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BOMB PRODUCED ^{14}C CONTENT IN TREE RINGS GROWN AT DIFFERENT LATITUDES

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ABSTRACT. The ^{14}C content in 1961–1967 rings of each of three spruce pines grown at (68° N, 130° W), (47° 30′ N, 129° 16′ E) and (27° 13′ N, 100° 20′ E) were measured. $\Delta^{14}C$ values of the three specimens rise dramatically from a common level (~250‰) in 1961 to their respective maxima, 964‰, 909‰, and 743‰ in 1964 and then fall to a common level ~680‰ in 1967. The observed $\Delta^{14}C$ increase comes most likely from the nuclear bomb test of the USSR at 75° N in 1961, although there were many other tests since the 1950s. The different effects at different latitudes reflect the atmospheric circulation patterns in the stratosphere and the transport of ^{14}C nuclei from the stratosphere to the troposphere.

INTRODUCTION

Bomb ^{14}C in the atmosphere is produced in $^{14}N(n, p)^{14}C$ reaction by neutrons generated in nuclear weapon tests. As does natural ^{14}C, bomb ^{14}C combines with oxygen to become $^{14}CO_2$ molecules soon after production, and takes part in the circulation of carbon in nature. Fairhall and Young (1970) estimated that there were 2×10^{30} ^{14}C atoms in the globe before nuclear tests, and nuclear tests had added 6×10^{28} ^{14}C atoms to the atmosphere. A fraction of these atoms was produced by a thermonuclear bomb of the USSR in 1961 near 75° N. Compared with earlier tests, it was relatively localized in time and space. Thus, it proves of value in studying atmospheric mixing phenomena and the important question of the mean residence time of CO_2 in atmosphere before uptake by the sea.

The scientific value of bomb-produced ^{14}C was quickly recognized and atmospheric ^{14}C excess was measured by a number of investigators (see Fairhall & Young, 1970 and references therein). Three of the important results of the measurements are: 1) a pronounced seasonal fluctuation in the ^{14}C level in the northern hemisphere, 2) a meridional gradient, with the ^{14}C level decreasing from north to south, and 3) a striking difference in the intensity-time profile between the northern and the southern hemispheres. However, the ^{14}C excess in the 36°–71° N range does not show a clear latitude effect (Nydal, 1962; Fairhall & Young, 1970).

We have been interested for some time in $\Delta^{14}C$ variation in tree rings, anticorrelated with sunspot numbers. We measured $\Delta^{14}C$ in a white spruce grown in Mackenzie Delta, Canada (68° N, 130° W) and found that the $\Delta^{14}C$ values vary with an 11-year periodicity (Fan *et al,* 1983). The amplitude of the variation is ca 10‰, which is about three times larger than what were found by others in trees grown at lower latitudes (see Povinec, 1983 and references therein). This difference can be explained if there is a meridional ^{14}C concentration gradient. The lack of clear latitude effect in ^{14}C concentration by means of air sampling in the experiments of Nydal, Fairhall, and Young may be due to local atmospheric effects. We decided to obtain tree specimens from different geographic latitudes and measure the

$\Delta^{14}C$ in the rings from 1961 to 1967. The results reported here show an unmistaken latitude effect, thereby lending support to our assumption.

MEASUREMENTS AND RESULTS

The wood samples were from three locations: Mackenzie Delta, Canada (68° N, 130° W), Dailing, Heilongjiang Province, China (47° 30′ N, 129° 16′ E), and Mingyin, Yunnan Province (27° 13′ N, 100° 20′ E). They are located approximately under the three convection cells in the lower stratosphere of the atmosphere (Lamb, 1970).

Measurements were made by a liquid scintillation method. After being repeatedly treated with routine HCl-NaOH-HCl procedure, the wood samples were converted to Li_2C_2 by combustion with lithium, then to C_2H_2 by dripping water to it, and finally combined to C_6H_6 in a catalyst case. The sample measuring bottles were made of quartz. In the liquid scintillation counter, a pair of photomultiplier tubes were connected in coincidence to measure the electrons from the ^{14}C decay. A plastic scintillator anti-coincidence device and a lead shield, 6 to 10 cm thick, were used to reduce backgrounds. Each measurement used 5cc benzene sample mixed with 1cc scintillation liquid. The count rate of a background sample was 2 cpm when the measuring efficiency was 70%.

The $\Delta^{14}C$ values of 20 tree rings of the three specimens are listed in Table 1. Except for the 1967 and 1968 rings of the Mackenzie wood, which had to be combined because of their narrowness, each sample corresponds to an annual ring. The results, together with the $\Delta^{14}C$ in an oak grown in Bear Mountain Park, New York (43° N, 74° W) by Cain and Suess (1976), are plotted in Figure 1. The $\Delta^{14}C$ values in the trees from the three different latitudes rise dramatically from the 1961 level (~250‰) to their respective maxima (964‰, 909‰, and 743‰) in 1964, then fall to a level (~680‰) in 1967. The meridional gradient in ^{14}C concentration is clearly demonstrated. The agreement between the $\Delta^{14}C$ in the Dailing spruce and Bear Mountain Park oak is remarkable, indicating a rapid longitudinal mixing.

It is interesting to note that the $\Delta^{14}C$ in the Mackenzie spruce responds quickly to bomb-produced ^{14}C. Dailing spruce responds with a slight delay, whereas the Mingyin spruce even later. The yearly increment (or decrease) of $\Delta^{14}C$ in the three trees, *ie*, $[(\Delta^{14}C)_{n+1} - (\Delta^{14}C)_n]$, is plotted *vs* year in Figure 2. These differences presumably reflect the mechanism of meridional mixing in the troposphere.

TABLE 1

$\Delta^{14}C$ in 1961–1967 tree rings from three different latitudes (in ‰ ± 5‰)

	1961	1962	1963	1964	1965	1966	1967
Mackenzie (68°N,130°W)		606.2	895.2	963.5	914.7	870.4	704.1 (67–68)
Dailing (47°N,129°E)	251.1	392.4	770.5	909.1	842.7	763.6	682.2
Mingyin (27°N,100°E)	226.7	324.9	496.8	743.4	758.2	747.1	670.1

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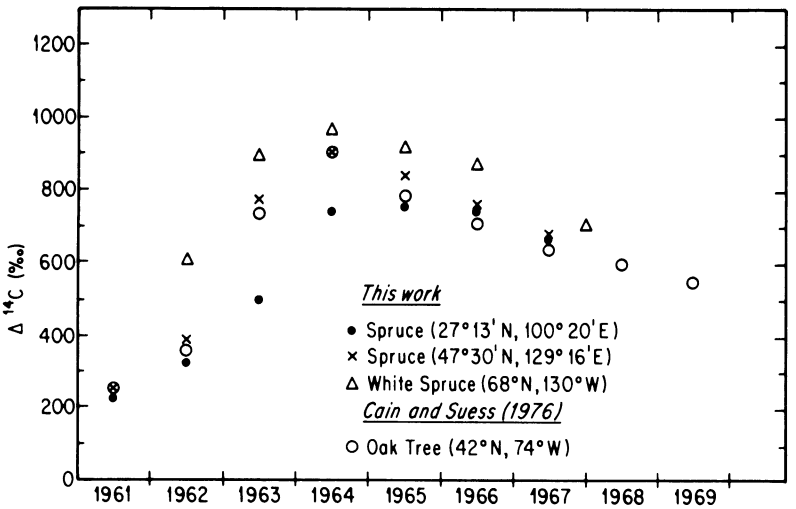

Fig 1. $\Delta^{14}C$ in tree rings from different latitudes

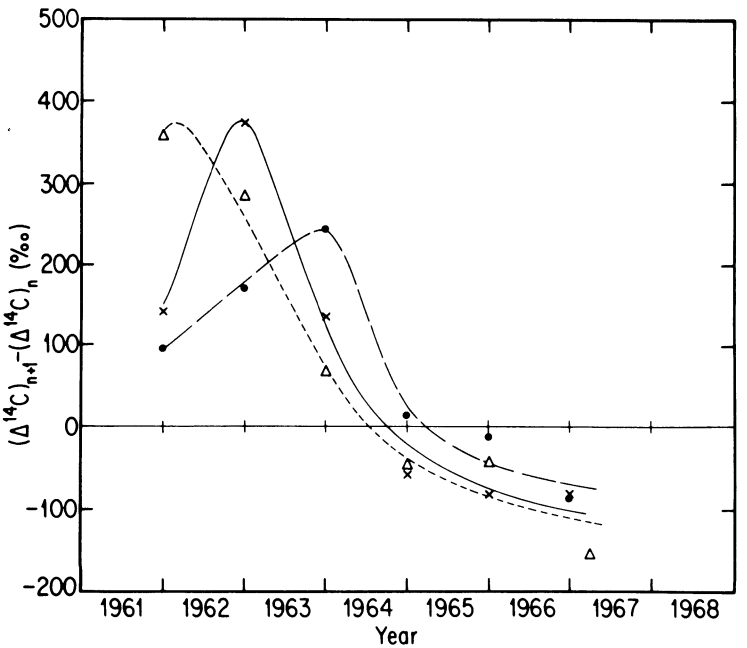

Fig 2. The increase in $\Delta^{14}C$ in (nth + 1) year over that in the previous (nth) year

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CONCLUSION

After several high-yield bomb tests in 1961 and 1962, the concentration of ^{14}C nuclei in the stratosphere was extensively monitored in the Project Stardust for several years (Feely *et al*, 1966). It was found that, by the end of 1965, the 60°–70° N latitude region remained as a high intensity "ridge." This was explained by the mixing model in the stratosphere advanced by a number of meteorologists (Lamb, 1970 and references therein). According to the model, the atmospheric circulation is in three cells: 1) from the equator towards mid-latitudes, 2) from high latitudes towards mid-latitudes, and 3) from high latitudes towards the pole. As a consequence, after the injection of ^{14}C in the stratosphere by the bombs in the 75° N region, many atoms remained in place for many years.

The bulk of the excess ^{14}C entered the troposphere mainly through the mid-latitude tropopause gap in the northern hemisphere during spring and early summer. Our experimental result suggests that the meridional mixing in the troposphere is sufficiently slow, resulting in a steady ^{14}C concentration gradient. Considering the fact that the longitudinal separations of Dailing and Bear Mountain Park from Mackenzie Delta are ca 100° in the west and 56° in the east, respectively, and yet the $\Delta^{14}C$ values in the trees from the two sites are in good agreement, we believe that the observed latitude effect is not due to local meteorologic circumstances but a global phenomenon.

The average number of ^{14}C nuclei produced by cosmic ray particles per year is ca 4×10^{26}/yr and 12% of them are over the 60°–90° region. During the solar minimum period, which lasts 3–4 years, the production could increase by 40%. The natural ^{14}C increase could be regarded as mini-bomb dropped in the polar region, yielding ca 6×10^{25} ^{14}C atoms every 11 years. It would then result in the $\Delta^{14}C$ variation in the tree with an amplitude 10‰ and an 11-year periodicity.

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