

# Tree-growth and meteorological factors

by

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**Preface.** The investigation contained in what follows has been made over 30 years ago. Its evident incompleteness has, up to the present, always withheld me from publishing my results in any of the scientific Journals. The only publicity given to them was that in some lectures held at various times before different audiences: in Groningen Febr. 1889, November or December 1900 and Febr. 1909; in Leeuwarden Jan. 1901, in Pasadena (California) in December 1908. The last lecture was printed *in extenso* in "the Pasadena Star" of 19 Dec. 1908. It is the reproduction of this lecture which I now venture to lay before the scientific public. With the exception of a couple of trifling changes I have adhered to the text of "the Star", but have now added at the end a few notes with numerical data, which cannot well be given in a popular lecture.

I do not, I think, overestimate the value of the results obtained. If I did, I would have published sooner. But I haven often thought that there might be in them matter for stimulating others to undertake this work in a more thorough way. Several botanists have confirmed me in this view. Still I could not well overcome my reluctance till, in June 1909, Prof. H. E. Douglas published a similar investigation in the Monthly Weather review. I then resolved to publish what I had, in some form or other, in the hope that my contribution might help that of Prof. Douglas in calling forth more fundamental work from

others. I hoped to do this in a more extensive and thorough way than it was done in my lectures and to add some materials about the period 1879 up to the present time. — Other work, however, has always made me delay this plan, so that finally I felt that nothing would ever come of the matter unless I resolved to publish just my lecture in Pasadena.

About the lecture itself I wish to make a few remarks.

1st. In expressing numerically the relation between wood-growth and rain, the most scientific way would have been to compute *correlation-coefficients*. Meanwhile I have on several occasions found that the real significance of this coefficient is very obscure even to biologists who are accustomed to express their results in this way. The cause of this lies undoubtedly in the fact that the coefficient had not been correctly defined. I have tried to remedy this defect myself (see Monthly Notices of the Royal Astron. Society, April 1912), but I have reason to think that the simple definition there given is not yet very widely known. This being the case I have preferred not to change anything in the way of expression adopted in the lecture and to retain it in the Notes. This way may be less scientific but it is more generally understood.

2nd. For the greater part of the lecture use has been made only of *part* of the wood collected. For the regions summarized in figs I—V *all* the trees measured were included. But I have not discussed the wood collected near Bonn and Wesel, in Holland, in Oldenburg and near the Baltic <sup>1)</sup>. Of what was obtained from the neighbourhood of the Ems only one batch, that which shows the 12 year-period in such a remarkable way, was considered. The trees from these regions which were

<sup>1)</sup> An exception has been made for the investigation of the influence of temperature. See Note II.

measured are about equal in number to those discussed in the present paper, but they are mostly much younger. They show relatively little regularity. I suspect that most of this wood grew not in extensive forests, and that it is mainly in such forests, well situated in respect to subsoil-water supply that we must look for uniformity.

3d. Though the nature of the soil and the situation of the trees with respect to rivers etc. must be of greatest importance, my data about these points are very scanty. The cause is that most of my specimens were obtained from wood-merchants, who could not of course be expected to take particular interest in these matters. Even in a few cases there remained a doubt of a year about the date at which the trees have been cut down. Happily these cases are rare. By careful comparison with trees from the same neighbourhood about the date of which there is no doubt, they could usually be assigned without trouble to their proper epoch.

What informations I obtained (about the trees discussed in this paper) is embodied in the following summary:

(See pag. 73.)

4th. The results for the different trees were combined into normals in such a way that no tree would have a predominant influence. In order to reach this aim smaller weight was given to those trees of which the breadth of the ring is very considerable. Where the average growth of the same tree is markedly different for different periods of their life, these weights were correspondingly altered. Where for some larger period the breadth of the ring is exceedingly small, no good measures could be made at all. Together with the somewhat different year of cutting this accounts for the fact that sometimes the number of trees on which our normals rest is somewhat smaller in the later years than in the former. The numbers of trees which have contributed to our normals have

	Numb. of trees.	Place from whence obtained.	Winter in which cut down.	Soil.	Remarks.
Spessart	3	No. 1. ? 2. Rothenbuch 3. Lohr	1878-'79 id. id.	? red sandstone red sandstone	(1) These trees were measured in the yard of a wood-merchant in Groningen. Only for one of the trees he could tell me that it had been obtained from Lohr (Spessart). For the others no nearer place was assigned than the Main.
Steigerwald Id.	3	Castell	1879-'80	Lime-Stone ?	
Unter-Franken Main (1)	2	1. Sulzthal	1878-'79	?	
	1	2. Schwarzenberg	1879-'80	?	
	6	Reichenberg	1879-'80	?	
Treves	5	?	3. 1879-'80	?	(2) Date of cutting has been fixed by a comparison with wood from Treves.
		?	1. '78-'79	?	
		?	5. '75-'76	?	
		6. *) Kortel wald (?) rest ?	1878-'79	White sand	
Saarbrücken (2)	2	?	1879-'80	?	
Kaiserslautern	4	?	1878-'79	?	
Coblentz	7	?	1879-'80	Rocks near Kaiserslautern	
		Mostly Westerwald	4. '79-'80	Westerwald: soil fairly rich, not stony	
Taunus Vogelsberg Odenwald	2	?	3. '78-'79	?	
	2	?	1879-'80	?	
	7	Lorsch & Bürstadt	1879-'80	Alluvial, fairly rich, sandy — Always sufficient sub-soil water.	
				Sometimes rather too much. Must give a good representation of the tree-growth in these parts of the Rhine (Oberförster Engelhard).	
Ems	5	?	1879-'80	?	

\*) There were in my possession 6 discs; 5 only have been measured.

been inserted in our figures alongside of the curves. So for instance for the Main-wood (fig. II) for the years 1879 and 1878, 7 trees have contributed; from 1877—1875, 11 trees; from 1874—1870, 15; from 1869 to 1841, 16 etc,

5th. Some measurements have been made on the transverse section of the trees, while lying in the wood or elsewhere. Mostly however discs from 3—7 centimetres thick were obtained. These were then measured at leisure at home. In the beginning each disc was measured along 6 radii; afterwards this number was lowered to 3, in many cases to 2. A few of the trees have been only measured once. The measures were made with a millimeter scale. A magnifier was used in reading this scale to the nearest tenth of a millimeter.

6th. Parallelism of wood-growth with sun-spots, might readily be supposed to exist if we compare for instance the wood-growth of the trees represented in fig. VII with Wolf's relative numbers. As however according to the Main- and Moselle-trees such parallelism does not show in the same manner in the 18th century, I think the probability of a real connection very slender.

7th. The inspection of even a moderate number of wood sections shows that there are influences which, for longer periods, cause a gradual change in the wood-growth as measured by the breadth of the ring, changes which in many cases are different for different trees. Such must be the influence of age. Such an effect will also be introduced if a tree gets more and more hindered by surrounding trees etc. These slow changes are very apt to vitiate to some extent, our conclusions about the changes of shorter period, especially where we combine several trees into a normal. It is in order to get rid of these gradual changes that I adopted the method of expressing the growth in percents over and below the

average of the surrounding 15 years. I found the method very efficient. But of course such a process eliminates every trace of the longer periods, be they accidental or in the climate. The present study does not therefore give any contribution to the determination of slower changes in the climate. Such a determination by means of growth-rings must not be impossible, but it will require a great mass of material and the utmost care in the discussion.

8th. I am sorry to say that many of the tree-sections used for the present investigation are no longer in my possession. What is still in existence is now safely deposited in the *Botanical Laboratory* of Groningen.

Ladies and gentlemen. I am going to talk to you to night on the growth-rings of trees. How they may be considered to a large extent as nature's own registers of at least some of the main elements of the weather in long past years and how they thus offer an occasion of investigating whether or not some regularity in the recurrence of these elements of the weather can be discovered. Could such a regularity really be discovered, the importance of the fact could hardly be overestimated, for it is evident how then a basis would have been obtained for forecasting, in general traits and to a certain extent, the weather in coming years.

My own investigations in the matter were made about the years 1880—81. Though I spent quite a considerable time on them, I could not bring myself to publish my results, because I sorely felt how incomplete they were and because I hoped that, perhaps after some years, occasion would offer to obtain more satisfactory materials, which would lead to more reliable results. I am now sorry that I took this course. Had I then published my results, it would possibly have encouraged other men, in

a better situation than myself, to take up the question and we might now have some further and better results.

My intended trip to California brought this old investigation again vividly before my mind, because of all the countries of the world, California, with its old trees, is perhaps the one offering the best conditions. I resolved to take at least some of my work with me. It might help me perhaps in interesting somebody in your country in the matter, possibly in inducing him to take up this fascinating work, which does not require any very special training and may possibly lead to such important results.

I will not enter into details of my way of treatment. It would be tiresome. If anybody of you might ever want to take up such a study as this, if he will then take the trouble of writing to me, I will gladly communicate to him such expedients und details as experience has shown me to be useful.

There is another point which I wish to bring up before I enter on my subject proper. You may well wonder that I, who am an astronomer, am about to speak to you on a subject which has nothing to do with astronomy, especially on a subject — the regularity in the weather in longer periods — on which a great number of competent investigators have worked and — though for instance *Brückner* has brought to light traces of some periodicity — I think I am not saying too much, in affirming that up to the present very little has been achieved. This being the case you may well think it presumptuous in me, not a meteorologist, to handle the subject at all. My answer to this is: I have not the least intention of starting any new theory or of explaining the phenomena to which I wish to draw attention. I could certainly not do it. I wish merely to lay before you some observations and to point out some singular regularities in them. Nothing would certainly please me so much as that some compe-

tent man would find it possible to point out the true cause of these regularities.

Meanwhile conversations with meteorologists and botanists have left me little hope that it will be so. What I heard and what I read has long brought me to think, that in the present state of science any investigation on long period regularity in the weather must be a purely empirical one. The case stands much as with another question in the olden time of the Chaldaeans. At that time the eclipses were the all-important astronomical phenomena and, wanting to be able to predict them, they sought whether there were any regularity in their occurrence.

They found that there was: that after the lapse of 6585 *days and 8 hours* they recurred pretty nearly in the same order and appearance. This is the famous period called the Saros. They must have found this simply by making long long lists of eclipses, continued for many many years, in very different places of the earth. From such lists they might find out what they sought for, without their knowing the true theory of the motions of Sun and Moon, that is without their being really scientific astronomers. Their hope was not in vain. It must have been by means of this Saros that Thales was enabled, 600 years before Christ, to predict his famous eclipse.

Now, as it was with the eclipses, it might be with the weather. Though the empirical finding out of a regularity may hardly be claimed as a scientific achievement, it may nevertheless become in future of the greatest utility in weather forecast a long time in advance.

But there is more, which makes that, at the present time, the problem may be taken up by other men nearly as well as by meteorologists. Take the rain. In order to find out whether there be any regularity in the recurrence of wet and dry years, if we will have any



reasonable hope of obtaining our end, we will necessarily, first: have to consider either the rainfall of the whole of the earth, or at least of large areas, for it is well known how much the rainfall may differ in different localities. That is, we will have to collect our data at a great number of different places. Meteorologists are so well convinced of this that for the British Isles alone they have over 2200 rainstations and they still complain that this number is hardly sufficient. Second: In order that any regularity, if it exists, may show itself clearly, we needs must have *extensive series*, series extending over more than a century, probably over many centuries. Now such series do not exist in meteorology. There are 2 or 3 somewhat long series, but these are evidently insufficient.

Of course the way of the meteorologists is the kingly road. If, as no doubt they will, they extend their observations to a still greater number of stations, they will, in a few centuries, collect materials such as we cannot imagine of getting in a different way. But we are impatient. In one of his letters Darwin says something to the effect that it is quite necessary to collect materials for future investigation, but that he has no respect for the man who is content to do that and nothing else.

The question in my opinion thus is: Leaving the refined investigation of the meteorological data to the competent men of the future, cannot we provisionally find another, be it far more imperfect, way, independent of any thing that is done by the professional meteorologist, to provide ourselves with data about the weather, which satisfy these two conditions:

*first:* of existing for a great number of different localities on the earth;

*second:* of extending over long series of years.

I think we can by consulting the registers kept by nature herself in our trees. For there are plenty of trees all over the world and many of them attain to a considerable age. By them we may get data not only of prehistoric, but even of geological time.

The idea of conceiving the trees as natural registers seems so natural that it must have occurred to several minds.

Even the use of the growth-rings as a means of finding out a connection between the weather in past years and the tree-growth is certainly not new. — Meanwhile I was unable to find any regular investigation on the subject extending over a period of more than just a few years. — This gives me the courage to lay before you my very fragmentary study, which, however, was carried through with the definite aim of finding out some regularity.

I have confined myself entirely to the investigation of oak-trees. Other kinds of trees may prove preferable for definite purposes. But as the limited time at my disposal made a choice necessary, I naturally chose the kind of wood which in our parts is easily obtainable from all sorts of localities and which usually is not cut down at so early an age as our other trees.

Suppose such an oak-tree cut down at the present moment and suppose that we get a cross-section of that tree at some distance from any place where a root branches off. The section will then show a series of pretty regular concentric rings, which we call the growth-rings. The wood between the bark and the first ring will represent the growth during the year 1908. The growth during the year 1907 will be represented by the wood between the 1<sup>st</sup> and 2<sup>nd</sup> ring counting from the outside towards the centre and so on. We thus have only to know the year in which the tree

was cut down to know the year corresponding to all the rings.

For my investigation I began by collecting discs of trees from various parts of Germany and Holland. In this lecture I will mainly confine myself to the forests along the Main, the Moselle and to some of the forests not far from the Rhine between Worms and Bonn. On each cross section under examination I first drew a pencil line beginning at the centre and crossing all the rings at right angles. Along this line I measured carefully the breadth of all the rings and they were recorded against the years in which they grew. In order to improve the accuracy I usually repeated the same thing along several other radii.

We thus obtain at once a fairly good measure of the yearly growth of the tree during the whole of its life.

Having done the same for all the trees in the region now under consideration, I found at once that there was a considerable agreement in the growth in contiguous forests. This is not always the case, proving that what the trees register depends on their situation. It is pretty evident that this must be so. For a tree standing on the border of a lake at a pretty constant level must not be so strongly dependent on the quantity of rain as other trees, not so well situated, and so in other cases. But for the forests now under consideration the parallelism is very striking and other and more direct data being not available, I took this as a proof that the trees in the different forests must have been growing under much the same conditions. This enabled me to combine all my results into four *definitive results*, (see Tab. III figs. II, III, IV, VI) three of which represent approximately the tree-growth for an area about equal to  $\frac{1}{6}$  part of Holland, while the fourth is restricted to a smaller area. The combination

of the several trees must be made in a particular way in order to give the most reliable result, but this is a point of detail into which I will not now enter.

Now let me show you what results the investigation brought to light.

I. *The very considerable fluctuations which appear in the yearly growth of the oak-wood of the region under investigation must in great part certainly be due to meteorological influences.*

*Proof.* The proof of this proposition is furnished by the figures I now throw on the screen (figs. II, III, IV, V). The tree-growth has been graphically represented in this figure. Each vertical line represents a determined year. On this line (see number at the top of the plate) has been plotted the growth in the year 1700 on the next line that of the year 1701 and so on. The growth itself was expressed as a fraction of the average growth and as average growth was considered the average growth of the surrounding 15 years.<sup>1)</sup> The number of trees on which the results depend have been marked on the curves. Owing to the different ages of the trees, this number generally decreases as we pass to earlier dates.

Now then: what proves that the fluctuations in the growth-curves are not due to local causes (depending, say, on cutting down of surrounding trees; on artificial irrigation questions etc.) is their parallelism. Generally

<sup>1)</sup> That is the mean growth of the 7 preceding years, the year itself and the of following years.

In Figs. I—V the average growth has been represented by 20. The interval between two consecutive lines thus represents 5 percent of the average growth. Thus in Fig. II the growth in the year 1834 is 31 percent above the average. In Figs. VI and VII the average growth is taken = 10 and the interval between two horizontal lines represents consequently 10 percent of the average growth.

where the growth is great in the upper curve, which is the Main curve, it is great in the two following ones which are the Moselle-curve and what we might perhaps call de Rhine-curve. Where the growth is small in the upper one it is generally small in the others. There are exceptions, but then the meteorological influences: temperature and especially rain are not the same for different regions. They have much in common but still are not at all the same. The point is that the parallelism is so great that on an average, if at the Main the growth is double the mean growth, it is more than 50 % above the mean at the Moselle, at a distance of 140 miles. Now this could never be if the fluctuation were due to local influences.

II. *The temperature has, generally speaking, a very small influence in these regions.*

*Proof.* Although we have no long series of temperature records for our regions, we have lists of

Hot summers

Cool „

Cold winters

Mild „

Now for all the hot summers I got out the average growth; likewise for the cool summers. There is hardly a difference.

In the same way the growth in the growth-season after very cold winters proves to differ but little from that after mild winters <sup>1)</sup>).

III. *For part of our materials at least, the rain, falling in spring and summer is of the greatest influence.* The fact can be proved only for *part* of our materials, because we have no extensive data about the rain near the greater part of our forests. But for the city of Treves we have respectable data and comparisons with the trees

<sup>1)</sup> See note I.

felled near Treves could be carried through. The figure thrown on the screen shows the result.

In the last figure (Tab. IV, Fig. IX) the full line represents the tree-growth in percents over or below the average growth. Each interval represents 5 percent of the mean growth.

The dotted line similarly represents the height of the rainfall in spring and summer over or below the average. Only the fluctuations have here been reduced about two times <sup>1)</sup>.

We see that the parallelism is quite close.

In fact I find that on an average, if at Treves the height of the rain during spring and summer has been 100 percent over the average, the growth of the trees here investigated has been 48 percent over the average. The result has been extended somewhat for years in which no rain measurements have been made, because we possess some further countings of the number of rainy days. The result has been shown in Tab. IV, Fig. VIII. Computation shows that on the average, when the number of rainy days in spring and summer is 100 percent above the mean number, the wood-growth is 40,6 percent above the mean. From a similar comparison made between winter-rain and wood growth, we find hardly any trace of an influence.

I know that this result is in contradiction with what so high an authority in forest matters as Ebermayer maintains, who judges that winter-rain and snow is of far greater importance for our forests <sup>2)</sup>. But I cannot see how, for the Treves wood under consideration, we can, with any possibility, escape from our conclusion. Meanwhile we must take care not to extend our conclusions farther than

<sup>1)</sup> See note II.

<sup>2)</sup> See for instance Ebermayer, *Die physikalischen Einwirkungen des Waldes etc.* Berlin 1873, p. 197 en 198.

we have a right to. So for instance we have some data for the rain at Frankfort, which is not far from the place of our Rhine wood. Now the comparison here led to the result that spring- and summer-rain, have but an insignificant influence, whereas winter-rain shows some, though not very appreciable influence. In fact we already drew attention to the fact that the influence of rain must not be the same for all trees. It is evident that in a more complete study than the present can pretend to be, we ought to try to obtain complete data of the soil and situation of each tree we use for our purpose. Meanwhile in many cases, having once found a tree which can be proved to have been sensitive to rain during, say, the last 20 years, as it has not changed place since its birth, if there seems to be little possibility of a fundamental change in the watersupply, it can be used as a rough sort of raingauge for all the preceding years of its life, which may be centuries.

IV. *In many cases, perhaps in all, increased tree-growth is not caused by the greater quantity of rain directly, but indirectly through the greater height of the subsoil water.*

*Proof.* This is proved by a case which at first puzzled me very much. Whereas, as you have seen, there is a striking parallelism between the growth in the forests of the Main and those of the Moselle, there is a forest *between* the two, part of the Odenwald <sup>1)</sup>, where the parallelism is no doubt still well recognisable, but where it still is far less.

I collected my tree-sections near a place called Bürstadt. My difficulty was later on removed by a report in the papers, of an inundation of the Rhine, which caused the

<sup>1)</sup> Locally the forest is called the Lorsch Wald but I understand that it is an outlying part of the Odenwald.

town of Bürstadt to be partly flooded. I thus got to know that my trees grew only very little above the level of the Rhine and it seemed at once rather probable that the growth might be mainly dependent on the height of the subsoil water which in its turn would depend on the level of the Rhine. To test this idea I hunted out some data about the level of the Rhine. — I did succeed only in finding the mean level of the Rhine

for each year between 1840—'74 at Mainz

" " " " 1770—1835 at Emmerich.

I had little hope that these would furnish a really definitive result because I wanted:

a. the mean levels for the different seasons and *not* for the whole of the year, and then

b. at a place nearer to my forest than Mainz and especially than Emmerich, which is already on the border of Holland.

To my surprise I found that notwithstanding this, the parallelism is quite evident. In years in which the mean level of the Rhine is one meter over the average level at Mainz, the growth in our forest is 32 percent above the average. Even with the Rhine-level at Emmerich, the parallelism is still clearly indicated. If the yearly mean level of the Rhine at Emmerich is one meter above the average, the average woodgrowth at Bürstadt is 12 percent above the average. I similarly find a strong parallelism between the tree-growth along the Weser and the height of the level of that river.

There are other facts pointing to the same conclusion, but these may be deemed sufficient.

*V. In every year there was produced but one single growth-ring, at least this was the case in the last 70 years. If, what seems improbable, the same thing does not hold in earlier years, then the anomaly must have occurred everywhere at the same time.*



*Proof.* I introduced this proposition because botanists told me that many cases are known in which it does not absolutely hold. For our trees there can be no serious doubt. For: suppose that between 1830—1850, not 20 but 21 rings had been formed. Then the parallelism which we see in our figure IX between the full-line—representing wood-growth and the dotted line representing rain, before 1830, would have to be regarded as accidental. For the full line would be out of place and would have to be shifted towards the right for one year. Now such parallelism can certainly not be accidental. Therefore our supposition of the growth of two rings in one year must be rejected. For the time before the beginning of our rain-data for Treves we cannot give this proof. — But the parallelism between the tree-growth at the Main and at the Moselle proves, in quite a similar way, that if an exception has happened at one place it must have happened at the same time elsewhere. For without that the parallelism would certainly have been destroyed.

VI. Lastly. *It seems as if during pretty long intervals of time, there is not only a regularity, but an actual pretty constant periodicity in the growth of the trees.*

*Proof.* Figs. I and V show this very clearly. The first curve was obtained by slightly smoothing the Main-curve. The smoothing was obtained by simply plotting over each year the mean growth of that year with the year preceding and the year following. From the year 1659 to 1784 at least, that is for a period of 125 years there is clearly indicated a period of about 12.4 years. After that year, though a pretty regular fluctuation continues, the period has become longer. That the *amplitude* of the fluctuations seems to die out at the same time is simply caused by the fact that in these later years, the greater part of our trees are pretty old. It seems that the variation in growth decreases with the age of the trees.

I possess a good many discs of wood from the North of Germany, near the Ems and the Weser. To my regret they are cut down at an earlier age, so that I could not procure specimens even fully 100 years old.

One batch of these, however, show a very suggestive fact.

The fact is that, whereas for the trees which we have been considering all along and which I will call our southern trees, the  $12\frac{1}{2}$  years period dies out shortly before the beginning of the 19th Century, it reappears or continues to exist in North Germany.

Not only is the length of the period exactly the same, but the years of maxima and minima occur just at those epochs at which the prolongation of the southern curve would place them. — So that finally, if we combined the results for this particular wood with those for our southern trees, we would have a curve showing a regular fluctuation in 12.4 years during the whole of the two centuries for which I have somewhat extensive materials <sup>1)</sup>. Only one minimum, that of 1794 would be missing.

VII. However I will not insist on the importance of this period. I feel that it is still strongly in need of confirmation.

But suppose that further materials confirm it. What would it mean? Would it mean a period of 12.4 years in the weather?

For me there is no doubt about it. Would it mean such a period in the spring and summer rain? This seems much more doubtful, although certainly it is not impossible. We have not to forget that, though we have proof of a strong influence of rain on the growth of our trees near Treves, we certainly cannot maintain that there are not several further factors, which have their influence also.

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<sup>1)</sup> See Note III.

And then that, though there is a strong parallelism of the Treves-growth with that of other parts of the region investigated, this parallelism is not in any way perfect.

I do not give the facts brought out in this lecture as well established proof of a regularity in the weather. The only thing I would claim for them is that they are full of promise.

And they lead us to put definite questions, which in my opinion is one of the main points in scientific research. To take one instance: what does the fact mean that this  $12\frac{1}{2}$  years period may disappear in one place, and the same time clearly show in another?

VIII. And now, to bring this talk to a close, a few words about the particular fitness of California for this particular branch of research. California has many trees, but especially California has her very very old trees. Think of the enormously improved chances of success if our series instead of embracing 2 centuries, would embrace ten times as long a time. Now trees of 2000 years must exist here. I was even told that actual count of the rings has proved the existence of trees of 4000 years! That is, provided that we admit that, here in California too, there never grows more than one ring in a year. A single tree of such an age, if favorably situated, I mean situated in such a position and in such a soil that it proves to be especially sensitive to some of the meteorological factors, or at least showing large fluctuations, may prove a real gold mine for the meteorologist. Through the courtesy of Prof. Mc Adie of San Francisco, I am enabled to show the representation of the rings of a Sequoia of 1244 years old.

Several of the principal historical events have been noted against the rings that grew at those times. The drawing cannot be well seen from your places, but those that are interested may see it after the lecture.

I do not know whether the breadth of the rings has been accurately reproduced and have not made measurements, therefore. Still I could not resist the temptation of reading off some of the times of conspicuous maxima in the growth.

To my satisfaction — also, I confess, to my small surprise, I find that they lie, nearly all, 12.4 years or multiples thereof, apart.

I do not mean that each 12 $\frac{1}{2}$ th year you will find a maximum. Often there will be no well marked maximum. But the existing maxima lie multiples of that period apart, or very nearly to. Not only that. This period leads us, in the 18th and 19th century exactly to the years of maximum found for the European trees.

There may be much in this which is accidental.

Still, I think, you will not wonder, that I conclude by expressing the hope that somebody may be found in your country to take up this interesting question, which, perhaps nowhere in the world holds out as good a promise of success.

As the time is still early let me add one last word.

It seems not probable that we will find trees wholly dependent on rain or wholly dependent on temperature or, in short, dependent on one single factor. Now in one sense this is certainly a great drawback. It would be beautiful if we could have some very old tree which would be practically a rain-gauge for the last 2000 years and another, of another species and perhaps very differently located, which would similarly have taken down the average summer temperature during that same interval and so on. Such an ideal case is too good to be believed in. In all cases the growth will certainly depend, though in a very different degree, on many, if not all the meteorological elements.

But just such a combination it might be interesting to find out.

Suppose for instance that in English India, in the region where famines occur somewhat periodically, we could find out some tree or other, the growth of which depends approximately on the same conditions of the weather as those on which the success of the rice-crop depends. It does not seem to me so improbable that such a thing might be found. Well then, if it so happens that this tree reaches a considerable age, we would have the means of studying whether there is a regular recurrence in the return of the bad conditions for the rice-crop. The importance of such a regularity caused, years ago, several investigations to be made into the existence or non existence of such regularity.

No conclusive results were reached.

The very long and authentic records of trees might perhaps have furnished the means of attaining an end that could not be attained by the more direct but very imperfect records of the past.

### Notes.

I. The following table rests on data more extensive than those mainly used for the lecture. The cold winters were borrowed from Köppen, *Zeitschr. Oesterr. Ges. für Meteor.* 1881, Vol. 16, p. 186.

The mild winters, cool and hot summers were borrowed from a work by Hahn on Sun spots. (See page 91).

The numbers in brackets represent number of winters or summers. In computing the means, the weights have been taken proportional to these numbers.

The only positive indication furnished by this table, is a slightly injurious effect of a cold winter, preceding the growth-season.

*Summary. Wood-growth in percentages above the average.*

	WINTER.		SUMMER.	
	Cold.	Mild.	Cool.	Hot.
Main . . . . .	— 4.0 (64)	+ 3.3 (23)	— 4.4 (31)	+ 3.7 (35)
Trier, Kaiserslautern, Saarbrücken	— 2.5 (33)	— 3.4 (23)	— 3.4 (31)	— 2.6 (35)
Coblentz, Taunus, Vogelsberg .	— 5.6 (51)	+ 1.9 (23)	— 4.4 (31)	+ 1.2 (35)
Lorsch (Odenwald) . . . . .	+ 2.5 (37)	— 2.4 (23)	+ 3.5 (31)	— 4.5 (35)
Meckenheim (near Bonn) . . . .	— 8.8 (7)	— 2.5 (9)	— 4.4 (13)	— 0.9 (16)
Apeldoorn (Holland) . . . . .	— 5.4 (37)	— 1.1 (23)	— 8.2 (31)	+ 2.4 (35)
Ems I, Oldenb. I . . . . .	— 12.3 (6)	+ 0.8 (7)	— 4.8 (8)	— 5.7 (9)
Ems I, Oldenb. I . . . . .	— 3.6 (6)	+ 14.2 (7)	— 4.1 (8)	+ 7.3 (9)
Ems I, Oldenb. I . . . . .	— 6.3 (6)	+ 5.4 (7)	— 0.1 (8)	— 2.0 (9)
Oldenburg II . . . . .	— 6.6 (6)	— 1.2 (7)	+ 3.6 (8)	— 4.3 (9)
Ems II . . . . .	— 11.3 (6)	— 8.8 (7)	+ 13.6 (8)	— 16.2 (9)
De Punt (near Groningen). . . .	— 11.9 (6)	— 8.9 (10)	+ 3.9 (11)	— 7.5 (15)
Weighted mean . . . . .	— 4.2	— 0.3	— 2.2	— 1.2

II. More accurately. They have been multiplied  
in the period 1806—1830 by 0.543  
" " " 1849—1878 by 0.442  
weighted mean 0.481.

Fig. IX therefore shows for instance that in the year 1870 the tree growth was 25 percent (of the average tree-growth) below the average, whereas the rain was  $20.5/0.481$ , that is 43 % (of the average rainfall) below the average. Of course the factors 0.543 and 0.481 were determined in such a way that the fluctuations in rain and wood growth in the figure become most nearly equal.

Adding the probable errors, what I found was:

A. On an average, if rain-height in spring and summer is 100 percent above the average, the growth is 48 percent  $\pm 5$  above the average.

B. If the number of rain-days is 100 percent above the average then the tree growth is  $40.6 \pm 6.5$  percent above the average.

As for the influence of winter-rains or snow I find in Treves that the influence is vanishing.

On the other hand the comparison of the wood growth of our trees from Coblenz, Westerwald, Taunus and Vogelsberg (see fig. IV) leads to a very small influence of spring and summer rain, whereas there is a decided favorable influence of winter-rain (or snow), the result being:

If at Boppard and Frankfort, the rain and snow in winter is 100 percent above the average, the tree growth in the following summer will be above the average (in the forests mentioned)

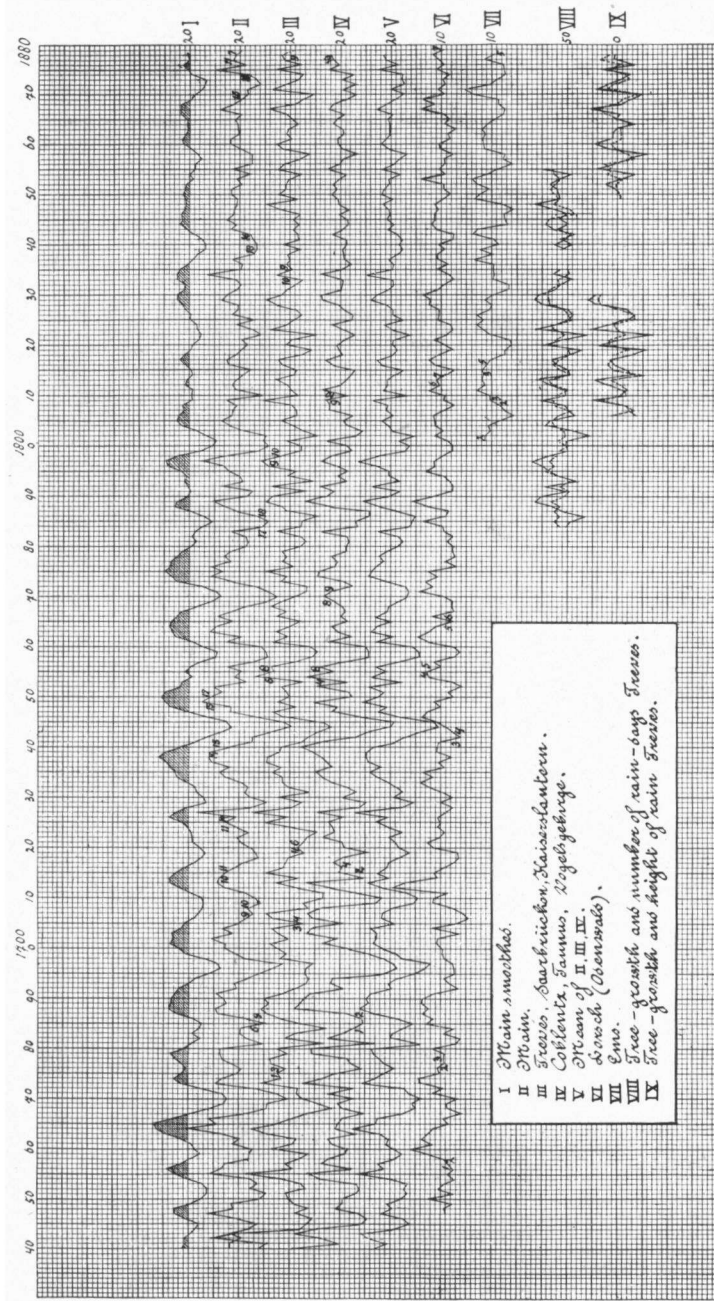
$13 \pm 3$  percent.

III. More accurately, I find from the Main and Ems curves: Epoch of minimum 1745.6, period 12.36 years. In other trees there is also the indication of a period of 16.54 years, with the epoch 1751.7 which may really have to be subdivided in two periods of 8.27 years. It is to be noted that  $12.41$  is exactly  $= \frac{3}{4} \times 16.54$  <sup>1)</sup>.

The theoretical times of minimum corresponding to the 12.43 year-period are:

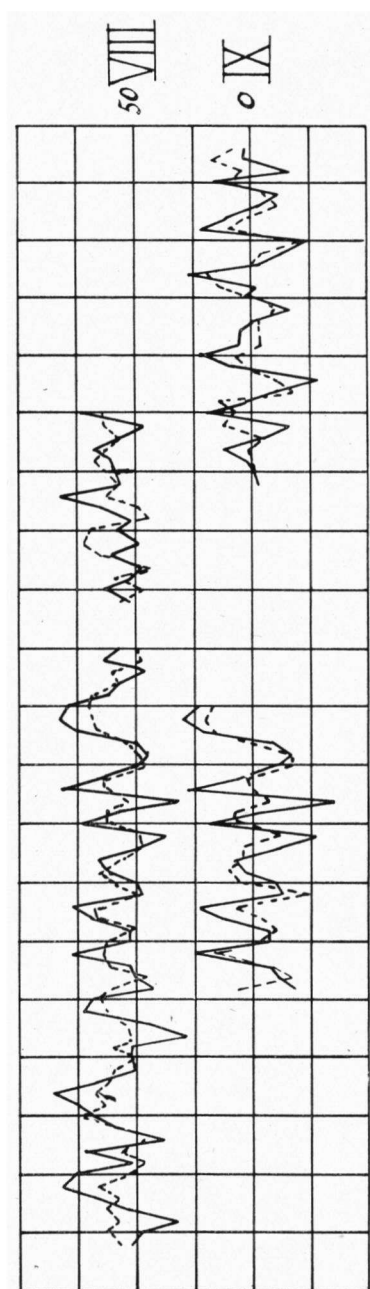
1659.1	1708.5
71.4	20.9
83.8	33.2
96.2	45.6

<sup>1)</sup> This fact might perhaps suggest the feasibility of the development of the wood-growth in a Fourier series.



Figures VIII and IX somewhat magnified see next tab.





1758.0	1819.8
70.3	32.1
82.7	44.5
95.0	56.8
1807.4	69.2

Fig. I shows that the first 11 actually agree very closely with all the minima of the Main-wood.

Fig. VII shows the 6 last to be very nearly accordant with the minima in the Ems-wood.

It is to be noted that in comparing these numbers with the years as read off from our figures, the latter have to be increased to 0.5 years, the middle of the growth period agreeing about with the middle of the year.