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Understanding the physical basis of climate change

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1. Aim

This paper explains the physical basis of climate change and its effects to interested non-scientists. Most of the data is taken from the IPCC fifth assessment reports, which can be found here: https://www.ipcc.ch/reports/. All other papers will be referenced in the text and can be found at the bottom of the document. For those who are interested in reading further scientific literature, the AR5 Synthesis Report will be particularly relevant, at least until the sixth assessment report is released in 2022.

2. Introduction

John Reisman once said, *"Science is not a democracy. It is a dictatorship. Evidence does the dictating".* In the current political climate, this is a dictatorship we need to fight to protect. The term 'climate emergency' has been thrust into our consciousness, at a time we have become ever more polarised. While climate change may not be the prominent cause of this polarisation, climate change policy requires a globally united front. The United States, under Donald Trump, has rolled back 85 environmental rules (Popovich et al., 2019), pulled out of the Paris Climate Accord and even claimed climate change is a Chinese hoax, aimed at targeting American manufacturing. Other key global players have followed suit with alacrity: Brazil, under Bolsonaro, has threatened to leave the Paris Climate Accord, with its foreign minister claiming climate change as a plot devised by "cultural Marxists". I'm not sure who the dictators are any more, but it's not science.

3. Earth's natural thermostat

Earth's habitability is the result of the steady surface temperature that is preserved by the amount of incoming solar energy and of greenhouse gasses which control the amount of solar radiation which can enter and leave the atmosphere. A look across at our planetary neighbour Venus can show us what a fine balance this can be. Venus, despite being closer to the sun than earth, absorbs about half the amount of solar radiation (Ruddiman, 2007). However, the surface of Venus is 460°C. This is due to the strength of the greenhouse effect in trapping most of the solar radiation that is absorbed on Venus. Fortunately for planet Earth, negative feedback loops in our living environment have largely kept carbon dioxide levels relatively stable, preventing the same effect on the Earth's surface – so far. These feedback loops are largely controlled by the inorganic carbon cycle which operates on a geological timescale.

The inorganic carbon cycle describes the movement of carbon between the earth's ocean, atmosphere and rocks. The vast majority of carbon is stored in rocks, from which carbon is released naturally into the atmosphere through volcanic eruptions, volcanic lakes and seafloor spreading. Carbon is subsequently removed from the atmosphere by the chemical weathering of silicate rocks such as granites and transported as dissolved ions to the oceans where they are absorbed into the shells of plankton. Large quantities of ocean plankton shells, spread ubiquitously over the ocean, die and sink to sea floor. Here they are buried as marine sediment, and the carbon in their shells are returned to the rock record.

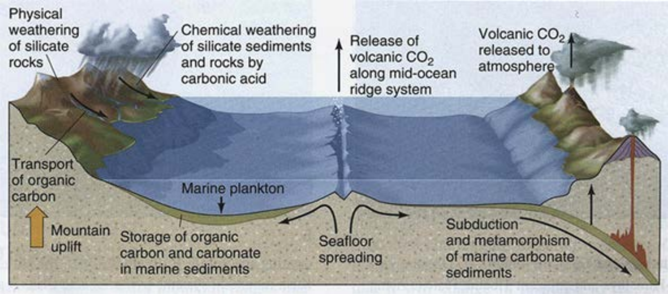


Figure1: Inorganic carbon cycle

Skinner B.J., S.C. Porter and J. Park (2004). Dynamic Earth, an introduction to physical geology, fifth edition. Wiley, 584pp.

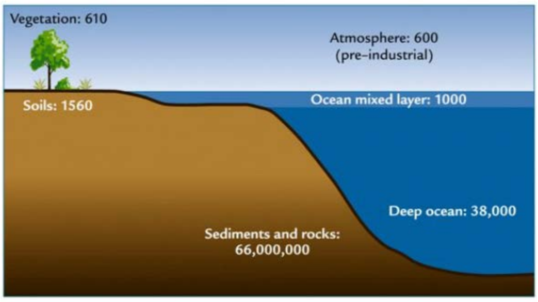


Figure 2: Relative sizes of reservoirs in the carbon cycle

Ruddiman, W. (2001). Earth's Climate: Past and Future. 1st ed.

Huge amounts of carbon are released into the atmosphere naturally every year with approximately the same being removed through chemical weathering (Ruddiman, 2007). As should be evident from figure 2, the atmosphere holds a relatively small amount of carbon compared to the ocean and particularly the rocks. This means that the levels of atmospheric CO_2 are extremely sensitive to any differences between carbon input or output. That's the principle of the carbon cycle, but here's the clever bit.

The amount of chemical weathering, which controls how much carbon is removed from the atmosphere, is dependent on three factors: temperature, precipitation and vegetation. These factors encourage each other; a hot planet is a wet planet with lots of vegetation – and lots of chemical weathering. So, the amount of carbon removed from the atmosphere is controlled by the earth's climate! We can imagine how this cycle would work; an increase in volcanism results in more atmospheric CO_2, which heats up the planet and leads to conditions which increase chemical weathering that eventually removes the CO_2 back from the atmosphere. The opposite scenario also holds true. This is what is meant by a negative feedback cycle. This process has acted as a natural thermostat for billions of years and, has prevented the earth from being frozen for the first two thirds of its history, when we had less solar radiation than today.

However, while Earth has always remained conducive to life, large-scale changes to the environment can have monumental impacts on animals which have evolved to a niche way of life. Environmental changes that have these effects are called mass extinctions. We have had 5 of these events in Earth's history, each causing between 70 - 96% of species to become extinct. While none of these mass extinctions had one singular cause, they were all to varying degrees related to the output of greenhouse gasses. These have occurred generally by changing sea levels causing flooding, asteroid impacts and massive volcanic activity. All previous mass extinctions have caused drastic declines to fauna and flora ecosystems, allowing large scale evolutionary change. With the current extinction of species occurring 1000x natural background rates (De Vos et al., 2014), we could be facing the 6th mass extinction event.

4. What's Changed?

In short: humans. The IPCC states the planet is unequivocally warming, and that it is extremely likely that anthropogenic emissions (the ones produced by human activity) are the primary cause. It has been argued for decades that climatic variability is a natural phenomenon which could account for the changes seen today. However, a recent study (Neukom et al., 2019) has shown that at no point in the Common Era (the last 2000 years) have natural fluctuations been able to cause extreme global temperature changes over a period of decades. By contrast, the study found that for 98% of the globe, the warmest temperature of the Common Era has occurred since the turn of the 20th century, showing that only human induced global warming had caused such increases in temperature on a global scale. Previous fluctuations in temperature, such as the Little Ice age or the Medieval warm period were not "globally widespread" to the same extent.

The IPCC says that current levels of carbon dioxide, methane and nitrous oxide are unprecedented over the last 800,000 years. Since the start of the industrial revolution in 1750, humans have released over 2,000Gt of CO_2 into the atmosphere. About 40% of the emissions have stayed in the atmosphere, 30% has been absorbed by the oceans, causing widespread ocean acidification and the remaining 30% is stored on land, within plants and soils. Half of the emissions produced since 1750 have been released in the last 40 years.

It is noted in the IPCC's AR5 synthesis report that combined anthropogenic forcings (human's total contribution to climate change) are consistent with the observed warming seen since 1950. By looking at figure 3 this is clear; natural forcings and natural internal variability has had a neutral or minor effect on observed warming. The combined effect of humans (orange bar) is clearly the primary cause of observed warming, as it is comparable to the level of observed warming (black bar).

It is interesting that there is a small range of estimates for combined anthropogenic forcings (orange) compared to uncertainty in levels of greenhouse gases (green) and other anthropogenic forcings (yellow). This is because the errors in each estimate partially compensate, resulting in a more accurate prediction.

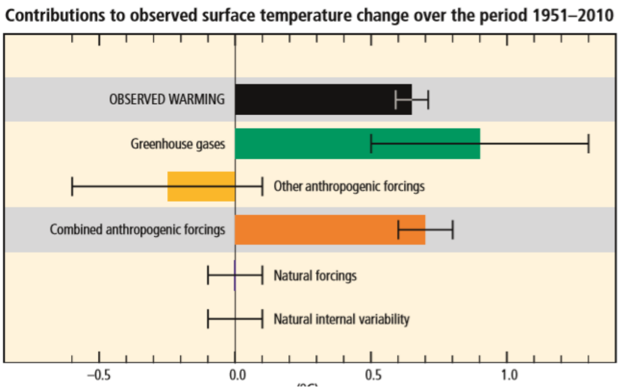


Figure 3: IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 151 pp.

The last three decades have been successively warmer than any decade before it since 1850. The IPCC estimates human activity has contributed about 1°C of warming since the industrial revolution. If warming continues at the current rate, it estimates we will reach 1.5°C between 2030 and 2052.

Climate change impacts the poles most intensely. Over the last century, air temperatures have increased by 5°C on average. The amount of Arctic sea ice in the summer is likely to be extremely limited within a few decades. The annual average amount of arctic sea-ice has reduced by about 0.4% every year between 1979 – 2012. Arctic sea ice has decreased in every season and successive decade since 1979. Conversely, the average annual Antarctic sea ice extent has increased by about 0.15% a year over the same time period. However, there are large regional differences, with ice increasing in some areas and decreasing in others. Antarctica lost 36 cubic miles of ice between 2002 and 2005. Global warming is melting ice from our glaciers. There are less than 30 glaciers worldwide, 20% of the number in 1910. Every year on average, 400 billion tonnes melts from glaciers and flows into the oceans, contributing to global warming.

Unfortunately, humans add about 100x the amount of CO_2 to the atmosphere compared to volcanos (Skuce, 2015), leading to the unprecedented rate of warming we see today. Carbon is being pumped, through the burning of fossil fuels, from the rocks into the atmosphere at a rate vastly greater than it can be removed. The inorganic carbon cycle works on geologic timescales and cannot remove the over 40% increase in atmospheric CO_2 since 1850.

5. Effects of Climate Change

> *"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen"* – IPCC AR5

Food Shortages

By 2050 there will be an estimated extra 2 billion mouths to feed (un.org, 2019), increasing demand for food production. With extreme poverty falling to below 8% of global population, a growing middle class is fuelling an increase in demand for a western meat and dairy based diet with a higher carbon footprint. The UN predicts that by the mid-point of this century, we will need twice as much food as we do today. Greenpeace have claimed that we need to half our current of meat and dairy production by 2050, to “avoid dangerous climate change”. Increasing CO_2 levels cause plants to produce more sugars, reducing the concentration of proteins and nutrients in the plants we consume. This decrease is predicted to leave hundreds of millions of the world’s poorest people at risk of protein, zinc and iron deficiencies in the future.

The 80% of the world’s crops that are rain-fed, will have to face more and more extreme weather. At the 2°C mark that we *aim* to restrict warming to, severe droughts will increase, with a marked affect to the production of grain in India and the Mediterranean. At current rates of warming, crop yields will likely decrease by more than 5% by 2050, with South Asia and southern Africa the worst affected. A warming climate also results in more insects, pests and disease; factors generally left out in future predictions.

Ocean

Since the industrial revolution, a 0.1 decrease in ocean pH has resulted in a 26% rise in ocean acidification. This occurs as a result of carbon dioxide in the atmosphere reacting with salt-water, to form carbonic acid which stabilises by releasing a hydrogen ion to become bicarbonate. The increased hydrogen ions reduce the pH of the ocean towards a more neutral state. The hydrogen binds with carbonate and prevents the growth of organisms such as molluscs and corals, with knock on effects throughout the ecosystem – bad news for the one billion people who rely on fish as their primary protein source. 500 million people rely on coral reefs for food, shelter and livelihoods but 75% of global reefs are currently under threat (Reefresilience.org, 2019).

Due to the thermal expansion of water in a warming climate and the melting of sea ice, sea levels are on the rise. The mean rate of global averaged sea level rise was 1.7 mm/year between 1901 and 2010 and 3.2 mm/year between 1993 and 2010. Over the period 1993–2010, global mean sea level rise is, consistent with the sum of the observed contribution. However, fluctuations in the oceans circulation cause rates of sea level rise to vary over large regions. Since 1993, the regional rate of rise for the Western Pacific are up to three times larger than the global mean, while those for much of the Eastern Pacific are near zero or negative.

Coastal communities make up 40% of the global population. These communities face challenges from rising sea levels, decreased food security and degradation of coastal ecosystems. If we continue without significant action to tackle our emissions, global damages as a result of sea level rise are predicted to reach over £11 trillion per year, nearly 20% current GDP.

Natural Disasters

Hurricanes (or tropical cyclones) require warm surface temperatures of 26.5°C to a depth of 50m (among other conditions) to form (Shapiro and Goldenberg, 1998). As the ocean warms, and holds more energy, the severity of cyclones is likely to increase. Each degree of future warming likely constitutes to a 30% increase in number of category 4 and 5 hurricanes. These tropical cyclones are disproportionately affecting low lying countries in south Asia with large population densities in vulnerable urban areas, with 86% of all tropical cyclone mortalities occurring in India and Bangladesh.

The Meteorological Office has said that by 2050, every other summer could be as hot as the European heatwave of 2003 which caused more than 20,000 deaths and cost European farming over $13 billion alone (Met Office, 2019). This was the hottest summer on record, and it is likely to be a regular occurrence.

Migration

As the world’s population increases (estimated to reach 9.8 billion by 2050 - UN.org, 2019), climate change is reducing the space able to support human life. Rising sea levels will flood cities, water and food supplies become increasingly scarce, the food we produce has less nutritional value and more people will be exposed to the effects of direct heat and extreme weather.

Climate change could well cause a massive wave of migration by the middle of the 21st century. Although the extent of this is unknown, one now famous estimate forecasts 200 million climate migrants by 2050 (Myers, 1993). This would represent over 2% of the world's population. However, estimating future climate refugees is a tricky business and Professor Myers who came up with that figure said himself it required some “heroic extrapolation”. Current estimates range substantially from 25 million to 1 billion climate refugees by 2050. Predictions of future migrations are uncertain due to future climate policies, changes to population growth and distribution and a lack of current regional migration data.

Of course, in the main it won’t be the inhabitants of rich western countries who must move. It will be Bangladesh that becomes largely flooded and increasingly battered by cyclones; it will be sub -Saharan Africa where a predicted 10% decrease in rainfall will have serious knock on effects on the yield production; and it will be the Marshall and Maldives, which are facing more and more flooding events before it will be flooded completely.

Where these migrants will go is unclear. History suggests migrants will move within their region as it is often easier and shares closer cultural ties. But how will India react to large volumes of migrants from Bangladesh, and how Europe will respond to unprecedented numbers of migrants is a question worth asking, especially in the wake of the Syrian refugee crisis.

6. What’s the significance between 1.5° and 2°C.?

The 2015 Paris Climate Accord specifically referenced the aim of restricting global warming to below 2°C and “pursuing efforts to limit the temperature increase to 1.5°C”. The associated effects of a warming of 1.5°C is significant but robustly different from a warming of 2°C. The differences between a 1.5°C and 2°C warming have been outlined by a recent IPCC report and are summarised here. The full document can be found at: https://www.ipcc.ch/sr15/

Sea level rise

By 2100, sea level rise is predicted to be 0.1m higher at 2°C than 1.5°C, putting up to 10million more people at risk of related effects (such as flooding and saltwater encroachment). Sea level rise will continue well beyond next century – although the extent and rate will depend on human emissions. It is noted that the rate of rise will be important for the adaption of humans/ecosystems in low-lying areas. Instabilities in Antarctica/ Greenland ice sheets could be triggered at around 1.5°C -2°C and could result in multi-metre sea level rise over hundreds – thousands of years.

Biodiversity

Approximately double the number of species will lose over 50% of their geographic range at 2°C compared to 1.5°C. The risks of other biodiversity- related impacts such as forest fires and invasive species increase at 2°C. 13% of the global land area is projected to undergo a transformation of ecosystems at 2°C, double the amount predicted for a 1.5°C increase. High-latitude tundra and boreal forests are particularly at risk of climate change with 1.5 – 2.5 million km2 more of permafrost is expected to be thawed at 2°C. Global warming is predicted to be the greatest cause of species extinctions this century. The IPCC says 20-30% of species are at risk of extinction at 1.5°C of global warming whereas at 2°C, most ecosystems will struggle.

Oceans

At 2°C there is predicted to be increased ocean temperatures, ocean acidity and ocean anoxia relative to 1.5°C, resulting in increased risks to marine biodiversity, fisheries and ecosystems. The probability of a sea ice-free Arctic Ocean is 10x higher (one per century at 1.5°C compared with one per decade at 2°C). The effects on Arctic sea ice cover is reversable on decadal timescales. Coral reefs are projected to decline by 70-90% at 1.5°C compared to >99% 2°C. The risk of irreversible loss of marine and coastal ecosystems is higher at 2°C and will damage fisheries, decreasing the global annual catch for marine fisheries by 3 million tonnes (double the loss at 1.5°C). An estimated 500 million people depend upon fish from coral reefs as their primary protein source.

Health and Livelihoods

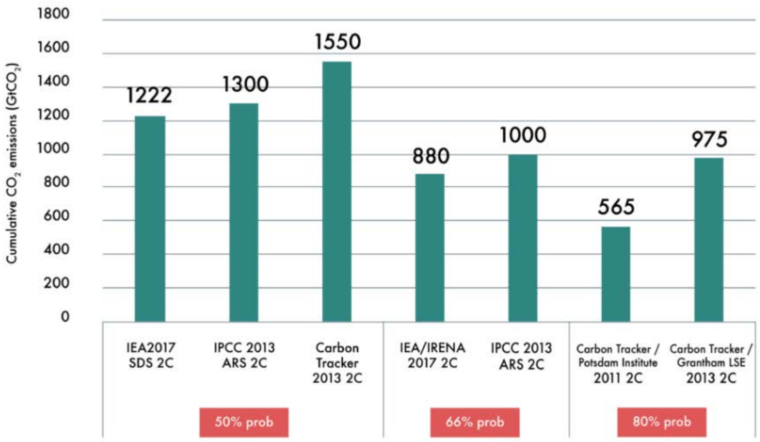
Disadvantaged and vulnerable populations, indigenous peoples, and local communities dependent on agricultural or coastal livelihoods are at disproportionately higher risk of adverse consequences due to global warming. Artic areas, dryland regions, small island developing states, and Least Developed Countries are the regions disproportionately at risk. Limiting global warming to 1.5°C could reduce the number of people susceptible to climate-related risks and poverty by several hundred million by 2050. A 2°C temperature rise will cause more heat- related morbidity and mortality and see more vector-borne diseases (such as malaria and dengue fever) compared to 1.5°C of warming. Heatwaves will be amplified in cities due to urban heat islands.

A warming of 2°C is likely to result in larger net reductions in yields of crops compared to 1.5°C, particularly in sub-Saharan Africa, Southeast Asia, and Central and South America. Reductions in projected food availability are larger at 2°C than at 1.5°C of global warming in the Sahel, southern Africa, the Mediterranean, central Europe, and the Amazon. Livestock are projected to be adversely affected. This is mainly due to changes in feed quality, spread of diseases, and water resource availability.

Limiting global warming to 1.5°C compared to 2°C may reduce the proportion of the world population exposed to a climate change-induced increase in water stress by up to 50%, although this is region dependent. 2°C of warming will cause a larger impact to global aggregated economic growth due to the impacts of climate change compared to 1.5°C, with the tropics and Southern Hemisphere subtropics the most affected.

7. Carbon Budget & Mitigation Pathways

A carbon budget is the total estimated amount of carbon that can be released globally while restricting global warming to a certain temperature threshold. Different institutions naturally come to different estimates or look to ascertain different levels of certainty. The graph below shows different estimates for the cumulative carbon emissions that would trigger 2°C of warming. Based on the IPCC predictions, there is a > 66% chance of restricting warming to 2°C if a maximum of 1000Gt of carbon dioxide is released from 2013 to the end of the century. With current emissions at about 40GtC/ year (Bertram, 2019), if emissions stay level, we would reach this amount by 2038.



Carbontracker.org

The upper limit of the 1.5°C budget is just 200GtC (Bertram, 2019), 5 years of total annual emissions. Clearly, reducing our emissions to 200GtC over a period of over 80 years isn't realistic and therefore, to reach this ambitious target would require the large-scale removal of our CO_2 back from the atmosphere. This requires substantially embracing Carbon Dioxide Removal (CDR) technologies. It is likely that even to keep to our 2°C carbon budget we will need to engage with these technologies. CDR technologies aim to remove carbon already in the atmosphere. Methods can range from simply planting trees (afforestation) or spreading crushed rocks naturally to take up CO_2 onto the ground (terrestrial enhanced weathering). More complex methods such as using chemicals to absorb CO_2 (air capture) or bioenergy with carbon capture and storage (BECC) also exist. All these methods have costs, whether it be financial or material, in requiring large areas of land. There are naturally large uncertainties in the scale, cost and availability of these technologies which contribute to uncertainties in predicting future carbon budgets and mitigation pathways. Institutions and academics compare the current amount of emissions we are producing to the carbon budgets in order to identify the mitigation pathways needed to avoid the most dangerous climate change. They also need to consider the positive feedback effect that greenhouse gasses already in the atmosphere will have.

The IPCC predicts that by 2035, the global temperature will increase by 0.3 – 0.7°C, on top of the nearly 1° already added. Current atmospheric CO_2 is just under 410ppm (parts per million), a rise of 45% since the industrial revolution. Scenarios in which global warming is *likely* to be limited to 1.5°C are characterised by atmospheric CO_2 less than 430ppm at the end of the century. Due to the drastic measures required to make this a possibility, only a few studies have explored the scenarios needed that make this the likely outcome, making assessment difficult.

Scenarios in which global warming is *about as likely as not* to be kept below 2°C typically have greenhouse gas emissions of 30-50Gt CO_2 by the year 2030. Scenarios with emissions that are higher than this require substantial emission reduction between 2300- 2050 which has long-term economic impacts. Most scenarios in which greenhouse gasses are above 55Gt CO_2 in 2030 result in more than 2°C warming by 2100.

Scenarios in which global warming is *likely* to be kept to below 2°C are characterised by atmospheric CO_2 levels less than 450ppm in the year 2100. These scenarios generally require a reduction of 2010 emissions of 40-70% by 2050 and net emissions near zero by 2100, requiring large scale changes to our energy systems and potentially to land usage. It also requires dramatic improvements in energy efficiency and nearly quadrupling the share of energy produced from zero and low carbon sources by 2050. Most of these scenarios involve "temporary overshoot" of emissions where emissions peak above 450ppm this century but fall by 2100 due to widespread deployment of CDR technologies.

8. Risks of abrupt climate change

It's important to realise that the globally agreed goals do not hold any weight with the climate system. 1.99°C of warming is not going to prevent us from the predicted dangers of a 2°C rise. It is an estimate based on current data as threshold for avoiding irreversible (largely) catastrophic climate change. Thresholds exist in our system where climate change exacerbates further climate change to a level to which we cannot stop the ball from rolling. In this section I have outlined a few of these thresholds.

Permafrost Carbon Feedback

Vast areas of Siberia and Canada are made up of permanently frozen soils (permafrost) that store huge quantities of carbon as organic matter such as plants. As the artic heats up disproportionately (2x the rate of the rest of the Earth), the soil thaws and the rotting organic material releases huge quantities of carbon dioxide and methane into the atmosphere. This adds to more warming, and causes more ice to be thawed, creating a positive feedback cycle. There is estimated to be twice as much carbon in these permafrost areas as in the entire atmosphere! This positive feedback causes global warming to increase on a significant scale over a period of years to decades. Perhaps most alarming is that the mechanisms that speed thawing of frozen ground and release soil organic carbon are missing from our global models used to predict the rate of climate change. While the vast amount of this permafrost is thought to be secure, it is estimated by Schuur et al. (2015) that at current rates of warming, 5-15% of permafrost is susceptible to melting – equivalent to about 150Pg carbon.

Increased atmospheric CO_2 causing decreased ocean and land CO_2 absorption

The carbon cycle is the cyclical movement of carbon by tectonic activity and chemical reactions, between the land, ocean, atmosphere and biosphere. The ocean currently absorbs a third of anthropogenic CO_2, mitigating increases of atmospheric carbon. It has been shown that an increase in atmospheric CO_2 decreases the ability of the ocean and land to absorb CO_2 from the atmosphere by 35% and 54% respectively at 4x pre- industrial CO_2 (Friedlingstein, 2001). This creates a positive feedback loop between the carbon cycle and climate system which is estimated to account for an extra 10% gain of CO_2 at 2x pre-industrial CO_2 levels (Friedlingstein, 2001).

In a study of when eleven uncoupled climate models are paired with historical emission data and the IPCC A2 anthropogenic emission projections, all eleven models showed with increased CO_2 levels a decrease in the efficiency of oceanic and terrestrial carbon uptake (Friedlingstein et al., 2006). However, the differences in the additional CO_2 levels predicted by the models, varied by one order of magnitude, resulting in additional temperature increases ranging between 0.1°-1.5°. A lack of consensus between the models as to whether to attribute the majority of this change to the ocean or to the land, reveals the limits of our current understanding.

Collapse of the Thermohaline Circulation (THC)

The thermohaline current, driven by differences in temperature and salinity, transfers warm equatorial water poleward, heating western Europe by up to 10 degrees a year (Challenor et al., 2004). Towards the poles this water sinks as colder, denser water, forming a global oceanic convection current. However, climate change increases the sea surface temperature and melts fresh-water ice at the poles, reducing the density and salinity of high latitude seas. The reduction of temperature and salinity differences could slow down and even stop this convection (Schlesinger et al., 2006).

While a total shutdown of the THC is generally considered a high impact, low probability event, there is a distinct lack of agreement in the literature as to the most likely outcome. None of the general circulation models (GCMs) used in the IPCC's 3rd report suggest a total shutdown of the ATHC in the 21st century when paired with a common greenhouse gas forcing scenario. Instead, they vary between a slight strengthening of the ATHC, to a weakening of up to 50%. Schlesinger et al. (2006) stated that ATHC would shut down if global warming reaches 2.3°C. While the models used are by necessity simplistic, it's worrying indication of the ATHC sensitivity to climate change. Similarly, Challenor et al. (2004) found that climate change posed a risk of a shutdown between 30-40% depending on likely scenarios.

In these climate models, assumptions mean that even the best of models have significant error. Firstly, the climate models make assumptions on unknown data (such as the quantity of Greenland meltwater runoff or how shutdowns of smaller circulation currents will affect global systems) and predictions on future population demographics and climate policy.

To investigate the effects of a shutdown of the THC, Vellinga and Wood (2006) used the HadCM3 climate model and IS92a emissions scenario to show a general cooling of the Northern Hemisphere by 1.7°C and up to 5°C in western Europe specifically, although this is dependent on sea-ice feedback. Precipitation over the Northern Hemisphere would be reduced by 6 cm per year, and sea levels along north Atlantic coastlines would be expected to rise by 25-50cm. These drastic changes over a short time period could pose fresh and urgent challenges in the event of the THC collapsing.

Destabilised Clathrates

Methane clathrates form where water freezes in the presence of gasses, usually methane, which become trapped within the ice. They are mainly found in permafrost regions of Siberia and Canada. Widespread destabilisation of these clathrates through the warming of subsurface sediments could cause a significant positive feedback loop by releasing methane (Dickens 2001), a gas 86x as damaging as carbon dioxide over a 20-year timescale, into the atmosphere (US EPA, 2019).

A key problem in assessing the risk posed by methane clathrates is the lack of understanding of the global volume of methane clathrates and their distribution. One study, (Krey et al., 2009) predicted the quantity of global methane hydrate is in the region of 1,000 to 10,000 GtC. However, an earlier study estimated the number of marine clathrates significantly higher at 74,400Gt CH_4 (Klauda and Sandler, 2005). Comparatively, the global quantity of fossil fuels is estimated to be 5,000 GtC, illustrating the scale of clathrate deposits (Rogner, 1997).

One 2004 model shows that 3°C of global warming will destabilise 85% of the clathrates (Buffet and Archer, 2004). The "gas hydrate disassociation" hypothesis suggests that methane destabilisation was at least partially responsible for the Paleocene - Eocene Thermal Maximum (Dickens, 1995). This was a widescale mass extinction event, in which ocean temperatures rose by up to 8°C within 10,000 years (Gibbs et al., 2006. However, another study (Harvey and Huang, 1995) argues that over 98% of marine clathrates are not at risk of destabilisation until warming at the water-sediment interface reaches 4°C. It suggests there is larger uncertainty in future climatic warming due to climatic sensitivity and fossil fuel use than due to potential destabilisation of methane clathrates. This suggests methane clathrates could only provide a strong positive feedback at temperatures which would have already resulted in dramatic impact to ecosystems and society.

9. Conclusion

Climate change is all around us. Sea ice is melting, water levels are rising, crops are failing, and extreme weather events are more frequent and devastating. As the amount of carbon in the atmosphere creeps up and temperatures rise slowly but surely, it feels like all of us are sleepwalking into a crisis of unparalleled significance. Climate change does not simply threaten the well-being of those affected by the increased hurricanes, droughts, floods and famines. Instead, it's a threat to all 7.7 billion people living and to all the future generations that will ever live. Climate change (on a human timescale) is not going away; it is something we have already set in motion.

However, while it is very easy to be pessimistic about our future, we can shape the world we live in. What is more, all of us know the solutions required to fix this mess. We need the political will to phase out dirty energy, we need a carbon tax and we need massive investment into CDR technologies and green energy. What is more, it is also the economic thing to do! While it may have huge initial costs, the cost of doing nothing will be far higher.

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