

1. Box Model, residence time.

Element "X" is at steady state in the contemporary ocean with a concentration of $1.0 \times 10^{-3} \text{ mol L}^{-1}$ (M). The main input is from rivers and the main removal is by the stripping of X from seawater during hydrothermal circulation (concentration of X in the return flow from the vents to the ocean is zero). The following information is available:

| | |
|--------------------------------|--|
| Volume of ocean | $1.4 \times 10^{21} \text{ L}$ |
| River Flow: | $3.2 \times 10^{16} \text{ L year}^{-1}$ |
| Concentration of X in rivers | $1.0 \times 10^{-4} \text{ M}$ |
| Concentration of X in seawater | $1.0 \times 10^{-3} \text{ M}$ |

a. Calculate the residence time of X with respect to total (e.g. river) inputs.

b. Set up the mass balance equation (sources = sinks) for X. Calculate the rate of water flow through the hydrothermal circulation that would have to exist for this to be a steady state system.

A change in climate patterns results in a new significant source of X to the ocean in the form of atmospheric deposition. Some phytoplankton in the surface ocean biota respond to the enhanced input by building their shells out of X, resulting in a new sedimentation flux as a sink of X from the ocean. The rate of water flow in the hydrothermal system is unchanged.

| | |
|-------------------------------------|--|
| Rate of atmospheric deposition of X | $2.0 \times 10^{12} \text{ mol year}^{-1}$ |
| Rate of burial of X in sediments | $0.5 \times 10^{12} \text{ mol year}^{-1}$ |

c. Set up the new mass balance equation for X. Calculate the concentration of X in seawater once the ocean reached its new steady state.

d. Calculate the new residence time of X with respect to total inputs.

2. Siegenthaler and Sarmiento (1993) have presented box models of the global carbon cycle for pre-industrial (PI) times and the present (1980-89). These are shown below. Answer the following questions and show all your work and calculations.

- Was atmospheric CO₂ in steady state in pre-industrial times?
- Is atmospheric CO₂ in steady state at present (1980-1989)?
- What is the residence time of atmospheric CO₂ for PI conditions?
- What was the residence time of carbon in biota in the surface ocean in PI time?
- How has the residence time of carbon in marine biota changed as a result of increased fossil fuel CO₂?

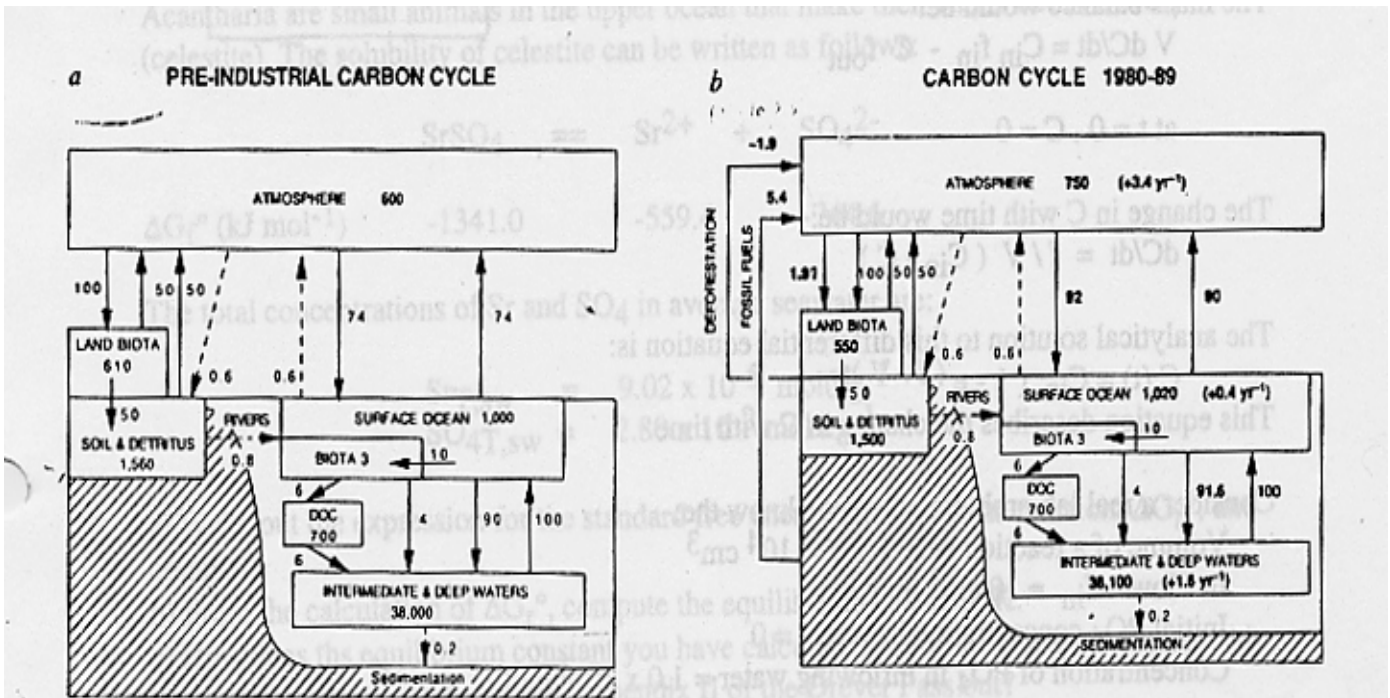


FIG. 1 Global carbon cycle reservoirs and fluxes, in Gt C and Gt C yr⁻¹, respectively (1 Gt C = 10¹⁵ g C). a, Reconstructed pre-industrial situation and b, present-day situation. In b, bold numbers denote fluxes or reservoir sizes which have changed due to human activities. The numbers in b correspond approximately to those given in the 1990 IPCC assessment² with the following exceptions: an oceanic pool of dissolved organic carbon (DOC) is included (E. Peltzer, personal communication). The marine biological new production (equal to particles plus DOC exported from the surface) is 10 Gt C yr⁻¹, taken from model calculations^{65,66}. The indicated transport by water circulation is much larger than in the IPCC assessment², but this is primarily a matter of

definition. The IPCC downward flux of 35 Gt C yr⁻¹ corresponds roughly to global deep-water formation (~46 × 10⁶ m³ s⁻¹). Our upward flux (100 Gt C yr⁻¹) is chosen such that it is about ten times the total new production, which in a 2-box model yields a surface water ΣCO₂ deficit of 10%, as observed. Our fluxes therefore represent exchange between the surface and a depth of perhaps 1 km where most of the particles and DOC have been remineralized. The cumulative land-use effect, assumed to be -120 Gt C, is divided equally between vegetation and soils. The difference between river input and sedimentation has been closed by fluxes of 0.6 Gt C yr⁻¹ from ocean to atmosphere and from atmosphere to biota (dashed arrows).

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RESERVOIRS IN Gt C
FLUXES IN Gt C yr⁻¹

3. Sodium (Na) is the highest concentration cation in seawater. What controls the concentration of Na in seawater?

4. Only one of the following is the essential approximation made when assuming steady state:

- a. ocean inputs from rivers equals the particle flux out of the euphotic zone
- b. the concentration does not change with time
- c. the removal flux must be proportional to how much is there.
- d. the river input must equal the atmospheric input.

5. Gypsum solubility is written as:



- a) If we added gypsum to distilled water (with no other salts present) and let it come to equilibrium, what would the equilibrium concentration of total Ca be? Use the Davies equation to calculate γ_i .
- b) If the total sulfate concentration of seawater is $25.0 \times 10^{-3} \text{ mol kg}^{-1}$, what would be the concentration of total Ca if gypsum was at solubility equilibrium? How does this compare with the actual concentration of seawater?