



HAL
open science

A high-resolution atmospheric CO₂ record from carbon isotopes in a peat core from Harberton, Argentina

R. Figge, J.W.C. White, V. Markgraf, Philippe Ciais, R. Kenny

► **To cite this version:**

R. Figge, J.W.C. White, V. Markgraf, Philippe Ciais, R. Kenny. A high-resolution atmospheric CO₂ record from carbon isotopes in a peat core from Harberton, Argentina. *El Cuaternario de America del sur*. Eds J.J., A. and Mourgiart P., ORSTOM. La Paz, pp.327-338, 1997. <hal-03380570>

HAL Id: hal-03380570

<https://hal.science/hal-03380570v1>

Submitted on 15 Oct 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/224942976>

A high-resolution atmospheric CO₂ record from carbon isotopes in a peat core from Harberton, Argentina

Chapter

CITATIONS

2

READS

11

5 authors, including:



[James W. C. White](#)

University of Colorado Boulder

366 PUBLICATIONS 34,284 CITATIONS

[SEE PROFILE](#)



[Vera Markgraf](#)

University of Colorado Boulder

144 PUBLICATIONS 9,244 CITATIONS

[SEE PROFILE](#)



[Philippe Ciais](#)

Laboratoire des Sciences du Climat et l'Environnement

1,290 PUBLICATIONS 120,813 CITATIONS

[SEE PROFILE](#)



[Ray Kenny](#)

64 PUBLICATIONS 499 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



Drought and forest response [View project](#)



YAK-AEROSIB [View project](#)

19. A HIGH RESOLUTION ATMOSPHERIC CO₂ RECORD FROM CARBON ISOTOPES IN A PEAT CORE FROM HARBERTON, ARGENTINA

*Regina A. FIGGE¹, James W.C. WHITE¹, Vera MARKGRAF¹,
Philippe CIAIS² & Ray KENNY³*

Abstract

Here we present a new method for detecting changes in atmospheric CO₂ based on δ¹³C analyses of selected peat components. The paleo-CO₂-record has decadal resolution spanning the last 14 kyr BP and compares well with Antarctic ice core CO₂ data. Sharp peaks in atmospheric CO₂ are detected at 10.2, 11.6, and 12.9 kyr BP and a possible mechanism for these peaks is explored.

1. INTRODUCTION

The carbon dioxide that makes up a small but vitally important constituent of the atmosphere is part of a larger planetary cycle, in which carbon circulates among three active reservoirs and undergoes several changes of chemical form. The reservoirs are the atmosphere, the oceans, and the biosphere. Of the three reservoirs, the oceans contain by far the largest amount of carbon, (*ca.* 39,000 gigatons [IPCC, 1990]) The atmosphere is the smallest carbon reservoir (*ca.* 750 gigatons [IPCC, 1990]) but it plays a significant role in the carbon cycle as a conduit between the two larger reservoirs. There is continuous exchange of CO₂ in both directions between the atmosphere and oceans through air sea exchange processes. There is also an exchange of CO₂ between the atmosphere and the biosphere as a result of plant photosynthesis and respiration.

Full understanding of carbon cycle dynamics is hindered by uncertainties associated with these fluxes between the three reservoirs and the feedback induced by climate change on the carbon cycle. For example, atmospheric CO₂ concentration, [CO₂]_a, is currently rising by 1.8 ppm per year due to fossil fuel emissions and deforestation (IPCC, 1990). About half of these emissions stays in the atmosphere whereas the other half seems to be partitioned between the oceans and biota. Precisely how each reservoir adjusts to such a perturbation is currently under investigation (Tans *et al.*, 1990; Keeling and Shertz, 1992; Ciais *et al.*, 1994). The greenhouse warming expected to result from the excess [CO₂]_a might stimulate secondary effects

¹ Institute of Arctic and Alpine Research, University of Colorado, Campus Box 450, Boulder, Colorado 80309-0450, United States of America.

² CEA Saclay, 91191 Gif-sur-Yvette, France.

³ Department of Geology, New Mexico Highlands University, Las Vegas, New Mexico 87701, United States of America.

such as surface ocean warming and/or carbon fertilization in the biosphere causing further adjustments in each carbon reservoir budget. Again, these effects are under investigation (Mooney *et al.*, 1991; Manabe & Stouffer, 1993; IPCC, 1990).

An improved understanding of the carbon cycle is essential to predict the future $[\text{CO}_2]_a$ increase. Apart from long-term studies and modeling efforts, the paleorecord provides another opportunity to observe large fluxes in $[\text{CO}_2]_a$ and concomitant changes in climate. These data offer valuable insight into the basic feedback and mechanisms that control the carbon cycle. This paper presents new evidence about the unperturbed rate of $[\text{CO}_2]_a$ change over the last 14 kyr BP. The $[\text{CO}_2]_a$ data are derived from $\delta^{13}\text{C}$ measurements from moss and sedge fragments within a peat core from Harberton, Argentina (54.43°S 67.10°W). The discrimination model used to translate $\delta^{13}\text{C}$ values into estimates of $[\text{CO}_2]_a$ is presented and the results are compared to those obtained from ice cores. From the decadal resolution of peat core measurements, several sharp excursions in $[\text{CO}_2]_a$ can be distinguished. Comparison with a marine paleorecord suggests a potential mechanism for these excursions.

2. MATERIALS AND CHRONOLOGY

The Harberton peat bog is located on the Beagle Channel in Tierra del Fuego. This is a cold, coastal site with an average temperature at present of approximately 6 °C. Because of the low temperature, preservation of both mosses and sedges is excellent throughout the 10.2 m peat core. Sedges are present throughout the core and mosses are sparse only between 6.5 and 8.0 m. From the base of the core to 8.0 m, the dominant moss is *Drepanocladus* s.l. whereas above that *Sphagnum magellanicum* dominates. The sedimentation rate can be interpolated from 16 radiocarbon dates on bulk sediment from various levels throughout the core (shown in Table 19.1). On average, a 1 cm sample represents approximately 10 years. The base of the core is approximately 14,000 years old BP.

3. METHODS

The moss and sedge fragments of each 1 cm sample are separated under the microscope. Then two fractions undergo the same chemical pretreatment separately which eliminates all but the cellulose of the plant structure (DeNiro, 1981; Epstein *et al.*, 1976; Green, 1963). An aliquot of the cellulose is combusted at 900 °C in a sealed quartz tube using cupric oxide as an oxygen source. The tubes, once cooled, are loaded into the multiport manifold of a VG SIRA mass spectrometer. The purification of the CO_2 and the determination of the isotopic ratios are done automatically. Reproducibility of $\delta^{13}\text{C}$ values of both moss and sedge cellulose is $\pm 0.2\text{‰}$ based on

replicate analyses of: 1.) downcore moss and sedge samples and 2.) an internal standard.

Depth (cm)	¹⁴ C age (yr B.P.)	stdev (±yr)	laboratory number
17-19	195	55	AA-9016
52-54	840	55	AA-9018
85-87	985	55	AA-9019
103-105	2440	60	AA-9020
201-203	2170	55	A-5486
310-311	3550	120	NSRL-830
415-416	4220	100	NSRL-831
496-498	4560	85	A-5942
561-562	5490	80	NSRL-832
760-763	8670	130	A-5089
780-782	9080	295	GX-15694
803-805	10670	150	A-6742
830-832	10490	475	GX-15695
848-850	10950	170	A-6743
890-892	11300	200	A-5050
997-999	13360	280	A-4817

Table 19.1. Conventional ¹⁴C dates on Harberton peat.

4. THE DISCRIMINATION MODEL

This model takes advantage of the fact that *i.*) mosses and sedges are physiologically different and *ii.*) higher plants with the C₃ pathway of carbon assimilation like mosses and sedges discriminate against ¹³C in ways that respond to these physiological differences (for a more complete discussion on plant discrimination see Rundel *et al.*, 1988). For mosses, this discrimination is a linear function of two unknowns: [CO₂]_a and water content. The ¹³C discrimination in sedges provides an indirect measure of water content and allows us then to infer past changes in [CO₂]_a.

The fractionation of both mosses and sedges can be described by the following equation (Farquhar *et al.*, 1982, 1988):

$$\delta^{13}\text{C}_{\text{plant}} = \delta^{13}\text{C}_{\text{atm}} - a - (b - a) \left(\frac{[\text{CO}_2]_i}{[\text{CO}_2]_a} \right) + \frac{f\Gamma^* + eR_d / k}{[\text{CO}_2]_a} \quad (1)$$

where **a** is the fractionation occurring due to the dominant diffusion through the boundary layer for mosses or through the stomata of the leaf for sedges estimated at 3‰ and 4.4‰ respectively. The larger fractionation associated with the enzyme-

controlled photosynthesis reaction is $b = 30\%$. This enzyme, rubisco, discriminates against ^{13}C because of the intrinsically lower reactivity of ^{13}C . Two smaller sources of fractionation, e and f , are associated with "dark" respiration in the light and with photorespiration estimated at 7% and 2% respectively. R_d is the rate of "dark" respiration in the light, k is the carboxylation efficiency, and G^* is the CO_2 compensation point that would occur if R_d were zero. Finally, $[\text{CO}_2]_i$ and $[\text{CO}_2]_a$ are CO_2 concentrations inside the leaf and in the ambient air. For both mosses and sedges, all the variables in equation (1) are either known or can be solved for except for $[\text{CO}_2]_i$. Although we could solve for $[\text{CO}_2]_i$ today using the modern $[\text{CO}_2]_a$, there is no reason to assume that $[\text{CO}_2]_i$ remained at this concentration over the last 14,000 years. However, we can apply our knowledge of the physiological differences in mosses and sedges to transform equation (1) into one that ultimately solves for $[\text{CO}_2]_a$.

The primary physiological difference between mosses and sedges is that sedges can control water loss and CO_2 uptake by regulating stomatal opening whereas mosses have no functional stomates. In addition, mosses lack a waxy cuticle on the leaf epidermis so water loss and carbon uptake occur by simple diffusion through the cell walls of the plant. Moss $\delta^{13}\text{C}$ values in part reflect the growth conditions available to the plant through assimilation, A , the rate of photosynthesis:

$$A = P_{\max} \cdot f(I) \cdot v(T) \cdot i(W) \cdot j([\text{CO}_2]_a) \cdot k(O) \quad (2)$$

Equation (2) describes assimilation as a combination of the functions of light (I), temperature (T), water content (W), $[\text{CO}_2]_a$, and factors such as nutrients, and soil pH, all multiplied by P_{\max} , the maximum rate of photosynthesis. As discussed in White *et al.*, 1994, $\delta^{13}\text{C}_{\text{moss}}$ responds most strongly to $[\text{CO}_2]_a$ and W . With ample water and atmospheric CO_2 , the moss will assimilate CO_2 rapidly, discrimination will decrease as the preferred pool of $^{12}\text{CO}_2$ molecules is consumed, and $\delta^{13}\text{C}_{\text{moss}}$ will become more positive. Equation (2) is substituted in for $[\text{CO}_2]_i$ in Equation (1) via the definition of assimilation:

$$A = \frac{[\text{CO}_2]_a - [\text{CO}_2]_i}{r} \quad (3)$$

where r is the total resistance to CO_2 diffusion dominated by boundary layer resistance for mosses. All of the functions in Equation (2) can be estimated at this

point (White *et al.*, 1994) except for $i(W)$. In order to obtain an estimate of water content over the last 14,000 years, we turn to sedges.

Sedges, unlike mosses, can regulate water loss (which by default controls CO₂ uptake) by closing the stomates on their leaves. The $\delta^{13}C$ of sedges is not a simple function of $[CO_2]_a$ and water content as in the case of mosses but is a function of that which controls the stomatal opening and closing, specifically, relative humidity, **RH** (Ball *et al.*, 1987; Reynolds *et al.*, 1992):

$$\delta^{13}C_{\text{sedge}} = \delta^{13}C_{\text{atm}} - a - (b - a) \left(1 - \frac{1}{g_1 RH} \right) + \frac{f\Gamma^* + eR_d / k}{[CO_2]_a} \quad (4)$$

where g_1 is a species-dependent constant. From these estimates of RH, $i(W)$ for mosses can be deduced for the mosses through an equation relating RH to W (Dilks & Proctor, 1979). By combining $\delta^{13}C$ measurements in sedges and mosses with estimates of atmospheric $\delta^{13}C$ (from Marino *et al.*, 1992; Leuenberger *et al.*, 1992), past $[CO_2]_a$ variations can be reconstructed.

5. RESULTS AND DISCUSSION

Figure 19.1 shows how the measurements of $\delta^{13}C_{\text{moss}}$ and $\delta^{13}C_{\text{sedge}}$ vary over the last 14 kyr BP. These measurements are listed in Table 19.2. Although there are some similarities in the behavior of the two curves, there are also striking differences. The first obvious difference is that the moss curve is characterized by a wider range of $\delta^{13}C$ values (12‰) relative to the sedge curve (8‰). Secondly, although three excursions at 7.7, 10.2, and 12.9 kyr BP appear in both curves, the trend in the sedge curve is relatively flat and depleted (-27‰) throughout the late glacial to early Holocene whereas during this same time the moss curve is characterized by large excursions (up to 12‰). From 6 kyr BP until present, the trend in the sedge curve is characterized by a broad hump with more enriched $\delta^{13}C$ values (-23‰) whereas the trend in the moss curve is flat with smaller perturbations (2-3‰). The differences in the overall behavior of the two curves observed in Figure 19.1 is consistent with our model described above. That is, that $\delta^{13}C_{\text{moss}}$ and $\delta^{13}C_{\text{sedge}}$ values respond to different environmental parameters: $[CO_2]_a$ and water content being primary for $\delta^{13}C_{\text{moss}}$ and relative humidity primary for $\delta^{13}C_{\text{sedge}}$. Figure 19.1 also shows that the two species of moss behave similarly during the overlap of the two records from 6-8 kyr BP.

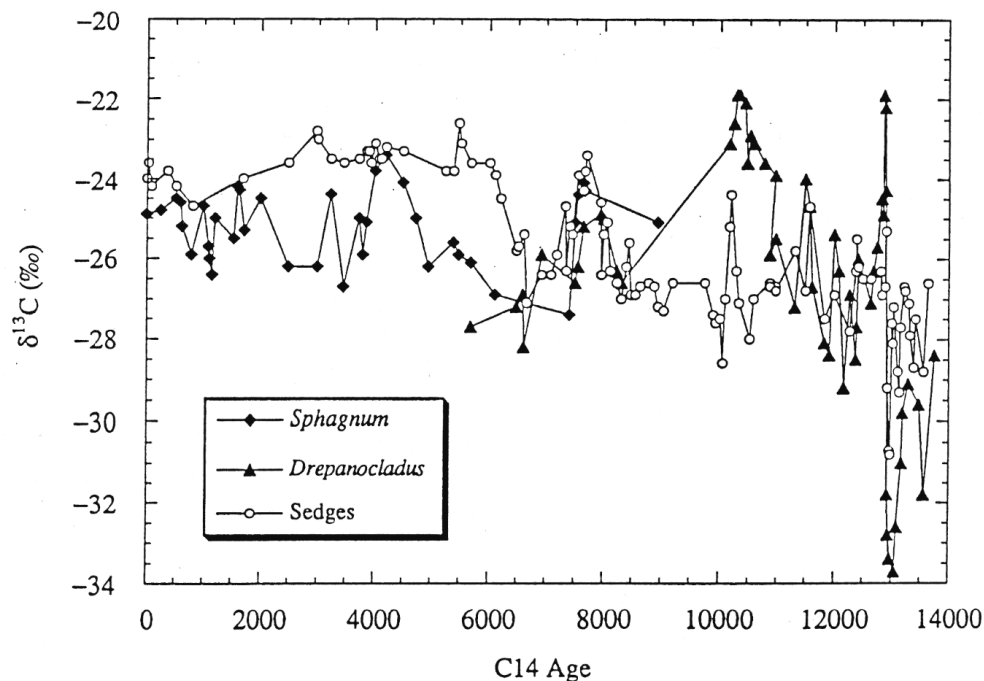


Figure 19.1. $\delta^{13}\text{C}$ values for sedges and two species of moss, *Sphagnum magellanicum* and *Drepanocladus sensulato*, vs. time in radiocarbon years from the peat core at Harberton, Argentina (54.43°S, 67.10°W). The age model is based on linear interpolation between radiocarbon dates (see Tables 19.1 and 19.2).

In Figure 19.2, the $[\text{CO}_2]_a$ reconstructed from the $\delta^{13}\text{C}$ values in mosses and sedges is compared with the values measured in two Antarctic ice cores, Byrd and Vostok.

Although there are gaps in the ice core data and a smoothing effect due to ice pore close-off time (~50 years at Byrd (Neftel *et al.*, 1988) and 300-750 years at Vostok (Barnola *et al.*, 1987)), the agreement between the two records is good. In contrast to the ice core $[\text{CO}_2]_a$ values, the high resolution of the moss $[\text{CO}_2]_a$ allows us to distinguish several $[\text{CO}_2]_a$ spikes at approximately: 4.2, 8, 10.2, 11.6, and 12.9 kyr BP. The Holocene features may be related to changes in climate as recorded by sedge $\delta^{13}\text{C}$ values (Figure 19.1), and pollen data (Markgraf, 1991). Although it is attractive to look toward ENSO (El Niño/Southern Oscillation) as a control on $[\text{CO}_2]_a$ at this time (during El Niño, $[\text{CO}_2]_a$ levels tend to rise faster than at other times) the duration of this excursion suggests that for an extended period the dominant ENSO mode was the low index mode followed by a period dominantly in a high index phase. This interpretation has been suggested in Markgraf *et al.* (1992).

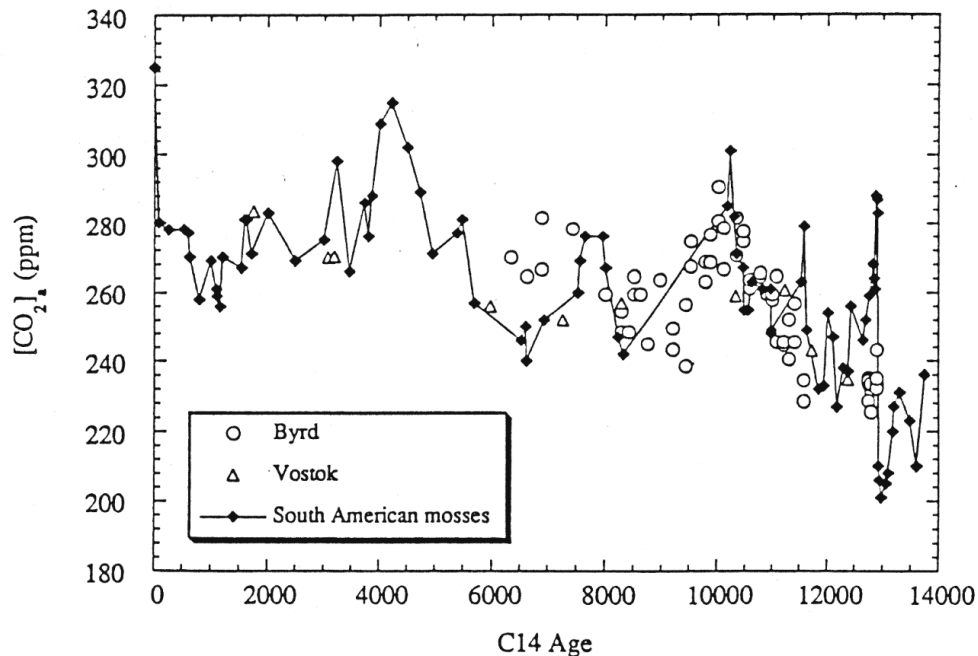


Figure 19.2. Comparison of $[\text{CO}_2]_a$ reconstructed from peat data with measurements from two Antarctic ice cores: Byrd and Vostok (Neftel *et al.*, 1988; Barnola *et al.*, 1987) over the last 14,000 radiocarbon years. The ice cores are dated using ice flow models. The accuracy of the Byrd record is ~5% (Hammer *et al.*, 1994) while the Vostok record is ~10% (Ciais *et al.*, 1992). The absolute age chronologies are converted to radiocarbon years using the relationship given by Bard *et al.*, 1990. Although the agreement between the peat and ice core $[\text{CO}_2]_a$ records is good, the decadal resolution of the peat $[\text{CO}_2]_a$ distinguishes several $[\text{CO}_2]_a$ excursions during the Holocene and late glacial which are smoothed or undetected by the ice cores.

In contrast to the Holocene excursions, the late glacial $[\text{CO}_2]_a$ spikes seem to be driven by a different mechanism. Comparison with the % *N. pachyderma* (*s*) in the AMS-dated, high resolution Troll 3.1 Norwegian Trench core reveals a link to the sudden changes in the thermohaline overturn of the North Atlantic as shown in Figure 19.3. The % *N. pachyderma* (*s*) in the Troll 3.1 core has been interpreted to reflect changes in the strength in the ocean conveyor belt (Lehman *et al.*, 1994) and may suggest a mechanism behind these "burps" in $[\text{CO}_2]_a$. Prior to each burp, the conveyor is strengthened or "turned on" after a period of collapse. Carbon stored in the deep ocean reservoir during a period of collapse would be released to the atmosphere in a large pulse as the conveyor strengthened. The balance of variations in ocean productivity, river input, and lysocline depth would affect the amount of CO₂ released to the atmosphere.

In order to verify whether a $[\text{CO}_2]_a$ spike and the preceding conveyor turn-on were discrete events, the closest radiocarbon date to each event was calibrated

according to Stuiver & Reimer (1993). If the calibrated ranges overlapped at 1s the events were considered coincident.

Depth (cm)	¹⁴ C Age (yr B.P.) ¹	<i>S.m.</i> $\delta^{13}\text{C}$ (‰) ²	<i>D.s.</i> $\delta^{13}\text{C}$ (‰) ³	<i>Sedge</i> $\delta^{13}\text{C}$ (‰)
0	0	-24.9		-24.0
3	30			-23.6
8	80			-24.2
25	250	-24.8		
37	370			-23.8
52	520	-24.5		-24.2
60	600	-24.6		
62	620	-25.2		
79	790	-25.9		
81	810			-24.7
100	1000	-24.7		
108	1080	-25.7		
110	1100	-26.0		
115	1150	-26.4		
120	1200	-25.0		
153	1530	-25.5		
159	1590	-24.2		
163	1630	-24.3		
169	1690			-24.0
171	1710	-25.3		
200	2000	-24.5		
249	2490	-26.2		-23.6
298	2980			-22.8
300	3000	-26.2		-23.0
323	3230	-24.4		-23.5
346	3460	-26.7		-23.6
373	3730	-25.0		-23.5
380	3800	-25.9		
386	3860	-25.1		-23.3
390	3900			-23.3
393	3930			-23.6
401	4010	-23.8		-23.1
408	4080			-23.5
412	4120			-23.5
420	4200	-23.4		-23.2
450	4500	-24.1		-23.3
473	4730	-25.0		
495	4950	-26.2		
525	5250			-23.8
539	5390	-25.6		-23.8
548	5480	-25.9		-22.6
550	5524			-23.1
574	5697	-26.1	-27.7	-23.6
594	6022			-23.6
600	6119	-26.9		-23.9
606	6216			-24.5
623	6492			-27.2
625	6525			-25.7
630	6606			-26.9
631	6622			-28.2
634	6671			-27.1
650	6930			-25.9
660	7093			-26.4
666	7190			-25.9
675	7336			-24.7
676	7352			-26.3
680	7417	-27.4		-25.2
683	7466			-25.4
686	7514	-25.1	-26.6	
689	7563	-24.4	-26.2	-23.9
695	7660	-24.1	-25.2	-24.3
696	7677	-24.3		-23.8
698	7709			-23.4
713	7953			-24.9
714	7969			-29.5
716	8001			-25.0
720	8066			-25.1
723	8115			-26.3
730	8228			-26.6
735	8310			-26.6
740	8391			-26.2
743	8439			-25.6
745	8472			-26.9
750	8553			-26.9
755	8634			-26.7
764	8780			-26.6
770	8877			-26.7
774	8942	-25.1		-27.2
780	9040			-27.3
790	9202			-26.6
792	9755			-26.6
798	9895			-27.4
800	9942			-27.6
803	10012			-27.5
805	10058			-28.6
807	10105			-27.0
810	10175			-23.1
811	10198			-24.4
813	10245			-22.6
815	10291			-21.9
817	10338			-21.9
821	10431			-22.1

Table 19.2. Data from Harberton peat core (see legend in the following page).

Depth (cm)	¹⁴ C Age (yr B.P.) ¹	<i>S.m.</i> δ ¹³ C (‰) ²	<i>D.s.</i> δ ¹³ C (‰) ³	Sedge δ ¹³ C (‰)
823	10478		-23.6	
825	10525		-22.9	-28.0
828	10595		-23.1	-27.0
836	10781		-23.6	
840	10874			-26.6
844	10970		-23.9	-26.7
853	10878		-25.9	-26.7
859	10979		-25.5	-26.8
879	11315		-27.2	-25.8
890	11500		-24.0	-26.8
894	11567		-24.7	-24.7
897	11618		-26.7	
910	11836		-28.1	-27.5
915	11920		-28.4	
920	12004		-25.4	-26.9
925	12088		-26.3	
930	12173		-29.2	
936	12273		-26.9	-27.8
940	12341		-35.3	
942	12374		-28.5	-26.3
943	12391		-27.7	-25.5
945	12425		-26.0	-26.2
950	12509		-26.5	-26.5
958	12643		-27.1	-26.5
961	12694		-26.3	
965	12761		-25.7	
969	12828		-24.5	-26.3
970	12845		-24.5	-26.9
971	12862		-24.9	

Depth (cm)	¹⁴ C Age (yr B.P.) ¹	<i>S.m.</i> δ ¹³ C (‰) ²	<i>D.s.</i> δ ¹³ C (‰) ³	Sedge δ ¹³ C (‰)
972	12879		-21.9	
973	12895		-22.2	-26.7
974	12912		-24.3	-25.3
975	12929		-31.8	-29.2
976	12946		-32.8	
977	12963			-30.7
978	12979		-33.4	-30.8
980	13013			-27.6
981	13030			-28.1
982	13047			-27.2
983	13063		-33.7	
985	13097		-32.6	
986	13114			-28.8
988	13147			-29.3
989	13164			-27.7
990	13181		-31.0	
991	13198		-29.8	
993	13232			-26.7
994	13248			-26.8
997	13299		-29.1	
998	13316			-27.1
999	13332			-27.9
1003	13400			-28.7
1005	13433			-27.5
1008	13484		-29.6	
1013	13568		-31.8	-28.8
1018	13652			-26.6
1024	13753		-28.4	

Table 19.2 (continued). Data from Harberton peat core.[1] Ages are calculated by interpolation between conventional ¹⁴C dated levels (see Table 19.1).[2] δ¹³C values for moss species *Sphagnum magellanicum*.[3] δ¹³C values for moss species *Drepanocladus sensulato*.

The results of this test showed that at 1s the conveyor turn-on and [CO₂]_a spikes occurring around 10.2 and 11.6 kyr BP were discrete i.e. the conveyor turned on prior to the [CO₂]_a spike. The closest date to the [CO₂]_a spike at 12.9 kyr BP was 13,360 ± 280 yr BP (see Table 19.1) and was more closely associated with the conveyor turn-on than the [CO₂]_a spike. Nonetheless, the timing of this 12.9 kyr BP [CO₂]_a spike as affected by calibration of the radiocarbon dates indicates that it occurred after the conveyor turn-on. Results from this test indicate that the relative timing of the events in the two records is not an artifact of either age model and that the conveyor turned on prior to the [CO₂]_a spike in all three cases. Clearly, modification of the reservoir correction factor for the marine record given in Figure 19.3 would affect these results.

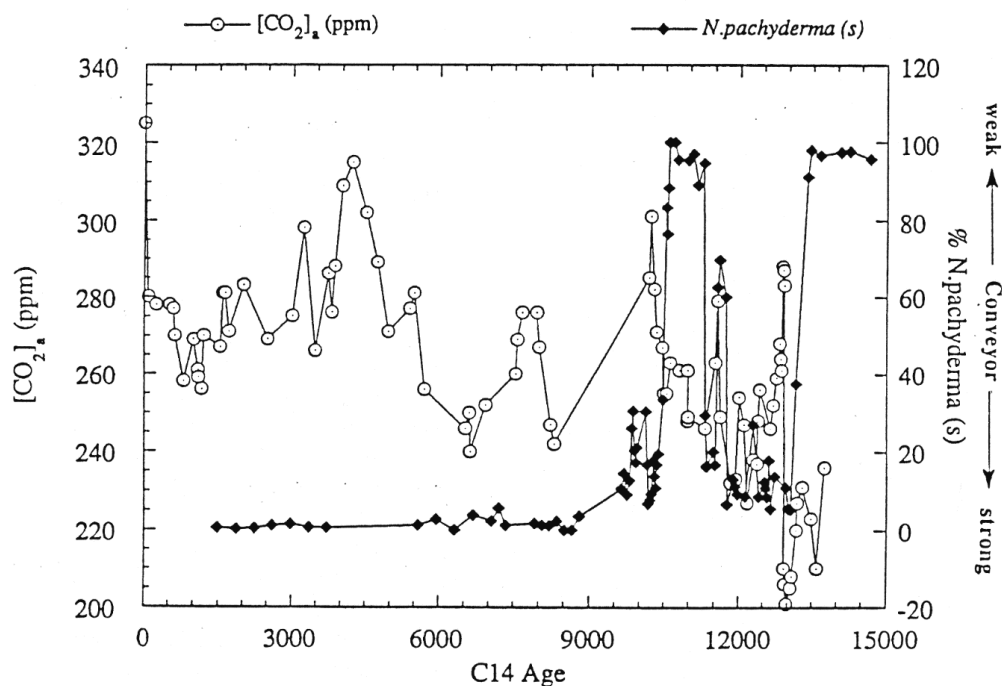


Figure 19.3. Comparison of $[\text{CO}_2]_a$ reconstructed from peat data and % *N. pachyderma* (s) from Troll 3.1 ($60^\circ 47'N$, $3^\circ 43'E$, 332 m water depth) in the Norwegian Trench over the last 14,000 radiocarbon years. The age model for the Troll 3.1 record is based on linear interpolation between eight AMS ^{14}C -dated levels. The AMS ^{14}C ages are corrected for surface ocean ^{14}C activity by -440 years.

During the late glacial, each $[\text{CO}_2]_a$ spike is preceded by rapid conveyor strengthening. Ventilation of the carbon-enriched deepwaters to the atmosphere provide a source of carbon for the $[\text{CO}_2]_a$ excursions as recorded by the peats.

Since the intermediate and deep ocean waters store about 50 times the amount of carbon in the atmosphere (IPCC, 1990), ventilation of these water masses to the atmosphere vis a vis conveyor strengthening is a potent explanation for the late glacial $[\text{CO}_2]_a$ excursions. The comparison of the Troll 3.1 record and our $[\text{CO}_2]_a$ record is consistent with this conceptual framework. Future research including δD analyses from mosses will target the connection between climate and $[\text{CO}_2]_a$ in an attempt to explain the Holocene $[\text{CO}_2]_a$ changes and the rapid decreases in $[\text{CO}_2]_a$ observed during the late glacial.

6. CONCLUSION

The $\delta^{13}\text{C}$ record from peat components represents the first decadal observation of changes in global atmospheric CO_2 over the last 14 kyr BP. This record shows several sharp atmospheric CO_2 excursions during the late glacial. When compared to a high-resolution record of changes in thermohaline circulation, these

CO₂ excursions seem to result from degassing of the ocean associated with periods of re-initiation of the conveyor circulation occurring during this time.

REFERENCES

- Ball JT., Woodrow IE, and Berry JA (1987) A model predicting stomatal conductance and its contribution to the control of photosynthesis under different environmental conditions *in* Progress in Photosynthesis Research. Biggins I (ed.) Proceedings of the VII International Photosynthesis Congress. Martnus Nijhoff, Dordrecht, Netherlands 1V.5, 221-224.
- Bard E, Hamelin B, Fairbanks RG, and Zindler A (1990) Calibration of the ¹⁴C timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados corals. *Nature* 345, 405-410.
- Barnola JM, Raynaud D, Korotkevich YS, and Lorius C (1987) Vostok ice core provides 160,000-year record of atmospheric CO₂. *Nature* 329, 408-414.
- Ciais P, Petit JR, Jouzel J, Lorius C, Barkov NI, Lipenkov V, and Nicolaiev (1992) Evidence for an early Holocene climatic optimum in the Antarctic deep ice-core record. *Climate Dynamics* 6, 169-177.
- Ciais P, Tans PP, White JWC, Trolier M, Francey RJ, Berry JA, Randall DR, Sellers PJ, Collatz JG, and Schimel DS (1994) Partitioning of ocean and land uptake of CO₂ as inferred from the NOAA/CMDL global air sampling network. *in prep.*
- DeNiro, MJ (1981) The effects of different methods of preparing cellulose nitrate on the determination of the D/H ratios of non-exchangeable hydrogen of cellulose. *Earth and Planetary Science Letters* 54, 177-185.
- Dilks TJK and Proctor MCF (1979) Photosynthesis, respiration and water content in bryophytes. *The New Phytologist* 82, 97-114.
- Epstein S, Yapp CJ, and Hall JH (1976) The determination of the D/H ratio of non-exchangeable hydrogen in cellulose extracted from aquatic and land plants. *Earth and Planetary Science Letters* 30, 241-251.
- Farquhar GD, O'Leary MH, and Berry JA (1982) On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. *Aust. J. Plant Physiol.* 9, 121-137.
- Farquhar GD, Hubick KT, Condon AG, and Richards RA (1988) Carbon isotope fractionation and plant water-use efficiency. *in* Stable Isotopes in Ecological Research. Rundel PW, Ehleringer JR, and Nagy KA (eds.) Springer-Verlag.
- Green JW (1963) *in* Methods in Carbohydrate Chemistry. Whistler RL (ed.), Academic, New York, 110-135.
- Hammer C (1994) The new dating of the Byrd ice core based on ECM stratigraphy. *Nature*, submitted.
- IPCC (1990) Houghton JT, Jenkins GJ, and Ephraums (eds.) *Climate Change, The IPCC Scientific Assessment*. Cambridge University Press.
- Keeling RF and Shertz SR (1992) Seasonal and interannual variations in atmospheric oxygen and implications for the global carbon cycle. *Nature* 358, 723-727.
- Lehman SJ, Wright DG, and Stocker TF (1994) Transport of freshwater into the deep ocean by the conveyor in Ice *in* the Climate System, WR Peltier (ed.), NATO ASI Series I12, Springer, 187-209.
- Leuenberger M, Siegenthaler U, and Langway CC (1992) Carbon isotope composition of atmospheric CO₂ during the last ice age from an Antarctic ice core. *Nature* 357, 488-490.
- Marino BD, McElroy MB, Salawitch RJ, and Spaulding WG (1992) Glacial-to-interglacial variations in the carbon isotopic composition of atmospheric CO₂. *Nature* 357, 461-466.
- Markgraf V (1991) Younger Dryas in southern South America? *Boreas* 20, 63-69.
- Markgraf V, Dodson JR, Kershaw AP, McGlone MS, and Nicholls N (1992) Evolution of the late Pleistocene and Holocene climates in the circum-South Pacific land areas. *Climate Dynamics* 6, 193-211.
- Manabe S and Stouffer RJ (1993) Century-scale effects of increased atmospheric CO₂ on the ocean-atmosphere system. *Nature* 364, 215-218.
- Mooney HA, Luxmoore RJ, Oechel WC, and Pitelka LF (1991) Predicting ecosystem responses to elevated CO₂ concentrations. *BioScience* 41(2), 96-104.
- Nefel A, Oeschger T, Staffelbach T, and Stauffer B (1988) CO₂ record in the Byrd ice core 50,000-5,000 years B.P. *Nature* 331, 609-611.

- Reynolds JF, Hilbert DW, Jia-lin C, Harley PC, Kemp PR, and Leadley PW (1992) Modeling the response of plants and ecosystems to elevated CO₂ and climate change. US. Dept. of Energy, Washington DC. DOE/ER-60490T-H1.
- Rundel PW, Ehleringer JR, and Nagy KA eds. (1988) Stable Isotopes in Ecological Research. Springer-Verlag.
- Stuiver M and Reimer PJ (1993) Extended ¹⁴C data base and revised CALIB 3.0 ¹⁴C age calibration program. Radiocarbon 35(1), 215-230.
- Tans PP, Fung IY, and Takahashi T (1990) Observational constraints on the global atmospheric CO₂ budget. Science 247, 1431-1438.
- Thompson LG, Mosley-Thompson E, Davis M, Lin PN, Yao T, Dyurgerov, and Dai J (1993) Recent warming: ice core evidence from tropical ice cores with emphasis on central Asia. Global and Planetary Change 7, 145-156.
- White JWC, Ciais P, Figge RA, Kenny R, and Markgraf V (1994) A high resolution record of atmospheric CO₂ content from carbon isotopes in peat. Nature 367, 153-156.

**CLIMAS CUATERNARIOS
EN AMERICA DEL SUR**

QUATERNARY CLIMATES
OF SOUTH AMERICA

Jaime Argollo y Philippe Mourguiart
editores

PROYECTO PICG - 281

PROJECT IGCP - 281

ORSTOM - Institut Français de Recherche Scientifique pour le Développement en Coopération

La Paz Bolivia 1995