RADIAL GROWTH OF SPRUCE IN CORRELATION TO METEOROLOGICAL PARAMETERS

G. Gietl

Bayerische Forstliche Versuchs- und Forschungsanstalt
Amalienstr. 52, D-8000 München 40, West-Germany

SUMMARY

By the means of electrical transducers the radial growth of spruce stems of different tree classes had been recorded in different heights above ground in the IHD/IBP Project "Ebersberger Forst". The data of 1965 had been investigated and correlated with meteorological factors. The daily radial increment D could be determined by the meteorological parameters air temperature, relative humidity and global radiation. A phase-displacement for each parameter and a feed back function had been integrated into the multiple regression equation.

Keywords: radial growth, spruce, forest meteorology.

Z U S A M M E N F A S S U N G

Mit Hilfe induktiver Weggeber wurde im IHD/IBP-Projekt "Ebersberger Forst" das radiale Wachstum von Fichten verschiedener sozialer Klassen in unterschiedlichen Höhen über dem Boden gemessen. Die Zuwachsdaten des Jahres 1965 wurden untersucht und mit meteorologischen Werten korreliert. Dabei konnte der tägliche Durchmesserzuwachs allein aus den meteorologischen Größen Lufttemperatur, relative Feuchte, Globalstrahlung und Niederschlag bestimmt werden. Eine Phasenverschiebung für die einzelnen Parameter und eine Nachwirkfunktion wurden hierzu in die Gleichung der Multiplen Regression integriert.

I N T R O D U C T I O N

This paper is based on the research work done under the guidance of Prof. Dr. Albert Baumgartner within the frame of IHD and IBP at the former Institute of Meteorology of the Forest Research Station in München, West-Germany. The matter used originates from the thesis by L. Klemmer (1969).

Stand

The experiments for the investigations were carried through the years 1963 to 1966 in the "Ebersberger Forst", an homogenous, about 73 years old spruce stand which can be characterized by the following indices:

mean upper height	29,7 m
mean height	27,2 m
mean diameter	29,4 cm
number of stems per ha	800
mean diameter increment (1963-1968)	0,28 cm a^{-1}
mean height increment (1963-1968)	0,15 m a^{-1}

The stand is growing on a gray brown podsolic soil of mean depth over gravels rich in lime.

Selected trees

For the studies in the experimental plot three vicinal stems of different social position were selected (fig. 1; tab. 1)

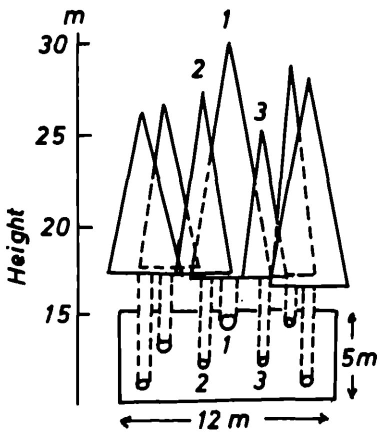

fig. 1: scheme of the experimental plot

Nr.	$d_{1.3}$ (cm)	height (m)	social class (acc. to Kraft)
1	42.0	30.4	I predominant
2	26.7	27.6	II dominant
3	21.0	25.2	IV a dominated

tab. 1: description of the selected trees

Measurements

To each of these three stems an electrical transducer was fixed in the height of 1.3 m in order to determine continually the radial change. For special investigations at tree Nr. 2 a second transducer was mounted in the height of 17 m just below the canopy. The degree of accuracy was in the range of 1 μm.

The meteorological parameters needed for the investigations were measured at a height of 32 m on a tower built up at the experimental plot. For the purpose of calculations they were summed up to hourly values.

DIURNAL VARIATION OF THE RADIUS

Observations

First results of the transducer-registration show two principally different diurnal variations of the stem radius belonging to two typic - in this connexion extreme - atmospheric conditions.

In a schematized way the change of the radius during an overcast day can be described by a continuously ascending curve. The radius increase corresponds - more or less - with the radius-increment. The daily increment can be calculated by the difference between the maximum (at 24^{00}) and the minimum (0^{00}) (fig. 2).

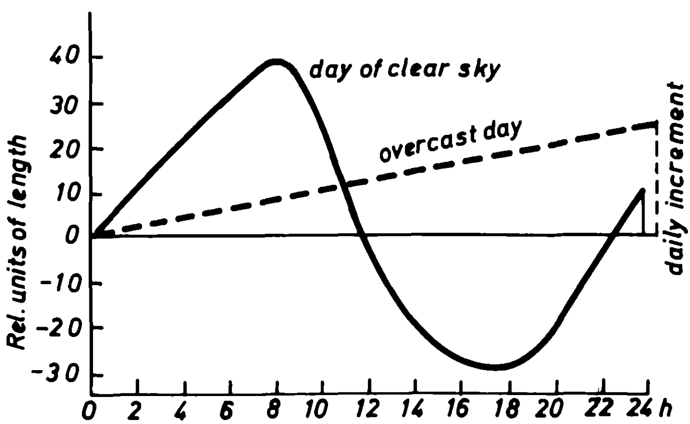

fig. 2: Schematized diurnal variation of the radius

During a clear day the radius variation related to the radius at 0^{00} can be reproduced by a sine curve. In the typic case the radius at the end of the day is greater than that at the beginning; in analogy to the first example the difference between both corresponds with the radius increment. The diurnal variation of the radius is caused by reversible processes, by swelling and shrinking of the whole stem or parts of it.

Reversible processes

Separate investigations have shown that the swelling and shrinking of the wood is less than 1 μm. For that reason it can be stated that the diurnal variation of the diameter, which superposes on the change of radius by the irreversible increment, is caused by swelling and shrinking of the bark. The variations of the water content in the bark are evoked by water diffusion from the stem into the air and by translocation of water from the bark into the sapwood (or vice versa), following the water potential gradient.

This influence of the transpiration process on the water content in the bark becomes evident by the time the minimum radius is reached. At first it occurs at the dominated tree, at last at the predominating tree due to the differences in the available energy for transpiration. Looking at only one tree the maximum and minimum of stem diameter occur sooner in the upper part of the stem than in the lower one. The time lag of swelling and shrinking in the vertical direction, owing to the vertical time lag of the water potential variation in the sapwood, is obsiously induced by transpiration.

Harmonic analysis

Because transpiration and diffusion are processes controlled by the atmospheric conditions one is enabled to relate the diurnal radius variation to meteorological parameters. A suitable way for it is the harmonic analysis since the change of the radius as well as most of the meteorological parameters have a wave-like diurnal variation.

In the ideal case the diurnal variation of the diameter, which includes the reversible and the irreversible increase, corresponds to a single wave with a length of 24 hours. In the reality oscillations of different frequencies are superposed on the fundamental wave. In this investigation a function of 5th order revealed to be sufficient for the description of the studied diurnal variations. For the correlation between the meteorological parameters and the radius variation the first approximation meets the requirements. In particular it is valid on clear days where the amplitude of the first approximation is high compared to those of the other oscillations. The rainfall-events and -intensities surely cannot be represented by means of harmonic analysis.

	maximum increase	maximum decrease
tree no. 1	0 h 30 min	12 h 30 min
tree no. 2	0 h 30 min	12 h 30 min
tree no. 3	23 h 15 min	11 h 15 min

tab. 2: times of extreme radial variations, calculated by the means of harmonic analysis.

The mean radius variations show the maximum increase about midnight and the maximum decrease at noon (tab. 2). Considering a phase-displacement they are positive correlated to the relative humidity and negative to the air temperature and the global radiation (tab. 3).

		pos. correlated	neg. correlated
global radiation	tree 1 and 2		- 15 min
	tree 3		- 1 h 30 min
air temperature	tree 1 and 2		- 1 h 45 min
	tree 3		- 3 h
relative humidity	tree 1 and 2	- 1 h 30 min	
	tree 3	- 2 h 45 min	

tab. 3: phase-displacement of the radius variation compared with meteorological factors

D A I L Y I N C R E M E N T O F T H E R A D I U S

In order to determine only the real irreversible increment by meteorological parameters it is necessary to use longer periods of observation, excluding more or less the diurnal variation. The daily radius increment therefore is defined as the difference between the radius at 24^{00} and that at 0^{00}.

$$D = \Delta_r = r_{24^{00}} - r_{0^{00}} \qquad (1)$$

O b s e r v a t i o n s

Periods of reversible increase

These daily increments are combined in a curve adding up the increment D during the growing season from May until September. As one can see in the curve of the month August 1965 (fig. 3) there are still periods of negative increment, clearly explainable as shrinking periods.

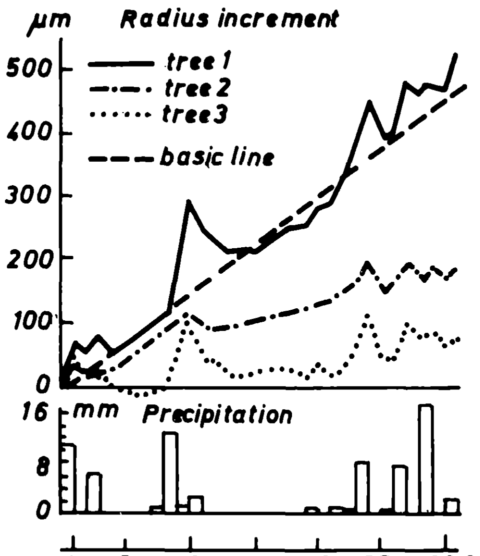

fig. 3: daily radius increment in August 1965

They follow a previous steep increase of the daily increment the starting point of which coincides with heavy rainfalls. In analogy one can conclude that the steep increase is caused by swelling processes. The irreversible increment is assumed to be represented by the basic line of the curve.

Seasonal increment

By plotting the basic lines for each month one gets a curve of the radius increment during the growing season with a gradual increase of radial growth in May, the main increment during June and July and a slow down in August and September (fig. 4).

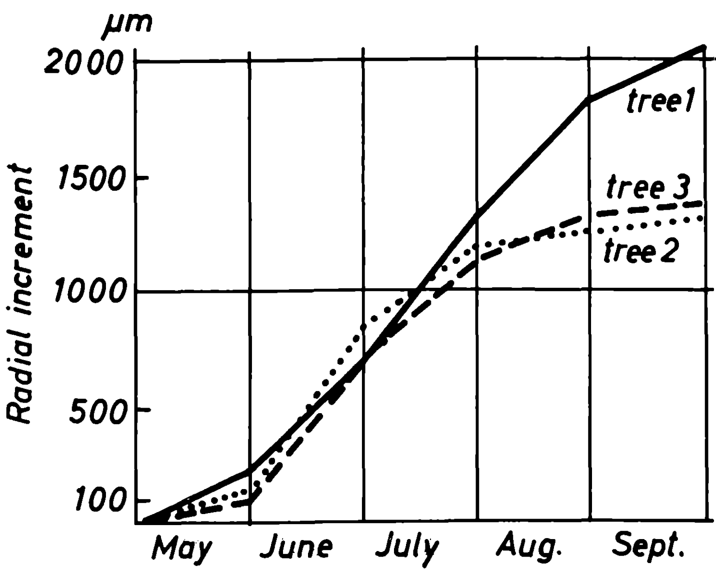

fig. 4: mean development of the irreversible radial increase (1965)

Investigations of this seasonal periodicity by means of harmonic analysis and correlations with the meteorological parameters did not yield utilizable results.

Multiple regression analysis

For this reason it was tried by means of multiple regression analysis to reproduce the relation between the radial growth and those meteorological parameters which are assumed to be of influence on the increment.

The used parameters were

global radiation	Q
relative humidity	U
air temperature	T
precipitation	P

For all variables daily values (for the period 0^{00} - 24^{00}) were used.

D, the radial increment, corresponds to Δ_r; T and U are mean values; P and Q are sums.

Phase displacement

First calculations showed, that the meteorological parameters - similar to the calculation of the diurnal variation - are well correlated with the radial increment taking into account a phase-displacement. The best results one will get is using phase-displacements of - 4 h for air temperature and relative humidity, - 6 h for precipitation. For this reason for the further calculations daily mean values of temperature and humidity were calculated over the period from 21^{00} of the day before to 20^{00} of the day of observation, the daily sum of precipitation from 19^{00} of the day before to 18^{00} of the day of observation.

Feed back function

According to the hypothesis, that atmospheric conditions of the days before have an influence on the radial growth decreasing with the distance in time, several feed back functions were tested. The best results were obtained by an exponential function in the following form:

$$f(t) = e^{1+t} \qquad (2)$$

where t is the number of the day with a meteorological feed back.

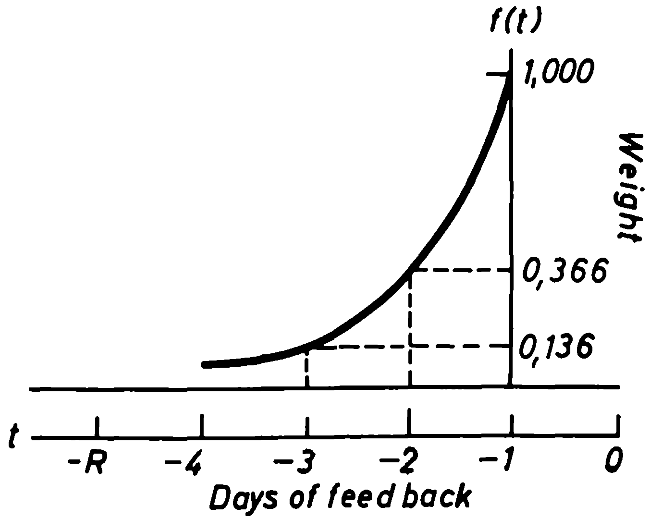

fig. 5: feed back function

This function assigns the weight factor 1 to the meteorological parameters of the last day, to these of the day before last the weight 0.366, and so on. The minimum range of feed back is 3 days.

Regression equation

By integrating the feed back function into the multiple regression equation the principle equation can be written as follows:

$$D = a\,Q + b\cdot U + c\,T + d.P + e\cdot\sum_{t=-1}^{-R} f(t)\cdot Q_t + f\sum_{t=-1}^{-R} f(t)\cdot U_t + g\cdot\sum_{t=-1}^{-R} f(t)\cdot T_t + h\cdot\sum_{t=-1}^{-R} f(t)\cdot P_t \left[+ i\cdot\sum f(t)\cdot D_t\right] \quad [3]$$

The dependent variable D is determined by the four independent meteorological parameters and the radial increase of the days before. The equation was solved for each month and each tree separately.

From the results of the multiple regression relative contributions X_i of the meteorological parameters to the radius increment D were calculated in the following way (e.g. for global radiation)

$$A_Q = a \quad Q + e \quad \sum_{t=-1}^{-R} f(t) \quad Q_t \tag{4}$$

$$X_Q = \frac{A_Q}{D} \quad 100 \tag{5}$$

As one can see in tab. 4, the relative contributions of the meteorological parameters change during the growing season. The air temperature is most important in July, while the relative humidity reaches its main importance during May and the global radiation in September. The relative small contribution of the precipitation may be caused by the compensating effect of the stored water in the soil.

	May	June	July	Aug.	Sept.
regression coefficient R	0.95	0.84	0.96	0.83	0.79
mean error (%)	20	34	19	41	39
mean radial ($\mu m \cdot d^{-1}$) increment	8.2	18.0	22.1	18.4	5.9
mean relative contributions					
X_Q	3	5	9	16	<u>31</u>
X_U	<u>73</u>	55	31	47	51
X_T	21	33	<u>43</u>	27	11
X_P	1	7	<u>13</u>	6	6
(X_D	2	0	4	4	1)

tab. 4: results of the multiple regression analysis for tree no. 1

C O N C L U S I O N S

Interpreting the results of the multiple regression the following conclusions can be stated:

- The correlation between the radius-increment and the studied meteorological parameters is significant.
- The weather conditions effect the radial increase after some hours of phase displacement.
- The weather of the days before influences the radial growth. The weight of the influence is representable by an exponential function.
- The individual meteorological parameters have a different influence on the radial growth during the different periods of the growing season. This fact is important especially in the field of dendro-climatology, where the total width of the annual rings is correlated with climatic data.

Literature

Klemmer, L., 1969: Die Periodik des Radialzuwachses in einem Fichtenwald und deren meteorologische Steuerung. Wissenschaftliche Mitteilung Nr. 17, Universität München - Meteorologisches Institut, 85 pp.

All figures are according to Klemmer, L. (1969).

September 1980