Characterized Growth Rings of Tropical Trees in Northern Borneo.

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Introduction.

Trees grow while recording climatic conditions of some sort in their trunks. In other words, a tree is a living recorder that records in growth environmental conditions such as climatic conditions. Each researcher has analyzed annual rings and growth rings. The results of research are systematized as dendrochronology and dendroclimatology. Now, voluminous knowledge has been accumulated [1].

Dendroclimatology and dendrochronology actually consist of analyzing annual rings. Therefore, the object region in many researches is almost limited to middle and high latitude regions. Until recently tropical regions have been largely neglected by researchers.

A stagnation period of growth does not always exist in the tropical rain forest. Due to a general lack of swasonality, in tropical rain forests, many species do not form distinct rings like the annual rings of wood in the Temperate Zone [2].

There are a few researches that target deciduous trees in tropics with a period of low precipitation lasting several months [3]. However, it is generally considered that the study of dendroclimatology in tropics is extremely difficult. The traditional methods of dendrochronology are completely unsatisfactory when determining yield characteristics such as tree age and radial growth in tropical forests [3].

If a method of dendroclimatology is to be completely satisfactory, it must provide better information about factors influencing growth rates, wood production and quality, rotation times, and replacement rates. Furthermore, it must be able to expect that data provides for better understanding of the global climate system [2].

The purpose of this research is to detect a presence of growth rings influenced with meteorological conditions in tree trunks that have grown in tropical rain forest area. Attention was paid to the climate anomaly in precipitation as a meteorological condition.

The extreme climatic events in 1982-1983 and tree growth.

The significant climate events caused by "abnormally little rainfall" occurred in the Tropical Zone in 1982 and 1983. Large-scale forest fire occured in Borneo during the period of the climate anomalies. It is well known as the big disaster. In Borneo, trees should be influenced

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by the abnormally little rain, and growth rings would be formed in the tree trunks. Woods from northern Borneo were investigated from this viewpoint.

If the characteristic growth ring was detected, then we were able to obtain the information about the period when the rings were formed. The discovery of the growth rings should give an index of chronology.

However, it is not certain that trees are influenced by water stress in tropical rain forest weather. It is not certain that growth rings formed under water deficit are distinguishable from growth rings formed under normal conditions.

It is said that there is a relation between tree growth and precipitation as far as height growth of a tree[4]. It is considered that there is some sort of influence of water stress during trees growth in tropical rain forests.

Series of monthly precipitation from 1982 to 1988 at some locations in Borneo are shown in Figure 1. The monthly precipitation varies even in the area that belongs to tropical rain forest weather. There are some months with low precipitation.

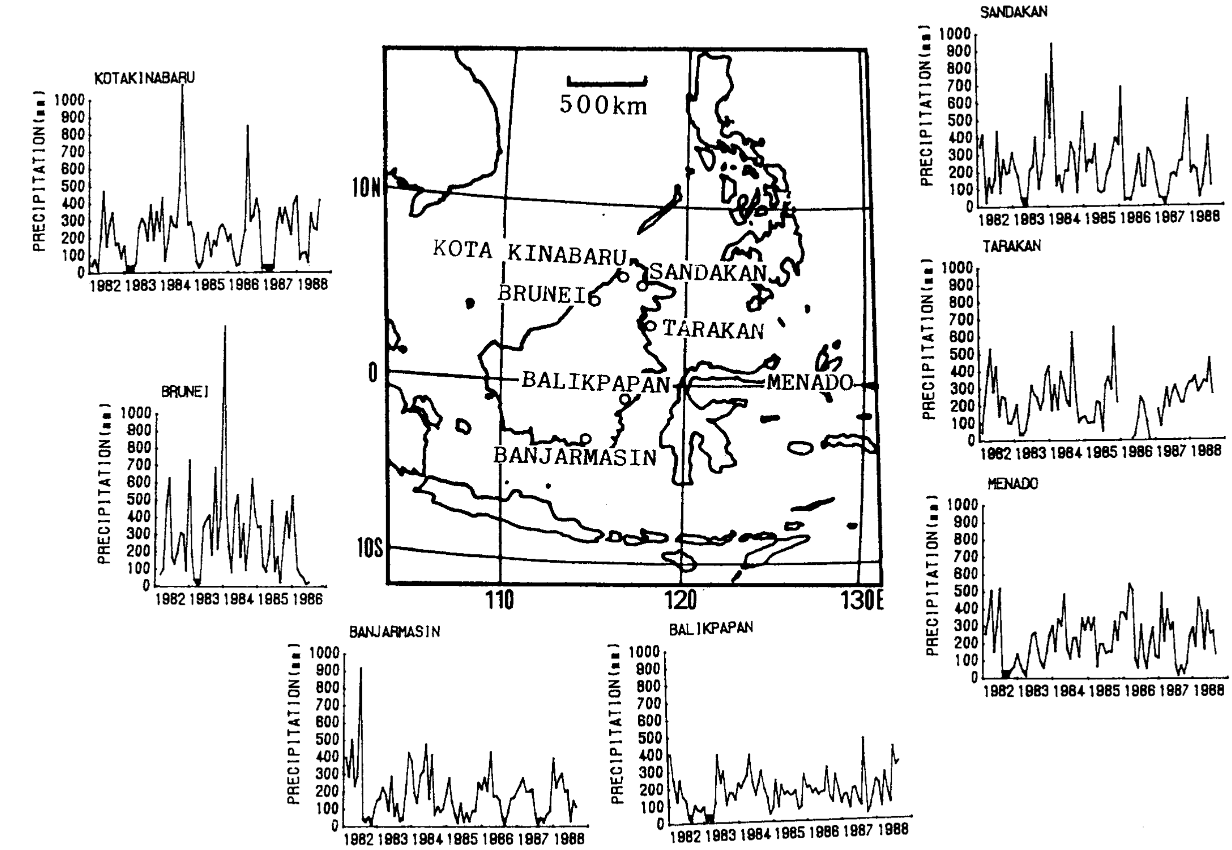


Figure 1 Series of monthly precipitation around Borneo from 1982 to 1988. Data source is Statistical Section of Japan Meteorological Agency.

In the south eastern parts of Borneo there were some drought months in 1982 and 1983. Especially in north Borneo, as far the drought months, the amount of monthly rainfall in 1983 was smaller than in 1982. There was no precipitation during three months from May to July

1983 in sandakan. The abnormally small precipitation is obvious in 1983 in north Borneo. It is confirmed that the abnormally low precipitation is common in a wide range of Borneo.

Materials and methods.

1. Origin of samples

Seraya (Shorea spp.) woods of 34 individuals grown in Borneo, Sabah, Malaysia were used. As shown in Figure 2, trees were logged at two locations of Tangkulap (T-location) and Naugoh (N-location).

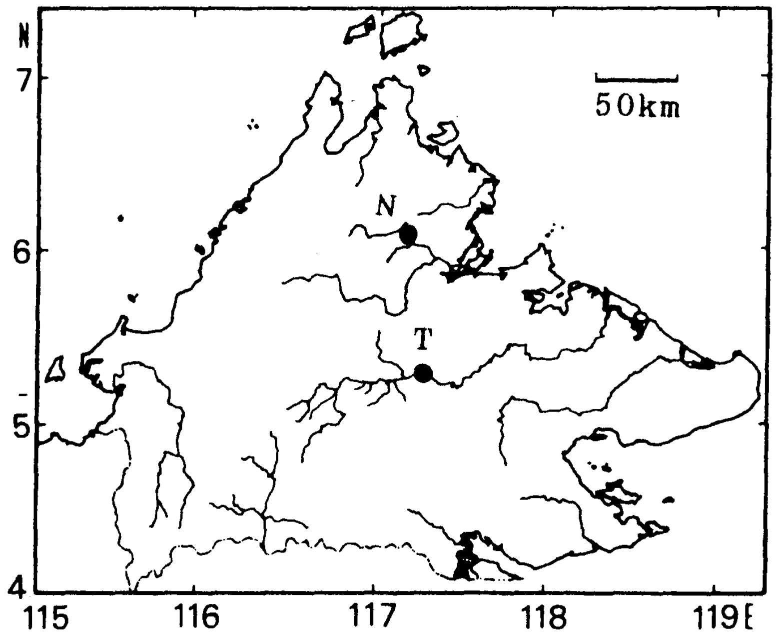


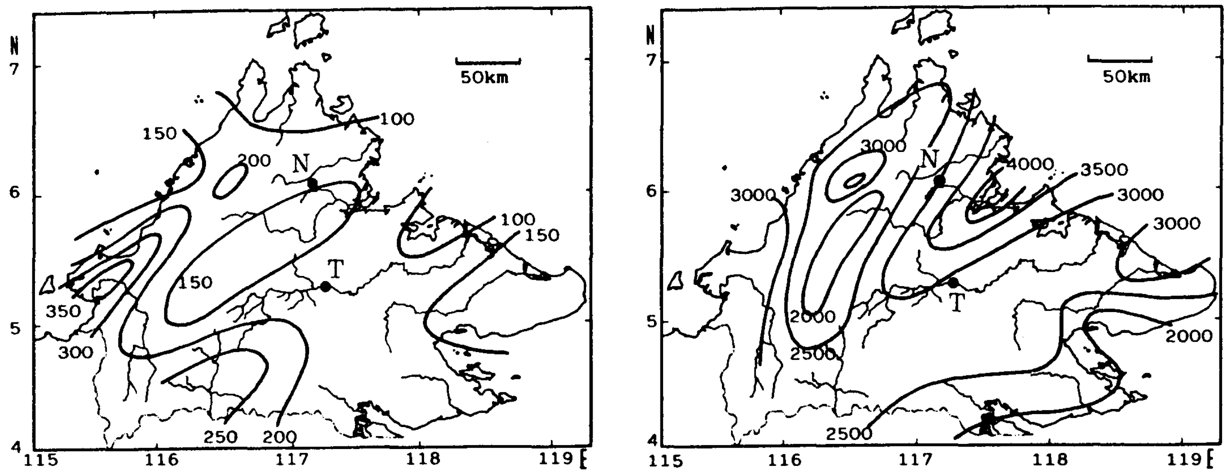
Figure 2 Sampling locations. Thirty-four trees were logged in May and June 1988 at T-and N-location in Sabah, Malaysia.

Twenty-five individuals gathered at T-location and nine individuals gathered at N-location were investigated. Distances between the two locations were about 100 km, and Mt. Melta (2000m) exists between the two locations. Sample trees were logged in May and June in 1988. Sample logs were cut to disks in a sawmill at Sandakan in Sabah. The disks were taken back to Japan.

The normal value of monthly precipitation of April when it is the most dried month and the normal value of yearly precipitation in Sabah are shown in Figure 3. It is confirmed that the precipitation of the two locations resembles that in an ordinary year.

2. Preparation of samples

A feature of the growth rings of the trees that grew in the T and N-locations was investigated. Soft x-ray photographs were used to observe growth rings. Samples were cut from four positions around a cross sectioned disk as shown in Figure 4. The thickness of each sample was 1 mm in longitudinal direction, about 20 mm in tangential direction, and about 60 mm in radial direction.



(a) Normal value in April when relatively low precititation (mm).

(b) The mean annual precipitation (mm).

Figure 3 Distributions of the precipitation.
Data source is "Hydrological Records for Sabah", Ministry of Agriculture and Fisheries, Sabah.

3. Soft x-ray shooting method.

A soft x-ray shooting apparatus (SOFTEX Co., Ltd., E3-type) was used. Films were Fuji soft x-ray films of FR-type. Exposure time was two minutes. The voltage of the x-ray tube was 11kV. Electric current of the x-ray tube was 4mA.

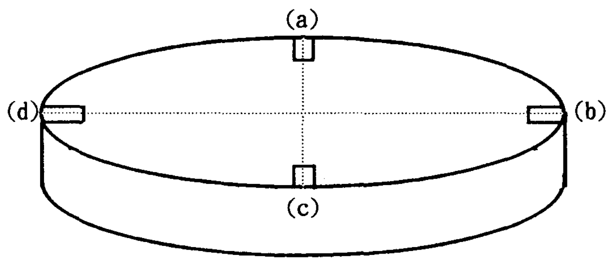


Figure 4 Four samples were cut from round of cross sectioned diskes.

4. Image processing.

The soft x-ray photographs were processed to make it easy to observe the growth ring as a wave of gray level in a digital image. The diagram illustrating the sequence of image processing methods is shown in Figure 5.

At first, the original image (a) was emphasized in gray level and an emphasized image (b) was obtained. The image (b) was averaged through 10mm width (100 picture cells) in a tangential direction (c). The gray level profile of the image (c) was calculated (d) in a radial direction. The profile was processed with a data-window of cosine type (e) to decrease an influence by the edges of the image. The processed profile (e) was converted to FFT (Fast Fourier

(a) Original image.

(b) Emphasized image.

(c) Averaged image in tangential direction.

(d) Profile of gray level of image in radial direction.

(e) Processing with a data-window of cosine type.

(f) FFT spectrum converted by discrete Fourier transformation.

(g) Processing with a band-pass filter.

(h) Converted with inverse Fourier transformation.

(i) Processed image.

Figure 5 Diagram illustrating sequence of image processing.

Transformation) spectrum (f) using discrete Fourier transformation. Sande-Tukey's algorithm was used [5]. The spectrum (f) was processed by a band passing filter of a rectangle window. High space frequent element (noise) and low space frequent element (component of long wave length) were eliminated (g). The spectrum (g) was converted with the inverse Fourier transformation (h), and final processed image (i) was obtained.

A biological image analyzer (IBAS 2, Zeiss-Kontron, West Germany) and a desk top computer (PC-9801VX, NEC) were used for the aforementioned image processing.

Results and discussion

1. Observation of soft x-ray photograph.

A stripe-pattern was observed as a concentric circle state in cross section even with the naked eye. In general it is considered that only a tropical deciduous species has distinct growth rings. However, even in evergreen trees, a nature of xylem varies in the radial direction of a tree trunk.

"Growth ring" is interpreted in a wide meaning in this paper. That is, the variation of wood structure, density, and anatomical feature in a radial direction as a concentric circle state is interpreted as a growth ring.

Photographs expressing density distributions of ten individuals were shown in Figure 6. The sample trees were logged at two locations, T and N, as mentioned before. These are soft x-ray positive photographs of cross sections. A dark part corresponds to a part of high density. Many white points correspond to vessels and white belts in tangential directions correspond to axial intercellular canals.

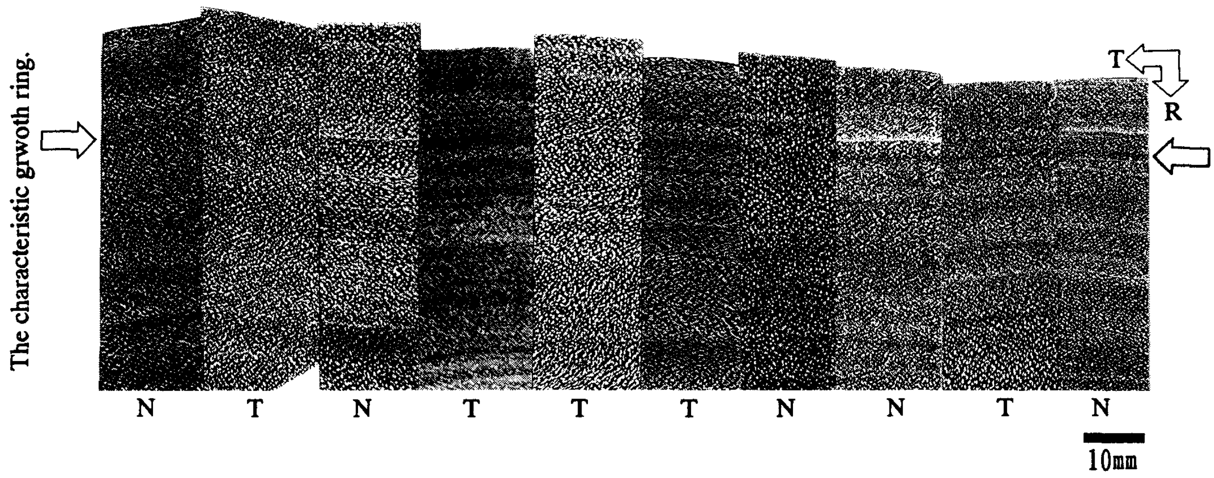


Figure 6 Soft x-ray positive photographs of closs-sections.
A dark part corresponds to high density.
N:N-location. T:T-location.

High density belts were observed at the positions of inside 15-20 mm from the surface of the individual tree trunk. Two features of the belts are as follows. (a) The high density belts are due to the existence of high density fiber. (b) The number of vessels per unit area is slightly low in the belts.

The difference in density is suggesting that there was a variation in cambium activity. Besides, it is considered that axial intercellular canals are unrelated to the variation in cambial activity.

As mentioned before, there are characteristic growth rings in the samples. Let's think about the year when the belts were formed.

The trees were logged in May or June 1988. It is considered that cells near the surface of the tree trunk were formed in the season. Some growth rings seem to exist between the surfaces and the characterized growth rings. However, it is difficult to count the number of growth rings because of indistinct rings. Therefore, certain processes that are described in the next paragraph were performed to the images.

2. Image processing for emphasizing and averaging.

Several images and profile curves of gray level are shown in Figure 7. The original image (a) was converted to digital image, and shading was emphasized (b). The emphasized image was averaged through tangential direction (b). The profile of gray level through radial direction was obtained from the image (c).

Many white points in the images of (a) and (b) correspond to vessel elements. The image (c) expresses variations both of fiber density and of vessel elements' number per unit area. Therefore, the profile curve presents the mean of the two parameters.

It is difficult to count growth rings in this stage, because the profile was composed from waves of many frequencies. As a results, digital filters were used to clear the growth rings.

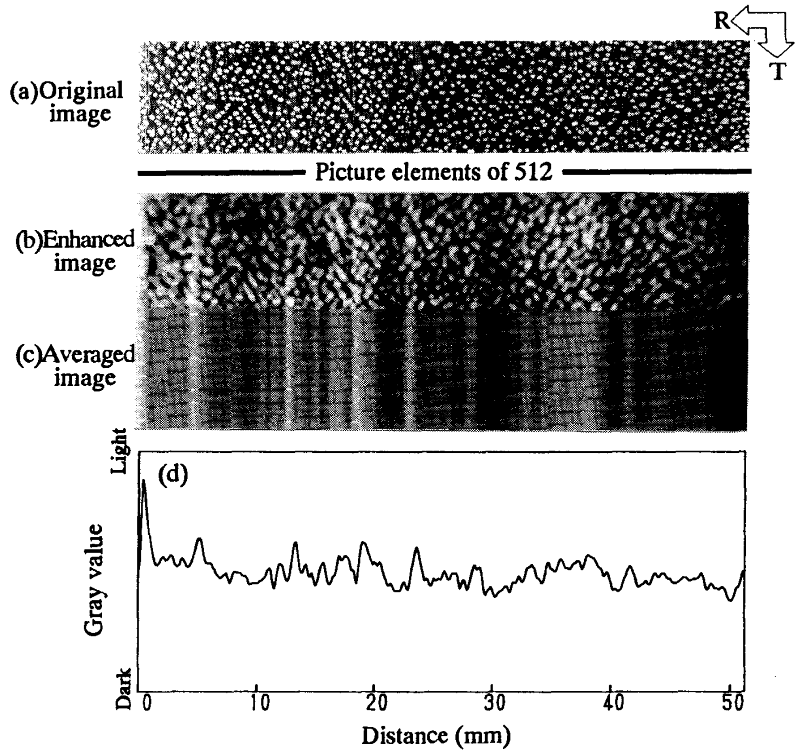


Figure 7 Some images of a cross-section and profile of gray level in radial direction. (a) Original image. (b) Enhanced image. (c) Averaged image in tangential direction. (d) Profile of gray level of averaged image(c).

3. Filtered images.

Figure 8 shows the profile curve of gray level (a), power spectrum (b) of the profile curve (a), power spectrum with the space wave length from 2 to 10 mm (c), and image profile obtained by inverse Fourier transform (d).

Figure 9 shows image profiles through the radial direction. Solid lines represent the profiles that were obtained by inverse Fourier transformation. Dotted lines represent the profile of averaged image (refer to Figure 7 (c)). After the high frequency components were eliminated (Figure 9 (a)), it was easy to observe individual peaks of waves. It is confirmed that waves of long wave lengths which are longer than 10 mm do not correspond to growth rings.

The radial growth rates per year in most of large trees (from 20 to 80 cm in diameter) of parashorea species were from 2 to 4 mm 6). The reason that limited the power spectrum from 2 to 10 mm wave length is the radial growth rate per year. Thus, the wave of high frequency components (short wave length components) was eliminated as noise. After processing the image, it became easy to observe the growth rings as a wave.

Figure 10 and Figure 11 show the images and profile curves in the radial direction of a sample of T and N-location. The original image(a), converted to the emphasized image(b), converted to the averaged image(c), and the image filtered with FFT (c), are shown individually. The profile (e) in the radial direction of the averaged image (c) and the profile (f) of the image (d) were filtered with FFT.

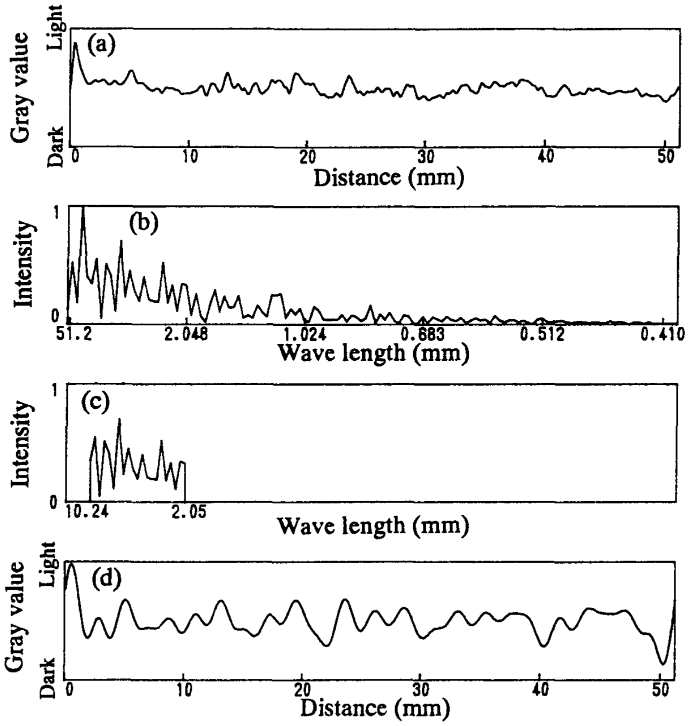


Figure 8 Profiles and spectrums of gray level.
(a) A proile of an averaged image. (b) A power spectrum. (c) A power spectrun limitted the space wave lengh from 2 to 10 mm. (d) A profile converted with the inverse Fourier transformation.

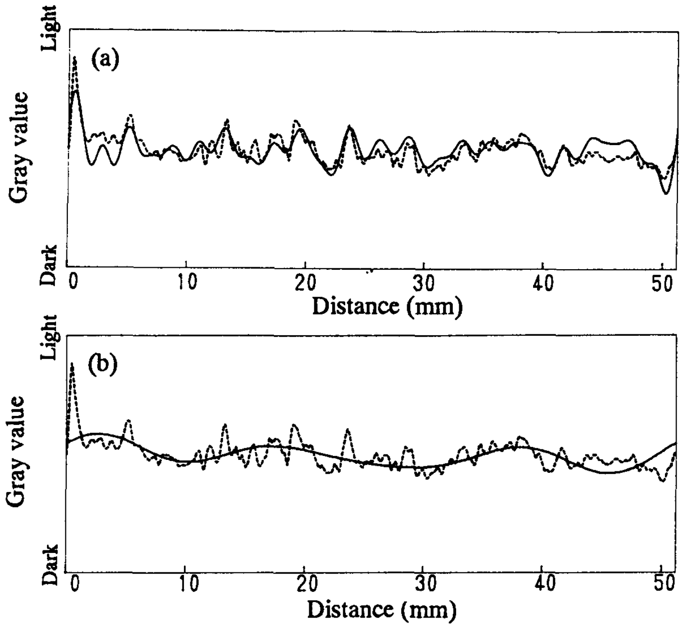


Figure 9 Profiles of gray level of image.
The dotted lines present the profile of the averaged original image.
The solid lines present the profile of the processed image with the inverse Fourier transformation limitted the wave length within the range of 2-10 mm (a) and limitted the wave length larger than 10mm (b).

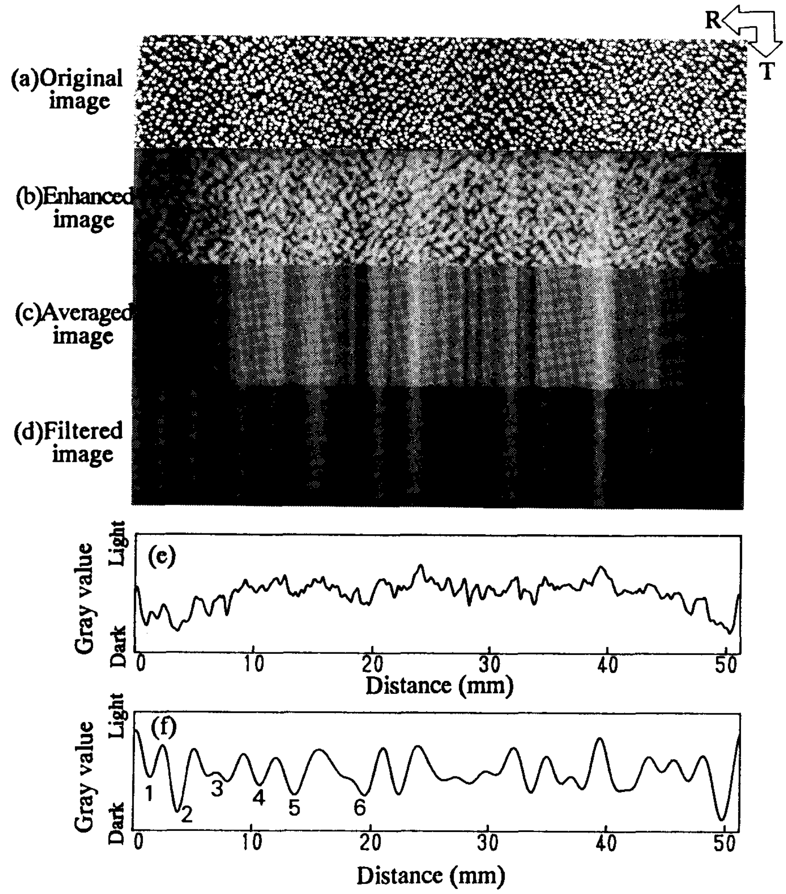


Figure 10 The images and the profiles in radial direction of the sample from T-location. (a) Original image. (b) Enhanced image. (c) Averaged image in tangential direction. (d) Processed image. (e) Profile of gray level of averaged image(c). (f) Profile of gray level of processed image.

The characterized growth rings, which were already shown in Figure 6, were able to be recognized as the 6th wave. It is clear that the first wave (the growth ring) was formed in 1988. Therefore, it is possible to determine that the 6th wave was formed in 1983.

Figure 12 shows the images and profiles of four samples obtained from a tree that was logged in N-location. Each sample was obtained from four positions that parted most in a cross section (refer to Figure 4). The 6th waves are detected in all profiles (a)-(d). And, the 6th waves in each profiles (a)-(d) are relatively large.

However, the 6th wave is not always relatively large in all individuals. Table 1 shows how many relatively large waves were detected in each individual. Each circle means that the relatively large wave was detected in a position. Four circles means the waves were detected in all positions. No circle means the 6th wave was not larger than other wave. As shown in table 1, samples in which the 6th wave was relatively large were 68% of individuals in T-location, 67% in N-location.

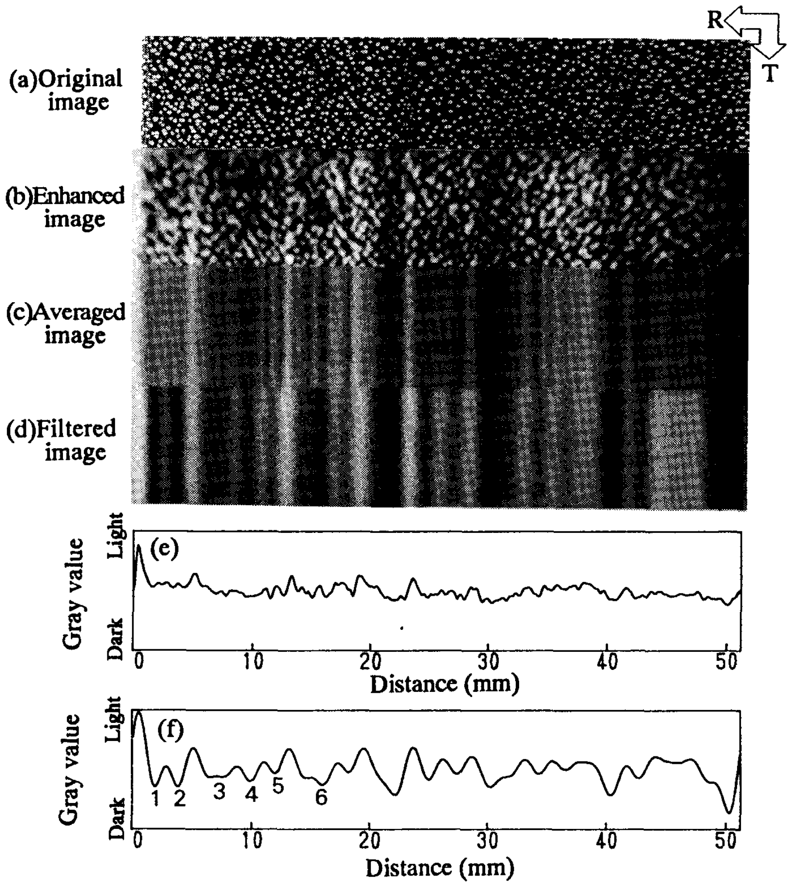


Figure 11 The images and the profiles in radial direction of the sample from N-location. (a) Original image. (b) Enhanced image. (c) Averaged image in tangential direction. (d) Processed image. (e) Profile of gray level of averaged image(c). (f) Profile of gray level of processed image.

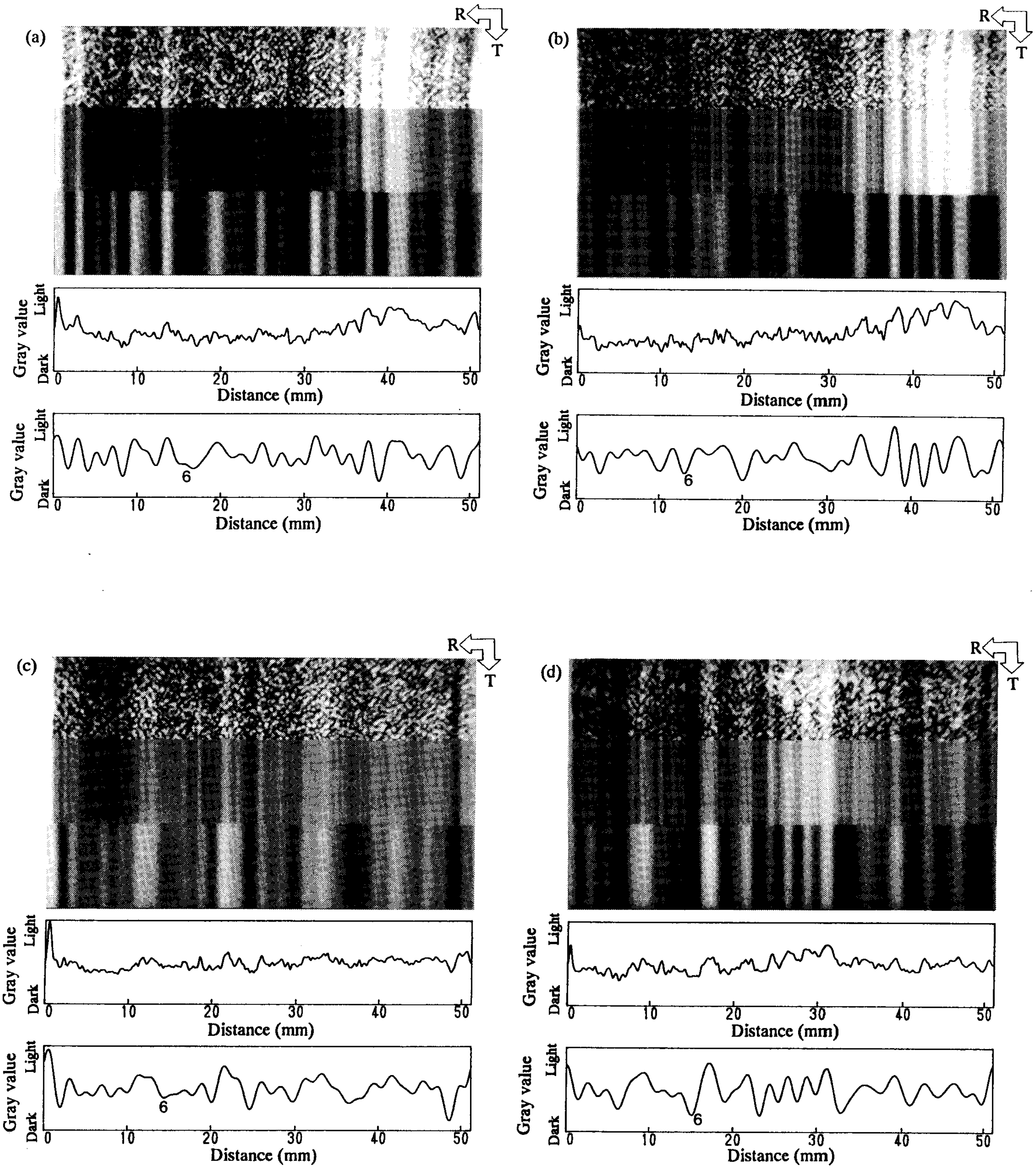


Figure 12 The image set and the profile set of (a)-(d).
The image set consists of three images that are enhanced (top), averaged (middle), and filtered (bottom) images, respectively. The profile set consists of two profiles that are averaged (top) and filtered (bottom) images, respectively. The samples (a)-(d) was taken from four positons of a cross sectioned disk (refer to Figure 4). The disk was taken from a tree that was grown in N-location.

Table 1. The number of the 6th characteried growth rings in each individual. The number of circles represents the number of the 6th ring.

	T-location		N-location
1	OO	26	O
2	OO	27	
3	O	28	O
4	OO	29	O
5	OOO	30	
6		31	OOO
7		32	OO
8	OO	33	
9	O	34	O
10	OO		
11	O		
12	O		
13			
14	O		
15			
16	O		
17			
18	O		
19	OO		
20			
21	OO		
22	OO		
23			
24			
25	OOOO		
	68%		67%

Note; The wave was surveied through the orthogonal two lines in each disk from surface to 60 mm inside.

4. Discussion.

The nature of xylem in a tree trunk is to some degree dependent on the cambial activity. Cambial activity is a function of moisture in many cases. In tropical regions, most species produce either no ring at all or just a suggestion of growth zone[3].

In tropics with small variation in annual temperature, moisture can become a primary factor causing cyclical tree growth[2]. However, in the tropical rain forest, it is difficult to expect seasonality in temperature and rainfall. If an extreme low precipitation period exists, then cambial activity is largely influenced by the period.

Extreme climatic events have been reported over much of the globe in 1982-83. Drought conditions also prevailed over southern and eastern Africa, North Australia, New Guinea, Indonesia and Northeast Brazil. According to the report of WMO[7], the drought over Southeast Asia-Australia has been linked to the 1982-1983 ENSO (El-Nino Southern Oscillation) event and consequent displacement of the tropical Walker Circulation.

The monthly precipitation from 1982 to 1988 in Borneo has already been shown in Figure 1. Monthly precipitation had been below 50 mm in 1983-82 in every area. The extreme low precipitation was found over much of Borneo.

It is thought that 160-200 mm water is consumed by evapotranspiration per month under the weather of tropical rain forests in case sunshine hours are more than 7 hours. Available water of 100-150 mm is held in ordinal red-yellow podzolic soil and lateritic soil. Therefore, it is considered that if monthly precipitation decreases more than 100 mm, trees assume the conditions of water deficit. Also, it is said that a seasonal drought will occur when rainfall is less than 50 mm per month[8]. If precipitation is continuously below 100 mm during two months, the condition of water deficit becomes more severe.

Therefore, it shall be assumed as follows. (1)Water deficit may occurs, even in trees of tropical rain forests with sufficient rainfall throughout the year in general. (2)Water deficit directly or indirectly influences cambium activity. Thus, it influences xylem formed during water deficit, and a characteristic growth ring is formed.

Under the above assumptions, growth rings were observed on thirty-four individuals. In this report an image processing method was proposed as a method of observations. That is, at the first step, the variation of gray level was obtained from the density of fiber and the proportion of occupied areas of vessels. As the second step, the gray level profile was processed with a band pass filter. Then the variation of gray level was extracted as waves in radial direction.

As a result of the observations, in an individual of 70 %, the characterized growth ring was found in about 70 % of all individuals, and it was estimated that the rings had been formed in 1983.

The range of wave length was limited from 2 to 10 mm by using the band pass filter. The range was determined by the annual increment of most trees in tropical rain forests, according to the records described as follows.

There are some reports described about the growth rate of tropical trees. The growth rates of radial increment of Parashorea sp. (10-80 cm in diameter) in the Philippines are 1.9-4.2 mm[6]. Middle-aged trees in the natural forest may add some 5-20 mm at the base of the main stem, while in very old emergent trees the amount is generally lower, sometimes less than 1 mm[9]. The estimation values of annual increment for 48 trees of 28 species from inundation forests in Central Amazonia showed a range from 0.7 to 8.2 mm of increment rates[10]. In natural forest trees in East Kalimantan, the annual diameter increment in Shorea spp ranges from 1.6-20 mm[11]. The average annual diameter increment of Shorea sp. from Sabah, Malaysia has decided with a radiocarbon variation pattern in the stem was 5.5 mm[12].

The reason the characteristic ring was not detected in all individuals is conceivable as follows. The annual increments of all trees are not necessarily in the range of 2-10 mm. Also, it is possible that the annual increments depend on the position in a stem. If the annual increments are not even in a stem, then some positions will be out of the range. The characterized growth rings are not always common in four directions (Table 1). The result may mean that cambial activity depends on the position in a stem.

However things come out, it is concluded from the preliminary study that the characterized growth rings are able to be detected in most trees. Water deficit for several months made growth rings of relatively high density even in trees from tropical rain forests. The image processing technique makes it possible to detect the characterized growth rings formed in 1983.

According to the meteorological data from 1953 to 1988, there were several periods when severe water deficit occurred. A survey must be done to show that the period corresponds with a characteristic growth ring. A discovery of the other characterized growth ring is hoped for. The results described in this report offer a key that substitutes a method of deciding a chronological age such as counting annual rings of trees in the Temperate Zone for a method deciding a chronological age of tropical tree.

Conclusions.

1) A characterized growth ring was found in about 70% of 34 individuals. The ring was different from other parts in density of fiber and in appearance number per unit area of vessels. The position of the growth rings was entered 15-20 mm from a surface of a tree trunk.
2) The characterized growth ring was detected in the trees in both T-location and N-location. The two locations parted 100 km in distance.
3) The formation year of the characterized growth rings was estimated to be 1983.
4) The results suggest that extreme low precipitation influences to cambial activity. As a result, a characterized growth ring is formed in a tree trunk even in the tropical rain forest climate where seasonality in precipitation is poor.

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References

1) Fritts, H. C.: "Tree Rings and climate", Academic press, London (1976)
2) Jacoby, G. C.: Overview of tree-ring analysis in tropical regions, *IAWA Bulletin n.s.* **10** (2), 47 & 99-108 (1989)
3) Fritz, H. S.:"Tree rings", D.Reidel Publishing Company, 108-109, 236-237, Holland (1988)
4) Kira, T. : "Ecology of Tropical Forest", 28-31, Jinbunsyoin, Kyoto (1984) (in Japanese)
5) Minami, S. :"Wave-data Processing for Scientific Measurement", CQ-syuppan, 140-165, Tokyo (1986) (in Japanese)
6) Richards, P. W. : "Tropical rain forest: An ecological study", translated by S. Uematsu and T. Kira, Kyoritsu-syuppan, 51-54, Tokyo (1978) (in Japanese)

7) WMO : "The Global Climate System: A Critical Review of the Climate system during 1982-1984", World Meteorological Organization, 5-19 (1985)

8) Eckstein, D.,J. Ogden, G. C. Jacoby, J. Ash : Age and Growth Rate Determination in Tropical Trees: The Application of Dendrochronological Methods, *Yale Univ. School of Forestry & Environm. Studies, Bull.* No.94, 83-106 (1981)

9) Longman, K. A. and J. Jenik : "Tropical forest and its environment", Longman Group Limited, 104-108, London (1974)

10) Worbes, M. : Growth rings, increment and age of trees in inundation forests, savannas and a mountain forest in the neotropics, *IA WA Bulletin n.s.,* **10** (2), 109-122 (1989)

11) Shiokura, T. : A method to measure radial increment in tropical trees, *IA WA Bulletin n.s.,* **10** (2), 147-154 (1989)

12) Nakamura, T., N. Nakai, M. Kimura, S. Ohishi, Y. Hattori, Y. Kikata : Variations in ^{14}C concentrations of tree rings (1945-1983), *Chikyukagaku,* **21**, 7-12 (1987) (in Japanese with English summary)