RADIOCARBON, Vol 44, Nr 2, 2002, p 559–566

^{14}C LEVEL AT MT CHIAK AND MT KYERYONG IN KOREA

J H Park[1,2] • J C Kim[1] • M K Cheoun[1] • I C Kim[1] • M Youn[1] • Y H Liu[1] • E S Kim[3]

ABSTRACT. We have observed $\Delta^{14}C$ concentrations in the northern hemisphere temperate region in the bomb pulse period, using cross-dated tree ring samples. The tree-ring samples were taken from one 70-year-old and two 50-year-old red pines (*Pinus densiflora*) on Mt Chiak, Korea and from a 50-year-old red pine (*Pinus densiflora*) on Mt Kyeryong, Korea. Twenty-two tree-ring samples from four red pines ranging from 1950 to 2000 AD were pretreated to obtain holo-cellulose, combusted to CO_2 by an element analyzer (EA) and converted to graphite for $\Delta^{14}C$ measurement using the accelerator mass spectrometry (AMS) facility at Seoul National University. Our results for $\Delta^{14}C$ showed good agreement with those measured by other researchers at similar latitudes. The observed steady decrease of $\Delta^{14}C$ from 1965 to 2000 AD is described by a single exponential function with a lifetime $\tau = 15.99 \pm 0.43$ yr. This lifetime is similar to that of the high-latitude region in Europe.

INTRODUCTION

Since 1945, nuclear weapons tests have led to an increase in atmospheric $\Delta^{14}C$. The atmospheric $\Delta^{14}C$ concentration in the northern hemisphere has approached a peak value of about twice the natural atmospheric $\Delta^{14}C$ concentration. Since then, the excess atmospheric ^{14}C has diffused into other reservoirs (mainly to the oceans) and, following the Limited Test Ban Treaty of 1963, the excess atmospheric ^{14}C has decreased exponentially (Povinec et al. 1986; Leung et al. 1995). However, the peak value, the time of peak value, and the speed of exponential decay for $\Delta^{14}C$ show differing trends in different latitudes.

Such studies had not been performed in Korea, therefore we obtained $\Delta^{14}C$ data in fresh air regions (Mt Chiak and Mt Kyeryong, Korea) and compared the characteristics of the $\Delta^{14}C$ value, namely the bomb peak value, the time of bomb peak value, and the speed of exponential decay for $\Delta^{14}C$ value with respect to other research results.

We assumed that Mt Chiak and Mt Kyeryong were in a fresh air region and selected tree-ring samples of red pine from those mountains. These tree-ring samples were used to obtain $\Delta^{14}C$ data for Korea for the period 1950–2000 AD.

SAMPLE DESCRIPTION AND DENDROCHRONOLOGY

Tree-Ring Samples from Mt Chiak

Mt Chiak (1288 m asl) is in the eastern part of Korea, 100 km from Seoul. It has a population of about 10 million. We collected red pine tree samples from Guryong temple and Bugok in Mt Chiak. Guryong temple (37°23′N, 128°3′E, 400 m asl) in Mt Chiak, 5 km from the Youngdong expressway, which, having been constructed after 1971 AD, did not influence the tree-ring samples in the the period 1950–1970 AD. However, the sample from 1975 AD (CH75, Table 1) was influenced by the expressway (Figure 1). The Bugok area (37°20′N, 128°4′E, 650 m asl) surrounded by Mt Chiak is 13 km from the Youngdong expressway and 9 km from the Chung-ang expressway still under construction. Moreover, both places are blocked by Mt Chiak, so that Wonju city, whose population is about 260,000, does not affect their tree-ring samples (Figure 1). Therefore, all of the samples except for CH75 (Guryong, Table 1) are safely assumed to be isolated from possible dead carbon sources nearby.

[1]Department of Physics, Seoul National University, Kwanak-ku, Seoul 151-742, Korea
[2]Corresponding author. Email: pjhun77@phya.snu.ac.kr.
[3]Department of Forest Resources, Kookmin University, Seoul 136-702, Korea

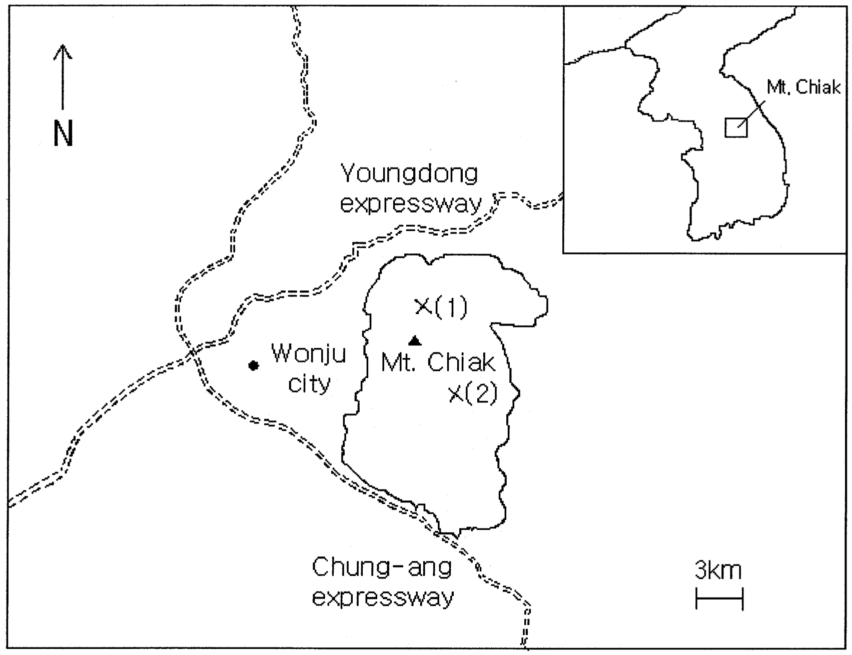

Figure 1 Map of the vicinity of Mt Chaik: (1) Guryong temple, (2) Bugok

Tree-Ring Samples in Mt Kyeryong

Mt Kyeryong (845 m asl) is located in the southern part of Korea at a distance of 140 km from Seoul. We collected red pine tree samples at Baekamdong (36°20′N, 127°13′E, 200 m asl) in Mt Kyeryong. Baekamdong is at a distance of 18 km from Daejeon city, whose population is about 1.5 million, and very near the Honam expressway, but it was also constructed after 1970 AD, so it did not influence the tree-ring samples in the period 1963–1964 AD. Therefore, the tree-ring samples used in this report were reasonably assumed to be collected in fresh air region in Korea.

Dendrochronology

The tree-ring samples were taken using an increment borer. The tree-ring samples showed clear annual ring structures. Each ring width was measured to a resolution of 0.01 mm using a microscope and a sliding linear table interfaced to a personal computer. The width data are presented in Figure 2. In these figures (A, B, and C), we grouped the width data by region. Group A contains the width data of Guryong temple's tree-ring samples, group B contains the width data of Bugok's tree-ring samples, and group C contains the width data of Baekamdong's tree-ring samples. In each group, Chiak-a1 and Chiak-a2, Chiak-d1 and Chiak-d2, and Kyerong-2-1 and Kyerong-2-2's tree rings are taken from the same red pine tree.

At first, we compared the widths of two tree-ring sets from the same red pine tree in each group. Both samples in each group from the same red pine tree show a strong correlation in Figure 2. To study the correlation in detail, we compared both two red pine tree ring sets with another red pine tree ring set. Chiak-c from a different red pine tree at Guryong temple shows a strong correlation with Chaik-a1 and Chaik-a2 in 1998, 1978, 1973, 1968, 1958, 1956, 1954, and 1949 (Figure 2[A]). Chiak-f from a different red pine tree at Bugok also shows a strong correlation with Chaik-d1 and Chaik-d2 in 1998,

https://doi.org/10.1017/S003382220003191X Published online by Cambridge University Press

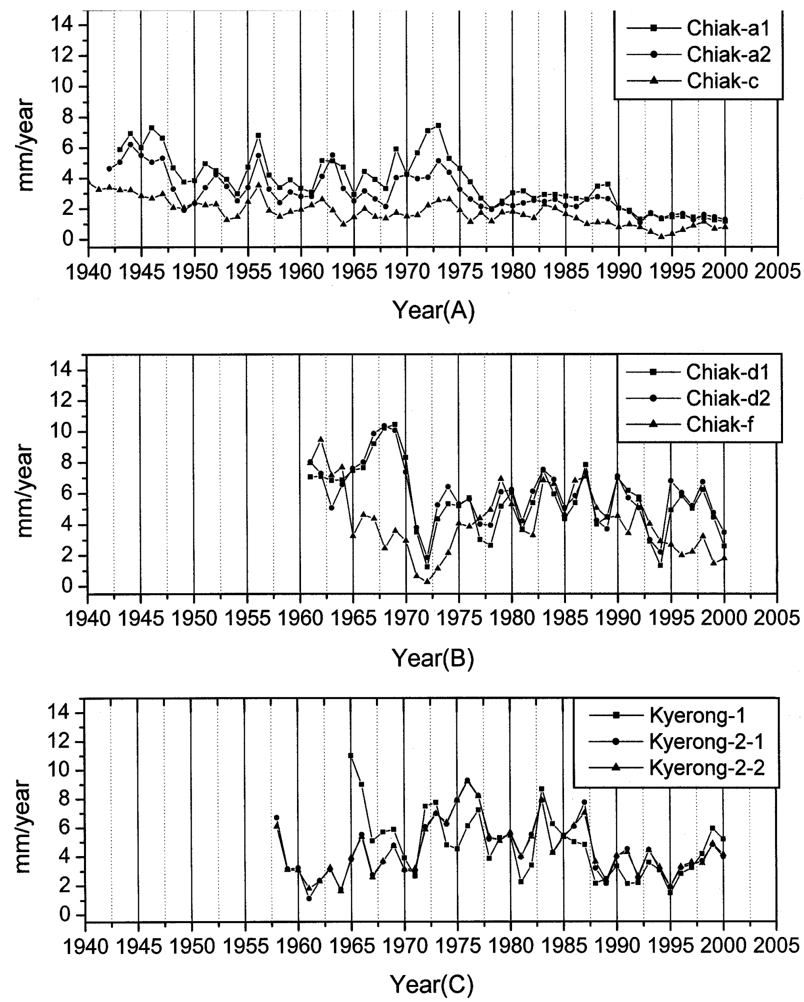

Figure 2 (A) tree-ring's width of Guryong temple area, Mt Chiak; (B) tree-ring's width of Bugok area, Mt Chiak; (C) tree-ring's width of Baekamdong area, Mt Kyeryong

1987, 1985, 1983, 1981, and 1972 (Figure 2[B]). Finally, Kyerong-1 from a different red pine tree at Baekamdong shows a strong correlation with Kyerong-2-1 and Kyerong-2-2 in 1999, 1995, 1992, 1983, 1981, 1973, 1971, 1969, and 1967 (Figure 2[C]). Therefore, our cross-dated tree-ring series show strong cross-correlations and are accurately identified in terms of their year.

For the study in this report, a 70-year-old red pine (Chiak-a2) from Mt Chiak was used for CH50, 55, 60, 62, 63, 64, 65, 66, 70, and 75 (Table 1), a 50-year-old red pine (Chiak-d1) from Mt Chiak for CH75-r, 79, 80, 81, 85, 90, 95, 99-r, and 00 (Table 1), a 50-year-old red pine (Chiak-d2) from Mt Chiak for CH00-r and a 50-year-old red pine (Kyeryong-2-1) from Mt Kyeryong for KR63 and 64 (Table 1), respectively.

Table 1 Δ^{14}C value from red pine in Mt Chiak and Mt Kyeryong

Ring formation (year)	Sample code	Site	δ^{13}C (‰ PDB)	Δ^{14}C (‰)
1950	CH50	Chiak (Guryong)	–19.5	–24.6 ± 10.5
1955	CH55	Chiak (Guryong)	–20.8	22.4 ± 11.3
1960	CH60	Chiak (Guryong)	–21.7	225.1 ± 11.7
1962	CH62	Chaik (Guryong)	–22.3	381.0 ± 12.7
1963	CH63	Chiak (Guryong)	–21.3	665.9 ± 21.0
1964	CH64	Chiak (Guryong)	–20.9	819.6 ± 14.7
1965	CH65	Chiak (Guryong)	–34.0	679.7 ± 29.1
1966	CH66	Chiak (Guryong)	–22.6	641.1 ± 13.9
1970	CH70	Chiak (Guryong)	–25.8	526.1 ± 14.5
1975	CH75	Chiak (Guryong)	–20.8	320.4 ± 13.4
1979	CH79	Chiak (Bugok)	–26.4	259.4 ± 13.3
1980	CH80	Chiak (Bugok)	–21.2	279.7 ± 14.9
1981	CH81	Chiak (Bugok)	–23.6	240.6 ± 14.8
1985	CH85	Chiak (Bugok)	–24.3	198.1 ± 10.6
1990	CH90	Chiak (Bugok)	–23.0	155.9 ± 10.5
1995	CH95	Chiak (Bugok)	–21.0	114.1 ± 13.9
2000	CH00	Chiak (Bugok)	–26.3	57.2 ± 9.9
1975(r)	CH75-r	Chiak (Bugok)	–23.5	393.0 ± 27.5
1999(r)	CH99-r	Chiak (Bugok)	–24.7	91.4 ± 19.9
2000(r)	CH00-r	Chiak (Bugok)	–28.5	50.0 ± 23.6
1963	KR63	Kyeryong (Baekamdong)	–24.0	751.7 ± 21.6
1964	KR64	Kyeryong (Baekamdong)	–25.4	841.9 ± 24.4

SAMPLE PREPARATION AND AMS ^{14}C ANALYSIS

Twenty-two tree rings were prepared for AMS analysis. Owing to the existence of very different levels of Δ^{14}C between consecutive tree rings, we removed the boundary region (~0.2 mm) of the tree ring. Each tree ring was carefully split and sliced to ~1 mm. Approximately 20 mg of each sample was used to extract cellulose. Cellulose was obtained for each sample by this process. The samples were heated to 80–85 °C in 0.5M HCl for 30 min and washed to neutral pH. The residues were heated again to 80–85 °C in 0.1M NaOH for 1 hr and washed to neutral pH. They were heated once more to 55–60 °C in a 4% solution of H_2O_2 at pH 11 for 1 hr and washed to neutral pH. Finally, they were heated to 80–85 °C in 0.5M HCl for 30 min (Sjören et al. 1981).

The obtained material was combusted to CO_2 using the element analyzer (EA). This CO_2 was reduced to graphite using H_2 and Fe catalyst (Lee et al. 2000; Vogel et al. 1987). The mass of the graphite was about 1 mg.

AMS Δ^{14}C measurements were performed using the AMS facility in Seoul National University (SNU) (Kim et al. 2000). The $^{14}C/^{12}C$ ratio of each sample was measured relative to the NIST standard of Oxalic Acid II. The Δ^{14}C of each sample was calculated after correcting for 1) the instrument's background, 2) isotopic fraction using δ^{13}C, and 3) radioactive decay of both tree ring and standard sample (Hua et al. 1999).

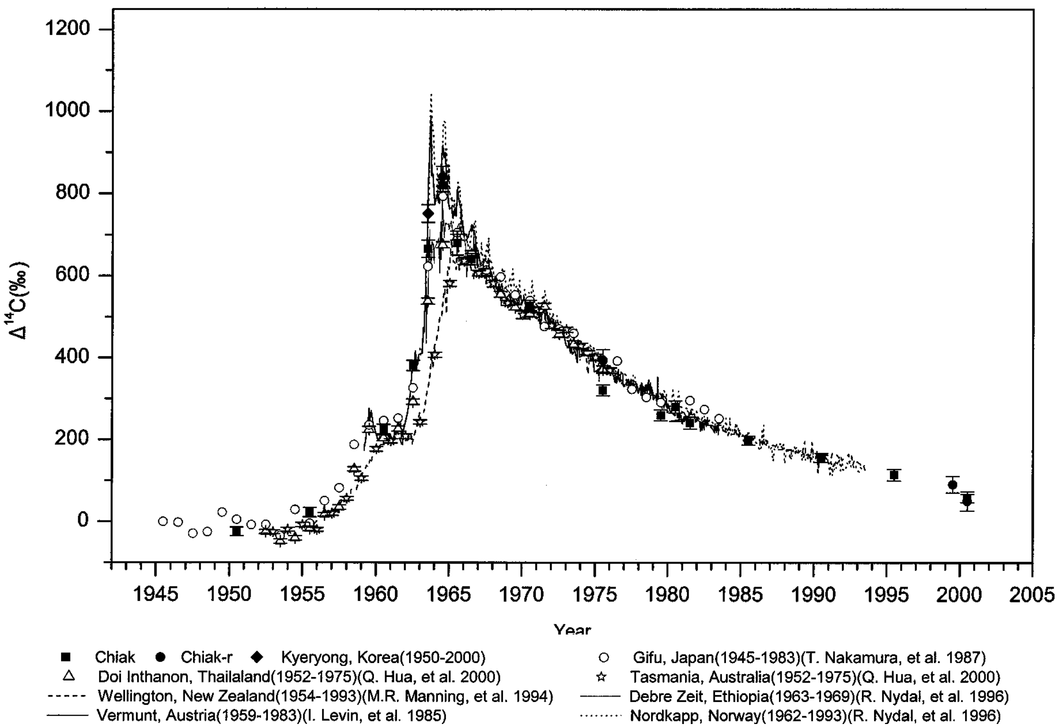

Figure 3 The observation of $\Delta^{14}C$ (‰) of atmospheric CO_2 and tree rings in the arctic zone, northern hemisphere temperate region, tropical zone

RESULTS AND DISCUSSION

The $\Delta^{14}C$ data for 1950–2000 AD are tabulated in Table 1 and illustrated in Figure 3. The growing season for red pine in Korea is from April to September, so the $\Delta^{14}C$ values for the tree rings are plotted as the points in the middle of the growing period.

For easy comparison, the atmospheric $\Delta^{14}C$ data from four regions—the arctic zone, northern hemisphere temperate region, tropical zone, and southern hemisphere temperate region—are plotted in Figure 3. They are the data for Nordkapp, Norway (71°06′N; 1962–1993 AD; Nydal et al. 1996a), Vermunt, Austria (47°N; 1959–1983 AD; Levin et al. 1985), Debre Zeit, Ethiopia (8°40′N; 1963–1969 AD; Nydal et al. 1996a), and Wellington, New Zealand (41°18′S; 1954–1993 AD; Manning et al. 1994).

Because the sample CH75 was taken in the vicinity of the Youngdong expressway, which was constructed in 1971 AD, the ^{14}C value appeared lower than the other regions, but there is general agreement between the ^{14}C tree-ring data in Korea and the atmospheric $\Delta^{14}C$ data in Vermunt and Nordkapp. The bomb peak in the $\Delta^{14}C$ tree-ring data in Korea appears in 1964 AD, whereas the atmospheric data in Vermunt and Nordkapp show the peak in 1963 AD. However, one should not regard this difference as a real delay between the ^{14}C tree-ring data in Korea and the atmospheric ^{14}C data in Vermunt and Nordkapp, as they are in good agreement on both the leading edge and the trailing edge sides of the bomb pulse. The apparent one-year difference is because although a dramatic increase in ^{14}C is peaked during 1963 for the atmosphere, the average over the growing season is lower in 1963 than in 1964. Thus, single whole growth ring for 1964 should (and does) have the higher ^{14}C value (Grootes et al. 1989).

Figure 3 also shows the data for Hinoki in Gifu, Japan (35.6°N; 1945–1983 AD; Nakamura et al. 1987), three-leaf pine in Doi Inthanon National Park, Thailand (18°33′N; 1952–1975 AD; Hua et al. 2000), and Huon pine in Tasmania, Australia (41°41′S; 1951–1975 AD; Hua et al. 2000).

The ^{14}C data from tree-ring samples in Mt Chiak and Gifu, which are in the northern hemisphere temperate region, show a similar tendency. The tree ring's bomb peaks in the northern hemisphere temperate region (Mt Chiak and Gifu) appear in the middle of 1964, while that in the tropical zone (Doi Inthanon National Park) is in the middle of 1965. There is a time delay of one year from the northern hemisphere temperate region to the tropical zone (Hua et al. 2000).

Figure 4 shows the exponential decay fitting of five data sets for $\Delta^{14}C$ data. They are respectively data for Mt Chiak, for Nordkapp (71°06′N; 1963–1993 AD; Nydal et al. 1996a), Vermunt (47°N; 1959–1983 AD; Levin et al. 1985), Gifu (35.6°N; 1945–1983 AD; Nakamura et al. 1987), and Doi Inthanon National Park (18°33′N; 1952–1975 AD; Hua et al. 2000). Because tree-ring sample CH75 is contaminated by dead carbon, the data of tree-ring sample CH75-r is used for fitting. The tree-ring sample CH00, CH00-r has similar ^{14}C value, so we chose CH00-r for fitting.

For comparison, the fitting interval for each data in Table 2 is chosen to start from 1965, and we used all available data points to calculate the decay lifetime. The plots are drawn from 1965 to last year by fitting, and from last year to 2000 by extrapolation. The fitting results are tabulated in Table 2.

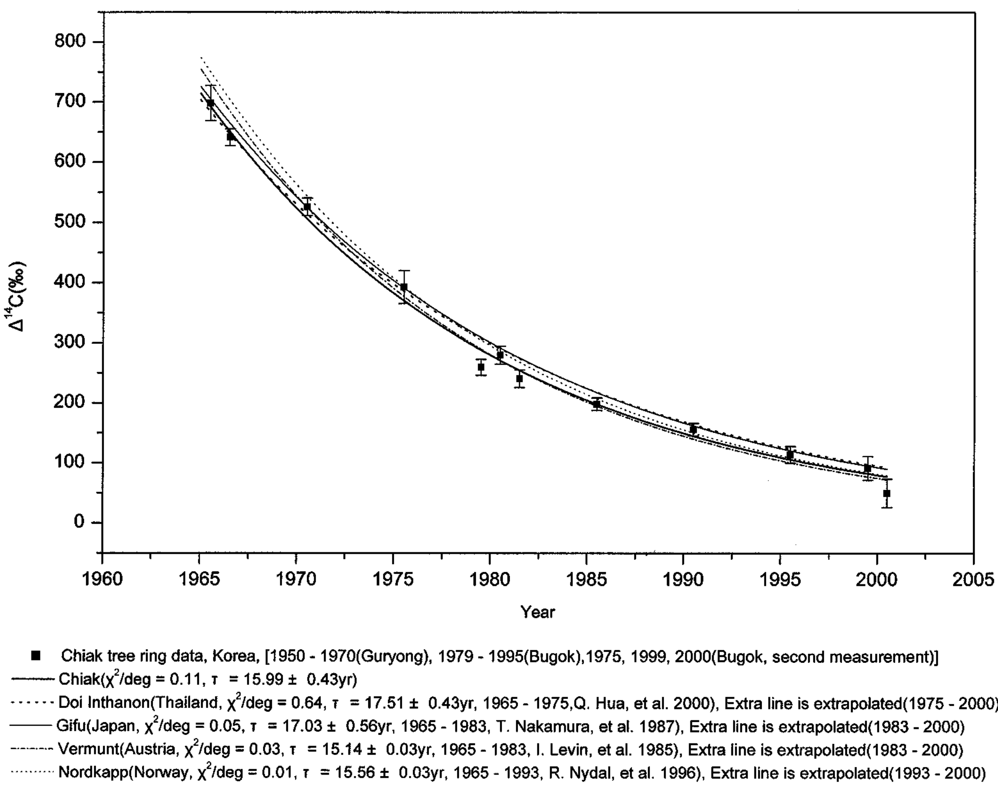

Figure 4 Chiak tree-ring data, Korea (1950–1970 [Guryong], 1979–1995 [Bugok], 1975, 1999, 2000 [Bugok, second measurement])

Table 2 The exponential decay fitting results for Mt Chiak and four other regions

Data set	Lifetime	Fitting interval	Location
Nordkapp, Norway	τ = 15.56 ± 0.03 yr	1965–1993	71°06′N
Vermunt, Austria	τ = 15.14 ± 0.03 yr	1965–1983	47°N
Mt Chiak, Korea	τ = 15.99 ± 0.43 yr	1965–2000	37°20´N, 37°23´N
Gifu, Japan	τ = 17.03 ± 0.56 yr	1965–1983	35.6°N
Doi Inthanon, Thailand	τ = 17.51 ± 0.43 yr	1965–1975	18°33'N

In fact, the decrease rate of the bomb peak is faster in the first years after 1965 than later on, since the ocean surface reservoir is gradually filled up with ^{14}C from the atmosphere. Our data and Nordkapp and Vermunt's data gives τ = ~13.5 yr, which is a little faster than the value in Table 2, when fitted using data at the interval 1964–1970 AD. The lifetime (τ = 18.2 yr) obtained by Nydal et al. (1996b) for Nordkapp's data at the interval 1973–1992 AD also conforms to this trend.

From the Table 2, we can say that the lifetime of low-latitude region (Doi Inthanon, Thailand) is long, while the lifetime of high-latitude regions (Nordkapp, Norway and Vermunt, Austria) are short. Although Mt Chiak, Korea and Gifu, Japan are located at the similar latitude, the lifetime of Mt Chiak, Korea is similar to that of high latitude region, while the lifetime of Gifu, Japan is similar to that of low latitude region. These trends of Mt Chiak, Korea and Gifu, Japan should be studied in more detail.

CONCLUSION

We have obtained bomb $\Delta^{14}C$ data for the northern hemisphere temperate region from red pines on Mt Chiak and Mt Kyeryong, Korea. These $\Delta^{14}C$ data show results consistent with other observations at the similar latitudes and, as a result, can be used for the study of the global carbon cycle, atmospheric transport and interaction between air and oceans. The lifetime of the $\Delta^{14}C$ data's exponential decay from 1965 to 2000 at Mt Chiak, Korea was obtained as 15.99 ± 0.43 yr.

ACKNOWLEDGMENTS

This work was supported by the Korea Engineering Science Foundation (KOSEF grant nr R01-2001-00022).

REFERENCES

Grootes PM, Farwell GW, Schmidt FH, Leach DD, Stuiver M. 1989. Importance of biosphere CO_2 in a subcanopy atmosphere deduced ^{14}C AMS measurements. *Radiocarbon* 31(3):475–80.

Hua Q, Barbetti M, Worbes M, Head J, Levchenko VA. 1999. Review of radiocarbon data from atmospheric and tree ring samples for the period 1945–1997 AD. *IAWA Journal* 20:261–83.

Hua Q, Barbetti M, Jacobsen GE, Zoppi U, Lawson EM. 2000. Bomb radiocarbon in annual tree rings from Thailand and Australia. *Nuclear Instruments and Methods in Physics Research* B172:359–65.

Kim JC, Lee CH, Kim IC, Park JH, Kang J, Cheoun MK, Kim YD, Moon CB. 2000. A new AMS facility in Korea. *Nuclear Instruments and Methods in Physics Research* B172:13–7.

Lee C, Kim JC, Park JH, Kim IC, Kang J, Cheoun MK, Choi SY, Kim YD, Moon CB. 2000. Progress in sample preparation system for the Seoul National University AMS facility. *Nuclear Instruments and Methods in Physics Research* B172:454–7.

Leung PL, Stokes MJ, Qiu SH, Cai LZ. 1995. A survey of environmental ^{14}C levels in Hong Kong. *Radiocarbon* 37(2):505–8.

Levin I, Kromer B, Schoch-Fischer H, Bruns M, Münnich M, Berdau D, Vogel JC, Münnich KO. 1985. 25 years of tropospheric ^{14}C observations in central Europe. *Radiocarbon* 27(1):1–19.

Manning MR, Melhuish WH. 1994. In: Boden TA, Kaiser DP, Sepanski RJ, Stoss FW, editors. *Trends 93 – a compendium of data on global change.* Oak Ridge National Laboratory: Carbon Dioxide Information Analysis Center. p 173.

Nakamura T, Nakkai N, Ohishi S. 1987. Applications of environmental ^{14}C measured by AMS as a carbon tracer, *Nuclear Instruments and Methods in Physics Research* B29:355–60.

Nydal R, Lovseth K. 1996a. Carbon-14 measurement in atmospheric CO_2 from Northern and Southern Hemisphere sites, 1962–1993. Oak Ridge National Laboratory: Carbon Dioxide Information Analysis Center.

Nydal R, Gislefoss J. 1996b. Further application of bomb ^{14}C as a tracer in the atmosphere and ocean. *Radiocarbon* 38(3):389–406.

Povinec P, Chudý M, Šivo A. 1986. Anthropogenic radiocarbon: past, present, and future. *Radiocarbon* 28(2A):668–72.

Sjoren B, Moldenius S. 1981. Effects of bleaching parameters on kinetics and stoichiometry of peroxide bleaching of mechanical pulp. *Chemistry and Biochemistry of Wood-based Processes and Products* 2: 125–31.

Vogel JS, Southon JR, Nelson DE. 1987. Catalyst and binder effects in the use of filamentous graphite for AMS. In: Gove HE, Litherland AE, Elmore D, editor. Proceedings of the 4th International Symposium on Accelerator Mass Spectrometry. *Nuclear Instruments and Methods in Physics Research* B29:50–6.