TREE-RINGS AND CYCLE ANALYSIS

BY EDMUND SCHULMAN

I. THE PROBLEM

When Dr. A. E. Douglass first turned his attention to the study of the annual growth-rings of trees in 1901, it was with the hope of finding a general variation in growth that might be traced back through the medium of climate to variations in solar radiation, and thus greatly extend the known history of the latter. Early work consisted largely in the acquisition of data; at the same time the best methods of collection, preparation and reduction of specimens were established. It soon became evident that trees undergo not only a general variation in growth, but that time leaves an indelible signature on the individual rings. Through the medium of cross-dating part of an undated specimen with part of a dated one, an exact date could be assigned to any rings in a sequence. A precise and ever-lengthening chronology for Northern Arizona and analogous ones for other regions began to emerge.

As it developed, the investigation began to make increasingly insistent calls on neighboring sciences; botany, geology, meteorology, and astronomy are only some of these. In particular, the precision in dating found a fertile domain in archaeology. The dating of prehistoric Southwest Indian ruins through their building timbers offered inviting prospects, and proved enormously fruitful.

From the standpoint of climatology, the archaeological activity in dating rings was of great value in furnishing a continuous, accurate, and highly sensitive record of variation in tree-growth over a period of some nineteen hundred years in Arizona. Together with the records of growth of the California Sequoias extending back over three thousand years, and the tree-growth data from other parts of the world, it forms a most promising subject for an investigation of the climatological problem.

The fundamental problem of tree-ring analysis may be formulated as follows, in three phases: (1) Are these recurrence phenomena in past climate? (2) What are the elements of such recurrence phenomena? and (3) Is there sufficient law and order in these elements to enable the accurate long-range prediction of future climate?

Climatically speaking, the primary source of activation of the atmosphere is the sun. And one evidence of at least an approach to law and order in recurrence phenomena is found in the number of sun-spots, in the familiar sun-spot cycle of about eleven years. At minimum sun-spots appear infrequently; soon they grow more numerous and some four or five years after minimum the mean number of spots reaches a maximum; activity then declines, at a slower rate, to a minimum again in six or seven years, when the next wave of the cycle begins. Since the phenomena of sun-spot variation are probably intimately connected with variation in solar radiation, it is evident that some effect of this cycle may well exist in climate. But meteorological records are on the whole much shorter than even sun-spot records; perhaps much too short to give any real insight into what is happening in climate. On the other hand, the long records in trees offer a proper study of the problem.

Dr. Douglass discovered in the early years of the investigation that the faithfulness with which tree-rings in Northern Arizona recorded in the more favorable cases the annual fluctuations in rainfall were truly remarkable. The extension to other areas, in some cases with different dominating climatic factors than rainfall, was no simple task and is yet far from complete.

But regardless of the climatic **interpretation** of the cycles found in tree growth, we are confronted with the problem of determining the **nature** of the cycles that may exist in climatic data or tree-growth variation. Consideration of a plot of the annual tree-growth in, let us say, Arizona or California, or even of the short meteorological records, shows that if cycles are operating they are probably quite complex. There is furthermore no particular *a priori* reason why the cycles should be regular in form or period, like the sine-curve. The comparatively simple sunspot curve is an example. Ordinary mathematical methods for the analysis of data containing periodic variations become extremely cumbersome, or fail completely, when the factor of unknown variability is present in the length, strength, duration and other elements of those variations.

It is for this season that Dr. Douglass developed (1) in 1914-1915 an instrument which, after undergoing considerable evolution, is now called the Cyclograph.

II. THE CYCLOGRAPH AND CYCLES

The cyclograph has been in use for twenty years, and has yielded information (2) about the nature of recurrence phenomena in tree-ring and other data almost unobtainable by present day mathematical analysis.

For purposes of cycle analysis with the instrument, tree-ring material must be processed to a much greater degree than is necessary when the objective is the date of the specimen. The width of each ring of a sequence is measured quite exactly. A plot then made with time as usual along the horizontal axis and corresponding ring width as the vertical coordinate yields the specimen growth curve. To remove very short period variations the curve is next smoothed. It is then transferred to a strip of opaque paper and the maxima isolated and cut out; the result is called a cycleplot, and the curve is ready for cycle analysis. However, mean growth curves of cross-dated groups are usually analyzed. To derive these, each individual reserve must have its non-climatic variations, such as age trend, eliminated and must be reduced to an average ring size of approximate unity. This may be accomplished in a single step. The sequences of reduced ring-widths are then averaged together, and a cycleplot made of the mean smoothed curve.

When placed in the illuminated window of the cyclograph, the cycle-

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2. Douglass, A. E.

1919. C C & TG. Vol. I, 98-110.

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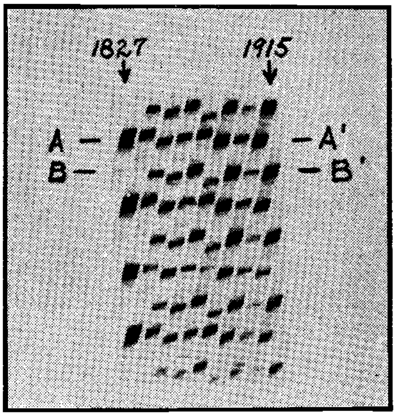
1933. Tree growth and climatic cycles. Scientific Monthly, Vol. XXXVII, 481-495, Dec. 1933.

plot permits light to pass only through the maxima. By means of an optical train of lenses, including a cylindrical one, and a grating, the curve is transformed into a pattern (as seen in the eye-piece) of patches of light, each representing a maximum. Every maximum in the curve has corresponding images in the pattern. Cycles are indicated by alignments of these patches; because of five-fold duplication of every maximum, these alignments are multiple and symmetric, and strikingly catch the eye. One of the distinctive features of the instrument is that alignments in different directions are visible at once; thus, for instance, the mutual relationship of several neighboring cycles shows up immediately. By moving a set of mirrors along a calibrated track an alignment may be brought to a horizontal position and the length of the cycle for normal scale curves read off directly from the mirror setting. Thus is any curve all the cycles between the scale limits of 5 to 42 units may be discovered and their elements approximately determined in a few minutes of analysis. Longer or shorter cycles may be found by replotting the curve on a different horizontal scale. The cyclograph admits a determination of the elements of cycles having a duration which does not cover the entire data, with a length not necessarily constant, with changes of phase at any point, and with variable amplitude.



The accompanying cyclogram is one of the cyclograph patterns of the Grand Canyon modern tree-growth curve. Every spot in the pattern represents the center of mass of a maximum in the growth curve. The photograph was taken with the cyclograph mirrors set so than at 11.6-year cycle would show a horizontal alignment of spots. It is evident that a strong cycle of this length is present in the last eighty years. This is approximately the length of the sun-spot cycle in the interval.

The row AA′, repeated four times, represents growth maxima very nearly as follows, from left to right: 1827, 1839, 1850, 1862, 1875, 1885, 1898, 1909. If there are maxima which fall between the recurrent crests of the main cycle there will be spots in the pattern between the main rows. The cyclogram shows alignment of these spots into intermediate rows BB′, indicating that the 11.6-year cycle is two-crested. The maxima are approximately: 1844, 1855, 1868, 1878, 1891, 1903, 1915. —E.S.

Hundreds of tree-growth curves have now been analyzed by Dr. Douglass and the results published. Of several hundred analyses by the writer, a considerable portion represented a check on previous work, the results of which were completely verified. While a complete discussion of the complex character of the cycles in tree growth is beyond the scope of this paper (3), two features apparently characteristic of tree-growth phenomena, and possibly of meteorological phenomena, may be mentioned.

First, there is in general no one cycle that dominates in tree-growth. In fact, if a number of groups in a geographically homogeneous area are analyzed, cycles of many different lengths will usually be found to occur. These cycles at first sight seem quite irregular, differ decidedly from each other in relative strength, and may start and stop at any point in the curve.

The second characteristic is that in spite of this apparent chaos, in-

3. An extensive treatment of cycle analysis, by Dr. Douglass, is expected to appear shortly.

vestigation of the frequency and strength of the cycles in any area has invariably shown that there are some half-a-dozen cycles that dominate. What is more, these dominating cycles are approximately the **same** in all areas, and thus form a characteristic cycle family. And more striking still is the fact that these cycles are almost exactly those which are associated with the major sun-spot cycle of 11 plus years.

It is probable that cycles not belonging to this dominating family are due to random effects operating in the trees or local effects of a non-climatic nature. It is noteworthy that some tree-ring groups, in particular the Yellowstone Fossil Trees, are governed almost exclusively by the characteristic cycle family, given below. The various controlling factors, principally climatic and geologic, are perhaps less complex in these cases than is usually true.

The tree-ring cycle family centers about the sun-spot cycle of 11 plus years. This cycle, frequently split into two maxima, is often found in trees but does not usually dominate. Associated with it are cycle lengths near 8+, 10, 14, 17, 19-20, and 23-24 years. These cycles are not equally strong and in general vary in strength in different areas. A short cycle of about two years is not uncommon. Dr. Douglass remarks: "Dating of specimens is largely done by the effects of the two year cycle." Of the long cycles, one very close to 100 years is of importance in tree-growth in the Southwest; associated with it is a strong cycle somewhat less than 300 years in length. A very strong 37 year cycle has operated for much of the last thousand years. Cycles near 55-60 years have been prominent in Ariona tree-growth for at least the last two millenia.

Much ground has been won, and a vantage point gained from which a commanding view of the field of cyclic variation is possible. To be sure, there remains much that is unexplained. Cycles suddenly appear in natural prenomena, perhaps suffer changes of phase, amplitude and length, and as suddenly disappear in a manner in many cases not yet completely understood. Again, where there is no single dominating climatic factor, such as rainfall, in our dry Southwest, tree-rings are less straight-forward "climatic indicators." These and similar problems have been receiving much attention in late years.

The cycles operating in different areas, and in different centuries, represent a study with which the Tree-Ring Laboratories is at present intensively concerned. The remarkable consistency thus far found in the cycle pattern over hundreds of miles and across millions of years points to a dependable and consistent framework in the "vagaries" of climate, and a promising basis for the long-range prediction of climatic phenomena.

THE FIELD COLLECTOR OF BEAM MATERIAL

BY LYNDON L. HARGRAVE

The rapid progress made in the field of dendro-chronology during the past few years and the dual application of the results of dating by this method, to the studies of climate and archaeology is tending to develop two classes of students of dendro-chronology: those interested mainly in the study of climatic cycles, and those interested in archaeology. Closely associated with members of each class is the field collector of beam material from historic and prehistoric sites, with whose qualifications and responsibilitities this brief paper deals.