Table 1. Model Parameters

	Value	Unit
Air-Sea Gas Transfer Coefficients		
Box-diffusion model	0.0626	mol m^{-2} ppm^{-1} yr^{-1}
HILDA model	0.0539	mol m^{-2} ppm^{-1} yr^{-1}
2.5-D model	0.0655	mol m^{-2} ppm^{-1} yr^{-1}
GFDL/Princeton 3-D model	0.0638	mol m^{-2} ppm^{-1} yr^{-1}
^{13}C Fractionation Factors		
Air-to-sea flux (F_{as})		
Ocean average (BD, HILDA, 2-D, 3-D)	1.7944	‰
HILDA, high-latitudes	1.7800	‰
HILDA, low-latitudes	1.8700	‰
Sea-to-air flux (F_{sa})		
Ocean average (BD, HILDA, 2-D, 3-D)	10.3624	‰
HILDA, high-latitudes	9.9800	‰
HILDA, low-latitudes	12.3700	‰
Air-to-biota flux (F_{ab})	18.72	‰
Biota-to-air flux (F_{ba})	0	‰
Transport Parameters of the HILDA Model		
Background eddy diffusivity (K_0)	465	m^2 yr^{-1}
Eddy diffusivity at bottom of mixed layer	7561	m^2 yr^{-1}
Eddy diffusivity at 1000 m	648	m^2 yr^{-1}
High-latitude surface-to-deep exchange (u)	38	m yr^{-1}
Upwelling velocity in interior box (w)	0.44	m yr^{-1}
Inverse of exchange coefficient (q^{-1}) between deep ocean reservoirs	538	years

Air-sea gas transfer coefficients of the four ocean models are such that the models roughly reproduce the observed oceanic inventory of bomb-produced radiocarbon at time of the Geochemical Ocean Sections Study (GEOSECS) survey. Isotopic fractionations for air-sea exchange were calculated according to *Mook* [1986] and *Siegenthaler and Münnich* [1981]. Transport equations in the spatially resolved three-dimensional (3-D) and 2.5-D models are determined from first-order physical principles and by tuning the models to observed tracer distributions. The box-diffusion and the High-Latitude Exchange / Interior Diffusion-Advection (HILDA) models are spatially aggregated models. Eddy diffusivity in the box-diffusion model is set to 7100 m^2 yr^{-1} in order to match the observed penetration of bomb-produced radiocarbon. The transport parameters of the HILDA model (Figure 1) were determined by fitting the model to both the observed distribution of natural and bomb-produced radiocarbon. The eddy diffusivity in the interior reservoir is described as a function of depth z below the bottom of the mixed layer ($K(z)$= [465 + 7096 exp(-z/253 m)] m^2 yr^{-1}). It has been found that such a diffusivity parameterization of the surface-to-deep transport is justified by analyzing results of the Geophysical Fluid Dynamics Laboratory (GFDL)/Princeton 3-D model [*Joos et al.*, 1997].

Table 2. Comparison of the Results From a Single and Double Deconvolution

	Biospheric Carbon Release, Gt C yr^{-1}		Oceanic Carbon Uptake, Gt C yr^{-1}	
Period	Single Deconvolution	Double Deconvolution	Single Deconvolution	Double Deconvolution
		1800-1990: 50 Year Intervals		
1800-1850	0.256	0.253	0.172	0.169
1850-1900	0.652	0.173	0.371	−0.108
1900-1950	0.369	−0.061	0.722	0.293
1950-1990	−0.266	−1.077	1.413	0.603
		Whole Period		
1800-1990	0.280	−0.131	0.630	0.220

Results are obtained by using the Bern model and prescribed atmospheric CO_2 and $^{13}CO_2$ history. The atmospheric CO_2 history was reconstructed using the Law Dome ice core data from *Etheridge et al.* [1996] and atmospheric measurements at Mauna Loa and the south pole from *Keeling and Whorf* [1994] (see Figure 2a). The atmospheric $^{13}CO_2$ history was reconstructed from the Antarctic ice core Siple [*Friedli et al.*, 1986] and the Arctic ice core Dye-3 [*Leuenberger*, 1992] in combination with direct atmospheric measurements around 1956 [*Keeling et al.*, 1979] and from Cape Grim [*Francey et al.*, 1996] (see Figure 2b). Cutoff periods of 50 and 10 years were applied for the ice core and atmospheric data, respectively.

Table 3a. Budgets of δ^{13}C and Δ^{14}C Obtained With the Bern Model

Term		δ^{13}C, 1970-1990. ‰ Gt C yr^{-1}	Δ^{14}C, 1860-1950 ‰ Gt C yr^{-1}
1	$F_{\text{fossil}} \cdot \delta C_{\text{fossil}}$	−143	−659
2	$-N_{\text{a}} \cdot \frac{d}{dt}\delta C_{\text{a}}$	22	143
3	$-\frac{d}{dt}N_{\text{a}} \cdot \delta C_{\text{a}}$	21	6
4	$-F_{\text{as,net}} \cdot (\delta C_{\text{a}} + \varepsilon_{\text{as}})$	9	7
5	$-F_{\text{sa}} \cdot [(\delta C_{\text{a}} + \varepsilon_{\text{as}}) - (\delta C_{\text{s}} + \varepsilon_{\text{sa}})]$	39	306
6	$-F_{\text{ab,net}} \cdot (\delta C_{\text{a}} + \varepsilon_{\text{ab}})$	30	−5
7	$-F_{\text{ba}} \cdot [(\delta C_{\text{a}} + \varepsilon_{\text{ab}}) - (\delta C_{\text{b}} + \varepsilon_{\text{ba}})]$	23	205
	Airborne fraction (γ)	0.20	0.22

The contribution to total budget of the fossil production (term 1), the change in atmospheric composition (term 2)+(term 3), the ocean and biospheric uptake as attributed to carbon net fluxes (term 4)+(term 6) and the isotopic disequilibrium fluxes (term 5)+(term 7) are listed separately. The ^{13}C budget was calculated by applying the double deconvolution methodology; the Δ^{14}C budget was calculated by a single deconvolution of atmospheric CO_2 and prescribed atmospheric Δ^{14}C. Indices a, s, and b denote the atmosphere, the surface ocean, and the terrestrial biosphere, respectively. F_{fossil} represents the fossil carbon source. N_{a} represents the atmospheric carbon content, F_{ij} and $F_{\text{ij,net}}$ denote carbon gross fluxes or net fluxes from reservoir i to j, and δC refers either to δ^{13}C or Δ^{14}C; fractionation factors, ε_{ij}, are zero for the budget of the fractionation corrected Δ^{14}C. The airborne fraction is the fraction of the total fossil perturbation in the atmospheric isotopic ratio as expressed in units of per mill, which is still found in the atmosphere. It was calculated as described in the text using (19). The airborne fraction, γ, can be approximated using the absolute values of the above budget terms. It is roughly term 2 divided by the difference of term 1 and term 3 (e.g., for Δ^{14}C, γ=143/(659-6)).

Table 3b. Budgets of Bomb-Produced ^{14}C Obtained With the Bern model

	Changes in ^{14}C Inventory, 10^{26} Atoms	
	Mid-1965 to Mid-1989	1, 1974 to 1, 1992
	Changes in Reservoir Size	
Biosphere		
$-F_{\mathrm{ab,net}}(R_{\mathrm{a}}\alpha_{\mathrm{ab}})$	5	1.7
$-F_{\mathrm{ba}}(R_{\mathrm{a}}\alpha_{\mathrm{ab}} - R_{\mathrm{b}})$	85	0.3
Ocean		
$-F_{\mathrm{as,net}}(R_{\mathrm{a}}\alpha_{\mathrm{as}})$	35	28
$-F_{\mathrm{sa}}(R_{\mathrm{a}}\alpha_{\mathrm{as}} - R_{\mathrm{s}}\alpha_{\mathrm{sa}})$	268	107
Troposphere	−145	−65
Stratosphere	−105	−34
Total	143	38
	Sources and Sinks	
Production by nuclear industry	3	3
Radioactive decay	−2	−2
Production by bomb detonations	52	23
Total	53	24
	Overall Budget	
Total changes in reservoirs	143	38
Total sources minus sinks	53	24
Imbalance	90	14

The decrease in tropospheric ^{14}C inventory is derived from atmospheric CO_2 and Δ^{14}C observations. The increase in oceanic and terrestrial storage is calculated by using the Bern model; the isotopic fluxes are attributed to net carbon fluxes and carbon exchange fluxes (disequilibrium fluxes). Bomb test production is estimated based on bomb test statistics [*Hesshaimer et al.*, 1994]. Prior to 1969, the stratospheric decrease is prescribed according to data published by *Tans* [1981] (original measurements corrected downward by 17%). For 1990 an average stratospheric Δ^{14}C of 200‰ was assumed on the basis of observations above Japan [*Nakamura et al.*, 1992, 1994]. Between 1969 and 1992 these data were exponentially interpolated.

Table 4. Sensitivity Study Regarding a Range of Ocean Models and Model Parameters in the Bern Model

Model	Disequilibrium Fluxes (1970-1990), Gt C‰ yr^{-1}		Carbon Sinks (1970-1990), Gt C yr^{-1}	
	Sea to Air	Biosphere to Air	Ocean	Biosphere
		Four Ocean Models and Four-Box Biosphere		
HILDA	−39.2	−22.5	0.98	1.14
3-D	−40.9	−22.5	1.08	1.04
2-D	−45.9	−22.4	1.37	0.75
BD	−44.2	−22.4	1.27	0.85
		Sensitivity Analysis (HILDA and One-Box Biosphere)		
Standard	−39.3	−23.0	1.02	1.10
$\varepsilon_{\mathrm{ab}} \pm 20\%$	±0.43	±0.12	±0.27	∓0.27
$k_{\mathrm{g}} \pm 20\%$	∓5.53	±0.12	±0.32	∓0.32
$N_{\mathrm{b}} \pm 20\%$	±0.14	∓2.35	±0.13	∓0.13
NPP ±20%	±0.16	∓2.55	±0.14	∓0.14

The disequilibrium fluxes and oceanic and biospheric carbon uptake were calculated using the approximate $^{13}CO_2$ budget equation (equation 16, double deconvolution). Results obtained by four different ocean models as applied in their non-linear pulse response representation [*Joos et al.*, 1996] are presented. The atmosphere to biosphere fractionation factor, $\varepsilon_{\mathrm{ab}}$; the gas exchange rate, k_g; the biospheric mass, N_{b}; and the terrestrial net primary productivity, NPP, have been varied by ±20% around their standard value in HILDA model coupled to a one-box biosphere.

Table 5. Comparison of Carbon Cycle Quantities

Period	Value	Source
	Oceanic Carbon Uptake	
1970-1990	2.1 Gt C yr^{-1}	*Heimann and Maier-Reimer* [1996]
	1.8 Gt C yr^{-1}	*Bruno and Joos* [1997]
	0.91 Gt C yr^{-1}	this study
1982-1992	1.1 Gt C yr^{-1}	*Francey et al.* [1995]
	0.95 Gt C yr^{-1}	this study
1980-1989	2.0 Gt C yr^{-1}	*Schimel et al.* [1996]
	Biospheric ^{13}C Disequilibrium Flux	
1970-1990	23.4 Gt C ‰ yr^{-1}	*Heimann and Maier-Reimer* [1996]
	12.0 Gt C ‰ yr^{-1}	*Quay et al.* [1992], *Tans et al.* [1993]
	22.5 Gt C ‰ yr^{-1}	this study
1987	25.8 Gt C ‰ yr^{-1}	*Francey et al.* [1995]
	26.4 Gt C ‰ yr^{-1}	this study
1970-1987	17.8 Gt C ‰ yr^{-1}	*Wittenberg and Esser* [1997]
	Oceanic ^{13}C Disequilibrium Flux	
1970-1990	50.6 Gt C ‰ yr^{-1}	*Heimann and Maier-Reimer* [1996]
	36.6 Gt C ‰ yr^{-1}	*Tans et al.* [1993]
	39.2 Gt C ‰ yr^{-1}	this study
1987	43.8 Gt C ‰ yr^{-1}	*Francey et al.* [1995]
	50.4 Gt C ‰ yr^{-1}	this study
	Air-Sea ^{13}C Disequilibrium	
1970-1990	0.43‰	*Tans et al.* [1993]
1980	0.60‰	this study
	Air-Biota ^{13}C Disequilibrium	
1970-1990	0.20‰	*Tans et al.* [1993]
1980	0.38‰	this study
1988	0.33‰	*Fung et al.* [1997]
1988	0.43‰	this study
	Vertically Integrated Rate of Change of $^{13}C/^{12}C$ in DIC	
1970-1990	−10.40‰ m yr^{-1}	*Quay et al.* [1992]
	−8.94‰ m yr^{-1}	*Heimann and Maier-Reimer* [1996]
	−8.02‰ m yr^{-1}	this study
	Oceanic Bomb ^{14}C Inventory	
1975	305×10^{26} atoms	*Broecker et al.* [1995]
	315×10^{26} atoms	this study
1992	435×10^{26} atoms	this study
	Bomb ^{14}C Budget Imbalance	
1965-1989	82×10^{26} atoms	*Joos* [1994]
	90×10^{26} atoms	this study
1974-1992	14×10^{26} atoms	this study
	$\Delta^{14}C$ Suess Effect	
1860-1950	17.3‰	*Stuiver and Quay* [1981]
	20‰	this study

DIC is dissolved inorganic carbon