6. Initialisation

6a Budgets

A key specification in the modelling exercise was the requirement for a balanced atmospheric carbon budget consistent with observations. Table 6.1 summarises the way in which various models achieved this balance over the period 1980–89. Figures 6.1 and 6.2 show more detail, giving the time history of calculated concentrations (for forward initialisations) and calculated emissions (for inverse initialisations) respectively.

	Initialisation	Fossil	Ocean	Fertil	Land-use	Biota	$\frac{dC}{dt}$
A_1	Inverse*	5.65	2.03	1.85	1.56	0.29	1.59
F_2	Inverse	5.50	1.99			1.72	1.59
H	Inverse*	5.63	1.47			0.76	1.59
J	Inverse	5.45	2.16			−0.08	1.59
L	Inverse	5.45	2.14		1.60	0.12	
M	Inverse	5.58	1.72			0.48	1.59
Q	Inverse*		1.81				
T	Inverse	5.41	1.79	1.95	1.68		1.59
W	Inverse	5.45	2.00	1.67	1.60	0.07	1.59
A_2	Forward	5.49	2.00	1.87	1.29	0.58	1.39
E	Forward	5.48	2.10			0.27	1.50
O	Ocean-only		2.10				

Table 6.1. Mean budgets (or budget components) for 1980–89. Fluxes are in GtC/yr and are sinks except for the fossil and land-use terms. The ‘biota’ term is the annual mean increase in biomass, equal to fertilisation minus land-use. The mean atmospheric increase is in ppmv/yr. The * denotes a modified inverse initialisation.

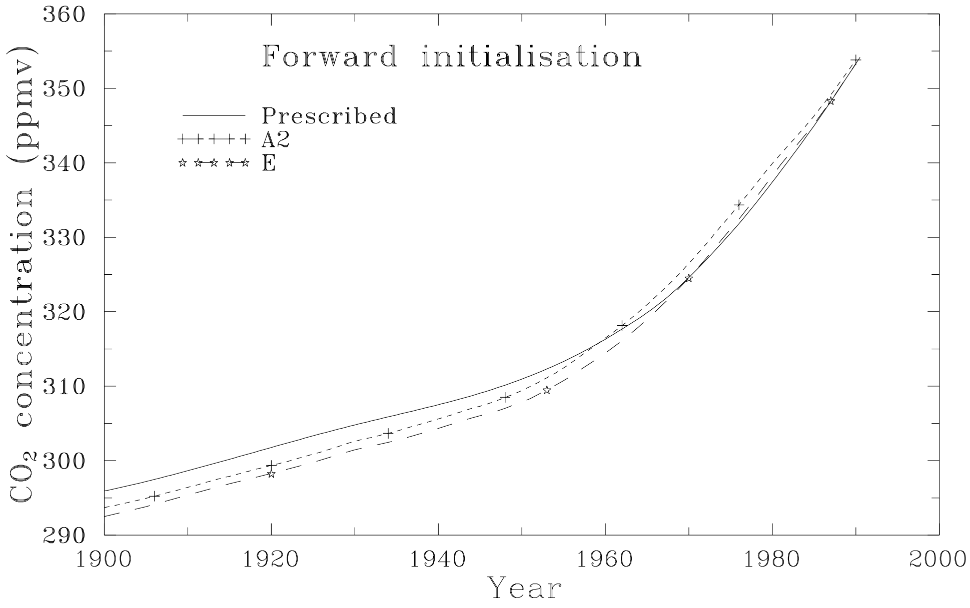

Figure 6.1. Calculated concentrations for models with forward initialisation.

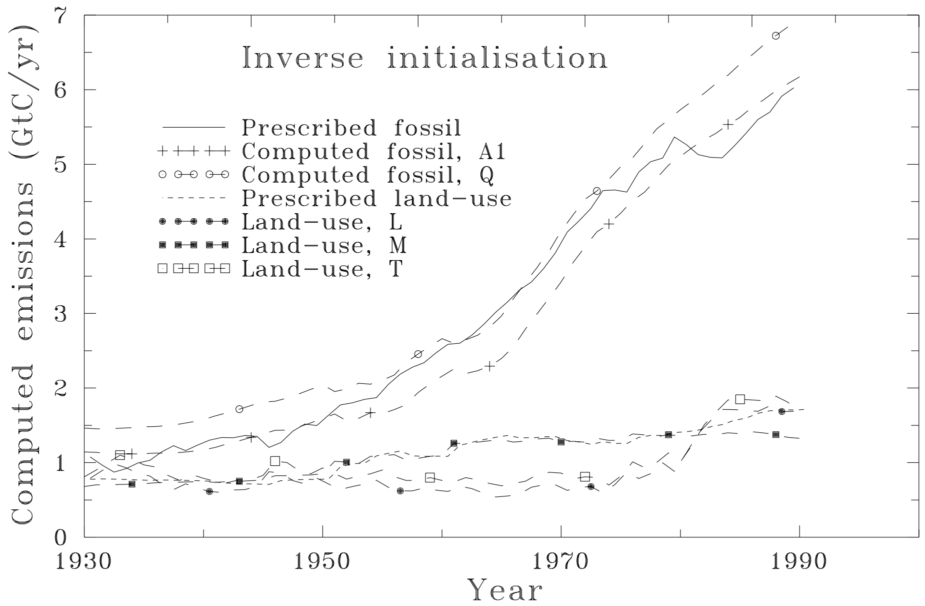

Figure 6.2. Calculated emissions for models with inverse initialisations, compared to prescribed functions. There are two groups, depending on whether the fossil or the land-use component was deduced in the inversion.

6b Validation

The validation of carbon cycle models is a key issue in establishing the credibility of the projections that can be made for future concentrations. The main scope for validation is for the ocean component, for the following reasons:

- The chemical relations between ocean carbon content and CO_2 partial pressure are well-known from measurement.
- The atmosphere and the ocean surface mixed layer are close to equilibrium; uncertainties in the air-sea gas exchange coefficient have little impact on carbon cycle model projections, even though they are critical in the interpretation of ocean P_{CO2} data.
- The rate-limiting process for oceanic uptake of CO_2 is the rate of physical mixing of water masses. This will have the same impact on all oceanic constituents and makes it possible to use other passive tracers to validate ocean carbon models.
- The biotic processes affecting ocean carbon do not affect the rate of uptake of anthropogenic CO_2 unless these biotic processes actually change.

The radioactive isotope ^{14}C plays a key role in the calibration and validation of ocean carbon models. Two aspects of the ^{14}C distribution are important: the natural distribution, in which different ^{14}C levels reflect the effect of radioactive decay (half-life 5730 years) and the excess ^{14}C from nuclear testing when atmospheric ^{14}C levels almost doubled in the early 1960s. Extensive data sets of oceanic ^{14}C were obtained in the GEOSECS program (circa 1973), the TTO program (1981–3) (Brewer et al., 1985) and are part of the on-going WOCE program.

^{14}C data play a small role in validating models of terrestrial carbon. As noted above, ^{14}C data have been used to estimate turn-over times for soil carbon. One important use of terrestrial ^{14}C data is as a proxy for atmospheric ^{14}C in determining the Suess effect (i.e., the decline in the proportion of atmospheric ^{14}C due to dilution of the atmospheric reservoir by CO_2 derived from fossil sources in which all the ^{14}C has decayed).

The use of bomb-^{14}C poses some difficulties because the sources are poorly known, due to military secrecy. The usual way of using bomb-^{14}C in carbon cycle models is to specify the atmospheric ^{14}C levels from observations. For the present exercise, specified ^{14}C levels were provided. These are plotted in Figure B.5. To make best use of such data, the ^{14}C calculation should be performed in 'inverse' mode, deducing the sources to ensure that the calculated source went to zero after the cessation of atmospheric testing. Alternatively, the calculation could be performed in inverse mode during the period of testing and 'forward' mode therafter, to check that the decline in atmospheric ^{14}C levels matched observations. Enting and Lassey (1993) addressed this problem by performing the ^{14}C calculations in 'forward' mode throughout, with a 'bomb-^{14}C production factor' to take account of source uncertainty and tuned to match observations. Some aspects of the ^{14}C calibration issue are analysed by Enting (1990).

In analysing oceanic ^{14}C data, it has become common to use the penetration depth z_{pen} as a measure for comparing models. The penetration depth is defined as the ratio of the volume-integrated bomb-^{14}C inventory to the area-averaged surface bomb-^{14}C levels. (Each of the factors requires an estimate of pre-bomb levels in order to calculate the excess from current observations.) The penetration depth gives a measure of transport out of the surface mixed layer. This is the quantity of most interest for the uptake of anthropogenic CO_2. In contrast, the mixed-layer ^{14}C level is strongly influenced by the air-sea gas exchange rate, a quantity that is somewhat uncertain but which has little influence on long-term rates of uptake of CO_2.

A small number of modelling groups submitted specific results for ^{14}C. Other groups referred to their published model descriptions in which results for ^{14}C (and in some cases other tracers) were included.

The summary of ^{14}C validation data relevant to the present calculations is:

Not applicable The ocean ^{14}C data can not be applied to the models that do not resolve the ocean: Model C which parameterises atmospheric response, Model F which is biosphere-only, Models T, V and W which represent the ocean in terms of response functions, and Model Z which has too little resolution. The validation of response function representations derived from other models can be achieved by reference to the original model, but this linkage is lost if there is subsequent 'tuning' of the response function. A closer linkage between CO_2 and ^{14}C could be achieved in terms of response functions describing perturbations to the mixed layer (as used in other contexts by Enting, 1990, and Heimann and Maier-Reimer, 1994).

Contributed The models for which ^{14}C data were calculated were E, J, L, O, Q, with Table 6.2 giving a summary of what was provided.

Published In addition Models H, J, L, Q referred to work, published or in preparation, describing aspects of the model calibration.

Table 6.3 compares some of the key results.

	t	E	J	L	O	Q
Mixed layer	all	Y	Y	Y	Y	Y
Inventory	all	-	Y	-	Y	Y
Mixed layer	1974	Y	Y	Y	Y	Y
Inventory	1974	Y	Y	-	Y	Y
z_{pen}	1974	Y	Y	-	Y	Y

Table 6.2. ^{14}C calibration data. 'Y' denotes ^{14}C data contributed. For the box-diffusion models (A,B,E,P) various analyses of ^{14}C have been published.

	Total 1950	Mixed 1950	Total 1973	Mixed 1973	ΔTotal $50-73$	ΔMixed $50-73$	z_{pen}	S_{ocean} 1980
Obs.						157		—
E		-60.5		101.9		162		2.00
H					9.27	189	320	1.32
J	0.78	-59.1	8.62	93.6	7.84	155		1.94
L					8.4		310	1.95
O					7.18	159		1.89
Q	525.2	-52.1	533.6	145	8.42	197	304	2.39

Table 6.3. Ocean ^{14}C levels. The mixed layer values are in ‰. Depth-integrated totals are in 10^9 atoms cm^{-2}. The penetration depth z_{pen} is in metres. The observations are from the analysis by Broecker et al. (1985).

One aspect of the importance of the ^{14}C calibration is indicated by Model A. As indicated in Table 3.2, this uses the calibration from Siegenthaler and Oeschger (1987) based on natural ^{14}C. Siegenthaler and Oeschger suggested that this should give a lower bound on the oceanic carbon uptake. Calibrations based on bomb-^{14}C give higher eddy diffusion coefficients (see Table 3.2) and thus greater uptake (see Table 8.3).

A recent study by Hesshaimer et al. (1994) (see also Joos, 1994) has re-analysed the ^{14}C records using an approach similar to the ‘inverse’ followed by ‘forward’ procedure described above. They have queried the conventional anlysis of the ^{14}C budget. This result requires further analysis.

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