The Impact of Human CO_2 on Atmospheric CO_2

Edwin X Berry

Ed Berry, LLC, Bigfork, Montana 59911, USA

Correspondence to ed@aedberry.com

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Abstract

A basic assumption of climate change made by the *United Nations Intergovernmental Panel on Climate Change* (IPCC) is natural CO_2 stayed constant after 1750 and human CO_2 dominated the CO_2 increase. IPCC's basic assumption requires human CO_2 to stay in the atmosphere longer than natural CO_2. But human CO_2 and natural CO_2 molecules are identical. So, human CO_2 and natural CO_2 must flow out of the atmosphere at the same rate, or e-time. The $^{14}CO_2$ e-time, derived from $\delta^{14}C$ data, is 10.0 years, making the $^{12}CO_2$ e-time less than 10 years. The IPCC says the $^{12}CO_2$ e-time is about 4 years and IPCC's carbon cycle uses 3.5 years. A new physics carbon cycle model replicates IPCC's natural carbon cycle. Then, using IPCC's natural carbon cycle data, it calculates human carbon has added only 33 [24-48] ppmv to the atmosphere as of 2020, which means natural carbon has added 100 ppmv. The physics model calculates if human CO_2 emissions had stopped at the end of 2020, the human CO_2 level of 33 ppmv would fall to 10 ppmv in 2100. After the bomb tests, $\delta^{14}C$ returned to its original balance level of zero even as $^{12}CO_2$ increased, which suggests a natural source dominates the $^{12}CO_2$ increase.

Keywords: carbon cycle; carbon cycle model; carbon dioxide; climate change; CO_2 increase; human carbon.

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1.Introduction

1.1 Definitions

The *Intergovernmental Panel on Climate Change* (IPCC) defines two carbon cycle domains, the *slow* carbon cycle and the *fast* carbon cycle. IPCC (2013, p. 470) explains,

> "The first is a fast domain with large exchange fluxes and relatively 'rapid' reservoir turnovers, which consists of carbon in the atmosphere, the ocean, surface ocean sediments and on land in vegetation, soils and freshwaters."
>
> "A second, slow domain consists of the huge carbon stores in rocks and sediments which exchange carbon with the fast domain through volcanic emissions of CO2, chemical weathering, erosion and sediment formation on the sea floor."

This paper uses the following definitions:

- "Natural carbon" is carbon from natural actions.
- "Human carbon" is from burning carbon fuels and producing cement.
- "Land carbon" is from human-caused land-use changes.

Human carbon moves carbon from the slow carbon cycle to the fast carbon cycle. Land carbon moves carbon from the land to the atmosphere, all within the fast carbon cycle.

This paper assumes human carbon transferred to the fast carbon cycle stays in the fast carbon cycle forever. This paper focuses on how long human carbon stays in the atmosphere in the fast carbon cycle.

The level or concentration of atmospheric CO_2 is in units of ppmv (parts per million by volume in dry air). However, it is customary to omit the "v" and write ppm. To convert CO_2 in ppmv into the mass of carbon in PgC (petagrams), multiply the ppmv by 2.12. GtC (Gigatons of car-

bon) is numerically equivalent to PgC.

1.2 The IPCC basic assumption

The IPCC, its supporting papers and climate models, assume that human CO_2 causes all or most CO_2 increase above 280 ppmv. This assumption is the basis of worldwide climate laws and treaties.

The IPCC (2013, p. 467, Executive Summary) says,

> "With a very high level of confidence, the increase in CO_2 emissions from fossil fuel burning and those arising from land use change are the dominant cause of the observed increase in atmospheric CO_2 concentration."

The IPCC (2013, pp. 470-471) assumes the natural CO_2 level remained at 280 ppm after 1750 and, therefore, human CO_2 caused all the CO_2 increase since 1750. This paper uses IPCC's own data to argue this IPCC assumption is incorrect.

Fig. # 1 (IPCC, 2013, p. 471, Fig. # 6.1) shows IPCC's natural carbon cycle (in black) and IPCC's human carbon cycle (in red). The title bar shows 589 PgC (278 ppmv) of *natural* carbon and 240 PgC (113 ppmv) of *human* carbon is in the atmosphere as of about 2005. So, according to the IPCC, human CO_2 has caused 29% (= 240/829) of the CO_2 in the atmosphere.

Fig. # 1 also shows annual *human* carbon emissions in 2005 are 8.8 PgC per year (7.8 PgC per year of human carbon and 1.1 PgC per year of land carbon) while *natural* carbon emissions are 168 PgC per year (107.2 PgC per year from land and 60.7 PgC from surface ocean).

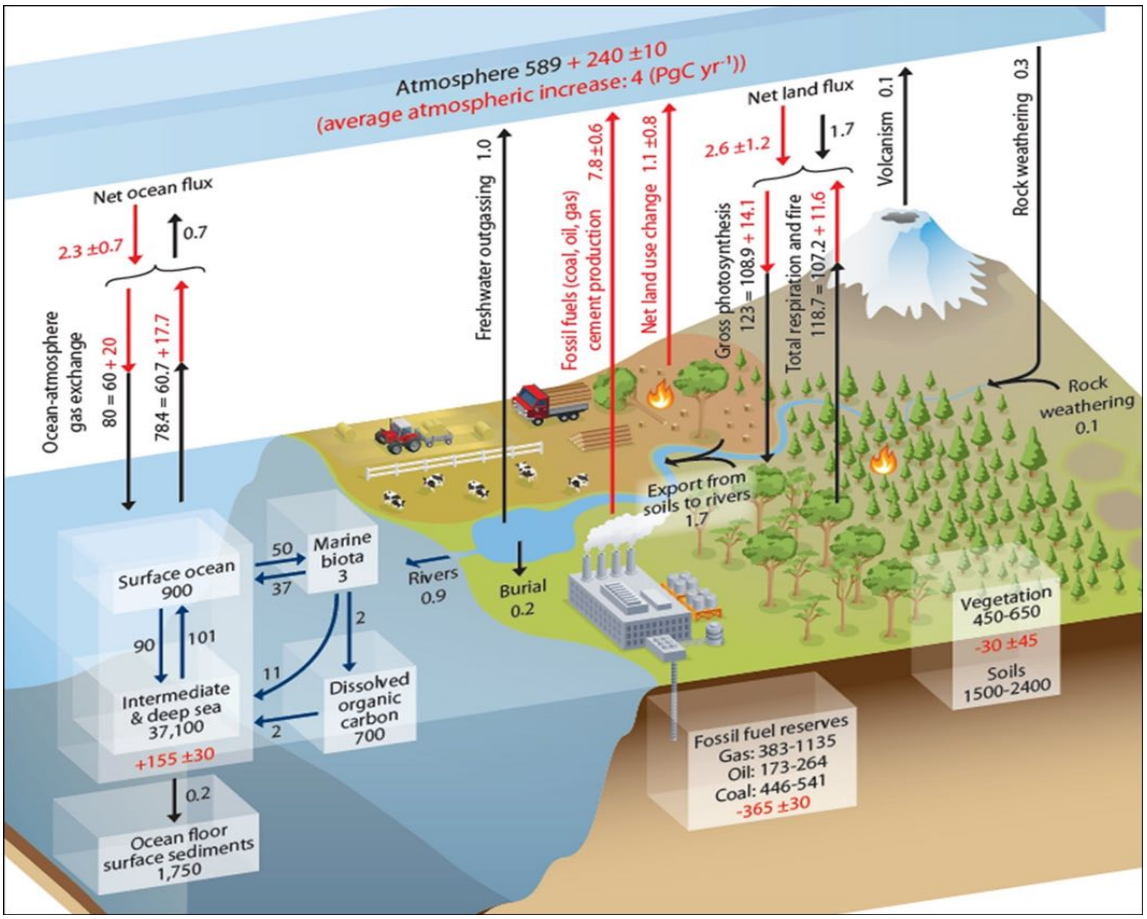

Figure 1. IPCC Figure 6.1 for 2010 shows IPCC's data for its natural and human carbon cycles.

Therefore, the IPCC assumes annual *human* emissions, which are only 5% of the total CO_2 inflow, have become 29% of the CO_2 in the atmosphere in 2010. Data for 2020 show 33%. How can 5% of the annual inflow become 29% or 33% of the total CO_2 in the atmosphere?

To achieve this result, the IPCC assumes *human* CO_2 stays in the atmosphere longer than *natural* CO_2. But this cannot be true because human and natural CO_2 molecules are identical. Therefore, they stay in the atmosphere for equal times. This is the *climate equivalence principle*.

IPCC's turnover time, which this paper calls "e-time," measures how long CO_2 stays in the atmosphere.

IPCC (2007, p. 948) defines turnover time to make outflow proportional to the first power of the level,

> "Turnover time (T) is the ratio of the mass M of a reservoir (e.g., a gaseous compound in the atmosphere) and the total rate of removal S from the reservoir: T = M / S. For each removal process, separate turnover times can be defined."

IPCC (2007, p. 948) says the turnover time (T) for natural CO_2 is about four years.

> *"Carbon dioxide* (CO_2) is an extreme example. Its turnover time is only about four years because of the rapid exchange between the atmosphere and the ocean and terrestrial biota."

However, IPCC (2013, p. 469) assumes human CO_2 turnover time is much larger than four years,

> "The removal of human-emitted CO_2 from the atmosphere by natural processes will take a few hundred thousand years (high confidence). Depending on the RCP scenario considered, about 15 to 40% of emitted CO_2 will remain in the atmosphere longer than 1,000 years. This long time required by sinks to remove anthropogenic CO_2 makes climate change caused by elevated CO_2 irreversible on human time scale. {Box 6.1}"

IPCC's Box 6.1, mentioned above, merely assumes the natural CO_2 level has remained at 280 ppmv while human CO_2 caused all the CO_2 increase. There are no data to prove this is the case.

This IPCC assumption requires *human* CO_2 to have a much longer turnover time (and therefore stay in the atmosphere much longer) than natural CO_2.

Turnover time is critical. If it is less than 10 years, then natural CO_2 caused most CO_2 increase. If it is greater than 100 years, then human CO_2 caused most CO_2 increase. The reason (more fully explained in Section 4) is CO_2 outflow from the atmosphere is fast when the turnover time is small and vice-versa. So, for a given inflow of human CO_2, more will remain in the atmosphere if the turnover time is large.

Revelle and Suess (1957) used ^{14}C data to calculate the turnover time "of a CO_2 molecule in the atmosphere … is of the order of 10 years," and correctly concluded,

> "This means most of the CO_2 released by artificial fuel combustion since the beginning of the industrial revolution must have been absorbed by the oceans."

Starr (1992) found several papers that assume human CO_2 caused all the CO_2 increase. By removing this assumption, Starr found the data show turnover time is 4 to 5 years. He correctly wrote,

> "The short residence time suggests that anthropogenic emissions contribute only a fraction of the observed atmospheric rise, and that other sources need be sought."

Segalstad (1998) lists 36 independent studies from 1957 to 1992 that used 6 different methods to estimate turnover time that show it is less than 10 years and dominantly between 5 and 10 years.

Rorsch et al. (2005) show if human and natural carbon have the same e-times, as physics re-

quires, then IPCC's assumption is wrong.

Essenhigh (2009) calculated the $^{12}CO_2$ e-time is about 4 years.

Ballantyne et al. (2012) found "there is no empirical evidence" that the ability of the land and oceans to absorb atmospheric CO_2 "has started to diminish on the global scale." This means human CO_2 has not changed the turnover time.

Munshi (2015a) shows the "detrended correlation of annual emissions with annual changes in atmospheric CO_2" is zero, which proves anthropogenic emissions are not the primary cause of the increase in CO_2 concentration. A non-zero correlation does not prove a cause-effect relationship is true, but a zero correlation proves there is no observable cause-effect. Correlations of time-series data must be detrended to remove overall trends before calculating cause-effect correlations.

Harde (2017, 2019) concluded the $^{12}CO_2$ e-time is about 4 years. Harde (2019) and Berry (2019) use one-reservoir models (that do not allow human carbon to flow of from land and oceans back into the atmosphere) to conclude that human emissions have added about 17 ppmv to 18 ppmv to the atmosphere.

Kohler et al. (2017) criticized Harde (2017), claiming human (but not natural) CO_2 reduced the "buffer capacity" of the carbonate system, conflicting with Ballantyne et al. (2012),

> "… the rise in atmospheric and oceanic carbon content goes along with an increase in the Revelle factor, a phenomenon which is already measurable. This implies that the oceanic uptake of anthropogenic carbon will become slower if we continue to increase anthropogenic CO_2 emissions. This is already seen in all CHIMP5 model simulations."

However, Kohler et al. arguments use the IPCC assumption – that human CO_2 dominated the CO_2 increase – to conclude human (but not natural) CO2 reduced ocean "uptake," caused the Revelle factor (that Ballantine et al. conclude is not measurable), and use CHIMP5 models that make the same assumption, to conclude (in circular fashion) the IPCC assumption is true so they can claim Harde (2019 is wrong.

Gruber et al. (2019) assume human carbon dominates the CO_2 increase to analyze their data to conclude the IPCC assumption is true.

1.3. The IPCC ice-core assumption

IPCC (2013, pp. 467-468) uses reconstructed ice core data to support its assumption that human CO_2 has caused all the CO_2 increase above 280 ppmv,

> "During the last 7000 years prior to 1750, atmospheric CO_2 from ice cores shows only very slow changes (increase) from 260 ppmv to 280 ppmv, in contrast to the human-caused increase of CO_2 since pre-industrial times."

IPCC's last phrase – "*in contrast to the human-caused increase of* CO_2 *since pre-industrial times*" – is IPCC's assumption that IPCC uses to conclude its assumption is true, which is circular reasoning.

The IPCC uses the *absence* of ice-core data – that show the natural CO_2 level was greater than 280 ppmv before 1750 – to assume natural CO_2 remained at 280 ppmv after 1750. Here are some problems for this IPCC ice-core assumption.

First, IPCC's antecedent is questionable.

- Segalstad (1998) shows why ice core reconstructions of CO_2 levels are not reliable.
- Kouwenberg (2004) and Kouwenberg et al. (2005 a, b) used conifer stomata data to reconstruct CO_2 levels that increased to 350 ppmv several times in the last 1200 years.
- Beck (2007) published thousands of direct chemical measurements of CO_2 that show much higher CO_2 levels than those reconstructed from ice cores.

- Jaworowski (2007) shows ice cores underestimate CO_2 levels.
- Salby (2012, pp. 21, 66) shows ice-core reconstructions of CO_2 levels do not accurately measure historical CO_2 levels.

Second, these papers negate IPCC's consequent:

- Segalstad (1998) shows the turnover time is 3.5 years to 5 years.
- IPCC (2007, p. 948) says the CO_2 turnover time is "about 4 years."
- IPCC (2013, pp. 470-471) Fig. # 1 shows the CO_2 e-time is 3.5 years.
- Harde and Salby (2021) show the $^{14}CO_2$ e-time is 10.0 years, which proves $^{12}CO_2$ e-time is much smaller, which proves human CO_2 did not cause all the CO_2 increase.
- The return of $\delta^{14}C$ to its original level of zero after the bomb tests, even as $^{14}CO_2$ and $^{12}CO_2$ increased, proves the added $^{12}CO_2$ came from a natural source that existed before the bomb tests (Section 6.1).

1.4 Isotope data show CO_2 increase is natural

IPCC (2007, p. 512) says,

> "The increase in atmospheric CO_2 concentration is known to be caused by human activities because the character of CO_2 in the atmosphere, in particular the ratio of its heavy to light carbon atoms, has changed in a way that can be attributed to addition of fossil fuel carbon."

This IPCC argument has no numbers. But isotope data contradict IPCC's assumption that human CO_2 caused all the increase and show the human effect is small (Segalstad, 1998; Quirk, 2009; Harde, 2017, 2019; Berry, 2019; Harde and Salby, 2021).

2. Method

2.1 The data

This paper uses these data,

- IPCC's natural carbon cycle data (IPCC, 2013, pp. 470-486)
- $\delta^{14}C$ data (Turnbull et al., 2017)
- ^{14}C data (Turnbull et al., 2017)
- ^{12}C data before 1960 (Etheridge et al., 1996; Jaworowski, 2007)
- ^{12}C data after 1960 (Keeling et al., 2001)
- Human carbon emissions data (Gilfillan et al., 2020)

2.2 The basics

According to the scientific method, data cannot prove an assumption is true, but only one contradiction to data proves an assumption is false.

IPCC (2013, p. 467, Executive Summary) says human CO_2 is the "dominant" cause of the increase. IPCC (2013, pp. 470-486) says human CO_2 caused all the increase. This paper shows both versions of IPCC's assumption conflict with IPCC's data.

The IPCC did not derive its human carbon cycle from IPCC's natural carbon cycle data, as it should have, but merely assumed that human CO_2 caused all the CO_2 increase above 280 ppmv. But scientific assumptions should be compatible with all available data.

This paper shows IPCC's assumed human carbon cycle contradicts IPCC's natural carbon cycle data. Therefore, IPCC's assumed human carbon cycle cannot be true.

2.3 The physics carbon cycle model

The physics carbon cycle model, derived in this paper, has only one hypothesis, namely, outflow is proportional to level. The IPCC (2013, p. 470, turnover time) uses this same hypothesis, so the physics carbon cycle model agrees with IPCC's natural carbon cycle (Section 3.1).

IPCC's natural carbon cycle (Fig. # 1) has four main carbon reservoirs, e.g., land, atmosphere, surface ocean, and deep ocean, in that order. The land connects only with the atmosphere and the deep ocean connects only with the surface ocean. The atmosphere and surface ocean have two connections.

IPCC's natural carbon cycle shows data for each of the four levels and the six flows between the four reservoirs at equilibrium.

The physics carbon cycle model uses IPCC's levels and flows to calculate the turnover times (now e-times) for the six outflow nodes. With these six e-times, the physics carbon cycle model calculates how the carbon levels change when the carbon cycle is not at equilibrium.

The physics model is a systems model where levels calculate flows, and flows calculate new levels.

For verification, the physics carbon cycle model replicates IPCC's natural carbon cycle. Then the physics model calculates the human carbon cycle using IPCC's natural carbon cycle e-times.

The atmospheric CO_2 e-time for IPCC's natural carbon cycle is 3.5 years (Equation 23), which approximates IPCC's (2007, p. 948) estimated turnover time of about 4 years.

This physics model is an extensible, documented, open-source model that other researchers can use to make carbon cycle calculations.

2.4 Data contradict IPCC's basic assumption

The IPCC assumes natural CO_2 stayed constant at 280 ppmv after 1750 while human CO_2 caused all the CO_2 increase above 280 ppmv. This assumption contradicts data.

First, $^{14}CO_2$ data show its e-time is 10 years, making the $^{12}CO_2$ e-time less than 10 years (Section 6.1). This contradicts IPCC's assumption.

Second, the return of $\delta^{14}C$ data to its original balance level of zero even as $^{12}CO_2$ increased, suggests the added $^{12}CO_2$ has a natural source independent of human emissions (Section 6.1).

Third, IPCC's assumption requires human CO_2 to have a much larger e-time than natural CO_2 to dominate the CO_2 increase. But human and natural e-times are the same because human and natural CO_2 molecules are identical. Different e-times would require a "carbon demon" in the atmosphere to separate human from natural CO_2 and then restrain the human CO_2 from flowing out of the atmosphere as fast as natural CO_2.

Fourth, the physics carbon cycle model uses IPCC data to show human carbon has added only 33 [24-48] ppmv to the atmosphere as of 2020, which means natural carbon has added 100 ppmv.

The physics model calculates if human CO_2 emissions had stopped at the end of 2020, the human CO_2 level would fall from 33 ppmv in 2020 to 16 ppmv in 2040, to 10 ppmv in 2100, and to 5 ppmv by 2180.

Fig. # 1 (IPCC, 2013, p. 471, Fig. # 6.1) shows the total natural carbon in the fast carbon cycle is 41,089 PgC and the added human carbon is 365 PgC as of about 2010. So, human carbon has added only 0.89% to the carbon in the carbon cycle as of 2010. This change of less than one percent diffuses arguments that human CO2 changed the e-times.

The physics carbon cycle model calculates IPCC's land use effect adds little carbon to the atmosphere because this carbon moves quickly from the atmosphere, through the surface ocean, and on to the deep ocean, without adding new carbon to the carbon cycle.

The physics model calculates, deductively, the consequences of IPCC's natural carbon cycle data. Therefore, these calculations are independent of outside data.

2.5 The Bern model

The Bern model (Siegenthaler and Joos, 1992; Strassmann and Joos, 2018) uses IPCC's assumption that human CO_2 dominates the CO_2 increase.

The Bern model uses Green's functions to calculate the evolution of one pulse in the atmosphere. Section 5.4 compares the Bern model with the physics model for a single carbon pulse in the atmosphere. The Bern model uses long e-times that leave 15% of carbon in the atmosphere at equilibrium. The physics model uses IPCC's e-times that leave only 1.4% of total carbon in the atmosphere at equilibrium.

Then, to calculate the results of continuing pulses, the Bern model must integrate successive Green's functions. The physics model for a single pulse could use Green's functions, but that would require integrating sequential Green's functions, which is unnecessary.

The physics model uses recursive calculations to quickly solve for any scenario in a single process. The physics model is a true systems model that allows levels to set flows and these flows to set new levels. It is simpler and more versatile than the Bern model.

The physics model (Section 4) shows how inflow sets a balance level where outflow equals inflow. The level always moves to the balance level. Once at the balance level, continuing constant inflow does not change the level.

3. Carbon data review

3.1 IPCC's carbon cycle data

IPCC (2013, p. 470) introduces IPCC's carbon cycles,

> "Atmospheric CO_2 represents the main atmospheric phase of the global carbon cycle. The global carbon cycle can be viewed as a series of reservoirs of carbon in the Earth System, which are connected by exchange fluxes of carbon. Conceptually, one can distinguish two domains in the global carbon cycle."
>
> "The first is a fast domain with large exchange fluxes and relatively 'rapid' reservoir turnovers, which consists of carbon in the atmosphere, the ocean, surface ocean sediments and on land in vegetation, soils and freshwaters."
>
> "Reservoir turnover times, defined as reservoir mass of carbon divided by the exchange flux, range from a few years for the atmosphere to decades to millennia for the major carbon reservoirs of the land vegetation and soil and the various domains in the ocean."
>
> "A second, slow domain consists of the huge carbon stores in rocks and sediments which exchange carbon with the fast domain through volcanic emissions of CO_2, chemical weathering, erosion and sediment formation on the sea floor."

IPCC's reference to "turnover times" clarifies that it defines outflows to be directly proportional to the reservoir levels and that IPCC's data include biogeochemical processes for the carbon cycle.

Fig. # 1 (IPCC, 2013, p. 471, Fig. # 6.1) shows IPCC's carbon cycle with its four major carbon reservoirs – land, atmosphere, surface ocean, and deep ocean – and its separation of the natural (in black) and human (in red) carbon cycles.

IPCC (2013, p. 470) says its Fig. # 6.1 applies to the fast domain,

> "A schematic of the global carbon cycle with focus on the fast domain is shown in Figure 6.1. The numbers represent the estimated current pool sizes in PgC and the magnitude of the different exchange fluxes in PgC/year averaged over the time-period 2000-2009."

IPCC (2013, p. 471) Fig. # 6.1 legend says it is a "simplified schematic of the global carbon cycle. Numbers represent reservoir mass in PgC and annual carbon exchange fluxes (in PgC per year)."

Fig. # 1 separates the natural carbon cycle (in black) from the human carbon cycle (in red),

> "Black numbers and arrows indicate reservoir mass and exchange fluxes estimated for the time prior to the Industrial Era, about 1750."
>
> "Red arrows and numbers indicate annual 'anthropogenic' fluxes averaged over the 2000-2009 time-period."
>
> "Uncertainties are reported as 90% confidence intervals. Individual gross fluxes and their changes since the beginning of the Industrial Era have typical uncertainties of more than 20%, while their differences are determined from independent measurements with a much higher accuracy."

The Gilfillan et al. (2020) data for human carbon emissions show human carbon inflow was 7.8 PgC per year in about 2005 and the accumulated human carbon emissions was 365 PgC in 2010, agreeing with Fig. # 1 data for the 2000-2009 time-period.

3.2 IPCC's natural carbon cycle

Fig. # 1 shows annual natural carbon emissions to the atmosphere are 107.2 PgC per year from the land and 60.7 PgC from the surface ocean for a total of 168 PgC per year.

IPCC's natural carbon cycle is at equilibrium. Fig. # 1 shows IPCC's net natural flows between the reservoirs are near zero, but they must be at net zero to truly be at equilibrium.

Fig. # 2 shows IPCC's natural net flows set to zero (a 1% adjustment to IPCC's data) to keep the IPCC's reservoir levels constant. The boxes represent reservoirs, and the arrows represent flows between the reservoirs. The origins of the arrows are "nodes."

Fig. # 2 uses IPCC's assumption that the natural level remained constant at 589 PgC (278 ppmv) after 1750. The Land 2500 PgC in Fig. # 2 is the total of averages of Vegetation (550 PgC) and Soils (1950 PgC) in Fig. # 1.

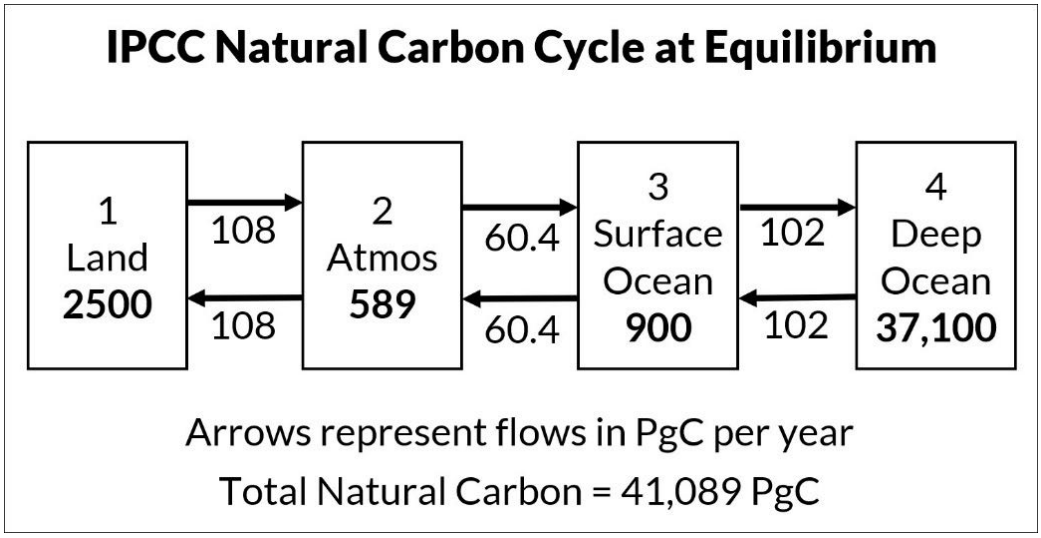

Figure 2. Levels and flows for IPCC's (2013) natural carbon cycle shown in Figure 1. The boxes represent the reservoirs and arrows represent the flows between the reservoirs.

Fig. # 3 shows the percent of natural carbon in each reservoir from Fig. # 2. Only 1.43% of natural carbon is in the atmosphere and 90% is in the deep ocean.

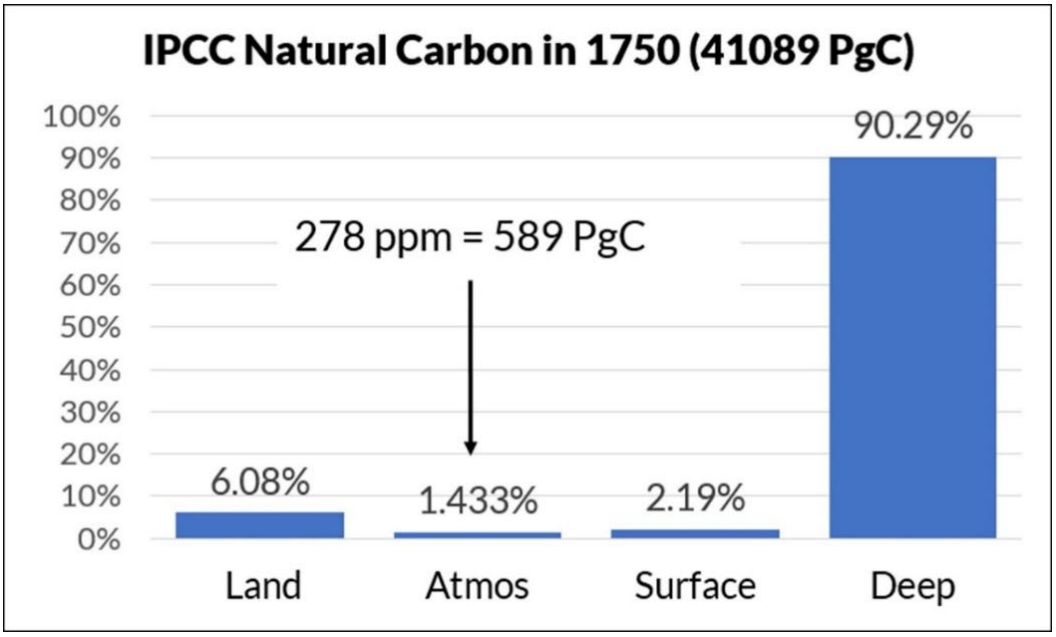

Figure 3. The percent of natural carbon in each reservoir for IPCC's natural carbon cycle in Figure 2.

The Fig. # 3 reservoir percentages are a fingerprint of the IPCC's natural carbon cycle at equilibrium. Since human carbon has the same turnover times as natural carbon, the human carbon cycle will have this same equilibrium fingerprint. If all human carbon emissions were to stop, the human carbon percentages would move toward the natural carbon percentages shown in Fig. # 3.

3.3 IPCC's human carbon cycle

Fig. # 1 shows annual human carbon emissions in 2005 were 7.8 PgC per year and land carbon emissions were 1.1 PgC per year for a total of 8.8 PgC per year which is 5% of the annual natural emissions of 168 PgC per year.

Fig. # 4 shows IPCC's human carbon cycle values in Fig. # 1 for the 2000-2009 time-period. Fig. # 4 shows human carbon emissions added 365 PgC to the human carbon cycle as of 2010.

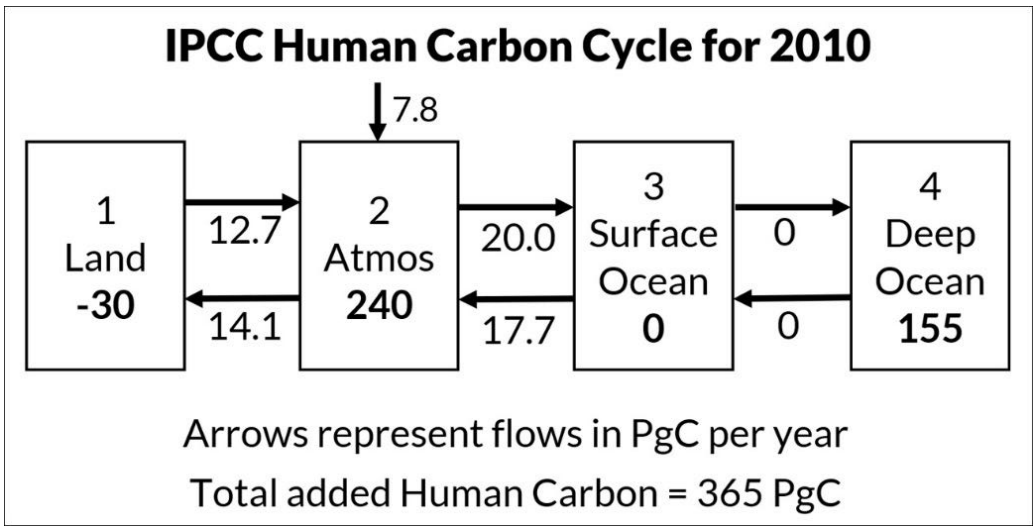

Figure 4. Levels and flows for IPCC's human carbon cycle shown in Figure 1. The boxes represent the reservoirs and arrows represent the flows between the reservoirs.

Fig. # 5 shows the percent of the 365 PgC of human carbon in each reservoir for IPCC's human carbon cycle shown in Fig. # 4. These percentages show 8% of 365 has moved from the land to the atmosphere to the deep ocean, 66% is in the atmosphere, and 42% is in the ocean.

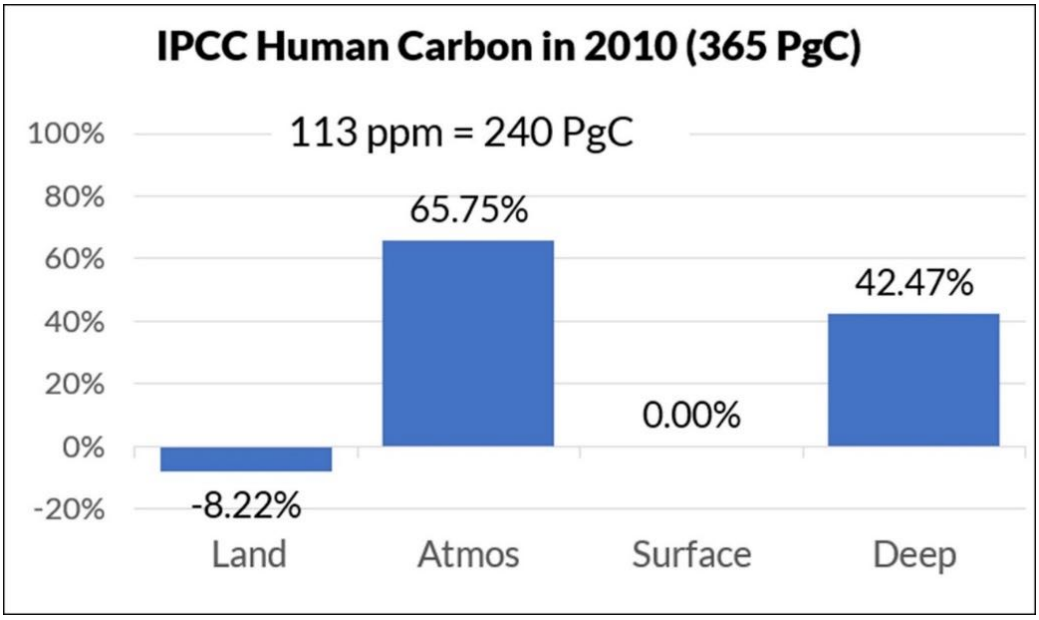

Figure 5. The percent of human carbon in each reservoir for IPCC's human carbon cycle in Figure 4.

Ignoring the 8% percent loss in the land carbon, which has large errors and could even be positive, Fig. # 5 shows the IPCC's human carbon cycle percentages do not resemble IPCC's natural carbon cycle percentages in Fig. # 3.

This difference suggests that IPCC's human carbon cycle uses different physics than IPCC's natural carbon cycle. Rather than calculate a human carbon cycle, the IPCC simply assigned 240 PgC or 66% of the human carbon 365 PgC to the atmosphere based solely on its assumption that natural CO_2 remained at 280 ppmv while human carbon caused all the increase in atmospheric CO_2. Then the IPCC assigned the remaining human carbon to the deep ocean.

IPCC's human carbon data in Fig. # 1 are from IPCC's (2013, p. 486) Table 6.1 "Global anthropogenic CO_2 budget" for the decade 2000 to 2009.

Table 1 shows IPCC's Table 6.1 with the Row 3 signs reversed to show positive flow from the atmosphere to the ocean. Positive flux numbers are in the direction of the flux title. IPCC writes,

> "Global anthropogenic CO_2 budget, accumulated since the Industrial Revolution (onset in 1750) and averaged over the 1980s, 1990s, 2000s, as well as the last 10 years until 2011."

The uncertainty range is for a 90 confidence interval.

Table 1. IPCC's (2013, p 486) Table 6.1

IPCC (2013, p 486) Table 6.1. Row-3 signs reversed to show positive flow from atmosphere to surface ocean.	*1750-2011 Cumulative* PgC	*1980-1989* PgC/Year	*1990-1999* PgC/Year	*2000-2009* PgC/Year	*2002-2011* PgC/Year
Atmospheric increase	240 ± 10	3.4 ± 0.2	3.1 ± 0.2	4.0 ± 0.2	4.3 ± 0.2
Fossil fuel and cement production	365 ± 30	5.5 ± 0.4	6.4 ± 0.5	7.8 ± 0.6	8.3 ± 0.7
Atmosphere-to-ocean flux	155 ± 30	2.0 ± 0.7	2.2 ± 0.7	2.3 ± 0.7	2.4 ± 0.7
Land-to-Atmosphere flux	30 ± 45	-0.1 ± 0.8	-1.1 ± 0.9	-1.5 ± 0.9	-1.6 ± 1.0
Net land use change	180 ± 80	1.4 ± 0.8	1.5 ± 0.8	1.1 ± 0.8	0.9 ± 0.8
Residual land sink (inferred)	-150 ± 90	-1.5 ± 1.1	-2.6 ± 1.2	-2.6 ± 1.2	-2.5 ± 1.3

The IPCC calculates the "inferred" values of Residual land sink as follows,

> [Residual Land Sink] = [Fossil fuel and cement production] + [Net land-use change] – [Atmospheric increase] – [Atmosphere-to-Ocean flux]

This formula finds the Cumulative Residual land sink is -150 PgC rather than -160 PgC and Table 1 corrects this IPCC error.

This paper uses Table 1 values to calculate the effect of IPCC's net land use change on the human carbon cycle.

4. Physics model

(The casual reader may skip Section 4 that develops the mathematics for the physics model.)

4.1 Physics model for one reservoir

The physics carbon cycle requires a theoretical base. All models are approximations to reality. Scientists and engineers define systems to approximate a subset of nature. A system includes levels and flows between levels. Levels set flows and flows set new levels. The mathematics used in the physics model are analogous to the mathematics used to describe engineering and chemical systems.

Fig. # 6 shows the one-level physics model with one outflow for carbon in the atmosphere. The same model applies to all carbon in any reservoir.

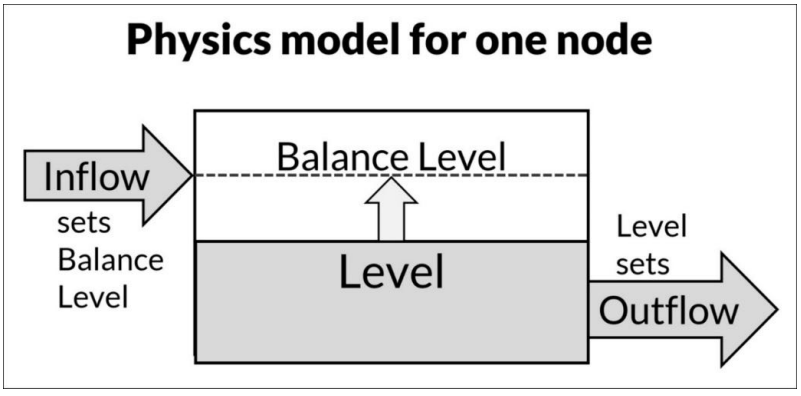

Figure 6. The physics model for one level and one outflow node.

Following Berry (2019), the physics model derivation begins with the continuity equation (1) which says the rate of change of level is the difference between inflow and outflow,

$$dL / dt = Inflow - Outflow \quad (1)$$

where,

L = carbon level (PgC)

t = time (years)

dL / dt = rate of change of L (PgC / year)

Inflow = carbon inflow (PgC / year)

Outflow = carbon outflow (PgC / year)

When *Outflow* = *Inflow*, then $dL/dt = 0$. The flows continue while the level is constant.

The physics model has only one hypothesis, outflow is proportional to level,

$$Outflow = L / T_e \quad (2)$$

where T_e is the "e-time," so defined because it is an exponential time. Equation (2) shows e-time *Te* is the same as IPCC's turnover time, *T*.

E-time is the time for the level to move (1 - 1/e) of the distance from its present level to its balance level.

Substitute (2) into (1) to get,

$$dL / dt = Inflow - L / T_e \quad (3)$$

When dL/dt is zero, the level will be at its balance level, L_b, defined as,

$$L_b = Inflow\ T_e \quad (4)$$

Substitute (4) for *Inflow* into (3) to get,

$$dL / dt = - (L - L_b) / T_e \quad (5)$$

Equation (4) shows how inflow sets the balance level. Equation (5) shows the level always moves toward the balance level set by the inflow. The variables L, L_b, and T_e are functions of time.

In the special case when L_b and T_e are constant, which means *Inflow* is constant according to (4), there is an analytic solution to (5). Rearrange (5) to get,

$$dL / (L - L_b) = - dt / T_e \quad (6)$$

Then integrate (6) from L_0 to L on the left side, and from 0 to t on the right side to get,

$$\text{Ln}\ [(L - L_b) / (L_0 - L_b)] = - t / T_e \quad (7)$$

where,

L_0 = Level at time zero ($t = 0$)

L_b = the balance level for a given inflow and T_e

T_e = time for L to move (1 – 1/e) from L to L_b

e = 2.7183

Define half-life, T_h, as the time for the level to fall to half its original level. Then (7) becomes,

$$\text{Ln}\,(1/2) = -\,T_h / T_e \tag{7a}$$

$$T_h = T_e\,\text{Ln}\,(2) = 0.6931\;T_e \tag{7b}$$

The original integration of (6) has two absolute values, but they cancel each other because both L and L_0 are always either above or below L_b.

Raise e to the power of each side of (7), to get the level as a function of time,

$$L(t) = L_b + (L_0 - L_b)\,\exp(-\,t / T_e) \tag{8}$$

Equation (8) is the analytic solution of (5) when L_b and T_e are constant.

All equations after (2) are deductions from hypothesis (2) and the continuity equation (1).

4.2 Physics model properties

The physics model's only hypothesis (2) is a linear function of level. This means the physics model applies independently and in total to human and natural carbon, and independently and in total to all definitions of carbon or CO_2 (Berry, 2019).

However, if outflow (2) were a strictly increasing function of level other than level to the power of one, then the physics model would *not* apply independently and in total to human CO_2 and natural CO_2.

The *superposition principle* says for all linear systems,

> the net response caused by two or more stimuli is the sum of the responses caused by each stimulus individually. So, if input A produces response X and input B produces response Y then input (A + B) produces response (X + Y).

Dalton's law of partial pressures applies to a linear system. It says,

> the total pressure in a mixture of non-reacting gases equals the sum of the partial pressures of the individual gases.

The linear physics model applies independently to human CO_2, natural CO_2, and their sums, and to $^{12}CO_2$, $^{13}CO_2$, and $^{14}CO_2$, and their sums.

Hypothesis (2) shows it is preferable to calculate the natural and human carbon cycles separately. Just add another instance of the physics model for each carbon definition. Then add the results of the separate calculations to produce the total carbon cycle.

Hypothesis (2) is compatible with all applicable physical and chemical laws. It is the simplest hypothesis for carbon cycle models, and it replicates IPCC's natural carbon cycle.

Harde and Salby (2021) show how carbon isotope data confirms this hypothesis is valid for carbon dioxide flows out of the atmosphere,

> "The exponential decline of anomalous $^{14}CO_2$ establishes that absorption of CO_2 is determined, not by extraneous reservoirs of carbon, but autonomously by the atmosphere. Specifically, the rate at which CO_2 is absorbed from the atmosphere is directly proportional to the instantaneous abundance of CO_2 in the atmosphere."

This statement supports hypothesis (2). Systems models must calculate outflows as functions of their levels. That the physics model replicates IPCC's natural carbon cycle shows there is no need to talk about uptakes. "Uptakes" cannot form a systems model because "uptakes" are not functions of their levels.

The physics model allows external processes to change reservoir levels only by changing the inflows, outflows, or e-times. The physics model *includes all effects of external processes* (chemical, biological, etc.) on the level of carbon in a reservoir because IPCC's natural carbon

cycle data include these effects.

Equation (5) shows how the level moves toward its balance level with a speed set by the e-time. When the level equals its balance level, outflow will equal inflow. At the balance level, constant inflow sets a constant level. Carbon will not accumulate in the reservoir.

The balance level (4) shows that neither human nor natural emissions accumulate in the atmosphere beyond their balance level. Constant inflows create constant outflows when the levels are at their balance levels.

4.3 Physics carbon-cycle model

All the definitions and properties of the physics model for one reservoir apply to the physics model for multiple reservoirs.

IPCC (2013) carbon cycle has four key carbon reservoirs, e.g., land, atmosphere, surface ocean, and deep ocean. We apply the physics model to each reservoir and each outflow node. The "level" of each reservoir is the mass of carbon in each reservoir.

The physics model is not a static mass balance, or a statistical curve fit to data. It is a dynamic flow model that accurately computes the evolution of levels and flows as functions of time, based on a given set of initial conditions, which define model outcomes. It may be the first fully functional mathematical model of IPCC's carbon cycle. It follows the numerical mathematics methods of Berry (1967, 1969) and Berry and Reinhardt (1974a, b, c, d) to calculate cloud droplet growth by stochastic collection.

Fig. # 7 shows the physics carbon cycle model with IPCC's four reservoirs and six outflows, where the arrows are all positive numbers. The origin of each arrow is a "node."

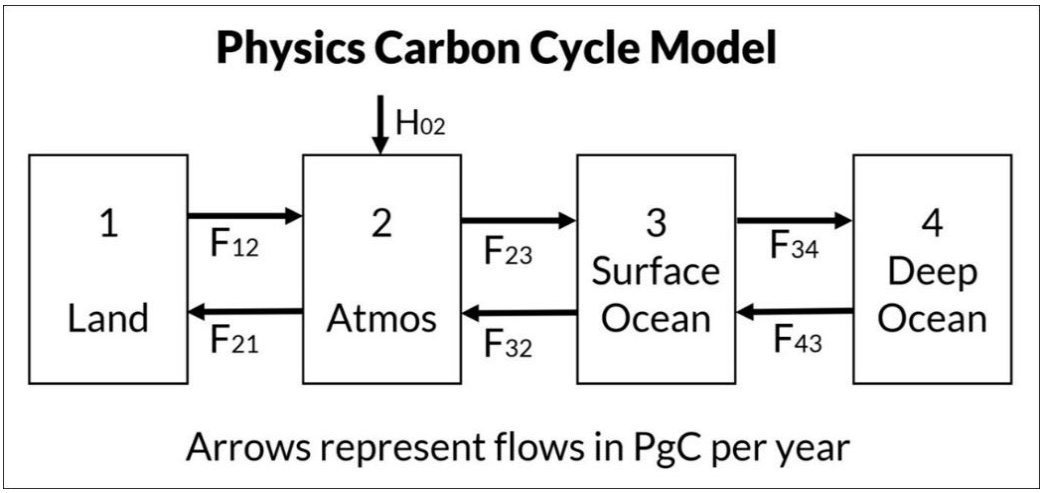

Figure 7. The physics carbon cycle model for IPCC's carbon cycles.

Define the Levels,

L_1 = level of carbon in the land

L_2 = level of carbon in the atmosphere

L_3 = level of carbon in the surface ocean

L_4 = level of carbon in the deep ocean

Define the individual flows out of the six nodes,

F_{12} = flow from land to atmosphere

F_{21} = flow from atmosphere to land

F_{23} = flow from atmosphere to surface ocean

F_{32} = flow from surface ocean to atmosphere

F_{34} = flow from surface ocean to deep ocean

F_{43} = flow from deep ocean to surface ocean

Define other variables,

t = time in years

H_{02} = human carbon flow to atmosphere

H_{12} = land carbon flow to atmosphere

Using (2), the flows out of the six nodes are,

$$\begin{aligned} F_{12} &= L_1 / T_{12} \\ F_{21} &= L_2 / T_{21} \\ F_{23} &= L_2 / T_{23} \\ F_{32} &= L_3 / T_{32} \\ F_{34} &= L_3 / T_{34} \\ F_{43} &= L_4 / T_{43} \end{aligned} \tag{9a}$$

The same equations in terms of e-times are,

$$\begin{aligned} T_{12} &= L_1 / F_{12} \\ T_{21} &= L_2 / F_{21} \\ T_{23} &= L_2 / F_{23} \\ T_{32} &= L_3 / F_{32} \\ T_{34} &= L_3 / F_{34} \\ T_{43} &= L_4 / F_{43} \end{aligned} \tag{9b}$$

Using (1) and (9), the rate equations for each reservoir are,

$$\begin{aligned} dL_1 / dt &= F_{21} - F_{12} - H_{12} \\ dL_2 / dt &= F_{12} - F_{21} + F_{32} - F_{23} + H_{02} + H_{12} \\ dL_3 / dt &= F_{23} - F_{32} + F_{43} - F_{34} \\ dL_4 / dt &= F_{34} - F_{43} \end{aligned} \tag{10}$$

The physics model uses (9) and (10) to calculate the natural and the human carbon cycles.

4.4 RC Network analogy

Fig. # 8 shows the RC network analogy to the physics carbon cycle model shown in Fig. # 7 (suggested by Happer and van Wijngaarden, 2020).

The four capacitors simulate the four reservoirs. The capacitor charge simulates the carbon levels. Charge is proportional to voltage, so voltage represents charge and carbon level.

The resistors simulate the "resistance to flow" between the reservoirs. Reservoir level differences drive flow. Voltage differentials drive the current between the capacitors, and current, which is flow of charge, simulates carbon flow.

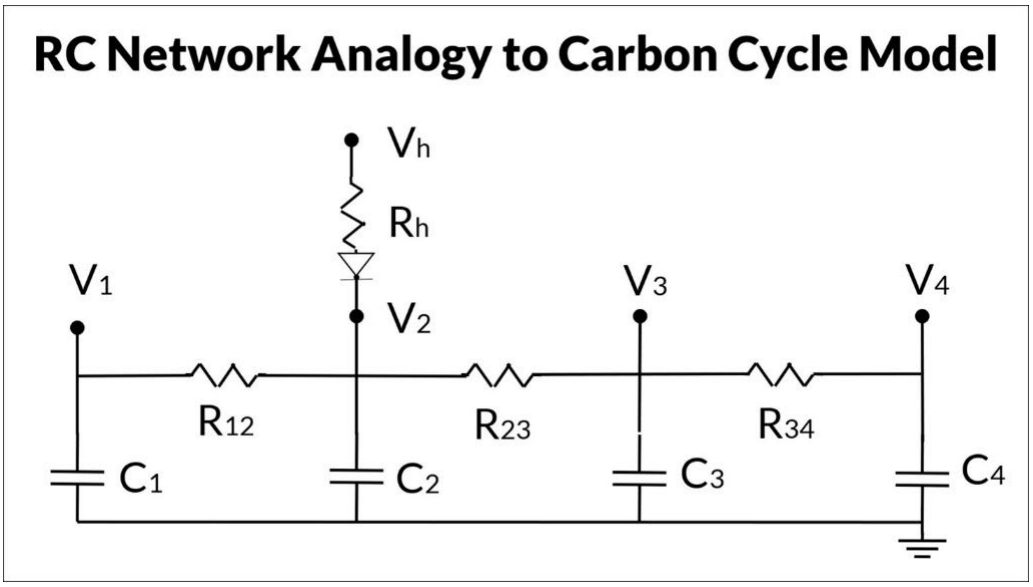

Figure 8. RC Network analogy to Physics carbon cycle model.

Fig. # 8 shows above V_2 a diode, resistor R_h, and voltage V_h, to simulate the inflow of human carbon into the atmosphere. The diode prevents reverse flow. To simulate human emissions, set $(V_h - V_2) / R_h$. To simulate the land-use effect shown in Fig. # 10, set $(V_1 - V_2) / R_{12}$.

The following derivations show how electrical circuit theory uses the physics model hypothesis (2).

The physics model defines the ends of each resistor as "nodes." Equation (11) shows how the outflow hypothesis (2) is the same as electrical circuit theory,

$$Outflow = L / T_e = I = V / R = Q / RC \tag{11}$$

where,

I = current outflow

V = voltage on the capacitor

R = resistance to outflow

Q = charge on the capacitor

C = capacitance

In electrical terms, Ohm's law requires the net flow between nodes to be,

$$Net\_F_{jk} = (V_j - V_k) / R_{jk} \quad (12a)$$

$$Net\_F_{jk} = F_{jk} - F_{kj} \quad (12b)$$

Therefore, the outflow from each node is,

$$F_{jk} = V_j / R_{jk} \quad (13)$$

where the resistance between nodes j and k is bidirectional,

$$R_{jk} = R_{kj} \quad (14)$$

The charge on a capacitor is the analog of the carbon level, L, so

$$V_j = L_j / C_j \quad (15)$$

Substituting (15) into (13), the flow out of each node is,

$$F_{jk} = L_j / R_{jk} C_j \quad (16)$$

Comparing (16) to (9) shows the capacitor analogy of T_e is,

$$T_{jk} = R_{jk} C_j \quad (17)$$

Therefore, the nodal flows for the capacitor analogy are the same as the nodal flows for the physics model (9) when (17) replaces the T_{jk} in (9).

At equilibrium, all V_j are equal. Therefore, (15) means,

$$L_j / C_j = L_k / C_k \quad (18)$$

In an electrical RC circuit, the time constant "*Tau*" is,

$$Tau \text{ (seconds)} = C \text{ (Farads)} * R \text{ (Ohms)} \quad (19)$$

The capacitor analogy uses the same equations and data as the physics carbon cycle model. Therefore, their results will be identical. Perhaps students can build a capacitor model.

4.5 Method of calculation

Set the flows in (9a) to equal IPCC's equilibrium flows shown in Fig. # 2 (in PgC/Year),

$$\begin{aligned} F_{12} &= L_1 / T_{12} = 108.0 \\ F_{21} &= L_2 / T_{21} = 108.0 \\ F_{23} &= L_2 / T_{23} = 60.4 \\ F_{32} &= L_3 / T_{32} = 60.4 \\ F_{34} &= L_3 / T_{34} = 102.0 \\ F_{43} &= L_4 / T_{43} = 102.0 \end{aligned} \quad (20)$$

Set the levels to equal IPCC's equilibrium levels shown in Fig. # 2 (in PgC),

$$\begin{aligned} L_1 &= 2500 \\ L_2 &= 589 \\ L_3 &= 900 \\ L_4 &= 37{,}100 \end{aligned} \quad (21)$$

Use (9b) to calculate the nodal e-times and use (17) to equate to RC e-times (in Years),

$$\begin{aligned} T_{12} &= 2500 / 108 = 23.1481 = R_{12}\, C_1 \\ T_{21} &= 589 / 108 = 5.4537 = R_{12}\, C_2 \\ T_{23} &= 589 / 60.4 = 9.752 = R_{23}\, C_2 \\ T_{32} &= 900 / 60.4 = 14.9007 = R_{23}\, C_3 \\ T_{34} &= 900 / 102 = 8.8235 = R_{34}\, C_3 \\ T_{43} &= 37100 / 102 \quad = 363.7255 = R_{34}\, C_4 \\ T_{43} &= 37100 / 102 \quad = 363.7255 = R_{34}\, C_4 \end{aligned} \tag{22}$$

The extended decimal places in (22) are not physically relevant. These decimal places are relevant only to those who wish to check the carbon cycle calculations.

Equation (22) shows the atmosphere has two outflows and two e-times, T_{21} = 5.4 years for flow to land and T_{23} = 9.8 years for flow to the surface ocean. The outflows (2) add up,

$$Outflow = L\,(1 / T_{21} + 1 / T_{23}) = L / 3.5 \tag{23a}$$

We can calculate the same e-time using the total outflow from the atmosphere in Fig. # 2, or

$$Te = L / Outflow = 589 / 168.4 = 3.5 \text{ years} \tag{23b}$$

Therefore, the overall e-time for atmospheric CO_2 for the IPCC (2013) natural carbon cycle is 3.5 years which is less than IPCC's estimate of about 4 years. Harde and Salby (2021) show this is a valid approximate e-time for atmospheric $^{12}CO_2$.

Happer and van Wijngaarden (2020) used a relaxation method to perform independent calculations using the equations in this paper and same input data. Their results matched the numerical calculations of this paper to two decimal places, which, of course, exceeds the accuracy of the data.

The numerical calculations use annual time steps,

1. Set initial levels.
2. Calculate nodal flows using (22) and (9a).
3. Calculate level rates of change using (10).
4. Multiply level rates of change by time step to get changes of levels.
5. Add changes of levels to the levels to get new levels.
6. Repeat for next time step.

The physics model allows the e-times to change with time. However, all calculations in this paper keep the (22) and (9a) e-times constant. Ballantyne et al. (2012) found "there is no empirical evidence" that the ability of the land and oceans to absorb atmospheric CO_2 "has started to diminish on the global scale."

Data and Calculations Availability gives links to download the Excel file that includes all the data, numerical calculations, and plots used in this paper.

5. Physics model results

5.1 The physics human carbon cycle

The physics carbon cycle model correctly simulates IPCC's natural carbon cycle. Since human carbon must obey the same physics as natural carbon, the physics carbon cycle model computes the human carbon cycle using the e-times found in IPCC's natural carbon cycle (22).

These calculations use Gilfillan et al. (2020) data for human carbon emissions from 1750 to 2017, and this paper's estimates of human emissions for 2018 and 2019.

The physics carbon cycle model hypothesis (2) allows independent calculations of natural and human carbon cycles. The sum of the human and natural carbon-cycles equals the total carbon cycle. Therefore, the physics model calculates the human carbon cycle independently.

The calculation begins with the human carbon levels at zero in 1750. Each numerical time step inserts human carbon and allows carbon to flow between reservoirs.

Fig. # 9 shows how the reservoir levels change with time for human carbon. The purple dashed line shows the cumulative human carbon inserted into the fast carbon cycle since 1750.

The solid bold line shows the measured atmospheric carbon level *above* 594 PgC (280 ppmv) using Etheridge et al. (1996) for Antarctic ice and firn data before 1960 and Keeling et al. (2001) for measured data thereafter.

Both natural and human carbon contribute to the measured carbon level, but the IPCC assumes human carbon caused all or most CO_2 increase above 280 ppmv. However, cumulative human carbon is greater than measured total carbon only after about 1955. Before 1955, it looks like natural carbon may have caused part of the increase.

Furthermore, the argument – that because cumulative human carbon exceeds the measured carbon level proves human carbon caused all the increase – is not valid because cumulative *natural* carbon is much greater than cumulative *human* carbon, and if natural carbon did not flow rapidly out of the atmosphere the measured carbon level would be much greater than the measured carbon level today. So, that argument omits proper account of the flow of human carbon out of the atmosphere.

Another invalid argument used to support the IPCC basic assumption is because nature absorbs human carbon from the atmosphere, therefore nature cannot add carbon to the atmosphere. This argument neglects the physics model *superposition principle* that explains why the natural carbon cycle is independent of the human carbon cycle.

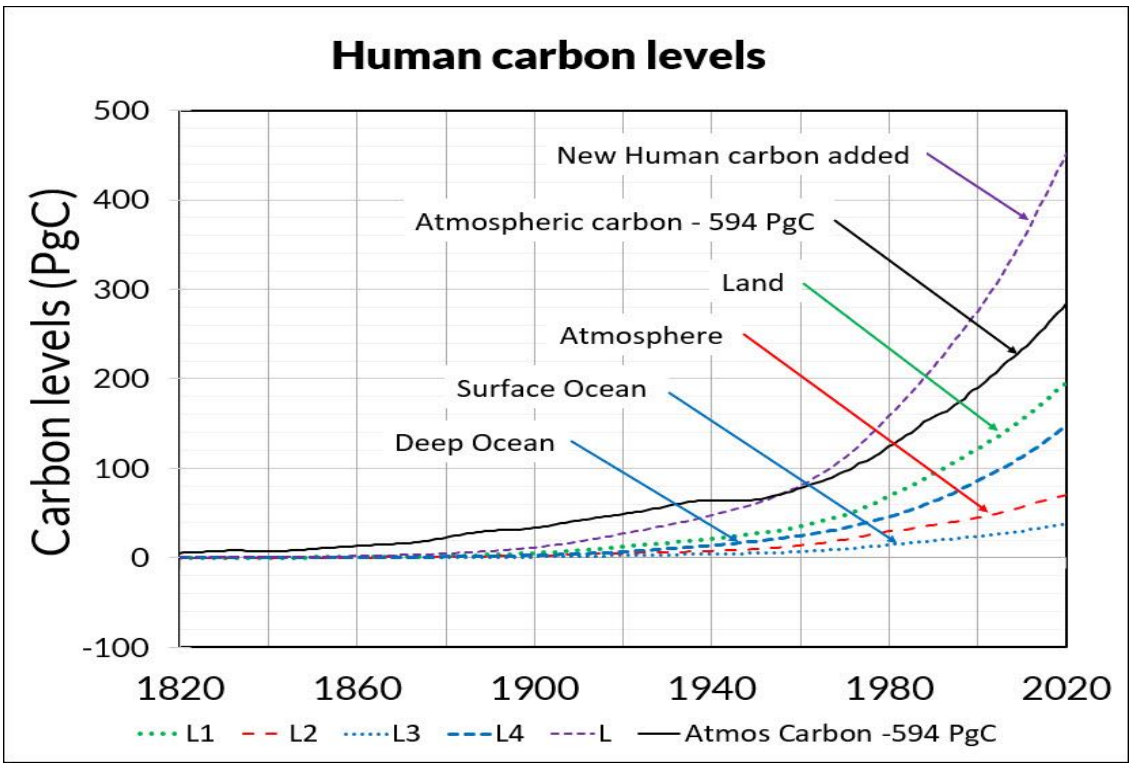

Figure 9. The dashed lines show the calculated human carbon levels for each reservoir.

Table 1 shows accumulated "Net Land Use Change" is 180 PgC over 260 years, for an average of 0.6923 PgC per year. These calculations use a larger land to atmosphere flow of 1.0 PgC per year beginning in 1750.

Net land use change of 1.0 PgC per year has almost no effect on atmospheric CO_2 because this carbon flows rapidly from the atmosphere to the deep ocean, and it adds no carbon to the carbon cycle.

Fig. # 10 shows the levels for land carbon.

Fig. # 11 shows the total effect (by adding them up) of human carbon and land carbon. Although calculated separately, this combination equals the sum of its two components.

Fig. # 9 and 11 show the total human carbon added to the carbon cycle is well below the measured atmospheric carbon before 1950, proving that nature has played a major part in the increase of atmospheric CO_2 after 1750, according to IPCC's data.

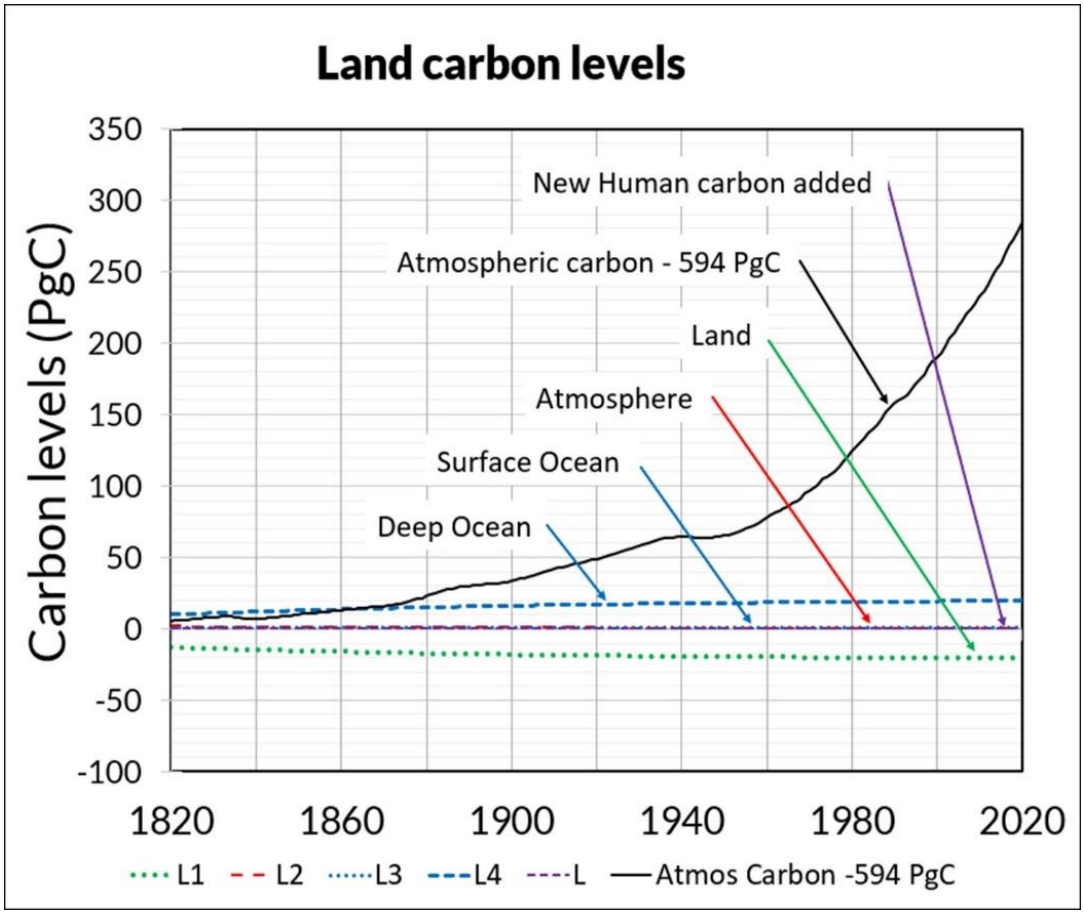

Figure 10. Same as Figure 9 but for Land carbon. Calculations set the land use change carbon flow from land to atmosphere at 1.0 PgC per year.

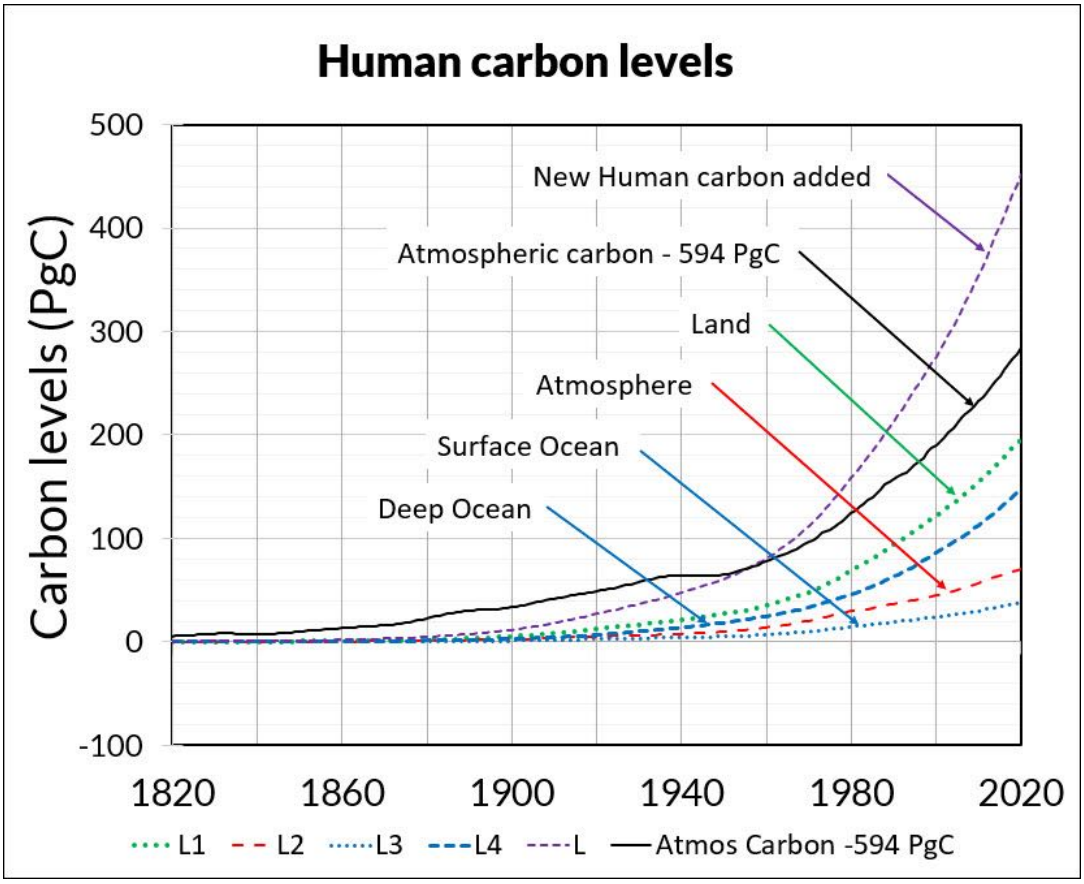

Figure 11. Same as Figure 9 but for all human carbon.

Tables 2, 3, and 4 show the calculated levels of human, land, and total carbon for selected years. All three calculations are independent, yet the independent values for human carbon in Table 2 and land carbon in Table 3, when summed, equal the total values for human carbon in Table 4. The levels for 2100 assume emissions of human carbon stop at the end of 2020.

Table 2. Calculated values of human carbon for selected years.

Year	L_1	L_2	L_3	L_4	*Total*	L_2 *ppmv*
1820	0.19	0.08	0.04	0.11	0.21	0.02
1900	5.27	2.49	1.18	2.84	11.78	1.17
2000	121.86	44.66	24.03	85.50	276.05	21.07
2010	154.35	57.05	29.98	112.77	354.14	26.91
2020	196.10	70.18	37.95	147.32	451.55	33.11
2100	110.77	21.31	17.14	302.33	451.55	10.05

Table 3. Calculated values of land carbon for selected years.

Year	L_1	L_2	L_3	L_4	*Total*	L_2 *ppmv*
1820	-13.02	1.89	1.27	9.87	0.00	1.06
1900	-18.00	1.00	0.83	16.17	0.00	0.47
2000	-20.45	0.56	0.62	19.26	0.00	0.27
2010	-20.58	0.54	0.61	19.43	0.00	0.25
2020	-20.69	0.52	0.60	19.58	0.00	0.24
2100	-21.29	0.41	0.55	20.33	0.00	0.19

Table 4. Calculated values of human carbon and land carbon for selected years.

Year	L_1	L_2	*L3*	L_4	*Total*	L_2 *ppmv*
1820	-12.82	1.97	1.31	9.98	0.21	1.08
1900	-12.73	3.49	2.01	19.01	11.78	1.64
2000	101.41	45.22	24.65	104.76	276.05	21.33
2010	133.77	57.59	30.58	132.20	354.14	27.16
2020	175.41	70.70	38.55	166.90	451.55	33.35
2100	89.48	21.72	17.69	322.67	451.55	10.25

Table 3 shows the flow of 1.0 PgC of land carbon to the atmosphere flows rapidly to the deep ocean, leaving little in the atmosphere, and it adds no new carbon to the fast carbon cycle.
Fig. # 12, 13, and 14 show the calculated level percentages for human carbon in Table 4 for the years 2010, 2020, and 2100, respectively.

Fig. # 12 shows in 2010, 16% of human carbon is in the atmosphere, 38% is in the land, and 37% is in the deep ocean. The percentages are significantly different than IPCC's (2013) human carbon cycle shown in Fig. # 5.

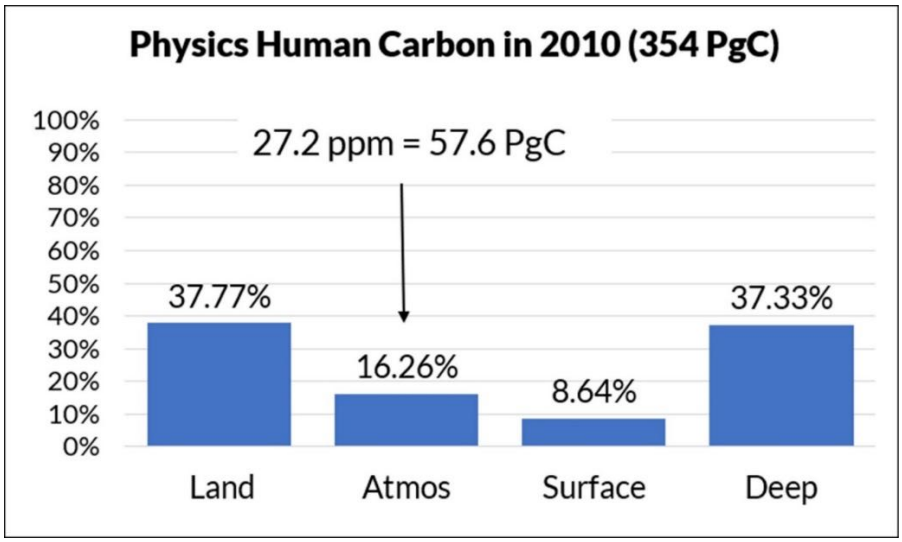

Figure 12. Physics model calculation of human carbon percentages in 2010.

Fig. # 13 for 2020 shows the percentage of human carbon in the atmosphere deep ocean have decreased while the percentage in the land has increased, while the total carbon has increased from 354 PgC in 2010 to 452 PgC in 2020. The 33 ppmv of human carbon in the atmosphere means nature added about 100 ppmv to the 280 ppmv in 1750 to get 413 ppmv.

Fig. # 14 for 2100 shows how fast human carbon in the atmosphere would flow to the deep ocean if all human emissions were to stop in 2020. The level percentages move toward IPCC's natural carbon cycle percentages shown in Fig. # 3.

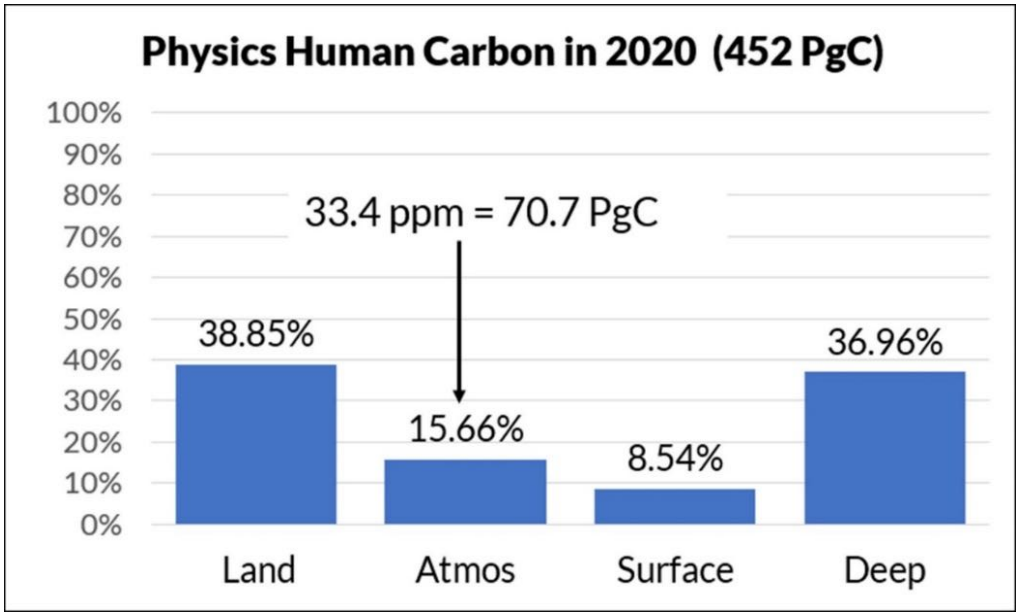

Figure 13. Physics model calculation of human carbon percentages in 2020.

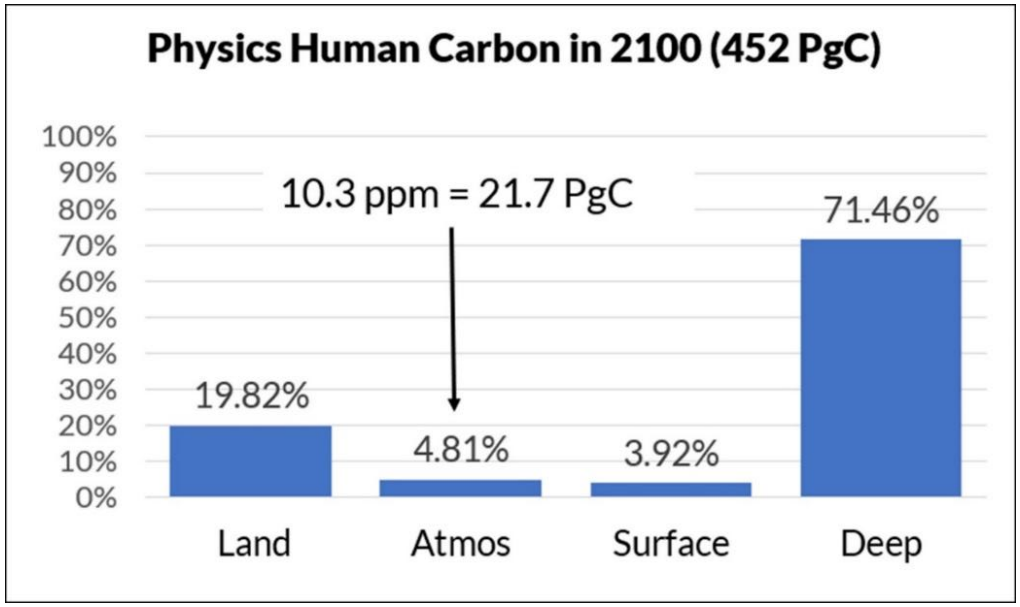

Figure 14. Physics model calculation of human carbon percentages in 2100 assuming all human carbon emissions were to stop in 2020.

Fig. # 15 shows the time plot of human carbon in the atmosphere. It peaks at 33 ppmv in 2020 and this level falls rapidly if human carbon emissions were to stop at the end of 2020, showing human carbon flows rapidly from the atmosphere.

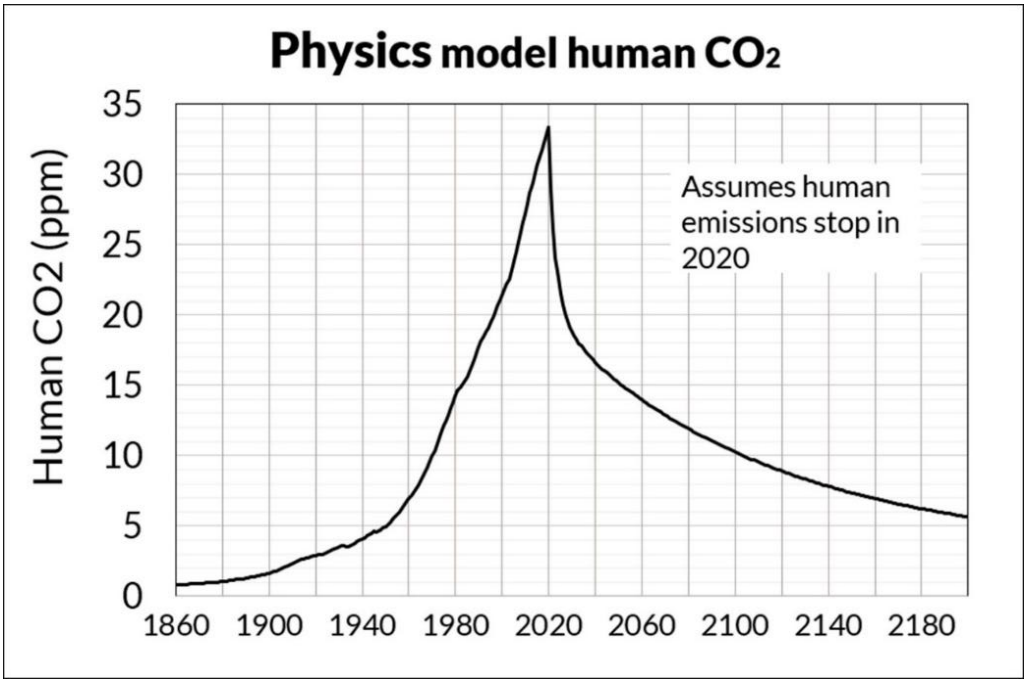

Figure 15. Physics model calculation of the human CO2 level from 1900 to 2100 assuming all human CO2 emissions stop in 2020.

5.2 Values at IPCC's extreme error bounds

IPCC (2013, p. 471) Fig. # 6.1 legend says,

> "Uncertainties are reported as 90% confidence intervals. Individual gross fluxes and their changes since the beginning of the Industrial Era have typical uncertainties of more than 20%, while their differences are determined from independent measurements with a much higher accuracy."

To find the extreme values for the physics human carbon cycle, adjust the e-times in (22) to their 20% borders that maximize and minimize the human CO_2 level. The deep ocean e-time has little effect on the level of atmospheric CO_2.

These e-times (years) maximize atmospheric CO_2 from 33 ppmv to 48 ppmv,

$$\begin{aligned} T_{12} &= (2500 / 108 = 23.1481) * 0.67 \quad = 15.43 \\ T_{21} &= (589 / 108 = 5.4537) * 1.20 \quad = 6.544 \\ T_{23} &= (589 / 60.4 = 9.752) * 1.20 \quad = 11.70 \\ T_{32} &= (900 / 60.4 = 14.9007) * 0.67 \quad = 9.98 \end{aligned} \tag{24}$$

These e-times (years) minimize atmospheric CO_2 from 33 ppmv to 24 ppmv,

$$\begin{aligned} T_{12} &= (2500 / 108 = 23.1481) * 1.49 \quad = 34.49 \\ T_{21} &= (589 / 108 = 5.4537) * 0.80 \quad = 4.36 \\ T_{23} &= (589 / 60.4 = 9.752) * 0.80 \quad = 7.80 \\ T_{32} &= (900 / 60.4 = 14.9007) * 1.49 \quad = 22.20 \end{aligned} \tag{25}$$

In summary, IPCC's natural carbon cycle data with 20% error bounds show human CO_2 has increased atmospheric CO_2 by 33 ppmv with a range of 24 ppmv to 48 ppmv, as of 2020. The

probability of occurrence of the extremes of 24 ppmv and 48 ppmv is small because all e-times were set to their limits.

5.3 Physics model carbon cycle pulse decay

Fig. # 16 shows how a single pulse of carbon in the atmosphere will flow to the other reservoirs in 100 years using IPCC's e-times for natural carbon.

After 10 years, only 15% of the carbon pulse is in the atmosphere. After 100 years, 5% of the carbon pulse is in the atmosphere, 28% is in the land, and 64% is in the deep ocean. This approximates the distribution of human carbon in Fig. # 13 for 2020.

The land reservoir is the fastest to accept carbon from the atmosphere. But after 10 years, the atmosphere level decreased so much that the land reservoir sends its carbon back to the atmosphere and thereby to the deep ocean. The land reservoir controls the initial decay of atmospheric carbon, but the deep ocean controls the final decay.

The atmosphere carbon does not have a constant e-time even though all six flows have constant e-times. The presence of multiple flow paths can make constant individual e-times appear to be variable e-times.

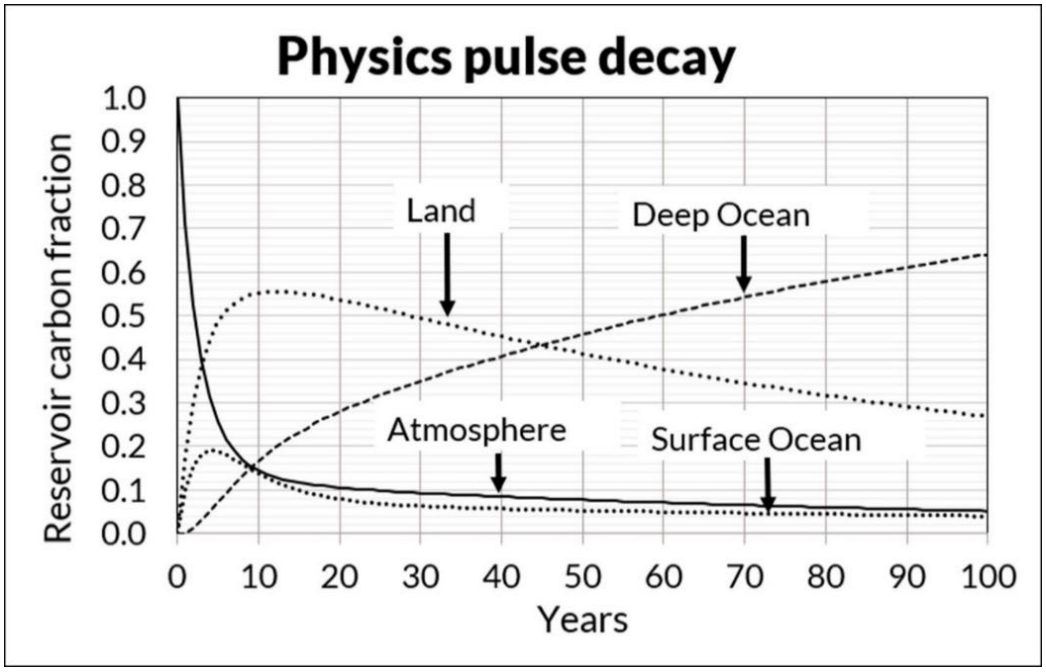

Figure 16. The physics model calculation of how a pulse of carbon in the atmosphere moves through the reservoirs.

5.4 The physics model vs the Bern model

Siegenthaler and Joos (1992) created the original Bern model. They used ^{14}C data to trace the flow of $^{12}CO_2$ from the atmosphere to the upper ocean and to the deep and interior oceans. However, they assumed human CO_2 caused all the increase to analyze their data.

The Bern model is based on IPCC's assumption that the human CO_2 causes all the CO_2 increase. This assumption requires the human CO_2 e-time to be much larger than ten years. Therefore, the Bern model prediction is wrong even though its math may be correct.

Joos (2002) calculated a Green's function for the Bern model. Then he assumed human carbon enters the atmosphere in sequential annual pulses and the carbon in each pulse flows out of the atmosphere independently according to his Green's functions.

To resolve the conflict with data that show e-time is less than 10 years, Joos assumed human

CO_2 (but not natural CO_2) decreases buffer capacity, which is incorrect because it has added less than one percent to the carbon in the natural carbon cycle.

To deconstruct Joos' integral equation, let inflow occur only in the year when *t*' equals zero. Then the integral disappears, and the Bern model becomes a level equation that depends on its starting level, L_o,

$$L(t) = L_0 \left[A_0 + A_1 \exp(-t / T_1) + A_2 \exp(-t / T_2) + A_3 \exp(-t / T_3) \right] \tag{26}$$

where,

t = time in years

L_0 = level of atmospheric CO_2 in year t = 0

$L(t)$ = level of atmospheric CO_2 in year t

Joos derived these TAR (Third Assessment Report) standard values for the Bern coefficients,

$$\begin{aligned} A_0 &= 0.152 \\ A_1 &= 0.253 \\ A_2 &= 0.279 \\ A_3 &= 0.316 \\ T_1 &= 171 \text{ years} \\ T_2 &= 18.0 \text{ years} \\ T_3 &= 2.57 \text{ years} \end{aligned} \tag{27}$$

where,

$$A_0 + A_1 + A_2 + A_3 = 1.000 \tag{28}$$

In (26), set t equal to infinity to get,

$$L = \mathrm{A}_0 L_0 = 0.152 L_0 \tag{29}$$

Equation (29), or the first term in (26) with values (27), predicts 15.2% of each one-year inflow will remain in the atmosphere forever.

For comparison, the (26) Green's function values for the physics carbon cycle (10) with the values of (20), (21), and (22) are,

$$\begin{aligned} A_0 &= 0.014 \\ A_1 &= 0.758 \\ A_2 &= 0.122 \\ A_3 &= 0.106 \\ T_1 &= 94.9 \text{ years} \\ T_2 &= 6.67 \text{ years} \\ T_3 &= 2.84 \text{ years} \end{aligned} \tag{30}$$

The physics model A_0 in (30) is one-tenth of the Bern model A_0 in (27). The A_0 in the Green's

functions are the equilibrium percentages for atmospheric CO_2 as shown in Fig. # 17. Thus, the physics model predicts only 1.4% of human carbon emissions will remain in the atmosphere forever while the Bern model predicts 15.2%.

Joos et al. (2013) compared the response of atmosphere-ocean models to a pulse emission of human CO_2 and found all the models predicted a "substantial fraction" of pulse would remain in the atmosphere and ocean for millennia. However, all models they compared assumed human carbon caused all the CO_2 increase.

Fig. # 17 compares the physics model (9) and (10) with the Bern model (27). The solid lines in Fig. # 16 and 17 are the same line for the physics pulse decay.

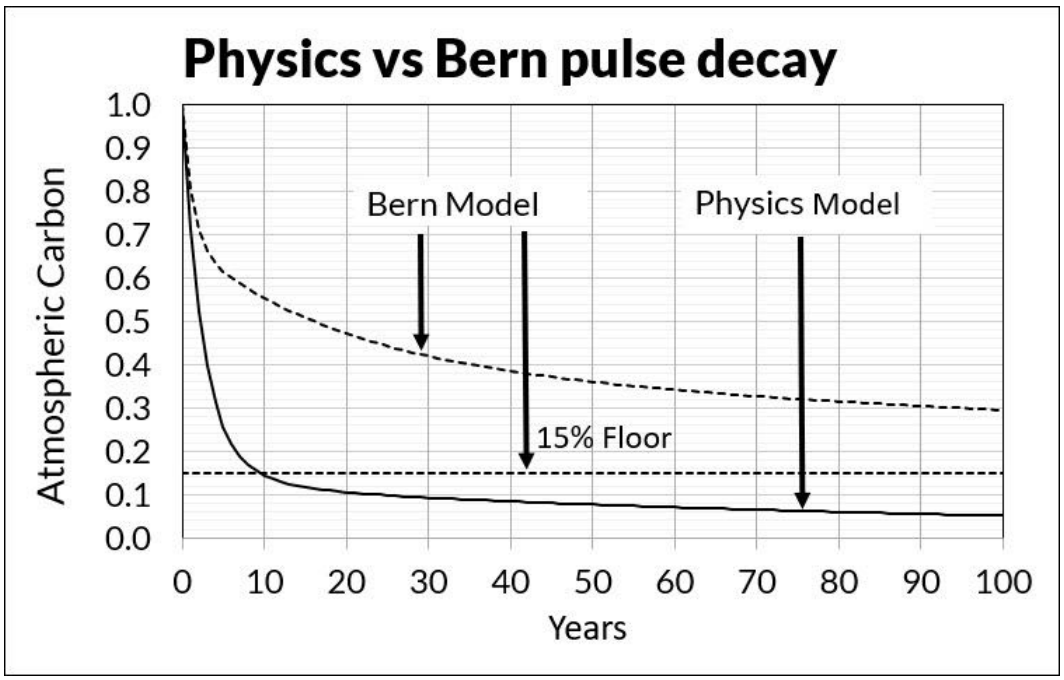

Figure 17. Pulse decay calculations by the physics model using (9) and (10), and the Bern model using (26).

In the Bern model, human CO_2 decays to 55% in 10 years and to 30% in 100 years and will never get below 15% because the Bern model's follows invalid assumption.

In the physics model, human CO_2 decays to 15% in 10 years and to 5% in 100 years and will never get below 1.4% because the physics model follows IPCC's natural carbon cycle data.

6. Discussion

6.1 $\delta^{14}C$ data show the CO_2 increase is natural

The above-ground atomic bomb tests in the 1950s and 1960s almost doubled the $\delta^{14}C$ in the atmosphere. $\delta^{14}C$ is the fractionation, age-corrected deviation from the standard pre-industrial atmospheric ^{14}C concentration (Stuiver and Polach, 1977).

The bomb tests ended in 1963 but it took about seven years for the $^{14}CO_2$ to mix between the hemispheres and to move from the stratosphere to the troposphere. The ^{14}C data in both hemispheres were virtually identical after 1970 (Turnbull et al., 2017).

Hua et al. (2013) processed $\delta^{14}C$ data for both hemispheres from 1954 to 2010. Turnbull et al. (2017) processed $\delta^{14}C$ data for Wellington, New Zealand, from 1954 to 2014. Their ^{14}C data are in units of $\delta^{14}C$ per mil where the $\delta^{14}C$ lower bound of -1000 equals the zero ^{14}C level. The "natural" $\delta^{14}C$ balance level, defined by the average measured level before 1950, is zero.

The physics model is based on hypothesis (2) that Outflow equals Level divided by e-time. All

physics model curve fits use both an e-time and a balance level.

Fig. # 18 plots these data,

- $\delta^{14}C$ data (black solid line) and its curve fit after 1970 (black dashed line).
- ^{14}CR or ^{14}C data relative to the $\delta^{14}C$ value in 1970 (blue sawtooth line) and its curve fit.
- $^{12}CO_2$ data in ppmv (red sawtooth line).

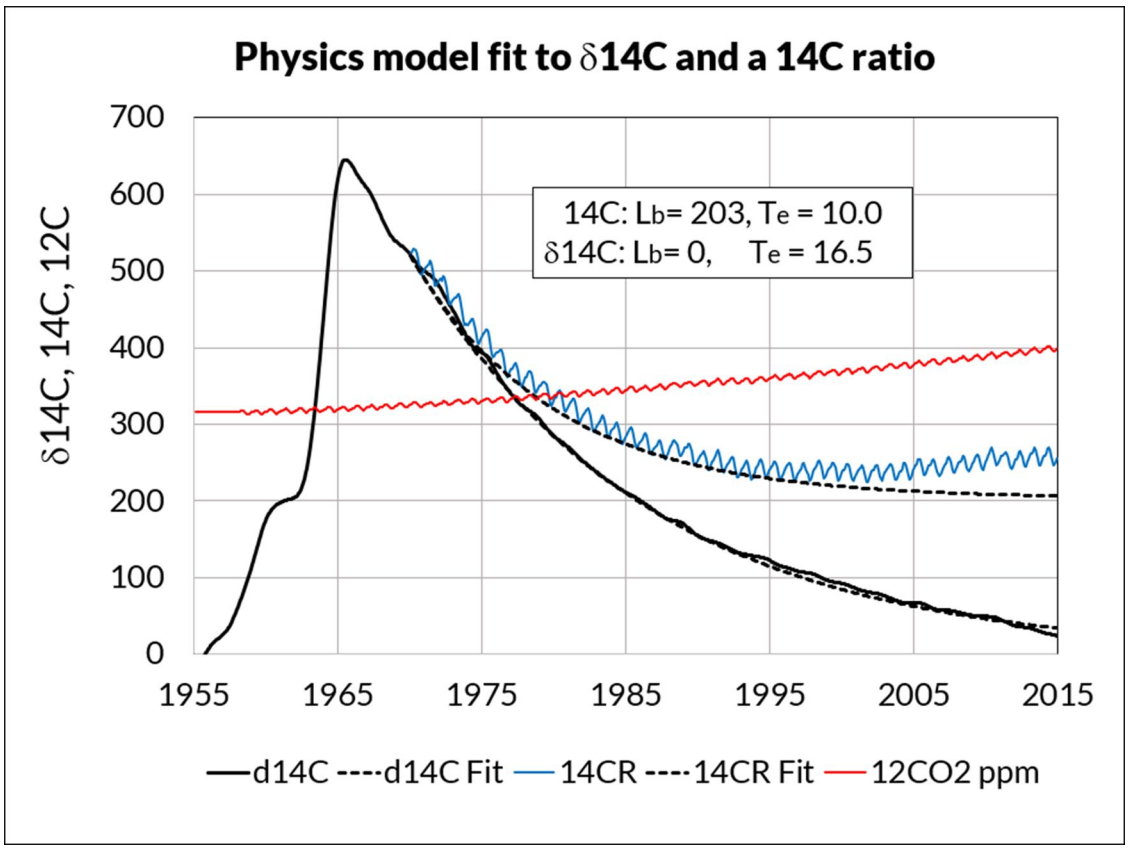

Figure 18. δ14C data (Turnbull et al., 2017, black line), the physics model fit to δ14C (black dashed line), 14CR (blue sawtooth line), physics model curve fit to 14CR (black dashed line), and 12CO2 ppmv (red line).

Equation (8) for a constant e-time fits the $\delta^{14}C$ data from 1970 to 2014 with a constant e-time of 16.5 years and a balance level of zero (Berry, 2019).

To plot ^{14}C on the scale of Fig. # 18, we define "^{14}CR" that will have the same e-time as ^{14}C.

To calculate ^{14}CR use,

$$^{14}CR = (\delta^{14}C + 1000)\ (^{12}CO_2 / {}^{12}CO_2(1970)) - 1000 \qquad (31)$$

Equation (8) fits ^{14}CR from 1970 to 1995 with e-time of 10.0 years and balance level of 203. Thereafter, ^{14}C is close to its balance level of 203, so it no longer follows its e-time curve.

The physics carbon cycle model has six different e-times. When a level is far from its balance level the level's own e-time dominates its return to its balance level and therefore is measurable. When a level approaches its balance level, other e-times control its path.

IPCC (2007, p. 948, Lifetime) explains why the "adjustment time" will equal the turnover time when the level is far from its balance level because it is unaffected by other reservoirs. However, "when several reservoirs are involved" (i.e., when it is near its balance level) then the adjustment time no longer equals the turnover time.

IPCC's "adjustment time" is not a physical parameter. Rather, it is IPCC's way to describe how

a level will approach its balance level in a multiple reservoir system.

Fig. # 18 is similar to Harde and Salby (2021, Figure 3) who also find the e-time for $^{14}CO_2$ is 10.0 years,

> "It operates with a single time scale, which reflects the collective absorption by all sinks of CO_2 at the Earth's surface. The long-term decline of anomalous $^{14}CO_2$ reveals an effective absorption time of about 10 years."

The $^{14}CO_2$ e-time of 10 years is an upper limit for the $^{12}CO_2$ e-time because the $^{14}CO_2$ isotope is heavier and slower (Van Langenhove, 1986).

The $\delta^{14}C$ curve is also significant because its return to its original balance level of zero even as ^{12}C has increased, means the dominant carbon flow into the atmosphere has its $\delta^{14}C$ equal to zero. This suggests the ocean, not human emissions, is the dominant source of the CO_2 increase after 1750.

Andrews (2020) criticisms of Harde (2019) and Berry (2019) are invalid because Andrews omits that the ^{14}C e-time of 10 years and the $\delta^{14}C$ return to zero show nature is the primary source of the CO_2 increase.

The physics model, using IPCC's natural carbon cycle data, calculates that human CO_2 adds only 33 ppmv to the atmosphere as of 2020.

However, Salby and Harde (2021) use short-term changes in ^{14}C between 1965 to 1970 to find the atmospheric CO_2 e-time is about 1 year rather than 3.5 years as used in the IPCC (2013) natural carbon cycle.

The physics model can simulate the Salby and Harde shorter e-time by reducing T_{21} from 5.45 to 1.56 years and T_{23} from 9.75 to 2.79 years (22), to get an overall CO_2 e-time of 1.0 years (23a). These revised e-times reduce the calculated human CO_2 increase from 33 ppmv to 10 ppmv as of 2020.

Quirk (2009) examined ^{13}C data and seasonal and hemispherical variations of CO_2, to find,

> "The constancy of seasonal variations in CO_2 and the lack of time delays between the hemispheres suggest that fossil fuel derived CO_2 is almost totally absorbed locally in the year it is emitted. This implies that natural variability of the climate is the prime cause of increasing CO_2, not the emissions of CO_2 from the use of fossil fuels."

6.2 How nature may have increased its CO_2 level

The physics model can show how nature may have increased its natural level of CO_2. To show how, we can apply the calculation method described in Section 4.5 by setting new e-times and calculating the result, through the recursive procedure, from 1750 to 2020.

For reference, Table 5 shows IPCC's natural carbon levels and Table 6 shows the e-times that keep IPCC's natural carbon equilibrium levels constant.

Table 5. IPCC's natural carbon cycle levels in PgC.

L_1	L_2	L_3	L_4
2500	589	900	37100

Table 6. Physics model e-times in PgC per year that keep IPCC's natural carbon levels constant.

T_{12}	T_{21}	T_{23}	T_{32}	T_{34}	T_{43}
23.15	5.45	9.75	14.90	8.82	363.73

Table 7 shows changes in T_{32} and T_{43} that would increase the natural CO_2 level by 100 ppmv.

Table 7. How changes in T32 and T43 would increase the natural CO2 level by 100 ppmv.

T_{32}	T_{43}	*Natural CO_2 level* (ppmv)	*Human CO_2 level*	*Simulation*
14.90	363.73	277.8	33.11	Equilibrium values
10.45	363.73	**377.9**	35.03	Desorption in surface ocean
14.90	**254.00**	**377.4**	33.54	Overturning of deep ocean

If T_{32} for the ^{12}C flow from the surface ocean to the atmosphere decreases from 14.90 to 10.45 PgC per year, the *natural* level of atmospheric CO_2 will increase by 100 ppmv, from 277.8 ppmv to 377.9 ppmv, simulating desorption of carbon in the surface ocean.

If T_{43} for the ^{12}C flow from the deep ocean to the surface ocean decreases from 363.73 to 254.00 PgC per year, the *natural* level of atmospheric CO_2 will increase by 100 ppmv, from 277.8 ppmv to 377.4 ppmv, simulating overturning of the deep ocean.

These e-time changes have insignificant effect on the calculated level of *human* CO_2 because the percent of human carbon in the ocean is still below its equilibrium levels.

Salby (2012, p. 253) uses data to derive an equation that shows how the rate of change of CO_2 level is a function of surface temperature *T*s. If all other things are constant, the rate of increase (dL_2 / dt) in the CO_2 level equals the rate of increase in the flow F_{32}. Then Salby's equation becomes,

$$dF_{32} = 3.5 \text{ (ppmv/year /K) } dTs \qquad (32)$$

The above reduction of T_{32} from 14.90 to 10.45 increases the flow F_{32} by 25.7 PgC per year, from 60.4 to 86.1 PgC per year.

Using (32), an increased flow F_{32} of 25.7 PgC per year, or 12.1 ppmv per year, would require a surface temperature increase of (12.1 / 3.5) = 3.5 C.

Salby shows how the increase in *Ts* since the Little Ice Age in 1650 explains the increase in the level of atmospheric CO_2 from 1750 to 2020.

Harde (2017) concluded that natural CO_2 causes most of the CO_2 increase above 280 ppmv,

> "These results indicate that almost all of the observed change of CO_2 during the Industrial Era followed, not from anthropogenic emission, but from changes of natural emission. The results are consistent with the observed lag of CO_2 changes behind temperature changes (Humlum et al., 2013; Salby, 2013), a signature of cause and effect."

Harde (2017, Figure 3) shows how the CO_2 level has changed with surface temperature. His equation (17) is his curve fit to these data.

Fig. # 19, calculated using Harde's equation (17) and his dates in his Fig. # 3, shows how the natural CO_2 level has increased with surface temperature.

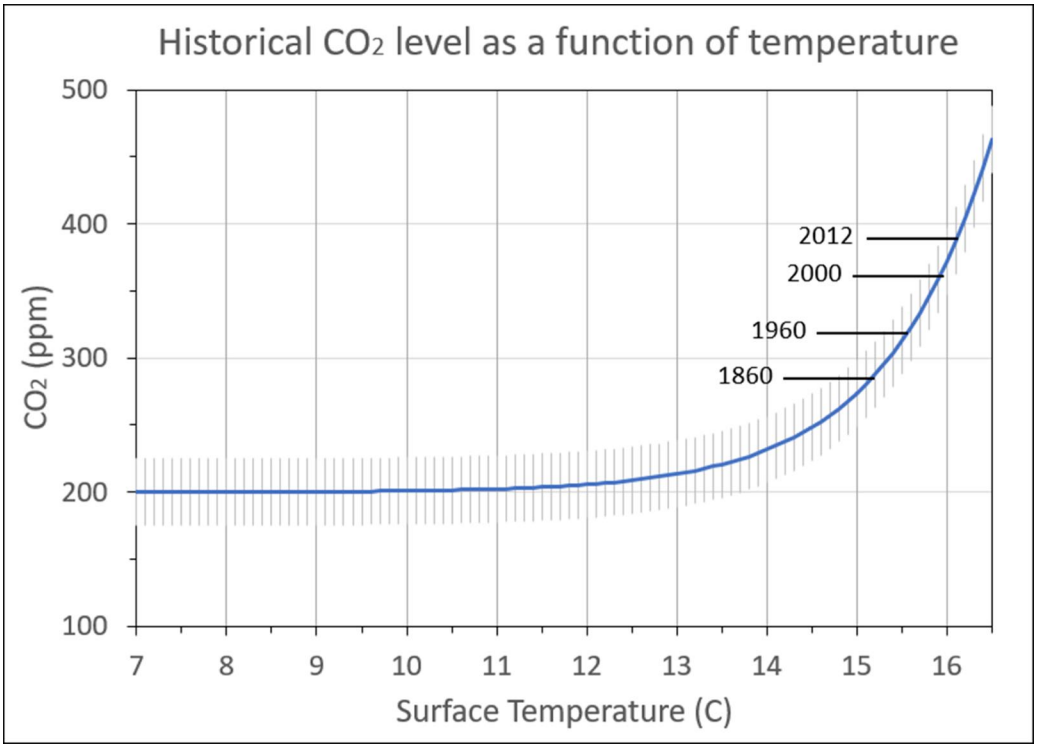

Figure 19. Harde (2017, Figure 3) curve fit by to CO2 and surface temperature data.

Kuo et al. (1990) uses time-series analysis to confirm that temperature and atmospheric carbon dioxide are significantly correlated and found that changes in atmospheric CO_2 lag temperature changes by five months.

Fischer et al. (1999) show the CO_2 increase in Antarctic ice cores increased occurred 600 ± 400 years after the warming of the last three deglaciations.

Caillon et al. (2003) show the CO_2 increase during the Antarctic Termination III occurred 800 ± 200 years after the Northern Hemisphere deglaciation.

Kouwenberg (2004) shows evidence that temperature controls the CO_2 level,

> "… temperature-driven changes in CO_2 flux between ocean surface waters and atmosphere may be invoked as a plausible mechanism to explain at least a substantial part of the reconstructed CO_2 variations over the last Millennium."

Rorsch et al. (2005) conclude the main cause of the CO_2 increase since 1750 is ocean outgassing.

MacRae (2008) found the rate of change of the CO_2 level (dL_2/dt) correlates with the surface temperature and thus atmospheric CO_2 changes lag atmospheric temperature changes by about nine months.

Humlum et al. (2013) show CO_2 increases do not correlate with human CO_2 emissions but consistently follow temperature increases by about 9 to 12 months. A correlation of zero between cause-effect data proves there is no observable cause-effect.

Salby (2013) shows how CO_2 follows changes in the integral of surface temperature.

Munshi (2015b) found there is no statistically significant correlation between the rate of human carbon emissions and the rate of change of global surface temperature even using time lags up to 20 years.

Quirk and Asten (2022) used CO_2 and 13C data from 1978 to 2017 to conclude that 50% of the CO_2 increase comes from the oceans and 50% comes from plants and fossil fuel emissions. If

fossil fuel and natural plant sources are about equal, then Quirk's results support the physics model predictions that about 25% of the increase comes from fossil fuel emissions.

Skrable et al. (2022) conclude from $d^{13}C$ and $\delta^{14}C$ data that the CO_2 increase after 1750 is due primarily to increasing net inputs of non-fossil CO_2 from the oceans due to temperature increases, not anthropogenic CO_2.

Courtney (2008) concludes that temperature can change carbon desorption from the oceans,

> "Qualitative consideration of the carbon cycle suggests the carbon cycle cannot be very sensitive to relatively small disturbances such as the present anthropogenic emissions of CO_2. However, the system could be quite sensitive to temperature. Indeed, the considerations suggest that the relatively large increase of CO_2 concentration in the atmosphere in the twentieth century is likely to have been caused by the increased mean temperature that preceded it. The main cause may be desorption from the oceans. The observed time lag of half a century is not surprising."
>
> "Assessment of this conclusion requires a quantitative model of the carbon cycle, but such a model cannot be constructed because the rate constants are not known for mechanisms operating in the carbon cycle."

Upon reviewing this paper's Preprint, Courtney (2019) wrote:

> "Your "physics model" quantifies the anthropogenic and natural contributions to changes in atmospheric CO_2 concentration without need for knowledge of rate constants for individual mechanisms. This is a breakthrough in understanding which [others] and myself all failed to make."

6.3 COVID-19 CO_2 data suggest the increase is natural

The Global Monitoring Laboratory (2020a, b) asks if the 2020 emissions reductions due to COVID-19 lowered the CO_2 level. The following approximate numbers illustrate how to answer this question.

The physics carbon cycle model calculates that reducing human CO_2 emissions by 20% in 2020 would reduce the CO_2 level from 33.5 ppmv in 2020 to 33.1 ppmv in 2021, which is unmeasurable, especially when added to an increasing natural CO_2 level.

However, if human carbon caused all the CO_2 increase of 133 ppmv, as the IPCC assumes, then reducing human CO_2 emissions by 20% would reduce the CO_2 level from 414.0 ppmv in 2020 to 412.4 ppmv in 2021, according to the physics model. This reduction would be measurable.

The Global Monitoring Laboratory (2020b) data show the COVID-19 decrease in human CO_2 did not affect the annual increase in CO_2, which contradicts IPCC's assumption.

6.4 The physics model will help future research

The physics model is a basis for future carbon cycle research. It can include more levels for land, atmosphere, and oceans to better simulate the carbon cycle. It can be adapted into a professional software platform to use monthly time steps and other numerical methods to improve its calculations.

Conclusions

IPCC's basic climate change assumption is natural CO_2 stayed constant after 1750 as human CO_2 causes all (or dominates) the increase in atmospheric CO_2.

To support its basic assumption, the IPCC claims "The removal of human-emitted CO_2 from the atmosphere by natural processes will take a few hundred thousand years (high confidence)." But the human carbon e-time must equal the natural carbon e-time because human and natural CO_2 molecules are identical.

The $^{14}CO_2$ e-time, derived from $\delta^{14}C$ data, is 10.0 years, making the $^{12}CO_2$ e-time less than 10 years. The IPCC says the $^{12}CO_2$ e-time is about 4 years and IPCC's carbon cycle uses 3.5 years.

After the bomb tests, $\delta^{14}C$ returned to its original balance level of zero even as $^{12}CO_2$ increased. This suggests the added $^{12}CO_2$ came from a natural source.

The physics model calculates, deductively, the consequences of IPCC's natural carbon cycle data. The physics model first replicates IPCC's natural carbon cycle. Then, using the same IPCC data, it calculates that human carbon has added only 33 [24-48] ppmv to the atmosphere as of 2020, which means natural carbon has added 100 ppmv. The physics model further calculates if human CO_2 emissions had stopped at the end of 2020, the human CO_2 level of 33 ppmv would fall to 10 ppmv by 2100.

The IPCC argues the *absence* of ice-core data – that might show the natural CO_2 level was greater than 280 ppmv before 1750 – supports its basic assumption. But the physics model shows IPCC's basic assumption, and therefore IPCC's ice-core assumption, contradict IPCC's natural carbon cycle data.

Data and Calculations Availability
Berry, E.X: BerryCarbonCycle_2021. Excel file that includes all the data and numerical calculations described in this paper. https://edberry.com/wp-content/uploads/Climate/BerryCarbonCycle-Atmosphere-2021.xlsx

Open discussion for readers of this paper: https://edberry.com/blog/climate/climate-physics/the-impact-of-human-co2-on-atmospheric-co2/

Guest editor: Jan-Erik Solheim, Referee: Stein Storlie Bergsmark

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Conflicts of Interest:
The Author declares he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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