



---

Oceanic Uptake of Fossil Fuel CO<sub>2</sub>: Carbon-13 Evidence

Author(s): P. D. Quay, B. Tilbrook and C. S. Wong

Source: *Science*, New Series, Vol. 256, No. 5053 (Apr. 3, 1992), pp. 74-79

Published by: [American Association for the Advancement of Science](#)

Stable URL: <http://www.jstor.org/stable/2876724>

Accessed: 21/01/2014 12:11

---

Your use of the JSTOR archive indicates your acceptance of the Terms & Conditions of Use, available at <http://www.jstor.org/page/info/about/policies/terms.jsp>

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact support@jstor.org.



*American Association for the Advancement of Science* is collaborating with JSTOR to digitize, preserve and extend access to *Science*.

<http://www.jstor.org>

species, and contributed to the discoloration and defoliation of trees. Attention should be paid to such early warning signs, bearing in mind the irretrievable value of forest growth potential. Past development, nonetheless, guarantees that during the next 10 to 20 years, wood resources are plentiful and can be allocated among traditional forest industries, eventual novel technologies such as ethanol production (31), and nature protection and conservation purposes.

## REFERENCES AND NOTES

- M. Kuusinen, K. Mikkola, E.-L. Jukola-Sulonen, in *Acidification in Finland*, P. Kauppi, P. Anttila, K. Kenttämies, Eds. (Springer-Verlag, Berlin, 1990), pp. 397–420.
- Acidic Deposition: State of Science and Technology* (Superintendent of Documents, Government Printing Office, Washington, DC, 1990), vols. 1–4; *The Canadian Long-range Transport of Air Pollutants and Acid Deposition Assessment Report* (Environment Canada, Toronto, 1990), parts 1–8; P. Kauppi, P. Anttila, K. Kenttämies, Eds., *Acidification in Finland* (Springer-Verlag, Berlin, 1990); G. J. Heij and T. Schneider, Eds., *Acidification Research in the Netherlands* (Elsevier, Amsterdam, 1991); G. Landmann, Ed., *French Research into Forest Decline* (ENGREF, Nancy, France, 1991).
- European Timber Trends and Prospects to the Year 2000 and Beyond* (United Nations ECE/FAO, Publ. E.86.II.E.19, New York, 1986).
- F. Loetsch, F. Zöhrer, K. E. Haller, *Forest Inventory* (Verlagsgesellschaft, Munich, Germany, 1973), vols. 1 and 2.
- In Austria, *Mitt. Forstl. Bundes-Versuchsanst. Wien* 154 (1985) and *Oesterr. For. Auswertung, 1981–1985*; in Finland, K. Kuusela and S. Salmiinen, *Acta For. Fennica* 220 (1991) and E. Tomppo and M. Siitonen, *Paper Timber* 73, 2 (1991); in France, J. C. Deheeger, *Rev. For. Fr. (Nancy)* 40, 131 (1988); and in Sweden, *Statistical Yearbook of Forestry 1991* (National Board of Forestry, Jönköping, Sweden, 1991).
- In Germany, according to *Agrarbericht 1991* (Deutscher Bundestag, Bonn, 1991) the growing stock per unit land area was about  $160 \text{ m}^3 \text{ ha}^{-1}$  in 1961 and  $300 \text{ m}^3 \text{ ha}^{-1}$  in 1987. The forest land area in 1987 was  $77,500 \text{ km}^2$ . We assume the same figure for 1961; in Switzerland, *Schweizerisches Landesforstinventar, Ergebnisse der Erstaufnahme 1982–1986* (Birmensdorf, Switzerland, 1988).
- E. Tikkanen and M. Varmola, Eds. *Report 373* (Finnish Forest Research Institute, Rovaniemi, 1991).
- M. Becker, *Can. J. For. Res.* 19, 1110 (1989); J. L. Innes and E. R. Cook, *ibid.*, p. 1174; H. Spiecker, *Water, Air, Soil Pollut.* 54, 247 (1990/91).
- G. Kenk and H. Fischer, *Environ. Pollut.* 54, 199 (1991); G. Kenk, H. Spiecker, G. Diener, *Referenzdaten zum Waldwachstum. Summary: Reference Data on Forest Growth*, (Projekt Europäisches Forschungszentrum für Massnahmen zur Luftreinhaltung, Freiburg, Germany, 1991).
- L. Hallbäck and C. O. Tamm, *Scand. J. For. Res.* 1, 219 (1986).
- U. Falkengren-Grerup and H. Eriksson, *For. Ecol. Manage.* 38, 37 (1990).
- M. Clawson, *Science* 204, 1168 (1979).
- Additional  $\text{CO}_2$  in the air can stimulate photosynthesis and alleviate drought [R. M. Gifford, *Aust. J. Plant Physiol.* 6, 367 (1979)].
- Forest Damage and Air Pollution. Report of the 1990 Forest Damage Survey in Europe*. (UN ECE Convention on Long-Range Transboundary Air Pollution, International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests, GEMS, Hamburg, 1991).
- European Community Forest Health Report 1989* (Commission of the European Communities, Directorate-General for Agriculture, Luxembourg, 1990).
- P. Nöjd, in (1), pp. 507–522.
- J. L. Innes, *Can. J. For. Res.* 18, 560 (1988); E.-L. Jukola-Sulonen, K. Mikkola, M. Salemaa, in (1), pp. 523–560.
- E. Gorham, *Nature* 279, 148 (1979).
- K. Kuusela, *The Dynamics of Boreal Coniferous Forests* (Gummerus, Jyväskylä, Finland, 1990).
- A. Eliassen, Ö. Hov, T. Iversen, J. Saltbones, D. Simpson, *Report 1/88* (Norwegian Meteorological Institute, Meteorological Synthesizing Centre, Oslo, 1988).
- M. G. R. Cannel, *Scan. J. For. Res.* 4, 459 (1989).
- E.-D. Schulze, *Science* 244, 776 (1989).
- G. Kenk and H. Fischer, *Environ. Pollut.* 54, 199 (1991); H. Spiecker, *Fert. Res.* 27, 87 (1991).
- E. Mälkönen, J. Derome, M. Kukkola, in (1), pp. 325–347; *Yearbook of Forest Statistics* (Finnish Forest Research Institute, Helsinki, 1990), p. 760.
- Forest-2000 Program* (Finnish Ministry of Agriculture and Forestry, Helsinki, 1984).
- N. van Breemen and J. M. Verstraten, in *Acidification Research in the Netherlands*, G. J. Heij and T. Schneider, Eds. (Elsevier, Amsterdam, 1991), pp. 289–352; G. M. J. Mohren, *ibid.*, pp. 387–464.
- R. P. Detwiler and C. A. S. Hall, *Science* 239, 42 (1988).
- R. A. Sedjo, *Science* 241, 1737 (1988); C. S. Binkley, *ibid.* 243, 991 (1989); P. Kauppi and M. Posch, *ibid.*, p. 1535; R. A. Sedjo, *ibid.* 244, 631 (1989).
- In 1980, the growing stock in Europe excluding the former Soviet Union was 15.9 billion cubic meters (overbark) according to *The Forest Resources of the ECE region (Europe, the USSR, and North America)* (UN ECE/FAO, ECE/TIM/27, Geneva, Switzerland, 1985).
- S. Brown and A. E. Lugo, *Science* 223, 1290 (1984).
- L. R. Lynd, J. H. Cushman, R. J. Nichols, C. E. Wyman, *ibid.* 251, 1318 (1991).
- P. Hakila, *Utilization of Residual Forest Biomass* (Springer-Verlag, Berlin, 1989).
- Intergovernmental Panel on Climate Change. Energy and Industry Subgroup Report* (U.S. Environmental Protection Agency, Washington, DC, 1991).
- We thank N. van Breemen, G. Landmann, S. Linder, and P. Nöjd for comments, and M. S. Jarvis for editing.

## RESEARCH ARTICLE

# Oceanic Uptake of Fossil Fuel $\text{CO}_2$ : Carbon-13 Evidence

P. D. Quay,\* B. Tilbrook, C. S. Wong

The  $\delta^{13}\text{C}$  value of the dissolved inorganic carbon in the surface waters of the Pacific Ocean has decreased by about 0.4 per mil between 1970 and 1990. This decrease has resulted from the uptake of atmospheric  $\text{CO}_2$  derived from fossil fuel combustion and deforestation. The net amounts of  $\text{CO}_2$  taken up by the oceans and released from the biosphere between 1970 and 1990 have been determined from the changes in three measured values: the concentration of atmospheric  $\text{CO}_2$ , the  $\delta^{13}\text{C}$  of atmospheric  $\text{CO}_2$  and the  $\delta^{13}\text{C}$  value of dissolved inorganic carbon in the ocean. The calculated average net oceanic  $\text{CO}_2$  uptake is 2.1 gigatons of carbon per year. This amount implies that the ocean is the dominant net sink for anthropogenically produced  $\text{CO}_2$  and that there has been no significant net  $\text{CO}_2$  released from the biosphere during the last 20 years.

The fate of  $\text{CO}_2$  loaded into the atmosphere by fossil fuel combustion and deforestation has been uncertain. Direct measurements of the increase in atmospheric  $\text{CO}_2$  levels, when compared to the rates of fossil fuel combustion and cement production, indicate that about 57 percent of the  $\text{CO}_2$  produced from these sources has accumulated in the atmosphere (1). The other 43 percent of the industrially derived  $\text{CO}_2$  is in either the biosphere or ocean, the two carbon reservoirs that can exchange significant

amounts of  $\text{CO}_2$  on the time scale of the anthropogenic perturbation. Two recent studies of the atmospheric  $\text{CO}_2$  budget came to opposite conclusions with regard to whether the ocean or biosphere has been the predominant  $\text{CO}_2$  sink (1, 2).

Our uncertainty about the fate of anthropogenically produced  $\text{CO}_2$  results from the lack of direct measurements of changes in the carbon content of the biosphere and ocean. As a result we have had to rely on model parameterizations to estimate oceanic and biospheric  $\text{CO}_2$  uptake rates (1–3). Because the uncertainty in these parameterizations is substantial, the question of whether the ocean or biosphere is the major  $\text{CO}_2$  sink has remained unanswered.

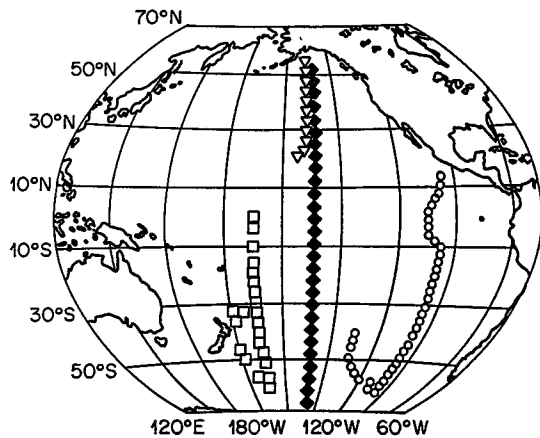
In this article, we use measurements of the decrease in the  $^{13}\text{C}/^{12}\text{C}$  ratio of the total dissolved inorganic carbon (DIC) in

P. Quay is with the School of Oceanography, University of Washington, Seattle, WA 98195.

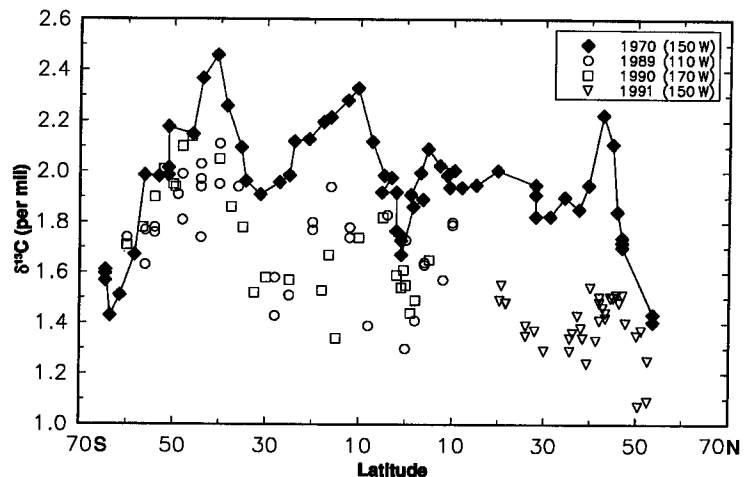
B. Tilbrook is with the Commonwealth Scientific and Industrial Research Organization, Division of Oceanography, Hobart, Tasmania, 7001 Australia.

C. S. Wong is with the Centre for Ocean Climate Chemistry, Institute of Ocean Sciences, Sidney, British Columbia, Canada V8L 4B2.

\*To whom correspondence should be addressed.



**Fig. 1.** The location of the cruise tracks for the HUDSON-70 cruise in May 1970 (solid diamonds) and the three NOAA cruises in February and March 1989 (circles), March and April 1990 (squares), and March and April 1991 (triangles).



**Fig. 2.** The decrease of the  $\delta^{13}\text{C}$  values of dissolved inorganic carbon in the mixed layer of the Pacific Ocean since 1970. Symbols correspond to those in Fig. 1.

the ocean since 1970 to determine the rate of oceanic uptake of anthropogenically produced  $\text{CO}_2$ . The  $^{13}\text{C}/^{12}\text{C}$  ratio, expressed as  $\delta^{13}\text{C}$  (4), is a useful tracer of  $\text{CO}_2$  derived from fossil fuel and deforestation sources. The tracer quality of the  $\delta^{13}\text{C}$  value results from a difference between the  $\delta^{13}\text{C}$  value of  $\text{CO}_2$  in the atmosphere (about  $-8$  per mil) and that of  $\text{CO}_2$  released during the combustion of fossil fuels and biomass (about  $-27$  per mil). The difference between the  $\delta^{13}\text{C}$  values for plant material and atmospheric  $\text{CO}_2$  results from the isotopic fractionation during photosynthetic fixation of  $\text{CO}_2$  (5). Although the  $\delta^{13}\text{C}$  values of terrestrial plants range from  $-27$  per mil to  $-12$  per mil depending on whether the plant uses a three-carbon or four-carbon intermediate to fix  $\text{CO}_2$  (5), that is,  $\text{C}_3$  or  $\text{C}_4$  plants, the terrestrial biomass is overwhelmingly ( $>95$  percent)  $\text{C}_3$  plant material (6).

The  $\delta^{13}\text{C}$  value of atmospheric  $\text{CO}_2$  is decreasing because  $\text{CO}_2$  input from fossil fuel combustion and deforestation has a  $\delta^{13}\text{C}$  value about 20 per mil lower than the  $\delta^{13}\text{C}$  value of atmospheric  $\text{CO}_2$ . The  $\delta^{13}\text{C}$  value of atmospheric  $\text{CO}_2$  has decreased by 1.4 per mil during the last 300 years on the basis of measurements of air bubbles trapped in ice (7). Direct measurements show that the  $\delta^{13}\text{C}$  value of atmospheric  $\text{CO}_2$  decreased from  $-7.5$  per mil in 1978 to  $-7.8$  per mil in 1988 (1). Similarly, the  $\delta^{13}\text{C}$  value of DIC in the ocean should have decreased if anthropogenically produced  $\text{CO}_2$  has entered the oceans. A decrease of about 0.5 per mil from 1900 to 1970 for the surface layer of the tropical ocean has been inferred from measurements of the  $\delta^{13}\text{C}$  value of aragonite in a sclerosponge (8). In order to quantify the amount of anthropogenic  $\text{CO}_2$  taken up by the oceans we must determine the depth-integrated change in

the oceanic  $\delta^{13}\text{C}$  on an oceanwide scale.

On three National Oceanographic and Atmospheric Administration research cruises during the last 3 years we measured the  $\delta^{13}\text{C}$  value of DIC in the Pacific Ocean from  $60^\circ\text{S}$  to  $60^\circ\text{N}$  (Fig. 1). Seawater samples, poisoned with  $\text{HgCl}_2$ , were collected and stored in prewashed and baked ( $450^\circ\text{C}$ ) ground glass-stoppered bottles. In the laboratory, we extracted the  $\text{CO}_2$  from seawater using a helium stripping technique (9). The efficiency of the extraction was  $100 \pm 0.5$  percent based on gravimetrically prepared  $\text{Na}_2\text{CO}_3$  standards. The overall precision of the  $\delta^{13}\text{C}$  analysis was  $\pm 0.02$  per mil based on a replicate analysis of standards and seawater samples.

To recognize changes over decadal time scales we compared our  $\delta^{13}\text{C}$  data with similar measurements made in 1970 and 1971.  $\delta^{13}\text{C}$  values for the mixed layer in the Pacific Ocean in 1970 were measured during the Canadian HUDSON-70 cruise along  $150^\circ\text{W}$  between  $65^\circ\text{S}$  and  $55^\circ\text{N}$  (10). Depth profiles were measured in 1970 at eight stations during the HUDSON-70 cruise, five stations during the SCAN-X cruise along  $90^\circ$  to  $114^\circ\text{W}$ , five stations during the Tow-7 cruise along  $165^\circ$  to  $171^\circ\text{W}$ , and in 1971 at one station during the Antipodes-15 cruise along  $172^\circ\text{W}$  (11). We estimated the uncertainty in the  $\delta^{13}\text{C}$  data from 1970 at  $\pm 0.04$  per mil on the basis of reported replicate analyses (11).

**Oceanic  $\delta^{13}\text{C}$  decrease.** Comparison of the data shows that the average  $\delta^{13}\text{C}$  value of DIC in the mixed layer of the Pacific Ocean decreased by 0.4 per mil during the last 20 years (Fig. 2), if we assume that the values obtained in 1970 are representative of the latitudinal variations over the entire Pacific Ocean. This assumption is supported by the similarity in the  $\delta^{13}\text{C}$  values measured along  $110^\circ\text{W}$  and  $170^\circ\text{W}$  in 1989

and 1990, respectively. Data from the two NOAA cruises in the southern ocean along  $110^\circ\text{W}$  and  $170^\circ\text{W}$  show average decreases of 0.33 and 0.36 per mil, respectively, and data from the northern ocean cruise along  $150^\circ\text{W}$  in 1991 shows a 0.45 per mil decrease. The average basin-wide decrease in  $\delta^{13}\text{C}$  values for the mixed layer, calculated by weighting the latitudinal trends according to ocean surface area, is 0.40 per mil.

With the  $\delta^{13}\text{C}$  data available for the water column (Fig. 3), we can compare the change in the oceanic depth distribution of  $\delta^{13}\text{C}$  values in the Pacific ocean since 1970 at seven sites (12). The average depth-integrated  $\delta^{13}\text{C}$  value has decreased by 203 per mil meters, with a range of 60 to 305 per mil meters (Table 1); the units represent the integration of the area between the  $\delta^{13}\text{C}$  depth profiles measured in 1970 and 1989 to 1991. A comparison of  $\delta^{13}\text{C}$  values measured at depths below 2000 m in 1970 and 1989 to 1991 (Fig. 3) indicates that there is no systematic offset in the data sets. The average difference between 14 pairs of samples collected at comparable locations and depths below 2000 m was  $-0.01 \pm 0.06$  per mil.

The largest decreases in mixed layer and depth-integrated  $\delta^{13}\text{C}$  values occurred in the subtropical gyres; smaller decreases occurred in the equatorial and subpolar oceans (Fig. 4 and Table 1). These  $\delta^{13}\text{C}$  trends are consistent with the increase in mixed layer and depth-integrated  $^{14}\text{C}$  activity (Fig. 4 and Table 2) resulting from nuclear weapons testing (13). The similarity of these carbon isotope changes is not surprising because both the  $^{13}\text{C}$  and  $^{14}\text{C}$  perturbations are input to the ocean by way of  $\text{CO}_2$  gas exchange and affected by the same basin-wide patterns of upwelling and downwelling within the upper portion ( $<1000$  m) of the Pacific Ocean. The

oceanic  $^{13}\text{C}$  and  $^{14}\text{C}$  changes are not likely to be completely correlated because the atmospheric source functions differ. The magnitude of the oceanic  $^{13}\text{C}$  and  $^{14}\text{C}$  changes indicate where these anthropogenically derived carbon tracers have accumulated and not, necessarily, where they have entered the ocean. For example, the small changes in the mixed layer  $^{13}\text{C}$  and  $^{14}\text{C}$  south of  $50^\circ\text{S}$  (Fig. 4) do not imply that there has been no anthropogenic  $\text{CO}_2$  or bomb  $^{14}\text{C}$  uptake in this region.

We estimate an oceanwide decrease in the depth-integrated  $\delta^{13}\text{C}$  by normalizing our measurements at seven sites to the increase in depth-integrated  $^{14}\text{C}$  activity resulting from atmospheric nuclear testing

(bomb  $^{14}\text{C}$ ) measured at nearby stations during GEOSECS (Table 2). The relation between the decrease in  $\delta^{13}\text{C}$  values and increase in bomb  $^{14}\text{C}$  activity (Fig. 5) is:  $^{13}\text{C} = -18.2 \text{ }^{14}\text{C} - 55.7$ , where  $^{13}\text{C}$  is the depth-integrated decrease in  $\delta^{13}\text{C}$  in per mil meters and  $^{14}\text{C}$  is the depth-integrated increase in  $^{14}\text{C}$  activity in  $10^9$  atoms per square centimeter. The standard error (SE) of the slope and intercept is 5.0 and 45.2, respectively. From the oceanwide average bomb  $^{14}\text{C}$  burden of  $8.4 \times 10^9$  atoms of  $^{14}\text{C}$  per square centimeter measured during GEOSECS (13), we calculate that the average oceanwide decrease in depth-integrated  $\delta^{13}\text{C}$  values was  $208 \pm 45$  per mil meters; the uncertainty is the standard

error of the estimate derived from the regression analysis.

**Time rates of change of atmospheric  $^{12}\text{CO}_2$  and  $^{13}\text{CO}_2$ .** In order to determine the amount of fossil fuel  $\text{CO}_2$  taken up by the oceans from the change in the  $^{13}\text{C}/^{12}\text{C}$  ratio of the DIC in the ocean between 1970 and 1990, we must examine the change in the  $^{13}\text{C}/^{12}\text{C}$  ratio and concentration of atmospheric  $\text{CO}_2$  that occurred over this time interval. The change of atmospheric  $\text{CO}_2$  concentrations between 1970 and 1990 depends on the time-integrated  $\text{CO}_2$  releases from fossil fuel combustion and cement production ( $S_{\text{ff}}$ ) and the biosphere ( $S_{\text{br}}$ ),  $\text{CO}_2$  uptake by the biosphere ( $S_{\text{bu}}$ ), and net  $\text{CO}_2$  uptake by the ocean ( $S_{\text{oc}}$ ). This dependency is expressed as:

$$V(C_t - C_o) = (S_{\text{ff}} + S_{\text{br}} - S_{\text{bu}} - S_{\text{oc}})\Delta t \quad (1)$$

where  $V$  is the volume of the atmosphere ( $3.9 \times 10^{18} \text{ m}^3$ ),  $C$  is the atmospheric  $\text{CO}_2$  concentration (grams of carbon per cubic meter),  $t$  refers to 1990,  $o$  refers to 1970,  $S$  is a  $\text{CO}_2$  source or sink flux (grams of carbon per year), and  $\Delta t$  is 20 years. Because 99% of the carbon atoms exist as the  $^{12}\text{C}$  isotope, Eq. 1 represents essentially the time rate of change of the  $^{12}\text{CO}_2$  species. The net biospheric  $\text{CO}_2$  flux is represented by  $S_{\text{br}} - S_{\text{bu}}$ .

Because the net oceanic  $\text{CO}_2$  uptake between 1970 and 1990 equals the oceanwide increase in the depth-integrated concentration of DIC, Eq. 1 can be expressed as:

$$V(C_t - C_o) = (S_{\text{ff}} + S_{\text{br}} - S_{\text{bu}})\Delta t - A_{\text{oc}} \int (DIC_t - DIC_o) dz \quad (2)$$

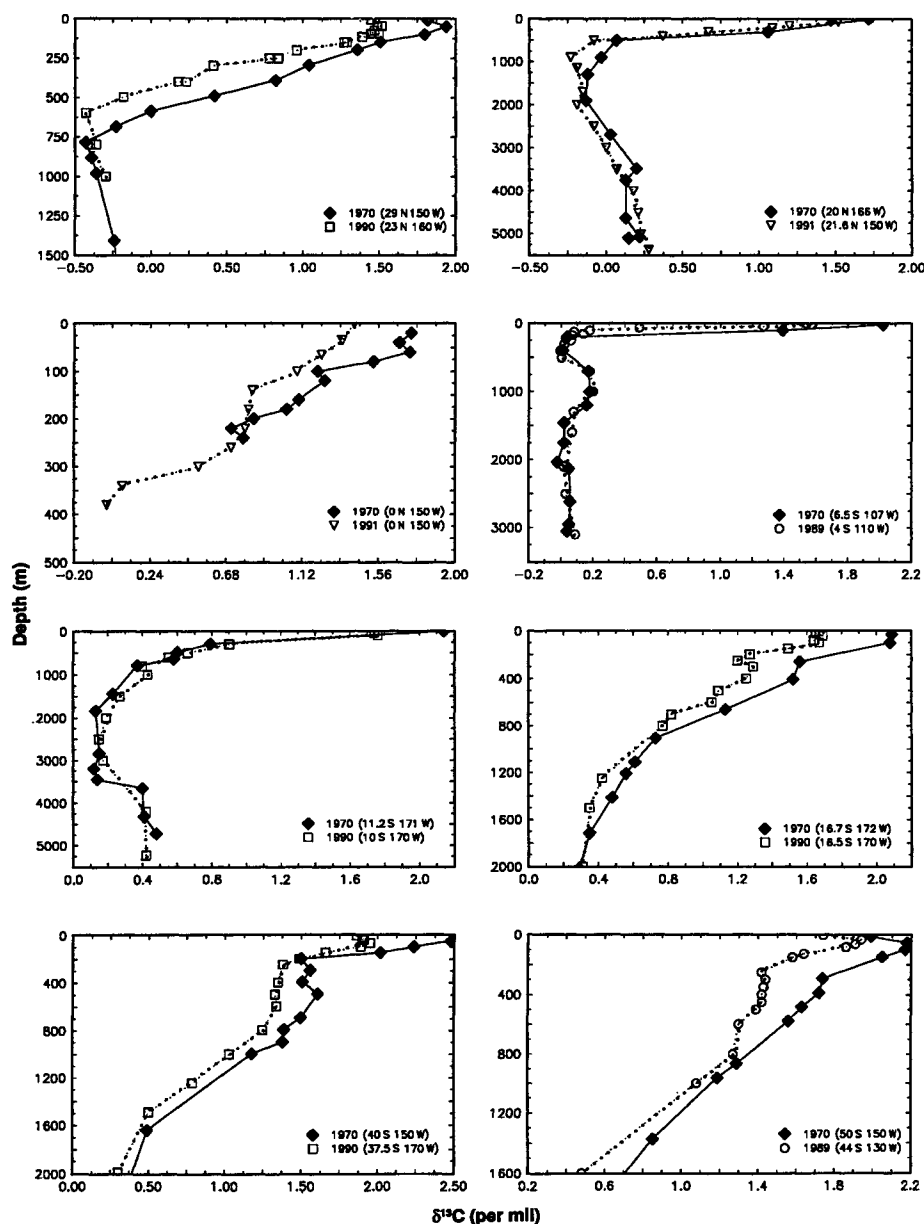
where  $A_{\text{oc}}$  is the global ocean surface area ( $361 \times 10^{12} \text{ m}^2$ ),  $\text{DIC}$  is the  $\text{DIC}^{12}$  concentration (grams of carbon per cubic meter), and  $z$  is ocean depth.

The change of the concentration of atmospheric  $^{13}\text{CO}_2$  between 1970 and 1990 can be expressed, with the use of a formulation similar to Eq. 2, as:

$$\begin{aligned} V[C_t (^{13}\text{C}/^{12}\text{C})_{\text{at}} - C_o (^{13}\text{C}/^{12}\text{C})_{\text{ao}}] &= [S_{\text{ff}} (^{13}\text{C}/^{12}\text{C})_{\text{ff}} + S_{\text{br}} (^{13}\text{C}/^{12}\text{C})_{\text{br}} \\ &\quad - S_{\text{bu}} (^{13}\text{C}/^{12}\text{C})_{\text{bu}}]\Delta t \\ &\quad - A_{\text{oc}} \int [DIC_t (^{13}\text{C}/^{12}\text{C})_{\text{st}} \\ &\quad - DIC_o (^{13}\text{C}/^{12}\text{C})_{\text{so}}] dz \quad (3) \end{aligned}$$

where  $(^{13}\text{C}/^{12}\text{C})_{\text{a}}$ ,  $(^{13}\text{C}/^{12}\text{C})_{\text{ff}}$ ,  $(^{13}\text{C}/^{12}\text{C})_{\text{br}}$ , and  $(^{13}\text{C}/^{12}\text{C})_{\text{bu}}$  represent the isotopic compositions of  $\text{CO}_2$  in the atmosphere,  $\text{CO}_2$  released from fossil fuel combustion and cement production, and  $\text{CO}_2$  released from and taken up by the biosphere, respectively.  $(^{13}\text{C}/^{12}\text{C})_{\text{s}}$  represents the isotopic composition of oceanic DIC.

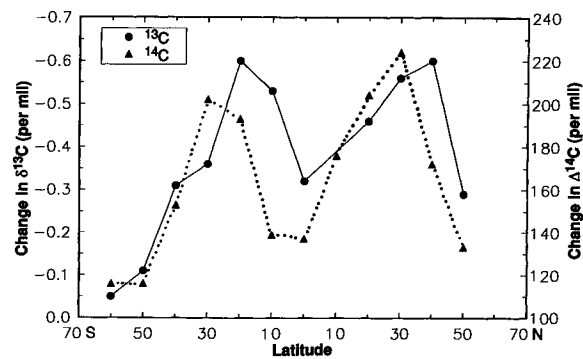
In order to describe the change in the atmospheric  $^{13}\text{CO}_2$  concentration in terms



**Fig. 3.** The change in the depth distribution of the  $\delta^{13}\text{C}$  of the dissolved inorganic carbon since 1970 in the Pacific Ocean. The station comparison at  $0^\circ\text{N}$  uses  $\delta^{13}\text{C}$  measurements on samples collected in September 1991 at Station 282 of the WOCE P16C cruise. The uncertainty of the measurements is approximately  $\pm 0.04$  per mil for the 1970 data and  $\pm 0.02$  per mil for the 1989 to 1991 data.



**Fig. 4.** The latitudinal trends in the changes in the  $\delta^{13}\text{C}$  values (per mil) and nuclear-weapons produced  $\Delta^{14}\text{C}$  (per mil) (20) in the mixed layer of the Pacific Ocean. The  $\delta^{13}\text{C}$  values are determined from the data presented in Fig. 2 and the  $\Delta^{14}\text{C}$  values are determined from GEOSECS data (13).



of the measured change in the depth-integrated  $^{13}\text{C}/^{12}\text{C}$  ratio of the DIC, the change in the oceanic DIC<sup>13</sup> concentration is expressed as the sum of the changes in the oceanic DIC<sup>12</sup> concentration and the ( $^{13}\text{C}/^{12}\text{C}$ ) of the DIC, as follows:

$$\begin{aligned} & [DIC_t(^{13}\text{C}/^{12}\text{C})_{st} - DIC_o(^{13}\text{C}/^{12}\text{C})_{so}] \\ &= (^{13}\text{C}/^{12}\text{C})_{st}(DIC_t - DIC_o) \\ &+ DIC_o[(^{13}\text{C}/^{12}\text{C})_{st} - (^{13}\text{C}/^{12}\text{C})_{so}] \quad (4) \end{aligned}$$

The change in atmospheric  $^{13}\text{C}$  concentration can be expressed as:

$$\begin{aligned} & V[C_t(^{13}\text{C}/^{12}\text{C})_{at} - C_o(^{13}\text{C}/^{12}\text{C})_{ao}] \\ &= [S_{ff} (^{13}\text{C}/^{12}\text{C})_{ff} + S_{br} (^{13}\text{C}/^{12}\text{C})_{br} \\ &\quad - S_{bu} (^{13}\text{C}/^{12}\text{C})_{bu}] \Delta t \\ &- \{(^{13}\text{C}/^{12}\text{C})_{st}\} A_{oc} \int [DIC_t - DIC_o] dz \\ &\quad - \{DIC_o\} A_{oc} \int [(^{13}\text{C}/^{12}\text{C})_{st} \\ &\quad - (^{13}\text{C}/^{12}\text{C})_{so}] dz \quad (5) \end{aligned}$$

where the  $\{DIC_o\}$  and  $\{(^{13}\text{C}/^{12}\text{C})_{st}\}$  terms represent values averaged over the integration depth.

The net oceanic  $\text{CO}_2$  uptake rate ( $S_{oc}$ ) can be expressed in terms of the measured changes in the concentration and  $^{13}\text{C}/^{12}\text{C}$  ratio of atmospheric  $\text{CO}_2$  and changes in the depth integrated  $^{13}\text{C}/^{12}\text{C}$  ratio of the DIC by substituting for  $S_{br}$  and  $A_{oc} \int [DIC_t - DIC_o] dz$  in Eq. 5 as follows:

$$\begin{aligned} & S_{oc} [\{(^{13}\text{C}/^{12}\text{C})_{st}\} - (^{13}\text{C}/^{12}\text{C})_{br}] \\ &= S_{ff} [(^{13}\text{C}/^{12}\text{C})_{ff} - (^{13}\text{C}/^{12}\text{C})_{br}] \\ &- S_{bu} [(^{13}\text{C}/^{12}\text{C})_{bu} - (^{13}\text{C}/^{12}\text{C})_{br}] \\ &\quad + (V/\Delta t)(C_t - C_o)(^{13}\text{C}/^{12}\text{C})_{br} \\ &- (V/\Delta t)[C_t(^{13}\text{C}/^{12}\text{C})_{at} - C_o(^{13}\text{C}/^{12}\text{C})_{ao}] \\ &\quad - \{DIC_o\}(A_{oc})/\Delta t \int [(^{13}\text{C}/^{12}\text{C})_{st} \\ &\quad - (^{13}\text{C}/^{12}\text{C})_{so}] dz \quad (6) \end{aligned}$$

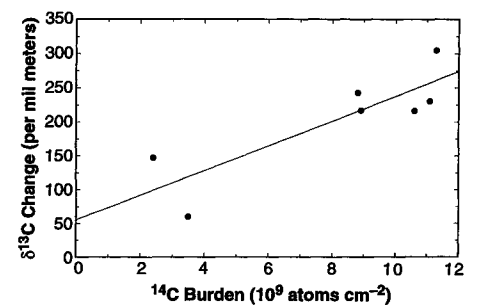
Calculation of the rate of net oceanic  $\text{CO}_2$  uptake requires estimates of the  $\delta^{13}\text{C}$  values for the  $\text{CO}_2$  released from fossil fuel combustion and cement production and taken up by and released from the bio-

sphere. The  $\delta^{13}\text{C}$  of the  $\text{CO}_2$  released by fossil fuel combustion and cement production during the last 20 years was  $-27.2$  per mil (1). The  $\text{CO}_2$  taken up currently by the biosphere has a  $\delta^{13}\text{C}$  value about 20 per mil lower than the  $\delta^{13}\text{C}$  of atmospheric  $\text{CO}_2$  on the basis of isotopic fractionation during carbon fixation in, and predominance of,  $\text{C}_3$  plants (5, 6). If we assume that the isotopic fractionation during carbon fixation has remained constant over time, then the  $\delta^{13}\text{C}$  value of  $\text{CO}_2$  taken up by the biosphere has decreased at the same rate as the  $\delta^{13}\text{C}$  value of atmospheric  $\text{CO}_2$ .

Currently the  $\delta^{13}\text{C}$  value of the  $\text{CO}_2$  released from the biosphere is likely to be higher than that of the  $\text{CO}_2$  taken up by the biosphere because of the lag time between photosynthetic carbon fixation and microbial degradation of woody plant material (14). Estimates of the net primary production rate for the terrestrial biosphere ( $S_{bu}$ ) average about 60 gigatons (Gt) of carbon per year: About 40  $\text{Gt yr}^{-1}$  enter a biospheric carbon pool with a short turnover time ( $<3$  years) and about 20  $\text{Gt yr}^{-1}$  enter into woody plant material with a decadal (about 30 years) turnover time (15). By coupling these biospheric carbon turnover times and flux rates with the measured change in the atmospheric  $\delta^{13}\text{C}$  value, we estimate that the  $\text{CO}_2$  currently released from the biosphere is, on average, about 0.2 per mil enriched relative to the  $\text{CO}_2$  entering the biosphere.

Determining the rate of net oceanic  $\text{CO}_2$  uptake in terms of the mass balances of atmospheric  $^{12}\text{CO}_2$  and  $^{13}\text{CO}_2$ , as presented above, eliminates the need to specify both the rate and isotopic fractionation effect of air-sea  $\text{CO}_2$  gas exchange and an oceanic mixing depth.

**Rates of oceanic and biospheric net  $\text{CO}_2$  uptake.** Between January 1970 and 1989 the mean atmospheric  $\text{CO}_2$  concentration increased from 324.0 to 351.0 ppmv (1). Detailed  $\delta^{13}\text{C}$  measurements have been made only since 1978; between 1978 and 1988 the  $\delta^{13}\text{C}$  decreased from  $-7.49$  to  $-7.74$  per mil (1). We used an empirical relation between the changes in these data and  $\text{CO}_2$  concentration ( $\delta^{13}\text{C} = -0.0147$



**Fig. 5.** The correlation between the depth-integrated changes in  $\delta^{13}\text{C}$  and bomb-produced  $^{14}\text{C}$  activity at the seven locations in the Pacific Ocean where both the  $^{13}\text{C}$  and  $^{14}\text{C}$  changes have been determined (see Tables 1 and 2). The linear regression, represented by the line, is defined by  $^{13}\text{C} = -18.2 \text{ }^{14}\text{C} - 55.7$ , where  $^{13}\text{C}$  is in per mil meters and  $^{14}\text{C}$  is in  $10^9$  atoms per square centimeter; the standard error of the Y estimate is  $\pm 45$  per mil meters.

$[\text{CO}_2] - 2.60$ , where  $\delta^{13}\text{C}$  is in per mil and the  $\text{CO}_2$  concentration is in parts per million; the SE of the slope and intercept is 0.0019 and 0.65, respectively) to estimate the atmospheric  $\delta^{13}\text{C}$  in 1970 and 1990. The estimated  $\delta^{13}\text{C}$  values were  $-7.36$  per mil in 1970 and  $-7.76$  per mil in 1990; for the latter value, we assumed that the atmospheric  $\text{CO}_2$  concentration was 351.5 ppmv in January 1990, which was determined by a regression between  $\text{CO}_2$  concentration and time derived from values measured between 1978 and 1988 (1). The ocean-wide change in the depth-integrated  $^{13}\text{C}/^{12}\text{C}$  ratio between 1970 and 1990 was  $-208$  per mil meters based on our measurements in the Pacific Ocean and an oceanwide extrapolation with the use of the bomb  $^{14}\text{C}$  burden, as discussed above. In order to determine  $S_{oc}$  we assumed that the depth-averaged concentration of DIC in 1970,  $\{DIC_o\}$ , was 2  $\text{mmol liter}^{-1}$  and that the depth-averaged  $\delta^{13}\text{C}$  value for the DIC in 1990,  $\{(^{13}\text{C}/^{12}\text{C})_{st}\}$ , was 1.7 per mil on the basis of our measured values in the Pacific Ocean.

The amount of  $\text{CO}_2$  released from fossil fuel combustion and cement production is estimated to have been 101.6 Gt of carbon between 1970 and 1990, on average 5.1  $\text{Gt yr}^{-1}$  (16). During the same period, the atmospheric  $\text{CO}_2$  increase was 58 Gt of carbon or 2.9  $\text{Gt yr}^{-1}$ , that is, 57 percent of the fossil fuel release. Our calculations indicate that the net oceanic uptake ( $S_{oc}$ ) was 42 Gt of carbon C or 2.1  $\text{Gt yr}^{-1}$ , that is, 41 percent of the industrial  $\text{CO}_2$  release; we have assumed that the flux and time rate of change terms represented in Eq. 6 were constant between 1970 and 1990. If Eq. 1 properly represents all the major carbon reservoirs, then there has been little net  $\text{CO}_2$  release from the biosphere, that is,  $(S_{br} - S_{bu}) = -0.1$  Gt of carbon per year during the last 20 years. If deforestation was occur-

**Table 1.** Change in the  $\delta^{13}\text{C}$  value of dissolved inorganic carbon in the mixed layer (in per mil) and integrated over depth in the Pacific Ocean (in per mil meters). Data for stations TOW-7, SCAN10, and ANTIPODES 15 are from Kroopnick (11). Lat., latitude; Long., longitude; HUD, HUDSON.

Station	Lat.	Long.	Date	Station	Lat.	Long.	Date	$\delta^{13}\text{C}$ change	
								Mixed layer	Integrated
HUD 297	29°N	150°W	5/70	HOTS	23°N	160°W	4/90	-0.42	-305
TOW 7-146	20°N	166°W	6/70	CGC91-19	21.6°N	150°W	3/91	-0.25	-231
HUD EQ	0°S	150°W	5/70	W16C-268	0°S	151°W	9/91	-0.39	-60
SCAN 10-38	6.5°S	107°W	1/70	RITS89-12	4°S	110°W	2/89	-0.46	-147
ANTI 15-06	16.5°S	170°W	8/71	CGC90-3	16.5°S	170°W	2/89	-0.41	-243
HUD 282	40°S	150°W	5/70	CGC90-14	37.5°S	170°W	3/90	-0.57	-216
HUD 280	50°S	150°W	5/70	RITS89-46	44°S	130°W	3/90	-0.24	-217

ring at  $1.6 \pm 0.8$  Gt of carbon per year between 1970 and 1990 (16, 17), then the biosphere grew by almost an equivalent amount during this period. These results are similar to the conclusions reached a decade ago (18), but are not dependent on ocean ventilation models used for those and subsequent calculations of oceanic  $\text{CO}_2$  uptake.

We evaluated the error of the calculated values of  $S_{oc}$  using a numerical bootstrap procedure (19). The uncertainties in the three measured time rates of change were  $\pm 45$  per mil meters for the depth-integrated  $^{13}\text{C}/^{12}\text{C}$  ratio (equal to the standard error of the estimate derived from the regression analysis of the depth-integrated  $^{13}\text{C}$  and  $^{14}\text{C}$  changes, as discussed above), and  $\pm 0.2$  ppm and  $\pm 0.03$  per mil for the changes of the concentration and  $\delta^{13}\text{C}$  value of atmospheric  $\text{CO}_2$ , respectively (1). We estimated the uncertainties in  $S_{bu}$ ,  $S_{ff}$ ,  $(^{13}\text{C}/^{12}\text{C})_{br}$ , and  $(^{13}\text{C}/^{12}\text{C})_{ff}$  to be  $\pm 30$  and  $\pm 10$  percent and  $\pm 2$  and  $\pm 1$  per mil, respectively. The difference in  $\delta^{13}\text{C}$  values between  $\text{CO}_2$  currently fixed into and released from woody plant material was taken as  $-0.6 \pm 0.4$  per mil. The estimated uncertainties in  $\{DIC_o\}$  and  $\{(^{13}\text{C}/^{12}\text{C})_s\}$  were  $\pm 2$  percent and  $\pm 0.3$  per mil, respectively. On the basis of these uncertainties, we derived an error ( $\pm 1$  standard deviation) of  $\pm 15$  Gt of carbon for  $S_{oc}$  and  $S_{br}$ . The error in  $S_{oc}$  and  $S_{br}$  depends on primarily (about 50 percent) the uncertainty in the magnitude of the depth-integrated change in the  $^{13}\text{C}/^{12}\text{C}$  ratio of the DIC.

The uncertainty in  $S_{oc}$  depends mainly on how well the measured depth profiles of the change in  $\delta^{13}\text{C}$  values from 1970 to 1990 represent the entire ocean. Thus, improved estimates of  $S_{oc}$  will be possible as more station comparisons are made, especially when  $\delta^{13}\text{C}$  data from the Indian and Atlantic oceans are obtained. With the data available, the seven profiles we have compared appear to be fairly representative of the global ocean. The average decrease in  $\delta^{13}\text{C}$  values for the mixed layer at these seven sites was 0.39 per mil, close to the

Pacific Ocean average of 0.40 per mil, which is derived from the data presented in Fig. 2. For the GEOSECS stations in close proximity to the stations where the  $\delta^{13}\text{C}$  values were compared, the average bomb  $^{14}\text{C}$  burden of  $8.1 \times 10^9$  atoms  $^{14}\text{C}$  per square centimeter is close to the oceanwide average of  $8.4 \times 10^9$  atoms  $^{14}\text{C}$  per square centimeter (13). The mean depth-integrated change in  $\delta^{13}\text{C}$  value at the seven stations was  $-202$  per mil meters, close to the oceanwide mean  $-208$  per mil meters value derived from the bomb  $^{14}\text{C}$  normalization procedure. Our measurements indicate that the average penetration depth of the change in  $\delta^{13}\text{C}$  values over the last 20 years was 520 m, that is, the depth-integrated  $\delta^{13}\text{C}$  decrease divided by the mixed layer decrease (208 per mil meters/0.4 per mil). This  $\delta^{13}\text{C}$  penetration depth is consistent with the average ocean-wide penetration depth of about 350 m determined for the bomb-produced  $^{14}\text{C}$  (13) after consideration of the shorter time history (about 10 years) of the  $^{14}\text{C}$  perturbation at the time of measurement (1972 to 1978).

The measured time rates of change of atmospheric and oceanic  $^{13}\text{C}/^{12}\text{C}$  ratios yield values for oceanic net  $\text{CO}_2$  uptake

**Table 2.** The increase in  $^{14}\text{C}$  activity produced from testing of nuclear weapons measured at seven GEOSECS stations in the Pacific Ocean (13). These station locations correspond to the stations listed in Table 1. The mixed layer  $^{14}\text{C}$  changes are in per mil (20) and the depth-integrated changes are in  $10^8$  atoms per square centimeter.

Station	Lat.	Long.	Date	$^{14}\text{C}$ Change	
				Mixed layer	Depth integrated
213	31.0°N	168.5°W	9/73	237	11.3
227	25.0°N	170.1°E	11/73	235	11.1
334	0.1°N	124.6°W	5/74	143	3.5
331	4.6°S	125.1°W	5/74	111	2.4
263	16.7°S	167.0°W	1/74	187	8.8
303	38.6°S	170.1°W	3/74	160	10.6
296	44.9°S	166.6°W	3/74	135	8.9

rates that are not model-dependent. Until direct measurements can be made of the changes in the carbon content of the ocean and biosphere, continued oceanic and atmospheric  $\delta^{13}\text{C}$  measurements may provide the best determination of the fate of fossil fuel  $\text{CO}_2$ .

## REFERENCES AND NOTES

1. C. Keeling *et al.*, in *Aspects of Climate Variability in the Pacific and Western Americas*, D. H. Peterson, Ed. (Geophysical Monograph 55, American Geophysical Union, Washington, DC, 1989), pp. 165-236.
2. P. P. Tans, I. Y. Fung, T. Takahashi, *Science* **247**, 1431 (1990).
3. H. Oeschger, U. Siegenthaler, U. Scotterer, A. Gugelmann, *Tellus* **27**, 168 (1975).
4. The  $^{13}\text{C}/^{12}\text{C}$  ratio is expressed using  $\delta$  notation where  $\delta^{13}\text{C}$  (per mil) =  $[(^{13}\text{C}/^{12}\text{C})_x / (^{13}\text{C}/^{12}\text{C})_s - 1]1000$ ,  $x$  is the unknown, and  $s$  is the Pee Dee Belemnite standard; see H. Craig, *Geochim. Cosmochim. Acta* **3**, 53 (1953).
5. M. H. O'Leary, *Phytochemistry* **20**, 553 (1981).
6. R. Warrick, R. Gifford, M. Parry in *The Greenhouse Effect, Climatic Change, and Ecosystems*, SCOPE 29, B. Bolin, B. Döös, J. Jäger, R. Warrick, Eds. (Wiley, Chichester, England, 1987), pp. 393-473.
7. H. Friedl, H. Lotscher, H. Oeschger, U. Siegenthaler, B. Stauffer, *Nature* **324**, 237 (1986).
8. E. R. M. Druffel and L. M. Benavides, *ibid.* **321**, 58 (1986).
9. The  $\delta^{13}\text{C}$  value of DIC in seawater was measured by: (i) drawing the seawater sample into a gravimetrically calibrated burette; (ii) transferring the sample to a bubbler; (iii) acidifying with phosphoric acid; (iv) stripping with 99.999% pure He at a flow rate of  $40 \text{ cm}^3/\text{min}^{-1}$  for 30 minutes and collecting the  $\text{CO}_2$  at  $-196^\circ\text{C}$ , after trapping out water at  $-70^\circ\text{C}$ ; and (v) measuring the  $\delta^{13}\text{C}$  of the  $\text{CO}_2$  gas on a Finnigan MAT 251 mass spectrometer. The  $\text{N}_2\text{O}$  correction was  $<0.02$  per mil based on the measured mass 30/44 ratio; see H. Friedl and U. Siegenthaler, *Tellus* **40**, 129 (1988). The extraction method is a modification of the one used by P. Kroopnick, *Deep-Sea Res.* **21**, 211 (1974). The bottles used for the HUDSON-70 sample collections were soaked in chromic acid but not pre-baked; for the collection and storage methods, see C. S. Wong, *Deep-Sea Res.* **17**, 9 (1970).
10. P. M. Kroopnick, S. V. Margolis, C. S. Wong, in *The Fate of Fossil Fuel  $\text{CO}_2$  in the Oceans*, N. Andersen and A. Malahoff, Eds. (Plenum, New York, 1977), pp. 295-321. The oceanic  $\delta^{13}\text{C}$  measurements made from 1989 to 1991 were not compared to  $\delta^{13}\text{C}$  measurements made during the GEOSECS expedition in the Pacific Ocean (1972 to 1974) because of the problems in the GEOSECS  $\delta^{13}\text{C}$  data; see (11).
11. P. Kroopnick, *Deep-Sea Res.* **21**, 211 (1974); *ibid.* **32**, 57 (1985).
12. The depth-integrated change in  $\delta^{13}\text{C}$  values was not calculated for the station pair at  $10^\circ\text{S}$  and  $11^\circ\text{S}$ , shown in Fig. 3, because  $\delta^{13}\text{C}$  values in 1970 were not measured between 1 and 294 m, where most of the change in  $\delta^{13}\text{C}$  values was likely to have occurred. However, this station pair does provide a useful comparison of deepwater  $\delta^{13}\text{C}$  values measured in 1970 and 1990. In the station comparison at  $0^\circ\text{S}$   $150^\circ\text{W}$  we used  $\delta^{13}\text{C}$  values measured at station 268 during the WOCE P16 cruise in September 1991. A comparison of two stations at  $54^\circ\text{N}$  and  $150^\circ\text{W}$  (HUDSON 301 in 1970 and CGC91-58 in 1991) yielded a consistent offset in  $\delta^{13}\text{C}$  values of about  $-0.2$  per mil between 200 and 2500 m; we did not include this station in Table 1 because of this deep water offset.
13. W. S. Broecker, T. H. Peng, G. Ostlund, M. Stuiver, *J. Geophys. Res.* **90**, 6953 (1985).
14. P. Tans, personal communication.
15. J. Goudriaan and P. Ketner, *Clim. Change* **6**, 167 (1984); W. R. Emmanuel, C. G. Killough, W. M.

- Post, H. H. Shugart, *Ecology* 65, 970 (1984); B. Bolin in *The Greenhouse Effect, Climatic Change, and Ecosystems*, SCOPE 29, B. Bolin, B. Döös, J. Jäger, R. Warrick, Eds. (Wiley, Chichester, England, 1987), pp. 93–155.
16. T. A. Boden, P. Kanciruk, M. P. Farrell, Eds., *Trends '90: A Compendium of Data on Global Change* (Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, ORNL/CDIAC-36, Oak Ridge, TN, 1990).
  17. J. Houghton, G. Jenkins, J. Ephraums, Eds., *Climate Change: The IPCC Scientific Assessment* (Cambridge Univ. Press, New York, 1990), p. 13.
  18. W. S. Broecker, T. Takahashi, H. J. Simpson, T. H. Peng, *Science* 206, 409 (1979).
  19. In the error analysis we used a random selection of values for each measured parameter based on their respective means and standard deviations. A large number, for example, 1000, of calculations of the calculated parameter,  $S_{cc}$ , were made with the randomly selected values for each measured parameter. Then the mean and standard deviation of  $S_{cc}$  were determined from the 1000 calculated  $S_{cc}$  values; see B. Efron, *Biometrika* 68, 589 (1981).
  20. The  $^{14}\text{C}$  activity is expressed as  $\Delta^{14}\text{C} = [(A_s/A_{ox}) - 1]1000$  in per mil, where  $A_s$  is the activity of the sample and  $A_{ox}$  is the age-corrected activity of the oxalic acid standard after  $^{13}\text{C}$  normalization [M. Stuiver and H. A. Polach, *Radiocarbon* 19, 355 (1977)].
  21. We thank the group at NOAA–Pacific Marine Environmental Laboratory, in particular D. Feely

and P. Murphy, and M. Dudley for sample collections. J. Zhang helped with sample collection and extraction. S. Moe, M. Knox, and L. Lu helped with sample extraction, and D. Wilbur oversaw the mass spectrometer measurements. P. Kroopnick provided tabulated  $\delta^{13}\text{C}$  data from SCAN and ANTIPODES cruises. T. Brazunias, U. Siegenthaler, S. Smith, and P. Tans provided helpful reviews. The U.S. work was supported by NOAA's Climate and Global Change Program (NA90AA-D-AC828) and the Canadian work was supported by the Department of Fisheries and Oceans and the Panel of Energy Research and Development (Project 48115).

3 September 1991; accepted 27 January 1992

(Continued from p. 14)

what we know, or are troubled by, but don't know that we know (or don't admit that we are troubled by) because we don't have a satisfying explanation.

David P. Barash  
Department of Psychology,  
University of Washington,  
Seattle, WA 98195

#### REFERENCES

1. W. D. Hamilton, *J. Theor. Biol.* 7, 1 (1964).
2. D. P. Barash, *Sociobiology and Behavior* (Elsevier, New York, ed. 2, 1982).

#### The Search for Eve

Marcia Barinaga's article "‘African Eve’ backers beat a retreat" concerning the debate about modern human origins (*Research News*, 7 Feb., p. 686) contains many examples of the kind of thinking that still

plagues the study of human evolution. It was clear by 1987 that new methods of phylogenetic analysis for reconstructing human history would be necessary, and not just new DNA sequences from more people or a 4.0 version of some existing software package that violated present knowledge of the system (unequal sample sizes and varying rates of evolution).

Breakthroughs in extraction of DNA from human fossils must now be accompanied by better methods to absorb large data sets for analysis of variance and clustering. DNA sequences from actual fossils, not reconstructed hypothetical ancestors, are the key. Further arguments are tedious and wasteful of limited resources and predispose observers to equate evolutionary biology with street theater.

Rebecca L. Cann  
Department of Genetics and  
Molecular Biology,  
University of Hawaii at Manoa,  
Honolulu, HI 96822

#### Corrections and Clarifications

The News & Comment article "Wilson slashes spending for antismoking effort" by Marcia Barinaga (13 Mar., p. 1348) erroneously stated that the California legislature approved the shut-down of California's antismoking ad campaign. The legislature approved the removal of \$29 million from the smoking-initiative budget, but those funds do not influence the ad campaign. The ad campaign funding was removed by an action of the governor that did not have legislative approval.

In Joseph Palca's News & Comment article "AAAS in Chicago: Dawn of a new era?" (21 Feb., p. 918), University of Miami philosopher Kenneth Goodman's name was inadvertently misspelled.

The name of the associate vice chancellor for research at the University of Illinois, Tina Gunsalus, was inadvertently misspelled in the News & Comment article "What's left on the table" by David P. Hamilton (13 Mar., p. 1345).

## AAAS–Newcomb Cleveland Prize

### To Be Awarded for an Article or a Report Published in *Science*

The AAAS–Newcomb Cleveland Prize is awarded to the author of an outstanding paper published in *Science*. The value of the prize is \$5000; the winner also receives a bronze medal. The current competition period began with the 7 June 1991 issue and ends with the issue of 29 May 1992.

Reports and Articles that include original research data, theories, or syntheses and are fundamental contributions to basic knowledge or technical achievements of far-reaching consequence are eligible for consideration for the prize. The paper must be a first-time publication of the author's own work. Reference to pertinent earlier work by the author may be included to give perspective.

Throughout the competition period, readers are invited to nominate papers appearing in the Reports or Articles sections. Nominations must be typed, and the following information provided: the title of the paper, issue in which it was published, author's name, and a brief statement of justification for nomination. Nominations should be submitted to the AAAS–Newcomb Cleveland Prize, AAAS, Room 924, 1333 H Street, NW, Washington, D.C. 20005, and **must be received on or before 30 June 1992**. Final selection will rest with a panel of distinguished scientists appointed by the editor of *Science*.

The award will be presented at the 1993 AAAS annual meeting. In cases of multiple authorship, the prize will be divided equally between or among the authors.