ADDENDUM

Estimates of natural flows in the MPO model

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The MPO model complies with the three compartments and four natural flows used in IPCC reports.
This simplification is implemented here over a limited period, covering the years **1980 to 2025**.

Stocks : 1 ppm → 7,8 Gt-CO_2 = 7,8 x 10^{12} kg of CO_2 → 2,12 Gt-C = 2,12 x 10^{12} kg of carbon
Flows : 1ppm/year → 2,12 Gt-C/year ; 1 Gt-C/year → 3,67 Gt-CO_2/year → 0,47 ppm/year

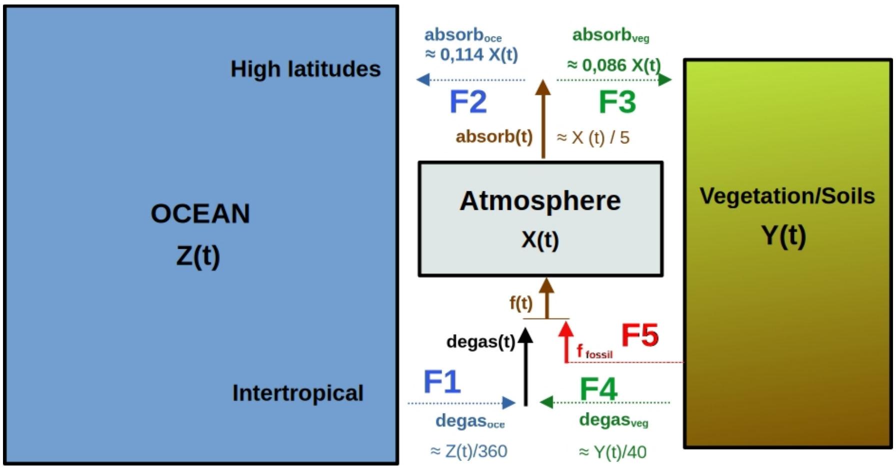


Figure 1: Ratings of the five fluxes and stocks in the three compartments (Figure 15 in Revisiting the carbon cycle)

1. Flows leaving the atmosphere F2 and F3

1.1 Dimensioning of F3

Flow 3 is calibrated so as to:
- correspond to NPP estimates according to Haverd et al 2009.
- be proportional to atmospheric CO_2 concentration.
- be virtually compatible with the 6 WG1 reports of the IPCC → F3 ≈ 0.078 X(t)

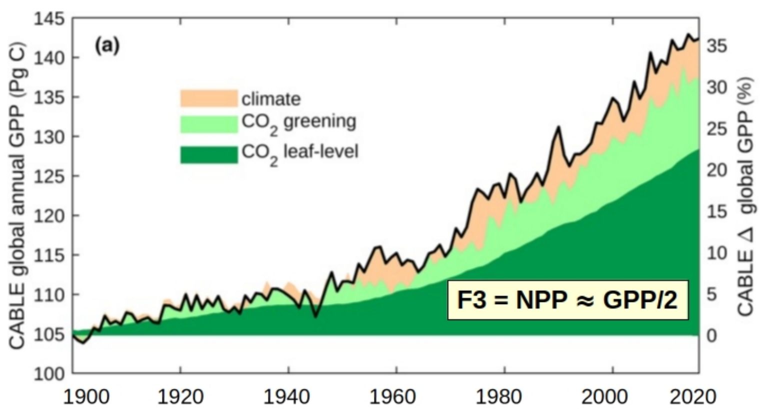


*Figure 2: GPP ≈ 2 * NPP according to Figure 2 in Haverd et al, 2019 https://onlinelibrary.wiley.com/doi/pdfdirect/10.1111/gcb.14950*

For **effective multi-year** carbon sequestration by vegetation, i.e., F3, **N**et **P**rimary **P**roduction → NPP ≈ GPP/2 must be used, where GPP = **G**ross **P**rimary **P**roduction (see here).

		Flow in Gt-C / yr					X(t) = [CO2]	Length of stay (year) = X(t) / (flow 2 + flowx 3)	
Dates	Assessment Report	Flow 2	F2/X(t)	*Flow 3 if **GPP***	Flow 3 if **NPP**	F3/X(t)	in Gt-C	*if flow 3 = **GPP***	if flow 3 = **NPP**
1990	AR1 fig 1.1	**92**	**12,3 %**	*102*	**51**	**6,8 %**	**750**	*3,87*	**5,24**
1995	AR2 fig 2.1	**92**	**12,3 %**	*GPP ?*	**61,8**	**8,2 %**	**750**	*GPP ?*	**4,88**
2001	AR3 fig 3.1a	**90**	**11,9 %**	*120*	**60**	**7,9 %**	**730?** **755**	*3,60*	**5,03**
2007	AR4 fig 7.3	**92,2**	**12,1 %**	*122,6*	**61,3**	**8,0 %**	**762**	*3,55*	**4,96**
2013	AR5 fig 6.01	**80**	**9,7 %**	*123*	**61,5**	**7,4 %**	**829**	*4,08*	**5,86**
2021	AR6 fig 5.12	**79,5**	**9,1 %**	*142*	**71**	**8,2 %**	**870**	*3,93*	**5,78**
Average **(F2+F3) / X(t) = 19 %** = 1 / **5,3** 11,2 % + 7,8 % = **19 %**			**11,2 % = Average**		**Average = 7,8 %**		average length of stay (year)	*3,8*	**5,3**

Figure 3: According to the six WG1 reports of the IPCC, on average F2 ≈ 0.112 X(t) and F3 ≈ 0.078 X(t)

We finally adopt F3 = 0.086 X(t), which is consistent with Haverd 2009 and close to 0.078 X(t), the average of the six WG1 reports of the IPCC.

1.2 Dimensioning of F2

Flow 3 is calibrated so as to be :
- proportional to atmospheric CO_2 concentration.
- virtually compatible with the figure 3.1a AR3 WG1 report of the IPCC → F2 ≈ 90 Gt-C/year around 2000 .
- compatible with the previous choice of F3 = 0.086 X(t).

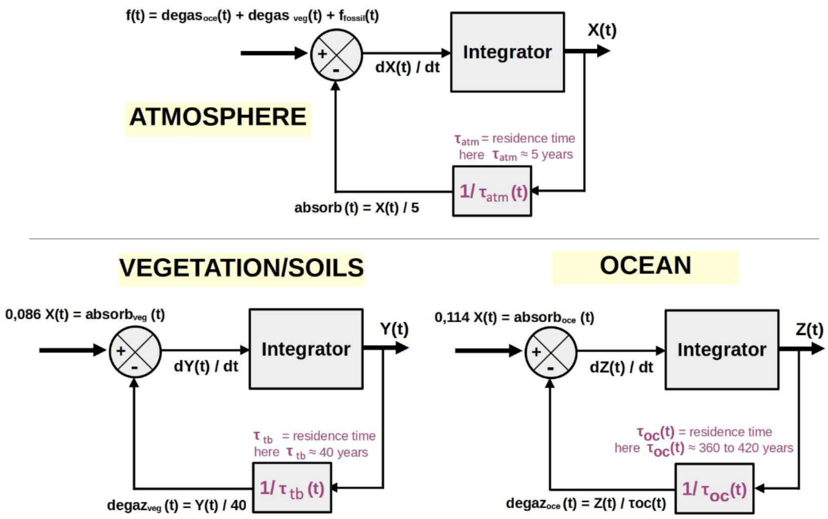


Figure 4: The three compartments have a common simple model but different residence times → τ = Stock / outgoing flow (Figure 14 in Revisiting the carbon cycle)

The MPO model adopts a residence time in the atmosphere of 5 years.
We therefore have (F2 + F3) = X(t)/5 = F2 + 0.086 X(t). We finally adopt F2 = 0.114 X(t).

2. Flows entering the atmosphere F1 and F4

We follow the simple models shown in Figure 4: flows will be calculated using an expression based on stocks Y(t) and Z(t) and the residence time of the compartment. The calculations will use observations of atmospheric CO2 (ratio and $\delta^{13}C$) from 1980 to 2025.

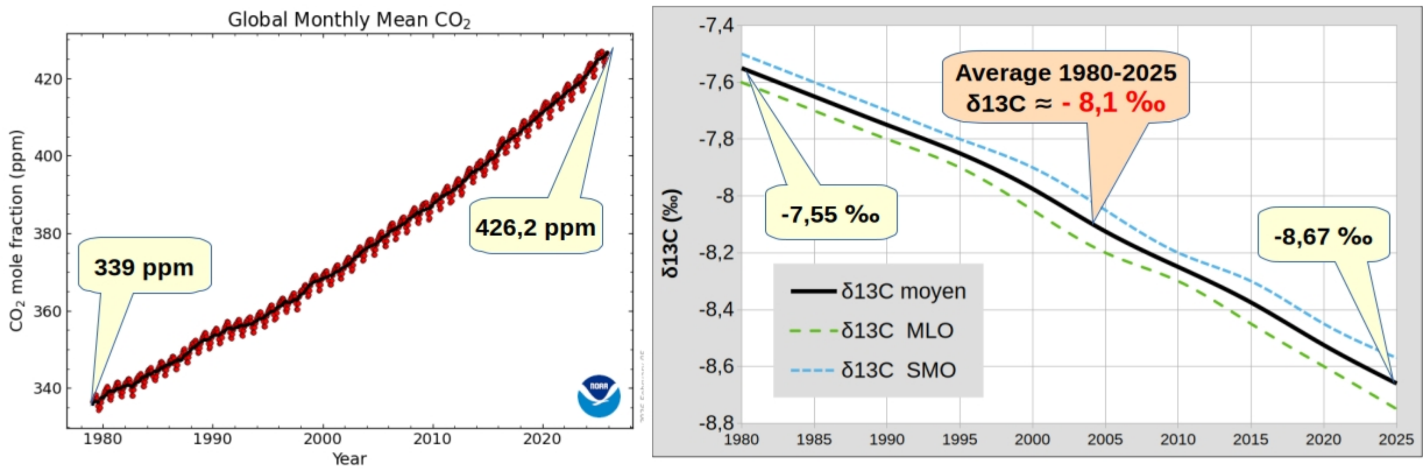


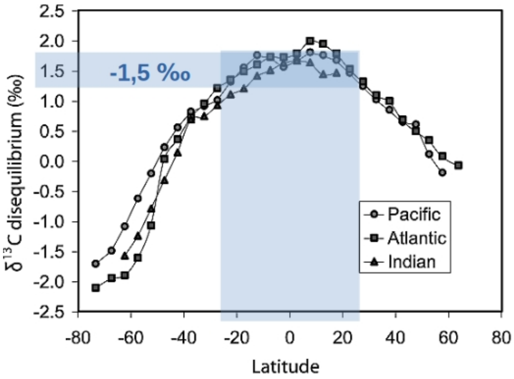
Figure 5 : Global atmospheric CO_2 levels according to NOAA (1 ppm → 2,12 Gt-C); $\delta^{13}C$ in the atmosphere according to Scripps CO2

Between 1980* and 2025, the CO2 level in the atmosphere will increase: 426.2 - 339 = +87.2 ppm, representing a net contribution of +185 Gt-C. This net contribution must be such that $\delta^{13}C$ = -13.0‰, because between 1980 and 2025 we have:

ppm : **(339 * -7,55) + (87,2 * -13,0) = (426,2 * -8,67)**

Gt-C : **(719 * -7,55) + (185 * -13,0) = (904 * -8,67)**

***** *1980 because we need to have measurements of δ13C and CO2 levels in both hemispheres.*



Plants	ratio	δ13C ‰	ratio x δ
C3	85 %	-25	-21,3
C4	14 %	-13	-1,8
CAM	1 %	-18	-0,2
		Average =	**-23,3**

*Figure 6: For δ^{13}C, the net intertropical ocean contribution is < 1.5% to the atmosphere (fig 8 Quay et al., 2003) → -8,1 - 1,5 ≈ **-9,6‰***
*For net vegetation/soil input, δ^{13}C depends on the type of vegetation → on average, δ^{13}C ≈ **-23.3‰***

2.1 Estimating net contributions to the atmosphere for oceans and vegetation/soils

• Between 1980 and 2025, anthropogenic emissions will contribute 360* Gt-C to the atmosphere, but growth will only be 185 Gt-C. According to the IPCC model, the Ocean and Vegetation/Soil compartments would absorb about half of the 360 Gt-C of anthropogenic carbon, thereby offsetting the 185 Gt-C increase observed in the atmosphere.
** ~1260 Gt-CO_2, or ~343 Gt-C according to World Energy Outlook, but the IPCC adds approximately 5% LUC → 343 * 1.05 ≈ 360 Gt-C.*

• Let z be the net contribution from the ocean and y the net contribution from vegetation/soils.
According to the IPCC model, we would therefore have z ≈ y ≈ - (360-185)/2 = - 87.5 Gt-C (both compartments are carbon sinks). The table below shows that observations contradict this IPCC model.

Balance sheet 1980-2025	Anthropogenic	Ocean	Vegetation/soils	Net contribution
Atmosphere **in** (Gt-C)	360			
Atmosphere **out** (Gt-C)				
Net (Gt-C)	**360**	**-87,5**	**-87,5**	**185** Gt-C
δ13C (‰)	**-29**	**-9,6**	**-23,3**	**-40,9** ‰
Net x δ13C	-10440	837	2040	**-7563**

Figure 7a: The IPCC model does not allow for a net input of 185 Gt-C with δ^{13}C = -13‰
*360 + -87.5 +-87.5 = 185; but -10440 + 837 + 2040 = **-7563 and -7563** / 185 = -40.9‰*

- According to the MPO model, which contradicts the IPCC model, the ocean is a net source with respect to the atmosphere, i.e., z is positive → F1 > F2.

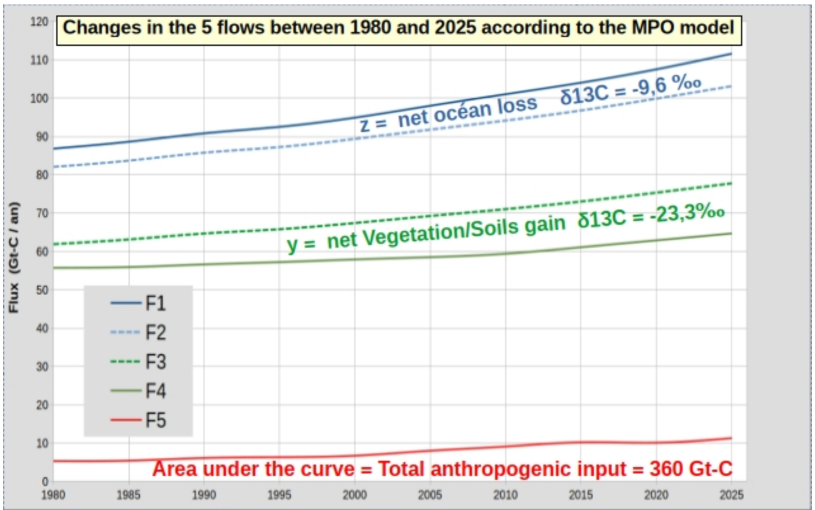


Figure 7b: According to DFO, the ocean is a net source for the atmosphere (F1 > F2), while vegetation/soil is a sink (F3 > F4).
*However, the sum (ocean + vegetation/soil) **is overall a sink** (y > z) with respect to the atmosphere.*

In order to comply with the observations in Fig. 5 (which imply a total net input of 185 Gt-C with δ^{13}C = -13.0 ‰), we must simultaneously have (Gt-C) :

360 + z + y = 185
(360 * -29) + (z * -9,6) + (y * -23,3) = (185 * -13,0)

Solving the system of two equations gives: z = 288 Gt-C and y = -463 Gt-C.
The net contribution of the ocean = z is positive, but nature is overall a sink because (y + z) is negative.

These two net contributions y and z between 1980 and 2025 allow us to place a constraint on each of the flows F1 and F4.

2.2 Dimensioning of F1

F1 will be almost compatible with figure 3.1a of the AR3 WG1 report, which proposes F1 ≈ 90 Gt-C/year around 2000. **Constraint 1**: The ocean must provide a net input of 288 Gt-C over 45 years (F1 > F2).

Rough estimate in Gt-C/year: 288 / 45 = 6.4 → with **F1 ≈ F2 + 6.4,** we comply with a net input of 288 Gt-C over 45 years. Note that F2 is estimated by F2(t) = 0.114 X(t).

Rather than using a rough estimate, we ultimately adopt F1 = Z(t) / τ_{oc} with a **variable** residence time (for **1980-2025**, τ_{oc} ≈ 335 to 440 years), which allows us to comply with constraint 1 but also to have τoc as a function of SSTi (intertropical ocean surface temperature).

2.3 Dimensioning of F4

Constraint 2: Vegetation/Soil must provide a net input of -463 Gt-C over 45 years (F3 > F4).

Rough estimate in Gt-C/year: -463 / 45 = -10.3 → with **F4 ≈ F3 – 10.3**, the net contribution of -463 Gt-C over 45 years is respected. Note that F3 is estimated by F3(t) = 0.086 X(t).

Rather than the rough estimate, we ultimately adopt F4 = Y(t) / τ_{Veg} with τ_{Veg} ≈ 40 years, which allows us to meet constraint 2.

______________Summary____________

- The estimation of the four natural fluxes is based mainly on observations of [CO2] and δ13C.

- These data were obtained from measurements taken at several observatories across both hemispheres between 1980 and 2025.

- The estimates of the four natural fluxes proposed by the MPO model remain broadly similar (± 25% except for F1) to those proposed by the IPCC.