and could account for a significant part of the variation observed. If $\delta_L - \delta_E > 0$ then the ring-width effect would be in the opposite direction and the variation observed by Gray and Thompson[1] would be even more significant.

The results of Libby *et al.*[2] are more difficult to interpret. One of their oak samples shows variations in δD and $\delta^{18}O$ of approximately 180‰ and 9‰ respectively (for 30-yr means). This variability is much larger than one would expect from the ring-width effect. As Epstein and Yapp[6] point out, however, the magnitudes of the variations observed by Libby *et al.*[2] are much larger than one would expect from precipitation isotope variations (which Libby *et al.*[2] state to be the dominant control). Such large variability is even more unexpected when one recalls that Libby *et al.*[2] use 30-yr means. Nevertheless, their results do correlate reasonably well with central England temperature data.

Isotopic data from tree rings are potentially a powerful indicator of past climate. There is, however, considerable disagreement between the opinions of different workers in this field, and many of the results seem to be mutually incompatible. The simple analysis presented here suggests that variations in whole ring isotope data may be significantly influenced by variations in ring width, and that such isotope data need not be an independent climate indicator. This additional complicating factor may help to explain some of the incompatibilities. We suggest that a comparison between ring width and isotopic variations should be a first step in any analysis of whole ring isotopic data, whether the data comes from whole wood or chemically more specific isotope measurements.

T. M. L. WIGLEY
B. M. GRAY
P. M. KELLY

Climatic Research Unit,
University of East Anglia,
Norwich, UK

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WILSON REPLIES—Wigley, Gray and Kelly make the valid point that isotopic measurements on whole wood may give results which merely reflect the ring width. One aspect of the problem was discussed by Wilson and Grinsted[1] who pointed out that whole wood contains a mixture of lignin and cellulose which have different isotope compositions. Since early and late wood can have different lignin to cellulose ratios, isotopic measurements on whole wood may merely reflect the ratio of late wood to early wood which may in turn be a simple reflection of ring width. Wilson and Grinsted suggested that this and other problems could be avoided if isotope dendroclimatologists measured only pure cellulose or pure lignin.

The comments of Wigley *et al.* on the climatic interpretation of the isotopic measurements on tree rings and the relationship of these to past climate involve the fundamental principles on which isotope dendroclimatology is based. Much of the controversy in this field stems from certain misconceptions of the aims of isotope dendroclimatology and the basic plant physiology involved.

Isotopic dendroclimatology studies face two problems. First, at what times of the year is the material that is ultimately formed into wood components fixed from the atmosphere? And second, how does the isotopic composition of a wood component such as cellulose vary with changing climate?

A conifer manufactures photosynthates at all times of the year except when climatic conditions are unsuitable, due for example to low temperatures or drought stress. These photosynthates are stored for short or extended periods before they are laid down as wood. Most conifers (*Pinus radiata* is one of the exceptions) lay down wood only during a brief period of the year. The actual period of wood deposition is not controlled by net photosynthesis but is under hormone control, the production of hormones being controlled principally by day length and to a lesser extent by temperature. For example, in trees suffering from drought stress wood can be laid down during periods when net photosynthesis is negative[2].

The above considerations apply to any isotopic work on trees. But in the case of isotopic work on oxygen and hydrogen another factor is important. The isotopic composition of rain or snow depends on many factors including the temperature history of the air masses which bring the precipitation to an area[3]. This is not the end of the problem, however. Once the water is taken into the tree transpiration processes in the leaves can cause very large fractionations particularly in arid environments[4].

Wigley *et al.* state that "early wood and late wood generally have different isotopic composition". Leaving aside the point, discussed above, that early and late wood generally have different D/H ratios because they are a variable mixture of more than one compound each with its own isotopic composition. Latewood cellulose and early-wood cellulose generally have different isotope composition because they represent material fixed from the atmosphere at different times of the year and hence in different climatic conditions. For example in New Zealand *Pinus radiata* early wood is laid down in the spring and summer and late wood in the winter, that is, early wood is laid down at a warmer time than the late wood. On Mt Lemon, Arisona, *Pinus ponderosa* lays down early wood in the spring and late wood in the summer[2]. That is, early wood is laid down at the colder time than the late wood. The important point is that the isotopic composition is determined by the climate at the time the carbohydrate was fixed from the atmosphere and not whether it is early or late wood that is being formed.

Isotope dendroclimatology can never be expected to produce a mean annual temperature curve as might be produced by a meteorological observer or from measurements of speleothems[5]. It will only produce a curve representative of some period of the year for example 'a spring and early summer' temperature curve. Different trees may fix from the atmosphere the carbohydrate ultimately formed into wood at different times of the year and hence record climate at different periods of the year. Obviously a deciduous stress such as an oak growing in New Zealand only carries out photosynthesis in the spring and summer, whereas at the same site a conifer such as *Pinus radiata* can fix material from the atmosphere all times of the year. Thus the wealth of palaeoclimatic data recorded in the isotopic ratios of the constituents of tree rings and the superb time base provided by dendrochronology makes the potential of isotopic dendroclimatology very great indeed.

A. T. WILSON

Chemistry Department,
University of Waikatu,
Hamilton, New Zealand

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GRAY AND THOMPSON REPLY—The 'ring width effect' discussed by Wigley *et al.* is relevant in two regards to our findings of significant correlation between $\delta^{18}O$ values in cellulose and mean annual temperatures[1]. First, as stated by Wigley *et al.*, there is a possibility that an appreciable fraction of the variation in the $\delta^{18}O$ values may be due to varying proportions of early and late wood in the tree rings used for analysis. Second, the possibility exists of a sampling error being introduced when a 5-yr group of rings is analysed.

To evaluate the first effect we have made measurements of late-wood width (L), early-wood width (E), and total ring

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