The IPCC and the Carbon Cycle – Fact or Fantasy?

Dai Davies
brindabella.id.au
PERPETUAL DRAFT, 160901, 160926

Introduction

We are told by the IPCC that CO2 emissions from burning fossil fuels are causing atmospheric CO2 levels to rise and that these are causing global warming. Of the two links in this chain of reasoning this article addresses the first. The IPCC position is stated in AR5 Chapter 6 (1) as:

> ***The removal of human-emitted CO2 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 CO2 will remain in the atmosphere longer than 1,000 years. This very long time required by sinks to remove anthropogenic CO2 makes climate change caused by elevated CO2 irreversible on human time scale.* [original bold]

In this review I show that the IPCC view of the carbon cycle is fundamentally flawed in many ways, and is not supportable at any meaningful level of confidence. This is not esoteric science to be left to specialists or 'great minds'. Any numerate person who cares to look and think can understand the insignificance of our total industrial era CO2 emissions at less than 1% of the carbon cycle and our annual emissions at just 5% of the air-sea fluxes.

The basis of the assumed causal link between our emissions and rising atmospheric CO2 has been that they have both risen over the last century or more. Plotted together, appropriately scaled and smoothed, it once looked plausible to me, but the price of fish and many other things have risen over that time, too. We need to look at the whole carbon cycle to put that relationship into perspective.

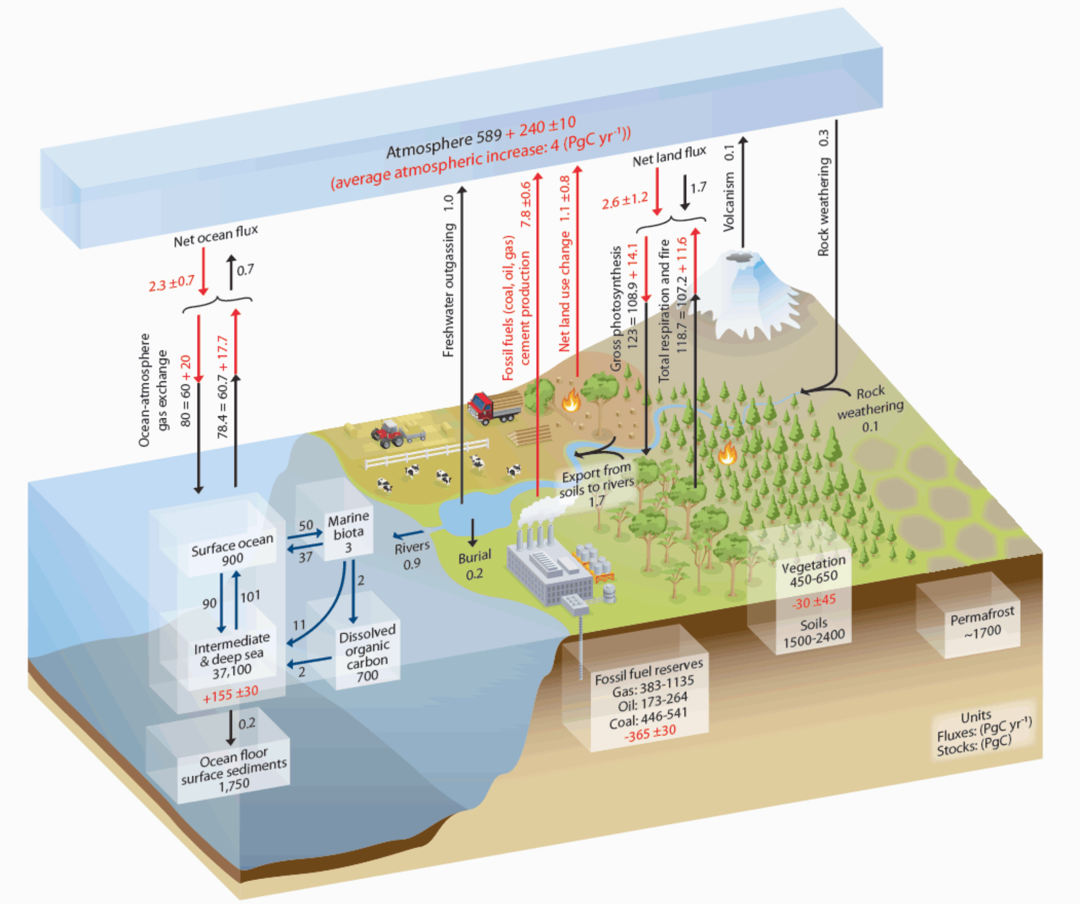


Figure 1: The Carbon Cycle - IPCC AR5 Fig. 6.1

Figure 1 shows a summary of the IPCC version of the cycle. The unit PgC is petagrams of carbon or billions of tons or gigatons. I use GtC. Arrows represent transfers, or fluxes, expressed in PgC per year.

Atmospheric carbon is only 2% of the cycle total but a highly transient part. We can see that in this model the sum of fluxes to and from the air (sources and sinks) are both around 200 GtC/y, which means that a third of the atmospheric CO2 is turned over each year. Our contribution is about 5% of this turnover, or possibly much less if these fluxes are underestimated as I suggest later.

The atmosphere is a small reservoir but an important conduit – not just between the oceans and land but between their many sub-regions. The figures in the diagram represent aggregates of multiple stores and fluxes that each vary over space and time, and each with their own dynamics.

My starting point, and the main focus of this article, is the carbon in marine biota. I show that the IPCC value of 3 GtC is too low, and misleading. This reservoir is much larger, highly labile, and a major player in the cycle.

To put this misrepresentation into perspective I look at other reservoirs and fluxes along with general problems in the IPCC view of the cycle: sparse data; lack of understanding and probable understatement of the polar seas as a sink; the poor to nonexistent historical perspective over the industrial era and before; the understatement of volcanic emissions by as much as a factor of 1,000; flawed use of carbon isotope analysis; and the reliance on simplistic models.

First impressions

My initial reaction to this and other representations of the cycle was to note the scarcity of error estimates. See note (a) for a discussion of errors, but it doesn't take much scientific nous to guess that nothing here is better than ±10% and generally much worse. Quoting such numbers to four significant digits is deceptive and goes against accepted scientific practice.

Taking air to surface fluxes as about 200 GtC/y, the error range is at least ±20 GtC/y or twice our annual industrial emissions of 9 GtC/y. The total mass of labile carbon reservoirs in the diagram is at least 5,000 GtC. Again, with a minimal estimate of 10% uncertainty we have ±500 GtC which is 50 times our current annual emissions and greater than our total historical emissions of 360 GtC.

Our emissions are lost in the noise. Munshi (2) has done a more detailed analysis that agrees. That's just in the rough snapshot we have for the present. We have no reliable historical perspective for most of the elements of the cycle and poor data for the others.

Another thing I noticed, comparing various plots of our CO2 emissions and atmospheric CO2 levels for the last century or so, was that except for a common upward trend the detailed fluctuations don't correlate visually. In particular, at the turn of this century the rate of increase in our emissions trebled with no visible response in the rate of atmospheric CO2 increase. Munchi (c) has done this analysis and found that when you look at the detail, atmospheric CO2 correlates with surface temperature, as expected from solubility laws, but not our CO2 emissions.

These considerations and others, which have been publicly discussed for over a decade, should have ended the debate, but they haven't, so I decided to dig deeper. I found that the fluxes and labile reservoirs are likely to be much larger, and with higher uncertainties, than the IPCC view, and that the IPCC claims are based on invalid assumptions of past stability in the Earths natural systems.

Problems in the IPCC analysis of the cycle

Missing data: Marine biomass

The figure of 3 GtC for marine biota is wrong and seriously misleading. Moreover, it is not just an isolated error in a diagram. It is repeated in the adjacent text without attribution and implied elsewhere in the literature cited by the IPCC.

From note (b), the value of 3 GtC for marine biota seems to be a mislabelling in the IPCC reports and some of the surrounding literature, and based on satellite chlorophyl measurements which represent a highly dynamic photosynthetic sub-population of plankton (phytoplankton) at the base of the marine food chain – a small mass but with a high turnover as it is quickly consumed by other marine organisms.

I've collected together some references I found on marine biomass to give an idea of the state of the art. Total terrestrial bioactive carbon is taken from the diagram as 1,950+550 or 2,500 GtC.

1. IPCC (1), unattributed: 3 GtC [see (b) for discussion] – an instantaneous value
2. From various IPCC related sources (b): 'marine biomass is 0.2% of total biomass' implying about 5 GtC
3. Hansell et.al. (3), 2009: 662 GtC in DOM (Dissolved Organic Matter) is 200 times marine biomass, so implies 3.3 GtC
4. Hansell et.al. (3): Phytoplankton lifetimes are about 4-6 days. For 3 GtC and 5 day mean lifetime, total annual production = 5*365/5 = 365 GtC/y as a sink.
5. Whitman et.al. (4), Total ocean bacterial mass is 300 GtC – a partial component of the biota.
6. Census of Marine Life (5), 2010, 'more than 90% of the biosphere' = 2500*9 = 22,500 GtC
7. Arı´stegui et.al. (6): a 'conservative' estimate of deep ocean respiration of 20 GtC/y [old] to 33 GtC/y [theirs] – up to 3 times IPCC's 11 GtC/y for marine biota as a deep sink.
8. Massey (7): 'Phytoplankton are believed to produce 80 percent of the organic material in the world.' So scaling the terrestrial photosynthesis, 123*80/20 = 490 GtC/y as a sink.
9. EARTHSKY (8), 2015, 'Estimates of the marine biota contribution to oxygen production vary from 50% [NASA, old] to 85%.' This is linked to CO2 uptake in photosynthesis, so implies 123 to 700 GtC/y
10. My high school biology: marine life is the vast majority of biosphere, so at least 75% or 7,500 GtC.

From this we have 365,490 or up to 700 GtC/y for primary production. Pre-satellite estimates – e.g. 6 and 10 – were far higher than recent ones and little more than guesstimates, but phytoplankton blooms are most concentrated in nutrient rich coastal waters that are turbid, which make the satellite estimates unreliable, too. Bacteria alone may be 100 times the IPCC's 3 GtC figure, but it has been ignored. It is largely dormant but highly labile. Assuming a 1 day lifespan it has a potential productivity of 100,000 GtC/y.

Our emissions are in the order of 2% of marine primary production, which means that the IPCC is assuming that the marine ecosystem has been stable to within a fraction of a percent for a century or two. How stable has it been recently? A report (9) that plankton mass might have dropped by more than 10 to 40% in recent decades was criticised on the grounds of inadequate sampling – a criticism that can be made of all the measurements involved in the CO2 cycle. The authors reevaluated their results (10) and stuck to the qualitative result of an overall drop. Other research suggests large regional variations. In just six years, Gregg et.al. (11) measured an increase of 10% for chlorophyll in coastal waters, little change in open ocean, and reductions in mid-ocean gyres. Another report gave a sixfold increase in the Arabian sea.

Satellite imagery has shown a growth in the surface terrestrial biosphere of more than 10%, or 50 GtC, in recent decades. This has been attributed to increased atmospheric CO2 and temperatures. Over the industrial era it is likely to have increased by double this, absorbing around 100 GtC and far more if, as can be expected, soil life has also increased.

The growth and decay of plants and plankton follow complex dynamics that can vary on timescales of months to decades and millennia. Increased coastal runoff of nutrients, changing ocean currents and temperatures, overfishing, and other factors have had an impact on ocean life. We clearly have a poor grip on the assessment of marine biota, but it is a major labile reservoir.

Missing data: CO2 dissolved in oceans

The rate of exchange of CO2 between air and sea is determined by the solubility of CO2 in water as described in note (d) – Henry's law – solubility decreases with increasing water temperature. There is no evidence that solubility has decreased over the industrial era any more than Henry's law would produce, and nothing but speculation to suggest it will decrease in the near future. Rather, if we are at a climate millennial optimum (note g) future cooling will increase solubility.

A major role that the atmosphere plays in the cycle is carrying CO2 outgassed in warm equatorial waters poleward in the atmospheric circulation cells where it then dissolves in the cold polar seas. This part is a rapid process that runs on timescales of months to years rather than centuries to millennia.

The air-sea transfer of CO2 varies spatially and temporally and depends on surface temperatures and wind speeds in a highly nonlinear manner – i.e. a doubling of wind speed can increase solubility by a factor of 8 to 16 (12) as high winds create waves, spray, bubbles, and surface water turnover, but the details are poorly understood.

Across many areas of science and economics a mathematical error is commonly made in averaging values that are part of nonlinear systems. You can't. Wind speed is a good example of this as it varies greatly over short time periods and small distances. Averaging over time and space will tend to underestimate affects.

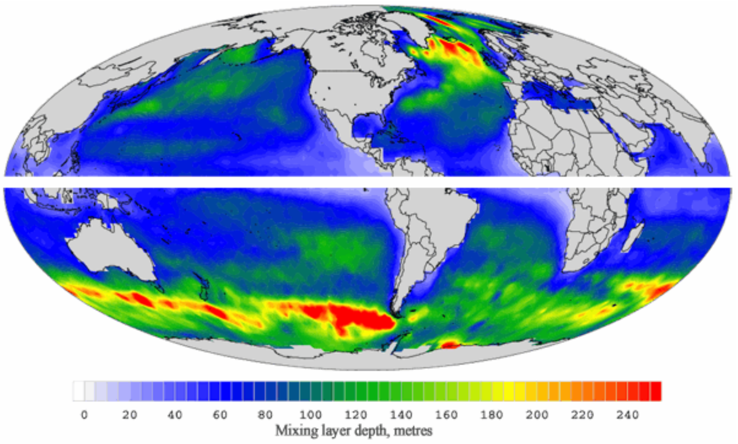


Figure 2: Winter mixing layer depth (13)

Figure 2 shows the vast areas of deep mixing in the subantarctic ocean. It is relatively unrestrained by land masses, but still has complex dynamics. Along with the major global ocean cycles there are local circumpolar currents and strong winds. There are localised carbon rich upwellings, CO2 sequestering downwellings, and a rich marine biota that is changing with the impact of whaling, among other factors. All this is poorly understood since data is sparse or nonexistent, but overall it is a downwelling zone – a rapid, high capacity sink.

Globally aggregated flux to lower ocean depths is given by the IPCC as 90 GtC/y. Given the poor understanding of the polar sinks and the localised overturning of water caused by storms and currents in other regions, this value is likely to be understated. That aside, there is no plausible argument that it can't handle an extra 5 to 10% from our annual output. It represents water flows which can carry whatever CO2 the upper levels have absorbed.

Once dissolved, CO2 takes a longer slower path. Enriched water downwelling from polar seas is taken on a journey for 800 to 1000 years. Along the way it upwells to release some of the CO2.

Recent increases in atmospheric CO2 are likely to be a consequence of the upwelling of warm CO2 saturated waters from previous millennial temperature maxima – the historians' ‘climate optima’ of the Medieval, Roman, Minoan and Akkadian peaks (note g).

At 38,000 GtC this reservoir is more than 100 times our accumulated emissions of 365 GtC. We have no reliable estimate of how this might have changed over the recent centuries or millennia at the small fraction of a percent accuracy needed claim that it's stable. We have no reason to believe that it has been stable, rather we know it must have changed with temperature changes.

The IPCC asserts that it must be returned to an assumed stable pre-industrial state, and points to the slow flux to ocean sediments of 0.2 GtC/y to justify its long time scales. That is a slow exit, but we don't need our 1% addition removed and lost to an appreciative biosphere.

Missing data: The poor historical perspective

The climate alarmist case was originally supported by the ‘hockey stick’ diagram showing flat global temperatures for the past millennium then a recent sharp rise since industrialisation. This has been refuted by demonstrating flawed mathematics and clear historical evidence of the Little Ice Age and past millennial peaks.

A corollary of this is that CO2 levels must have changed, too, so the IPCC's equivalent hockey stick representation for atmospheric CO2, as in Figure 3, based on ice core data is also refuted. Levels inferred from ice cores have had short term variations smoothed out by gas diffusion, cracking of the ice, and a host of other problems in the methods used. Data from past chemical measurements (14) and inference from plant stomata show large variations.

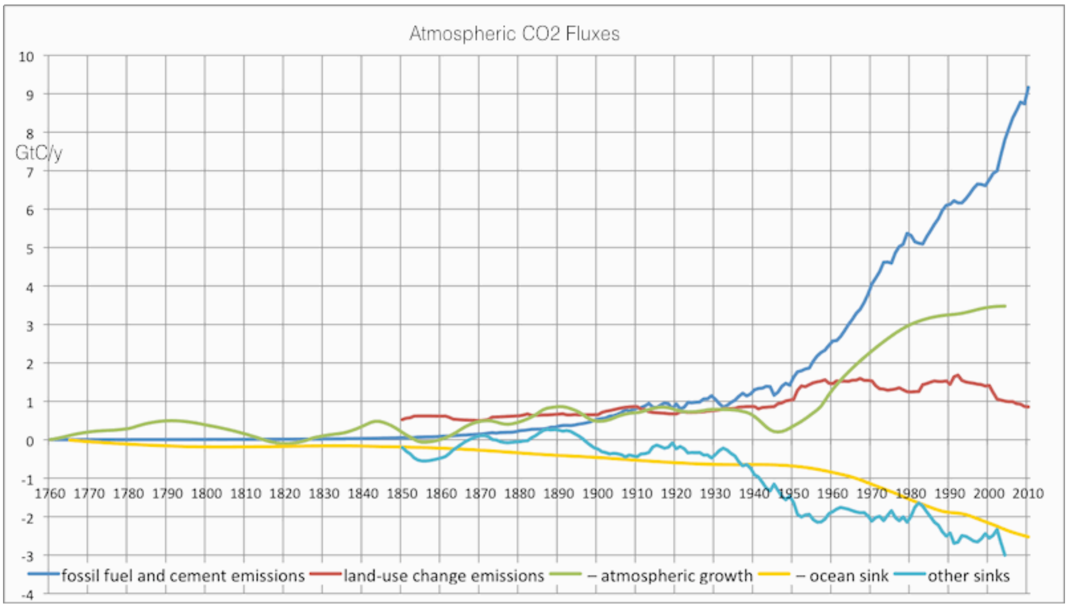


Figure 3: Global Carbon Project historical CO2 fluxes from (15)
Other sinks (my addition) = emissions - atmospheric growth - ocean sink.

Figure 3 shows data accumulated by the Global Carbon Project. To put the human emissions into perspective, if all fluxes were shown the full vertical scale would be 150 GtC/y. The IPCC classifies the residual ‘other sinks’ as land sinks. The ‘land-use change emissions’ are only guesstimates of the more politically prominent human induced changes, and their ‘ocean sink’ ignores biota.

I don't have confidence in this data, but it doesn't support the IPCC narrative. As our emissions climb over the last 60 years, atmospheric growth starts to plateau around 1960 after a deep dip of over 50% in the 1940s that doesn't match any comparable dip in the emissions. These are examples of the lack of detailed correlation mentioned earlier.

Notably, the ocean sink capacity increases steadily, steepening after 1950 with no sign of a plateau, so no sign of it saturating, which supports the conclusions of the last section. This suggests, as far as this data is meaningful, that the atmospheric increase is the result of an additional source, or sources, and that they are peaking. If our rising emissions have had any impact at all then the other sources must have already peaked and be rapidly dropping. In note (g) I discuss ocean temperature cycles that are just now peaking, so ocean emissions should be plateauing, which would match the plateau in atmospheric growth. In the next section I look at soil degradation and associated CO2 emissions that are, hopefully, peaking.

They are not included in the IPCC land use change, and are likely to be far greater than the IPCC value. The recent increase in land biota, discussed later, will also have had an impact as an additional rising sink.

Missing data: Soils

The uncertainty range in soil carbon (1500 to 2400 GtC) is more than twice the total industrial era human emissions. Zero change is assumed, but the real Green Revolution represented a shift in agricultural practices from traditional ones that were geared to soil maintenance, to regimes based on inorganic fertilisers. This has resulted in neglect of soil biomass and increased nutrient runoff to the oceans, which is thought to have increased over the last century then stabilised in recent decades. Human populations have increased as has the area of land used.

In AR5 6.1 the IPCC is frank:

> *... export of carbon from soils to rivers, burial of carbon in freshwater lakes and reservoirs and transport of carbon by rivers to the ocean are all assumed to be pre-industrial fluxes, that is, unchanged during 1750–2011. Some recent studies (Section 6.3) indicate that this assumption is likely not verified, but global estimates of the Industrial Era perturbation of all these fluxes was not available from peer-reviewed literature.*

And later:

> *Finally, processes that transport carbon at the surface (e.g., water and tillage erosion; Quinton et al., 2010) and human managements including fertilisation and irrigation (Gervois et al., 2008) are poorly or not represented at all [in models]. Broadly, models are still at their early stages in dealing with land use, land use change and forestry.*

In the summary section below I discuss the observed recent increase in land biota, which will have had a positive impact on soil biomass.

Missing data: Volcanic emissions of CO2

The IPCC gives CO2 emissions from volcanos as 0.1 GtC/y. It has apparently based this on the assumption that volcanos are evenly distributed across the Earth's crust. Geologists disagree. The Earth's crust is much thinner under the oceans. Recent thinking is that the numbers of sea floor volcanos may be several orders of magnitude greater than assumed, and CO2 diffuses from a large surrounding area even when a volcano is otherwise inactive.

Casey (16) summarised the state of our understanding of volcanic emissions. He takes an estimate of 3,500,000 submarine volcanos (17) and, assuming 4% of these as active, calculates possible emissions of 120 GtC/y. He gives a conservative minimum of 24 GtC/y. My reading of his analysis is that his high figure is already conservative because he is knowingly leaving out diffusion from around the inactive volcanos.

Either way, these figures dwarf our 9 GtC/y making it quite irrelevant. They also imply the existence of unaccounted rapid sink capacity 3 to 10 times larger than our annual emissions.

Meaningless data: Isotopic analysis

One line of reasoning meant to show that much of the increased atmospheric CO2 must be anthropogenic is based on carbon isotope ratios. Most photosynthesis preferentially selects ^{12}C over ^{13}C and the isotope ratios in the atmosphere suggest a partial contribution from organic origins or fossil fuels (old plant material).

Segalstad (18) says,

> *The isotopic mass balance calculations show that at least 96% of the current atmospheric CO2 is isotopically indistinguishable from non-fossil-fuel sources, i.e. natural marine and juvenile sources from the Earth's interior.*

and from Coe (19),

> *Far from being a fingerprint for anthropogenic sources of CO2, the isotopic ratio variation suggests conversely that the main source of CO2 is NOT in fact retained anthropogenic emissions.*

Additionally, the isotopic analysis ignores the impact of photosynthesis in phytoplankton and assumes a constant pre-industrial past. It also ignores volcanos as a source. Casey provides many journal references confirming that volcanic CO2 emissions can also be ^{13}C depleted, so can't be isotopically distinguished from fossil fuels. There is no isotope ‘signature’ pointing to anthropogenic fossil fuel use.

Corrupted data: The artificial balancing act

One obvious artefact in the IPCC carbon fluxes is that they balance to 0.1 GtC/y – i.e. to within 0.05% for air – from data that is at best 10% accurate. The figures have been adjusted to balance. The most obvious, and openly admitted, example of this is assuming the whole air to land flux is the remainder of the others – the ‘other sinks’ data added to Figure 3.

The rest is more subtle. The net atmospheric sink has been estimated using a combination of carbon isotope analysis and the slight reduction measured in atmospheric oxygen, both of which suffer from the problems of ignoring marine biota and assuming a fixed past. The fluxes have been made up to fit this net value.

In financial accounting, every cent is countable and a strict balance is a desirable goal. Here we are dealing with science and engineering where even countable values are rarely precisely known. Things never add up exactly. Mining geologists would end up in prison for such deception.

Meaningless analysis: Models

The IPCC bases its analysis on model outputs. This issue is touched on in note (e). With models as complex as needed for the carbon cycle, all we can expect are hints not solutions. With sparse current data, historical data missing, and our poor understanding of real world mechanisms, all we can expect is a reflection of the modellers' expectations.

As admitted in the literature and elsewhere, confidence in the models has been built up through a cyclic process of consensus building over decades of annual conferences, and publications with mutually reenforcing peer review. In science, confidence comes from the alignment of theories and models with real world data. If we don't have the data we suspend belief until we do.

Ignored Data: Ice cores

I have doubts about the relibility of measurements of past temperature and CO2 levels based on air trapped in ice cores, but since the IPCC and retinue use them when it suits them it's reasonable to point out that long term data shown, for example, in Figure 4 starkly contradict their whole CO2 scare narative. We see CO2 levels 2 to 5 times recent levels between 70 to 250 My ago and 7 to 17 times higher between 390 and 550 My ago. Over this whole time period, temperatures are clearly regulated by the water thermostat I discuss in *Energy and Atmosphere* (25), which limits surface temperatures to below 30 C^{o}.

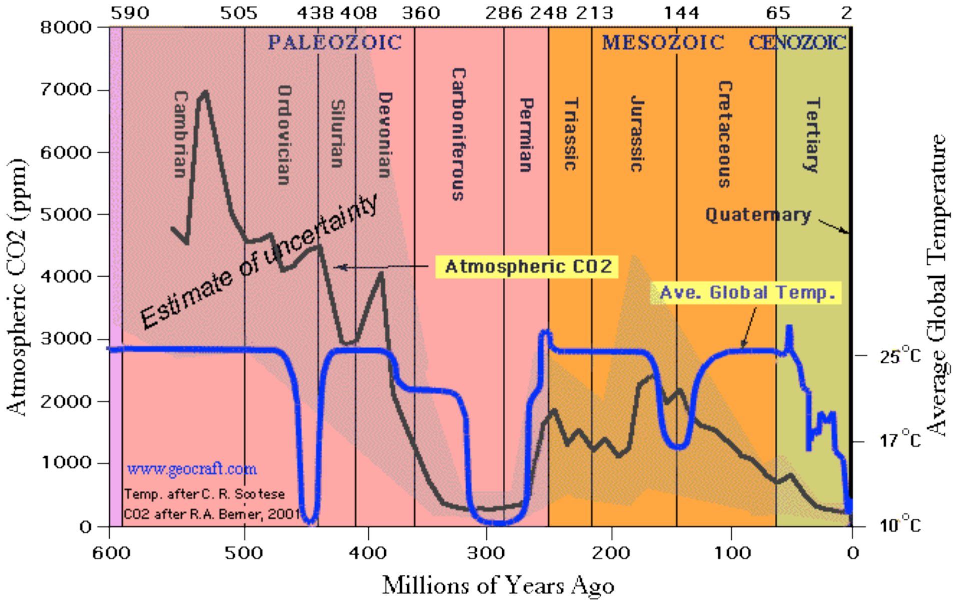


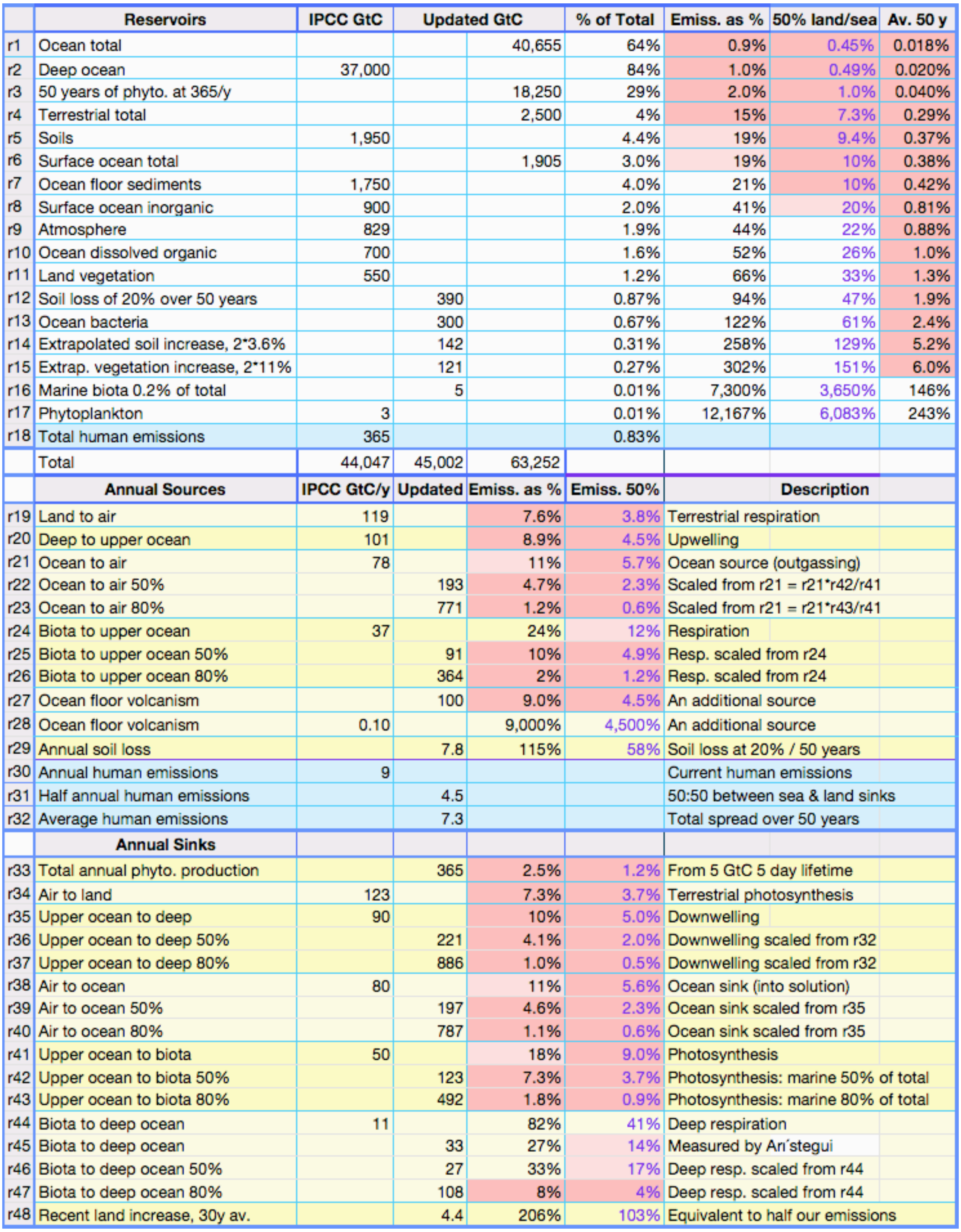
Figure 4: Ice core data for Temperature and atmospheric CO2 levels

Overview

Table 1 lists IPCC values for CO2 reservoirs and fluxes then my updates. This is an overview and sensitivity analysis rather than suggesting an alternative model. The ‘% of total’ column shows the relative size of each reservoir. ‘Emissions as %’ show our total and annual emissions as fractions of reservoirs and fluxes. For reservoirs, our total emissions are also shown spread over a 50 year period to give a rough indication of our average annual impact. For fluxes, three scenarios are presented: the IPCC figures, then values based on marine primary production being 50% or 80% of the total (9, 8). A 50 year total for phytoplankton production (r2) has been included to provide a sense of perspective.

The dark red highlighted values show where our emissions are less than 10% of the component, so well within a plausible range of natural variation on scales of years to millennia. Along with the light red, they are also lost within a 20% uncertainty range for the data, so not only negligible but unmeasurable.

A brief perusal of these figures shows the small affect we are having on the cycle – less if we divide the cycle into its land and sea components as represented by the blue figures, which assume that **the equivalent** of 50% of our emissions go to land biota. Although our emissions are rising, the highlighted figures can double and still have little significance for the whole cycle.



	Reservoirs	IPCC GtC	Updated GtC		% of Total	Emiss. as %	50% land/sea	Av. 50 y
r1	Ocean total			40,655	64%	0.9%	0.45%	0.018%
r2	Deep ocean	37,000			84%	1.0%	0.49%	0.020%
r3	50 years of phyto. at 365/y			18,250	29%	2.0%	1.0%	0.040%
r4	Terrestrial total			2,500	4%	15%	7.3%	0.29%
r5	Soils	1,950			4.4%	19%	9.4%	0.37%
r6	Surface ocean total			1,905	3.0%	19%	10%	0.38%
r7	Ocean floor sediments	1,750			4.0%	21%	10%	0.42%
r8	Surface ocean inorganic	900			2.0%	41%	20%	0.81%
r9	Atmosphere	829			1.9%	44%	22%	0.88%
r10	Ocean dissolved organic	700			1.6%	52%	26%	1.0%
r11	Land vegetation	550			1.2%	66%	33%	1.3%
r12	Soil loss of 20% over 50 years		390		0.87%	94%	47%	1.9%
r13	Ocean bacteria		300		0.67%	122%	61%	2.4%
r14	Extrapolated soil increase, 2*3.6%		142		0.31%	258%	129%	5.2%
r15	Extrap. vegetation increase, 2*11%		121		0.27%	302%	151%	6.0%
r16	Marine biota 0.2% of total		5		0.01%	7,300%	3,650%	146%
r17	Phytoplankton	3			0.01%	12,167%	6,083%	243%
r18	Total human emissions	365			0.83%			
	Total	44,047	45,002	63,252				
	Annual Sources	**IPCC GtC/y**	**Updated**	**Emiss. as %**	**Emiss. 50%**	**Description**		
r19	Land to air	119		7.6%	3.8%	Terrestrial respiration		
r20	Deep to upper ocean	101		8.9%	4.5%	Upwelling		
r21	Ocean to air	78		11%	5.7%	Ocean source (outgassing)		
r22	Ocean to air 50%		193	4.7%	2.3%	Scaled from r21 = r21*r42/r41		
r23	Ocean to air 80%		771	1.2%	0.6%	Scaled from r21 = r21*r43/r41		
r24	Biota to upper ocean	37		24%	12%	Respiration		
r25	Biota to upper ocean 50%		91	10%	4.9%	Resp. scaled from r24		
r26	Biota to upper ocean 80%		364	2%	1.2%	Resp. scaled from r24		
r27	Ocean floor volcanism		100	9.0%	4.5%	An additional source		
r28	Ocean floor volcanism	0.10		9,000%	4,500%	An additional source		
r29	Annual soil loss		7.8	115%	58%	Soil loss at 20% / 50 years		
r30	Annual human emissions	9				Current human emissions		
r31	Half annual human emissions		4.5			50:50 between sea & land sinks		
r32	Average human emissions		7.3			Total spread over 50 years		
	Annual Sinks							
r33	Total annual phyto. production		365	2.5%	1.2%	From 5 GtC 5 day lifetime		
r34	Air to land	123		7.3%	3.7%	Terrestrial photosynthesis		
r35	Upper ocean to deep	90		10%	5.0%	Downwelling		
r36	Upper ocean to deep 50%		221	4.1%	2.0%	Downwelling scaled from r32		
r37	Upper ocean to deep 80%		886	1.0%	0.5%	Downwelling scaled from r32		
r38	Air to ocean	80		11%	5.6%	Ocean sink (into solution)		
r39	Air to ocean 50%		197	4.6%	2.3%	Ocean sink scaled from r35		
r40	Air to ocean 80%		787	1.1%	0.6%	Ocean sink scaled from r35		
r41	Upper ocean to biota	50		18%	9.0%	Photosynthesis		
r42	Upper ocean to biota 50%		123	7.3%	3.7%	Photosynthesis: marine 50% of total		
r43	Upper ocean to biota 80%		492	1.8%	0.9%	Photosynthesis: marine 80% of total		
r44	Biota to deep ocean	11		82%	41%	Deep respiration		
r45	Biota to deep ocean		33	27%	14%	Measured by Arístegui		
r46	Biota to deep ocean 50%		27	33%	17%	Deep resp. scaled from r44		
r47	Biota to deep ocean 80%		108	8%	4%	Deep resp. scaled from r44		
r48	Recent land increase, 30y av.		4.4	206%	103%	Equivalent to half our emissions		

Table 1: Human emissions of CO2 as % of cycle reservoirs and fluxes.

The two scenarios for phytoplankton primary production (50% and 80% of biosphere total) provide a plausible range that illustrates the high sensitivity of the cycle to this parameter. The alignment of the 50% respiration figure with measurements (r46, r45) provides some support for this lower value.

The impact of phytoplankton mass on the upper ocean dissolved CO2 will depend on the degree of local recycling of CO2. For an extended, static ecosystem this may be high, but phytoplankton blooms are localised and highly dynamic, which means they will draw down dissolved CO2 as populations rise and enhance absorption from the atmosphere. Much of this will then be lost to deep waters.

As an aside, apart from their significance in the carbon cycle, their neglect has wider implications. The growth and decay of phytoplankton blooms has an impact on the global energy balance since they produce aerosols capable of seeding clouds, which reflect incoming solar radiation. At some stage, perhaps early in their evolutionary history, they have evolved the ability to protect themselves from damaging UV and excess heat.

The recent CO2 assisted increase in terrestrial biomass (r14, r15) is calculated as the observed 11% for vegetation over 1982 to 2010 plus a fairly arbitrary 3.6% for soils, assuming they take longer to catch up – set to make this flux equivalent to 50% of our 1982 to 2010 emissions – up from 30% if soils are excluded. As a reservoir, this is then doubled as a rough estimate of total industrial era change.

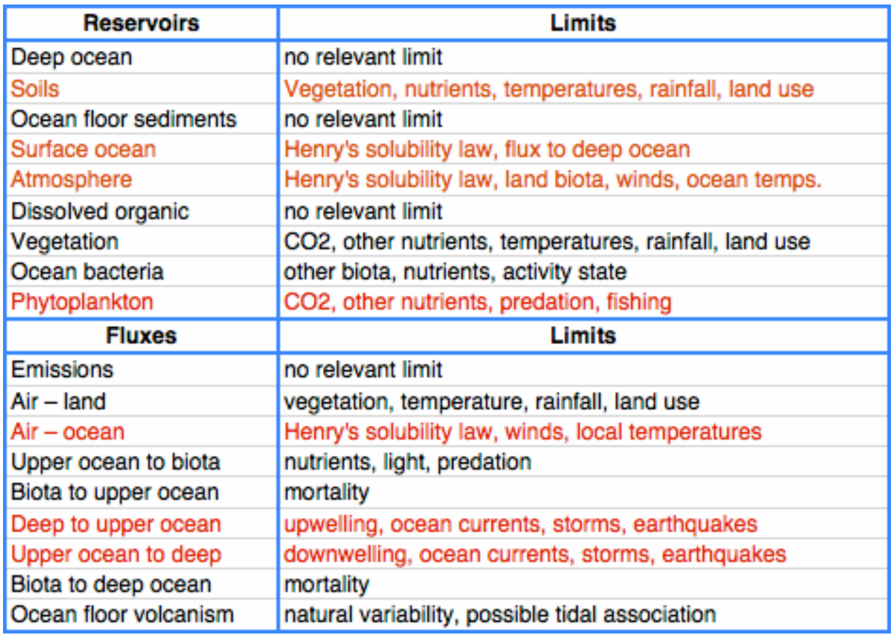
This is countered by the overall degradation of soils from our poor management of them. Soils are a large highly labile reservoir, and one I understand better than the others (f). It's one part of the carbon cycle we do have a significant affect – a seriously negative one. Reversing this impact and building up soil fertility will improve agricultural productivity and food security. It has the added advantage of increasing moisture retention, reducing the impact of droughts.

They are a good example of our lack of knowledge. The estimates for this reservoir are based on simplistic formulas built on limited data, guesswork, and broad generalisations. We need hundreds, if not thousands, of times more data, and spread over many decades if we are to have any chance of understanding the dynamics.

Despite the positive affect the recent greening of the planet will have had on soils, overall they've been a major net source of atmospheric CO2. The IPCC definitions of land use change are far narrower than I'm considering. Farming practices are of no interest to urban Greens. More broadly, any suggestion that there might have been negative consequences from the real Green Revolution undermines the popular narrative of progress. If soils have degraded and eroded by 20% or more over the last century – a plausible, even minimal, estimate – the CO2 emissions will have exceeded our industrial emissions. The beneficial side of soil erosion is the nutrients provided to phytoplankton.

Table 2 is a brief summary some of the constraints on reservoirs and fluxes. All natural parameters have limits, so the label 'no relevant limit' means no limit relevant to this discussion. The main elements are highlighted in red. The most significant are transfers across the air-water interface, and the mixing of the upper and lower ocean levels by currents, storms, and earthquakes.

Both these processes are localised and highly variable over short and long timescales. There are always large areas of undersaturated surface water and high winds at the poles. The most consistent are in the subantarctic seas where we have the strongest of the Earth's ocean currents, strong winds, and plenty of open sea not constrained between land and sea ice as the case with the Arctic. Tropical storms ensure rapid turnover of oceans there. It's a matter of timing, and the timescales are months to decades not millennia.



Reservoirs	Limits
Deep ocean	no relevant limit
Soils	Vegetation, nutrients, temperatures, rainfall, land use
Ocean floor sediments	no relevant limit
Surface ocean	Henry's solubility law, flux to deep ocean
Atmosphere	Henry's solubility law, land biota, winds, ocean temps.
Dissolved organic	no relevant limit
Vegetation	CO2, other nutrients, temperatures, rainfall, land use
Ocean bacteria	other biota, nutrients, activity state
Phytoplankton	CO2, other nutrients, predation, fishing
Fluxes	**Limits**
Emissions	no relevant limit
Air – land	vegetation, temperature, rainfall, land use
Air – ocean	Henry's solubility law, winds, local temperatures
Upper ocean to biota	nutrients, light, predation
Biota to upper ocean	mortality
Deep to upper ocean	upwelling, ocean currents, storms, earthquakes
Upper ocean to deep	downwelling, ocean currents, storms, earthquakes
Biota to deep ocean	mortality
Ocean floor volcanism	natural variability, possible tidal association

Table 2: A summary of natural constraints

We don't need CO2 removed from the sea, or for us to stop adding it. Our whole industrial era contribution is insignificant. We don't need to get CO2 out of the atmosphere, either, and shouldn't want to, but that's another issue.

The IPCC claim, and with ‘high confidence’, that the time taken for the atmosphere and ocean CO2 levels to come to equilibrium is centuries to millennia. That's if we ignore the claim of ‘a few hundred thousand years’ – political hype, which suits the Summary for Policy Makers not the technical review. Its view of the carbon cycle has been distorted from the start. Its politically motivated brief from the UN was to build a case against fossil fuel use, which has lead it to ignore or deny natural change.

For our emissions to be dominant, the reservoirs and fluxes must have been long term stable to within a small fraction of the highlighted percentages, yet the IPCC doesn't even attempt to make a case for this. Clearly it can't. A combination of small natural variations in marine biomass and other reservoirs, along with increased CO2 concentrations in atmospheric transport to polar waters, provide rapid sinks that can keep the CO2 cycle in a shifting equilibrium as sources vary. There is nothing here to suggest that our emissions are overloading the carbon cycle.

As global temperatures have risen from the depths of the Little Ice Age causing increasing CO2 outgassing from warming ocean surfaces, upwelling old waters, rich in CO2, will also have been returning CO2 from the peaks experienced in the earlier climate optima as the major ocean currents go through their millennial cycles.

Fact or Fantasy – A Review:

Most facts are fragile mercurial creatures – often spotted in the distance flitting about in thickets of data, but rarely captured for close examination when they usually collapse into a small pile of pixy dust. As a writer of Near Future Fiction who tries to keep to the Hard SciFi genre rather than veer too far into Fantasy I often find myself confronted with the distinction. I'm generous with myself in these judgements, so I'm obliged to apply the same standards to others when I believe they are acting in good faith.

The simplest approach is to forget about fact and concentrate on plausibility – how well does an idea conform to what we believe we know about the universe – the probable to the possible. How much tends to support an idea and how much tends to undermine it. When all we know, however little, undermines the idea, we have crossed a boundary into Fantasy.

All nontrivial attempts to portray the future are Future Fiction. With the IPCC's attempts, the fact that our emissions are lost in the noise still leaves their narrative plausible, though wildly overstated, but their assumption that the planet's physical systems and ecologies have been minutely stable for millennia contradicts all the extensive historical evidence we have.

I can excuse small excursions into fantasy if they're not essential to the plot, but this is not a fringe assumption it's the foundation stone of their plot, so I'm bound to see their work as Fantasy. But, as they and Al Gore have demonstrated, it's a very popular genre, particularly when it has a strong apocalyptic theme.

Notes:

a. Errors

The reliability of data is particularly important if we are to take trillion dollar carbon markets or carbon taxes seriously. The gold standard was used for currency because the reserves were controlled and assay was accurate. The reverse is true for the carbon cycle. Little of the data we have is reliably known. For carbon accounting, an overall estimate of ±20% has been mentioned in the literature. The output of the models used by the Global Carbon Project disagree by this amount.

I delved into a few references for the marine data, and the most detailed used the instrument error of the readings. This ignores the fact that the reservoirs and fluxes are aggregates of heterogeneous data that is geographically sparse and scattered over time, so the actual uncertainty was unknown.

The IPCC fallback for error estimates is to ask a few of their mutually self anointed experts to guess. All that can be guessed here is that most of the values in the above diagram are more accurately known than their value for marine biomass.

b. Marine biota

The value of 3 GtC for marine biota is unattributed in AR5 and referred to as ‘phytoplankton and other microorganisms’. I tried to find an original source in nearby citations. The value seems to have been for phytoplankton only and generated from models estimating ocean chlorophyll from satellite data then calculating Net Primary Production. In this branch of the literature I found repeated references to the figure for marine biomass of 0.2% of total biomass, with circular attribution and no original source. This implies a marine biomass of 5 GtC.

It's a current or instantaneous value for a biomass. Hansell et.al. (3) give a turnover cycle of 4 to 6 days with a possible extreme of two weeks mentioned. Taking 5 GtC and a lifetime of 5 days, over a full year the total production would be 365 GtC/y.

c. Correlation

Munshi (20) found that the correlations between our emissions and atmospheric CO2 change were $R^2 = 0.45$ and $R^2 = 0.0068$ for raw and detrended data respectively. This means the correlation is only in the trends, as can be seen in Figure 3. The correlations between atmospheric CO2 change and surface temperatures were $R^2 = 0.56$ and $R^2 = 0.45$ for raw and detrended, so atmospheric CO2 varies with temperature as we expect from solubility laws.

d. The solubility of CO2

For pure water, this is well understood and its temperature dependence is given by Henry's law – relatively uncontroversial physics. Increased atmospheric concentration pushes CO2 into the water surface. Higher water temperatures push it out – as we see when a can of carbonated drink is opened after sitting in the sun. But the oceans aren't pure water. It is claimed (21) that IPCC have reinvented the laws of physics to reduce the ocean sink. If carbonated drinks behaved as the IPCC thinks they should, they'd be flat.

The IPCC retinue focus on the inorganic chemistry that takes place after CO2 is dissolved – the Reville Factor. I looked for the scientific basis for this approach and found only theory and no reference to experiment. The soft drink companies must have researched this extensively over the years and gone beyond inorganic chemistry with the inclusion of fruit juices. The oceans go further with complex ecological dynamics.

Egleston et. al. (22) admit that the Revelle factor of the oceans hasn't changed much over the industrial era, but add to the speculation that it might in the future, causing the oceans to take up CO2 less readily. Some simple laboratory work might clarify this, but New Age Climate Science seems to have an aversion to experimentation, preferring supercomputer models and globetrotting fieldwork. The Argo buoys are now automating ocean survey, so we may eventually have a detailed and coherent physical view of the oceans. As can be seen from my discussion of marine biota, a full picture is a long way off.

e. Models

Models underly almost everything the IPCC says – layers of model upon model. I've built a few mathematical models over the years – simple models that have complex through to chaotic behaviour, and complicated models with many parameters or dimensions. The amount of data needed goes up with power of the number of dimensions. This is easy to understand. If you take 10 samples along a line you need 100 samples over a square and 1000 through a cube to sustain the sampling density. IPCC models have hundreds of parameters, so with scarce and unreliable data the modellers are lost.

Scattered through the IPCC literature base are many pleas for more and better data. They have my sympathy there, but they lose it by not insisting that the data limitations and uncertainties in model structures that reflect our poor understanding of real world mechanisms are not reflected in the IPCC rhetoric.

f. Soils

I've had a lifelong interest in soils, starting with my first few years living in a house built on a sand dune by a beach. One of my earliest memories was discovering clay – amazed that it didn't run through my fingers. Then came maintaining the garden of a newly built family home from an early age. Below a shallow surface layer it was sterile clay that had a faint musty smell when dug deep, as though it hadn't breathed fresh air for a million years. The ornamental Australian natives out the front coped well enough, but the lawns, fruit trees, and vegetable gardens struggled. Someone commented on the problem of soils being poor in the newly developing suburb.

An understanding of what good soil was like came when the government dumped a truckload of rich dark loam outside every home in the suburb. It had realised that creating a lake over the flats of the river that ran through the centre of the city was going to drown the best expanse of fertile soil in the district.

I later helped a friend build a farm-scale composting process in his effort to revive some badly worked-out land to start a small market garden. I remember seeing one of the huge chainsaw hewn bins, early in the morning in a beautiful creek-side glade, jetting mist from the crowbar holes that ventilated it.

A neighbour, an old man who had grown up in the district, described how in his youth it had been highly productive dairy country with deep rich soils, but by then much of the land had turned to poor scrub with patches of sand in places or, at best, supporting a few beef cattle. He inspired me to plough through F.E. Allison's massive tome on soil organic matter (23) – starting with geology, through a multitude of microbes and fungi, and, as I recall, finishing with larger creatures like worms and insects.

Eventually, with a backyard of my own and starting with the same clay as my parents' home, I've spent the last few decades building it up. When I'm gone it will probably be excavated to provide a basement car park for a block of apartments, but it's been an interesting and educational experience for myself and others.

Humans are already using most of the viable agricultural land on the planet and generally degrading it. In the past, vast areas of rich agricultural land supporting whole civilisations have been turned to desert, or near desert, when climate optima have ended. Where the soils have been destroyed – most of the Middle East, North Africa and across the north of the Mediterranean, parts of India and China – there sometimes remained what Carter and Dale (24) refer to as ‘rained-on deserts’ – regions that have water but not the soils that can capture and hold it.

The challenge for this century is to replace quantity with quality, and to do it voluntarily and productively rather than let it happen by destructive default.

g. Natural cycles

Ocean currents have quasi-millennial timing of around 800 to 1000 years. Along with climate optima, they are probably best seen as geographical events that are influenced by weak external drivers that have a more regular cyclic pattern.

My small excursion into climate modelling consisted of looking at published models of sunspot cycles and adjusting them to fit surface temperature data for the southern oceans – initially, a few hours work with a spreadsheet. The accuracy and simplicity of the result spurred me on to explore further. The model already fitted the data far better than the supercomputer models used by the IPCC.

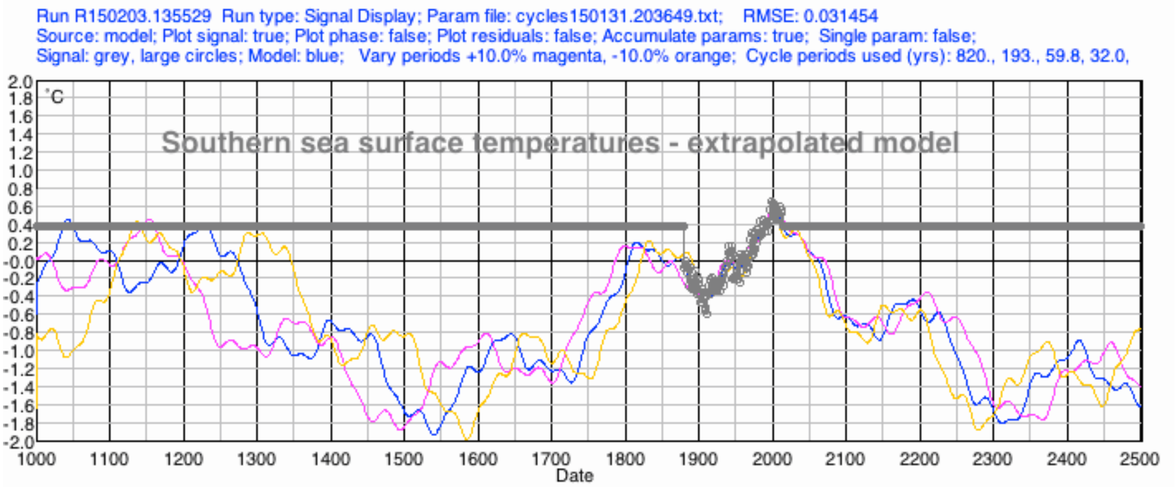


Figure 5

The model has been extrapolated to show the last millennial peak, the Little Ice Age, and future trends. Atmospheric CO2 levels can be expected to follow a similar cycle as it outgasses in warmer climes and is more readily absorbed as the water cools. (25)

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