THE OCEAN CARBON CYCLE

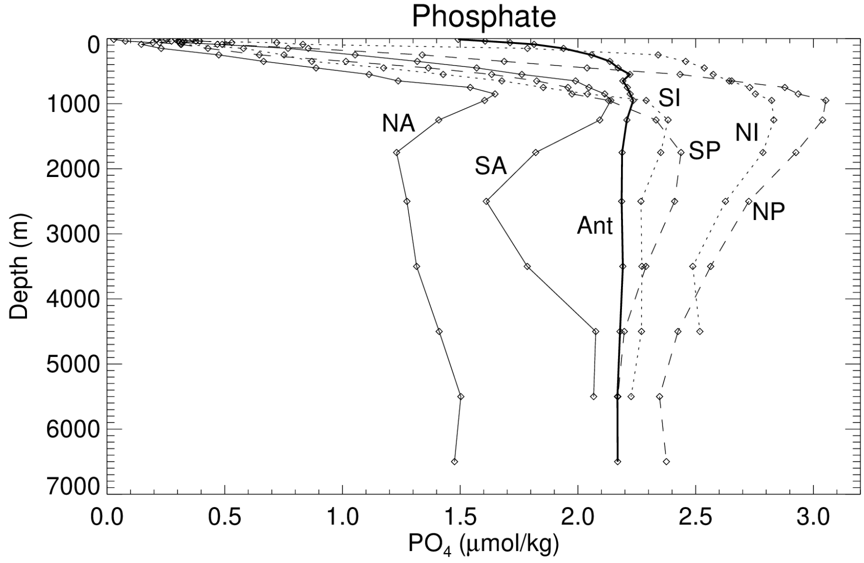
21st February 2024

1 Box-model of the global ocean
phosphorus, alkalinity, carbon
2 Pre-industrial model
3 Evolution during the industrial period
4 ^{13}C isotopic evolution

BOX-MODEL OF THE GLOBAL OCEAN

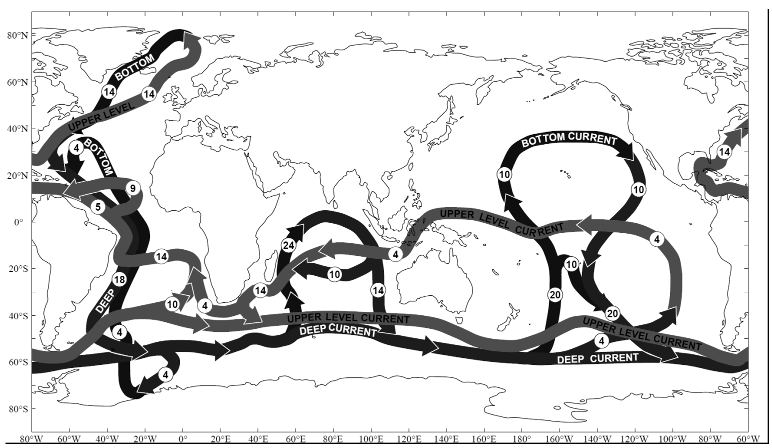
Phosphorus, Alkalinity, Carbon

PHOSPHATE DISTRIBUTION IN THE OCEAN

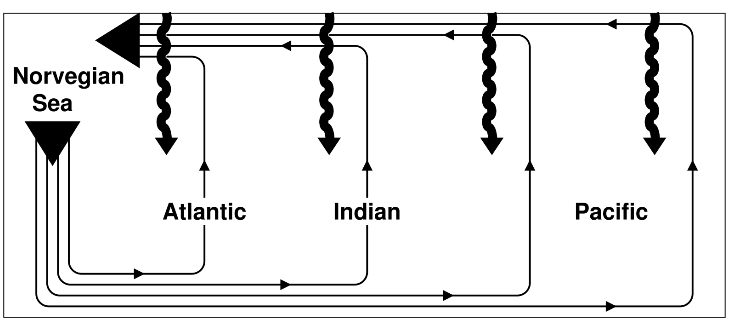


Ant – Antarctic; •A – Atlantic; •I – Indian; •P – Pacific; N• and S• – Northern and Southern parts of •, resp.

THERMOHALINE CIRCULATION

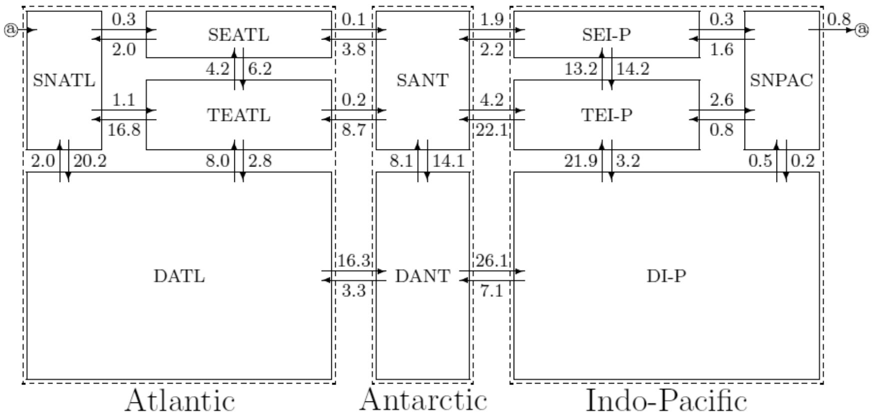


surface-to-deep-sea gradient



inter-basin gradient

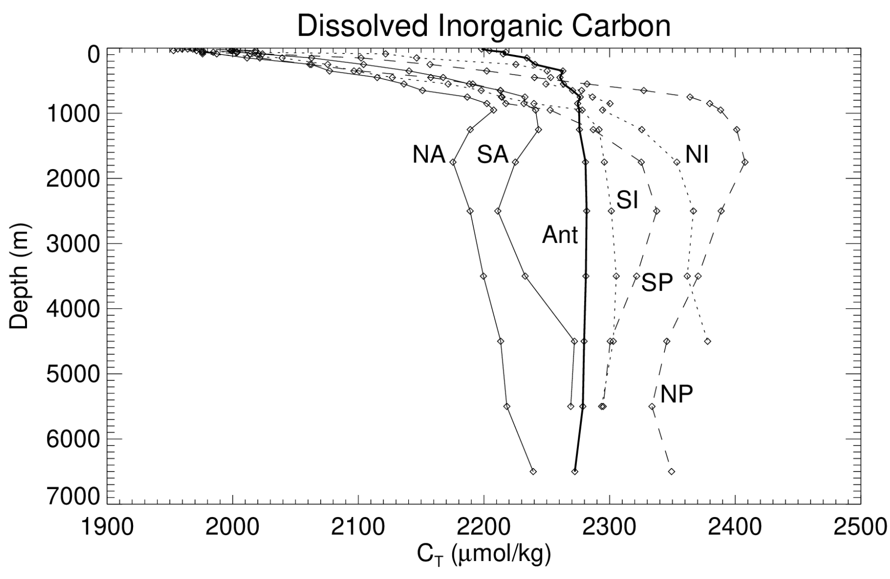
MODEL STRUCTURE



Water fluxes in Sverdrup (Sv): 1 Sv = 10^6 m^3 s^{-1}

	Basin	Input flux (m3/yr)	Output flux (m3/yr)	Reservoir budget (m3/yr)	Turnover Time (yr)
1	SNATL	0.68117760E+15	0.68117760E+15	0.00000000E+00	17.62
2	SEATL	0.26174880E+15	0.26174880E+15	0.00000000E+00	22.92
3	SANT	0.10312272E+16	0.10312272E+16	0.00000000E+00	70.79
4	SEI-P	0.52665120E+15	0.52665120E+15	0.00000000E+00	34.18
5	SNPAC	0.10722240E+15	0.10722240E+15	0.00000000E+00	121.24
6	TEATL	0.75686400E+15	0.75686400E+15	0.00000000E+00	72.67
7	TEI-P	0.12961296E+16	0.12961296E+16	0.00000000E+00	120.36
8	DATL	0.82939680E+15	0.82939680E+15	0.00000000E+00	245.96
9	DANT	0.11826000E+16	0.11826000E+16	0.00000000E+00	184.34
10	DI-P	0.93031200E+15	0.93031200E+15	0.00000000E+00	628.82

DIC DISTRIBUTION IN THE OCEAN



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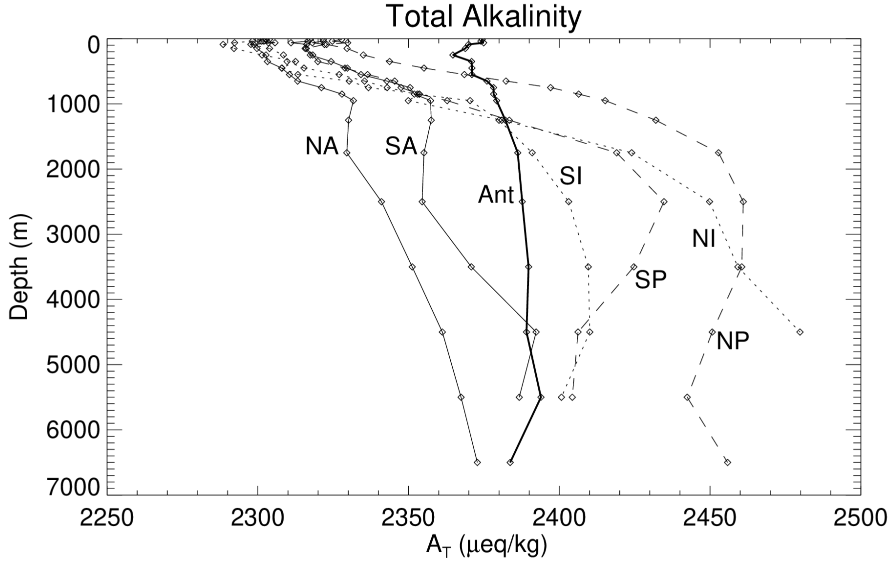
ALKALINITY DISTRIBUTION IN THE OCEAN



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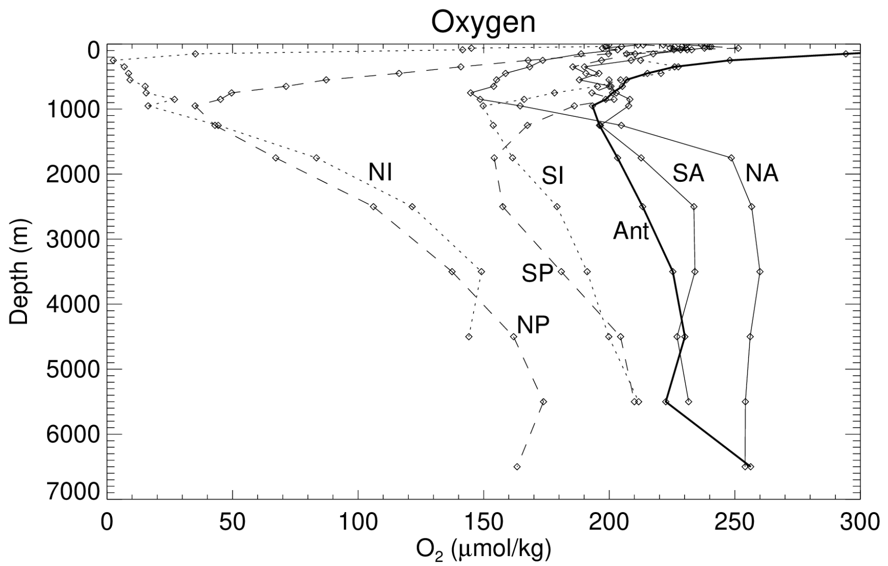
OXYGEN DISTRIBUTION IN THE OCEAN



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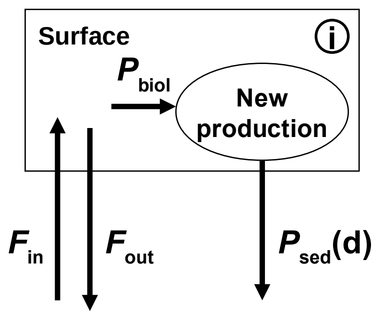
PRE-INDUSTRIAL MODEL

PHOSPHORUS: PRODUCTIVITY CONTROL

Surface boxes



Input Fluxes:

$F_{in} = \sum_j w_{ji} c_j$ (advection) with $c_i = Q_i/V_i$

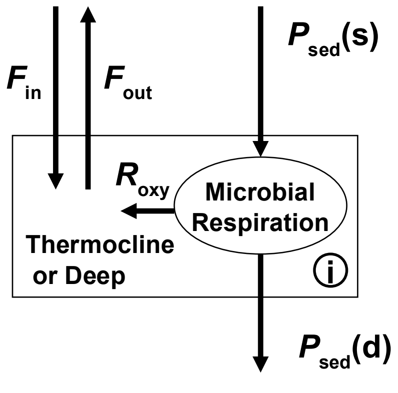
Output Fluxes:

$F_{out} = (\sum_j w_{ij})\ c_i$ (advection)

$P_{sed}(d) = P_{biol} = \Phi_{ut} . F_{in}$ (new production)

➔ Φ_{ut} lower at high latitudes

Thermocline and deep boxes



Input Fluxes:

$F_{in} = \sum_j w_{ji}\ c_j$ (advection)

$R_{oxy} = k_{oxy} . P_{sed}(s)$ (microbial respiration)

$P_{sed}(d) = P_{sed}(s) - R_{oxy}$

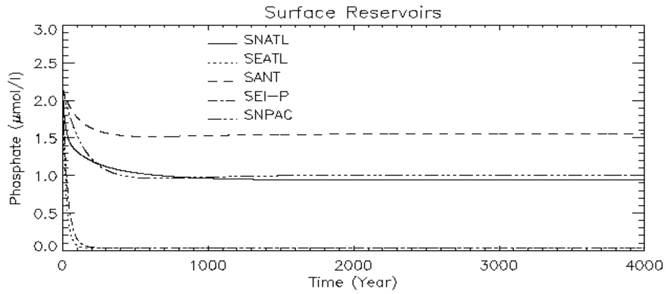
Output Fluxes:

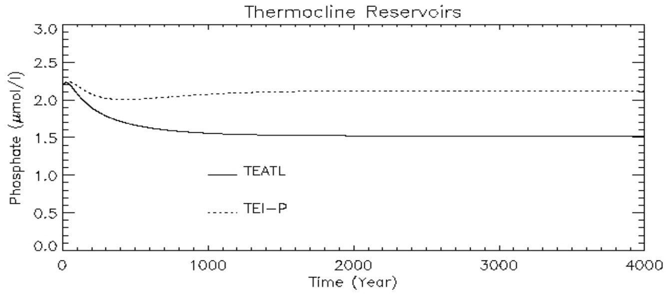
$F_{out} = (\sum_j w_{ij})\ c_i$ (advection)

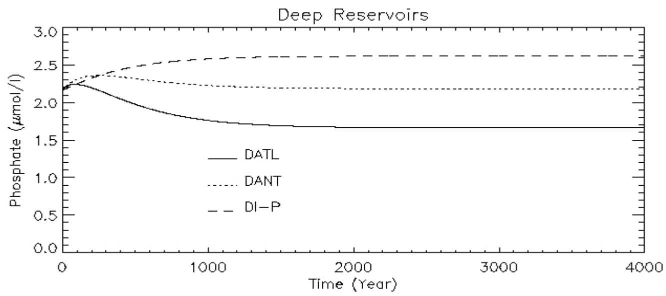
PRE-INDUSTRIAL STEADY-STATE SOLUTION (PHOSPHORUS)

→ **Integration: 4000 years**

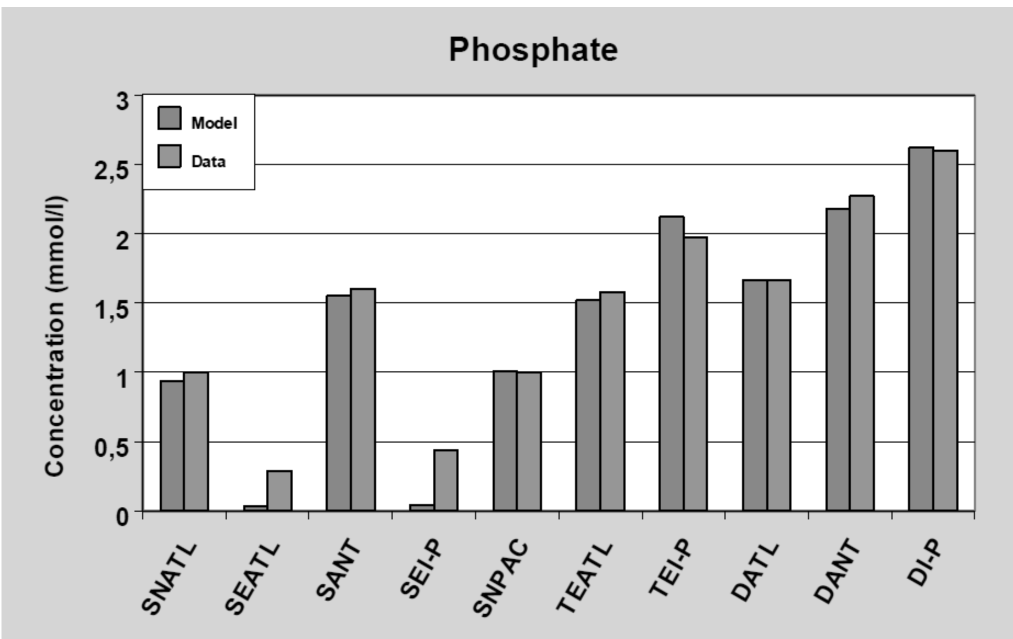
→ **Initial conditions: Homogeneous ocean (c = 2.164 µmol P/litre)**







COMPARISON WITH DATA: PHOSPHORUS



Data: Geosecs ('70)

CARBON AND ALKALINITY

- Model linked to the phosphorus model through the usage elemental ratios
- At the surface: C_{org} and $CaCO_3$ (aragonite/calcite) production
  - → C_{org}: C/P = 106/1 (Redfield)
  - → $CaCO_3$: $r_{carb} = CaCO_3/C_{org}$ (adjustable parameter)
- In the thermocline: partial oxidation of C_{org} (→k_{oxy})
  - → C/P = 106/1 (Redfield)
- At depth:
  - → oxidation of the remaining C_{org} (→ 1-k_{oxy})
  - → dissolution of $CaCO_3$
- In each box: *p*H calculation and carbonate speciation
- Exchange with the atmosphere in each surface reservoir *i*:
  - → $F_{ao} = k_{ao} \cdot area(i) \cdot (pCO_2 - pCO_2(i))$

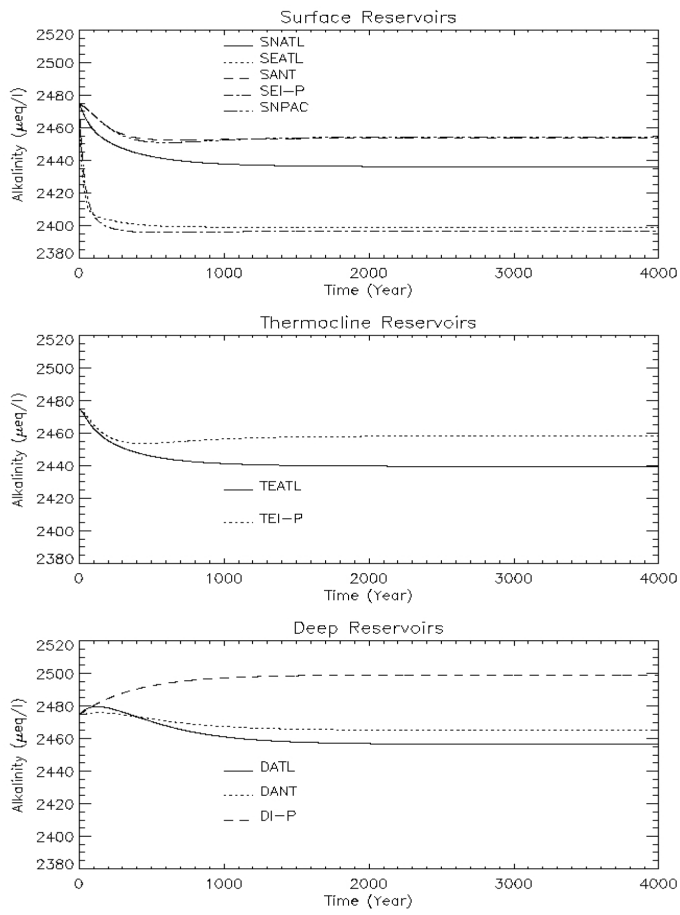
PRE-INDUSTRIAL STEADY-STATE SOLUTION (ALKALINITY)

→ integration: 4000 years

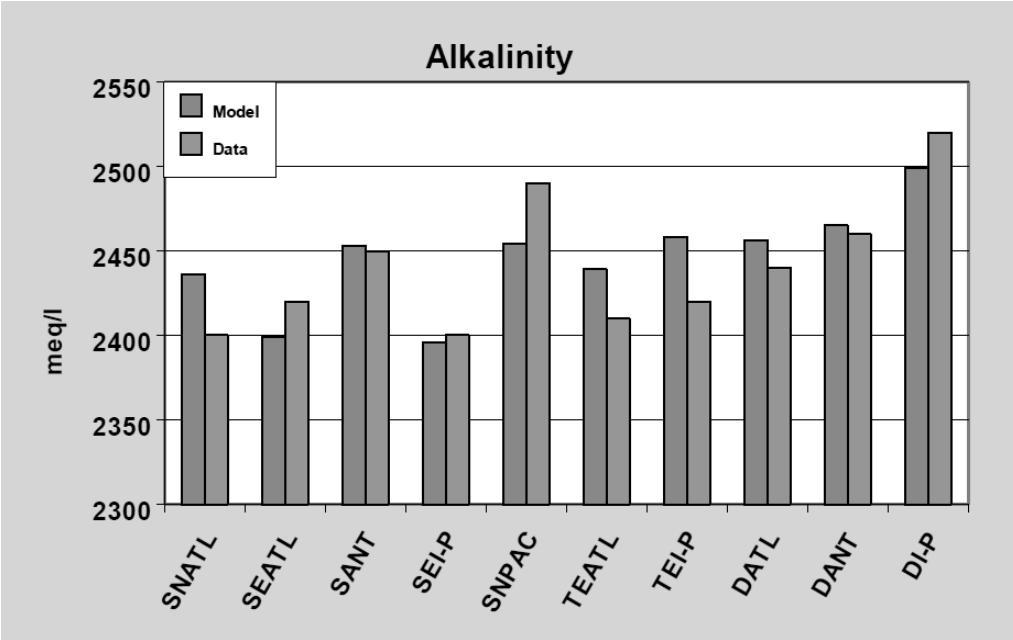
→ initial conditions: homogeneous ocean (Alk = 2474 µeq/litre)

→ $r_{carb} = CaCO_3/C_{org}$

$$= \begin{cases} 0.15 \text{ (equator. box)} \\ 0.02 \text{ (polar boxes)} \end{cases}$$

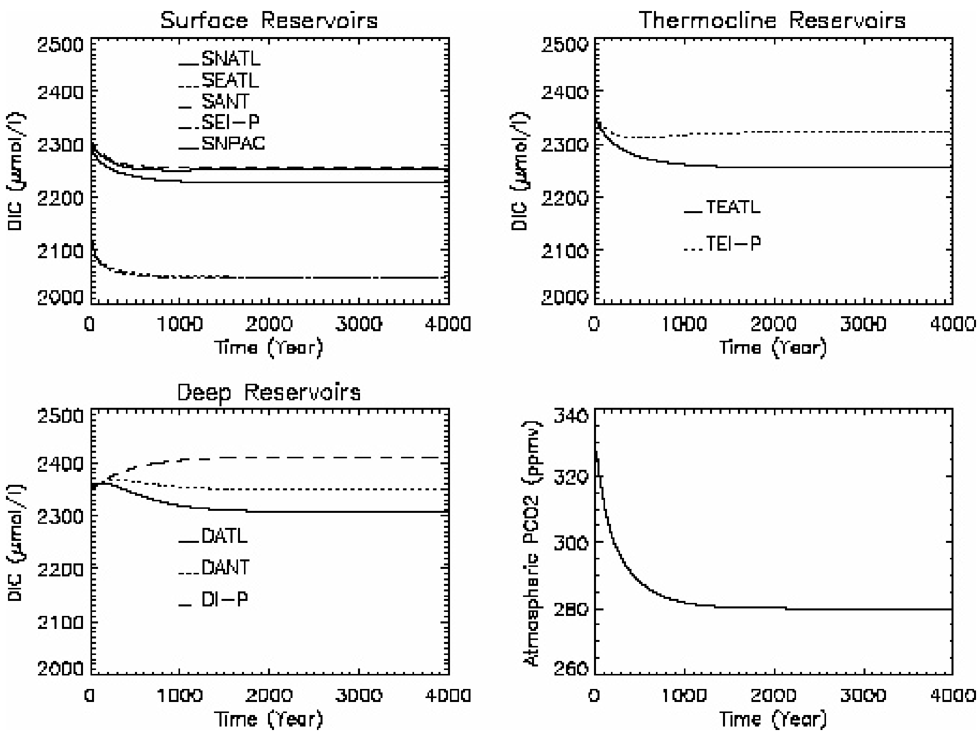


COMPARISON WITH DATA: ALKALINITY



Data: Geosecs ('70)

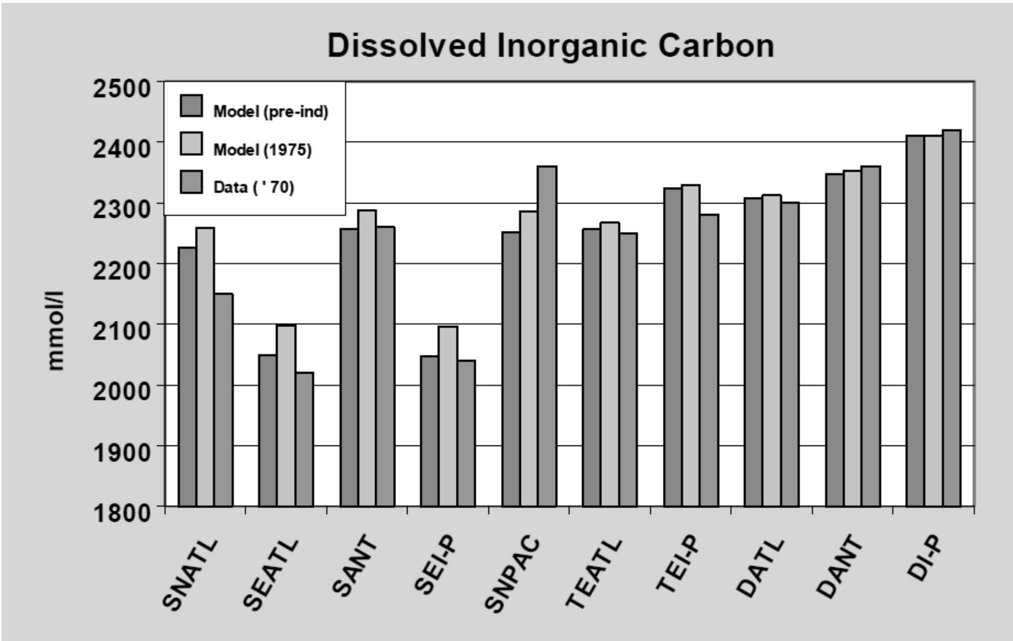
PRE-INDUSTRIAL STEADY STATE (CARBON)



Initial conditions:

Homogeneous ocean (DIC = 2350 μmol/l), pCO_2(atm) = 280 ppmv

COMPARISON WITH DATA: CARBON



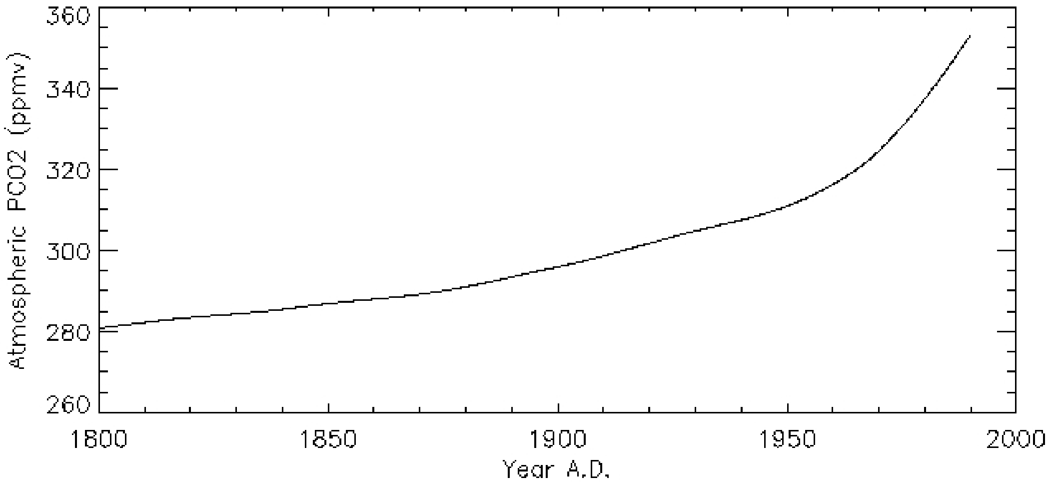
Data: Geosecs ('70)

EVOLUTION DURING THE INDUSTRIAL PERIOD

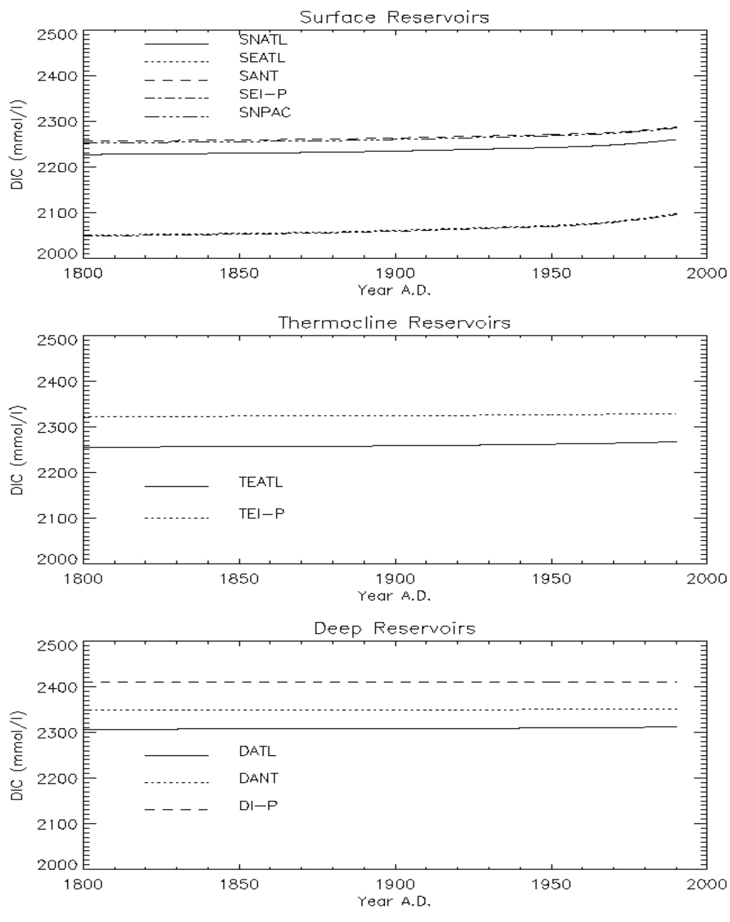
FORCING OF THE MODEL FOR THE INDUSTRIAL PERIOD

→ Initial conditions in 1800 provided by the previously calculated pre-industrial steady state

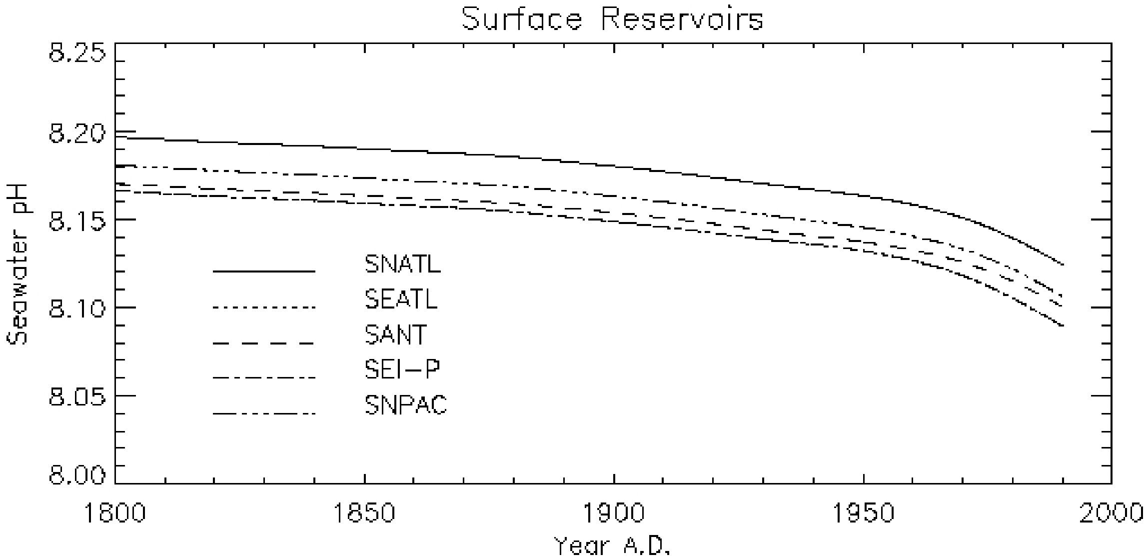
→ Evolution of atmospheric CO_2 prescribed from 1800 to 1990



EVOLUTION OF DISSOLVED INORGANIC CARBON

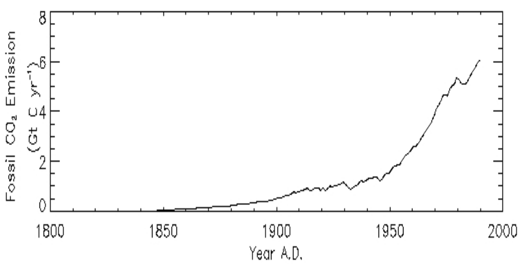


EVOLUTION OF *p*H IN THE SURFACE RESERVOIRS

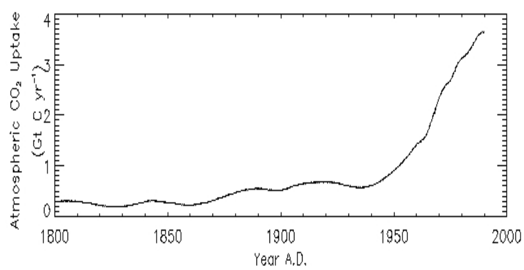


FLUX BALANCE OF ATMOSPHERIC CO_2 FOR THE INDUSTRIAL PERIOD

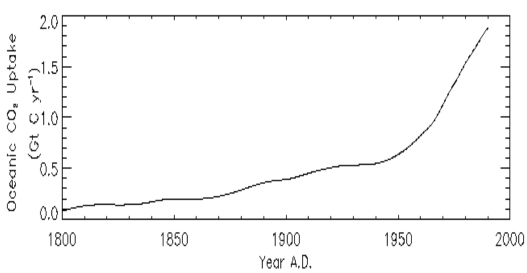
Fossil fuel CO_2 emissions



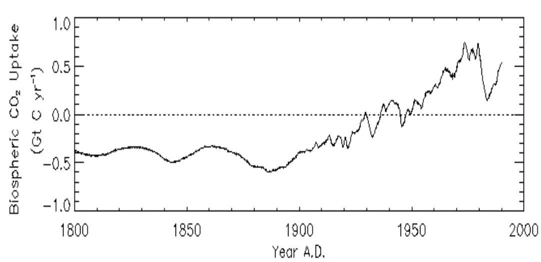
Rate of change in the atmosphere ($dpCO_2/dt$)



Transfer to the ocean (model)



Transfer to the biosphere (by difference)



ATMOSPHERIC CO_2 BALANCE (1980-1990)
(Gt C yr^{-1})

SOURCES

	This work	IPCC 1995
Fossil fuels & cements	5.44	5.5 ± 0.5
Land-use change	1.57	1.6 ± 1.0
Total	*7.01*	*7.1 ± 1.0*

SINKS

Atmosphere	3.40	3.3 ± 0.2
Ocean (Model)	1.71	2.0 ± 0.8
Difference (→ terrestrial biosphere)	*1.90*	*1.8 ± 1.5*

^{13}C ISOTOPIC EVOLUTION

CARBON ISOTOPES

Three naturally occuring carbon isotopes:
^{12}C ~ 98.94 ± 0.10%
^{13}C ~ 1.06 ± 0.10%
^{14}C (radiogenic, radioactive) trace amounts

where:

C_i = carbon content of reservoir *i*
F_{ji} = flux entering reservoir *i* (from reservoir *j*)
F_{ij} = flux leaving reservoir *i* (for reservoir *j*)
δ_i = $\delta^{13}C$ of the carbon in reservoir *i*
δ_{ji} = $\delta^{13}C$ of flux F_{ji} (into reservoir *i*)
δ_{ij} = $\delta^{13}C$ of flux F_{ij} (out of reservoir *i*)

<u>Notice:</u> output fluxes only have to be considered if they are subject to fractionation, i. e., if $\Delta = \delta_{ij} - \delta_i \neq 0$

ISOTOPIC EVOLUTION EQUATION

The equation describing the evolution of the isotopic composition of a reservoir *i* in time can be written (approximation):

$$d\delta_i / dt = \left[\sum_{j \neq i} F_{ji} (\delta_{ji} - \delta_i) - \sum_{j \neq i} F_{ij} (\delta_{ij} - \delta_i) \right] / C_i$$

where:

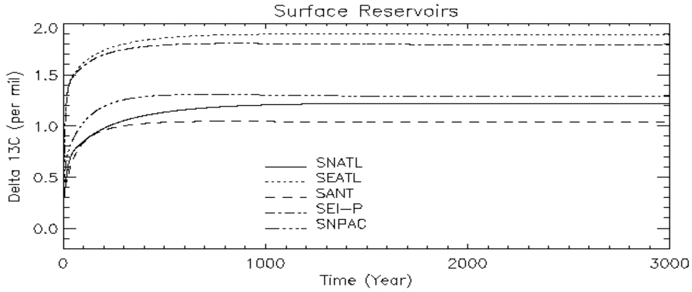
C_i = carbon content of reservoir *i*
F_{ji} = flux entering reservoir *i* (from reservoir *j*)
F_{ij} = flux leaving reservoir *i* (for reservoir *j*)
δ_i = $\delta^{13}C$ of the carbon in reservoir *i*
δ_{ji} = $\delta^{13}C$ of flux F_{ji} (into reservoir *i*)
δ_{ij} = $\delta^{13}C$ of flux F_{ij} (out of reservoir *i*)

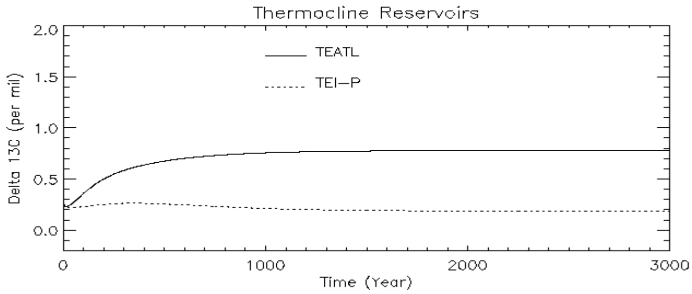
<u>Notice:</u> output fluxes only have to be considered if they are subject to fractionation, i. e., if $\Delta = \delta_{ij} - \delta_i \neq 0$

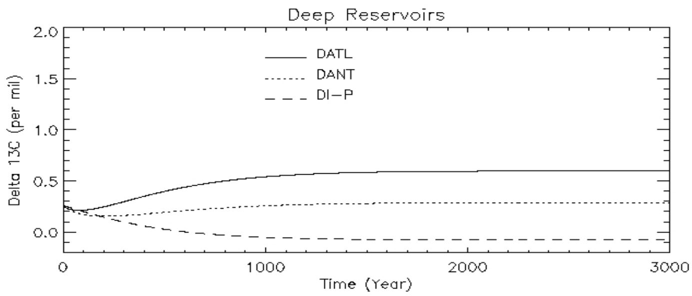
PRE-INDUSTRIAL STEADY-STATE SOLUTION ($\delta^{13}C$)

→ **integration: 3000 years**

→ **initial conditions: homogeneous ocean ($\delta^{13}C$ = 0.259 ‰)**







EVOLUTION OF $\delta^{13}C$ DURING THE INDUSTRIAL PERIOD (coupled ocean-atmosphere-biosphere model)