Chapter 5

A Warmer Future

The previous chapter explained the science of climate change and some remaining scientific disagreements. This chapter explains what scenarios humanity should prepare for. There is no scientific disagreement that the global temperature is rising and at an increasing rate. NASA satellites tell us that the world is not even close to a new temperature equilibrium yet. Global warming is about to accelerate — and it will do so for a long time even if humanity managed to greatly reduce its emissions.

In the last chapter, we explained that a minority of scientists are wondering whether anthropogenic greenhouse gases are solely or just largely responsible for global warming. *From our book's perspective*, this does not matter much. The economic theory, models and evidence (explained in detail in Chapter 6) strongly suggest that humanity would collectively be better off if it greatly reduced its fossil-fuel emissions. And when one country reduces its emissions it has a positive effect on the others. The world is better off not just for global greenhouse gas reasons, but also for local particle pollution reasons.

Our perspective is that the real problem is not that the world has not yet gone far enough in its assessment of the needed cuts, but that individual decision-makers — countries and people — have their own and different incentives. It is in their self-interest to pollute when they don't bear the entire cost of polluting — and we see no realistic scenario in which this will change.

The world as a whole is currently so far from where it should optimally be that environmentalists' penultimate goals seem irrelevant to us. It is not important how far fossil-fuel reductions should go. It is important to get viable cost-effective reductions jump-started. For now, although climate science and activism have successfully saturated the media, they have not meaningfully reduced worldwide emissions.

To us, the world seems like a team that is behind 0:5 and its players and coaches are now arguing about whether they will need to score 5 goals or more than 5 goals (because the other team could score again). Meanwhile, ten of the team's players have already sat down on the field or gone to the locker room, unwilling to suffer more personal exhaustion and injury, while a minority of fans (activists) are impotently yelling at their TV screens that the coaches should get the players running again.

It seems to us that environmentalists should care less about Utopian changes, and more about getting the world going *now* on realistic and cost-effective reductions in fossil fuel consumption that policy makers and the general public *world-wide* (and not just in the US and Europe) can sign onto.

This chapter also covers a related and perhaps even more important issue. In our view, the world has to be prepared for the unexpected. There is tremendous risk and uncertainty in climate forecasts. What could plausibly happen but is unlikely to happen is potentially far worse than what scientists *expect* to happen. Worst-case scenarios are important and have to enter the analysis — but they must also be kept in perspective. Ships are "overengineered" with safety features and even carry life boats, but they are not built and operated for worst-case scenarios. That is, they still set sail despite the fact that there is a danger of sinking. Climate policy cannot be based exclusively on the worst possible outcomes — though worst cases must still be evaluated. Moreover, there are also more than a handful of other existential risks for our civilizations. If we live to ensure against all of them, the only thing that will be ensured is that our civilizations will slowly disappear. An analogy is a soldier in a battle who knows that death could come from many places. It is impossible to avoid them all. It's not a situation one wants to be in, but it is what it is. Earth is not and never has been a safe place.

This chapter will first look at the most likely scenario — accelerating global warming — and then pivot to further risks, such as feedback loops and tipping points.

joke

> According to a new U.N. report, the global warming outlook is much worse than originally predicted. Which is pretty bad when they originally predicted it would destroy the planet. — Jay Leno, comedian

1 The Expected Warming Path

Adjustment Speed

For a comprehensive analysis of Earth's expected warming path, we recommend Archer's book. This section is our quick-take.

Assuming that civilization were to stop all emissions today and the CO_2 concentration remained at 410 ppm, how long would it take for the planet to settle down to a new equilibrium temperature? The best-case answer is...*centuries*. The planet has many heat buffers. The most important ones are again the oceans. The oceans are large and warm only slowly. And glaciers, polar caps, and Siberian permafrost are melting into the oceans, spreading the rate of temperature increases further over longer time spans.

What do the mainstream physics models say? As noted in the previous chapter, they predict roughly an ultimate increase of 1.5°C for the 50% increase in CO_2 that human fossil-fuel use has caused.[1] Only about half (0.8°C) of this increase has occurred to date. If CO_2 concentration stabilized at today's 410 ppm level (not a chance!), the planet would reach the three-quarters point of adjustment to final equilibrium by about 2100 — in other words, there would be a further increase of 0.3–0.5°C. The remaining 0.3–0.5°C warming would then take centuries.

This description is a good first take, but it is also an impossibly static view. It ignores the fact that civilization continues to pump ever more GHGs into the atmosphere. It ignores further amplifying or mitigating effects. To prepare for climate change, the world needs to work with more detailed projections.

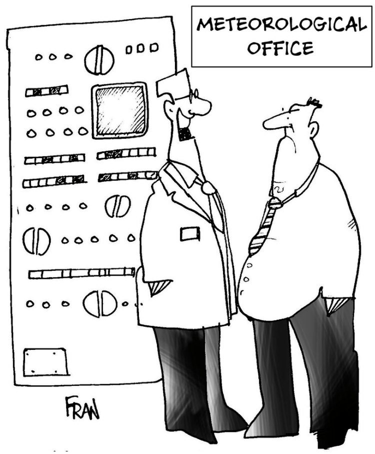
Common Representative Scenarios (RCPs)

Historically, one of the many problems of planning for global temperature change on human time scales was that different scientists had used different models that had resulted in different predictions. And before they could even discuss any new findings, they always first had to synchronize their jargon, data, models, and backgrounds.

In response to this cacophony, the World Meteorological Association decided in 1988 that it needed more standardized assessments. Thus, it founded

[1] The increase from 280 ppm to 410 ppm is about 50%. Applying this 50% increase to the aforementioned effect of doubling (3°C) gives this 1.5°C.

the Intergovernmental Panel on Climate Change (IPCC). The IPCC has developed a set of scenarios that are designed to summarize broadly the impact of rising greenhouse gases from many different models.[2]



With our new super-fast computers, we can get the forecast wrong TWICE as fast as we used to!

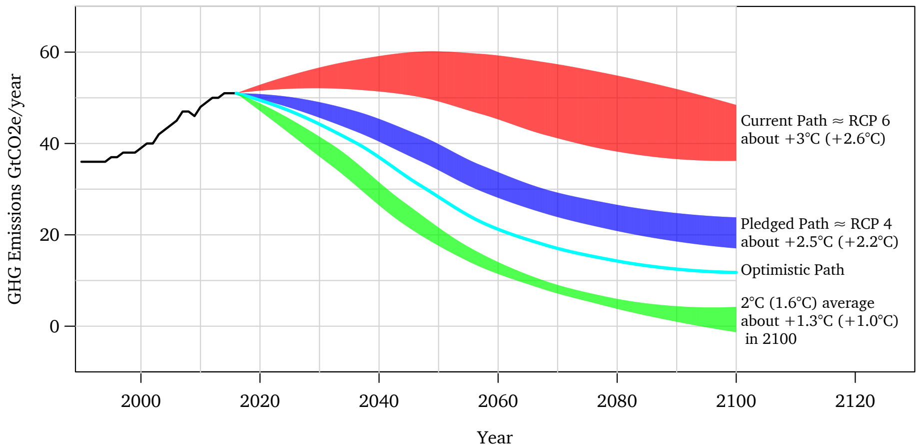
The most useful IPCC scenarios have the "memorable" name of Representative Concentration Pathways, more commonly abbreviated RCP. The name designates the extra net solar radiation in Watts per Square-meter that will heat up Earth. There are many paths that remain on the same pathway. (For example, the world could emit more this year and less next year.) We will use reasonably representative numbers for emissions, CO_2 in the atmosphere, and temperature based on pathways that we will be discussing.

The RCPs are firmly based on the mainstream view that water vapor and clouds produce an amplification factor of approximately 2–3 in order to best reconcile the historical global trends in CO_2 and temperature. The RCP model scenarios primarily consider how much pollution humans emit; how long these emissions will stay in the atmosphere; and how much solar radiation the atmospheric gases, water vapor, and clouds will trap. The RCPs are a group of reasonable scenarios that describe the paths of future warming under different assumptions.

The RCPs have also played important roles in all international climate negotiations. Their key advantage over the even simpler "ultimate-equilibrium-outcome temperature" models is that they provide dynamic time paths, rather than just the static equilibrium end-points with which we started this section.

[2]The IPCC has also developed social, political, and economic analysis, called SSPs. As economists with knowledge of the performance of macroeconomic models, we find these to be less convincing. Our disagreements are not important here. We just advise our readers to keep an open but skeptical mind when reading IPCC reports. Importantly, SSP1-2.6, SSP2-4.5, SSP4-6.0, SSP4-7.0, and SSP5-8.5 are SSP scenarios that follow RCP 2.6, RCP 4.5, RCP 6, RCP 7.0, and RCP 8.5. The SSPs can be thought of as potential narratives that feed into the RCPs. (We sometimes abbreviate RCP 4.5 as RCP 4. Scientists do not have enough data to reliably distinguish between the two, because the differences are minor.)

Figure 1. IPCC Emission Pathways With Uncertainty



Note: The first temperature increase quoted on the right is relative to pre-industrial times; the second (in parentheses) is reasonably human-caused and thus about 0.3–0.4°C lower.

Source: ClimateActionTracker, May 2021 update.

Figure 1 includes reasonable time paths of future emissions and temperatures for the two most important and widely-referenced RCPs.

RCP 6 (in red) is a realistic "modest effort" scenario. As of 2020, think of it as a "minimal-intervention business as usual" scenario. Under RCP 6 (i.e., net warming of 6 W/m^2) global emissions would peak in about 30 years,[3] and temperatures would rise by about 3°C by 2100 relative to pre-industrial times. We consider it the most realistic scenario looking forward 50 years. Few analysts predict much higher emissions paths (such as RCP 8.5).

Beginning with the 2021 IPCC report, RCP 7 has become a newly prominent scenario—with modestly more warming than RCP 6, of course.

RCP 4 (or its near twin RCP 4.5, in blue) is an "active intervention" scenario, based on current government pledges. World emissions would peak this decade. Global temperature would rise by about 2.5°C by 2100. This

[3]This is in line with current expectations by the U.S. Energy Information Association.

scenario seems unrealistically optimistic. The world is already falling short of RCP 4. Few believe that it could be rescued.

Just like simpler models, the RCP estimates are expected values with a lot of uncertainty around them (shown as bands in the figure, which become larger further into the future). Think of the RCPs as discussion scenarios, not as famous last words.

Look closely at Figure 1: The *expected* differences between the RCP 4 and RCP 6 scenarios is 0.4–0.5°C, the difference between 2.5°C (requiring a lot of effort in RCP 4) and 3.0°C (requiring little effort in RCP 6). Recent estimates of the global damage are that the economic effect of the extra 0.4–0.5°C warming will be a lowering of GDP by about 0.1%, with perhaps half coming from agricultural damage. (We have never seen GDP damage increase estimates above 0.3% when comparing RCP 4 and RCP 6.) This 0.1% of world GDP is a lot of money — a few hundred billion dollars — but these are damages that are eminently survivable for human civilization.

The World Health Organization (WHO) predicts about 250,000 additional deaths per year from climate change by about 2050.[4] It also suggests that these extra deaths will occur almost exclusively in poorer countries.

The prediction is based on two primary causes. The first is more disease. After HIV, Cholera and Malaria are the top killers in tropical regions today. Yet, contrary to WHO predictions, it seems plausible that medical progress — fueled partly by economic growth — could greatly reduce these diseases. Fighting Cholera and Malaria by limiting GHG emissions to slow down warming does not seem like the wisest use of limited resources. Investing in medical research (such as vaccine development) or even eradicating the Mosquito vector altogether appear far more promising.

The second is malnutrition. Harvest failures and famines have been common throughout history. In 2023, 43,000 Somalis may die because of failed harvests after the fourth year of drought. (And no matter what emission reductions the world will undertake, many more years of drought will likely follow.) Yet, contrary again, famine mortality in the world could also continue

[4]The latest (2020 academic research predicts significantly more deaths after 2050 (mostly in Africa) under RCP 8.5 — although this research also states that its mortality estimates are so uncertain that it cannot even reject the null hypothesis that there will be zero excess deaths due to climate change. It's hard to predict 80 years into the future. How would you have predicted 2020 in 1940?

to decline — largely because fossil-fueled ships have been providing ever-cheaper every-larger amounts of food to ever-more famine-stricken areas. The primary reason why so many Somalis and so few Sahel-ians are dying today is that the country is in the midst of a civil war, which makes supplying its people difficult.

In short, if you suffer from existential climate-change anxiety, you need perspective. Although 250,000 is a lot of people, it is "only" 0.003% of humanity. Far more people die from poverty every year. It's cruel, but economists have to think in millions and billions of people. Under RCP 6, high emissions will continue well into the next century. (Fossil fuels will become more difficult to find at that point, too.) Thus, the RCP 6 harm will be worse and more persistent than the RCP 4 harm. The temperature under RCP 6 will likely not stabilize until 2200-2300, whereas under RCP 4 it would stabilize around 2100-2200.

Any damages beyond the year 2100 will be caused more by future generations than by us (except in the sense that we are responsible for getting them accustomed to more wealth and higher standards of living). And those future generations will likely be richer than us. With better technologies, they may find it easier to get off fossil fuels. Furthermore, it seems unlikely that today's world cares more about the poor in this world three generations into the future than it cares about the poor already here today. The evidence is harsh and depressing. But it is what it is.

The modest *percentage expected* temperature and GDP differences should not be interpreted to imply efforts to reduce emissions are unimportant, but they put the *expected* outcomes into perspective:

1. Even with great effort and activism success in stemming climate change, Earth will still be warming. Realistically, activist effort is only about slowing down warming by a modest amount. No one believes that it is possible to reduce warming to less than 2.5°C (1.5°C above today).
2. Even without special efforts, i.e., if the world ignores climate activists altogether, Earth will be warming by a similar magnitude, maybe 3.0°C instead of the just-mentioned 2.5°C. As long as "only" the *expected* bad outcomes occur, humanity will end up worse off, but by no more than, say, about 0.1–0.3% in welfare. This may be bad, but it is far from the end of the world.

However, from our perspective, the precise expected temperature change is not what really matters. We leave it to others to debate whether the ultimate global temperature increase is likely to be 2°C or 4°C. We think it doesn't even matter whether the optimal intervention from a global perspective is to keep the temperature increase under 2°C or under 4°C. Our book's "shtick" (colloquial for "theme") is that the best global choice is ultimately irrelevant. There is "no one home" who can pursue the optimal choice for the global collective. Individual decision-makers can only decide for themselves. Because the decision-makers do not receive all the benefits, they don't lower their emissions enough. Whenever they do lower their emissions, it has further positive effects on everyone else.

Thus, in our view, activists should care about how they can realistically nudge decision-makers towards *moving the needle* **now**. Lower fossil fuel consumption may not help one's own country, but the effects on other countries will be positive not negative... And, as we previewed in Chapter 1, there are good choices (and bad ones). We will return to them many times in later chapters.

At the time of the 2016 Paris International Climate Accords, the IPCC had also laid out the already briefly mentioned RCP 2.6, roughly the same as the green band in Figure 1. This scenario could have been met only under unrealistically aggressive policies. This scenario is basically obsolete. That train has already left the station. RCP 8.5 was the opposite — a pessimistic scenario based on the assumption that humanity would take no steps to abate emissions. This would have resulted in about 4.5°C of warming. Technological advances have thankfully rendered RCP 8.5 obsolete as well. (However, the ghosts of RCP 8.5 still haunts many analyses on the Internet and pieces in the popular press.)

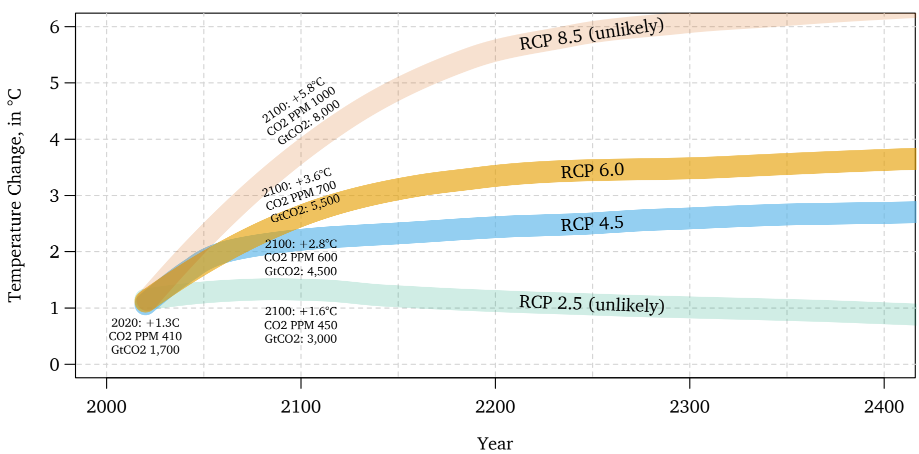
2 The Expected Warming Harm

Planet Earth has been warming at an accelerating rate, and we have seen only a small part of it so far. How bad should we expect the harmful economic consequences of global warming to be? Of course, that depends on which RCP we are talking about, but we can sketch the general mechanisms.

RCP-Based Temperature Changes

To review, the world currently emits about 30 $GtCO_2$ per year, with about equal shares of 10 $GtCO_2$ each by the OECD (6 $GtCO_2$ from the USA alone), by China, and by everyone else. Adding other greenhouse gases and a charge for land use (deforestation) brings this up by another 20–25 $GtCO_2e$. In cumulative total, humans have emitted about 1,700 $GtCO_2$ since about 1800, of which about 1,000 $GtCO_2$ have remained in the atmosphere. The temperature is now about 1.4°C higher than it was before industrial times and 1°C higher than it was before the Renaissance. (Table 7 on pg. 20 provides a handy summary.) An increase of at least 0.7°C has already been caused by human greenhouse gas emissions, perhaps more, but only half of this effect has occurred so far.

Figure 2. Climate Change Under RCP Scenarios



Source: IPCC, Nazarenko et al. and Meinhausen et al.. The base year is 1980, suggesting a world temperature increase of about 1°C by 2020. The more important aspects are the relative temperature paths.

Figure 2 plots the expected temperatures over the next few hundred years under four RCP scenarios. Let us start with the two implausible extreme scenarios. To limit Earth to the current temperature would require us to stay on RCP 2.5. Total emissions would have to be no more than about 3,000 $GtCO_2$ by 2100. With 1,700 $GtCO_2$ already emitted, the remaining 1,300 $GtCO_2$ budget allows for about 20 $GtCO_2$ per year *on average*. This scenario has become so exceedingly unlikely that it is now only an interesting hypothetical. Emissions are already running closer to twice this 20 $GtCO_2$ and they have not yet peaked. The opposite extreme is RCP 8.5. It assumes continued fossil-fuel use at peak levels without much regard for climate change. It is outdated largely because clean energy technology has been progressing at a rapid rate.

Very importantly, you should not think of RCP 8.5 as 40% more CO_2 concentration or emissions than RCP 6.0. This is because RCPs are an exponential scale. It takes about twice the human emissions to push from RCP 6 to RCP 8.5—and, at this point in 2023, it has become hard even to imagine how this could possibly come about. It also means that while it is easy to reduce emissions to lower the RCP by two notches at the high end, it would be very difficult to do so at the low end, say, from RCP 4 to RCP 2.

This leaves the two plausible scenarios. RCP 4 limits humanity to about 45 $GtCO_2$ per annum, while RCP 6 limits it to about 55–60 $GtCO_2$ per year by mid-century. We deem RCP 6 to be more likely than RCP 4, because many poorer nations still want to develop and this requires more energy. Roughly speaking, the goal of climate conferences is to push civilization from RCP 6 to RCP 4. By 2050, the differences will still be quite small, perhaps too small (0.1–0.2°C?) even to distinguish between the temperatures in the two RCP scenarios. The main difference is what will happen after 2050. By 2100, the two RCPs are expected to diverge by about 0.3–0.5°C.

Interestingly, as of 2021, the MIT Technology Review reports that some trackers are beginning to revise their expected temperature estimates *downwards*. Both the climate action tracker and the United Nations now forecast a best-estimate scenario squarely between the two RCPs. The former expects a temperature increase of about **2.7°C** this century, on top of the 0.7°C last century. Perhaps even more importantly, their estimates of the extent to which activist policies could reduce global warming reductions have also moved towards the lower end. Their activist intervention scenario may only offer an expected reduction of 0.3°C, down from 0.5°C.

Terrestrial Changes: What does 2°C Really Mean?

What will be the impact of climate change? We start with the direct impact of warming on land.

The temperature on the planet drops *on average* by about 1°C every 100 miles away from the equator. This means that everyone in the Northern Hemisphere is *on average* about to make a move 200 miles south. We also know the average temperatures in different cities today, which helps to judge the meaning of such changes. In the United States:

Boston	New York City	Washington DC	Atlanta
11°C	13°C	15°C	18°C

In Europe,

Stockholm	Berlin	Milan	Rome	Palermo
8°C	10°C	13°C	15°C	18°C

In Asia,

Beijing	Tokyo	Shanghai	Hong Kong	Singapore
13°C	16°C	17°C	23°C	28°C

Clearly, the feelings of these cities would change with a 2°C increase in annual temperature, but it wouldn't mean the end of habitability for any of them. Even 4°C would qualify as more of a major nuisance than an outright catastrophe to most Carolinians. And so what if New York's climate would become more like Atlanta's? There would be transition costs, but it would seem unlikely that it would make the world much worse off.

It is also not the case that 2–3°C would suddenly render much of Arizona or the Sahara uninhabitable. For practical purposes, they have already largely been uninhabitable for millennia. With little access to water, hot deserts are inhospitable.

The real problem lies in the middle. Parts of the adjacent Sahel would, however, likely become newly uninhabitable. This would heavily impact its 135 million inhabitants — but there is a lot of uncertainty even here. It could be that changing weather patterns could turn the Sahel wetter again, which could offset the harmful increase in temperature in terms of human habitability. Yet the change in precipitation patterns could then devastate altogether different areas. (Active human replanting, a form of geoengineering, could probably help in the Sahel, too.)

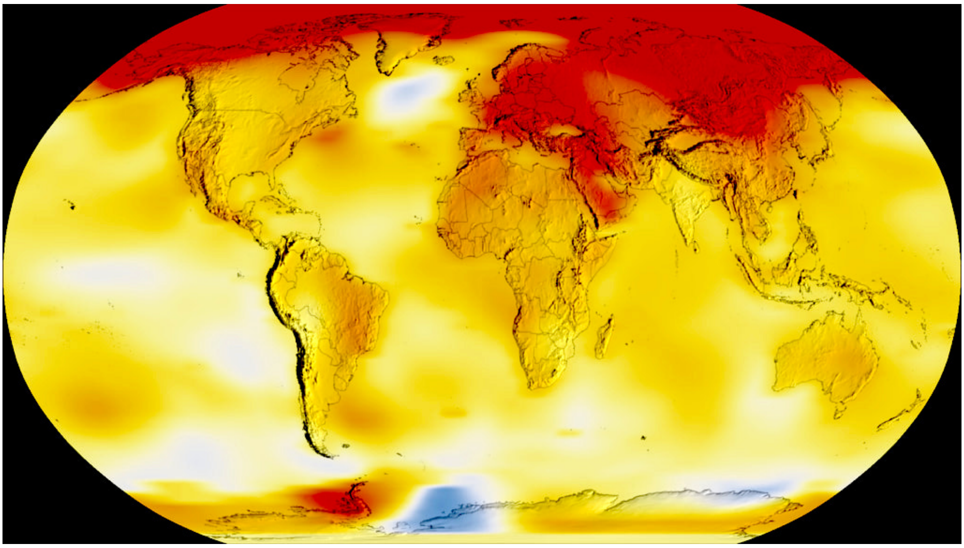
Have you noticed global warming?

Perhaps even more importantly, what is the *avoidable* climate change? This is where the limitations of fighting climate change come into clear and depressing focus. The 0.5°C avoidable climate change is the difference in temperature between, say, Queens and Manhattan, or Beverly Hills and Santa Monica. Humanity needs to steel itself against climate change. It's coming for us. Although humanity would ideally also do more to reduce climate change and especially fossil fuel emissions, the avoidable rise is small. It is the unavoidable rise that is large.

Now, these may be the expected global changes, but there is no guarantee that they will apply in any particular location. In fact, in some locations, they could be devastating. Some climate researchers have warned of possible scenarios in which Europe could plunge into the equivalent of an ice age, with temperatures 10°C colder than it is today. Such scenarios are of course exceedingly unlikely — but perhaps not impossible. And, moreover, the probability of avoiding them through an 0.5°C effective emission reduction is not zero, but even more exceedingly unlikely.

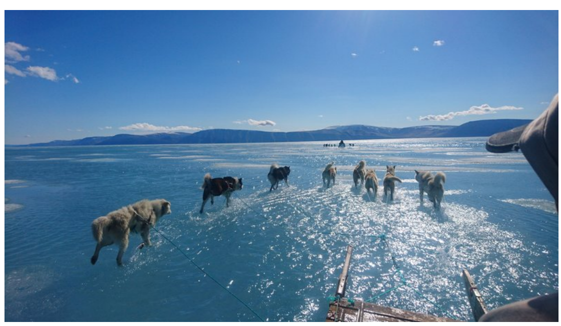
The evidence shows that global warming has not been uniform, either. Figure 3 shows the changes in temperature across different regions of the globe so far. The warming has been most dramatic around the poles on the Eurasian continent and in Western Australia. In the tropics, where relatively more poorer people live, the increase has so far been more modest. Much of the United States has not been greatly affected by climate change yet. This could change. Where will the most dramatic warming and cooling occur? Scientists don't know the answer. It's a tough risk to take.

Figure 3. Map of Planetary Global Temperature Anomaly



Source: NASA Scientific Visualization Studio. The increased temperature in 2021 is measured relative to 1951-1980. Except a small portion of Antarctica and south of Greenland, all temperatures have increased. The strongest increase has occurred over Eurasia. Similar to Figure ??.

Sea Level Rise

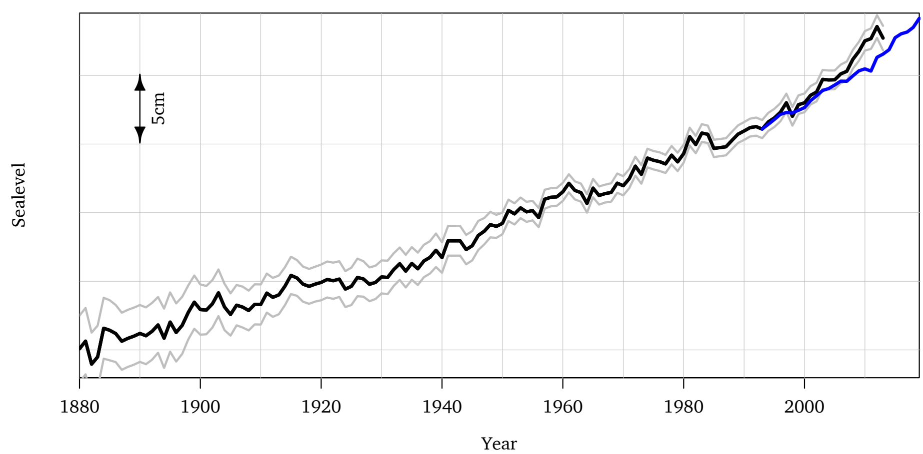


The second important consequence of global warming is rising ocean temperatures and sea levels.[5] (Ocean acidification, discussed in Chapter 2, is not primarily a warming consequence.) The sea level rises primarily because warmer water expands in volume. Glacial meltwater from land (primarily from Antarctica and Greenland) raises global sea levels further.

[5] Koonin, Unsettled, Chapter 8 offers a more detailed but controversial discussion of sea level rise predictions.

The oceans are an effective heat buffer, because water holds much more heat than air. Whereas land temperatures have risen by about 1°C over the last 100 years, even the upper layers of the ocean have warmed "only" by about 0.13°C. The lower layers have probably warmed much less, but scientists have no long-term measurements of how far down global warming has reached and how unusual any warming would have been.

Figure 4. Global Mean Sea Level Rise Since 1880



Source: Environmental Protection Agency (EPA). The blue line shows satellite data; the other data are from tide gauges. For a longer-term perspective and predictions, see Realclimate.org.

For now, the sea level rise seems to have been a slow and steady process. (Maybe it is very mildly accelerating.) Figure 4 shows that the rate was about 2 mm per year for the last 150 years or so.[6] Not shown in this graph, it also seems that this 2 mm was much faster than it was for millennia before. The increase almost surely indicates a warming ocean.

However, there is a small mystery here. Recall from Figure ?? on Page ?? that Earth has warmed much more since about 1950. The temperature anomaly was barely 0.3°C by 1950. The warming rate was much slower before then. (And warming likely wasn't due to the still small human CO_2 accumulations in the atmosphere.) Yet, why was the sea level rising at almost

[6]Interestingly, it is difficult just to measure what the global sea level actually is, in part because water and ice themselves have enough weight to press down entire continents.

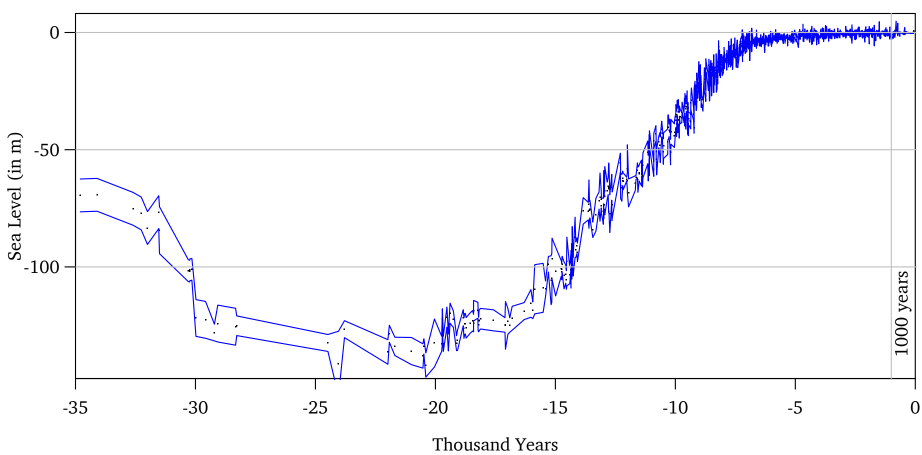
the same rate around 1900 — before most of the temperature anomaly took hold — as it has been rising after 1950?

As of 2022, the IPCC projects for 2021 a global sea water rise of 55 cm (22 in), plus or minus 20 cm, under RCP 4 and about 65 cm (25 in), plus or minus 22 cm, under RCP 6. Some critics (specifically Koonin, Chapter 8) have argued that the IPCC has predicted a sea-level rise that is too high.

Other considerations, however, suggest that there is a risk that the sea level rise could turn much higher. Accelerated melting of ice sheets could increase the rate to as much as 180 mm/year (about 3.4 meters per century) in a near-worst-case scenario. An increase of 60 cm is bad but not catastrophic; 340 cm is on a totally different level!

There is good reason to be more concerned about long-run future sea levels (though humans can move over time spans of millennia). Figure 5 shows that just 20,000 years ago — about the time when modern humans spread across the continents — ocean levels were likely 120 meters lower than they are today. *This 120 meter figure is not a typo!* Some forecasts 10,000 years into the future even predict sea levels that will be 35 meter higher than they are today.

Figure 5. Long-Term Global Mean Sea Level Rise



Source: Clark et al., 2016, Consequences of twenty-first-century policy for multi-millennial climate and sea-level change, Nature.

sidenote

There are many lost lands — perhaps not Atlantis, but surely a lot more than just Doggerland, a large swatch of land connecting Britain to the continent that was settled by ancient and now displaced tribes.

The harmful consequences of sea-level rise are easier to predict than the harmful consequences of terrestrial weather changes. This is because annual water temperature variation is smaller and satellites provide near perfect elevation data. Shore dwellers can look up online whether they will be harmed by future sea-level rise. The most vulnerable region in the United States is Florida. Worldwide, the most exposed regions include Bangladesh, Indonesia, the Netherlands, Venice, and parts of England. Some islands will disappear. But for most of the rest of the world, sea-level rise will be a yawn. Don't expect residents of Nebraska or Russia to be greatly concerned.

3 Inevitable Change and Associated Harm

Earth has always been changing. Maybe it was an accident or maybe it was not, but civilization has evolved in the most pleasantly warm and least volatile 4,000 years of the last few hundred thousand years. We cannot expect this unusual low environmental variability to continue forever — and even the best geoengineering will not be able to stave off large climate changes at some point in our (hopefully more distant) future.

Civilization will have to learn how to deal with more climate change — if not now, then in the future. For readers prone to fear and anxiety, we can provide some comfort (although there are better other books dealing with climate anxiety). If the IPCC's most likely outlook is correct, climate change will be modestly harmful, but it will be no threat to human civilization. The majority of humans (and especially those in rich countries) will come out just fine. They will barely be affected. A minority of humans (most of them in poor countries) may not.

All change creates winners and losers. And change is itself costly. On average, any change creates harm, because adapting is costly (just as fighting to prevent it is). For this reason, any change typically imposes suffering disproportionately on poorer people.

Nevertheless, there is an important point to keep in mind. Environmentalists and activists often paint a distorted picture, because they count up only the losses of climate change without netting these losses against the gains that will accrue to others. (Yes, climate change will create winners, too!)

Where?

Unfortunately, the temperature map in Figure 3 does not show what economists are most interested in: where do we expect the most extreme economic consequences of warming?

Many terrestrial impacts are difficult to judge; some are easy. The worst harm to humanity will clearly not occur in the Sahara or in the Antarctic. They are already uninhabited. Instead, the worst harm will occur somewhere in between.

However, the economic effects are also not always intuitive. If Earth warms by, say, 3°C on average, it could be that it warms 6°C in parts of Canada and Siberia. If you now rejoice that this is great, because the Northern regions would become more pleasant, this conclusion may well be wrong. Although warmer temperatures will lengthen the Northern growing seasons, make their climates more temperate, and raise Russian and Canadian GDP in some areas first and the rest in the very long run, the melting permafrost could initially turn large parts of these regions into uninhabitable and stinking slush for decades, if not centuries.

To date, future terrestrial impacts due to global warming are difficult to judge. Scientists neither fully understand where most future global warming will occur nor how bad the consequences will be. (And they understand even less when they try to take into account changes in future weather patterns.) At best, scientists can offer only rough overall global guesswork with few confident specifics.

Sea-level impacts near shores are much easier to judge than terrestrial impacts. For one, we can comfortably predict that inland residents of continents will suffer little harm. Residents of Denver, La Paz, Addis Ababa, and Kabul have nothing to fear. Many million people who have settled near shorelines do — about 770 million people live at elevations lower than 5 meters. For them, sea level rise could cause a lot more misery.

The first harm will be that local drinking water becomes salt-water contaminated and useless. This is already a concern in Miami. Bangladesh could lose 10% of its land over the next century. As many as 400 million people could be forced to move, primarily in Bangladesh and Indonesia. It is cold comfort to those affected, but sea-rise caused and climate-change-caused migrations have happened many times before in human history — sometimes accompanied by warfare.[7]

In rare cases, communities have built sea barriers. The Dutch have shown the rest of the world how to survive below the sea-level by building dykes (which they built when they were still quite poor). Manhattan will almost surely not recede underwater for centuries, although it will have to pay dearly for better flood control measures. Some valuable land and beach houses will be lost to erosion (expensive when summed up over all the world's coastlines), but there will still be plenty of newly habitable oceanfront, too.

Who?

Many of the remaining chapters of our book will focus on how civilization should respond to impending warming. But one thing is clear: environmental changes will always harm the poor more than the rich. Wealth makes adaptation to change easier. At an individual level, rich people can buy air conditioning and move away more easily. At the country level, rich countries can build better sea barriers. It has simply always been better to be rich and healthy than poor and sick.

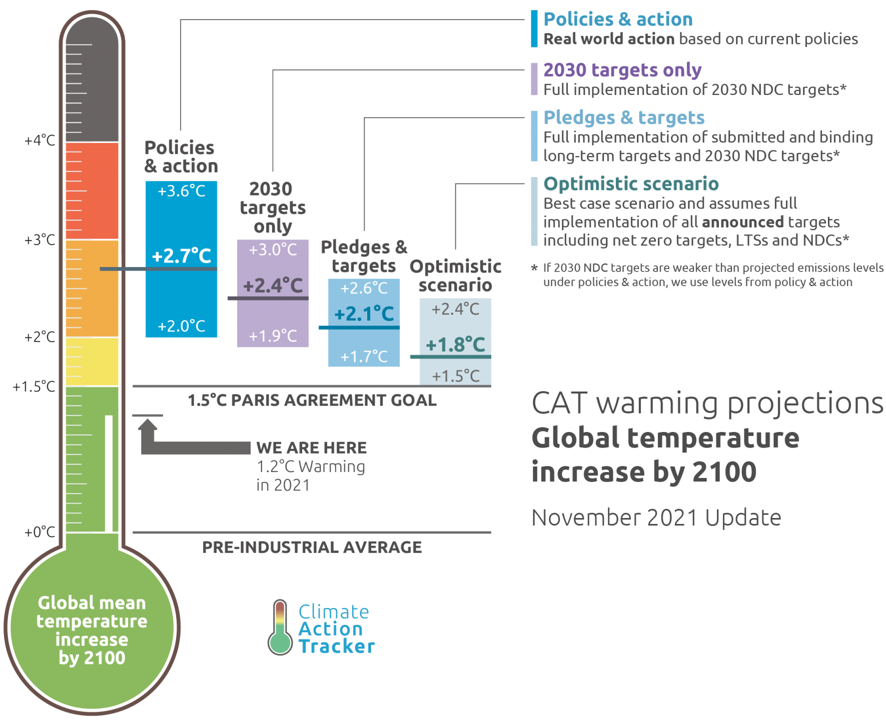
Realistically, it seems unlikely that the disproportionate climate suffering of the poor will sway anyone (other than a few activists who will dedicate much of their lives to helping them). If we rich cared more for humanity's poor, we would not have to wait for climate change. We could alleviate plenty of human suffering, malnutrition, homelessness, sickness, and death *today*, e.g., by donating money to UNICEF.[8] The fact that the rich collectively and individually (including most "salon activists") do not send significant fractions of their incomes to the poor speaks volumes about how much voluntary altruism and poverty concern we can expect to see from humanity in the future. It's a lot cheaper to lament poverty than to alleviate it.

[7] Besides, the central problem in those countries may not be sea-rise over the next 200 years, but widespread poverty. If they were richer, they could also deal better with rising sea-levels.

[8] However, no country has ever escaped poverty through global donation. Countries escape poverty through economic growth.

4 Temperature Change Summary

Figure 6. Climate Action Tracker Summary, Nov 2021



Source: Climate Action Tracker: Glasgow's 2030 credibility gap: net zero's lip service to climate action for more detail.

The climate action tracker (CAT) is a non-profit collaboration of scientific institutions. It tracks forecasts of global warming on a monthly basis.

Figure 6 shows their thermometer as of November 2021. We recommend reading the CAT source web-page more carefully. It offers more insight into their analysis, including further details on countries and policies. If the 2030 targets of Glasgow are fully implemented, CAT forecast a reduced temperature increase of about 0.3°C by 2100 relative to a scenario of current policies. Full target implementation is already a big and optimistic *if*, as we will explain in

Chapter 7. We consider pledges and optimistic scenarios not to be realistic—best-case and beyond best-case scenarios. We suspect that the CAT scientists would largely agree with our assessment, some exceptions notwithstanding.

Table 7. Summary of Mainstream Temperature Estimates

Renaissance Decrease (1450–1800)	−0.4°C	
Increase, 19th Century (1800–1900)	+0.2°C	
Increase, 20th Century (1900–2000)	+0.7°C	
Increase, Recent (2000–2020)	+0.6°C	(included below)
Exp. Increase, 21st Century (2000-2100)	+2.7°C	(IPCC: 2.1–3.4°C)
Optimistic Activist Scenario (2000-2100)	+2.4°C	(COP26, Glasgow 2021)
Activist Curtailment		
Global, Effect by 2100	0.3–0.5°C	
All-OECD, Effect by 2100	0.1–0.2°C	(pro-rated)

Source: These are rough estimates. Note that differences of 0.1–0.2°C are within margins of error and quoted differently by different sources (e.g., relative to slightly different benchmarks or updated over time). The top part of this table is based on Mann et al., as in Figure ??. The 21st Century estimates in the bottom part were summarized by the MIT Technology Review, which in turn based its estimates on the IPCC and Climate Action Tracker assessments.

For easy reference and discussion in later chapters, we summarize the (majority) assessment in Table 7. For perspective, 2–3°C is bad and almost surely unavoidable — but remember that Earth has already warmed by a much starker 6°C since the last glacial maximum just 15,000 years ago. The current predicted increase of 2–3°C is so remarkable only because (a) the change is very rapid; (b) Earth has not seen such large temperature changes, up or down, since the advent of advanced human civilization about 5,000 years ago; and (c) Earth is already at the high end of its temperature range at least since the appearance of the human species.

To make smart decisions, it is important to understand that climate-change activism is *not* about avoiding expected global warming of about 2–3°C. Instead, it is about pushing Earth from about RCP 6 to RCP 4, i.e., from 2.7°C to 2.4°C. Consequently, activist intervention could at best push down warming by about 0.3–0.5°C. Reducing future emissions in all OECD countries to become consistent with RCP 4 could reduce global warming by only 0.1–0.2°C, because the OECD is only responsible for about one-third of the world's emission. We will pick up the subject of economic *analysis on the margin* in Chapter 5.

Don't be too comforted by this relative comparison of 3°C now vs. 6°C a few millennia ago, though. The 3°C is based on expectations — and what if those expectations are off?

5 The Well-Known Unknowns

We have focused thus far on the *most likely* changes in planetary temperature associated with human emissions of GHGs. But our discussion of the most likely scenario has hidden the risks associated with deviations from expectations. Fortunately, the scientific models make it possible to assess not only the most likely outcomes but also *some* of the modeling uncertainty.

Given that there are still many active debates in the climate sciences even in the best-understood and most-likely scenarios (that is, on a global basis over long time horizons), it is not surprising that it is even more difficult to quantify the uncertainty. Thus, without trying to referee the science we discuss the evidence primarily from the perspective of the mainstream IPCC viewpoint. As a handy approximation, imagine that the minority view predicts only about one-half the temperature increase that the mainstream predicts.

With this caveat, Table 8 shows how higher future CO_2 concentrations will likely affect future average temperatures, including an estimate of the uncertainty around the prediction. At the current state (410 ppm) and rate of net increase in atmospheric CO_2 of about 2.5 ppm per year, scientists expect an eventual GHG-caused annual temperature increase of about 0.025°C per year. This does not sound like much, until you think in decades. It amounts to just under 1°C for every human generation (35 years) — and that *is* a lot.

We can summarize mainstream scientists' current understanding of the influence of the link between CO_2 and temperature *with uncertainty* as follows: The predicted long-term global temperature increase for a doubling of CO_2 in the atmosphere ranges from 1.5°C to 4.0°C, with **2.5°C** a good working middle. By this metric, civilization's 50% increase from 280 ppm to 410 ppm has pushed up the new and not yet fully realized long-term equilibrium temperature by about **1–2°C** (rather than a precise 1.5°C), with ongoing

Table 8. A Map from CO_2 Concentration to Global Temperature in Long-Run Equilibrium, Mainstream View

Estimated 66% Range			Temperature
Low ⟵	Mid	⟶ High	Increase
	270		0
320 ⟵	340	⟶ 380	+1°C
370 ⟵	430	⟶ 540	+2°C
440 ⟵	540	⟶ 760	+3°C
530 ⟵	670	⟶ 1,060	+4°C
620 ⟵	840	⟶ 1,490	+5°C

Note: The range is the 66% confidence range of atmospheric concentrations associated with warming *above pre-industrial levels*. In other sciences, it is often more common to cite 95% confidence levels, which would be bands that are roughly twice as wide as those quoted in this table.

Source: Azimuth and the Climate Modelling Intercomparison Project.

emissions now pushing the planet towards **2–4°C**. (The minority view would lower this to "only" 0.5–1°C and 1–2°C, respectively. Of course, even this would still be a stunning increase over such a short time frame.)

6 The Less-Known Unknowns

A 2–3°C increase is bad enough, but we are far more worried about unknown worst-case scenarios than we are about the expected scenario or even an expected wors**e**-case (but not wors**t**-case) scenario. Because humanity is conducting an unprecedented gigantic experiment in climate engineering by raising CO_2 concentrations in the atmosphere, it is possible that scientists have not recognized all that could happen — and what could happen could be *a lot* worse! 4-6°C is commonly cited as a really unlikely worst-case scenario, perhaps at a 1-2% probability. (This probability is roughly as low as that of seeing no climate change, at all, in the future.) Some scientists suggest that it is not even completely impossible — though exceedingly unlikely — that Earth could even heat up by 10°C. It would not be wise to make policy based on this number at the moment, but it would also be wise not to ignore it. We need to keep a close eye on how warming develops.

The Unprecedented Speed of the Human Impact

Our first worry is not the equilibrium temperature at which Earth will settle in 100 years, 500 years, or 1,000 years, but the sheer speed with which the planet is being pushed. Because scientists know of no recent historical analog for such a fast rate of change, they find it hard to predict whether the impact of such a rapid change will be worse and cause new problems (such as temporary exhaustion of buffers).

The fossil record tells us that 75% of all species vanished in response to the great asteroid strike of 65 million years ago. Only a few creatures weighing more than 25 kg survived. Of course, this comparison is a bit over the top. Human-induced climate change is neither as fast nor as dramatic as this asteroid strike.

However, human changes are still lightning-fast and dramatic by geologic standards. They are so fast that our scientific methods are not yet precise enough to allow us to detect whether there have been short-term isolated CO_2 shocks in the last 50 million years comparable to those created by civilization over the last 50–100 years. Even the largest events, like the volcanic eruptions 250 million years ago that created the Siberian traps (roughly the size of the United States) and wiped out 80% of all species, took more than a million years. Although humanity will never match the total CO_2 released by the

Siberian eruptions, the average speed with which CO_2 in the atmosphere is rising is more than ten times faster than it was then.

How many species will be unable to cope? We do not know. How will this impact the biosphere and food chain? We do not know.

sidenote

Climate change is a contributor to the biodiversity crisis, but it is not the only one. Human population growth, with accompanying appetites and habitat reductions, is probably more central. We agree with scientists and environmentalists that ecosystem collapse is another existential crisis for humanity — perhaps even more than climate change. It's good to see the United Nations raise the issue and see the media report on it. There is a danger that the attention on climate change could distract from ecosystem collapse. Humanity needs to urgently address both.

We see technology as a good non-collaborative universal approach to reducing emissions and slowing climate change. We don't see good universal approaches to extinction crises and ecosystem preservation. However, we do know that workable solutions will have to make it in the self-interests of local populations to protect ecosystems. (And unfortunately, local populations do not own and thus cannot cover ocean habitat protection.) We hope that younger generations will do a better job of protecting the world's ecosystems than our generation has.

Harmful Feedback Loops

Our second worry is feedback loops. A perfect example is the impact of thawing permafrost already mentioned in Chapter 2. The frozen ground, which covers large areas of the near-arctic north, holds 3,000 $GtCO_2e$ — potentially 300–600 ppm worth of atmospheric CO_2. Worse yet, it could be released in the form of methane, which is even more potent than CO_2. The rising temperatures would release yet more methane from the permafrost. And so on.

It is unknown how realistic and damaging the permafrost feedback loop is, but the signs are not good. Scientific studies have been revising upward their estimates of thawing speed almost as fast as the thawing itself is happening.

Table 9 shows a few more possible harmful feedback examples. The most important one is the (also aforementioned and central) water-vapor feedback loop. As the atmosphere starts to warm, the amount of water vapor in the atmosphere tends to rise. As a result of the increased water vapor, the atmosphere warms further, enabling more water vapor to be held in the atmosphere, and so on.

Table 9. Examples of Feedback Loops

Harmful, Amplifying	Helpful, Reducing
• Permafrost melt (methane) • Less ice albedo • Ocean circulation disruptions • Sea level rise to glacier melt • Rainforest drought and loss • Wetland methane release • Forest fires • Shallow gas hydrates	• More cloud reflectiveness • Higher rainfall • Photosynthesis • Chemical weathering • Meltwater CO_2 absorption. • Altitude temperature

Source: Earthhow Climate Feedback Loops.

Even clouds could constitute a harmful feedback loop. Depending on where the clouds form, they can either warm or cool the atmosphere. High-level clouds tend to keep heat in. Low-level clouds tend to reflect heat. Unfortunately, it seems now that both a warming atmosphere and increasing water vapor favor the formation of high-level clouds — but scientists are not yet certain which way this will go.

Melting ice can also produce a feedback loop. Sea-ice and ice sheets provide large white surfaces, reflecting solar radiation. As long as melting ice does not expose darker soil or ocean below, the melting process is slow and steady. However, once ice has melted enough (usually first near the edges), the darker surface below absorbs more solar radiation rather than reflecting it. This solar absorption in turn speeds up the heating and melting process. Warming climate and associated fires, along with rising human population, are also leading to an increase in deforestation. (This feedback loop could have created the Sahara in the first place.) Deforestation is currently particularly pronounced in tropical forests such as the Amazon. The deforestation reduces the uptake of CO_2, which in turn leads to more warming, which in turn leads to more forest fires, and so on.

Not all feedback loops are harmful. Some feedback loops are beneficial, partially offsetting of the impact of warming. For instance, a rise in CO_2 speeds up the growth of plants that remove CO_2 from the atmosphere. This beneficial feedback helps stabilize the climate. The oceans and terrestrial sinks have always been working against global warming, stabilizing atmospheric GHGs, absorbing relatively more CO_2 when the atmospheric CO_2 concentration is higher. (However, higher temperatures can be destabilizing, because they can cause the bubbling release of CO_2 from the oceans.)

Scientists do not understand all possible feedback loops, if only because they have never observed in real time the large temperature increases and high temperatures that may be required to initiate many of these loops. The uncertainties regarding these feedback loops are also partly why the bands associated with the RCP scenarios in Figure 1 are so wide. But what we don't know yet should scare us, not comfort us.

Catastrophic Tipping Points

Our third worry is tipping points. Think of a glass of water on a table. With small nudges, the glass shakes and the water sloshes but soon everything returns to normal. However, if the initial shock is big enough, a sudden harmful feedback effect appears: the glass tips over and the water pours out. Such thresholds are called "tipping points."

An example of a smaller tipping point being triggered occurred in 2012. It is ordinarily unimportant to New Yorkers whether the sea-water level is a little lower or higher. Even normal storm surges don't matter much. Yet Hurricane Sandy exposed a tipping point. It caused little damage — up until the moment when its storm surge reached the level that it could enter the subway and basements — and then it caused $70 billion of damage!

Humanity has never lived through a period of sharply rising greenhouse gases above 400ppm. All that humanity has lived through have been small nudges. The tipping points could be a "killer."

Table 10 lists a number of tipping points that could be triggered by climate changes. (No one knows for sure.) Many scientists suspect that we are just about to cross the first one. Our children may get to observe the melting of the Arctic and Greenlandic ice sheets and perhaps also the disappearance of the Indian Monsoon.

The faster the climate changes, the more harmful its effects are likely to be. This is because species and civilization will have less time to adapt. If the Indian monsoon were to stop and/or the Himalayan glaciers were to melt, it could destroy the livelihoods of more than a billion people. If the Atlantic

Table 10. Predicted or Plausible Tipping Points

1–2°C	Arctic and Greenland Melt; Indian Monsoon disappears
2–4°C	West-Antarctic and Amazon
3–5°C	West-African Monsoon, Boreal Forest Disappears
3–6°C	El Nino ceases
4–5°C	Atlantic Circulation ceases
5 °C+	East-Antarctic Melts

Source: Bild der Wissenschaft, July 2019, p22f.

circulation were to change and the jet stream moved north, Great Britain could turn into the climatic equivalent of Iceland. If India and Great Britain had centuries, they could slowly plan and adapt. But if these changes occur too fast, say, within one generation, the result is likely to be much greater human misery.

Previously, we described the IPCC estimate of up to 45 cm of sea level rise by the end of the century. It's harmful, but not catastrophic. However, the IPCC suggests that the sea level rise could increase to 90 cm under a higher RCP — and this would matter more. OK, but even this is not our main worry. We fear that it is possible that sea level rise could suddenly become far more abrupt. Global warming could quickly melt Greenland's and part of Antarctica's ice sheets. (We may already be beyond the point of no return.) In fact, paleo-historic records show that both the Greenland and the West-Antarctic ice sheets have melted and collapsed in the last 125,000 years. They may well do so again, this time perhaps within our lifetimes. David Archer warns that ice sheet collapses could conceivably increase the global sea level by — get this — 3,000 cm. Obviously, unlike the 1 meter increase in the IPCC scenario, such a 30 meter increase would be catastrophic. Are such multi-meter-level changes in sea levels so high that their predictions can be dismissed as absurd alarmism? No. Just 20,000 years ago, the sea level was 120 meters lower, so another 30 meters is not inconceivable. Again, we are not suggesting that 5, 10, or 20 meters of sea level rise is likely. We are only suggesting that it is not impossible.

Given our three grave concerns (speed, feedback loops, tipping points), basing climate policy decisions on the middle of the band seems dangerous.

What if the outcome turned out to be on or beyond the extreme of the band — and not on the good side? Heaven (won't) help us.

7 Appropriate Perspectives

We started this chapter with a description of our planetary temperature history. The civilizations of the last 5,000 years have evolved in a temperature interval of about plus or minus 1–2°C. Such climate stability has been unusual. Our current stable temperature is *not* Earth's "standard normal." Earth's climate is variable and it will change again.

quote

> 'All conditioned things are impermanent' – when one sees this with wisdom, one turns away from suffering. — The Buddha, Dhammapada v 277.

Normal Variation

Earth was approximately 8°C *colder* than it is today just about 20,000 years ago in the most recent glacial maximum. As we have stated repeatedly, we are currently enjoying as high and stable a temperature as the world has seen for millions of years. Primates have lived in worlds colder than it is today, but never in one 2–3°C *warmer*.

The large and long planetary cycles in Earth's deep geological past (with Earth remaining in a greenhouse or icehouse for hundreds of millions of years) raise the specter that there could be stark hidden positive feedback loops, invoked by tipping points, perhaps even Domino-like, just waiting for us around the next corner.

There is a realistic chance that by pushing Earth's temperature to levels not seen in millions of years, civilization may wake long-dormant processes and feedback loops that could push us much further — perhaps out of the planet's current ice age altogether. We wish scientists could run a quick "high-temperature trigger test" to learn what is lurking behind the corner without triggering it permanently. This is wishful thinking. Our scientists and policy makers are essentially driving blind.

As if global warming wasn't bad enough, there is even more to worry about. Although it seems far less likely, there has been enough natural variation on

Earth to remain concerned about the opposite, too. Scientists are not sure what drove the onsets of glacial periods. They do know that glacial periods have tended to occur every 100,000 years or so, perhaps related to astronomical phenomena. Many scientists think that humanity's CO_2 emissions may have nipped the next glacial maximum in the bud — but they again are not sure.

The error terms in climate models are about the sudden and unexpected. These include possible unforeseeable random disasters. In less than a decade, on April 13, 2029, the 200 meter Asteroid Apophis — with an energy potential roughly equivalent to all human nuclear arsenals together — will whiz by Earth *inside* the orbits of our geostationary satellites. An asteroid of this size hits Earth on average every 40,000 years. And asteroids with ten times more energy hit Earth about every 100,000 years.

In addition to asteroids, there are about 20 supervolcanoes, and one or the other has erupted every 50,000 to 100,000 years or so. If the Lake Toba Supervolcano were to erupt, Earth's temperature could fall by 5–15°C for a decade or more and even trigger another glacial period. An even bigger supervolcano eruption could lower Earth's temperature by as much as 15°C.

I am an optimist. I have every confidence that global warming will be nullified by nuclear winter.

Either a large asteroid or a supervolcano could wipe out most human crops for a few years and dramatically reduce agricultural output for decades. The fatalities would be much worse than those from the expected 2–3°C human-made global warming (that we should rightly be more worried about today). Fortunately, this is exceedingly unlikely within the next thousand years. Unfortunately, this is not impossible. In fact, over long enough a time span, it is a near certainty.

Our point here is not that a change of 2–3°C is little to be concerned about, much less to expect global cooling. Our point is that large temperature surprises are nothing unusual. Yes, if Earth experiences 3°C warming, it can cause a lot of human misery — but it's nothing compared to the environmental changes that bigger 5–10°C changes have brought in the past and could bring again. Should we be ready for either?

The Power To Alter Our Fate

Human civilization developed in a 5,000 year period of remarkably stable conditions and largely has come to rely on them. It may not last.

But there is something new. Technology has now advanced so far that, for the first time, humanity has the power to influence the planet via actively designed geoengineering — directed human intervention in climate on a world-wide scale.

We think it is important that humanity develops the means to react — if need be, to stabilize the planet's temperature. Naturalists will of course recoil. But hear us out first. Simpler geoengineering is nothing new. Humanity has been actively geoengineering for millennia, possibly since it had mastered fire. Agriculture is geoengineering at a gigantic scale.

But humanity now has something more powerful at its disposal — scalpels rather than a stone knife. Scientific advances have brought more powerful technologies within civilization's grasp. More are being developed all the time.

Among the better geoengineering ideas are technologies to remove CO_2, including reforesting and accelerated stone weathering, and solar radiation management, including cloud seeding and rain-making (without the prayers). More radical and controversial interventions could send reflective sulfur dioxide (SO_2) particles into the upper atmosphere (as explained in Chapter 2), where they will last for a few years (and before they will eventually come down again in the form of mild acid rain). Unlike CO_2 reductions, whose temperature effects will take many decades to start working, geoengineering can reduce temperature almost immediately. And deflecting an asteroid is similarly human tampering with natural processes.

Geoengineering may turn out to be a terrible idea. But we believe that if planetary warming awakens catastrophic feedback loops, scientists should understand all choices for last-resort interventions. We judge the "moral hazard" (of no longer worrying about climate change) that this would engender as relatively modest. Humans are already polluting without much abandon. We view geoengineering as "in case of emergency, break glass." We will return to geoengineering in Chapter 12.

Natural vs. Man-Made?

This brings us to our final point. When should humans intervene? Does it matter that (or even whether) humans are the primary cause of global warming?

The answer should be an emphatic no *No*!

Even if the current temperature increases had come entirely from natural sources, civilization should still want to learn what the effects are and how to manage them.

Mass extinctions are entirely natural, too — but we wouldn't want to live through one if scientists could do something about it. Climate change and CO_2 changes may have caused or contributed to the five major mass extinctions in the last 500 million years. The volcanic release of 36,000 $GtCO_2$ over 15,000 years is a prime suspect for the Permian mass extinction about 250 million years ago. It wiped out 90% of all species. In the Devonian extinction, about 370 million years ago, an estimated 96% of all species disappeared.

Stop being a naturalist! Just because something is "natural" does not mean that it is good and that it is in the interest of humanity not to interfere with it. The Black Death was natural! Even if the sun were the cause of all global warming, if its activity were increasing, the planet would still suffer the same temperature consequences. Scientists should still research how humanity could respond.

8 Planetary Roulette, Anyone?

Knowledgeable climate skeptics no longer deny global warming. Instead, they point out that the *expected* harm from slow planetary warming may not be that damaging. They may even be right (depending on how bad is bad). But for a long time, many of these critics were missing an important point. (Although most no longer do today.)

The impact of the expected warming scenarios pale in comparison to the unlikely, but not impossible, worst-case scenarios. Many of us pay for home insurance, not because we believe that our houses will burn down, but because we do not want to take the small risk of a really bad outcome. Most of us also pay for the opposite, water and flood insurance. Of course, buying insurance makes sense only if the insurance is less expensive than the house. On a planetary level, humanity should be prepared for global warming, but being prepared for (far less likely) unexpected cooling is also not a bad idea.

At the same time, humanity cannot make decisions for the absolute worst-case scenario. Yes, an asteroid could hit us. (Or, more realistically, nuclear weapons could destroy our cities.) However, we cannot move our civilizations underground in order to avoid such worst-case scenarios. In fact, there are so many worst-case scenarios, we don't have the resources to avoid them all. The universe has never been risk-free and never will be risk-free. What are prudent risks to take, what are not?

Perhaps the best way to describe the global climate situation is that civilization is playing Russian roulette. What would you pay for not having to participate in one round of Russian roulette? What should civilization be willing to pay for not having to participate in one round of climate-catastrophe roulette? How does it depend on the number of loaded and unloaded slots in the magazine?

Further Readings

Please see also the references in Chapter 3. In addition:

Books

- Lomborg, Bjorn, 2020, False Alarm, Hachette Book Group, New York. An opinionated view of the costs and benefits of climate change.
- Lomborg, Bjorn, 2001, The Skeptical Environmentalist, Cambridge University Press. Well worth considering, despite receiving scathing critiques upon publication. Provocative. Deserved more sober disagreement and critique.
- Mann, Michael E., 2021, The New Climate War, Hachette Book Group, New York, NY. Describes the misinformation and delay campaign of the fossil-fuel lobby.
- Robert Pindyck, 2022, Climate Future: Averting and Adapting to Climate Change covers uncertainty and unknowable much better than we do.
- Wagner, Gernot and Martin L. Weitzman, 2016, Climate Shock: The Economic Consequences of a Hotter Planet, Princeton University Press, Princeton, NJ. Focuses on risks off the "expected" path.
- Wray, Britt. Generation Dread: Finding Purpose in an Age of Climate Crisis, Knopf 2022, discusses how to handle climate anxiety (not climate change).

Reports and Academic Articles

- IPCC, Climate Change 2014 Synthesis Report Summary for Policymakers (AR5); IPCC Synthesis Report: Future Climate Changes, Risks and Impacts (AR5); and Climate Change 2021 The Physical Basis: Summary for Policy Makers (AR6).
- Lenton, Timothy M., et al., 2019, "Climate tipping points — too risky to bet against." Nature.
- Martin, Ian, and Robert S. Pindyck, 2015. Averting Catastrophes: The Strange Economics of Scylla and Charybdis, American Economic Review.
- Nazarenko, L. et al., 2015, Future climate change under RCP emission scenarios with GISS ModelE2, Journal of Advances in Modeling Earth Systems.
- Wayne, G.P., 2021, The Beginner's Guide to Representative Concentration Pathways, Skeptical Science.
- Sayedi, Sara Sayedah, et al., 2020, Subsea permafrost carbon stocks and climate change sensitivity estimated by expert assessment, Environmental Research Letters.
- Zhao, Zi-Jian et al. 2020, Global climate damage in 2°C and 1.5°C scenarios based on BCC_SESM model in IAM framework, Advances in Climate Change Research. Suggests most warming damage will be in agriculture.

Shorter Newspaper, Magazine Articles, and Clippings

- Chavez, Erik, et al, 2024: Crossing planetary boundaries could lead to Hothouse Earth, Nature, in review.
- Dietz, Simon, et al., 2021, Economic impacts of tipping points in the climate system, PNAS. Estimates a 25% increase in the SCC due to tipping point—including a 10% chance that it could double the SCC.
- Hausfather, Zeke, 2021, Explainer: The high-emissions 'RCP 8.5' global warming scenario. Views RCP 8.5 as an unlikely but not impossible scenario.
- Herr, Alexandria et al., Points of No Return, Grist.
- Johnson, Scott K., Study finds we're already committed to more global warming—sort of, Ars Technica, 2021/01/06.
- Johnson, Doug, 36,000 gigatons of carbon heralded history's biggest mass extinction, Ars Technica, 2021/09/17
- Lavelle, Marianne, 2016, Crocodiles and Palm Trees in the Arctic at 8°C, National Geographic.
- Lee, Howard, 2021, How will our warming climate stabilize? Scientists look to the distant past. 2012/12/20. The Eocene was dramatically hotter than today. The article also describes different proxies for warming and uncertainty estimates.
- Lindsey, Rebecca, 2021, Sea Level Rise. NOAA.
- Moor, Rose, 2019, 15 USA Cities That Will Be Underwater By 2050 (10 Already On The Ocean Floor), The Travel.
- Nuccitelli, Dana, 2013, A Glimpse at Our Possible Future Climate, Best to Worst Case Scenarios, Skeptical Science.
- Rahmstorf, Stefan, 2016, Millenia of Sea Level Change, 2016, and Sea level in the IPCC 6th assessment report (AR6), 2021, RealClimate.org.
- Rutgers University, 2020, New Research Affirms Modern Sea-Level Rise Linked to Human Activities, Not to Changes in Earth's Orbit.
- Sobel, Adam, 2021, How Climate Change Fuels Extreme Weather, a podcast analyzing the link between climate change and extreme weather events.
- Stockholm University, 2021, Sea Water Predictions Are Tough.
- Temple, James, 2021, The rare spot of good news on climate change, MIT Technology Review.
- Various, 2020, Explainer: Nine 'tipping points' that could be triggered by climate change, Carbonbrief.
- Wikipedia, List of cities by average temperature.

Websites

- Munich Re's Climate Change Edition: An insurance-based risk assessment site for climate change. (From an insurance perspective, it can make sense to plan for a low-probability RCP 8 scenario.)
- NOAA Sea Level Rise Viewer shows whether you should consider moving.
- Sea Level under IPCCs.
- RCP Database.

Film and Television

- An Inconvenient Truth, 2006, Al Gore's path-breaking documentary raising public awareness.
- PBS, 2020, Climate Change — The Facts.

request for select reader feedback

Request for Reader Feedback: We were surprised not to be able to identify more catastrophic global harms in the *expected* IPCC scenarios of RCP 4–6 (in the first half of this chapter). Of course, on a worldwide basis and in specific locales, the absolute harm can be large. Yet the % total harm seemed not as bad as we thought, and the latest 2021 IPCC report was as vague as alarming. (We could identify enumerated sets of damages in here, plus some proprietary insurance estimates.) Please email us if we have forgotten to describe other major (in %) detrimental consequences that a 2–3°C expected rise in global temperature would bring (or any other relevant omissions and errors for this matter). In particular, please email us links to damage estimates.

Personally, and largely evidence-free, perhaps internecine conflict (especially in Africa) in the face of shrinking resources could cause the violent deaths of millions of people. However, should this be attributed to climate change or to tribalism and warlords? If an effect is based on "$x \times y \times z$", how do you causally attribute a problem to x, especially if it is possible to intervene on y and z, too?

(We do discuss the more serious consequences of worse-case scenarios, such as a small probability of a catastrophic rise of 6–10°C, e.g., through sudden permafrost melts with feedback loops, in the second half of this chapter.)