The Uninhabitable Earth

Life After Warming

David Wallace-Wells

TIM DUGGAN BOOKS
New York

Published in the United States by Tim Duggan Books, an imprint of the Crown Publishing Group, a division of Penguin Random House LLC, New York.

crownpublishing.com

TIM DUGGAN BOOKS and the Crown colophon are trademarks of Penguin Random House LLC.

Library of Congress Cataloging-in-Publication Data.

Names: Wallace-Wells, David, author.

Title: The uninhabitable earth : life after warming / David Wallace-Wells.

Description: First edition. | New York : Tim Duggan Books, 2019. | Includes bibliographical references.

Identifiers: LCCN 2018051268| ISBN 9780525576709 (hardback) | ISBN 9780525576723 (ebook)

Subjects: LCSH: Nature--Effect of human beings on. | Global warming--Social aspects. | Climatic changes--Social aspects. | Global environmental change--Social aspects. | Environmental degradation--Social aspects. | BISAC: NATURE / Environmental Conservation & Protection.

Classification: LCC GF75 .W36 2019 | DDC 304.2/8--dc23

LC record available at https://lccn.loc.gov/2018051268

ISBN 9780525576709
Ebook ISBN 9780525576723
International edition ISBN 9781984826589

Cover design by Richard Green
Cover photograph: Paustius/Shutterstock

v5.4
a

II

Elements of Chaos

Heat Death

Humans, like all mammals, are heat engines; surviving means having to continually cool off, as panting dogs do. For that, the temperature needs to be low enough for the air to act as a kind of refrigerant, drawing heat off the skin so the engine can keep pumping. At seven degrees of warming, that would become impossible for portions of the planet's equatorial band, and especially the tropics, where humidity adds to the problem. And the effect would be fast: after a few hours, a human body would be cooked to death from both inside and out.

At eleven or twelve degrees Celsius of warming, more than half the world's population, as distributed today, would die of direct heat. Things almost certainly won't get that hot anytime soon, though some models of unabated emissions do bring us that far eventually, over centuries. But at just five degrees, according to some calculations, whole parts of the globe would be literally unsurvivable for humans. At six, summer labor of any kind would become impossible in the lower Mississippi Valley, and everybody in the United States east of the Rockies would suffer more from heat than anyone, anywhere, in the world today. New York City would be hotter than present-day Bahrain, one of the planet's hottest spots, and the temperature in Bahrain "would induce hyperthermia in even sleeping humans."

Five or six degrees is unlikely by 2100. The IPCC furnishes us with a median prediction of over four degrees, should we continue down the current emissions path. That would deliver what today seems like unthinkable impacts—wildfires burning sixteen times as much land in the American West, hundreds of drowned cities. Cities now home to millions, across India and the Middle East, would become so hot that stepping outside in summer would be a lethal risk—in fact, they will become that way much sooner, with as little as two degrees of warming. You do not need to consider worst-case scenarios to become alarmed.

With direct heat, the key factor is something called "wet-bulb temperature," which also measures humidity in a combined method as home-laboratory-kit as it sounds: the temperature is registered on a thermometer wrapped in a damp sock as it's swung around in the air. At present, most regions reach a wet-bulb maximum of 26 or 27 degrees Celsius; the true red line for habitability is 35 degrees, beyond which humans begin simply dying from the heat. That leaves a gap of 8 degrees. What is called "heat stress" comes much sooner.

Actually, we're there already. Since 1980, the planet has experienced a fiftyfold increase in the number of dangerous heat waves; a bigger increase is to come. The five warmest summers in Europe since 1500 have all occurred since 2002, and eventually, the IPCC warns, simply working outdoors at that time of year will be unhealthy for parts of the globe. Even if we meet the Paris goals, cities like Karachi and Kolkata will annually encounter deadly heat waves like those that crippled them in 2015, when heat killed thousands in India and Pakistan. At four degrees, the deadly European heat wave of 2003, which killed as many as 2,000 people a day, will be a normal summer. Then, it was one of the worst weather events in Continental history, killing 35,000 Europeans, including 14,000 French; perversely, the infirm fared relatively well, William Langewiesche has written, most of them watched over in the nursing homes and hospitals of those well-off countries, and it was the comparatively healthy elderly who accounted for most of the dead, many left behind by vacationing families escaping the heat, with some corpses rotting for weeks before the families returned.

It will get worse. In that "business as usual" scenario, a research team led by Ethan Coffel calculated in 2017, the number of days warmer than what were once the warmest days of the year could grow by a factor of 100 by 2080. Possibly by a factor of 250. The metric Coffel uses is "person-days": a unit that combines the number of people affected with the number of days. Every year, there would be between 150 and 750 million person-days with wet-bulb temperatures equivalent to today's most severe—i.e., quite deadly—heat waves. There would be a million person-days each year with intolerable wet-bulb temperatures—combinations of heat and humidity beyond the human capacity for survival. By the end of the century, the World Bank has estimated, the coolest months in tropical South America, Africa, and the Pacific are likely to be warmer than the warmest months at the end of the twentieth century.

We had heat waves back then, of course, deadly ones; in 1998, the Indian summer killed 2,500. More recently, temperature spikes have gotten hotter. In 2010, 55,000 died in a Russian heat wave that killed 700 people in Moscow each day. In 2016, in the midst of a heat wave that baked the Middle East for several months, temperatures in Iraq broke 100 degrees Fahrenheit in May, 110 in June, and 120 in July, with temperatures dipping below 100, most days, only at night. (A Shiite cleric in Najaf proclaimed the heat was the result of an electromagnetic attack on the country by American forces, according to *The Wall Street Journal,* and some state meteorologists agreed.) In 2018, the hottest temperature likely ever recorded in April was registered in southeast Pakistan. In India, a single day over 95 degrees Fahrenheit increases annual mortality rates by three-quarters of a percent; in 2016, a string of days topped 120—in May. In Saudi Arabia, where summer temperatures often approach that mark, 700,000 barrels of oil are burned each day in the summer, mostly to power the nation's air-conditioning.

That can help with the heat, of course, but air conditioners and fans already account for fully 10 percent of global electricity consumption. Demand is expected to triple, or perhaps quadruple, by 2050; according to one estimate, the world will be adding 700 million AC units by just 2030. Another study suggests that by 2050 there will be, around the world, more than nine billion cooling appliances of various kinds. But, the climate-controlled malls of the Arab emirates aside, it is not remotely economical, let alone "green," to wholesale air-condition all the hottest parts of the planet, many of them also the poorest. And indeed, the crisis will be most dramatic across the Middle East and Persian Gulf, where in 2015 the heat index registered temperatures as high as 163 degrees Fahrenheit. As soon as several decades from now, the hajj will become physically impossible for many of the two million Muslims who currently make the pilgrimage each year.

It is not just the hajj, and it is not just Mecca. In the sugarcane region of El Salvador, as much as one-fifth of the population—including over a quarter of the men—has chronic kidney disease, the presumed result of dehydration from working the fields they were able to comfortably harvest as recently as two decades ago. With dialysis, which is expensive, those with kidney failure can expect to live five years; without it, life expectancy is measured in weeks. Of course, heat stress promises to assail us in places other than our kidneys, too. As I type that sentence, in the California desert in mid-June, it is 121 degrees outside my door. It is not a record high.

—

This is among the things cosmologists mean when they talk about the utter improbability of anything as advanced as human intelligence evolving anywhere in a universe as inhospitable to life as this one: every uninhabitable planet out there is a reminder of just how unique a set of circumstances is required to produce a climate equilibrium supportive of life. No intelligent life that we know of ever evolved, anywhere in the universe, outside of the narrow Goldilocks range of temperatures that enclosed all of human evolution, and that we have now left behind, probably permanently.

How much hotter will it get? The question may sound scientific, inviting expertise, but the answer is almost entirely human—which is to say, political. The menace of climate change is a mercurial one; uncertainty makes it a shape-shifting threat. When will the planet warm by two degrees, and when by three? How much sea-level rise will be here by 2030, by 2050, by 2100, as our children are leaving the earth to their children and grandchildren? Which cities will flood, which forests will dry out, which breadbaskets will become husks? That uncertainty is among the most momentous metanarratives that climate change will bring to our culture over the next decades—an eerie lack of clarity about what the world we live in will even look like, just a decade or two down the road, when we will still be living in the same homes and paying the same mortgages, watching the same television shows and making appeals to many of the same justices of the Supreme Court. But while there are a few things science does not know about how the climate system will respond to all the carbon we've pumped into the air, the uncertainty of what will happen—that haunting uncertainty—emerges not from scientific ignorance but, overwhelmingly, from the open question of how we respond. That is, principally, how much more carbon we decide to emit, which is not a question for the natural sciences but the human ones. Climatologists can, today, predict with uncanny accuracy where a hurricane will hit, and at what intensity, as much as a week out from landfall; this is not just because the models are good but because all the inputs are known. When it comes to global warming, the models are just as good, but the key input is a mystery: What will we do?

The lessons there are unfortunately bleak. Three-quarters of a century since global warming was first recognized as a problem, we have made no meaningful adjustment to our production or consumption of energy to account for it and protect ourselves. For far too long, casual climate observers have watched scientists draw pathways to a stable climate and concluded that the world would adapt accordingly; instead, the world has done more or less nothing, as though those pathways would implement themselves. Market forces have delivered cheaper and more widely available green energy, but the same market forces have absorbed those innovations, which is to say profited from them, while continuing to grow emissions. Politics has produced gestures of tremendous global solidarity and cooperation, then discarded those promises immediately. It has become commonplace among climate activists to say that we have, today, all the tools we need to avoid catastrophic climate change—even major climate change. It is also true. But political will is not some trivial ingredient, always at hand. We have the tools we need to solve global poverty, epidemic disease, and abuse of women, as well.

It was as recent as 2016 that the celebrated Paris climate accords were adopted—defining two degrees of global warming as a must-meet target and rallying all the world's nations to meet it—and the returns are already dispiritingly grim. In 2017, carbon emissions grew by 1.4 percent, according to the International Energy Agency, after an ambiguous couple of years optimists had hoped represented a leveling-off, or peak; instead, we're climbing again. Even before the new spike, not a single major industrial nation was on track to fulfill the commitments it made in the Paris treaty. Of course, those commitments only get us down to 3.2 degrees; to keep the planet under 2 degrees of warming, all signatory nations have to significantly better their pledges. At present, there are 195 signatories, of which only the following are considered even "in range" of their Paris targets: Morocco, Gambia, Bhutan, Costa Rica, Ethiopia, India, and the Philippines. This puts Donald Trump's commitment to withdraw from the treaty in a useful perspective; in fact, his spite may ultimately prove perversely productive, since the evacuation of American leadership on climate seems to have mobilized China—giving Xi Jinping an opportunity and an enticement to adopt a much more aggressive posture toward climate. Of course those renewed Chinese commitments are, at this point, just rhetorical, too; the country already has the world's largest footprint, and in the first three months of 2018 its emissions grew by 4 percent. China commands half of the planet's coal-power capacity, with plants that only operate, on average, half of the time—which means their use could quickly grow. Globally, coal power has nearly doubled since 2000. According to one analysis, if the world as a whole followed the Chinese example, it would bring five degrees of warming by 2100.

In 2018, the United Nations predicted that at the current emissions rate the world would pass 1.5 degrees by 2040, if not sooner; according to the 2017 National Climate Assessment, even if global carbon concentration was immediately stabilized, we should expect more than half a degree Celsius of additional warming to come. Which is why staying below 2 degrees probably requires not just carbon scale-back but what are called "negative emissions." These tools come in two forms: technologies that would suck carbon out of the air (called CCS, for "carbon capture and storage") and new approaches to forestry and agriculture that would do the same, in a slightly more old-fashioned way (bioenergy with carbon capture and storage, or "BECCS").

According to a raft of recent papers, both are something close to fantasy, at least at present. In 2018, the European Academies' Science Advisory Council found that existing negative-emissions technologies have "limited realistic potential" to even slow the increase in concentration of carbon in the atmosphere—let alone meaningfully reduce that concentration. In 2018, *Nature* dismissed all scenarios built on CCS as "magical thinking." It is not even so pleasant to engage in that thinking. There is not much carbon in the air, all told, just 410 parts per million, but it is everywhere, and so relying on carbon capture globally could require large-scale scrubbing plantations nearly everywhere on Earth—the planet transformed into something like an air-recycling plant orbiting the sun, an industrial satellite tracing a parabola through the solar system. (This is not what Barbara Ward or Buckminster Fuller meant by "spaceship earth.") And while advances are sure to come, bringing costs down and making more efficient machines, we can't wait much longer for that progress; we simply don't have the time. One estimate suggests that, to have hopes of two degrees, we need to open new full-scale carbon capture plants at the pace of one and a half per day every day for the next seventy years. In 2018, the world had eighteen of them, total.

This is not good, but indifference is unfortunately nothing new when it comes to climate. Projecting future warming is a foolish game, given how many layers of uncertainty govern the outcome; but if a best-case scenario is now somewhere between 2 and 2.5 degrees of warming by 2100, it seems that the likeliest outcome, the fattest part of the bell curve of probability, sits at about 3 degrees, or just a bit above. Probably even that amount of warming would require significant negative-emissions use, given that our use of carbon is still growing. And there is also some risk from scientific uncertainty, the possibility that we are underestimating the effects of those feedback loops in natural systems we only poorly understand. Conceivably, if those processes are triggered, we could hit 4 degrees of warming by 2100, even with a meaningful reduction in emissions over the coming decades. But the track record since Kyoto implies that human shortsightedness makes it unproductive to offer predictions about what *will* happen, when it comes to emissions and warming; better to consider what *could* happen. The sky is literally the limit.

—

Cities, where the world will overwhelmingly live in the near future, only magnify the problem of high temperature. Asphalt and concrete and everything else that makes a city dense, including human flesh, absorb ambient heat, essentially storing it for a time like a slow-release poison pill; this is especially problematic because, in a heat wave, nightly reprieves are vital, allowing bodies to recover. When those reprieves are shorter, and shallower, flesh simply continues to simmer. In fact, the concrete and asphalt of cities absorb so much heat during the day that when it is released, at night, it can raise the local temperature as much as 22 degrees Fahrenheit, turning what could be bearably hot days into deadly ones—as in the Chicago heat wave of 1995, which killed 739 people, the direct-heat effects compounded by broken public health infrastructure. That commonly cited figure only reflects immediate deaths; of the many thousands more who visited hospitals during the heat wave, almost half died within the year. Others merely suffered permanent brain damage. Scientists call this the "heat island" effect—each city its own enclosed space, and hotter the more crowded it is.

Of course, the world is rapidly urbanizing, with the United Nations estimating that two-thirds of the global population will live in cities by 2050—2.5 billion new urbanites, by that count. For a century or more, the city has seemed like a vision of the future to much of the world, which keeps inventing new scales of metropolis: bigger than 5 million people, bigger than 10, bigger than 20. Climate change won't likely slow that pattern by much, but it will make the great migrations it reflects more perilous, with many millions of the world's ambitious flooding into cities whose calendars are dotted with days of deadly heat, gathering in those new megalopolises like moths to a flame.

In theory, climate change could even reverse those migrations, perhaps more totally than crime did in many American cities in the last century, turning urban populations in certain parts of the world outward as the cities themselves become unbearable. In the heat, roads in cities will melt and train tracks will buckle—this is actually happening already, but the impacts will mushroom in the decades ahead. Currently, there are 354 major cities with average maximum summertime temperatures of 95 degrees Fahrenheit or higher. By 2050, that list could grow to 970, and the number of people living in those cities and exposed to that deadly heat could grow eightfold, to 1.6 billion. In the United States alone, 70,000 workers have been seriously injured by heat since 1992, and by 2050, 255,000 are expected to die globally from direct heat effects. Already, as many as 1 billion are at risk for heat stress worldwide, and a third of the world's population is subject to deadly heat waves at least twenty days each year; by 2100, that third will grow to half, even if we manage to pull up short of two degrees. If we don't, the number could climb to three-quarters.

In the United States, heat stroke has a pathetic reputation—a plague you learn about from summer camp, like swimming cramps. But heat death is among the cruelest punishments to a human body, just as painful and disorienting as hypothermia. First comes “heat exhaustion,” mostly a mark of dehydration: profuse sweating, nausea, headache. After a certain point, though, water won’t help, your core temperature rising as your body sends blood outward to the skin, hoping desperately to cool it down. The skin often reddens; internal organs begin to fail. Eventually you could stop sweating. The brain, too, stops working properly, and sometimes, after a period of agitation and combativeness, the episode is punctuated with a lethal heart attack. “When it comes to extreme heat,” Langewiesche has written, “you can no more escape the conditions than you can shed your skin.”

Hunger

Climates differ and plants vary, but the basic rule of thumb for staple cereal crops grown at optimal temperature is that for every degree of warming, yields decline by 10 percent. Some estimates run higher. Which means that if the planet is five degrees warmer at the end of the century, when projections suggest we may have as many as 50 percent more people to feed, we may also have 50 percent less grain to give them. Or even less, because yields actually decline faster the warmer things get. And proteins are worse: it takes eight pounds of grain to produce just a single pound of hamburger meat, butchered from a cow that spent its life warming the planet with methane burps.

Globally, grain accounts for about 40 percent of the human diet; when you add soybeans and corn, you get up to two-thirds of all human calories. Overall, the United Nations estimates that the planet will need nearly twice as much food in 2050 as it does today—and although this is a speculative figure, it's not a bad one. Pollyannaish plant physiologists will point out that the cereal-crop math applies only to those regions already at peak growing temperature, and they are right—theoretically, a warmer climate will make it easier to grow wheat in Greenland. But as a pathbreaking paper by Rosamond Naylor and David Battisti pointed out, the tropics are already too hot to efficiently grow grain, and those places where grain is produced today are already at optimal growing temperature—which means even a small warming will push them down a slope of declining productivity. The same, broadly speaking, is true for corn. At four degrees of warming, corn yields in the United States, the world's top producer of maize, are expected to drop by almost half. Predicted declines are not quite as dramatic in the next three biggest producers—China, Argentina, Brazil—but in each case the country would lose at least a fifth of its productivity.

A decade ago, climatologists might have told you that although direct heat undermined plant growth, the extra carbon in the atmosphere would have the opposite effect—a kind of airborne fertilizer. The effect is strongest on weeds, though, and does not seem to hold for grain. And at higher concentrations of carbon, plants grow thicker leaves, which sounds innocuous. But thicker leaves are worse at absorbing CO_2, an effect that means, by the end of the century, as much as 6.39 billion additional tons in the atmosphere each year.

Beyond carbon, climate change means staple crops are doing battle with more insects—their increased activity could cut yields an additional 2 to 4 percent—as well as fungus and disease, not to mention flooding. Some crops, like sorghum, are a bit more robust, but even in those regions where such alternatives have been a staple, their production has diminished recently; and while grain breeders have some hope that they can produce more heat-tolerant strains, they've been trying for decades without success. The world's natural wheat belt is moving poleward by about 160 miles each decade, but you can't easily move croplands north a few hundred miles, and not just because it's difficult to suddenly clear the land occupied now by towns, highways, office parks, and industrial installations. Yields in places like remote areas of Canada and Russia, even if they warmed by a few degrees, would be limited by the quality of soil there, since it takes many centuries for the planet to produce optimally fertile dirt. The lands that are fertile are the ones we are already using, and the climate is changing much too fast to wait for the northern soil to catch up. That soil, believe it or not, is literally disappearing—75 billion tons of soil lost each year. In the United States, the rate of erosion is ten times as high as the natural replenishment rate; in China and India, it is thirty to forty times as fast.

Even when we try to adapt, we move too slowly. Economist Richard Hornbeck specializes in the history of the American Dust Bowl; he says that farmers of that era could conceivably have adapted to the changing climate of their time by cultivating different crops. But they didn't, lacking credit to make the necessary investments—and were therefore unable to shake inertia and ritual and the rootedness of identity. So instead the crops died out, in cascading waves crashing through whole

American states and all the people living in them.

As it happens, a similar transformation is unfolding in the American West right now. In 1879, the naturalist John Wesley Powell, who spent his downtime as a soldier during the Battle of Vicksburg studying the rocks that filled the Union trenches, divined a natural boundary running due north along the 100th meridian. It separated the humid—and therefore cultivatable—natural farmland of what became the Midwest from the arid, spectacular, but less farmable land of the true West. The divide ran through Texas, Oklahoma, Kansas, Nebraska, and the Dakotas, and stretches south into Mexico and north into Manitoba, Canada, separating more densely populated communities full of large farms from sparser, open land that was never truly made valuable by agriculture. Since just 1980, that boundary has moved fully 140 miles east, almost to the 98th parallel, drying up hundreds of thousands of square miles of farmland in the process. The planet's only other similar boundary is the one separating the Sahara desert from the rest of Africa. That desert has expanded by 10 percent, too; in the winter, the figure is 18 percent.

—

The privileged children of the industrialized West have long laughed at the predictions of Thomas Malthus, the British economist who believed that long-term economic growth was impossible, since each bumper crop or episode of growth would ultimately produce more children to consume or absorb it—and as a result the size of any population, including that of the planet as a whole, was a check against material well-being. In 1968, Paul Ehrlich made a similar warning, updated for a twenty-first-century planet with many times more people on it, with his widely derided *The Population Bomb,* which proposed that the economic and agricultural productivity of the earth had already reached its natural limit—and which was published, as it happened, just as the productivity gains from what's called the "green revolution" were coming into focus. That term, which today is sometimes used to describe advances in clean energy, first arose to name the incredible boom in agricultural yields produced by innovations in farming practices in the middle of the twentieth century. In the half century since, not only has the world's population doubled but the fraction of people living in extreme poverty has fallen by a factor of about six—from just more than half of humanity to 10 percent. In the world's developing countries, undernourishment has dropped from more than 30 percent in 1970 to close to 10 percent today.

These developments counsel sanguinity in the face of all kinds of environmental pressures, and in his recent book on the meaning of the twentieth-century agricultural boom, the writer Charles Mann divides those who respond to the seeming challenge of resource scarcity with reflexive optimism, whom he calls "wizards," from those who see collapse always around the corner, whom he calls "prophets." But though the green revolution seems almost too perfectly conceived and executed to refute Ehrlich's alarmism, Mann himself is not sure what the lessons are. It may yet be a bit early to judge Ehrlich—or perhaps even his godfather, Malthus—since nearly all of the astonishing productivity gains of the last century trace back to the work of a single man, Norman Borlaug, perhaps the best argument for the humanitarian virtue of America's imperial century. Born to Iowa family farmers in 1914, he went to state school, found work at DuPont, and then, with the help of the Rockefeller Foundation, developed a new collection of high-yield, disease-resistant wheat varieties that are now credited with saving the lives of a billion people worldwide. Of course, if those gains were a onetime boost—engineered, in large part, by a single man—how comfortably can we count on future improvements?

The academic term for the subject of this debate is "carrying capacity": How much population can a given environment ultimately support before collapsing or degrading from overuse? But it is one thing to consider what might be the maximum yield of a particular plot of earth and another to contemplate how fully that number is governed by environmental systems—systems far larger and more diffusely determined than even an imperial wizard like Borlaug could reasonably expect to command and control. Global warming, in other words, is more than just one input in an equation to determine carrying capacity; it is the set of conditions under which all of our experiments to improve that capacity will be conducted. In this way, climate change appears to be not merely one challenge among many facing a planet already struggling with civil strife and war and horrifying inequality and far too many other insoluble hardships to iterate, but the all-encompassing stage on which all those challenges will be met—a whole sphere, in other words, which literally contains within it all of the world’s future problems and all of its possible solutions.

Curiously, maddeningly, these can be the same. The graphs that show so much recent progress in the developing world—on poverty, on hunger, on education and infant mortality and life expectancy and gender relations and more—are, practically speaking, the same graphs that trace the dramatic rise in global carbon emissions that has brought the planet to the brink of overall catastrophe. This is one aspect of what is meant by the term “climate justice.” Not only is it undeniably the case that the cruelest impacts of climate change will be borne by those least resilient in the face of climate tragedy, but to a large degree what could be called the humanitarian growth of the developing world’s middle class since the end of the Cold War has been paid for by fossil-fuel-driven industrialization—an investment in the well-being of the global south made by mortgaging the ecological future of the planet.

This is one reason that our global climate fate will be shaped so overwhelmingly by the development patterns of China and India, who have the tragic burden of trying to bring many hundreds of millions more into the global middle class while knowing that the easy paths taken by the nations that industrialized in the nineteenth and even twentieth centuries are now paths to climate chaos. Which is not to say they won’t follow them anyway: by 2050, milk consumption in China is expected to grow to triple the current level, thanks to the changing, West-facing tastes of its emerging consumer classes, a single-item boom in a single country that is expected, all by itself, to increase global greenhouse-gas emissions from dairy farming by about 35 percent.

Already, global food production accounts for about a third of all emissions. To avoid dangerous climate change, Greenpeace has estimated that the world needs to cut its meat and dairy consumption in half by 2050; everything we know about what happens when countries get wealthier suggests this will be close to impossible. And turning away from milk is one thing; turning down cheap electrification, automobile culture, or the protein-heavy diets the world’s wealthy rely on to stay thin are much bigger asks. In the postindustrial West, we try not to think about these bargains, which have benefited us so enormously. When we do, it is often in the guilty spirit of what critic Kris Bartkus has memorably called “the Malthusian tragic”—namely, our inability to see any remaining innocence in the quotidian life of the well-to-do West, given the devastation that wealth has imposed on the world of natural wonder it conquered and the suffering of those, elsewhere on the planet, left behind in the race to endless material comforts. And asked, functionally, to pay for them.

Of course, most have not embraced that tragic, or self-pitying, view. A state of half-ignorance and half-indifference is a much more pervasive climate sickness than true denial or true fatalism. It is the subject of William Vollmann's grand, two-part *Carbon Ideologies,* which opens—beyond the epigraph "A crime is something someone else commits," from Steinbeck—like this: "Someday, perhaps not long from now, the inhabitants of a hotter, more dangerous and biologically diminished planet than the one on which I lived may wonder what you and I were thinking, or whether we thought at all." For much of the book's prologue, he writes in a past tense rendered from an imagined, devastated future. "Of course we did it to ourselves; we had always been intellectually lazy, and the less asked of us, the less we had to say," he writes. "We all lived for money, and that is what we died for."

—

Drought may be an even bigger problem for food production than heat, with some of the world's most arable land turning quickly to desert. At 2 degrees of warming, droughts will wallop the Mediterranean and much of India, and corn and sorghum all around the world will suffer, straining global food supply. At 2.5 degrees, thanks mostly to drought, the world could enter a global food deficit—needing more calories than the planet can produce. At 3 degrees, there would be further drought—in Central America, Pakistan, the western United States, and Australia. At 5 degrees, the whole earth would be wrapped in what the environmentalist Mark Lynas calls "two globe-girdling belts of perennial drought."

Precipitation is notoriously hard to model in detail, yet predictions for later this century are basically unanimous: both unprecedented droughts and unprecedented flood-producing rains. By 2080, without dramatic reductions in emissions, southern Europe will be in permanent extreme drought, much worse than the American Dust Bowl ever was. The same will be true in Iraq and Syria and much of the rest of the Middle East;

some of the most densely populated parts of Australia, Africa, and South America; and the breadbasket regions of China. None of these places, which today supply much of the world's food, would be reliable sources going forward. As for the original Dust Bowl: the droughts in the American plains and Southwest would not just be worse than in the 1930s, a 2015 NASA study predicted, but worse than any droughts in a thousand years—and that includes those that struck between 1100 and 1300, which dried up all the rivers east of the Sierra Nevada mountains and may have been responsible for the death of the Anasazi civilization.

Remember, even with the remarkable gains of the last decades, we do not presently live in a world without hunger. Far from it: most estimates put the number of undernourished at 800 million globally, with as many as 100 million hungry because of climate shocks. What is called "hidden hunger"—micronutrient and dietary deficiencies—is considerably higher, affecting well over 1 billion people. The spring of 2017 brought an unprecedented quadruple famine to Africa and the Middle East; the United Nations warned that those separate starvation events in Somalia, South Sudan, Nigeria, and Yemen could kill 20 million that year. That was a single year in a single region. Africa is today straining to feed about 1 billion people, a population expected to quadruple over the course of the twenty-first century to 4 billion.

One hopes these population booms will bring their own Borlaugs, ideally many of them. And already there are some hints of possible technological breakthroughs: China has invested in truly customized farming strategies to boost productivity and cut the use of greenhouse-gas-producing fertilizer; in Britain, a "soil-free startup" announced its first "harvest" in 2018; in the United States, you already hear about the prospects for vertical farming, which saves farmland by stacking crops indoors; and lab-grown protein, which does the same by culturing meats inside test tubes. But these remain vanguard technologies, distributed unequally and, being so expensive, unavailable for now to the many who are most in need. A decade ago, there was great optimism that GMO crops could produce another green revolution, but today gene modification has been used mostly to make plants more resistant to pesticides, pesticides manufactured and sold by the same companies engineering the crops. And cultural resistance has grown so rapidly that Whole Foods now advertises its house brand of seltzer as "GMO-free sparkling water."

It is far from clear how much benefit even those able to take advantage of vanguard techniques will be able to reap. Over the past fifteen years, the iconoclastic mathematician Irakli Loladze has isolated a dramatic effect of carbon dioxide on human nutrition unanticipated by plant physiologists: it can make plants bigger, but those bigger plants are less nutritious. "Every leaf and every grass blade on earth makes more and more sugars as CO_2 levels keep rising," Loladze told *Politico,* in a story about his work headlined "The Great Nutrient Collapse." "We are witnessing the greatest injection of carbohydrates into the biosphere in human history—[an] injection that dilutes other nutrients in our food supply."

Since 1950, much of the good stuff in the plants we grow—protein, calcium, iron, vitamin C, to name just four—has declined by as much as one-third, a landmark 2004 study showed. Everything is becoming more like junk food. Even the protein content of bee pollen has dropped by a third.

The problem has gotten worse as carbon concentrations have gotten worse. Recently, researchers estimated that by 2050 as many as 150 million people in the developing world will be at risk of protein deficiency as the result of nutrient collapse, since so many of the world's poor depend on crops, rather than animal meat, for protein; 138 million could suffer from a deficiency of zinc, essential to healthy pregnancies; and 1.4 billion could face a dramatic decline in dietary iron—pointing to a possible epidemic of anemia. In 2018, a team led by Chunwu Zhu looked at the protein content of eighteen different strains of rice, the staple crop for more than 2 billion people, and found that more carbon dioxide in the air produced nutritional declines across the board—drops in protein content, as well as in iron, zinc, and vitamins B_1, B_2, B_5, and B_9. Really everything but vitamin E. Overall, the researchers found that, acting just through that single crop, rice, carbon emissions could imperil the health of 600 million people.

In previous centuries, empires were built on that crop. Climate change promises another, an empire of hunger, erected among the world's poor.

Drowning

That the sea will become a killer is a given. Barring a reduction of emissions, we could see at least four feet of sea-level rise and possibly eight by the end of the century. A radical reduction—of the scale that could make the Paris two-degree goal a conceivably attainable if quite optimistic target—could still produce as much as two meters, or six feet, by 2100.

Perversely, for a generation now, we've been comforted by numbers like these—when we think the worst that climate change can bring is an ocean a few feet higher, anyone who lives even a short distance from the coast feels like they can breathe easy. In that way, even alarmist popular writing about global warming has been a victim of its own success, so focused on sea-level rise that it has blinded readers to all the climate scourges beyond the oceans that threaten to terrorize the coming generations—direct heat, extreme weather, pandemic disease, and more. But as "familiar" as sea-level rise may seem, it surely deserves its place at the center of the picture of what damage climate change will bring. That so many feel already acclimated to the prospect of a near-future world with dramatically higher oceans should be as dispiriting and disconcerting as if we'd already come to accept the inevitability of extended nuclear war—because that is the scale of devastation the rising oceans will unleash.

In *The Water Will Come,* Jeff Goodell runs through just a few of the monuments—indeed, in some cases, whole cultures—that will be transformed into underwater relics, like sunken ships, this century: any beach you've ever visited; Facebook's headquarters, the Kennedy Space Center, and the United States' largest naval base, in Norfolk, Virginia; the entire nations of the Maldives and the Marshall Islands; most of

Bangladesh, including all of the mangrove forests that have been the kingdom of Bengal tigers for millennia; all of Miami Beach and much of the South Florida paradise engineered out of marsh and swamp and sandbar by rabid real-estate speculators less than a century ago; Saint Mark's Basilica in Venice, today nearly a thousand years old; Venice Beach and Santa Monica in Los Angeles; the White House at 1600 Pennsylvania Avenue, as well as Trump's "Winter White House" at Mar-a-Lago, Richard Nixon's in Key Biscayne, and the original, Harry Truman's, in Key West. This is a very partial list. We've spent the millennia since Plato enamored with the story of a single drowned culture, Atlantis, which if it ever existed was probably a small archipelago of Mediterranean islands with a population numbering in the thousands —possibly tens of thousands. By 2100, if we do not halt emissions, as much as 5 percent of the world's population will be flooded every single year. Jakarta is one of the world's fastest-growing cities, today home to ten million; thanks to flooding and literal sinking, it could be entirely underwater as soon as 2050. Already, China is evacuating hundreds of thousands every summer to keep them out of the range of flooding in the Pearl River Delta.

What would be submerged by these floods are not just the homes of those who flee—hundreds of millions of new climate refugees unleashed onto a world incapable, at this point, of accommodating the needs of just a few million—but communities, schools, shopping districts, farmlands, office buildings and high-rises, regional cultures so sprawling that just a few centuries ago we might have remembered them as empires unto themselves, now suddenly underwater museums showcasing the way of life in the one or two centuries when humans, rather than keeping their safe distance, rushed to build up at the coastline. It will take thousands of years, perhaps millions, for quartz and feldspar to degrade into sand that might replenish the beaches we lose.

Much of the infrastructure of the internet, one study showed, could be drowned by sea-level rise in less than two decades; and most of the smartphones we use to navigate it are today manufactured in Shenzhen, which, sitting right in the Pearl River Delta, is likely to be flooded soon, as well. In 2018, the Union of Concerned Scientists found that nearly 311,000 homes in the United States would be at risk of chronic inundation by 2045—a timespan, as they pointed out, no longer than a mortgage. By 2100, the number would be more than 2.4 million properties, or $1 trillion worth of American real estate—underwater. Climate change may not only make the miles along the American coast uninsurable, it could render obsolete the very idea of disaster insurance; by the end of the century, one recent study showed, certain places could be struck by six different climate-driven disasters simultaneously. If no significant action is taken to curb emissions, one estimate of global damages is as high as $100 trillion *per year* by 2100. That is more than global GDP today. Most estimates are a bit lower: $14 trillion a year, still almost a fifth of present-day GDP.

But the flooding wouldn't stop at the end of the century, since sea-level rise would continue for millennia, ultimately producing, in even that optimistic two-degree scenario, oceans six meters higher. What would that look like? The planet would lose about 444,000 square miles of land, where about 375 million people live today—a quarter of them in China. In fact, the twenty cities most affected by such sea-level rise are all Asian megalopolises—among them Shanghai, Hong Kong, Mumbai, and Kolkata. Which does cast a climate shroud over the prospect, now so much taken for granted among the Nostradamuses of geopolitics, of an Asian century. Whatever the course of climate change, China will surely continue its ascent, but it will do so while fighting back the ocean, as well —perhaps one reason it is already so focused on establishing control over the South China Sea.

Nearly two-thirds of the world's major cities are on the coast—not to mention its power plants, ports, navy bases, farmlands, fisheries, river deltas, marshlands, and rice paddies—and even those above ten feet will flood much more easily, and much more regularly, if the water gets that high. Already, flooding has quadrupled since 1980, according to the European Academies' Science Advisory Council, and doubled since just 2004. Even under an "intermediate low" sea-level-rise scenario, by 2100 high-tide flooding could hit the East Coast of the United States "every other day."

We haven't even gotten to inland flooding—when rivers run over, swollen by deluges of rain or storm surges channeled downstream from the sea. Between 1995 and 2015, this affected 2.3 billion and killed 157,000 around the world. Under even the most radically aggressive global emissions reduction regime, the further warming of the planet from just the carbon we've already pumped into the atmosphere would increase global rainfall to such a degree that the number affected by river flooding in South America would double, according to one paper, from 6 million to 12 million; in Africa, it would grow from 24 to 35 million, and in Asia from 70 to 156 million. All told, at just 1.5 degrees Celsius of warming, flood damage would increase by between 160 and 240 percent; at 2 degrees, the death toll from flooding would be 50 percent higher than today. In the United States, one recent model suggested that FEMA's recent projections of flood risk were off by a factor of three, and that more than 40 million Americans were at risk of catastrophic inundation.

These effects will come to pass even with a radical reduction of emissions, keep in mind. Without flood adaptation measures, large swaths of northern Europe and the whole eastern half of the United States will be affected by at least ten times as many floods. In large parts of India, Bangladesh, and Southeast Asia, where flooding is today catastrophically common, the multiplier could be just as high—and the baseline is already so elevated that it annually produces humanitarian crises on a scale we like to think we would not forget for generations.

Instead, we forget them immediately. In 2017, floods in South Asia killed 1,200 people, leaving two thirds of Bangladesh underwater; António Guterres, the secretary-general of the United Nations, estimated that 41 million people had been affected. As with so much climate change data, those numbers can numb, but 41 million is as much as eight times the entire global population at the time of the Black Sea deluge 7,600 years ago—reputedly so dramatic and catastrophic a flood that it may have given rise to our Noah's Ark story. At the same time as the floods hit in 2017, almost 700,000 Rohingya refugees from Myanmar arrived in Bangladesh, most of them in a single settlement site that became, in months, more populous than Lyon, France's third biggest city, and was erected in the path of landslides just as the next monsoon season arrived.

—

To what degree we will be able to adapt to new coastlines is primarily a matter of just how fast the water rises. Our understanding of that timeline has been evolving disconcertingly fast. When the Paris Agreement was drafted, those writing it were sure that the Antarctic ice sheets would remain stable even as the planet warmed several degrees; their expectation was that oceans could rise, at most, only three feet by the end of the century. That was just in 2015. The same year, NASA found that this expectation was hopelessly complacent, suggesting three feet was not a maximum but in fact a minimum. In 2017, the National Oceanic and Atmospheric Administration (NOAA) suggested eight feet was possible—still just in this century. On the East Coast, scientists have already introduced a new term, "sunny day flooding"—when high tide alone, aided by no additional rainstorm, inundates a town.

In 2018, a major study found things accelerating faster still, with the melt rate of the Antarctic ice sheet tripling just in the past decade. From 1992 to 1997, the sheet lost, on average, 49 billion tons of ice each year; from 2012 to 2017, it was 219 billion. In 2016, climate scientist James Hansen had suggested sea level could rise several meters over fifty years, if ice melt doubled every decade; the new paper, keep in mind, registers a tripling, and in the space of just five years. Since the 1950s, the continent has lost 13,000 square miles from its ice shelf; experts say its ultimate fate will probably be determined by what human action is taken in just the next decade.

All climate change is governed by uncertainty, mostly the uncertainty of human action—what action will be taken, and when, to avert or forestall the dramatic transformation of life on the planet that will unfold in the absence of dramatic intervention. Each of our projections, from the most blasé to the most extreme, comes wrapped in doubt—the result of so many estimates and so many assumptions that it would be foolish to take any of them, so to speak, to the bank.

But sea-level rise is different, because on top of the basic mystery of human response it layers much more epistemological ignorance than governs any other aspect of climate change science, save perhaps the question of cloud formation. When water warms, it expands: this we know. But the breaking-up of ice represents almost an entirely new physics, never before observed in human history, and therefore only poorly understood.

There are now, thanks to rapid Arctic melt, papers devoted to what are called the "damage mechanics" of ice-shelf loss. But we do not yet well understand those dynamics, which will be one of the main drivers of sea-level rise, and so cannot yet make confident predictions about how quickly ice sheets will melt. And even though we now have a decent picture of the planet's climatological past, never in the earth's entire recorded history has there been warming at anything like this speed—by one estimate, around ten times faster than at any point in the last 66 million years. Every year, the average American emits enough carbon to melt 10,000 tons of ice in the Antarctic ice sheets—enough to add 10,000 cubic meters of water to the ocean. Every minute, each of us adds five gallons.

One study suggests that the Greenland ice sheet could reach a tipping point at just 1.2 degrees of global warming. (We are nearing that temperature level today, already at 1.1 degrees.) Melting that ice sheet alone would, over centuries, raise sea levels six meters, eventually drowning Miami and Manhattan and London and Shanghai and Bangkok and Mumbai. And while business-as-usual emissions trajectories warm the planet by just over 4 degrees by 2100, because temperature changes are unevenly distributed around the planet, they threaten to warm the Arctic by 13.

In 2014, we learned that the West Antarctic and Greenland ice sheets were even more vulnerable to melting than scientists anticipated—in fact, the West Antarctic sheet had already passed a tipping point of collapse, more than doubling its rate of ice loss in just five years. The same had happened in Greenland, where the ice sheet is now losing almost a billion tons of ice every single day. The two sheets contain enough ice to raise global sea levels ten to twenty feet—each. In 2017, it was revealed that two glaciers in the East Antarctic sheet were also losing ice at an alarming rate—eighteen billion tons of ice each year, enough to cover New Jersey in three feet of ice. If both glaciers go, scientists expect, ultimately, an additional 16 feet of water. In total, the two Antarctic ice sheets could raise sea level by 200 feet; in many parts of the world, the shoreline would move by many miles. The last time the earth was four degrees warmer, as Peter Brannen has written, there was no ice at either pole and sea level was 260 feet higher. There were palm trees in the Arctic. Better not to think what that means for life at the equator.

—

As with all else in climate, the melting of the planet's ice will not occur in a vacuum, and scientists do not yet fully understand exactly what cascading effects such collapses will trigger. One major concern is methane, particularly the methane that might be released by a melting Arctic, where permafrost contains up to 1.8 trillion tons of carbon, considerably more than is currently suspended in the earth's atmosphere. When it thaws, some of it will evaporate as methane, which is, depending on how you measure, at least several dozen times more powerful a greenhouse gas than carbon dioxide.

When I first began seriously researching climate change, the risk from a sudden release of methane from the Arctic permafrost was considered quite low—in fact so low that most scientists derided casual discussion of it as reckless fearmongering and deployed mockingly hyperbolic terms like "Arctic methane time bomb" and "burps of death" to describe what they saw as a climate risk not much worth worrying about in the near term. The news since has not been encouraging: one *Nature* paper found that the release of Arctic methane from permafrost lakes could be rapidly accelerated by bursts of what is called "abrupt thawing," already under way. Atmospheric methane levels have risen dramatically in recent years, confusing scientists unsure of their source; new research suggests the amount of gas being released by Arctic lakes could possibly double going forward. It's not clear whether this methane release is new or just that we finally began to pay attention to it. But while the consensus is still that a rapid, sudden release of methane is unlikely, the new research is a case study in why it is worthwhile to consider, and take seriously, such unlikely-but-possible climate risks. When you define anything outside a narrow band of likelihood as irresponsible to consider, or talk about, or plan for, even unspectacular new research findings can catch you flat-footed.

Today, all do agree that that permafrost is melting—the permafrost line having retreated eighty miles north in Canada over the last fifty years. The most recent IPCC assessment projects a loss of near-surface permafrost of between 37 and 81 percent by 2100, though most scientists still believe that carbon will be released slowly, and mostly as less-terrifying carbon dioxide. But as far back as 2011, NOAA and the National Snow and Ice Data Center predicted that thawing permafrost would flip the whole region from being what is called a carbon sink, which absorbs atmospheric carbon, to a carbon source, which releases carbon, as quickly as the 2020s. By 2100, the same study said, the Arctic will have released a hundred billion tons of carbon. That is the equivalent of half of all the carbon produced by humanity since industrialization began.

Remember, that is the Arctic feedback loop that does not much concern many climate scientists in the near term. The one that concerns them more, at present, is what is called the "albedo effect": ice is white and so reflects sunlight back into space rather than absorbing it; the less ice, the more sunlight is absorbed as global warming; and the total disappearance of that ice, Peter Wadhams has estimated, could mean a massive warming equivalent to the entire last twenty-five years of global carbon emissions. The last twenty-five years of emissions, keep in mind, is about half of the total that humanity has ever produced—a scale of carbon production that has pushed the planet from near-complete climate stability to the brink of chaos.

All of this is speculative. But our uncertainty over each of these dynamics—ice sheet collapse, Arctic methane, the albedo effect—clouds our understanding only of the pace of change, not its scale. In fact, we do know what the endgame for oceans looks like, just not how long it will take us to get there.

How much sea-level rise is that? The ocean chemist David Archer is the researcher who has focused perhaps most acutely on what he calls the "long thaw" impacts of global warming. It may take centuries, he says, even millennia, but he estimates that ultimately, even at just three degrees of warming, sea-level rise will be at least fifty meters—that is, fully one hundred times higher than Paris predicted for 2100. The U.S. Geological Survey puts the ultimate figure at eighty meters, or more than 260 feet.

The world would perhaps not be made literally unrecognizable by that flooding, but the distinction is ultimately semantic. Montreal would be almost entirely underwater, as would London. The United States is an unexceptional example: at just 170 feet, more than 97 percent of Florida would disappear, leaving only a few hills in the Panhandle; and just under 97 percent of Delaware would be submerged. Oceans would cover 80 percent of Louisiana, 70 percent of New Jersey, and half of South Carolina, Rhode Island, and Maryland. San Francisco and Sacramento would be underwater, as would New York City, Philadelphia, Providence, Houston, Seattle, and Virginia Beach, among dozens of other cities. In many places, the coast would retreat by as much as one hundred miles. Arkansas and Vermont, landlocked today, would become coastal.

The rest of the world may fare even worse. Manaus, the capital of the Brazilian Amazon, would not just be on the oceanfront, but underneath its waters, as would Buenos Aires and the biggest city in landlocked Paraguay, Asunción, now more than five hundred miles inland. In Europe, in addition to London, Dublin would be underwater, as would Brussels, Amsterdam, Copenhagen and Stockholm, Riga and Helsinki and Saint Petersburg. Istanbul would flood, and the Black Sea and the Mediterranean would join. In Asia, you could forget the coastline cities of Doha and Dubai and Karachi and Kolkata and Mumbai (to name just a few) and would be able to trace the trail of underwater metropolises from what is now close to desert, in Baghdad, all the way to Beijing, itself a hundred miles inland.

That 260-foot rise is, ultimately, the ceiling—but it is a pretty good bet we will get there eventually. Greenhouse gases simply work on too long a timescale to avoid it, though what kind of human civilization will be around to see that flooded planet is very much to be determined. Of course, the scariest variable is how quickly that flood will come. Perhaps it will be a thousand years, but perhaps much sooner. More than 600 million people live within thirty feet of sea level today.