‘Revisiting the carbon cycle’

2/3 Introduction to the MPO model

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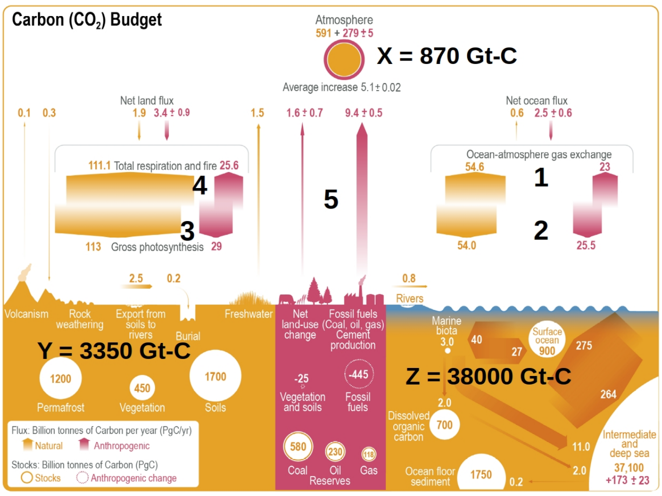
The peer-reviewed scientific journal Science of Climate Change published an article in 2025 entitled ‘*Revisiting the carbon cycle*’. **This 50-page paper comprehensively challenges the carbon cycle as modeled by the IPCC**. The first part presents the evidence that led to the development of the model proposed in Revisiting the Carbon Cycle, while the second part describes the model itself. According to the IPCC, natural carbon exchanges are almost balanced and relatively constant, while anthropogenic emissions are increasing. Under this assumption, human activity would be **solely responsible** for the recent increase in atmospheric CO_2. In contrast, the Revisiting the Carbon Cycle model proposes **M**ixed causes, both anthropogenic and natural. It suggests that carbon flows leaving the atmosphere are **P**roportional to its carbon content and that all flows have increased, mainly due to **O**cean degassing. This model, called the **MPO** model, is briefly described in this second part.

Here we are interested in multi-year changes in atmospheric CO_2, not seasonal changes. For this reason, we have adopted a time step of **one year**. We rely exclusively on modern measurements (MLO from 1959 onwards).
Carbon is present in the atmosphere mainly in the form of CO_2: we can use a unit of **mass of CO_2** (1 Gt-CO_2 = 10^{12} kg of CO_2), or a **proportion** relative to the atmosphere (1 ppm = parts per million = 0.0001% → 7.8 Gt-CO_2).
However, these units are poorly suited for exchanges with the ocean or the biosphere: here, it is preferable to use **carbon mass** (1 gigaton of carbon = 1 Gt-C = 1Pg-C = 10^{12} kg of carbon → 0.47 ppm → 3.66 Gt-CO_2).

1. Orders of magnitude

• To align with IPCC modeling and terminology, the carbon cycle is simplified to include exchanges between three compartments: ocean, atmosphere, and vegetation/soil. Since the 1960s, direct measurements [1] at several sites have provided a good understanding of the carbon stock in the atmosphere = X(t). However, the carbon stock in the ocean = Z(t) is only estimated, and that of the vegetation/soil compartment = Y(t) is poorly understood (it is difficult to estimate the proportion of soil carbon that could be exchanged with the atmosphere over the course of a century).

• The flows exchanged between the three compartments are **even less well understood** (except for anthropogenic flow at ± 5%) because they are assessed indirectly via the stock/outflow ratio. This ratio is referred to as the residence time.
For the atmosphere, estimates of the residence time range from 3 to 10 years [1].
For example, if the residence time = 5.8 years and the atmospheric stock = 870 Gt-C, then the outgoing flow is 870 / 5.8 ≈ 150 Gt-C/year (see table below: 150 ≈ 79.5 + 71 = outgoing flows = flow 2 + flow 3).



Compartments	Gt-C or PgC	*ratios*
Ocean Z =	**38000**	*90 %*
Atmosphere X =	**870**	*2 %*
Vegetation/Soils Y =	**3350**	*8 %*
Total (circulating carbon)	42220	*100 %*

Error margins flow > ± 20% according to fig 6.1 AR5WG1

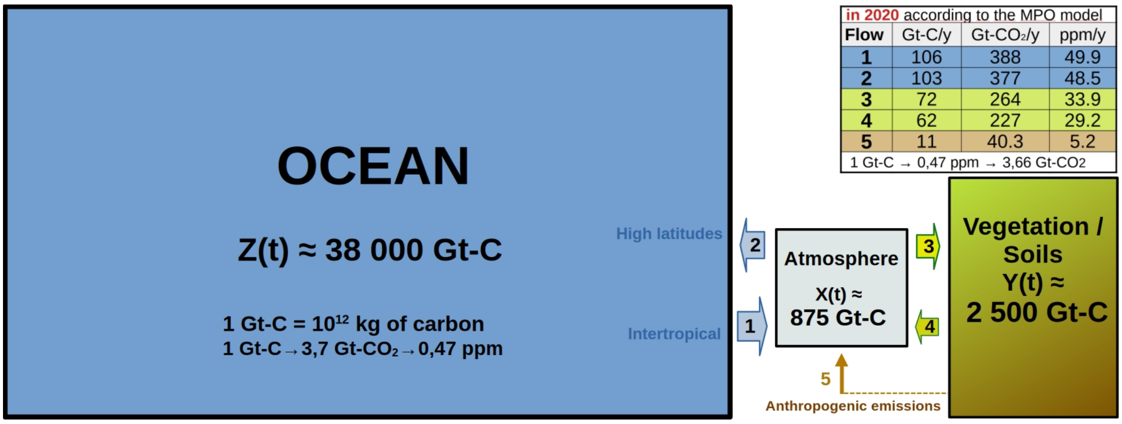
Flow	Gt-C/an	Flow 1,2,3,4 with margin of error = ± 25 % > 20 %
1	**77.6**	58 to 97
2	**79.5**	60 to 99
3	142 **(71)**	53 to 89
4	136,7 **(68,3)**	51 to 85
5	**11**	10,4 to 11,6 (± 5%)

Figure 1: **IPCC** estimates of X Y Z stocks in the three compartments (1Gt-C = 1 Pg-C = 10^{12} kg of carbon) and carbon exchanges (Gt-C/year) according to Figure 5.12 published in AR6 in **2021**. The table on the right summarizes the IPCC estimates. Margin of error for natural flows = ± 25% > 20%.

• For convenience, the five carbon exchange flows have been numbered. In Figure 5.12 AR6, the IPCC adopts flows 3 and 4, which correspond to GPP = **G**ross **P**rimary **P**roduction. However, for the effective multi-year carbon fixation by vegetation, **N**et **P**rimary **P**roduction → NPP ≈ GPP/2 should be used instead (see here). **The IPCC's decision to use GPP rather than NPP tends to overestimate flows 3 and 4 for multi-year exchanges and therefore underestimate the role of the ocean** (which nevertheless accounts for 90% of 'circulating' carbon). In the table, GPP values are shown in gray and NPP values in red.

• In practice, we can consider that two main compartments (Z ≈ 90% and Y ≈ 8%) exchange carbon via the atmosphere (X ≈ 2%), which is simply a channel for exchange. Total inputs into the atmosphere (flows 1+4+5) would be ≈ 180 Gt-C/year, with anthropogenic inputs (flow 5 ≈ 10 Gt-C/year) representing ≈ 5% of total inputs [2].

• The figure below illustrates the relative sizes of the three compartments. It shows the estimates according to the MPO model for the three stocks (designated X, Y, and Z). The table gives the estimates for the five flows **in 2020 according to the MPO model** (close to the publication date of AR6 in 2021).



in 2020 according to the MPO model			
Flow	Gt-C/y	Gt-CO_2/y	ppm/y
1	106	388	49.9
2	103	377	48.5
3	72	264	33.9
4	62	227	29.2
5	11	40.3	5.2
1 Gt-C → 0,47 ppm → 3,66 Gt-CO2			

*Figure 2: Estimates (**around 2020 according to the MPO model**) of stocks X, Y, Z (3 compartments) and carbon exchanges (5 flows)*

2. IPCC model and MPO model

2.1 Need for a competing model

• The IPCC model has many inconsistencies (see §10 of "Revisiting the carbon cycle").
- The annual growth rate of atmospheric CO_2 is very poorly correlated with anthropogenic emissions (here).
- The IPCC model does not reproduce the variations measured in the atmosphere for the isotopes 13C and 14C.
- The IPCC model requires nature to select (at the atmosphere's **exit**) CO_2 according to its **origin**: anthropogenic (flow 5) or natural (flows 1 and 4). Indeed, the IPCC claims that 56% of the CO_2 contributed by flow 5 leaves the atmosphere, unlike the CO_2 contributed by flows 1 and 4 (here).
- The IPCC model struggles to explain global greening (quasi-constant flow 3 in AR2, AR3, AR4, AR5 → fig.4).

• The MPO model is guided by the following observation: the growth rate of atmospheric CO_2 correlates well with the temperature of the intertropical zone (Fig. 6e of 1/3 or Fig. 2 of "*Revisiting the carbon cycle*").

2.2 Stocks and flows according to the IPCC or MPO models

• The X, Y, and Z stocks estimated in 2020 according to the IPCC or MLO (Fig. 1&2) are similar, except for Vegetation/Soils. Indeed, for soils, the assessment is difficult: 2,900 Gt-C according to the IPCC versus 2,150 Gt-C according to the MPO model.

• The IPCC considers that natural flows (1, 2, 3, 4) are relatively stable and balanced (see Fig. 4 before 2021), while the MPO model considers that they have all been growing in recent decades.

• Carbon leaving the atmosphere would be distributed almost equally between the ocean (flow 2) and vegetation/soils (flow 3). This competing model from the IPCC is described here briefly and referred to as the MPO model. According to the IPCC, which uses the GPP, flow 3 > flow 2; whereas according to the MPO (or the IPCC using the NPP), flow 2 > flow 3.

• Comparison of the tables in Figures 1 and 2 shows that flows 3, 4, and 5 are compatible between IPCC and MPO models, while flows 1 and 2 appear to be less compatible **in 2020** (legend fig. 6.1 AR5 → margin of error greater than ±20%).

• According to the IPCC, since 1959, the ocean has been a **net carbon sink**: it absorbs carbon (flow 2 > flow 1). This point is disputed in § 8 of "Revisiting the carbon cycle": according to MPO, the ocean is a **net source** of carbon (flow 1 > flow 2).
The decline in average ocean pH would be incompatible with the ocean as a net source: this objection will be addressed in the third part of the article.

3. Introduction to the MPO model

- This article is a simple introduction: in 9 pages, it cannot summarize 50 pages of "Revisiting the carbon cycle."
The MPO model uses the three compartments and five flows used by the IPCC in Figure 5.12 AR6 WG1.
This simplifies the real world to obtain an approximation of the carbon cycle over a period of several decades.
- To do this, the MPO model uses an assumption that is not inconsistent with the IPCC WG1 ARx reports (see Fig. 4). The MPO model assumes that **the flows leaving the atmosphere (2 and 3) are approximately proportional to its carbon content = X(t).** The proportion would be 20% → each year, 1/5 of the atmospheric stock X(t) would be fixed by the Ocean = Z(t) and Vegetation/Soils = Y(t) compartments. In 5 years, flows 2 and 3 would therefore extract the equivalent of the entire atmospheric stock → residence time = 5 years, a value compatible with estimates between 3 and 10 years.

3.1 An atmosphere/reservoir analogy

The figure below offers an analogy: the atmosphere would behave approximately like a reservoir with respect to CO_2: the output flow (gravity flow) would be proportional to the pressure, and therefore to the height X(t) in the reservoir.

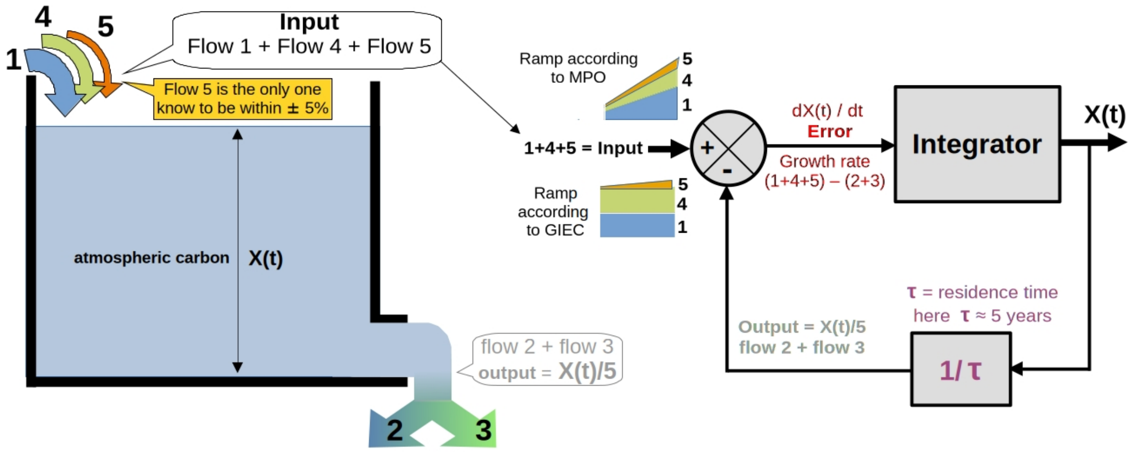


Figure 3a: left: analogy with a reservoir → output proportional to X(t) → first-order system; right: interpretation according to linear control theory (Fig.14 here)→ in this block diagram, the term "Error" refers to the difference between the reservoir's input and output.

• It is the difference between input flow (1+4+5) and output flow (2+3) that causes the annual change in X(t) = Growth rate = dX(t)/dt with dt = 1 year. It should be noted that the only flow estimated at ± 5% is flow 5 (anthropogenic or fossil emissions).

• In linear control theory [3], an input/command that grows almost linearly is called a "ramp". According to the IPCC, the growth in input (see the two ramps in the block diagram in Fig. 3a) is caused **solely** by flow 5. However, according to MPO, it is caused by the three flows : 5, 4, 1, but mainly by natural flow 1, which ultimately leads to the growth of natural flow 4.

• In "Revisiting the carbon cycle", § 4 compares dX(t)/dt = Growth rate with anthropogenic flow 5 → very poor correlation.
Figure 3 compares dX(t)/dt with lower atmospheric temperature UAH TLT → good correlation.
Assuming that 20% of carbon (anthropogenic **and** natural) leaves the atmosphere each year, we can separate the natural portion $X_{natural}$ and the anthropogenic portion X_{fossil}. Figure 2 compares $dX_{natural}(t)/dt$ with the intertropical Sea surface Temperature SSTi → excellent correlation.

• "Revisiting the carbon cycle" then makes the following interpretation: the SSTi temperature controls flow 1, which is the **driver** of successive increases: flow 1 → X(t) → flow 2 and flow 3 → Y(t) → flow 4 (the contribution of **ocean carbon** to the atmosphere causes vegetation to grow).

3.2 An analogy between growth rate and tracking error

The difference between input (1+4+5) and output (2+3) is shown below, which corresponds to the annual growth of atmospheric CO_2 = growth rate = dX/dt (dt = 1 year).

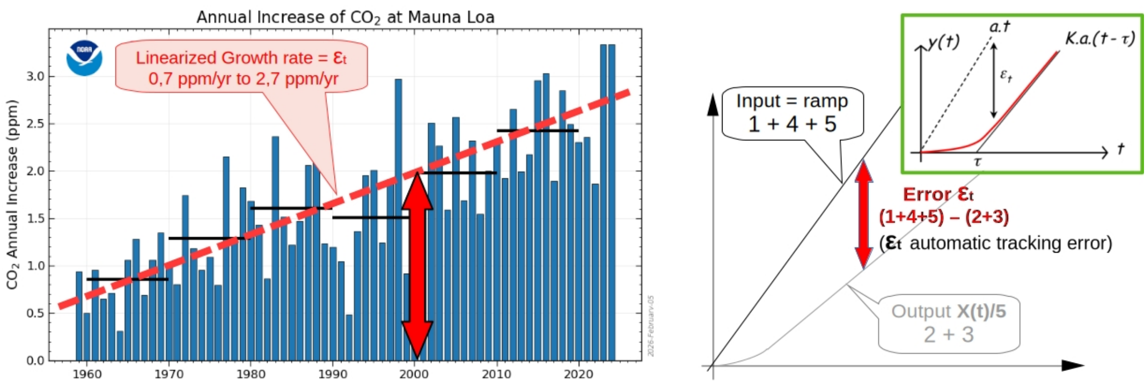


Figure 3b: left: annual growth measured at Mauna Loa = Growth rate = εt = Error according to block diagram fig 3a; right: theoretical output for a first-order system whose input is a ramp (the green box shows the relationships between the input and output slopes).

• Observations since measurements began at MLO show that the annual growth rate is highly variable, correlates with temperature, and tends to accelerate: 1960 → 0.7 ppm/year (1.5 Gt-C/year), 2015 → 2.7 ppm/year (5.7 Gt-C/year). The trend (in red, Fig. 3b left) shows the average change in growth rate = dX(t) /dt = Input – Output.

• The right-hand side of the figure suggests, within the framework of linear automation and the assumptions of the MPO model, a possible interpretation via the tracking error noted εt. Between 1959 and 2025, the increasing inputs (the cause) would never be caught up by the outputs, which would increase as X(t)/5 (the consequence). The analogy aids understanding but remains imperfect because the real world is less simple than the block diagram in Fig. 3a.

4. The MPO model

4.1 A hypothesis that is not inconsistent with six IPCC reports

The hypothesis of a constant residence time = **5** years (F2 + F3 = X(t)/5) is fairly consistent with the IPCC reports. Indeed, the table below shows that the IPCC residence time varies little with the date of the ARx reports and that its average value is between 3.8 and 5.3 (depending on whether GPP or NPP is used for F3).

		Flow in Gt-C / yr					X(t) → [CO_2]	Residence time (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 residence time (year)	3,8	5,3

Figure 4: Evolution, over time, of outflows F2 and F3 and residence time according to IPCC WG1 reports [1].

In the MPO model, carbon **leaving** the atmosphere is assumed to be equal to 1/5 or 20% of the stock X(t) of carbon in the atmosphere. This outflow is divided into F2 and F3 → 20% = 11.4% to the ocean (F2) + 8.6% to vegetation/soils (F3).
The IPCC (Fig. 4) uses similar values → 19% = 11.2% (F2) + 7.8% (F3) if NPP is used for F3.
The initial assumption of the MPO model is therefore fairly consistent with the six WG1 scientific reports of the IPCC.
However, the F1 and F4 flows entering the atmosphere (according to MPO) differ from IPCC estimates.

4.2 The main parameters of the MPO model

• Figure 15 from article [2] "Revisiting the carbon cycle" is reproduced below, setting out the notations. Paragraph 6 presents the equations (equation 12) linking these different quantities and deduces their changes using X(t) measured at MLO.

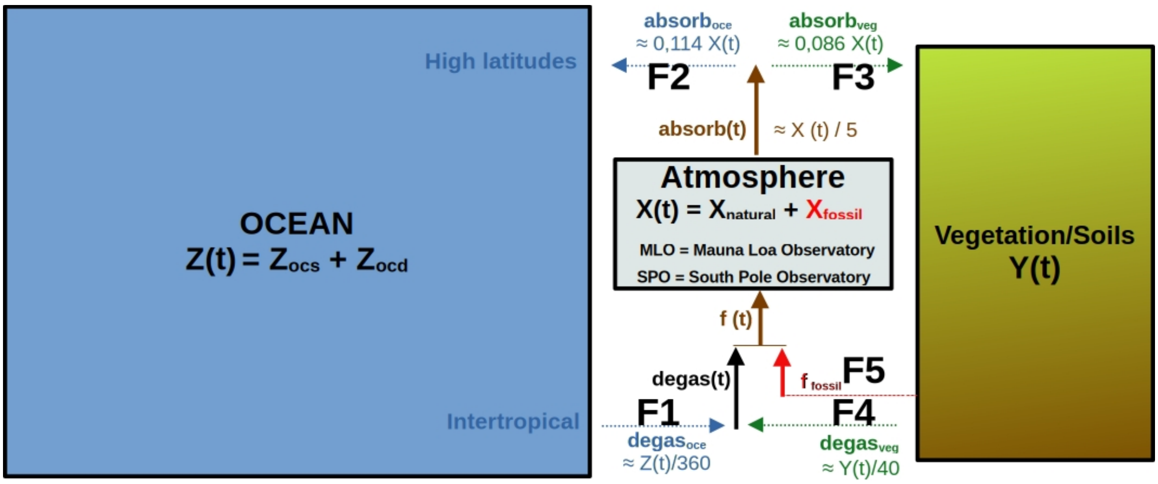


Figure 5: The "Revisiting the carbon cycle" model and its notations, superimposed on the previous flow numbering.
X(t), Y(t), Z(t) depend on the date and represent the carbon stocks of the three compartments: Atmosphere, Vegetation/Soils, and Ocean.

• Flows 2 and 3 leaving the atmosphere correspond to 11.4% of X(t) to the ocean and 8.6% of X(t) to Vegetation/Soils.

• Flow 4 comes from plant decomposition. The average residence time in Vegetation/Soils is estimated at 40 years → 1/40 of stock Y(t) leaves the compartment each year. If Y(t) increases between 1959 and 2025, then F4 will also increase.

• Flow 1 = Z(t) / 360 comes from ocean degassing: the residence time in the ocean would be ≈ 360 years **in 2020**. Section 8 of "Revisiting the carbon cycle" shows that the partial pressure of CO_2 in the ocean depends on the SST temperature and varies according to $(SST)^{12.5}$. As a result, the partial pressure in the intertropical ocean remains higher than that of the atmosphere between 1959 and 2025. Flow 1 therefore increases, driven by SST temperature to the power of 12.5. In order to satisfy the measured evolution of $\delta^{13}C$ (which requires a net carbon input such that $\delta^{13}C \approx -13‰$), the ocean must provide a net input (**F1 > F2**) that supplements that from anthropogenic emissions.

• The model then adopts a residence time that decreases if the intertropical ocean surface temperature = SSTi increases. In the MPO model, flow 1 is a function of Z(t) but also of the SSTi temperature, via a variable residence time τoc (τoc ≈ 420 years around 1960 and τoc ≈ 340 years around 2025).
The method for estimating the four natural flows is detailed in Addendum.pdf [4].

4.3 Some results from the MPO model

• '*Revisiting the carbon cycle*' (fig.2) allows for a prediction: **a deacrease in ocean temperature (SSTi) would lead to stabilization or even a decrease in the level of CO_2 in the atmosphere.** The increase in atmospheric CO_2 (+110.4 ppm between 1959 and 2025) would be divided into 87.3 natural and 23.1 anthropogenic. Section 7 shows that this distribution is perfectly compatible with the measured evolution of $\delta^{13}C$ in the atmosphere.

• The model results are presented in section 6 of "*Revisiting the carbon cycle*," some of which are shown in the table below.

Dates	[CO2] = **X(t)** (Gt-C)	Output = X(t)/5 = 0,2 X(t) = flow **2 + 3** (Gt-C/year)	Flow 2 0,114X	Flow 3 0,086X	Natural inputs = flow **1 + 4** (Gt-C/year)	Flow 1	Flow 4	Anthropogenic input = flow **5** (Gt-C/year)	Growth rate = **dX(t)/dt** (Gt-C/year)
1959	**669**	133,8	76,3	57,5	133,2	80	53,2	**2,4**	**1,8**
2025	**903**	180,6	102,9	77,7	175,2	112	63,2	**10,3**	**4,9**
Delta 1959-2025	↑ 234	↑ 46,8	↑ 26,6	↑ 20,2	↑ 42	↑ 32	↑ 20	↑ 7,9	
growth **Δ**	Δ = 234 Gt-C and Δ = Δ natural+Δ anthropogenic				Δ natural = 185 Gt-C			Δ anthropogenic = 49 Gt-C	

Dates	[CO2] = **X(t)** (ppm)	Output = X(t)/5 = 0,2X(t) = flow **2 + 3** (ppm/year)	Flow 2 0,114X	Flow 3 0,086X	Natural inputs = flow **1 + 4** (ppm/year)	Flow 1	Flow 4	Anthropogenic imput = flow **5** (ppm/year)	Growth rate = **dX(t)/dt** (ppm/year)
1959	**315,6**	63,1	36,0	27,1	62,8	37,7	25,1	**1,1**	**0,8**
2025	**425,9**	85,2	48,5	36,7	82,6	52,8	29,8	**4,9**	**2,3**
Delta 1959-2025	↑ 110,4	↑ 22,1	↑ 12,5	↑ 9,5	↑ 19,8	↑ 15,1	↑ 4,7	↑ 3,7	
growth **Δ**	Δ = 110,4 ppm and Δ = Δ natural+Δ anthropogenic				Δ natural = 87,3 ppm			Δ anthropogenic = 23,1 ppm	

*Figure 6: Flows in 1959 and 2025, with values calculated by modeling shown in blue. Top: changes in **Gt-C**; bottom: changes in **ppm**. According to the MPO model, between 1959 and 2025, F1 = ocean degassing will increase by +32 Gt-C/year, compared with only +7.9 Gt-C/year for anthropogenic flows.*

• The third part of the article will illustrate in detail the various developments (CO_2, $\delta^{13}C$, 5 flows, 3 stocks), present the overall balances for the period **1980-2025**, and respond to common objections.

5. Conclusions

• Natural phenomena are generally complex and very rarely linear. Furthermore, the considerable uncertainties surrounding natural carbon exchanges make any modeling uncertain. In this context, a model can only be a simplification of reality, a draft that could be greatly improved.

• The IPCC model adopts a **fixed and anthropocentric view** (in the spirit of Ptolemy's astronomical model).
Its competing model offers an alternative: a **dynamic view, based on reliable modern measurements**. Natural exchanges according to this model are within the margin of error (± 25% except for F1) of IPCC estimates.

• The carbon cycle **o**ver a period of several decades can be summarized as an exchange of carbon between two main compartments: Oceans → Z(t) ≈ 90% and Vegetation/Soils → Y(t) ≈ 8% through a third, smaller compartment: Atmosphere → X(t) ≈ 2%. In addition to natural carbon inputs into the atmosphere, currently around 180 (?) Gt-C/year ± 25% (?), there is a small anthropogenic/fossil input of around 10 Gt-C/year.

• Measurements at MLO since 1959 show that variations in atmospheric carbon = dX(t) /dt are very **poorly correlated** with this low anthropogenic/fossil input. "Revisiting the carbon cycle' (Figure 2) shows that dX(t)/dt is, in fact, s**trongly correlated** with temperature in the intertropical zone (see also Fig. 6e in Part 1/3).
The dynamics of atmospheric CO_2 therefore seem to be governed mainly by **natural** processes: the surface temperature of the ocean SSTi (induced by insolation), the net productivity of vegetation, and the physical chemistry of carbon in the ocean.

• '*Revisiting the carbon cycle*' proposes a simplified model in which the carbon leaving the atmosphere each year would be a proportion (1/5 or 20%) of the atmospheric stock X(t). Recent available measurements (CO_2 content, δ13C, Δ14C, SSTi temperature) are used to justify the model and the value of its parameters. This model shows that:
a) The atmosphere in 2025 is a mixture (natural + fossil) such that X(2025) = 426 ppm = Xnatural+Xfossil = 403 ppm + 23 ppm.
b) From 1959 to 2025, X(t) increases by +110.4 ppm, which breaks down into +87.3 ppm natural and +23.1 ppm anthropogenic.
c) Xfossil increases slowly (≈ +0.28 ppm/year) while Xnatural increases seven times faster (≈ +2 ppm/year since 2000).
d) Flow 1 (ocean degassing) increases sharply between 1959 (≈ 80 Gt-C/year) and 2025 (≈ 112 Gt-C/year). In fact, in seawater, the partial pressure varies with temperature to the **power of 12.5, and that temperature has risen**.
e) This increasing supply of **ocean** carbon into the atmosphere (**the cause**) then leads to the growth of vegetation : its net productivity (flow 3) increases between 1959 (≈ 57 Gt-C/year) and 2025 (≈ 78 Gt-C/year).

• In the article "*Revisiting the carbon cycle*" (see the 10 pages of § 10), it has been demonstrated that many of the concepts or assertions made by the IPCC/UN are illusory (*adjustment time*, *airborne fraction*, *Bern IRF*, *buffer factor*, etc.). For further information on other IPCC/UN assertions, readers may refer to article SCE_03/2025.

Part 1 of the article explains the reasons behind the model (study of correlations and δ13C).
Part 3 of the article illustrates the changes between 1980 and 2025 according to the MPO model and responds to common objections.

References

1 CO_2 in the atmosphere
Mauna Loa Monthly Averages CO_2
Tom V. Segalstad http://www.co2web.info/ESEF3VO2.pdf.
Compilation : Sundquist, E.T. 1985: Geological perspectives on carbon dioxide and the carbon cycle.
Carbon exchanges according to IPCC WG1 reports : AR6 Fig 5.12 | AR5 Fig 6,01 | AR4 Fig 7.3 | AR3 Fig 3.1a | AR2 p.77 (fig 2.1) | AR1 chap.1 p.8 (Fig 1.1)

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