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CO_2 Air-Water Exchanges during Seasonal and Glacial Cycles

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Abstract

Based on the photosynthesis-respiration reversible reaction and the available statistics, we attempted to quantify the planetary seasonal exchanges of CO_2 between air and water from 1970 and compared them to the glacial ACC cycles as reported from ice cores archives. In 2020, the overall continental absorption (AW) was 8.0 giga tonnes of carbon per year (GtC/y). Emissions into the atmosphere (EW) resulting from mineral degradation by respiration and combustion of biomass and fossil hydrocarbons were 14.7 GtC/y, an increase of 2.4% per year since 1970. The continental surplus balance (−AW+EW) of 6.7 GtC/y was shared between the atmosphere, which received 5.1 GtC/y (GATM), and the ocean which absorbed 1.6 GtC/y. This ocean contribution (OC) corresponded to 17% of the 9.2 GtC/y emissions by combustion of fossil hydrocarbons (EFOS). Analysis of the ACC oscillations during 2020 in the northern hemisphere showed that the ocean absorbed 11.1 GtC during the warm season and outgassed 9.5 GtC during the cold season. Assuming proportionality to world population, the ACC, 414 parts per million (ppm) in 2021, would reach 584 ppm in 2080, still growing at a rate of 0.6% per year. The gain of atmospheric CO_2 (GATM) and its absorption by the ocean (OC) were expected to peak at 7.0 and 2.2 GtC/y, respectively, in 2080. This increase in the availability of atmospheric CO_2 resulted in improved yields of agriculture which more than compensated for the reduction by half of food-producing areas per capita from 1970.

Keywords

CO_2 Budget, Ocean, Photosynthesis, Respiration, Seasonal Cycles, Glacial Cycles, Agriculture Yields, Food Availability

1. Introduction

The earth's climate is mainly dependent on the solar flux received on the surface which results from its astronomical environment. However, noting that the atmospheric carbon dioxide content (ACC) has increased since the beginning of the industrial era with the combustion of fossil fuels, some authors believed that this gas could be the major responsible for a global warming supposedly underway. They recommended a drastic reduction in human activities burning fossil fuels. This reduction, which could have no effect on the climate, has the advantage of preparing mankind for the gradual depletion of economic fossil carbon resources, but is detrimental to populations trying to get out of poverty and ignores the geological trend of shortage of this vital gas.

Geochemical analyzes of ice cores from eastern Antarctica are presented [1] [2] as a proof that climate change is dependent on atmospheric greenhouse gases, especially CO_2. This deduction is at least imprudent since it is based on unverified assumptions and false assertions, no scientific proof of the role of CO_2 in rising temperatures having been provided. On the contrary, the elements of presumption begin to converge towards the more nuanced conviction that CO_2 and its greenhouse effect play a minor role in the evolution of the climate. Here after we presented the main ones.

1.1. Solar Activity and Climate

Milankovitch [3] showed that the cycles of the quaternary glaciations resulted from the variations of the precession of the equinoxes which is the conical rotation of the axis of rotation of the earth around an axis perpendicular to the plane of the ecliptic (main period of 26 thousand years - ky), the inclination of the axis of rotation of the earth with respect to the plane of the ecliptic (the obliquity) from 22.1˚ to 24.5˚ (main period of 41 ky), the eccentricity of the earth's orbit (main period 100 ky), and solar radiation. Carbon 14 had made it possible to trace the activity (especially magnetic) of the sun over the last centuries and millennia and to compare it with the climatic variations listed by historians.

The question of a new ice age beginning before 2000 was discussed in the 1970s with a net cooling between 1940 and 1950 and then between 1970 and 1980. Short-term forecasts cannot be based on the Milankovitch theory which gives no clear century-wide trend. However, some climatologists, e.g. [4] [5] [6] [7] [8], suggest the preponderance of solar activity on the climate during the last millennia. They found that climate change and solar activity measured by radiative energy impacting the earth's surface were strongly correlated and that the influence of CO_2 on climate is secondary.

Proponents of the warming effect of CO_2 reduced the effect of the sun solely to variations in its luminosity, neglecting both the movements of the center of the sun around the center of gravity of the solar system, which causes the earth-sun distance to vary, and the modulation of cloud cover by solar radiation. The solar contribution to the determinism of the climate was, according to their report, close to zero. Some of the cited authors [4] [5] [6] [7] [8] invited the scientific community adhering to the CO_2 emissions reduction policy to reconsider the influence of the sun on the climate.

1.2. Ice Archives

Ice cores drilled at the Russian Vostok Station in East Antarctica provided the first climate record covering the last 423 ky [1] [2]. They indicated a periodicity of glaciations of 80 to 110 ky and a strong correlation between the ACC and the isotopic temperatures. During this recent history of the earth, the weakest ACCs were observed during the glacial periods and the strongest during the interglacial periods. But this correlation did not specify which is the cause and the effect among the two variables involved, ACC and temperature.

By trying to superimpose the variations of the isotopic temperature indicator Δ40Ar and the ACC of the Vostok glacial archives, Caillon *et al.* [9] found that the best correlation (R2 = 0.88) is obtained for an 800 years lag, the temperatures preceding the ACC. This unambiguously indicated a causality link opposite to the one defended by the proponents of the warming effect of CO_2 and on which all their predictions were based. The authors we just cited believe that this lag corresponded to the time required by deep ocean for a new air-water equilibrium to be established after a climatic disturbance.

As Richet [10] pointed out, the theory that temperature is driven by ACC was also invalidated by other epistemological considerations:

1) The peaks of ACC lasted longer than those of temperature, which could not be the case if the latter were induced by the former, a disturbance always lasting less or as long as its effects.

2) Two close peaks of temperature corresponded to a single peak of ACC. This would not be possible if the former were induced by the latter.

3) The principle of climate control by the ACC was incapable of explaining the episodes of glaciation that our planet experienced periodically.

1.3. CO_2 in Air and Water

The ACC is expressed in part per million in volume (ppm), which is equivalent to 7.84 giga {10^9} tonnes of CO_2 ($GtCO_2$), as given by $m_{air}*M_{CO2}/M_{air}$, where m_{air} is the total mass of air of the atmosphere (5.15×10^6 Gt) [11], M_{CO2} is the molar mass of CO_2 (44 g/mol), and M_{air} is the molar mass of air (28.9 g/mol).

ACC has been stable at 260 ± 15 ppm since the end of the last glaciation 13 ky ago and began to increase sharply a century and a half ago to exceed 414 ppm in 2021. This growth of 2.5 ± 0.1 ppm/y is certainly linked to emissions by human activities burning fossil hydrocarbons, natural gas, oil, coal, and wildfires.

Carbon dioxide is the natural component of the atmosphere to which we owe all forms of life. Its combination with water during photosynthesis produces the plant biomass and oxygen necessary for heterotrophic life. It dissolves in water to which it has a strong affinity, according to Henry's law which notably provides that its solubility decreases when temperature increases. Gas-liquid exchanges of CO_2 are a powerful ACC regulating process, including for photosynthesis since this gas is admitted into the plant cell in dissolved form to be metabolized there. The ocean will tend to absorb atmospheric CO_2 in cold regions and seasons and releases it (outgasses) in warm regions and seasons. In seawater, it combines to form bicarbonate and carbonate ions, which is why the carbon reserves of the ocean are presented as dissolved inorganic carbon and measured in giga {10^9} tonnes of carbon (GtC) instead of $GtCO_2$, according to the mass ratio of $CO_2/C = 44/12 = 3.67$.

1.4. Towards a CO_2 Shortage

ACCs were much higher in the geological past, including during glacial episodes (Carboniferous-Permian). Then, they reached 7000 ppm (0.7%) in the Cambrian (−540 million years - My) and again 1800 ppm (0.18%) in the Jurassic (−200 My), *i.e.* between 4.3 and 17 times more than today. Life has developed since the Precambrian without being interrupted by catastrophic warming. The worrying decrease in ACC over the history of the earth is mainly due to the trapping of carbon at the bottom of the ocean, no escape of CO_2 to space being possible due to the density of this gas, the heaviest of the atmosphere.

Carbon is falling in the depths of the ocean in dissolved form by density currents and in particular form by gravity and currents. Insoluble carbonates precipitate and accumulate on the bottom with organic matter to constitute the main stocks of carbon of the planet crust as limestone rocks (100,000 Tera {10^{12}} tonnes of Carbon (TtC) according to Sorokhtin *et al.* [12]) and hydrocarbons (oil, coal, bitumen and gas - around 1.6 TtC identified).

1.5. The Greenhouse Effect

ACC increase was presented as contributing to global warming by preventing the excess heat brought by the solar flux from being re-emitted towards space, causing its accumulation in the troposphere. The arguments of the proponents of the warming effect of CO_2 were mostly based on the theory of the greenhouse effect imagined by Joseph Fourier in 1824 and formulated by Svante Arrhenius in 1896 according to which the variation in temperature is proportional to the variation of the logarithm of the ACC. Their constantly evolving models approximated badly the annual variations in surface temperature over recent decades. Most models overestimated the observed warming trend in the tropical troposphere over the past 30 years and underestimated the long-term cooling trend in the lower stratosphere [13].

Other theories claimed to explain the radiative dynamics of the atmosphere and its thermal behavior. For example, Miskolczi [14] presented a theory of the greenhouse effect based on the virial theorem relating the kinetic and potential energies of several interacting bodies. He concluded on the one hand that the influence of greenhouse gases on global warming was overestimated by the proponents of the warming effect of CO_2 and, on the other hand, that the increase in the contribution of an atmospheric component to the greenhouse effect was offset by the decrease of that of another component. In other words, the greenhouse effect would be permanently saturated, and therefore would not exist, according to this author.

Reasoning through the absurd, if we cross the fact that the ocean outgasses CO_2 when the temperature increases with the putative principle of a climate influenced mainly by CO_2 greenhouse effect, the increase in ACC with the warming would be a self-sustaining process since it would generate a new warming through the greenhouse effect which would cause a new outgassing of the ocean, etc. This divergent process, which would end in boiling, should leave traces in the past of the earth. However, no sign of this runaway temperature has been reported despite ACCs much higher than today.

These considerations at least minimize the influence of the greenhouse effect, or even deny its very existence. The theory of warming by the greenhouse effect of CO_2 is therefore doubtful and its role at least exaggerated, which makes excessive the fears of its consequences and unfair the restrictions on fossil CO_2 emissions.

In this context, we checked the elements of the CO_2 budget with an approach based on the elementary reactions of polymerization and mineralization of carbon. We also examined seasonal variations, then tried some predictions. In the discussion, we completed with the role of the ocean and compared seasonal and glacial cycles. We concluded by some considerations on the effect of ACC increase on the supply of food for humanity.

2. Material and Methods

At the base of all life are photosynthesis and the degradation of the carbonaceous matter thus obtained by respiration and combustion. These reactions can be grouped under the same reversible chemical Equation (1).

$$6CO_2 + 6H_2O + E \leftrightarrow C_6H_{12}O_6 + 6O_2 \quad (1)$$

E is the visible light energy in the direction of photosynthesis (from left to right) and the metabolic or combustion energy in the direction of respiration (from right to left). This equation expresses that the consumption of CO_2, the production of oxygen and the production of organic matter in the form of hexoses correspond molecule for molecule.

Hexose is the building block of plant matter, and its amount can be measured by that of dry matter (dm) of plant biomass. We considered here the net primary production, after various deductions (autotrophic respiration, non-exported residues), involved in the carbon cycle as food or fuel, *i.e.* mainly the productions from agriculture, forestry, aquaculture and fisheries.

This Equation (1) lacks other essential but minor elements such as nitrogen, phosphorus, iron, etc. However, it was retained here because we limited our analysis to carbon. According to it, one tonne of dry plant biomass fixes 0.4 tonnes of carbon (C/dm) or 1.47 tonnes of CO_2 (CO_2/dm). In the other direction of the reaction, one tonne of dry organic matter releases 1.47 tonnes of CO_2

during its mineral degradation by respiration or combustion.

This C/dm ratio provided by the stoichiometry of the chemical reaction (1) is imperfect and should be adjusted for each type of biomass. Indeed, it is between 0.40 for glucose and 0.58 for ethanol. For microalgae, which constitute the most abundant terrestrial primary production, Cornet *et al.* [15] and Pruvost *et al.* [16] find a C/dm ratio of 0.51. To treat the generality of the cases in a unique way for all biomasses, we have retained this value in what follows to identify orders of magnitude of the absorption of carbon by photosynthesis and the emission of carbon by respiration and combustion at the planetary level.

The results confronted with ACC variations made it possible to specify the exchanges of CO_2 between the continents, the atmosphere and the ocean. By considering this system, we wrote that the carbon absorbed or outgassed by the ocean (denoted OC) is equal to the sum of the absorption by incorporation into the continental biomass counted negatively (AW), of the emission (EW) by mineral degradation (respiration and combustion) of organic matter, including fossils (EFOS), and of the increase in ACC counted negatively (GATM) according to Equation (2).

$$\mathrm{OC} = -\mathrm{AW} + \mathrm{EW} - \mathrm{GATM} \quad (2)$$

The calculation was carried out every ten years from 1970, with complete statistics made available. Our approach to the main elements of the carbon budget was of an accounting type and did not make use of numerical models. Given the extreme complexity of the behavior of the global ocean, heterogeneous in three dimensions and over time, the oceanic contribution OC is the unknown of Equation (2) to be determined.

3. Results

3.1. The Carbon Balance

The FAO statistics described accurately the productions of crops, pastures and forests that go into the composition of the absorptions of CO_2 on the continents AW (**Table 1**). The calculation of pastures was made every 10 years from the world production figures of livestock farms by applying an average trophic conversion index equal to 5.5 (5.5 tonnes of plants are needed per tonne of animal products). This value was rather low to correct the fact that certain field crops (e.g., sorghum, fodder maize, alfalfa) are used, at least in part, in the composition of poultry, cattle and pig feed. Dry matter (dm) over fresh weight rates of 50%, 70% and 60% were applied to crops, pastures and forest products, respectively, to obtain the dry biomass and then the quantities of CO_2 absorbed by application of the CO_2/dm rate.

We considered that unexploited primary forests have a zero photosynthesisrespiration balance over time, which is photosynthesized during the day being degraded at night or in the shade of the canopy. Only logged forests feed the flow of organic carbon and contribute to the fixation of CO_2. It appears from **Table 1**

Table 1. Global CO_2 absorptions by photosynthesis AW from 1970 to 2020, in $GtCO_2/y$.

	Crops	Pastures	Forests	Macroalgae	Total absorptions AW
1970	3.53	3.77	3.82	0.00	11.1
1980	4.32	4.62	4.35	0.00	13.3
1990	5.55	5.57	8.53	0.01	19.7
2000	6.58	6.55	9.15	0.02	22.3
2010	8.28	8.17	9.46	0.04	25.9
2020	9.97	9.80	9.59	0.06	29.4

that crops, pastures, and forests absorbed CO_2 at comparable levels. Minor stocks such as the carbon sequestered in cement or the increase in body mass of the human population, are too small to be considered. An example of these minor stocks, three orders of 10 smaller, was constituted by Macroalgae (**Table 1**).

In **Table 2**, we calculated the emissions of CO_2 of the continents EW by summing up the CO_2 resulting from the combustion of fossil hydrocarbons EFOS and the mineral degradation by respiration and combustion of the productions previously listed, with several corrections.

1) Fossil fuel combustion figures EFOS were provided by oil company BP and CDIAC[1]. These data differ by emissions from cement plants for which a correction of +5% is applied to the former.

2) The digestion of products from continental crops does not concern textile industry fibers (coton, jute, hemp, etc.) the mineralization of which was considered deferred for 10 years.

3) Non-harvested crop residues, roots, straws and tops, were not considered here, their mineralization by soil heterotrophs (bacteria, fungi, worms, etc.) being supposed to occur in place within the year.

4) The digestion of livestock products did not concern non-consumable slaughterhouse waste which was calculated considering an average carcass yield of 65%. Most of this waste was transformed into animal meal and incorporated into animal feed after 2 years.

5) Rural emissions were a distinct item in FAO statistics which includes forest and peatland fires, with some emitting methane items such as enteric fermentation and rice paddies.

6) Most forest products are transformed into construction materials, wood pulp and recycled packaging, which store carbon and are temporarily removed from its cycle. The mineralization of wooden construction materials was taken deferred for 50 years. Only firewood was directly included in the respiration/combustion balance.

[1]Carbon Dioxyde Information Analysis Center.

Table 2. Global CO_2 emissions by degradation of organic matter of rural and fossil origin, EW in $GtCO_2/y$.

	Fossil hydrocarbons combustion EFOS	Food crops	Rural emissions	Firewood	Animal products, excluding waste	Deferred emissions (textiles, wood, waste)	Total Emissions EW
1970	15.0	3.5	3.8	1.6	0.5	0.2	24.7
1980	19.7	4.3	4.4	1.8	0.7	0.2	31.0
1990	22.6	5.5	5.2	1.9	0.8	0.3	36.3
2000	25.0	6.6	4.9	1.9	0.9	0.3	39.7
2010	32.9	8.2	5.5	2.0	1.2	0.4	50.1
2020	33.9	9.9	6.3	2.1	1.4	0.5	54.1

7) Deferred yearly emissions from textiles, construction wood and slaughterhouse waste were calculated by dividing their weight by their lifetime.

Table 3 presents the main CO_2 budget elements of Equation (2) since 1970 every 10 years. Because of fossil emissions (EFOS, Table 2), absorptions (AW, Table 1) were lower than emissions (EW, Table 2), which resulted in an average excess balance (−AW+EW) of 19.0 ± 4.4 $GtCO_2/y$ emitted in the atmosphere, constantly increasing. The 13.2 ± 3.4 $GtCO_2/y$ increase of the ACC (GATM) was fueled by this surplus. The 5.8 ± 1.7 $GtCO_2/y$ remainder was absorbed by the ocean (OC).

The resulting carbon exchanges for year 2020 are summarized in Figure 1 in GtC.

3.2. The Seasonal Variations of ACC

Variations of the ACC were measured by Charles D. Keeling at the Mount Mauna Loa Observatory (MLO) on the Big Island of the Hawaiian archipelago from 1958. The last forty years data are presented in Figure 2, which shows:

1) a clear upward trend of more than 2.5 ± 0.1 ppm/y,

2) annual oscillations of 5.2 ppm/y mean amplitude,

3) a 6 ppm increase from August to April (cold season),

4) a 4 ppm decrease from April to August (hot season).

Although located far from the continents and at 3397 m altitude, these recordings indicated a strong influence of the continents of the northern hemisphere which emitted the greatest quantities of CO_2. Those seasonal ACC oscillations resulted from the high demand for CO_2 induced by photosynthesis during the hot season, and from high emissions by respiration and combustion during the cold season.

Contrary to what would be expected from the influence of temperature on the solubility of CO_2 in water (see 1.3), the oscillations of the ACC were in phase opposition with the temperature. Some explanations have been proposed and most authors (e.g. [17]) attributed these oscillations to biological activity. Some authors [18] invoke a North American sink in summer and a Eurasian source in winter.

Table 3. Evolution over half a century of the CO_2 balance of land absorptions AW and emissions EW, of the ACC increase GATM, and of the resulting contribution of the global ocean OC according to Equation (2), in $GtCO_2$/y.

	Continental balance	ACC increase	Ocean absorption
	−AW+EW	GATM	OC
1970	13.6	10.1	3.5
1980	17.8	10.7	7.0
1990	16.7	12.0	4.7
2000	17.4	11.6	5.7
2010	24.2	15.9	8.3
2020	24.7	18.75	5.9
Average 1970-2020	19.0	13.2	5.8
Standard deviation	4.4	3.4	1.7

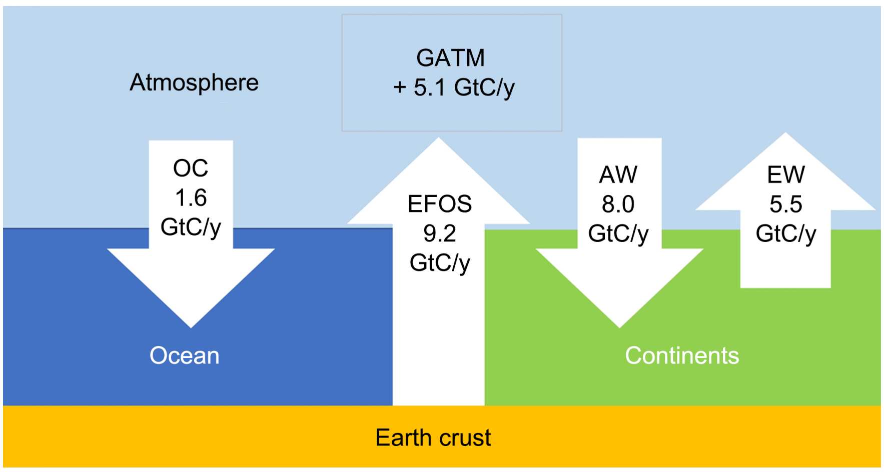

Figure 1. Exchanges of carbon between the 5 compartments of earth surface in year 2020 (GtC/y).

The air mass bathing the measurement point traveled two laps around the planet between summer and winter, flying over most regions of the world. During this journey, it mixed in altitude and latitude, and came into equilibrium with the surface water [19]. In what follows, we assumed the global mean measurements illustrated by **Figure 2** representative of the mixed air mass bathing the planet.

According to **Table 4**, continental primary production (Absorptions AW) was 75% distributed in the hot season and 25% in the cold season due to the strong influence of temperature and light on plant metabolism [20] [21]. The consumption of agricultural products intended for animal feed, mainly homeothermic, was homogeneously distributed over the year, as was their mineral degradation. Firewood entered the respiration/combustion balance with a distribution in the year opposite to that of photosynthesis, the main consumption occurring in the cold season. **Table 4** splits the previous results for year 2020 between hot and cold seasons.

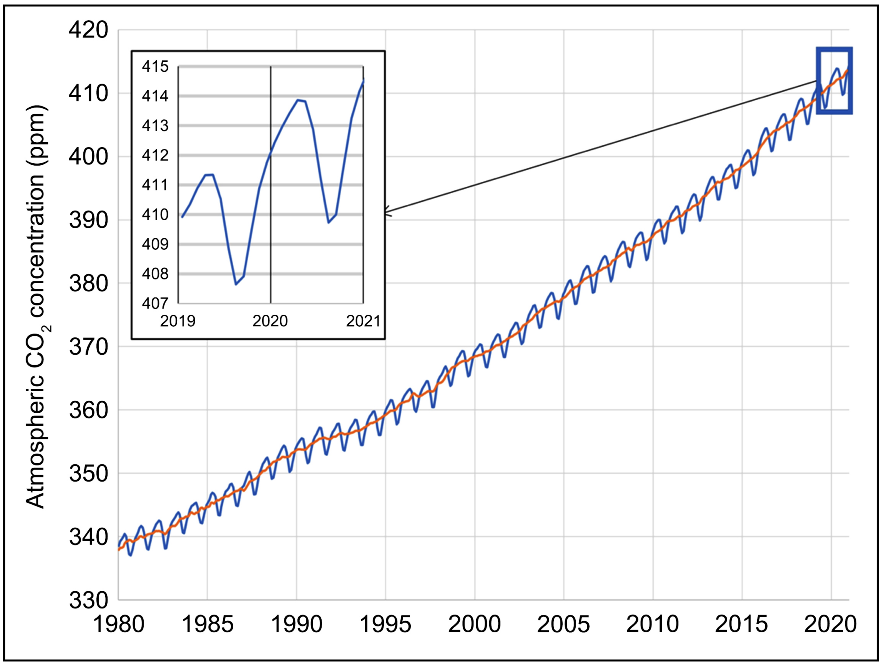

Figure 2. Evolution of average atmospheric CO_2 concentration ACC (ppm) measured at Mount Mauna Loa Observatory (MLO) from 1980 to 2021 and details 2019-2021. The trend curve is red. Scripps and NOAA data.

Table 4. Seasonal exchanges between the global ocean and the atmosphere for year 2020 expressed in $GtCO_2$ (deficit are negative). Atmosphere contributions GATM, continent contributions AW and EW are resulting from the ACC oscillations depicted in **Figure 2**. The ocean contribution OC is the unknown of Equation (2).

	Notation	Hot season	Cold season	Total/year
Absorptions	AW	22.0	7.4	29.4
Emissions	EW	30.6	23.5	54.1
Balance	−AW+EW	8.5	16.2	24.7
Atmosphere	GATM	−32.1	50.9	18.7
Ocean	OC	40.7	−34.7	5.9

It shows that, in the hot season, ACC deficit of 32.1 $GtCO_2$ (4.1 ppm) and the excess continental balance of 8.5 $GtCO_2$ enriched the ocean by some 40.7 $GtCO_2$. This supply together with good temperatures favored aquatic life. During the cold season, ACC increases by 50.9 $GtCO_2$ (6.5 ppm). This quantity was supplied by the 16.2 $GtCO_2$ excess of continental balance and by 34.7 $GtCO_2$ from the surface ocean. This oceanic outgassing (despite the lower temperatures) probably resulted from increased respiration and lower photosynthesis of the aquatic world. The ocean was therefore a sink during the hot season and a source during the cold season. In total over the year 2020, the atmosphere and the ocean had been enriched by 18.7 and 5.9 $GtCO_2$/y, respectively.

3.3. Projections

In a dream, suppose there is no anthropogenic release by fossil combustion (EFOS = 0 $GtCO_2/y$) and the ACC is stable (GATM = 0 $GtCO_2/y$), as it was the case before the industrial era. Continental absorptions AW would outweigh emissions EW with a deficit balance −AW+EW of −9.2 $GtCO_2/y$). To compensate this demand, the ocean would have been a source of 9.2 $GtCO_2/y$ (instead of a sink of 5.9 $GtCO_2/y$ in 2020). But this hypothesis remains an utopia since the world will not give up using fossil fuels before being forced to do so by their scarcity. Now let's look at what the situation could be in the decades to come with fossil hydrocarbons burning.

Since human activities exhibit the same evolutionary trend as the world population, and with the reservations attached to any prediction, the population-driven ACC over a time series from 1970 to 2080 was based on UN statistics till 2020 and then calculated according to UN median projections of world population. Figure 3 shows the results of the simulation that extends the ACC measurements beyond 2020 to the end of the century. An ACC of 585 ppm should be reached by 2080, still growing.

A maximum of annual increase of atmospheric CO_2 (GATM) of 26 $GtCO_2/y$ should be reached by 2080, as compared to present 19 $GtCO_2/y$. Simultaneously, the absorption of atmospheric CO_2 by the ocean should increase to a maximum of 8.1 $GtCO_2/y$, as compared to present 5.9 $GtCO_2/y$. This represents an increase of 40% of these two quantities as compared to present situation.

4. Discussion

4.1. Carbon Budget

Carbon budgets have previously been attempted by Le Quéré *et al.* [22], Roy-Barman & Jeandel [23], Friedlingstein *et al.* [24] [25] using Equation (3).

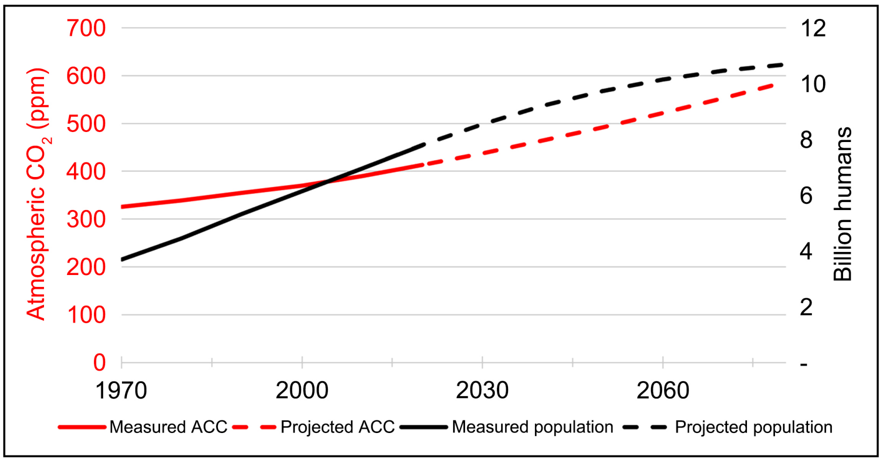

Figure 3. Measured ACC (ppm - red line) according to Scripps and NOAA data (solid line) and projection (dotted line). The identified and projected world population (billions of humans - black line) according to statistics (solid line) and to the UN median projections (dotted line) is scaled by the right axis.

$$\text{EFOS} + \text{ELUC} = \text{GATM} + \text{SOCEAN} + \text{SLAND} + \text{BIM} \quad (3)$$

This Equation (3) assumes that emissions from fossil combustion EFOS and other human activities ELUC are equal to the GATM increase of the ACC plus the sinks formed by the ocean SOCEAN and the continents SLAND. These terms are determined separately by numerical models and measurements. Introducing them into Equation (3) generates a residual budget imbalance BIM to be minimized. In **Table 5**, we compared our figures with those of Friedlingstein *et al.*

The main difference lies in continental absorptions (SLAND vs AW) and continental emissions (ELUC vs. EW-EFOS). However, it is preferable to compare the resulting continental balances (−SLAND+ELUC and −AW+EW-EFOS) which are of the same orders. Those figures also differ by the contribution of the ocean (SOCEAN vs OC). The ocean sink SOCEAN was 3.0 GtC/y in the first case, or 32% of fossil emissions, and OC was 1.6 GtC/y in our case, or 17% of fossil emissions.

The assessment of the ocean sink SOCEAN (3.0 GtC/y in 2020) was mainly the result of biogeochemical models established on the basis of surface CO_2 partial pressure measurements collected and verified by the "Surface Ocean CO_2 Atlas" (SOCAT) since 1957. The accuracy of this value depends on the density of the spatio-temporal coverage of the world ocean. The absence of observations in some sectors, particularly in the southern hemisphere, and at certain periods was compensated for by several interpolation models between the available data (Rödenbeck *et al.* [26]). Their uncertain reliability could at least partly explain the difference between our estimate and that of the authors cited. In our case, we recall that the ocean contribution OC is the unknown of Equation (2).

Table 5. Comparison between the 2019-20 carbon budgets from Friedlingstein *et al.* and the present budget for 2020.

	Friedlingstein *et al.*	Budget 2019 (GtC/y)	Budget 2020 (GtC/y)	Present work	Budget 2020 (GtC/y)
Increase in ACC	GATM	5.4	5.0	GATM	5.1
Ocean contribution	SOCEAN	2.6	3.0	OC	1.6
Continental absorptions	SLAND	3.1	2.9	AW	8.0
Fossil emissions	EFOS	9.7	9.3	EFOS	9.3
Continental emissions	ELUC	1.8	0.9	EW-EFOS	5.5
Budget imbalance	BIM	0.3	−0.8		-
Continental balance	−SLAND+ ELUC	−1.3	−2.0	−AW+ EW-EFOS	−2.5

The other values (GATM, EFOS) are taken from the same sources. The differences between the two approaches could therefore result from an overestimation of the ocean sink SOCEAN and/or, in our budget, of the –AW+EW-EFOS continental balance. The BIM residual, which reflects the accuracy of the budgets cited, is of the order of magnitude of these differences. The two approaches seem equivalent, without it being possible to say which is the best.

4.2. Primary Productions

By using isotopic or chemical indicators, some authors (e.g. Welp *et al.* [27]; Campbell *et al.* [28]; Haverd *et al.* [29]) estimated global gross primary production (GPP) between 150 and 175 GtC/y. Removing the share of the ocean (51 GtC/y, see below), the continental net primary production would be between 100 and 124 GtC/y, which is 12 to 16 times our estimates (AW, **Figure 1**), and 33 to 41 times those of Friedlingstein *et al.* (SLAND, **Table 5**). Then, the estimation of the GPP using those proxies seem to lead to a strong overestimation. Nevertheless, their interest lies in the relative values of the temporal distribution. This is how these authors highlighted a 31% increase in terrestrial primary production since 1900, which they attributed to the enrichment of the atmosphere in CO_2 and partly explains the improvement of crop yields.

4.3. The Ocean

In the above budgets, ocean life is expressed through absorptions and emissions to and from the ocean. We examined here the essential features that explain at least in part the complex behavior of the global ocean as a result of surface biological activity and vertical exchanges.

Oceanic primary production (OPP) is at the base of the aquatic food chain exploited by fisheries (96 million tonnes per year, steady) and aquaculture (114 million tonnes, 20% growth per year, FAO statistics, 2020). It has been the subject of many studies, mainly using satellites measuring chlorophyll.

Since 1970, OPP has been considered stable and equal to 51 GtC/y by close consensus (**Table 6**), with only events modifying upwellings disturbing the annual rhythm. This is more than 6 times greater than the primary production of the continents, according to our estimation, although the surface of the ocean is only 2.4 times greater. This indicates the extent to which aquatic life plays a preponderant role in the global terrestrial ecosystem to fix carbon and produce the oxygen and organic matter essential to animal life.

Falkowski and Raven [39] estimated between 0.25 and 0.65 GtC the instantaneous stock of phytoplankton in place in the world ocean. To ensure the primary production of **Table 6**, renewal must take place between 78 and 205 times per year, *i.e.* a lifespan of between 2 and 5 days. This is compatible with the doubling times of the populations of microalgae which are of the order of the day. Bacteria have a doubling time of 20 minutes, which suggests rapid mineralization of the biomass, including the remains of animals falling to the bottom.

Table 6. Estimates of the global primary production of the ocean (OPP) according to different sources (DIM = depth integrated model; GCM = global circulation model).

Authors	OPP (GtC/y)	Methods
Longhurst *et al.* [30]	50	Chl-based
Antoine & Morel [31]	46	Chl-based, WRM
Behrenfeld & Falkowski [32]	44	Chl-based, DIM
Moore *et al.* [33]	48	GCM
Behrenfeld *et al.* [34]	67	C-based, DIM
Carr *et al.* [35]	51	Mean of 31 global models
Westberry *et al.* [36]	52	C-based, spectral
Thornton D.C.O. [37]	50	Chl-based, DIM
Johnson K. S. & Bif M. B. [38]	53	O_2
Mean	51.2	

Vertical profiles of inorganic carbon have been established in all regions and at all seasons. They have different concavities depending on whether the ocean is a source or a sink. In the first case, the concavity is open to the left while in the second, it is open to the right. Source regions are mainly located at low latitudes and on the western shores of continents where deep waters rise. Sink regions are located at high latitudes where cooler, denser surface waters dive.

The vertical exchanges of inorganic and particulate carbon between the deep and the surface ocean ensure that it is renewed on the surface to seek equilibrium with the troposphere. Part of the OPP and of the animal biomass that feeds on it passes into the deep ocean in dissolved form by transport and in particulate form by gravity and transport. On the scale of an annual cycle, Falkowski *et al.* [40] estimated the primary production lost to the bottom at 16 GtC/y, *i.e.* one-third of OPP. On the contrary, Levi *et al.* [41] estimated the exchanges from the depth towards the surface at 275 GtC/y and, and in the opposite direction at 265 GtC/y, which leaves a gain of 11 GtC/y for the surface ocean. So, the balance of the surface ocean is not yet accurately assessed.

4.4. Seasonal and Glacial Cycles

During glaciations, ice accumulated on the high and middle latitudes of the continents. Several thousand meters thickness thus shaped their relief, while the sea level was 120 m lower. The increase in ACC following glaciations is a consequence of the outgassing of CO_2 from the ocean, which is a slow process involving the deep ocean. Those cycles differ from the seasonal cycles of the ACC which oscillations are in opposition with those of temperature.

According to ice cores, the atmosphere would lose 100 ppm, or 212 GtC while the temperature drop of some 8˚C in average during glaciations [7]. This carbonaceous mass would pass into the ocean which would restore it during postglacial warming. Such exchanges represent a tiny fraction (0.5%) of ocean carbon stocks estimated at 40 TtC [42]. Since the middle of the 19th century, the atmosphere has been enriched by 300 GtC thanks to anthropogenic emissions. Thus, during this short period, the losses of the last glaciation were largely compensated. The surface ocean acts as a sink absorbing part of the fossil emissions, which exempts it from contributing to the restoration of preglacial atmospheric carbon.

Seasonal cycles are due to the obliquity of the earth's axis with respect to the ecliptic plane, while glaciations are mainly the effect of changes in the earth's orbit around the sun. The seasonal temperature amplitude is of the same order as for glacial cycles. As a result, the variations in CO_2 solubility for both cycles should be similar. Unexpectedly, ACC amplitude is 5.2 ppm for a seasonal cycle and 100 ppm for a glacial cycle.

What differs between these cycles is the disturbance duration: a few months for the first against a few millennia (ky) for the second. In the case of the seasonal cycle, the physical equilibrium does not have time to settle before the next cycle, and the influence of the biosphere is preponderant. While for glacial cycles, the exchanges are over sufficient time for this equilibrium to be reached, the physico-chemical prevailing over the biosphere influence.

4.5. A Respite in CO_2 Shortage

Over geological eras, the ACC has drastically diminished, dropping a few dozen times, during early earth age to the actual values [43]. This heavy tendency is worrying as photosynthesis will ran out of fuel, and life with, when ACC reach 100 ppm and below [44]. The brutal release of fossil carbon trapped in the

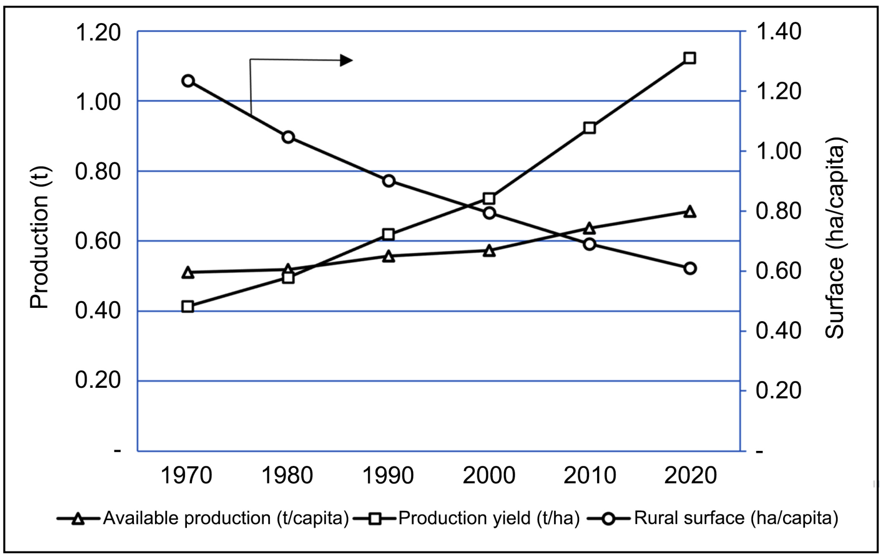

Figure 4. Recent evolution of available food production per capita (triangles, left axis) as the product of agriculture production surface yields (squares, left axis) by rural surface per capita (circles, right axis). Source: FAO statistics 2020.

terrestrial crust provide a respite in this context. The present solutions to limit the industry emissions of CO_2 to the atmosphere which consist in burying it in the ground or in the sea should keep it reversible in order to make this precious gas available again in the future.

As shown in **Figure 4**, the current favorable conditions of access to CO_2 are the main causes of improvement of overall yields of food production, which more than doubled from 0.5 to 1.3 t/ha in half a century. At the same time, mainly due to population growth, the agricultural area per capita has been halved from 1.2 to 0.6 ha/c. As a result, the food production per capita has increased from 0.6 to 0.8 t/c in the last decades, which contributed to reduce tensions on access to food for humanity.

5. Conclusions

We have tried to put into perspective the issue of climate change presented as a threat to the living world. The conclusions of authors supporting the assertion that CO_2 emissions are responsible for global warming and must be restricted as such seem to us to be weakened by some uncertainties due to the imprecision of their predictive models, and scientific imprudence in the deductions drawn from them. The reduction of fossil emissions they recommend appears to us as an excessive and damaging constraint weighing on humanity and especially to populations that try to get out of poverty. Access to fossil energy is a prerequisite for progress, and many countries wanting to improve their standards are not willing to do without it. However, current preventions against CO_2 emissions will serve to anticipate the world without fossil carbon by encouraging humanity to develop alternative sources of energy and commodities, and to change its behavior accordingly.

Our carbon budget differed from those of other authors by the contributions of the continents and of the ocean. In both budgets, however, the ocean plays an important role in regulating ACC. We highlighted here that it is a CO_2 sink during the hot season and a source during the cold season of northern hemisphere at least, with an annual sink contribution half that of other authors. Forecasts by 2080 based on global human demography showed that the ACC would reach 585 ppm, stills growing.

The earth is greening thanks to the increase in ACC. Thus, far from diminishing, coverage of the food needs of the still growing humanity is developing favorably with the availability of agricultural products, mainly because of fossil carbon emissions. Then, far from being a polluting process, the current recycling of fossil carbon incorporated in the earth's crust should be considered a chance as it provides a respite in the drought process due to sedimentation and lithification of carbon at the bottom of the ocean.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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