainfall then set in. The point B′ at 1804 marks the junction of the single record at Boston with the composite records beginning with New Haven, Conn., and including shortly thereafter New Bedford, Mass., then Albany, New York City, Lowell, Mass., Providence, and others, so that the complete number of 10 stations was reporting before the epoch 1849.

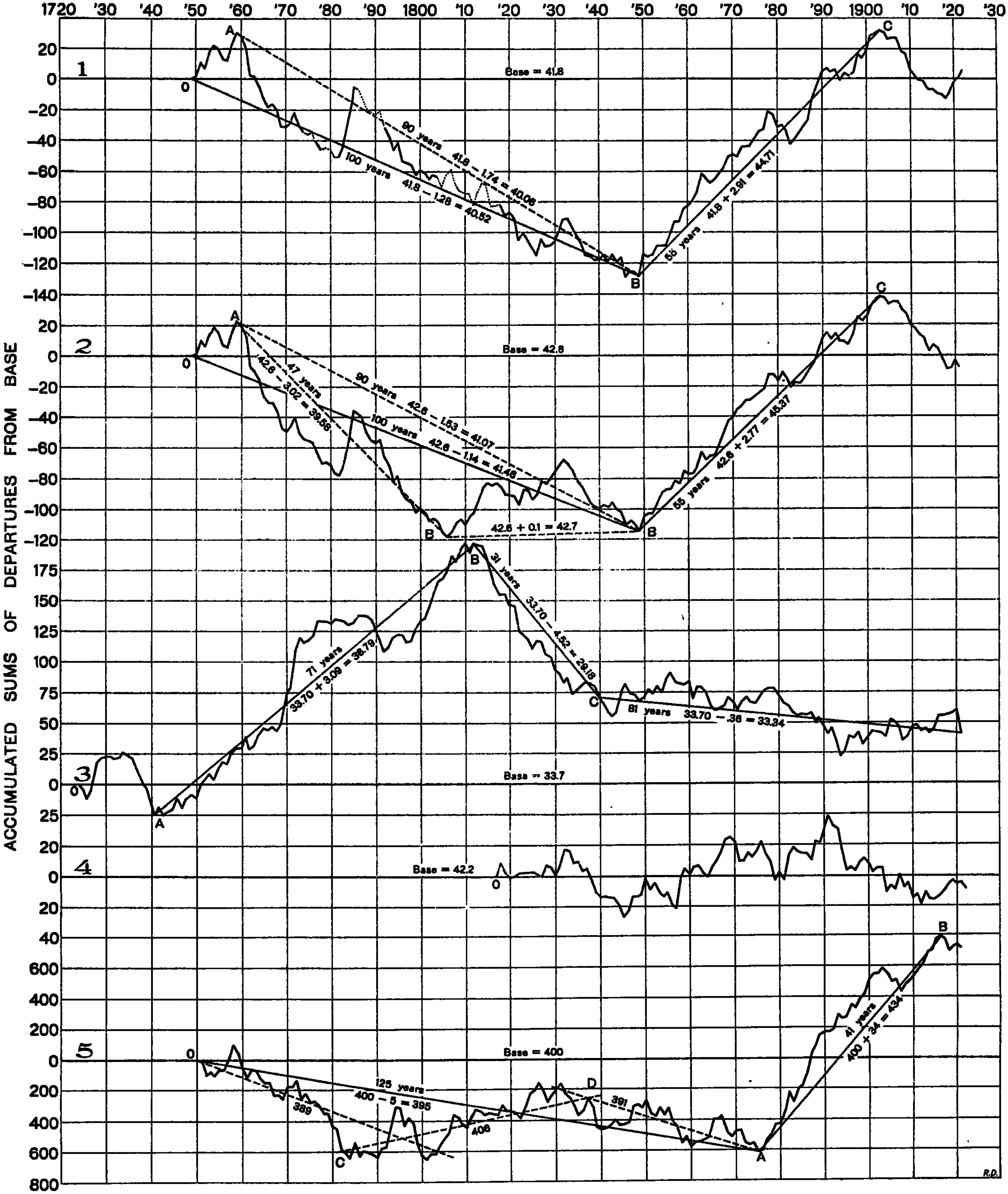

FIG. 1.—Annual precipitation at Boston and immediate vicinity for 173 years (1750–1923). FIG. 2.—Precipitation over southern New England at 1 to 10 stations for 172 years. Grand average 42.55 inches. y Accumulated sums of departures from base. FIG. 3.—192 years of precipitation at Padua, Italy. Accumulated sums of departures from base, 33.70 inches. FIG. 4.—Precipitation at Marietta, Ohio, 1818–1922. Accumulated sums of departures from base, 42.20 inches. FIG. 5.—Winter precipitation at 10 stations, southern New England. Ratios to annual $\frac{\text{November, December, February, March}}{\text{year}}$ 1000. (CORRECTION: A prime was inadvertently omitted from the B near the intersection of the coordinates 1800 and 120, figure 2. Should read B^1.)

TABLE 2.—*Annual precipitation in immediate vicinity of Boston, Mass., for 173 years from 1750 to 1922, departures from base and accumulated sums thereof—Base=B=41.8. (Inches.)*

Number of stations.	Year.	Precip. R	R-B d	Σd y	Number of stations.	Year.	Precip. R	R-B d	Σd y
1	1750	42.2	+0.4	+0.4	3	1837	34.1	−7.7	−114.5
1	1751	53.1	+11.3	+11.7	3	1838	40.3	−1.5	−116.0
1	1752	38.0	−.38	+7.9	3	1839	39.4	−2.4	−118.4
1	1753	52.0	+10.2	+18.1	3	1840	43.3	+1.5	−116.9
1	1754	46.5	+4.7	+22.8	4	1841	42.6	+0.8	−116.1
1	1755	38.5	−3.3	+19.5	5	1842	39.2	−2.6	−118.7
1	1756	35.5	−6.3	+13.2	5	1843	46.1	+4.3	−114.4
1	1757	41.3	−0.5	+12.7	5	1844	36.6	−5.2	−119.6
1	1758	53.7	+11.9	+24.6	5	1845	44.6	+2.8	−116.8
1	1759	48.9	+7.1	+31.7	5	1846	29.0	−12.8	−129.6
1	1760	39.0	−2.8	+28.9	5	1847	45.2	+3.4	−126.2
1	1761	32.8	−9.0	+19.9	5	1848	41.2	−0.6	−126.8
1	1762	24.5	−17.3	+2.6	5	1849	40.4	−1.4	−128.2
1	1763	40.5	−1.3	+1.3	5	1850	54.8	+13.0	−115.2
1	1764	36.8	−5.0	−3.7	5	1851	41.6	−0.2	−115.4
1	1765	32.8	−9.0	−12.7	5	1852	41.8	±0.0	−115.4
1	1766	37.7	−4.1	−16.8	6	1853	48.4	+6.6	−108.8
1	1767	42.4	+0.6	−16.2	6	1854	42.3	+0.5	−108.3
1	1768	36.8	−5.0	−21.2	6	1855	42.1	+0.3	−108.0
1	1769	31.8	−10.0	−31.2	7	1856	47.2	+5.4	−102.6
1	1770	41.3	−0.5	−31.7	8	1857	51.6	+9.8	−92.8
1	1771	45.3	+3.5	−28.2	8	1858	41.6	−0.2	−93.0
1	1772	49.0	+7.2	−21.0	8	1859	50.2	+8.4	−84.6
1	1773	32.6	−9.2	−30.2	7	1860	46.1	+4.3	−80.3
1	1774	37.4	−4.4	−34.6	8	1861	42.3	+0.5	−79.8
......	1775	*41.3*	*−0.5*	*−35.1*	7	1862	47.5	+5.7	−74.1
......	1776	*42.4*	*+0.6*	*−34.5*	8	1863	54.4	+12.6	−61.5
1	1777	35.5	−6.3	−40.8	8	1864	38.7	−3.1	−64.6
1	1778	37.1	−4.7	−45.5	10	1865	38.9	−2.9	−67.5
......	1779	*43.0*	*+1.2*	*−44.3*	9	1866	42.2	+0.4	−67.1
......	1780	*40.8*	*−1.0*	*−45.3*	9	1867	46.7	+4.9	−62.2
......	1781	*36.5*	*−5.3*	*−50.6*	10	1868	46.1	+4.3	−57.9
1	1782	40.8	−1.0	−51.6	10	1869	47.9	+6.1	−51.8
1	1783	49.7	+7.9	−43.7	8	1870	44.3	+2.5	−49.3
1	1784	60.3	+18.5	−25.2	8	1871	39.8	−2.0	−51.3
1	1785	62.5	+20.7	−4.5	8	1872	48.9	+7.1	−44.2
1	1786	41.5	−0.3	−4.8	10	1873	45.4	+3.6	−40.6
......	1787	*36.8*	*−5.0*	*−9.8*	11	1874	38.7	−3.1	−43.7
......	1788	*31.8*	*−10.0*	*−19.8*	11	1875	47.4	+5.6	−38.1
......	1789	*40.3*	*−1.5*	*−21.3*	15	1876	45.9	+4.1	−34.0
......	1790	*39.7*	*−2.1*	*−23.4*	14	1877	43.1	+1.3	−32.7
......	1791	*44.2*	*+2.4*	*−21.0*	17	1878	54.2	+12.4	−20.3
2	1792	32.2	−9.6	−30.6	17	1879	38.4	−3.4	−23.7
2	1793	35.4	−6.4	−37.0	18	1880	34.1	−7.7	−31.4
2	1794	33.0	−8.8	−45.8	17	1881	42.6	+0.8	−30.6
2	1795	47.0	+5.2	−40.6	17	1882	37.9	−3.9	−34.5
2	1796	30.1	−11.7	−52.3	17	1883	32.7	−9.1	−43.6
2	1797	39.4	−2.4	−54.7	16	1884	46.0	+4.2	−39.4
3	1798	40.8	−1.0	−55.7	18	1885	44.8	+3.0	−36.4
2	1799	35.4	−6.4	−62.1	21	1886	46.4	+4.6	−31.8
3	1800	45.2	+3.4	−58.7	20	1887	45.5	+3.7	−28.1
2	1801	39.7	−2.1	−60.8	22	1888	57.1	+15.3	−12.8
2	1802	38.4	−3.4	−64.2	23	1889	50.9	+9.1	−3.7
2	1803	43.3	+1.5	−62.7	28	1890	49.7	+7.9	+4.2
1	1804	41.0	−0.8	−63.5	29	1891	45.1	+3.3	+7.5
......	1805	*35.5*	*−6.3*	*−69.8*	28	1892	38.7	−3.1	+4.4
......	1806	*48.9*	*+7.1*	*−62.7*	29	1893	43.6	+1.8	+6.2
......	1807	*46.1*	*+4.3*	*−58.4*	30	1894	35.4	−6.4	−0.2
......	1808	*31.8*	*−10.0*	*−68.4*	30	1895	45.6	+3.8	+3.6
......	1809	*37.7*	*−4.1*	*−72.5*	30	1896	40.4	−1.4	+2.2
......	1810	*40.3*	*−1.5*	*−74.0*	29	1897	43.4	+1.6	+3.8
......	1811	*41.8*	*±0.0*	*−74.0*	27	1898	54.5	+12.7	+16.5
......	1812	*34.1*	*−7.7*	*−81.7*	28	1899	38.4	−3.4	+13.1
......	1813	*48.9*	*+7.1*	*−74.6*	30	1900	46.9	+5.1	+18.2
......	1814	*48.9*	+7.1	*−67.5*	30	1901	52.3	+10.5	+28.7
......	1815	*40.8*	*−1.0*	*−68.5*	30	1902	42.8	+1.0	+29.7
......	1816	*27.2*	*−14.6*	*−83.1*	32	1903	43.4	+1.6	+31.3
......	1817	*41.5*	*−0.3*	*−83.4*	32	1904	42.3	+0.5	+31.8
1	1818	43.0	+1.2	−82.2	30	1905	37.4	−4.4	+27.4
1	1819	35.5	−6.3	−88.5	34	1906	41.9	+0.1	+27.5
1	1820	44.2	+2.4	−86.1	32	1907	41.3	−0.5	+27.0
1	1821	36.9	−4.9	−91.0	34	1908	33.3	−8.5	+18.5
1	1822	27.2	−14.6	−105.6	32	1909	39.9	−1.9	+16.6
1	1823	47.3	+5.5	−100.1	34	1910	31.7	−10.1	+6.5
1	1824	36.0	−5.8	−105.9	33	1911	38.6	−3.2	+3.3
2	1825	36.7	−5.1	−111.0	33	1912	38.3	−3.5	−0.2
3	1826	37.0	−4.8	−115.8	33	1913	40.5	−1.3	−1.5
3	1827	52.8	+11.0	−104.8	12	1914	35.5	−6.3	−7.8
3	1828	37.3	−4.5	−109.3	12	1915	42.5	+0.7	−7.1
3	1829	42.0	+0.2	−109.1	11	1916	40.3	−1.5	−8.6
3	1830	44.7	+2.9	−106.2	11	1917	40.1	−1.7	−10.3
3	1831	49.7	+7.9	−98.3	11	1918	39.3	−2.5	−12.8
3	1832	48.9	+7.1	−91.2	11	1919	45.8	+4.0	−8.8
3	1833	41.8	±0.0	−91.2	11	1920	49.9	+8.1	−0.7
3	1834	36.1	−5.7	−96.9	11	1921	43.6	+1.8	+1.1
3	1835	36.5	−5.3	−102.2	11	1922	46.8	+5.0	+6.1
3	1836	37.2	−4.6	−106.8					

TABLE 3.—*Annual precipitation over southern New England as shown at from 1 to 10 stations—Base, 42.60. (Inches.)*

Year.	0	1	2	3	4	5	6	7	8	9
1750	42.2	53.1	38.0	52.0	46.5	38.5	35.5	41.3	53.7	48.9
1760	39.0	32.8	24.5	40.5	36.8	32.8	37.7	42.4	36.8	31.8
1770	41.3	45.3	49.0	32.6	37.4	*41.3*	*42.4*	35.5	37.1	*43.0*
1780	*40.8*	*36.5*	40.8	49.7	60.3	62.5	41.5	*36.8*	*31.8*	*40.3*
1790	*39.7*	*44.2*	32.2	35.4	33.0	47.0	30.1	39.4	40.8	35.4
1800	45.2	39.7	38.4	43.3	41.0	35.8	38.6	45.3	49.4	44.6
1810	39.4	47.6	44.2	53.4	49.6	45.7	41.1	43.4	40.6	36.3
1820	43.9	42.4	35.6	53.6	41.7	36.7	44.2	52.7	40.5	45.8
1830	47.1	48.6	45.3	39.6	37.6	36.3	39.9	35.3	38.7	39.3
1840	42.8	44.3	41.4	46.3	37.0	41.5	33.6	45.8	40.4	37.5
1850	52.7	43.6	43.3	51.1	46.7	45.0	43.2	48.1	40.9	49.9
1860	41.0	43.6	46.5	52.0	37.5	44.2	44.2	48.7	49.6	50.4
1870	45.1	47.9	45.5	45.6	43.2	44.5	46.1	44.3	52.6	42.7
1880	38.2	44.3	41.8	37.2	46.3	41.7	45.4	48.0	47.7	50.9
1890	51.0	46.6	37.9	45.9	38.1	41.6	40.9	49.7	53.4	40.7
1900	45.4	50.3	45.6	44.5	42.0	38.3	43.2	43.3	37.8	39.0
1910	35.4	39.7	39.5	40.2	35.3	45.2	38.9	37.7	36.0	43.4
1920	47.9	37.5	......	......	......	......	......	......	......	......

Values in italics are interpolated by rule of conformity as explained in text.

Stations (Cambridge, Charlestown or Boston): New Haven after 1804; New Bedford, 1814; New York City, Albany, and Lowell, 1826; Providence, 1832; Amherst, 1835; Worcester, 1841; and Hartford, 1849. Record from all stations nearly complete after 1849.

The writer is strongly of the conviction that the seeming inconsistencies in those portions of Figures 1 and 2 prior to 1849 are best explained from the necessity of uniting the Boston record prior to 1804 to the New Haven and other records beginning at that date without making any allowance for the fact that, as previously shown, the rainfall at New Haven and New Bedford was about 3.8 inches per year greater than at Boston during that period. In other words, the data in Figure 2 are distinctly less homogeneous than are those in Figure 1, and the feature at B′ is due to discontinuity of record rather than climatic change.

A long record of rainfall at Padua,[2] Italy, is given in Table 4 and shown by the method of accumulated sums in Figure 3. In the article cited the data end with the year 1900 and are brought down to date from sources in the library.

Lack of space prevents including many other cases nearly all of which show features like those here discussed. However, the secular trends and the epochs of change appear to be quite local features, and a much more extensive study of data is required before any generalizations are possible.

The method of accumulated sums promises to be invaluable for the purpose of investigating the nature of insidious errors affecting records, especially of rainfall, when data are available which permit of the accurate comparison of two or more records which should be more or less alike.

From the studies thus far conducted two types of conditions appear to prevail, namely:

Type I. Changeable climate, as exemplified by the illustrations cited above and which appear to afford the most numerous cases.—In Class I the accumulated sums of departures from base acquire very large positive or negative values separated by wide intervals of time. Steady secular trends fairly well represented by long straight lines, prevail between well-defined epochs at which important changes occur in such secular trends.

[2] J. Hann. Die Schwankungen der Niederslagsmengen in grösseren Zeiträume Sitzungsberichte Kais. Acad. Wiss. 111. 1902. P. 67.

In some cases, as in the Boston and New England records, the values of y with unimportant exceptions are negative for a hundred years or more. In the case of over 90 years rainfall record for Cincinnati, as also for the whole State of Ohio, the values of y are large and continuously *positive* except at the extreme beginning and end of the record.

It is largely a matter of accident or the choice of a base number and the particular time a record of Type I begins whether the values of y will run mostly positive or mostly negative. The Padua record, Table 4, figure 3, shows nearly all positive values, because the base number is a little smaller than the true average. If a base of 34 had been used, the record would have run negative from the start and later become positive, then probably negative at the end. If the record had begun in 1810 and the actual average used for the base number the values of y would all have been negative. with no important exceptions. None of these arbitrary changes in methods of calculation of y would, however, materially alter the epochal features A, B, C, etc.

Type II. Stable climates.—In the case of climatic records of this type, the values of the accumulated sums turn out more or less according to expectations or theory; that is, the values of y never become very large, the sum passes through zero, that is, changes sign frequently; epochal features like A, B, C, etc., are absent, and the base line itself is the best representation of secular trend that can be chosen. Such a climate is strictly a normal climate all the time and devoid of any of the long-time changes which are conspicuous in Type I.

The rainfall record covering a period of 105 years at Marietta, Ohio, Table 5, figure 4, is one of the best examples of the stable type of climate thus far examined.

In order to show the power of analysis of the method of accumulated sums, a final illustration will be given:

TABLE 4.—*Annual precipitation at Padua, Italy, 1725 to 1921 (centimeters).*

Year.	0	1	2	3	4	5	6	7	8	9
1720	......	......	......	......	......	759	629	1,162	1,348	924
1730	871	866	814	879	961	775	792	606	713	645
1740	570	614	991	717	906	963	1,056	649	1,052	918
1750	821	1,073	961	1,000	705	1,101	994	795	1,111	919
1760	887	1,126	572	947	1,069	982	841	902	763	1,061
1770	1,372	1,062	1,563	1,129	760	916	943	1,184	868	826
1780	812	940	821	825	791	918	1,037	852	824	748
1790	597	679	670	947	1,041	897	845	722	868	1,121
1800	1,003	903	1,110	1,142	1,130	893	991	1,184	738	1,089
1810	973	661	1,029	729	839	718	553	575	827	863
1820	515	671	480	779	763	660	990	841	617	800
1830	597	790	673	949	501	912	958	952	821	809
1840	614	713	699	752	933	1,265	957	748	843	680
1850	948	1,030	747	1,034	718	1,139	1,015	653	806	909
1860	884	533	1,128	789	790	619	731	862	913	1,083
1870	698	712	1,088	919	720	821	1,032	971	886	852
1880	747	684	813	701	768	892	835	908	648	963
1890	689	671	991	580	563	956	1,186	785	983	589
1900	993	1,006	851	800	794	1,206	819	716	572	924
1910	1,073	907	762	860	773	944	1,132	742	971	876
1920	910	430	......	......	......	......	......	......	......	......

TABLE 5.—*Annual precipitation at Marietta, Ohio, 1818 to 1922—Base, 42.20. (Inches.)*

Year.	0	1	2	3	4	5	6	7	8	9
1810	......	......	......	......	......	......	......	......	50.9	36.3
1820	39.1	43.3	43.4	*42.2*	*42.2*	*42.2*	41.6	41.5	49.5	39.5
1830	37.3	53.5	48.3	40.4	34.7	42.5	36.8	43.9	35.5	33.3
1840	39.1	42.8	42.1	41.8	36.6	33.9	46.3	52.3	43.2	42.9
1850	52.4	34.9	46.5	37.0	38.8	45.8	32.5	40.6	61.8	48.6
1860	38.9	46.4	42.7	37.1	40.9	48.8	47.3	46.7	50.1	42.9
1870	40.2	29.0	*42.2*	48.0	39.6	46.0	48.2	34.4	37.5	30.5
1880	46.4	36.8	60.0	46.8	38.5	41.7	42.1	37.2	55.4	41.0
1890	61.0	40.8	34.8	40.5	30.5	26.6	43.2	41.4	48.1	43.7
1900	38.4	37.6	44.1	41.9	26.0	46.4	40.6	53.1	32.5	45.4
1910	31.2	45.9	35.1	50.7	35.4	44.0	43.2	45.5	45.6	46.8
1920	40.8	51.3	46.4	......	......	......	......	......	......	......

Some will perhaps hesitate to believe that the precipitation in the vicinity of Boston, for example, was really less per annum for 90 or 100 years prior to 1849 but was only seemingly so because the untrained observers in those days did not measure all the snowfall, for example. This is a very plausible view, but it does not stand critical analysis, or better, we may say the cause, on the whole, is quantitatively inadequate and inconsistent with the facts. Anyone who goes into the details and history of early meteorological records must soon find a good deal of confidence in their general accuracy and a deserved respect for the motives, persistence, and intelligence which guided the enthusiastic observers of former years. Moreover, it will probably turn out that plenty of early records show excesses as compared with present-day values, so that the tentative impeachment of early records on the grounds of faulty methods of measuring snow must generally fail.

To test this question of winter and annual precipitation, we have reasoned and proceeded as follows:

(1) Most of the snowfall over southern New England occurs during the months of November, December, January, February, and March.

(2) In the absence of any evidence and demonstrations to the contrary, we are quite justified in assuming (*a*) that the ratio of the winter precipitation to that for the year at a given station tends to be a constant with the lapse of time; (*b*) that over the limited region now considered the winter ratio will be sensibly the same for all stations.

(3) If the snowfall is incompletely measured at any period of the record the ratio will necessarily be smaller and appear in the record, especially if analyzed by the method of accumulated sums. The result of such a study is shown in Figure 5 for the group of 10 stations in southern New England covering the period 1751 to 1921.

Four gaps in this record of 2, 3, 6, and 2 years have been filled by estimations based on the rule of conformity of missing record to actual records for dates, before and after the gaps. As this rule of conformity may not as yet have the indorsement and approval of meteorologists in general, it seems proper to give here the basis upon which the present application seems fully justified.

Average ratio 25 years unbroken record at Cambridge, 1751–1775	0.389
Average 4 winters at Andover, 1783–1786	.416
Average 10 winters at Charlestown, 1793–1802	.383
Average 10 winters at New Haven, 1805–1814	.417
General average	.401
General average for 171 years	.404

The first three records are for stations quite close to Boston, and there is a gap of two years from 1802 to 1804 when the record began far to the southwest. A critic of these values may regret that the individual values differ as much as they do, but the general agreement and the close identity of the mean of the four values with the mean for the whole period of 171 years can not be lightly disregarded, and the writer feels strongly inclined to regard this rule of conformity as a safe guide in filling such small gaps in the record as are involved in this example. As in the earlier case, we have resorted to the scheme of drawing numbers from a cup to secure individual values.

What is to be the interpretation of Figure 5, which was designed to show whether early measurements of snowfall and winter precipitation in general were as accurate and dependable as those of the present day?

The diagram presents one very striking feature, namely, the point *A* marking a decided epoch at 1875 when the ratio of winter precipitation changed from 39.5 per cent to 43.4 per cent (a still greater change might be claimed).

During the 125 years prior to 1875 a number of marked fluctuations in the average value of the ratio prevailed, but there is no evidence of conspicuous features. Making full allowance for the uncertainty in the interpolated missing values, it is obvious that the general results are not materially affected by these interpolated values. A few fairly well defined secular trends, such as shown by the dotted lines O, C, D, A, Figure 5, might be claimed, but it seems quite unlikely these are real. They are probably due to inherent uncertainties in the records, including the rather serious discontinuity at 1804 in passing from the early records at Boston to the series beginning at New Haven and New Bedford in 1804 and 1814. If they are real, we must say:

	Per cent.
Average winter ratio for 30 years, 1750 to 1780	38.9
Ditto for about 50 years, 1783 to 1832	40.6
Ditto for nearly 45 years, 1830 to 1875	39.1

It is probable that these different winter ratios represent different degrees of accuracy in the measurement of snowfall, or possibly some slight changes may have prevailed in the seasonal distribution during the different periods. On the whole, however, the quantitative magnitudes of the differences is quite too small to be significant, and the safest conclusion that can be drawn from the whole record is that during the 125 years prior to 1875 the ratio of winter precipitation to that of the whole year (beginning with April 1, not January 1) averaged 39.5 per cent, whereas following 1875 the winter ratio averaged over 43 per cent. The epoch 1875 coincides very closely with the beginning of observation by the Weather Bureau, which it might be supposed marked the beginning of the best possible measurement of snowfall, thus explaining the higher ratio of winter precipitation. This reasoning, however, can not be relied upon, because (1) the change in ratio was sudden, definite, and continuous; (2) the history of the Weather Bureau methods of snow measurement does not allow the belief that the records from other good observing stations in those early years could have been sufficiently inaccurate, compared with Weather Bureau records, to explain the considerable and abrupt change. Finally, (3) we are dealing with a composite record of 10 stations, only 3 of which in 1875 were Weather Bureau stations. The percentage influence of those stations is too small to affect the average of all the stations sufficiently to explain the result observed. The literature of the early observations shows that the importance and difficulties of correctly measuring snowfall was fully appreciated, and while the exact methods followed are not known, the observations must be accepted, in this case at least, as fairly homogeneous, and we are compelled to conclude that about 1875 some climatic changes occurred over the region embraced which caused the ratio of winter precipitation to change from about 39 to 43 per cent. While the smaller value of the ratio during the early years of the record is no doubt due in part to the incomplete measurement of winter precipitation, yet this influence alone fails to furnish a satisfactory explanation of all the record, and we must recognize that some significant climatic change has also been an important influence in fixing the annual distribution of precipitation.

It is not possible in this short article to give the results of similar studies of records for Washington, the State of Ohio, eastern Kansas, portions of Louisiana and elsewhere, and which include conditions of temperature and pressure as well as rainfall, all of which support the views advanced herein.

GENERAL CONCLUSIONS.

Normals.—The practical and useful significance of the concept *Normal* in weather and climatology is simply that of a convenient base number approximately equal to the average of observations over a period of, say, 50 years more or less. *A true or absolute normal* is, of course, the average of observations covering a period of several hundred years, but such a value will differ only slightly, in general, from an ordinary average, and it possesses no magic significance.

Accumulated sums of departures from base.—Tables and diagrams of the accumulated sums of departures from base and from a given epoch are most useful in exhibiting secular trends and epochal features in the data represented and show two distinct types, viz., (I) the changeable type, marked by secular trends away from the adopted normal which prevail steadily for many years and quite abruptly give place to definite trends of an opposite or different value, which in turn gives place to still other persistent trends.

Type II is a stable type in which departures of the same kind prevail for only short periods. In this type the normal, or base number itself, is the best representation of secular trend that can be chosen. It is quite probable that both types may be found combined in some way when records of several hundred years become available for analysis, so that in the end what now seems to be two types based on relatively short records will ultimately appear as different features of all very long records.

Climatic changes.—While there is no evidence indicating any permanent changes in climate, these studies demonstrate that more or less definite epochs occur from time to time when the climatic conditions of a more or less limited region suffer a material change in the value of the running average of conditions. These periods may prevail from 50 to 100 years or more, after which some other marked change occurs. Unquestionably, such features of records call for much further study and investigation. Shorter periods also are found and admit of more careful analysis because of their greater number and frequency.

Future studies facilitated.—The accumulated sums of departures from base have such a broad value of utility in all statistical studies that agencies responsible for the collection, compilation, and publication of meteorological and other data may well be justified in the systematic computation of this additional fundamental datum for all principal elements. The practice of printing *departures from normal* is already a very common one, and only slight additional work is required to include the *A. S.* in such data. This can not fail to furnish the student of climatic changes and weather sequences extremely valuable material.

Caution.—Two points in connection with this paper must be kept plainly in mind: (1) Straight lines are of course crude first approximations to secular trends; (2) the elimination of secular trends is necessary in the pursuit of many investigations, such as the evaluation of periodic and other recurrent features, solar and terrestrial correlations and the like. The method of accumulated sums seems superior to any other for accurately evaluating secular trends, and the use of ordinary averages, or of so-called normals based upon even 200 years' observations as secular trends is misleading unless it is shown the data used belongs to the stable class designated Type II.