UNIVERSITY OF PENNSYLVANIA
BICENTENNIAL CONFERENCE

Dendrochronology and Studies in "Cyclics"

By

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I. PRELIMINARY

Residence for years in what might be termed borderland climates has led the writer to the feeling that geographers and travelers, visiting all corners of the earth, see perhaps everything with one exception, namely, climate. They can see weather everywhere but not climate. And by climate I mean dynamic climate, not static. For example, people come to Arizona for the winter, but they learn little of the climate technically. To get that they must stay all the year. We have a temperate zone in winter and dry sub-tropical conditions the rest of the year with a second rainy season when the sun runs nearly overhead.

But to understand our climate the visitor must get acquainted with the immense climatic effects of our great mountain ranges and table lands in which rainfall increases with elevation for some thousands of feet of altitude, and he must see how very different is the climate on the east and west side of a big mountain mass with a relatively wet westerly exposure and a dry easterly "shadow." And lastly the visitor must reside here enough years to see the high percentage of change in any one season from year to year. These successive values form a pattern in successive years and this is the experience on which dendrochronology is founded.

In 1901, a trip by wagon from the forested top of the Kaibab Plateau in northern Arizona down to the desert of House Rock Valley several thousand feet below led to the following chain of ideas: (a) We get change of climate by going a few thousand feet vertically up or down a mountain slope; (b) In dry countries there is a high per cent of change of climate, i.e., rainfall,

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from year to year, chiefly in the winter precipitation, which is the main source of moisture supply in Northern Arizona; (c) Trees growing on the lower and drier border of forests may show these climatic changes from year to year in their ring widths; (d) In this case, with probable effects of solar activity on rainfall, and certain effects of rainfall on trees, it would be worth while to measure these rings and see if they show, for example, a sun-spot cycle; and finally (e) The best way to make such a test would be by cycle analysis of plotted curves of ring growth.

Measurement of rings began in January 1904, and it was at once evident that ring patterns could be traced in circuit about the tree. In the following month, similarity of recent patterns

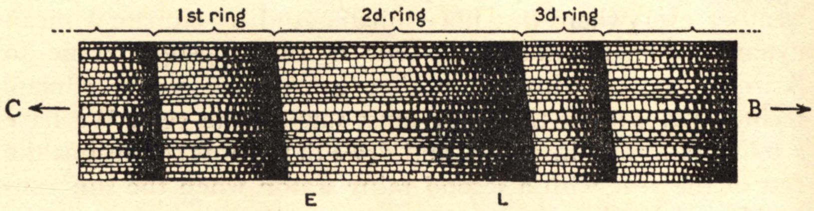


FIG. 1. Parts of a Ring. (From "Principles and Methods of Tree-Ring Analysis" by W. S. Glock, Carnegie Publication 486, 1938.)

in many trees was observed and their genuineness checked by calculating the cutting date of certain stumps from the ring patterns and then finding that the date was correct. Cuttings from the stumps of seventy trees near Prescott, Arizona, in 1911 showed that this similarity of ring patterns extended across fifteen miles of forest. On January 1, 1912, this was carried seventy miles to Flagstaff trees growing under similar general conditions. Thus crossdating was seen to be a general character of the region and not an accident, and all subsequent experience has confirmed this opinion.

This led to those rare but inevitable questions whether some one ring is annual or false, or whether another is missing in the radial under examination; in northern Arizona these questions were always settled by comparisons with other trees that grew farther and farther away. After thousands of trees had been examined and compared for cross identification of ring patterns, a few simple rules were found to decide questions of false or annual rings in this region. The chief guide is that in the trees we use, false rings are hazy, that is, *not* sharply defined on the outside. This applies easily to our western yellow pine, Douglas fir, and pinyon, but our junipers nearly always have indeterminate rings. Crossdating like ours does not necessarily extend outside the "Pueblo Area" of the Southwest, and lack of crossdating elsewhere has no bearing on our situation or upon our results. Since it is changing climate from winter to winter that causes these patterns, we can reverse the statement and say that definite ring patterns prevailing over a large area of country through long periods of time are climatic in origin

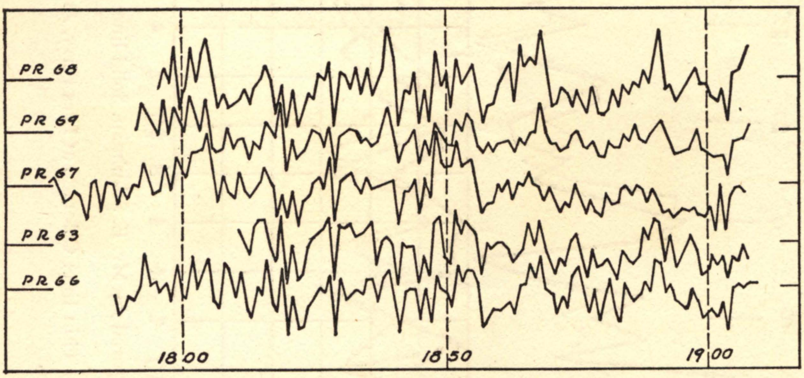
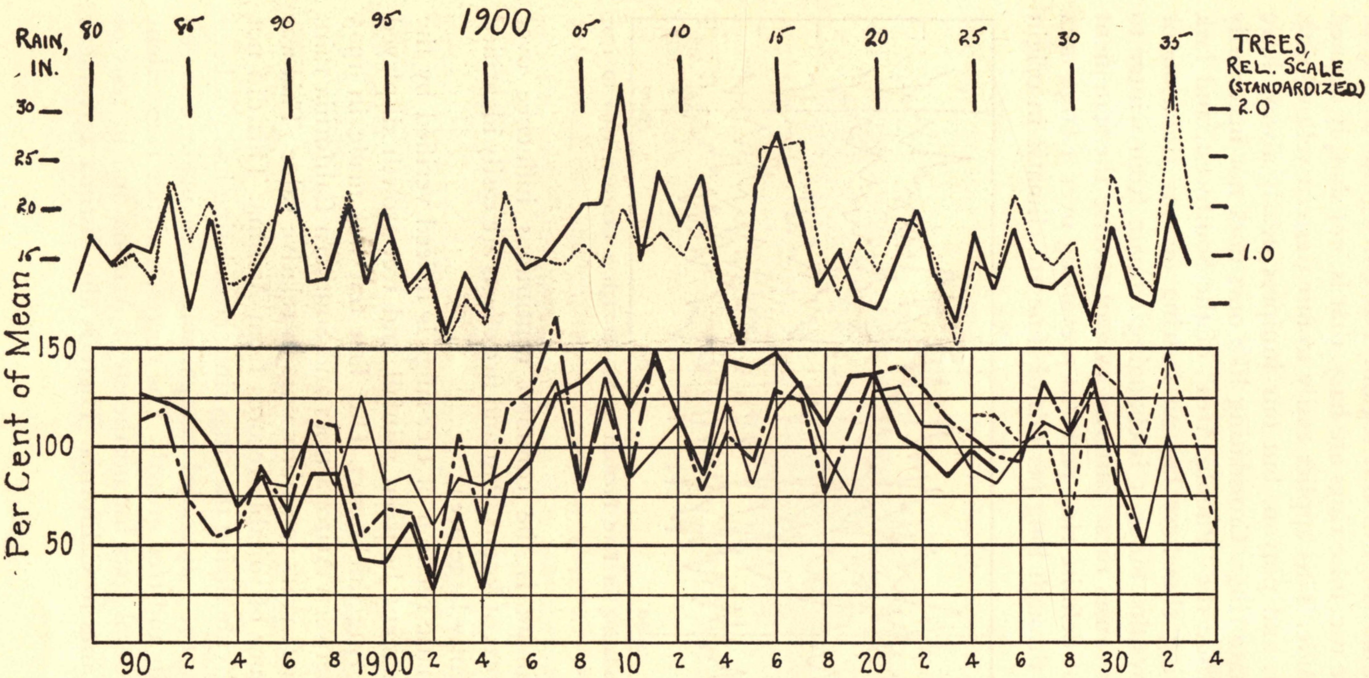


FIG. 2. Crossdating in Five Prescott Trees through a Century, 1796 to 1907 approximately.

because climate is the common continuous influence over immense areas of forests. Pest and fire effects are easily identified in a sufficiently large area.

The climatic relation of tree-rings is indeed verified by the actual agreement between rainfall and tree-growth displayed in relative ring thicknesses. Our first test was made in 1905 and 1906 between Arizona trees and Southern California rain, which in most years resembles ours in relative value. This was in the absence of suitable records from Arizona. This did not include individualizing the rings since crossdating had not been applied. In 1914 successful comparisons were made between Prescott rain and tree growth. The correspondence is excellent in more general tests for northeastern Arizona and in tests of Monterey pines in California. There is also distinct agreement



Above: Fig. 3. Monterey, California, Pines and Rainfall; prepared by Mr. E. Schulman. Solid line: Rain from Nov. 1 to Nov. 1. Dotted line: Tree Growth.

Below: Fig. 4. Dot-dash line: Rio Grande at Del Norte, Colo. Thin line: Colorado at Lees Ferry, Ariz. Heavy line: Tree Growth, Central Pueblo Area. Dotted line: Tree Growth, Defiance Plateau, Ariz.

Fig. 5. Type Site for Crossdating and Climatic Relation; Douglas Firs in Fewkes' Canyon, Mesa Verde.

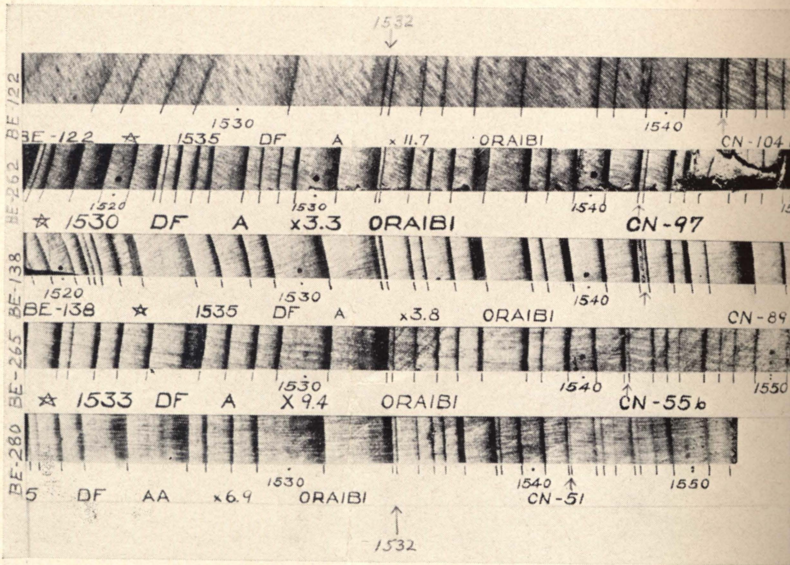


FIG. 6. Part of the 1900-year Chronology; Hopi Signature in five different trees.

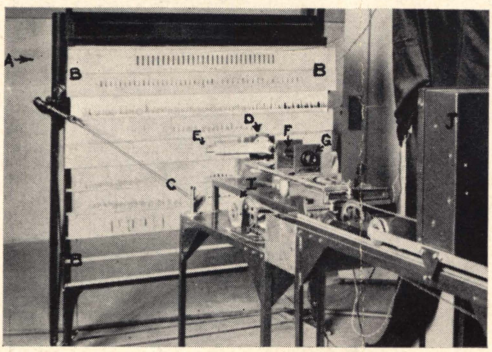


FIG. 7. Cycloscope: A, Illuminator; B, Comparator; C, Comparator control; D, Camera; E, Visual eyepiece; F, Grating; G, Main lens and cylindrical lens; H, Focussing Device; I, Mirror Control; J, Movable Mirrors.

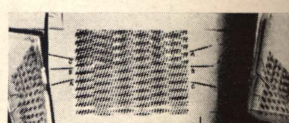


FIG. 11. Cyclograms showing solar rotation and magnetic character figure C, 1932-33-34 in part above live B-B; below is the cyclogram of synthetic curve showing 27-day double crested period with 6-month maxima alternating in opposite halves of the 27-day period. Thus the 6-month maxima in magnetism seem to originate in the sun, in part at least.

between Pueblo Area tree records and runoff of the Rio Grande and the Colorado rivers.

Recalling a note above that mountain slopes exhibit different climates at different altitudes, we see that in collecting ring samples from living trees for study the microclimatic effects of local topography bear powerful influence on the rings of trees, as for instance there is a great difference between rings in trees near a running stream and those that grow near a dry wash; between rings from a valley bottom and those from a steep upland slope perhaps only a hundred yards away. Miscellaneous collecting without regard to these factors produces in most cases quite worthless material. This has greatly misled several eminent investigators among those who have made checks on our results on a close relation between rings and rainfall.

This leads to another essential condition in making such tests, namely: All specimens to be used in such tests must be thoroughly crossdated *before* measurement and every ring fully identified by expert comparisons between definite patterns in different trees. If there are no definite patterns then there is no proof of climatic effects in the tree; and this applies to trees individually. In such cases it is not good sense to use the tree, it is not doing its climatic work. And incredible trouble is saved if surfaces are carefully prepared and illuminated in accordance with a highly developed technique too detailed to mention here. This technique takes into account some special characteristics of the cellular structure of the wood or charcoal.

We have been speaking of pines in Arizona; we now turn to the long-lived trees of the California Mountains. Fully fifty radial pieces cut chiefly from stumps of giant sequoias are in our laboratory; most of them have had all their rings measured for thickness. The writer made all these collections personally and observed especially the relation of ring types to the immediate environment of the tree. Nothing could be clearer than that large complacent rings easy to count but hard to identify (because they were all alike) occurred in the wet basin bottoms; while small sensitive rings, occasionally microscopic or even locally absent, occurred in trees high up on steep slopes or at the top of sharp ridges. It took a year to crossdate the first fifteen specimens. Eventually every tree was dated with confidence as to its accuracy. This happened even in the poorer (more complacent) specimens because the sequences were so long that check rings could be found even though five hundred years apart. Evidence showed abundantly that even though these trees give less accurate rainfall records than the pines and firs of Arizona, the ring growth is increased in wet years.

II. CHRONOLOGY BUILDING

From the above discussion of ring patterns prevailing extensively through large areas of sensitive trees, it follows that we may take a group of modern tree borings, V-cuts or other radials, and by carrying dates from one to the other by ring patterns we can check completely the correctness of count in the group, and reach complete identification of the rings in each tree. The series then becomes not merely a count but a real ring chronology based on climatic effects in the trees: it becomes therefore a bio-climatic chronology.

The first Arizona tree-ring chronology was published in 1909 in the *Monthly Weather Review* for June. In it only the last 200 years out of an available 500 were presented because many dating errors were expected. After crossdating was fully established in 1911, it was possible to return to this chronology-building in the spring of 1913 and to construct a 400-year record which has since been verified by fully a thousand trees. Two trees extended another hundred years and they differed in one point in the year 1463, and the apparent interpretation of the wrong one was adopted. That was corrected in 1919; such an error could not happen now, for it was merely mistaking a false ring in that year for an annual. With the rule mentioned above of examining closely the outside margin of a doubtful ring its true character would be seen at once.

This 500-year chronology was accurate (except as noted above). In the spring of 1913 it gave the long-sought chance to test by cycle methods the presence of long-time periodic changes that might originate in the sun. This was done by an entirely new instrument at first called the periodograph, later the cyclograph and now generally the cycloscope, which will be discussed below after the matter of chronology building is finished.

Among the happy circumstances that have aided this climatic chronology building in Arizona, no one has been more spectacular and appealing to the popular mind than the use of prehistoric beams by which a chronology of the highest quality has been carried back to 235 A.D.; thence it has been extended to 11 A.D., correct in count but with lessened sensitiveness to real climatic changes because the number of available trees dwindles to only one between 11 A.D. and 91 A.D., and that one happens to be rather indifferent to weather changes. However, other promising material is under examination. The great popular interest in this arises from the fact that the ruins whose beams contribute to the chronology become themselves dated accurately in our own A.D. dating.

The first suggestion for using prehistoric beams came in 1914 from Dr. Clark Wissler of the American Museum in New York. I answered in a letter describing the method that was later successful in building the beam-ring records into the chronology and dating the ruins. Financial aid was given by the American Museum of New York. In 1922 and until 1930 Dr. Gilbert Grosvenor and the National Geographic Society financed the search for proper beam material, through Mr. Neil M. Judd in charge of their excavations at Pueblo Bonito; it was through his active interest and keen understanding of the problem that this aid was successfully sought and applied.

In 1929, the Pueblo chronology was extended back to 700 A.D. Much aid came from Dr. Colton and the Museum of Northern Arizona. Early specimens from that area were of great importance. Then the splendid collections made by Mr. Earl H. Morris while working for the Carnegie Institution of Washington and the University of Colorado were sent to me. Former students in dendrochronology at the University of Arizona also came to our aid. A section found and dated by Miss Florence Hawley, then of the University of New Mexico, other sections found and dated by Mr. Carl Miller working with Dr. F. H. H. Roberts of the Bureau of Ethnology, and still others found and dated by Mr. John C. McGregor working with the Museum of Northern Arizona, were most important contributions in tracing the continuous ring series back to 11 A.D. as mentioned above.

Mr. W. S. Stallings of the Laboratory of Anthropology at

Santa Fe is making a very successful chronology in that part of the Rio Grande Valley. Other former students also have done very gratifying pieces of work. Mrs. Florence Hawley Senter is working in the midwest for the Universities of Chicago and New Mexico. Mr. J. L. Giddings of the University of Alaska at Fairbanks, and a student with us for a year, is building a very promising chronology of that region that has the interesting distinction of being based on temperature effects in the trees rather than moisture effects.

In similar manner by crossdating with infinite number of comparisons, the errors or doubtful points in the sequoia ring records were traced down and corrected if necessary, and a sequoia chronology was constructed going back in the oldest tree to 1305 B.C. The quality of this record as to climatic relation is excellent after about 600 A.D. There are many duplicates back to about 300 B.C. so the result is good back to that time. Previous to that date the number of trees rapidly diminishes, only four reaching the 3000-year age at 1100 B.C. or so. Probably the record before 700 B.C. is not strong as to climatic indications.

A sequoia chronology was published in 1919 (Carnegie Publication 289: *Climatic Cycles and Tree Growth,* Appendix). This and other collections made in later years have served as a basis for much cyclic analysis with results to be mentioned below. In working out these results and in the present continuation of this work, appreciation and thanks are due the University of Arizona for the housing of these large collections, for laboratory space and for financial aid. We have been very fortunate also in having the generous aid of the Carnegie Institution of Washington in carrying out the studies in climatic cycles. Grateful thanks are also given to other institutions and friends.

III. STUDIES IN CYCLICS

The word "cyclic" is here used as a noun with a specific meaning. This is because the writer has found it very hard to make himself understood from the lack of such a word. The old word "cycle," whether one likes it or not, has a very different meaning to different people. For instance, the people who are most active in harmonic analysis have defined a cycle as a suspected period; if it is proved permanent it is a period.

but if not then they say it is random and therefore it is nothing. Harmonic analysis originated in astronomical researches, and in the near absence of friction to planetary motion astronomical periods are permanent so far as the usual use of formulas is concerned. Cycle reality then by harmonic analysis methods is properly its certainty of permanence; then the application of that method to climatic or other phenomena whose recurrences are not permanent gives nothing definite and so naïvely it is said that there is nothing there.

Here is where the word "cyclic" comes in: it means significant repetition that may be permanent or may not. It is thus a general term under which "period" is a special case in which the repetition is permanent. An unstable or temporary period is a cyclic as is also any permanent period. Thus we have a name for the recurrences that appear so much in climate. The adjectives "real" and "random" in the harmonic sense disappear.

Cyclics exist in lot-drawn material; thus the burden of proof is to show their physical cause in observational data or to present relationship to possible physical causes or to establish characters that have physical significance. That constitutes advance and is material worth considering.

For example: We have been reaching many mass results in searching out preferential cyclic lengths. The question today is not whether they are permanent, but how general are they in different localities and what are the preferred cyclic lengths they indicate.

The cycloscope method is graphic. that is, open instead of hidden. The maxima whose periodic relationship is to be determined are all represented in duplicate by dots or other structural forms all visible at all times, and the desired relationships, if present, appear in the pattern these maxima form. If they form a straight line, they are giving an exact period; if a curved line then they show a variable period, or if a broken line then it means a series of fragmentary periods, i.e., cyclics; or finally if there is no obvious alignment then the maxima have pure random distribution without significant recurrence. The time of beginning and ending of any cyclic is immediately apparent as must necessarily be the case if one is studying these cyclics. Call the method by any adjective whatever, there is safety in it, as one could illustrate by many cases—for example, in terrestrial magnetism and solar rotation (see figure 11), or in tree-ring records sent from Canada, divided by some harmonic investigator in the middle instead of after the first third when the cycle length changed; one could see the point of change immediately in the cycloscope but its place was difficult to find by harmonic methods.

In the study of climate, the source of the recurrence becomes a vital matter because it controls the type of recurrence. Either in the earth's atmosphere or in the sun the changes take place in a fluid and so their recurrences are necessarily unstable. Thus our method is adapted to the conditions of the

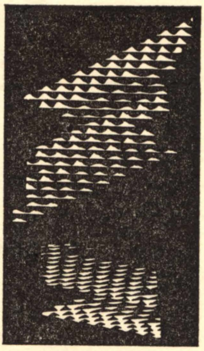


FIG. 8. Origin of Cyclics in a multiple plot of the sunspot annual numbers; made in 1913. See alignments in foreshortened reflection in lower part of picture. They were first called "cycles" and now recently "cyclics."

problem; if we are proposing to investigate unstable periods, we surely should be in error to use a method especially designed for the study of permanence and one whose probabilities are fundamentally dependent on permanence in time.

A very brief review of the development of this instrument will help in understanding it. The first cyclogram, called a multiple plot, consisted of rows of original data plotted solid white and mounted on a black background, one row under the other, parallel and equally spaced from each other, each successive row having an offset horizontally to the left compared to the next row above. If this offset or increment is made equal in length to the period under test, and if there is a recurrence as in the annual sunspot numbers, then an obvious alignment of maxima is developed in the vertical direction, whose character gives us at once many desired facts about the recurrence. These are the alignments showing significant recurrence. They were first called "cycles" (1913 and following years) and they are what we are now calling "cyclics" to avoid confusion.

This pattern method was used by the writer in 1913. In 1914 the production of the pattern was made automatic and instantaneous by the use of transparent solid curves mounted in front of highly illuminated ground glass and a simple optical train, involving movable mirrors; it proved advantageous to turn the pattern through nearly 90 degrees so that the main time scale goes horizontally left to right instead of up and down.

This method was worked out to test tree-ring records for the presence of solar cycle lengths; so its limitations were adapted to the end in view. We deal with any number of terms at a time up to 500, plotted on a horizontal time scale of one term to 2 mm. and test for cycle lengths between 5 terms and about 30. For increased lengths the data are replotted at 1/5 or 1/3 of the previous horizontal scale. We consider that anything under 5 maxima, that is, 5 repetitions, is too few to deserve much attention. We recognize harmonics easily, i.e., multiples and integral parts. We can change in a second from one set of data to any one of 5 or 10 other sets of data (our comparator attachment). We have in three hours made fairly complete analyses of forty curves of about 175 terms each for all cyclics between 5 and 30 years in cycle length.*

* Mr. Edmund Schulman has summarized some features of cycloscope analysis as follows:

The optical pattern viewed in the cycloscope, in which the cycle lengths and other cycle characters of data are read, is in principle an O-C diagram (as used, for example, in the study of variable star periods). The power of the latter diagram, a reconnaissance method, has however been tremendously increased in the cyclogram by the following new characters:

(1) The plot is automatic, optical, and practically instantaneous; this feature reduces greatly the time consumed in an analysis.

(2) Each maximum is plotted in its correct relative position in time with respect to its neighboring maxima.

(3) The complete string of maxima in the O-C diagram is duplicated as a set of rows, the equal vertical displacement between rows being a constant for all cycle lengths; (2) and (3) permit an analysis for several cycle-lengths in the same pattern, and give a standard form for harmonics and multiples.

(4) The computed or trial cycle length may be made to vary continuously between two limiting values by moving a set of mirrors; thus the analysis is

Generally in the matter of instrument the reader must keep in mind that in studying climatic changes we are not searching for microscopic periods that are permanent but for large amplitude recurrences that are significant because they agree with themselves over large terrestrial areas or agree with fluctuations on the sun which may take part in causing the terrestrial changes.

IV. RESULTS

We have made and used thousands of cycleplots of tree-ring records and other climatic phenomena, and from these we have made hundreds of lot drawings to test the significance of our methods. The process is so rapid that in lot-drawn data we have observed the frequent occurrence of short cyclic lengths in comparison with longer ones. We have tried out our reliability of results in the presence of definite quantitative errors. For example, we have introduced series of standard deviations from an epoch amounting to 10, 20, or 50 percent or more of the period and still find the period with ease. Also we have applied normal distributions of deviations to a time increment taken as a cycle length; the result is a series in which the errors are cumulative. With a standard deviation of some 20 percent, one set of data may or may not give the period; five or ten sets give the period with certainty, while forty or fifty give it with precision. This is by means of the frequency periodogram.

The former of these two types of series in which the maxima are independent and variations in successive spacing represent departures from an epoch date, is an astronomical type of recurrence, as in the case of a planet or a comet revolving about the sun. The latter, namely, the cumulative type, a time increment subject to errors, produces the type of recurrence we have in

continuous with respect to possible cycle lengths in the data, and the time-saving factor is immensely increased.

(5) The amplitude of each maximum is expressed in the cyclogram by means of light intensity; thus maxima in any set comprising a cyclic fall automatically into their relative weight in determining the strength of the cyclic, and cycle harmonics and multiples are readily analysed.

(6) By throwing the images of several curves in rapid alternation or succession into the cycloscope objective as the cycloscope mirrors move, it is possible to perform a continuous cycle analysis essentially simultaneous, on several different plots; this is the "comparator" feature of the instrument for studying the relation between different sources of data by their cycle characters.

(7) This method derives all results with all data in sight.

(8) Its double time-scale gives the time relation between two sets of phenomena.

the sunspot cycle or in geyser activity. We feel that this cyclogram method of representing an analytical pattern combines rapidity, efficiency, flexibility, and accuracy. Its condensed and yet informative description of sunspot variation puts it in a unique place, and we remember that the same type of variation is characteristic of climatic changes.

Historically, since 1750 the sunspot cycle has gone through a number of changes as to cycle length, such as 9, 14, 7 (for

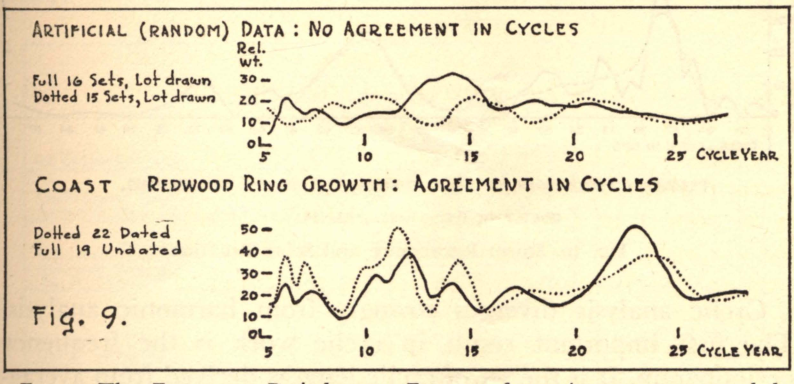


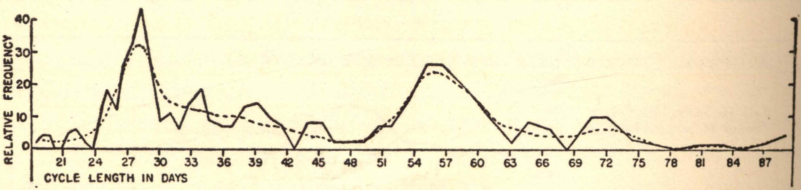
FIG. 9. The Frequency Periodogram Emerges from Averages; prepared by E. Schulman.

one interval between maxima) and 11.4 years.* Then there was a great dearth of sunspots from 1645 to 1715 (Maunder) and during that time the 11.+ year cycle in Arizona trees disappeared. Its existence in trees at other times since 1610 and in occasional intervals before that, one of those times being near the beginning of the Christian era, lead us to think of it as changing. At any rate the writer made a strong effort to carry a precise cycle of 11.0 to 11.5 years back for 2000 years to see if one would fit into the tree record, but it did not. But a small allowance for variation permitted a cycle almost in those limits to fit into the long tree-ring record.

So after one or two thousand very careful cyclic analyses of tree-ring records, we have failed to detect in these climatic changes any permanent exact periods except the day, the month, or the year, or their variants. For that reason we do not now feel it important whether the data in individual ring records has the characteristics of random material as judged by

* Compare this expression of its changes with Sterne.

time criteria (harmonic analysis way) or not. Even the mass results which we will enlarge upon in the next paragraph may be random (in time) from the point of view of changes in a great fluid body like the sun. Solar variations are so much more ponderous and slow-moving than those in our atmosphere that a connection (causal) to solar changes will give us a basis for prediction.



FREQUENCY PERIODOGRAM OF DAILY RAINFALL CYCLICS — 750 STATIONS, MOSTLY IN U.S. 1932,-33,-34.

FIG. 10. Storm Recurrence and Solar Rotation.

Cyclic analysis diverges strongly from harmonic analysis. The first important result in cyclic work is the frequency periodogram. It is the set of cyclic lengths derived from averaging the cyclics in many sets of data. When we average sets that are lot-drawn, the necessarily accidental complexes or groups of preferred cyclics occurring in these sets, are different in each set, and as the number of sets increases the average of the resulting periodograms (which we could call a summation periodogram) approaches and eventually reaches a straight line without preferred cyclic lengths. But in tree-ring data or in other natural data showing climatic influence, the greater the number of sets the stronger is the evidence of the existence of certain preferred cyclic lengths. A frequency periodogram, then, is a diagram showing the relative number of occurrences of a series of cyclic lengths when examined in many different sets of data from different sources. We have long known that large areas were alike meteorologically, but that there are preferred cycle lengths and that these agree with the sun, is new. We also find that we can differentiate a frequency periodogram with respect to time and obtain a chrono-periodogram. This is done in a diagram with two time scales and enlarged lines that give amplitudes. One notices an analogy between this differentiation and the cyclogram itself which may be regarded as the differentiation with respect to time, of a harmonic analysis result.

We have tested Tucson meteorological records for cyclics near 27 days in the recurrence of precipitation storms during the last sunspot minimum, 1932-33-34. In the result we suspected a 27-day period. On extending the test to 750 stations mostly in the United States, we found lengths of 27.0 to 28.5 days between maxima greatly preferred, and these values are

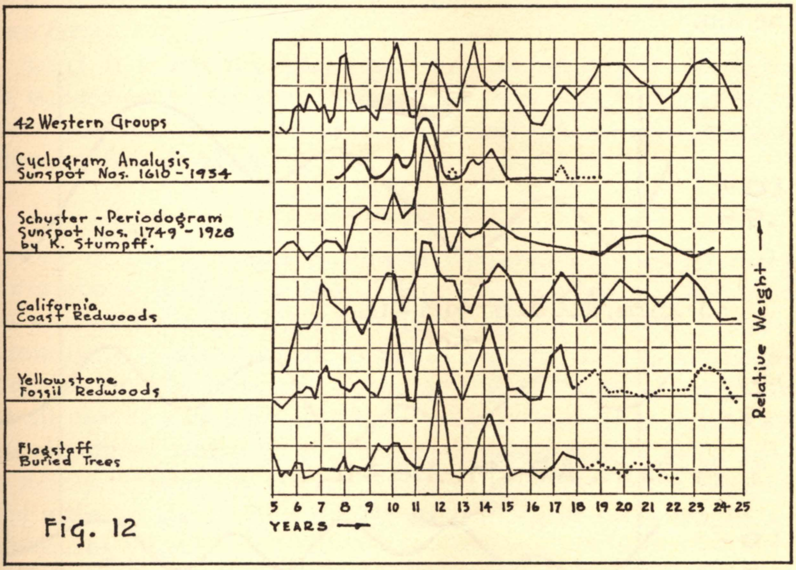


FIG. 12. Cyclic Complex in Solar and Terrestrial Data.

periods we have found prominent in solar rotation, in terrestrial magnetism, and in sunspots.

Studies in daily values of terrestrial magnetism have given some interesting results that are typical of the efficiency of our method. Our cyclogram may be expressed as a three-dimensional plot with two time scales (horizontally, there is the main condensed time scale; vertically, an enlarged or differential time scale) and a density and size value in the maximum mark representing amplitude of maximum. Hence we can show almost instantaneously such diagrams as in Figure 11 where we can see in the horizontal distribution the well-known 6-month maxima in the magnetic force, and at the same time

12-30-41 In these P'dgm fig 12 - possibly 11yr ± stands out for some other instrumental reason; how about going thru these data with variable grating analysis.

we see in the vertical time arrangement the alternating distribution of those maxima in opposite hemispheres of the sun, which plainly ties those maxima to the sun. These values are those found during the last sunspot minimum. A similar brief test upon Stetson's intensity of radio reception showed an almost exactly similar pattern in the cyclogram, but the values are reversed, that is, the radio reception is inversely proportional to the activity of terrestrial magnetism. This of course has been known for some time in a general way, but it was interesting to see radio reception tied to identifiable places on the sun.

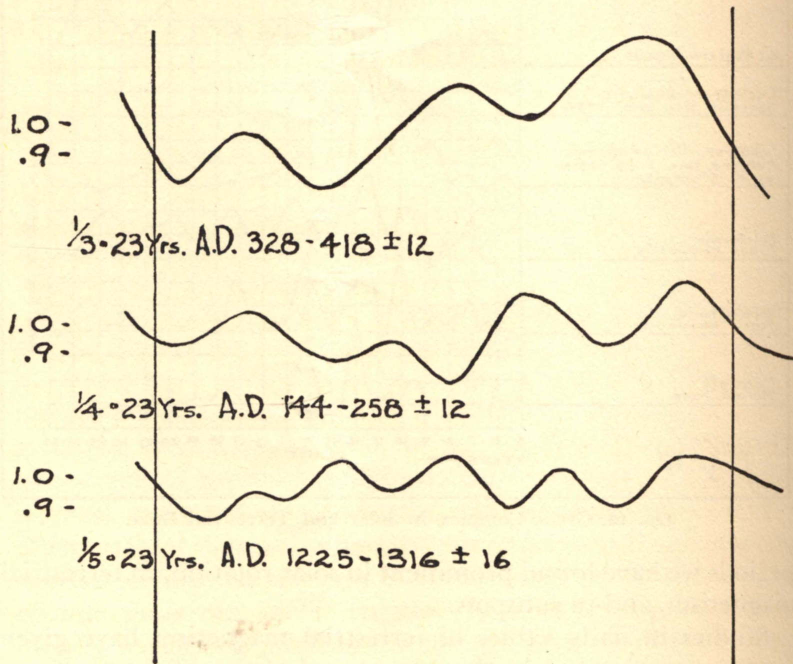


FIG. 13. Examples of subdivision of 23 years in 2000 years of Sequoia Records.

LISTED CYCLES OF COMMON OCCURRENCE

1. We find the following preferred cyclics in modern trees of the western U. S. areas: 5⅔, 7, 8.4, 10.1, 11.3, 14±, 17, 19-20, 22-23, 34, 38, 55-60, 100±, 260± years, etc.; in longer sets of data, longer cyclic lengths appear and amplitudes become greater.

2. These of 34 years or less coincide with cyclics in sunspot annual numbers.

3. Preferred cyclics in the coast redwoods today agree with those in the same species in the Yellowstone fossils that were living trees perhaps thirty million years ago.

4. Cyclics in pleistocene cypress (German) of a million years ago and in varves, show a resemblance to cyclics during the dearth of sunspots near 1700.

5. (a) In tree-ring records the solar (?) cycle of 11+ years is only one of a number and is not always conspicuous at all;

5. (b) In tree records and in weather it may sometimes have two crests;

5. (c) It is not necessarily the same in successive centuries. It is needless to say that cyclics from lot-drawn material have been studied, and averages of such analyses do not produce these preferred values.

LONGER CYCLICS

One of the first applications of the cycloscope in its early form about 1914 was a test of Huntington's big sequoia data in which a cycle of a little over 100 years was found to be very prominent. (This is shown in figure 40, page 109, of Carnegie Publication 289, *Climatic Cycles and Tree Growth,* 1919.) As in all uses of a cyclogram of this type, the cycle is indicated by an alignment which in this case, published twenty years ago, is nearly vertical; by tracing it out in direction till it reaches the scale on the margin we get its reading in cycle length as about 105 years.

The ring records in the trees of northern Arizona are very sensitive and have important relation to rainfall variation but, as is easily known, the trees are of ordinary age and so to cover 1900 years a great number have to be used in succession. In these short-lived trees the short cyclics above listed can be derived with confidence, for they have many maxima in the same tree, but longer cyclic lengths may include more than one tree in a single maximum and so some effect of age curve and other variables may creep in. Hence we have not tried to do so much with cyclics over 50 years in length in the Arizona material.

Tests of short cyclics in the giant sequoias show that while complacent compared to Arizona trees, these long-lived giants do give important information. The first indication of rather special strength in a 23-year cyclic in the California mountain trees came almost 20 years ago from examining the San Bernardino Mountain increment cores sent me by the U. S. Forest Service. It was strikingly prominent, but the records were not very long. Our first general collections were made in 1925 between Pine Valley near San Diego and Klamath Falls and Plumas County in the north and near Baker, Oregon, and in the Dalles on the Columbia. These when merged into a Sierra Nevada Mean (SNM) show an unmistakable 23-year cycle confirmed by Alter's "Correlation Periodogram" of the same

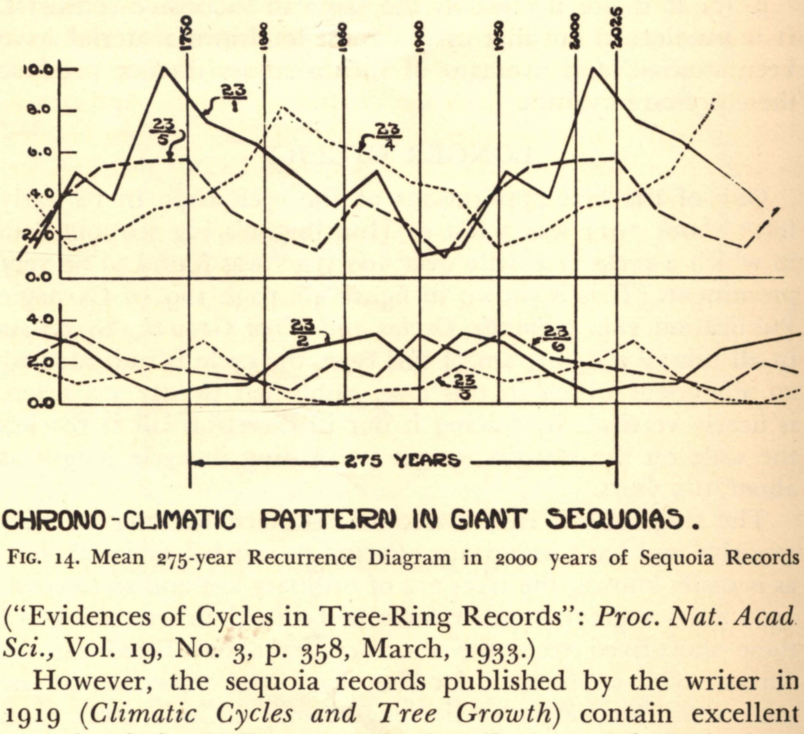


FIG. 14. Mean 275-year Recurrence Diagram in 2000 years of Sequoia Records

("Evidences of Cycles in Tree-Ring Records": *Proc. Nat. Acad. Sci.*, Vol. 19, No. 3, p. 358, March, 1933.)

However, the sequoia records published by the writer in 1919 (*Climatic Cycles and Tree Growth*) contain excellent records of the Hellmann cycle described extensively in later volumes of the same. Various attempts were made to find cycles in these records. A two-crested 11-year cycle showed occasionally (see publication 1919, plate 10) but then it was discovered that 23 years of cyclic length prevailed much more extensively in the last 2,000 years than either 11-year or 34-year. On examining the 23-year cycles more closely, it was apparent that their subdivisions were not always alike, that for a hundred years or more the 23 years might divide into four parts; then somewhere else it would run for a long time in five parts and occasionally in three or in no evident fractions. In 1927 the times of these various subdivisions were plotted, and there appeared a recurrence of these different types in an interval of about 275 years. This seemed to the writer to be the first approximation of an important cyclic or cycle. As it was consistent with our general conclusion that there are longer cyclics with greater amplitude than any we had had and, as it is not inconsistent with other hints in our work and several estimated periods from other investigators, it seems to deserve further study. Accordingly a rapid method for making tests of this sort has been worked out involving the use of prisms arranged in a certain way to cover parts of the main lens of the cycloscope. This became known to us as the "triple lag" study. And it was then evident that a considerable range of "lag" values besides 23 years should be tried. But that is a considerable task and we have not yet been able to do it.

However, a diagram is given herewith based on the evidence already obtained. In it we find that the persistence of the Hellmann relation (5.7 years) since 1750 agrees with previous recurrences of that cycle. If the various cyclics continue as they have done we have some reason to expect that through the next 10 years this Hellmann cycle will be less conspicuous or absent, with a probability of replacement by a 23-year cycle or the same divided into five equal parts.

V. PROGNOSTICATION

A. Long-range forecasting on the basis of permanent periods should not be expected except in terms of the day, month, and year, unless we tie our climatic changes to the sun, and the solar activity to the planets—which of course has often been attempted: probably Dinsmore Alter has made some of the best attempts and his results deserve consideration. Abbot and Clayton have done important work in direct effects from the sun.

B. Long-range forecasting by unstable cyclics has promising possibilities on the basis of the fact that a number of cyclics operate at the same time and that they do not all change at once; this gives an important expectation that forecasting will be improved by the use of these cyclics. We are trying this out.

There are further considerations: (1) There has been found evidence of orderly change in long periods, for example 275 years. This and other changes may depend perhaps on long slow changes in the sun; (2) from the presence of solar rotation in the recurrence of storms and from other facts we can count on solar effects in climate; the importance of such studies is obvious.

C. We have extraordinarily good climatic records in tree-rings extending back to about 235 A. D. and some even earlier. We have planned methods of turning these more precisely into rainfall records (though the change will not be great). These give us highly valuable data on the recurrence of droughts and moist periods. This kind of material is most important in planning reclamation projects, and is greatly desired by the engineers in charge, as they have had occasion to tell me. It is also the best quality of material on which to try out methods of forecasting.

FUTURE NEEDS

In view of these facts presented in the preceding pages, we can see the importance of every kind of record of solar activity. And further we see the equally great importance of developing every possible tree-ring record in the world that will throw light on climates of the past and of the present. This means special development in the near and far east, in the southern hemisphere, in the arctic regions; and if I may judge from several cases examined, such results will be safe only when carried on by some one trained in our methods as already developed.

SUMMARY

In this paper the following points have been discussed, related to Renewable Natural Resources as developed in various studies of dendrochronology at the Laboratory of Tree-Ring Research at the University of Arizona.

1. A precise annual identification of tree rings by aid of a process called Crossdating by Ring Patterns.
2. Long climatic records: (a) 1900 years in Arizona, New Mexico, etc., of very high climatic quality; and (b) 3250 year California giant sequoias, of definite climatic quality.

3. A rapid and flexible method of cyclic analysis applicable to unstable recurrence.
4. The frequency periodogram for mass results in cyclic analysis.
5. Periods corresponding to solar rotation in U. S. storm recurrence.
6. A complex of preferred cyclic lengths in ring records showing strong resemblance to a complex in sunspot numbers.
7. The same complex in geological material.
8. Evidence of the subdivisions of 23-year intervals into 5, 4, or 3 equal parts in certain tree-ring records from the California mountains.
9. Evidence for major cyclic recurrence in about 275 years 2000-year ring records in the big sequoias.

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