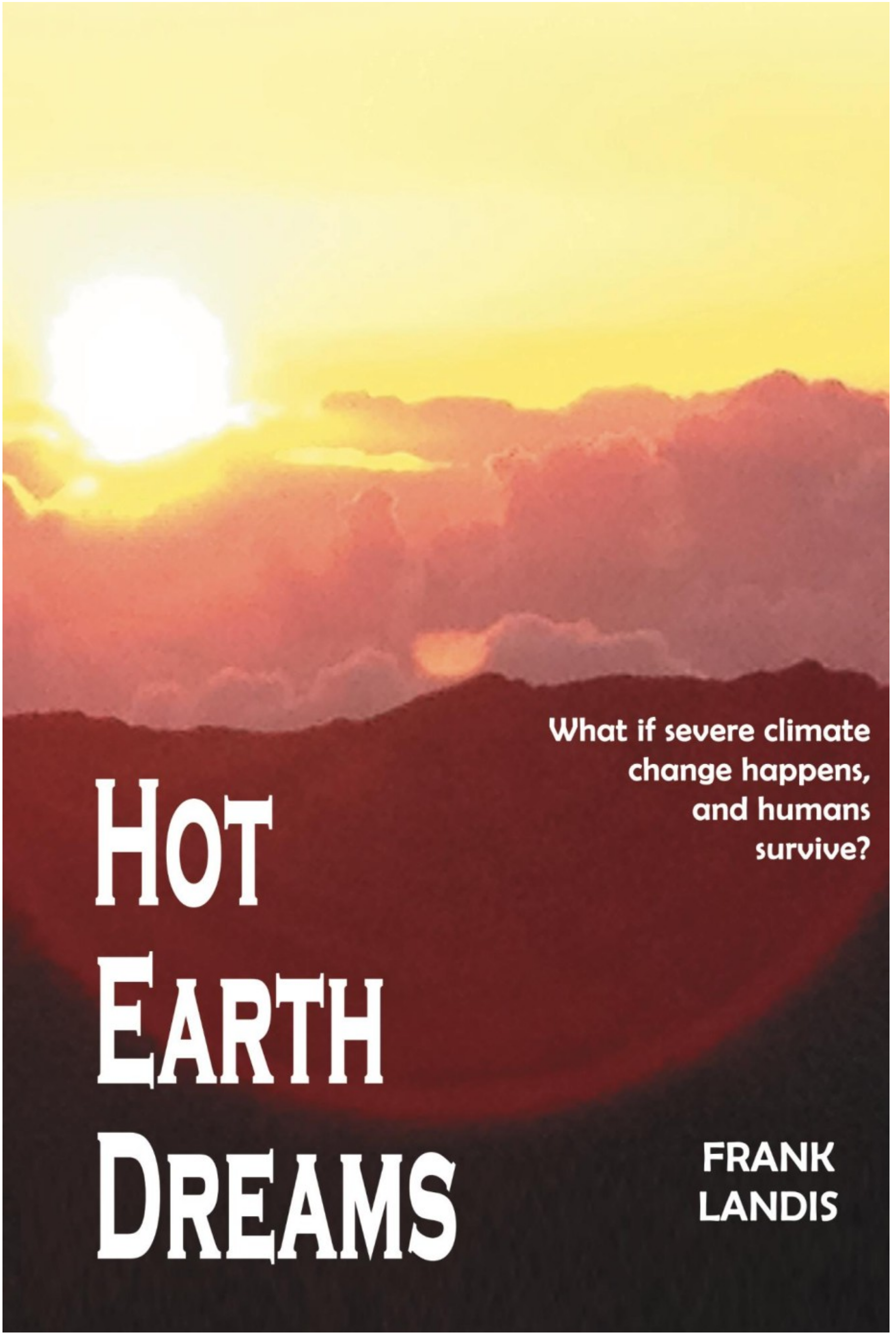
What if severe climate change happens, and humans survive?
HOT
EARTH
DREAMS
FRANK LANDIS

November 5, 2015 sample version

Introduction: To Dream the Unspeakable Dream

Warning: There will be warnings for every chapter

Years ago, as a grad student studying the sometimes dismal science of ecology, I learned that pessimism has its own rewards. One is that, whatever happens, as a pessimist you will either be right, or you will be pleasantly disappointed. This is a book about the future, and as you read it, especially if you are reading it many years after I wrote it, I hope you will be pleasantly disappointed by how pessimistic I was. Really. Nothing would theoretically please me more than for everything I predict here to have been too pessimistic. Theoretically, because I'll be dead by the time the events in this book could really start coming true, but as you read, I think you will understand.

This book is my attempt to answer a question: What will the Earth look like if severe climate change happens, and humans survive? If you're like the people whom I've asked, like me when I started writing this book, your answer to the question is to freeze in silence. Do you feel a horrible sinking sensation as you think about it? You're not alone. For everyone I've asked, this future is literally unspeakable. We can't speak meaningfully about it. When we try, our minds hit a wall, at best spin off quips from apocalyptic novels and movies before falling silent and changing the subject.

I wrote this book to change that. We need to talk about, dream about, the hot Earth that is our likely future.

This book is a book about what the future might be, not a prophecy of what the future will be. There are no certainties. Nor is it a set of prescriptions for how to avoid this future or how to prepare for it. Other authors have tackling these subjects in some detail, and I'd suggest reading their books (Greer 2008, McKibben 2010).

My goal is simply to help you understand one probable, plausible, deep future. This book is what ecologists call a conceptual model, what science fiction calls a "what-if" thought experiment. In other words, it's pure speculation, informed by the best scientific and humanities research I could find. It starts with a simple, published model for severe climate change caused by blowing all our fossil fuels into the atmosphere over the next century (Archer 2005), adds in the collapse of global civilization and mass extinction, and lays out an overview of what happens for hundreds of thousands of years after that, until the Earth enters its next ice age.

My hope is that it will make this future "speakable," make it possible for us to dream about the future, to enable us to explore that future creatively, to talk and write about it, and to inspire us care about the future and prepare for it, even though it is scary. Of course I also hope it will help lead to solutions to the problems we face, but as a wise teacher told me decades ago, if the solutions were simple, someone would have figured them out already.

It's natural to ask whether I used the right model or even asked the right question. Is my model probable? Right now, we're on track to emit the greenhouse gases this model requires within about 50 years. In stretching it out to 100 years, I assume we're going to partially gain control of our emissions, but that everything from war to disaster response and rebuilding cities will keep us from switching to 100 percent renewable energy, thereby dooming us to burn all our fossil fuels and deal with the consequences. Ten years from now, this prediction hopefully will be very wrong, but right now it's conservative.

As for asking the right question, let me ask you a few questions in return:

Do you think that the Earth will look very different in 100 years? I don't think anyone will disagree with this, simply because the Earth has looked very different every 100 years for the last 1,000 years and more. Change is something we can all agree on.

Do you think that global civilization will collapse in the next 100 years? If you're at all like me, you think it's possible, even likely. Of course we'd all rather be wrong, but it's going to take radical, global change to avoid collapse, and we're not doing that radical change thing very well right now.

Do you think that humanity will go extinct in the next 100 or 1,000 years? While I think this is possible…um. Eliminate every human being? That's really hard. I don't think that's going to happen. Do you?

My question seems plausible, doesn't it? That's why I decided to answer it.

The next natural question is why I am an authority on the future. As I write this, I'm a part-time environmentalist, a part-time consultant, a house-husband and a writer. I'm one of the people who earned a PhD, in my case in botany (I'm a plant community ecologist and mycorrhizast by training, with a background in environmental science), failed to land a job in academia, and got downsized out of the business world by the Great Recession.

In other words, I'm not an expert on most of the topics I discuss here, although I know a little about ecology, botany, and environmental science. As you read this, you really should be thinking about the Dunning-Kruger effect, the cognitive bias that people who don't know what they're doing tend to rate their ability to be much higher than it actually is (Kruger and Dunning 1999). It's been on my mind constantly as I've worked on this book. In my defense, there don't seem to be any experts on the deep future right now, so we all have to strive towards greater competency in the subject. Since I am a pessimist, I assume that I got some of this wrong, and hopefully readers will be kind enough to point out my mistakes.

However, being an untenured ecologist does give me two advantages. We ecologists are lateral thinkers by nature. We tend to take disparate lines of theory and data and combine them, Sherlock Holmes-style, into stories, then to figure out ways to test the truth of our stories. While no one is perfectly suited to talking about the interactions among climate change, mass extinction, and collapsing civilizations, an ecologist like me can turn these trends into models of what the vegetation will look like, reinterpret the vegetation in the light of mass extinction, talk about how to figure out which animals and insects will live where and what crops will grow, extrapolate from that

to talk about the challenges and opportunities these will pose for our descendants, and then talk about the consequences of their actions in turn, and put this all on one long timeline. That's why I'd suggest that ecologists are better candidates than most.[1]

Being outside academia gave me a second advantage: I don't have a lab to feed, which means that I'm not constrained by the eternal crisis of pulling contracts in and pushing papers out. When I started writing this book in 2013, I figured that it would take about six months, and it took over two years. This is not the kind of work that my friends in the universities, agencies, and consulting firms could easily have produced. Fortunately my wife has been extremely supportive throughout the process.

Generally, books like this are written by three groups of people: scientists, activists, and journalists. The scientists, people like David Archer, Curt Stager, Laurence Smith, Peter Ward, or Jared Diamond, have traveled all over the world, either directly researched the issues or have colleagues and students who did, and are recognized experts. The activists, people like Al Gore and Bill McKibben, are recognized, well-traveled leaders. Then there are the writers, people like David Quammen, Elizabeth Kolbert, and Annalee Newitz, who have traveled around the world talking to the scientists and people experiencing various events. All these frequent flyers rack up enormous carbon footprints to bring us their stories.

But what about the rest of us? Do you have to be a high-flying carbon bigfoot to understand climate change? No, and this book proves it.

I did not fly anywhere to interview anyone for this book. Instead I used published references, either books I purchased, checked out through my local library and their inter-library lending service, or documents I downloaded for free online. If you have access to the internet and a decent library (or booksellers and a sufficiently large budget), you can do the same. Thanks to the efforts of thousands of scientists, you can explore a climate-changed future as deeply as you wish.

Still, I want to give credit where it's due. This book owes a huge debt to David Archer's *The Long Thaw* and Curt Stager's *Deep Future* (Archer 2010, Stager 2011), and I used Archer's model as the

---

[1] Perhaps this is due to the Dunning-Kruger effect?

climatological basis for this work. Other influences include Bill McKibben's *Eaarth*, Laurence Smith's *The World in 2050,* Jared Diamond's *Collapse*, John Michael Greer's *The Long Descent,* Al Gore's *The Future*, even Peter Ward's *Under a Green Sky* (Diamond 2005, Ward 2007, Greer 2008, McKibben 2010, Smith 2010, Gore 2013).

Before I talk about what's in the book, let me discuss a term that some find problematic: environmental determinism, the idea that the environment helps determine the trajectory of history and human social development. Yes, I understand that it has a bad name in some circles, and Diamond's *Collapse* and *Guns, Germs, and Steel* have been panned as being inaccurate and biased due to his perceived bias towards environmental determinism (Diamond 1997, 2005).

Here's my take on environmental determinism: it doesn't rob anyone of their free will. In my opinion, many people suffer from an illusion that technology frees humans to do whatever we want to do, wherever we want to do it, that the environment plays no role in modern history, that our future is based solely on our current desires and politics. As an ecologist, my question is always: with what resources? Certainly, right now some 0.01-percenter could spend billions of dollars to create a tropical biosphere in Northern Greenland, live a life in it that was utterly inappropriate for the local environment. But how long would it last, especially once fuel gets expensive and the repairs get increasingly complex? The Biosphere II experiment taught us how little we really know about building such things, even in comparatively friendly places like the Arizona desert. So many people don't really understand that technology has environmental limits, that it frees us only temporarily and at a cost. When we deal with situations of resource scarcity, the environment increasingly determines our options, and right now, we're working perversely hard to insure that our future will be resource-scarce indeed. For example, someone who wants to live sustainably, using local resources in the frozen Arctic, probably will end up adopting many Inuit practices simply because they work, while someone living in the tropics will follow local practices for the same reason. That's just common sense, and it's the common sense I built this book from.

While the environment sets the stage, it doesn't write the play or determine the ending. This is critically important. In every case, what people do with their environment matters more than anything else. Everywhere we live, human life is impossible without culture, without

people taking the right actions at the right times, without people growing, finding, or making food, water, and every other resource we all need to live. Local environments determine how we go about doing all this, how much is available, when, and where, and these details matter more than you might think. For example, all of the experts I've read agree that, while environmental crises like drought are normal, resulting catastrophes like famine always are caused by poor decision making, sometimes by simple bad governance and corruption, often abetted by ignorance and bad planning. What people do with their environment always, always matters.

Since this is a book about how climate change and species loss affects humans, it is about environmental determinism. Still, you'll find quite a bit about humanity. I've tried, in my nerdish way, to talk about why some decisions are very hard for people to make, and also how environments affect the ways we go about solving various problems, from keeping ourselves fed to building new civilizations from the remains of old ones. People are an integral part of this book. It's about how we survive climate change, after all.

The book contains 42 chapters of 900-6,000 words each. I chose this format because world building of this kind requires lateral thinking, and it covers a wide range of topics. More to the point, I spent years stumbling through other peoples' long chapters as I researched this book, and I wanted to make it easier to read and easier to find things you've already read.

There's a reason for the chapter order, and I do suggest reading them in order, at least the first time. The first 17 chapters contain basic concepts and the basic model. Chapters 18-22 are about the 21st Century and the collapse of civilization. Chapters 23-29 are about the 1,500 years after the collapse, while chapters 30-40 are about the 400,000 years after that the collapse. The last two chapters wrap it all up, and consider how long we'll be around as a species.

Four of the early chapters are labeled "traps," the traps of binary logic, big numbers, cyclical thinking, and collapse. Each of these talks about mental traps I've fallen into repeatedly in creating this book, and I've seen other people make the same mistakes. The point isn't to be patronizing, it's simply that certain thinking styles, like focusing on either-or dualistic logic, or truncating dates into a few thousand or a few million years, or using the past uncritically to predict the future, or thinking that you know collapse when you see it, all of these really will

trip you up. They're useful in other contexts, but not here, and I hope these chapters will help you nimbly navigate the rest of the book.

Chapter 39, "Multitrack History," is another outlier. It's about one way to put all these disparate chapters together if you want to create your own future history. So far as I'm concerned, the concepts in this book are free for everyone, even though I've copyrighted the text that contain them. If this book inspires you to do something, go for it, and if you want to borrow any of my ideas or terminology without plagiarizing, be my guest.[2] If you feel like telling me what comes out of your inspiration, I'd love to hear about it.

In a way, I think of this book as a skeleton key for a deep future. It unlocks one particular future, not all of them. Even with 42 chapters, it's skeletal, a broad overview of processes and possibilities, not a detailed future history with names, cultures, regimes and life styles. If you want to bring some part of this future to life in your own world-building project, this book will give you the bones, but you have to put the meat on them, get them breathing, bring them to life.

You will find a lot of maybes, mights, and other squishy wording here. While I could edit all that out, make simple, declarative statements of what the future will be, there's a reason for the squishiness. Humans are an essential part of the process, of the future. Our decisions have enormous impacts, and it's not possible to forecast how we'll act in most circumstances. Moreover, there's simply a lot we don't know. I've tried to highlight that uncertainty, not to conceal it. This is an early draft of the future, not a definitive statement, and I'll be immensely disappointed if it actually comes to pass. Life with colonies on Ganymede might be more exotic, even though I doubt we'll get there anytime soon.

As for the black humor, sarcasm, and lame jokes, the warnings at the beginning of each chapter? There's a reason for them. A future where civilization collapses is an enormous tragedy, and it's a tragedy that anyone with even a gram of compassion is going to have trouble contemplating. With the pointless loss of billions of lives, our cultures will shatter in the collapse. The survivors won't be our intellectual heirs, they'll be scavenging pieces from which to build their new societies. What they create will look broken to us no matter how well it works for them. It hurts to think about this, just as it hurts to think

[2] I also suggest reading up on fair use and derivative works, just in case.

about mass extinctions if you love nature. That's the point of the humor and sarcasm—it's to help you get through it, just as it helped me.

If you want an overview, here's a thumbnail model of the next 400,000 years of the Anthropocene: over the next century, global civilization will release about the equivalent of 1,000-1,400 gigatonnes of carbon into the air. In doing so, it will exhaust all of Earth's usable fossil and radioactive fuels, and will mobilize some polar methane to boot. For about two hundred years after that, the global temperature will continue to rise, topping out around 2,300 CE. For perhaps another 1,300 years after that, the ice sheets will continue to melt until they are gone, and sea level will top out around 3,500 CE. After 2,300 CE, atmospheric CO_2 concentrations will start to fall, first rapidly, then increasingly slowly, so that it will take up to 400,000 years for air chemistry to settle back to 20th Century norms. During that time, wobbles in orbital Milankovitch cycles will shift temperatures several degrees near the poles, causing global climate fluctuations on a roughly 10,000 year cycle. There will be large volcanoes, perhaps a smallish asteroid strike. Eventually the ice will return, sea levels will fall, and there will be another ice age.

After the coming century, humans will have no fossil fuels to work with. Most of our metals and many other critical elements will have to be recycled from the ruins of ancient cities and their successor settlements. There will be fewer of the species we're currently used to, and new species will be evolving and adapting. Like it or not, we'll be a keystone species in Earth's biosphere, with more and more species evolving to depend on us and/or take advantage of us. Worse (if this sort of thing bothers you) we'll be stuck living sustainable lives, simply because the alternative, most of the time, will be watching our children go hungry or die of famine, disease, or the social unrest that typically accompanies both.

This doesn't mean life will be boring, though. It will be crazy, then horrible, then tough, then increasingly strange. If you want to know more, read on.

1. The Trap of Binary Logic

Warning: Mind games

Quick, would you categorize the color red as more black or more white?

No it's not a stupid question, what is your answer?

Well yes, actually it's a very stupid question, but it gets at a fundamental mental tool you might want to develop to understand possible futures. That tool is knowing when to set binary yes/no, either/or logic aside and use something a bit more sophisticated.

In the above question, it should be obvious that red is neither black nor white. However, if you're like most people, you tried to shoehorn red into one of those two categories, because you were nice and going along with me (thank you for that, incidentally).

Perhaps you were clever and thought, "red is not black or white. It's gray." Really? There are dark reds and light reds, and if you stripped the red hue out, you'd be left with, well, different shades of gray. What defines red is not its lightness (the gray scale from black to white) but its hue, which white, gray, and black lack. In mathematical color models, hue is a separate axis perpendicular to lightness, so you can't measure red in terms of how gray it is, any more than you can measure redness in terms of how light or dark it is.

This is the trap of binary logic: dealing with a problem within the either/or binary framework of a dichotomy, without stopping to ask whether such binary logic is appropriate. The solution is equally

simple: when you see an apparent dichotomy, ask yourself whether such logic is appropriate, and develop other methods for dealing with such situations.

Yes, it's totally obvious. I know, that's okay. It needed to be said. Now that you've got your mental toolkit updated, let's look at a slightly more complex question.

Some people tell us that if we don't move humans off the planet and into space, we'll go extinct. According to the esteemed Dr. Stephen Hawking, "humanity would not last another 1,000 years on Earth" and "we must 'escape beyond our fragile planet.'"(Prigg 2013). While these statements were made to encourage the US government to continue funding NASA, the idea is common in the space enthusiast community. According to this notion, because we apparently can't live in this enormous biosphere that we evolved in, this incredible planet that provides us with notionally free air, water, gravity, and meteor and radiation shielding, therefore our only hope is to pack ourselves into cans where all elements have to be totally recycled, where we hope our radiation and meteor shields are good enough, and where we're spun up to provide a centrifugal simulacrum of gravity, because, of course, we can more easily live packed in a can for 1,000 years traveling to Alpha Centauri B than we can for 1,000 years on this planet. Once we arrive at Our New Home, either we will colonize a totally alien biosphere after 1,000 years of living in a tightly confined, very simple ecosystem, or we'll terraform some planet or other to be just like the Earth we couldn't live on before, only simpler. The alternative is that we'll go extinct, because we "obviously" can't live here.

Yes, that was very sarcastic, but it's incredibly easy to fall into these kinds of false dichotomies when we speculate about the future: Progress or extinction. People or the environment. Civilization or nature. Singularity or apocalypse.

John Michael Greer, who is both a pagan and a futurist, pointed out in *The Long Descent* how much our view of the future is conditioned by the dichotomy of heaven or hell, even if we're militantly atheist (Greer 2008). This isn't a criticism of Christianity, just a point that we live in a "Christian society" to the extent that even people who aren't Christians unconsciously adopt a model of the future containing an end time for humanity with a binary outcome. They may call heaven the Singularity and hell the Apocalypse, but their memes are often, and unintentionally, rooted in the Book of Revelation. It takes a pagan like Greer to step outside the mainstream far enough to see how much our

vision of the future is constrained, to the point where it leaves out many more likely futures. That's why it's important to understand how binary logic can trap us, and to learn how to step out of the trap.

One solution here is to recognize dichotomies and then to decide whether they're real or not before going on. As you read this book, you'll quite likely find yourself thinking that "well, if it's not X, then it has to be Y." Stop when you think that, and ask yourself whether the dichotomy you just created is real. If it's not, don't think of it as a dichotomy.

Another solution is to use the four-cornered (catuskoti) logic of Buddhist traditions (Priest 2014). When confronted with an apparent dichotomy, call the two sides This and That, you can have four choices: Is it This? Is it That? Is it both This and That? Or is it neither This nor That? Red is neither black nor white, and in what you read here, human history ends neither with a singularity nor an apocalypse, and everything gets very complicated.

Got your brain rewired? Wonderful! Let's continue.

2. Mosaic World

Warning: Metaphor as model

Here's an insight, not my own, that you may find useful. Try looking at the world as a mosaic, a place where both the past and the present are unevenly distributed in patches and pieces. Mosaics are made of broken pieces, reassembled into a new whole, and that's a very good way to see the world. Things break, things die, things move, and then they become part of something else when they don't remake themselves. The world is always in process, always processing, always being processed. What we see now is the result of over four billion years of reprocessing.

What I've realized is that the future is a mosaic too. Certainly there are trends, great cycles, climate change, resource depletion, all that. But these trends all affect different places in different ways and rates and times. It's impossible to capture all of that in a finite work, much less a book of linear text. The best I can do, we can do, is to talk about metaphors, generalities, models, and the model of a mosaic is the one I use the most often.

This chapter was inspired by a radio interview I heard on public radio, as I drove home one night. The show was Krista Tippett's *On Being*, and she was interviewing the conservationist and writer Terry Tempest Williams on the subject of mosaics, a subject she wrote about in *Finding Beauty in a Broken World* (Williams 2008).

I'm not a huge fan of mosaics as art (and my apologies to those who are), but I was struck by Ms. Williams' use of the art form as a metaphor for healing. As with all art, mosaics are built by breaking something old to make something new, but the Italian mosaicists who taught Williams made this process more explicit than it is in other art forms. The point of the mosaic metaphor isn't that things become broken and then heal back into their old form, it's that they are broken and healed into something new and different, just as a mosaic is a whole composed of broken pieces. It's a useful metaphor that Williams extends to conservation, but I suspect it goes much further than that.

As an aside, one could easily argue that another term better fits this notion, say the art of collage, or the French term for tinkering, bricolage. Some people will even say that, dude, that's progress, get over it, the past gets broken all the time. Whichever. Mosaics have long been used as a metaphor in ecology, particularly landscape ecology, and I think it's worth using the mosaic metaphor as an alternative metaphor to linear progress. Things get broken, even shatter. Shards and remnants are united into something new. It's not an even process, either in time or in space, nor is the new necessarily better than the old. It's simply what came from the old shards.

As an environmentalist, I often deal with old development plans, ones that broke against reality and community opposition, only to be rebuilt and rise again like comic book supervillains. One I'm dealing with as I write this has been approved twice already but never built. The pieces are being united in a new plan as I write this, and the plan hopefully will have broken again by the time you read these words.

That's the problem with long-term plans. Reality breaks them, even as people struggle throughout their entire lives to see them through. Then people work to heal, create something new from what survives. It's the way civilization works.

We environmentalists are also realizing that our long-term conservation plans are breaking. As the wildlands get broken into smaller and smaller fragments, as the critical connections between them become more tenuous, they become more fragile. Our conservation plans, with their connectivity patterns, richness studies, and core habitats surrounded by development, now these all have to contend with a climate that's changing all the habitat parameters. Will the migration corridors work, or will they break? What will remain in the areas we set aside as preserves?

Business plans are breaking under climate change too. Even the auto industry is saying that shared cars like Car2Go are the next big area for new product development (Chase 2012). How will this break the designs of all the very conventional housing developments that are going in around me, all cars and no public transportation? Even the electrical utilities seem to be deeply afraid that rooftop solar will leave them stuck with maintaining a grid that no one particularly wants, except for emergencies. Old patterns are breaking all over.

Cities are mosaics too. They are the surviving pieces of old plans reshaped and repurposed to make something new, only to be broken and rebuilt again, and again, and again. They are processes as much as places.

Even the weather is a mosaic, highs and lows, heat waves and frosts, Santa Anas and storms, droughts and floods. The climate of the future is already here, but it's here in pieces, very unevenly distributed. We don't yet know which of those pieces will become more common until they become normal, which will become less common until they disappear from our lives. That's how the weather changes, not by a gradual wave of average change, but in the unevenly distributed events that generate those averages, heat waves becoming more common, snows disappearing.

The future is arriving, one broken piece at a time, each piece made out of the broken bits of the past, each piece breaking things as it comes. Still, we have to be careful about extending the mosaic metaphor too far.

A good example of metaphoric overreach comes from landscape ecology, where the mosaic concept has been put into practice with rather more zeal than reality allowed. Landscape ecology is what it says on the label, the ecology of landscapes. Landscape ecology maps are often mosaics of polygons, and each polygon has some supposedly homogeneous characteristic. One polygon may map grassland, another forest, and the polygon map assumes an edge between them..

What's wrong here is that sometimes there are no edges. I happened to do my PhD on oak savannas, which are a type of landscape whose edges are essentially impossible to define,[1] and that made me very aware of how artificial mosaic boundaries can be.

---

[1] Let's use beer as a metaphor for oak savannas. Think of a sudsy pint, sitting in the middle of an otherwise empty room. A delicious pint. Now imagine a beer world in

The problem isn't the artificiality of edges on maps, because any good scientist is perfectly aware of these issues and works around them. No, the problems started when scientist talked about how a "healthy" landscape is composed of different patches, say of different ages since the last fire. This was somewhat controversial (as in reality doesn't necessarily agree), but things started snowballing when land managers decided they could make their managed landscapes "healthier" by artificially breaking them into mosaics of different ages since last fire, and they did that by deliberately starting fires. If you're a pessimist, you already figured out that some of those fires got away from the land managers and destroyed things they were trying to save. As my late graduate adviser John Sawyer pointed out, managers get paid to manage, even if the best thing they could do is to leave well enough alone. After all, if they're sitting around doing nothing, they'll lose their jobs. As a result, we get managers trying to break landscapes and make mosaics, sometimes with tragic results.

Here's another way to understand the problem. When mosaicists make mosaics, they take specially prepared bits of glass and stone and carefully break them with special hammers so that the pieces will fit. It doesn't take much more than that to understand the technique, but it takes years of breaking pieces to get to the point where you can reliably break the pieces the way you want to make a beautiful mosaic. Beginners end up with messes, just as you'd expect. And mosaic tesserae (the pieces) are very, very simple in comparison to ecosystems.

When land managers start treating the landscape as something to be broken and made into a mosaic, they're basically amateurs. Of course they have degrees, experience, resumes, publications, and expert advice, but the hard truth is that landscapes are massively, perhaps infinitely, more complex than simple tesserae or even the most artistic mosaics. Everyone's an amateur at breaking them, and I'm not being very pessimistic when I point out that successes in deliberately breaking

---

which the oak forest is the beer, while the prairie grasses are the air around the beer. Oak savanna is the beer suds, a complex mix of oak forest species and prairie species. If you're working in a mosaic of beer and air, how do you map the beer-air boundary in the suds? It's nothing but beer and air, but at the same time, the suds collectively are nothing like beer and air. If you like, go ahead and map the boundary between beer and air in the foam of a pint. I'll be happy to wait. But you'd better work fast.

a landscape and remaking it as a mosaic happen as much by accident as by design.

I could expand on the examples almost endlessly, but hopefully you get the point. It's useful to think of the world, civilization, and the future, as mosaics, as a bunch of different, broken pieces doing their own things, coming together into new wholes, those new wholes breaking to provide the raw material for whatever happens next. In many circumstances, this is a better mental model than, say, linear extrapolation or continual progress. Just remember that it's a metaphor, and don't take it too literally.

3. The Trap of Big Numbers

Warning: Big numbers

Most people (including me) have trouble understanding large numbers. We tend to systematically distort them as we read. Take, for example, the series thousand, million, billion, trillion, quadrillion, using the American definitions of these terms. Without thinking about it, you'd probably say that there's a big difference between a thousand and a million, but less between a million and a billion (after all, they're spelled almost identically), and between a trillion and a quadrillion? That's abstract math land, la la la run away. Now, look at the following series:

1,000
1,000,000
1,000,000,000
1,000,000,000,000
1,000,000,000,000,000

Yes, it's the same series of numbers, but now it looks quite a bit different. The difference between a thousand and a million is 999,000, the difference between a million and a billion is 999,000,000, and the difference between a trillion and a quadrillion is 999,000,000,000, which is a million (1,000,000) times larger than the difference between a thousand and a million.

Those zeroes matter.

Most Americans who listen to the political news are at least familiar with the idea that our thinking about the US federal budget gets into crazy number territory, with trillions of dollars in play ($3,540,000,000,000 in 2013 expenditures (Costantino and Schwabish 2014)). I suspect a lot of us don't like to think about it for good reason, because we have to pay for that monster with less than 320 million people (317,292,487 people on December 31, 2013, according to the US Census Population Clock (US Census Bureau 2014)), or expenditures of about $11,156.90 per person per year in 2013.

Still, it's worth thinking about big numbers, because getting fuzzy about big numbers leads to trouble. For example, one may think that the US National Park Service, with its 2013 budget of $2,579,000,000, is a gold-plated waste of money that could easily be cut to give more money to, say, veteran's health care or some other perfectly worthy cause. However, when you divide it by the number of people in the US, we're each paying about $8.13 on average, or about 0.00729% of what the US government spends per citizen, per year. The entire Parks budget wouldn't even buy a single doctor's visit for every veteran. Park Service employees refer to their budget as being decimal dust, compared to big programs like the defense budget. Given what they accomplish with such a meager budget, one could almost wish to see the US military, with its 2013 budget of something like $713,000,000,000, do so much with so little[1] (Costantino and Schwabish 2014).

But enough politics. Big number blindness also affects the way we look at time. The Earth is about 4.54 billion years old, 4,540,000,000 years; animals galumphed onto land some 430,000,000 years ago, give or take; anatomically modern humans have been around something like 200,000 years; the last ice age ended about 12,000 years ago; the Common Era, source of the BCE/CE dating system used in this book, started 2,016 years ago, and the US is 238 years old. On this timeline, what was a long time ago, and what happened recently? All of it,

---

[1] Despite my snark, the US military does an extremely good and important job on conservation and other environmental issues. I suspect a number of species would be extinct were it not for their work, and I do seriously commend them for it. Where I get steamed as a taxpayer is when their silver plated weapons systems don't work when and where they are supposed to.

depending on how you look at it? Well, yes. And no. The problem is that we use so many different temporal yardsticks that we get confused.

For example, the deeper we go in history, the more the zeroes are ignored and the dates telescope into each other, causing a collective hallucination at its worst called "geologic time." My favorite example of the misperceptions fostered by thinking in geologic time is the "Great Oxygenation Event," wherein photosynthetic cyanobacteria cracked water to get at the hydrogen (for photosynthesis) and released oxygen into the atmosphere as an end product, thus dooming a whole biosphere of anaerobic bacteria to death through this horrible pollution[2]. The "Great Oxygenation Event" started around 2.4 billion years ago, although cyanobacteria were present shortly before at 2.6 billion years ago. Oxygen started accumulating in the atmosphere at something like modern levels around 0.85 billion years ago. Sounds like quite a sudden environmental catastrophe, doesn't it? It routinely gets written up this way (Pinti 2011).

Let's try this again, this time with all the zeroes added in. Real time, not geologic time. Cyanobacteria seem to have appeared around 2,600,000,000 years ago. 200,000,000 years later, the Great Oxygenation Event started. Oxygen was then taken up by the ocean, oceanic sediments, the terrestrial sediments for about 1,750,000,000 years before rising to something like what we consider atmospheric normal levels a mere 850,000,000 years ago. Animals galumphed onto land 430,000,000 years ago, or 420,000,000 years after that.

Great Oxygenation Event? Yeah right. By those terms, we're less than halfway through the Primitive Animal Invasion of Land Event (which has only happened in 430,000,000 years, not the 1,800,000,000 years of the Great Oxygenation Event). A blink of the geologic eye, really. Given that the sun will expand and make the Earth uninhabitable in about 1,000,000,000 years, we'll sadly never actually finish the Primitive Animal Invasion of Land Event, either, so we'll never know what truly complex animals look like. I've never seen people talking about the so-called Great Oxygenation Event actually put all the zeroes into their discussions, and I wish they would. When something went on for far longer than the history of animal life on land, it was not an event, it was an extremely gradual process.

---

2 Anaerobes are still around, and you smell them every time someone farts.

Why is this important? Well, 200 years is a long time ago if you're an American. If you have a genealogist in your family, you may well have names of ancestors going back that far, even if you know nothing else than that they lived, died, and gave rise to more ancestors you also know fairly little about. Then, when you read about, say, the rise of civilization, the whole "Neolithic Revolution" seems fairly brief, an "event" that took only 6,000 years or so (11,000 years to 5,000 years ago, very approximately). Then the paleontologists talk about how fast humans evolved in only 2.5 million years (2,500,000 years), and so forth. The bigger the dates are, the more they telescope in our heads. That's where the terrible misnomer of the Great Oxygenation Event came from. It's like looking through the wrong end of a telescope, truncating everything, thinking the times in the deep past or deep future are very short because we pay attention to the first digits and ignore all those scary zeroes.

But who cares, right? We're talking about the future in this book, not the past.

That's right: we're talking about the next 400,000 years. The last half of this book is deep into the Future of Many Zeroes.

It's hard to think about those big gulfs of time, but it's worthwhile. I know. A few years ago I wrote a mediocre and self-published time travel novel set partially in the Paleocene some 55,000,000 years ago. As I plotted that thing, I spent a lot of time contemplating big numbers with many zeroes. I came to understand why they call it deep time.

When you get those numbers into your head, the history of the Earth feels like a vast, deep gulf indeed. But you don't drown there. It's a gulf you can swim in. You may have to struggle through the stereotypical five Kübler-Ross stages of denial, anger, bargaining, depression, and acceptance, but life gets better once you learn to think this way.

I learned to think of future time with many zeroes as a great frontier, millions of unknown Earths down-time from us that we could colonize without a starship. Isn't that a goal worth working for?

So I'd advise this: add the zeroes in, except when there's a really good reason not to. Learn to use only one chronological yardstick, even though it won't be easy at first. Don't truncate time by using phrases like "a few million years." Shove historical time, evolutionary time, and geologic time into the junk closet and use only one numerical yardstick unless you're forced to do otherwise by the social conventions of your field. Don't confuse thousands, millions, billions,

and trillions. It doesn't matter if we're talking about gigatonnes (1,000,000,000 tonnes) of carbon or hundreds of thousands of years (100,000 years) of future human history. Life really is more interesting when you are comfortable with big numbers.

4. Apocalypse or Singularity or ???

Warning: Non-binary logic already

Let me start off on the defensive. Why not apocalypse or singularity?

I'll start by defining terms: If I wanted to be Biblical, I'd say the apocalypse is the literal end of the world, but everyone has their own version of what the "end of the world" means, from planetary destruction all the way down to "my daughter didn't get into the right nursery school." But to me, an apocalypse worthy of any consideration is somewhere between humans going extinct as a species and the world exploding. Anything less is merely a major catastrophe.

As for Ray Kurzweil's Singularity, in the most general terms, it's the point in time when artificial intelligence has progressed to a point where it's greater than human intelligence (Kurzweil 2005). At this point, the theoretical curve of technological progress rapidly increases, and whatever comes out the other side can't be predicted from our side of the progress curve.

Let's take these one at a time.

First off, the end of the world, the apocalypse.

This will eventually happen, if only because the sun will probably engulf the Earth as it expands something like 1,000,000,000 years from now. However, unless we humans figure out how to manufacture black holes and drop one into the Earth's core, we don't have anything

like the power to destroy the planet. And barring a black hole maker, it's unlikely that we ever will.

Similarly, we're incapable of killing all life on Earth, simply because most life consists of microbes hiding deep in the soil and bedrock. We can't kill them without destroying at least the top ten or twenty kilometers of the Earth's crust, so destroying life on Earth, while easier than destroying the entire planet, is still too hard for us to accomplish. We can't even bore a hole ten kilometers into our planet yet, let alone destroy that much.

Can we render ourselves extinct? Possibly. Perhaps total nuclear war, 1980s style, would do it, although even a horrible nuclear winter might simply mean that New Zealanders inherit the globe. Alternatively, the current mass extinction we're causing might so totally degrade the biosphere that we won't be able to survive. That too is a possibility, since previous mass extinctions don't appear to have left many human-sized animals alive afterward. Still, there are some very good survivalists out there, and I suspect it would be very difficult to kill every last human on the planet. After all, we are the most invasive mammal on Earth. Moreover, as a species we appear to have been close to extinction before (see Chapter 15), and if the evidence is correct, we recovered to conquer the globe. Anything that wants to kill our species has to make sure that all of us are dead.

Can we end global civilization? Absolutely. That's what a global nuclear war would definitely do, as would the collapse of our fossil fuel infrastructure, loss of any major crop, and so forth. In fact, if we seriously deal with climate change, we'll have to so radically transform civilization that one could argue we'll need to destroy it and remake it. Then again, we've pretty much destroyed and remade all of humanity's complex cultures and civilizations in the last 500-odd years, so horrible as it is, this kind of catastrophic destruction is scarcely new.

Sarcastic though this may be, there is an important point: the most fragile thing is our global civilization. Our species is less fragile than civilization, the biosphere is less fragile than our species, and the planet is less fragile than the biosphere. While many people are justifiably horrified by how much destruction we can cause at present, the best we can now do is to destroy civilization, or possibly our species if we go for something extra-special, super-duper, inhumanly stupid.

Pessimist that I am, I still doubt we can actually kill ourselves all off. But I could be wrong.

Still, there's another reason I'm not dealing with the human extinction here, and it has to do with human psychology. Way back in the Mesolithic, when I was a grad student at Humboldt State in northern California, TAing ecology and taxonomy classes, I taught a number of environmental studies students who had self-destructive habits such as chain smoking[1] and binge drinking. When I asked why they did what they did, the most common answer was that they believed the Earth was doomed, so why bother with a healthy lifestyle?

That's the pernicious problem with apocalyptic thinking. If the end is coming, why bother fighting it? Why worry about the consequences of anything? Apocalyptic thinking allows a vicious sort of freedom, because it says that your actions will never have consequences, because it will all be over before you have to pay any price.

But it's endlessly embarrassing when it's not over, isn't it? It's like the stories about people who believed that the world is going to end on a certain day, maxed out their credit cards until that day, only to see the world go on as usual, leaving them bankrupt (Gagne 2012). We can laugh at them, but how much has all the noise about Y2K, the Mayan End Times, the Zombie Apocalypse, ad nauseum, kept us from dealing with real problems like global climate change, problems that have long-term consequences?

Sometimes I wonder why Americans have been so addicted to apocalyptic stories recently. Perhaps it's because we're on top of the world, and we fear that we have nowhere to go but down as the great wheel of time rolls on? Sometimes it seems like, instead of dealing with the future hardships, we want to turn life on Earth into a game where, when the timer runs out and The Buzzer, excuse me, Gabriel's Trumpet, sounds, we have the highest score and get declared winners as the baptized get escorted off to Heaven (Carse 1986). Does that ring a bell?

In any case, I don't think the evidence favors an apocalypse greater than the collapse of civilization, and it's also not a story I'm interested in exploring. The story of the end of history has been told many, many times, and to date, every one of those stories has proved wrong. Let's try something else for a change.

So what about the Singularity?

---

[1] Generally, but not exclusively, tobacco.

Part of the weirdness with the whole Singularity mythos is that the machines are already smarter than we are in many ways. To cherry-pick some examples, computer systems run most of the stock market at faster speeds than we can even perceive, while the net gathers unusably vast stores of data on the Big Data theory that data-mining with multivariate statistics will stop throwing up false positives long enough to make all that data useful somehow. In so many ways, computers are better at processing data than we are. We even use them to design better, faster computers.

Yet they're not us, nor do they appear to be conscious.

And they are exquisitely fragile.

…

Now that you've calmed down and picked up the book from where you threw it, let me explain their fragility. Yes, a few computerized space probes are speeding out of the solar system. They've lasted decades, with reprogramming radioed out from Earth. Well and good. Unfortunately, most computers on Earth are built to last less than a decade, due to things like Moore's Law driving engineers to plan for obsolescence.

Worse, computers are global products. Their chips are made in one country, using elements dug up or recycled from all over the globe, based on a design from another country, for a market in machines built in still other countries.

This isn't an anti-globalization rant, it's simply to point out that computers depend on enormously long supply chains, and long supply chains are fragile. This is a very old problem that dates back to the Bronze Age if not before.

Old-fashioned bronze, as you probably know, is made out of copper and tin.[2] The problem with copper and tin is that they are very rarely found anywhere near each other in nature, and copper is much more common. In fact, it's not a stretch to say that bronze age cultures first started in the very few places in the world where people found deposits of copper and tin or arsenic within trekking distance of each other, started later where they could get tin or copper by trade, and never started at all where tin simply wasn't available[3] (Wertime and

[2] We'll ignore bronzes made with arsenic, lead, silicon, etc.—it's the same issue with supply chains.

[3] As in the Old Copper Complex Culture around the American Great Lakes, 6,000 to

Muhly 1980). During the European Bronze Age, civilizations in the Middle East traded all the way to Afghanistan, Scandinavia, and Cornwall to get the tin, copper, and the other products they needed, which is kind of neat considering that they had neither money nor free markets as we understand them now. Unfortunately, their great trading networks fell apart at the end of the Bronze Age, and for a while thereafter, bronze was reworked, not made from raw materials (Kristiansen 1998).

That's the fundamental vulnerability of any technology that requires a global supply chain: if any part of the supply chain fails, so does the technology. Today, computers are probably the most vulnerable in this regard, but our bewilderingly complex manufacturing ecosystem flows through global channels, seeking cheap labor, cheap materials, and required expertise. All of it is vulnerable to disruptions in trade.

As a mental exercise, it's worth considering how sophisticated a computer the average city could make using solely local resources gathered from, say, within 500 miles of it. That locally-sourced computer would be pretty puny using any technology we build today, wouldn't it? In most places in the world, it would not exceed the processing capacity of an engineer or accountant equipped with writing utensils and a slide rule (Greer 2014). A skilled carpenter can build a slide rule, while a skilled teacher can teach a smart student to use it. Engineers used slide rules to build our first spaceships, so they are a non-trivial and well-tested technology. All you need for this type of, um, biological computer system is enough wood for carpentry and iron for tools, some way of making a lot of paper or equivalent writing surfaces, writing and archiving tools, and some teachers, books, and skilled artisans. To make the equivalent computer using today's technology, you need silicon, rare earths, lithium, copper, iron, insulators, rubber and other polymers, electricity, etc., machinery to create integrated circuits, and a whole infrastructure to support the engineers while they build your computer. Plus some teachers, books, and skilled artisans, and possibly a few slide rules. Building complex computers locally is not easy.

3,000 years ago. So far as I know, the nearest tin mines to the Great Lakes copper were in Oaxaca, Mexico.

Turning back to the proposed Singularity, the machines' critical weaknesses are that they are short-lived (chips aren't built to last very long, years to a decade or two), and they depend on a vast and fragile trading network to make the equipment they need for their very existence. That network, in turn, depends on a complex global shipping network, which in turn depends on whole constellations of weather satellites and GPS satellites in order to meet its schedules and stay safe.

Here's the question: which of these systems isn't vulnerable to climate change, especially port-destroying sea level rise and increasingly powerful storms? They're all vulnerable, aren't they?

But perhaps these post-singularity intelligences will come up with a quick fix to global warming, thereby solving the problem with a wave of, I don't know, a nanotechnological wand or something. Perhaps. The big problem with this notion is that we know what the technological fixes are, and we've known them for years. National Public Radio reported that a Stanford University professor routinely presents this problem as a research project in an undergraduate engineering class, and the students routinely come up with technical solutions that will provide enough renewable and nuclear energy to run civilization (Harris 2013). The technology isn't the problem. Scientists and engineers know what they could do to fix things, if we gave them the chance, a big enough budget, and 30 to 50 years to make it work. Unfortunately, the real, difficult problems are primarily social, political, logistic, and a group of (ahem) "small" problems I tend to group together in a category called "difficult." This last category includes the trade-offs and sacrifices we would all need to make to create that much renewable power, and determining which sacrifices we can be persuaded and coerced to make.

An anecdote might illustrate the complexity of difficult problems. As a desert ecologist once asked at a conservation meeting, why should anyone destroy a 2,000 year-old intact desert ecosystem to build a power plant that would provide 20 years of power, especially if there was no plan to reuse the power plant site after it is decommissioned? The power plant design is totally logical to the engineers, but who is going to tell them about the other impacts of their work, who is going to decide whether it's appropriate, and who is going to clean up after them, if clean up is possible at all? Those are the real-world problems. In a world of growing deserts, we need desert biodiversity too, primarily because some of our descendants will be eating it. And due

to a peculiarity in US law going back to homesteading days, it can be cheaper to build huge solar plants in the wilderness areas that retain the highest biodiversity (google Ivanpah[4]), not near highways where the land has already been owned. Yes, it would be wonderful to change United States' property laws to protect wilderness. Want to guess how many years that would take, given that changing the law would affect the titles to everyone's property in the process?

Unfortunately, that's the reality that the Singularity's putative superhuman intelligences face: the technology that supports them ages fast, meaning they will frequently have to migrate to newer systems. They will depend for their very existence on a global civilization that is unsustainable. While they may have an incredibly good idea of the technical steps needed to make their continued existence more sustainable, it's unlikely that they will have the political, social, and logistical means to actually implement their solutions, because (surprise!) we humans will insist on having our say, whether we voice it with our ballots or our monkeywrenches. And unless they happen to figure out how to build themselves out of local materials, they will die and disappear as the global infrastructure that sustains them falls apart due to climate change.

That's why I'm not worried about a singularity remaking the world. Even if it happens, climate change will unmake it a decade or three later.

What I think will happen, at least for the purposes of this book, is that, over the next 100 years, our global civilization will release 1,000 to 1,400 gigatonnes of carbon dioxide and equivalents into the atmosphere. This is somewhere between the old "Business as Usual" model of IPCC 4 (Solomon et al. 2007) and the notion that we'll blow all the carbon from all fossil fuels into the air, along with some methane clathrates from the Arctic. In our entire previous history we've emitted a surplus of 370 GtC, so I'm suggesting that in the next century or so, we'll blow three to four times more carbon into the air than we've blown in human history. Given that, since 1970, we've blown twice as much carbon into the atmosphere as we did in all

---

[4] Actually, reality is a bit more complicated. Environmental groups like the Nature Conservancy have spent years finding less damaging sites for future solar plants, and many in the US solar industry are listening. Still, there are problems.

human history prior to 1970 (IPCC 2014), this won't be incredibly hard to achieve. It's literally business as usual.

What will happen once we do that is the subject of the rest of this book. It won't be the apocalyptic end of our species, but it will be very far from heaven.

5. The Fart that Broke Civilization

Warning: Sarcastic science content

Yes, this is about global climate change due primarily to our civilization's release of carbon dioxide that was previously trapped underground. It's arguably the biggest crisis we face because, far more than the threat of nuclear holocaust, it's wrapped up in our daily business as usual.

But the fart that broke civilization? Should I be, perhaps, a bit more sensitive? More respectful of its awful majesty? Should I call it global climate change and muffle its terrifying details in protective layers of acronyms?

Perhaps.

However, there comes a point when it's more productive to chuck the polite restraint and reach for the black humor, especially when talking about a crisis of this magnitude. When you think about it, it's a real monster, made far worse by our inability to digest it. Nonetheless, climate change is not Gaia's punishment of enviro-sinners who richly deserve it, nor is it our attempt to rerun Noah's flood. Rather, it's a lurking stinker that will displace many hundreds of future generations of climate refugees, all looking back at us and wondering what the (future expletive deleted) we were thinking, at least as long as they're aware that we even existed. At the very least, we owe it to them to think about their future, our future, even if it involves inappropriate jokes.

This is our civilization's most enduring contribution to the future of life on Earth: 1,000 to 1,400 gigatonnes of carbon (henceforth abbreviated GtC[1]) breaking into the wind over the next 100 to 1,000 years. If you remember your unit prefixes, 1 tera is 1,000 gigas, so we're going to emit 1 to 1.4 teratonnes of carbon.

Let's call it the terafart.

It is all the gas we're blowing out our collective exhaust pipes. We smelt it, we dealt it, we supplied it, we denied it, and there's nothing polite, appropriate, or laudable about it. It's the inevitable result of our all-consuming lifestyle, the kind of thing a bunch of frat boys would cheer on during a drunken debauch. In fact, that kind of describes the behavior of too many of our industrial leaders. Unlike a fart, whose odor is composed of unstable chemicals that only offend for a few minutes, the remnants of our outgassed carbon will be airborne for up to 400,000 years.

A good chunk of this book is about what the terafart will do to people and the planet, ushering in a 400,000 year-long period I'll call the Altithermal, because I find "Anthropocene Thermal Maximum" (ATM to the acronymicists) just too clunky.[2] This chapter is an overview of the outgassing itself, what happens to the carbon, and what that carbon does in turn to ocean and atmospheric chemistry, global air temperatures, and sea levels.

In the scenario presented in this book, I'm pessimistically assuming an outgassing of somewhere between 1,000 and 1,400 GtC because that's what we're on track to blow if emissions continue to increase. A tonne is 1,000 kilograms or about 2,205 pounds, so 1.4 teratonnes is 1,400,000,000,000 tonnes or about 3,086,471,670,588,286 pounds. The 1,000 GtC is a mix of current assumptions of how much existing fossil carbon fuel we will burn (IPCC 2013, Carbontracker 2014, Raupach et al. 2014), while the 1,400 GtC comes from earlier assumptions about the total amount of fossil fuels available to be burned and assumed we'll find and burn them all by around 2100 (Archer 2010),[3]

---

[1] But only because all the zeroes massively increased the length of this chapter.

[2] Apologies to those researchers who use the term altithermal for previous periods in history.

[3] Note, Archer consistently calls this 5,000 GtC, but the numbers only make sense if he was working with CO_2, which is 3.664 times heavier than C.

even though a lot of coal is so dirty it's hardly usable fuel. Since the 1,400 GtC is the only case I know of where someone has modeled it out into the deep future, I'm going to base this book on it. It is crudely equivalent to what the Intergovernmental Panel on Climate Change (IPCC) calls the RCP 8.5 scenario in its Fifth Assessment Report (IPCC 5).

Note that it's worth being suspicious about estimates of fossil fuel reserves. For example, Wikipedia states our fossil fuel supply is a suspiciously precise and high 1,126 GtC, but it's easy to confuse gigatonnes of carbon dioxide and carbon (one tonne of carbon converts to 3.664 tonnes of carbon dioxide), and different people use different units. Worse, it's not clear how open everyone is about how much coal, petroleum and natural gas they think they have in their reserves[4] (Deffeyes 2010). The precise number doesn't particularly matter, really, because this book is a crude model of our worst-case scenario.

There's also a big question about the size of natural pools of methane (methane clathrates and methane hydrates) that might get mobilized and erupt into the atmosphere in a sympathetic terafart from the Arctic. It may be up to 2,000 GtC (Smith 2010), or 1,000-5,000 GtC (Bollmann et al. 2010, Carbontracker 2014), or even better or worse. It's hard to get the data. Again, I'm not going to dive into the details. You have Google if you want to get into the minutiae of the science. Here I'm assuming the end result of all gas emitted in the terafart will be around 1,000-1,400 GtC in total trumpeted into the air from all sources.

Let's turn to the carbon and where it is, on and in Earth. Checking IPCC5 (IPCC 2013), vegetation contains 450-650 GtC, soils contain 1,500-2,400 GtC. Our atmosphere currently holds around 829 GtC, the ocean holds around 38,880 GtC, Ocean sediments hold around 1,750 GtC and the rocks of the planet, the lithosphere, contain more than 75,000,000 GtC (Falkowski et al. 2000), although some scientists say we don't know the total amount of carbon deep inside the Earth within a factor of 20 (Drahl and Wolf 2012).

---

[4] Google "Peak Oil" and settle in for a long reading session. Then turn to coal and natural gas.

In the last few years, we've been putting something like 8.1 GtC into the air annually, or around 1% of the terrestrial live biomass (which is mostly plants, not people). This 8.1 GtC is about 60 times the amount of carbon in all human bodies. Deforestation, primarily in the tropics, is contributing around another 1.1 GtC to the air when the wood is burned and the land is turned to annual crops, which don't store carbon for more than a few months. About 2.6 GtC goes out of the atmosphere and back into the biosphere every year, unfortunately not where it's being lost.

Now let's talk about where the carbon in our terafart could go. It would be cool if we could triple the carbon in the biosphere somehow, smother the fart inside a dense blanket of 100 meter-tall trees that covered all the continents. Unfortunately, that's not going to work, because the modern-day conditions that support 100-meter tall trees are very limited. To point out the obvious, it's hard to grow record-sized redwoods in the Sahara. A more realistic worldwide wood is more likely to capture 1-2% of the terafart. This is not to say that we shouldn't plant and nurture trees wherever they'll grow for at least a century (Archer 2005). Unfortunately, planting trees alone won't come close to saving us.

A rather more plausible possibility is that we will use our rapidly advancing technology to capture carbon out of the air and store it back underground. Some of this can be done through farming and ranching techniques that capture carbon in the soil through plant root activity. Capturing carbon in the soil is a really cool, often low-tech, way to sequester carbon (White 2014), and I hope every farmer and rancher will contribute to this practice, which is starting to be called regenerative agriculture. Problem is, if the farmers and ranchers aren't careful, the carbon can come out of the soil very quickly. To pick the worst example, modern agriculture and ranching have released a tremendous amount of soil carbon through what we consider standard practices. Trying to hold the terafart in soil carbon for 100,000 years or more is akin to chaining a dragon. It doesn't permanently solve the problem the way killing the dragon does, but it's massively better than doing nothing. It may, in fact, prove to be our primary means of carbon sequestration. Still, I'm uncomfortable counting on anything that requires humans to do the right thing consistently for 100,000 years or more.

As I write this, the fast money is pushing a scheme called underground carbon capture and storage (CCS), and people are experimenting with it now. Because we've pumped oil out of the lithosphere (the rocks beneath our feet) for well over a century, we know that the lithosphere can sequester carbon pretty well for millions of years. Industrial carbon capture is simply the idea of pumping the carbon deep underground, in sort of a reverse oil pumping maneuver.

One problem with this method is that some industry definitions of storing carbon "forever" allow for a 0.1% per year leak of that carbon back into the air. Remember that sending pressurized carbon back into the rock and groundwater is very similar to fracking, and the frackers have had more trouble than they want to admit keeping their pressurized fracking fluids out of the groundwater. Pressure tends to fracture rocks, which allows pressurized fluids and gases to escape. Keeping a pressurized gas underground "forever" will be even trickier. At 0.1% leakage per year, all the sequestered carbon will leak back to the atmosphere in 1,000 years. In other words, I pessimistically suspect that industrial sequestration will at best slow the terafart, not prevent it, although again, I'd love to be pleasantly surprised. Note that critics of CCS are even less optimistic about its prospects (Smil 2011).

Oceans cover about 70 percent of the Earth's surface, and while water can readily absorb some carbon when it's in contact with the air, most of the ocean can't readily absorb atmospheric carbon because it's deep water that's only exposed to the atmosphere in a few places off Greenland and Antarctica. The surface water does pick up carbon, but that carbon tends to stay near the surface, diffusing only slowly into the deeper waters. Currently the ocean absorbs about 2 GtC per year. According to Archer's model, the ocean's carbon will take 1,000 to 1,500 years or so to saturate with carbon after the terafart, but after it does, about 30 to 60% of the carbon would still remain in the air. The exact amount depends on how much we outgas. Out of 1,000-1,400 GtC, 300 to 840 GtC could remain in the atmosphere.

All that dissolved carbon doesn't just sit in the water; it becomes a weak acid (carbonic acid) that leaches more basic carbonate ions out of rocks like limestone and out of living carbonate structures like coral, seashells, and some very common types of plankton. This will be hard on the corals, seashells, and plankton, on the reefs they create and the limestones they form, and on everything that depends on them. This leaching, properly the carbonate buffering the carbonic acid solution, is

also hard on all the limestone that's in contact with seawater, as in south Florida. Still, by chewing up and dissolving all that carbonate, the ocean and sediments could absorb about another 10% of the terafart over another 20,000 to 40,000 years, according to Archer's model. During the Altithermal, little or no carbonate will be deposited in ocean sediments, so there will be a distinctive, very thick layer of non-carbonate clay in the geological record, along with an absence of coral reefs. It won't be the only such layer in Earth's geological record, but reef gaps are a story for Chapter 21.

The final remnants of the terafart will get taken out as part of the erosion of non-carbonate, primarily igneous, rocks, what Archer calls the Earth breathing (Archer 2010). As rocks erode, they break up, exposing new surfaces to the air, and these new minerals bind carbon to themselves, albeit slowly. The resulting rubble, gravel, sand, dust, and mud settles somewhere, becomes soil or sediment, which can also trap undecayed organic matter beneath it. In the very long fullness of time, all of this carbon gets trapped underground again. This is how carbon gets back into the lithosphere. Some of the carbon will form new oil and coal deposits in millions of years (unless we sequester it all underground, in which case there will be no more oil), some a substance called kerogen, some of it will become limestone, and so forth. But this slow "inhalation by the Earth" will take up to 400,000 years to finish off the terafart.

That's the story as Archer sees it: we fart out the carbon the next century or so. Perhaps the rip will extend out to 1,000 years if we get enamored with leaky underground carbon reservoirs. The ocean will take up a about half the carbon in 1,000 to 1,500 years, becoming acid enough to kill off coral reefs. Carbonate reactions will then take up to 40,000 years to take out about half of the carbon that's left, dissolving some really lovely islands and reefs. It will take up to 400,000 years for non-carbonate rocks to take the last of our fart out of the atmosphere.

During all this, our descendants have no useful fossil fuels, because these take millions of years to form.[5] Still, 400,000 years from now, the atmosphere and climate will look something like what we're experiencing now.

---

[5] Note that CCS sequestered CO_2 will never turn into future oil or coal, so far as we know.

That far future climate will, of course, be totally alien to people living in that future, and they'll undoubtedly be wondering how to stem this inevitable environmental crisis, this slow cooling of the world. That's humanity for you in a nutshell.

Global weirding: what the terafart does to the weather

That's the carbon story. Now let's look at the climatic effects.

To begin with, the terafart will most likely raise the global average temperature about 3-5°C (5-9°F) by 2100, a degree or three above the 2°C (3.5°F) that experts and politicians have compromised on as our safe upper limit for climate change.

At first this doesn't seem to be a lot of change: most of us experience greater temperature changes during the course of a single day, even inside. Thing is, our intuition doesn't really help here. Rather than global warming, it's more useful to think of this as "global weirding," to use a term reportedly coined by Hunter Lovins, co-founder of the Rocky Mountain Institute.

Global weirding better describes the real problem: when carbon captures heat energy in the atmosphere, it's going to do things to our weather. All that hot energy wants to fool around, go somewhere and make warm, sloppy entropy with willing matter. Like any steamy, turbulent romance, the relationship will generate lots of tempests and droughts as it winds down to its inevitable conclusion. And that conclusion will take so long that all the eye-rolling bystanders (our distant descendants) will simply accept the dysfunction as normal and forget how good things were before the relationship started.

Hot air can, of course, make deserts hotter and lead to longer and deeper droughts. But hot air can also absorb more water vapor than cold air can. This leads to greater humidity and long, hot, humid summers, and it can also lead to bigger storms, which occur when hot air cools enough that the water condenses out. Climate scientists currently believe there won't be more storms, but the storms that will occur are likely to be bigger and slower moving. The combination of giant storms and deep droughts leads to things like massive flash floods and heavy erosion, since dry soil can't immediately absorb massive amounts of water. This isn't so good for things like agriculture or groundwater recharge. Or for cities on coasts, for that matter. More and smaller storms would be better, actually, and we should earnestly hope that the climate scientists are wrong about this.

Additionally, the heat tends to disproportionately affect the poles, especially the Arctic. Normally, that region of the atmosphere is isolated from the more southerly temperate zones by the Jet Stream (Holdren 2014), which is powered by the temperature difference between cold polar air and warmer temperate air. However, as the poles warm, the difference in temperature between polar and temperate zones decreases. This causes the Jet Stream to wobble, veering north and south. It also slows down the Jet Stream, so that the wobbles stay in place longer. As a result, polar storms can drunkenly careen far south into North America and then just sit there, as we saw in the winters of 2014 and 2015. Similarly, masses of warm air can reach north into polar regions, causing ice to melt faster than expected. Ultimately, this boundary will break down, as the pole warms up to what we now consider temperate-zone temperatures, just as the temperate zone warms up to tropical temperatures.

The warmer the globe gets, the weirder the weather gets. We're already experiencing about a degree of increased weirdness, which contributed to events like Superstorm Sandy, Super-typhoon Haiyan, droughts in California, droughts and floods in the American Midwest, Australia, and elsewhere, as well as a bunch of meteorological crises that the US media largely ignored (National Center for Environmental Information 2014b, a).[6]

Shall we contemplate weather that's eight times weirder? The Here-Be-Dragons realm of megadroughts and giant storms? Yes, we shall contemplate it…in future chapters.

But some researchers suggest that the humidity may be as big a killer as storms and droughts. According to research by Steven Sherwood and others (including the US military and IPCC5) (Sherwood and Huber 2010, IPCC 2013), high humidity at high temperature can kill humans and other large mammals. At a "wet bulb temperature[7]" above about 35°C (95°F), humans stop being able to

---

[6] For the scoffers, yes, I know that the terafart won't "cause" each storm, because storms happen regardless. Similarly, steroids don't cause home runs in baseball, because there were home runs before the steroids era of the 1990s. Nonetheless, both the number and distance of the home runs during the steroids era are larger than seen before or (hopefully) since. In baseball terms, our terafart is juicing our weather, and unlike baseball, the CO_2 will stay in our system for a long time after we stop injecting it.

[7] You use a wet bulb thermometer and a dry bulb thermometer to determine relative

shed heat from our bodies by sweating, which means that, basically, we can't live under those conditions without air conditioning. I'll call this condition "black flag weather," as that is the color of the flag the US Marine Corps flies when wet bulb temperature gets around 32°C (90°F).[8] Since, among large mammals, humans are actually among the best at getting rid of waste heat through sweating, black flag weather represents a death zone for us, our livestock, and many wild mammals. The peak wet bulb temperature in the world was around 37°C (99°F) at the Somalian Red Sea town of Bosaso, and similar weather has been reported around the Red Sea and Persian Gulf annually (Burt 2004). Under the extreme climate change we're talking about here, there will be extended episodes of black flag weather over much of the western Sahara, much of the Middle East, Red Sea, and Persian Gulf, the Australian Outback, much of India, much of China, much of central Brazil, part of Spain, and much of the southeastern US. These places may be habitable seasonally in the cooler and drier months, but humans and other large mammals will have to migrate away from these zones during the hottest and most humid months. Black flag weather has the potential to displace more people than sea level rise, and unfortunately, it's much less studied (Sherwood and Huber 2010).

What's our deep future prediction for temperature after the terafart? According to models summarized in *The Long Thaw* and elsewhere (Shaffer et al. 2009, Archer 2010), we'll be dealing with around 6-8°C increase in global average temperature for about the next 1,500 years, with peak weirdness within 200 years after we've passed our maximum wind 50-100 years from now. This will be the time when black flag weather excludes people from large swaths of the globe. Here I'm going to call this 1,500-year period the High Altithermal, to distinguish it from the next 398,500 years, which I'm calling the Deep Altithermal (think high heat, deep future if it helps).

---

humidity, with the wet bulb thermometer equivalent to sweaty skin. A wet bulb temperature above 35°C means that the air is saturated and at or above body temperature, which means that sweat can't evaporate off your skin and cool you. Dry air can be much hotter than 35°C, but if it can evaporate sweat, you can stay alive in it as long as you stay hydrated and sweat fast enough.

[8] http://en.wikipedia.org/wiki/Wet_Bulb_Globe_Temperature, accessed 5/15/2014.

For about the next 10,000 years after the High Altithermal, we'll experience 3-5°C of weather weirdness. Over the subsequent 100,000 years, it will gradually cool to about 2°C of weirdness (e.g. typical 21st Century Weather, which we don't yet experience), and from there back to what we currently think of as normal in about 400,000 years.

So what's the problem with a little warm weather? Well, it's not the temperature, because outside black flag weather, people live with all sorts of temperatures. The problem is the change in temperature relative to our current normal temperature (Schmidt 2014) especially if the change is rapid and varies unpredictably. That's why global weirding is more dangerous than global warming.

History seems to show that changes in global average temperatures cause chaos. For example, about 1 to 2°C of cooling in the 17th Century, during the heart of the Little Ice Age, coincided with a period historians call the "General Crisis," which marked the chaotic era between the end of the Renaissance and the beginning of the Enlightenment in Europe (with civil wars, revolts, and famines across the continent), the fall of the Ming dynasty to the Qing dynasty in China, the Mughal Civil War in Asia Minor, the fall of the Kongo kingdom in West Africa, and colonial wars throughout the Americas (Parker 2013).

The change caused by the terafart will be much worse than the General Crisis—perhaps eight times worse—and last centuries longer. The change will reshape the entire planet: the world's climatic zones will be very different than what we have now, the coastlines will be different, the ocean's current patterns will be different, and the weather will be different. Every place on Earth will change, which means that global civilization will face a titanic adaptation challenge when we let the terafart fly.

So what are we thinking again? Who gives a toot?

Sea-level rise

Yes, I'm sure this isn't news to you. Average global sea level has been rising at 3 millimeters per year for the last decade, about twice the rate for the previous 80 years. This is above what the best-case models predicted (IPCC 2013).

About half of current sea level rise is due to simple expansion of the oceans (Purkey et al. 2014). Water expands as it gets warmer, and as we heat the air, some of the heat goes into the ocean. However, the oceans don't heat all at once. Deep waters are near freezing, and they

are kilometers down in the abyss. It will take a long time for them to heat up, and it's already happening. Even if we somehow stopped farting around tomorrow, the seas would still rise some part of a meter (a few feet) due to the heat that is already propagating through them.

Unfortunately that's the lesser source of sea level rise. The greater source is melting glaciers, almost all of which are in Greenland, West Antarctica, and East Antarctica. Yes, there are two sides to Antarctica, and there's a good reason to consider them separately: the Greenland and the West Antarctic ice sheets are melting now, while the much larger East Antarctic sheet is cooler and less reactive.

If we're very lucky, East Antarctica won't melt. This rather large patch of Antarctica, which includes the South Pole, averages something like 4,800 m (15,700 feet) in elevation. Roughly 3,000 meters (yes, 3 kilometers, or about 10,000 feet) of that is ice. East Antarctica has an annual temperature of -57°C (-70°F), and a high recorded temperature at the South Pole of -12.3°C (9.9°F). The East Antarctic ice sheet is currently increasing in size, not decreasing, due to increased snowfall, and even 16°C of terafart-added temperature increase[9] will rarely bring it above freezing, especially since most of the increase is modeled to occur in the winter, when it is at its coldest.

This is definitely not the case for West Antarctica nor for Greenland, which is why these smaller ice sheets will melt into the ocean over the next century or three.

Still, we probably won't be lucky enough to save even East Antarctica. Part of the reason for my pessimism is that the current models of ice behavior generally show ice sheets slowly melting away, whereas in real life, they can fall apart very quickly in ways that climate modelers have trouble duplicating in their models. This happened to the Larsen B Ice Shelf in 2002 and Arctic sea ice subsequently (Archer 2010). Geological evidence such as Heinrich Events and Meltwater Pulse 1A from the end of the last glacial period also suggest that ice sheets tend to rapidly fragment into icebergs, rather than to melt gradually. The climatologists and glaciologists don't fully understand how it all works, and that's not good. Worse, the last time the climate was as warm as the High Altithermal, there is no evidence of ice on the poles. Our deep past may be trying to tell us something.

---

[9] Remember that the poles heat much more than the Earth does as a whole.

If all the glaciers melt, they will add about 70 meters (230 feet) to mean sea level, according to David Archer (Archer 2010). According to a 2013 *National Geographic* article, it would be slightly less: 216 feet (about 66 meters). That's what I'll use as a model for the Altithermal, a full melt with mean sea levels topping out 65 meters above our current sea level. Thermal expansion accounts for a minority of this sea level rise, and the rest comes from melting ice.

When will it happen?

Absent glacial melting, ocean thermal expansion will cause sea level to rise a few centimeters per century for up to the next 5,000 years or so (Stager 2011). Since harbors have to be rebuilt every century or so anyway, just to accommodate wear, tear, siltation and changes in shipping, oceanic thermal expansion alone isn't a huge problem, so long as we have the capacity to cope with it by rebuilding or moving.

The steady, slow sea-level rise of thermal expansion may well be punctuated by rapid, probably unpredictable rises of a meter or more over a few weeks or months as large ice shelves fail around West Antarctica and Greenland, plus perhaps two meters of sea level rise per year from East Antarctica on average once its landlocked glaciers start melting. This last inflow will start as more and more of East Antarctica gets above freezing, which starts a century or more from now.

Much of West Antarctica's ice is actually below sea level or sitting on water, so it will melt fairly quickly, and recent reports suggest that its loss is now inevitable (Joughin et al. 2014, Sutterley et al. 2014). As the West Antarctic Ice Sheet disintegrates over the next 200-300 years or so, sea levels will rise by perhaps 4.8 meters (16 feet), with 3.3 meters (11 feet) of rise happening in spurts in the weeks and months after catastrophic ice sheet failures (note that I'm not modeling this as a slow trickle, as recent reports have described). The already-melting Greenland ice sheet will contribute another 6 to 7 meters (20 to 23 feet) of sea level over the coming centuries. Finally, the East Antarctic ice sheet will contribute perhaps 55 meters (180 feet) to sea level rise if it melts. This is why I earnestly hope that East Antarctica stays frozen, although I assume it will not here.

Spasmodic sea-level rises will wreak havoc on the coastal settlements and ecosystems for 200 to 1,500 years, perhaps longer. Then, once the glaciers have melted away, thermal expansion will continue to slowly raise sea level until seas reach their maximum levels in 2,000 to 5,000 years.

If anyone is monitoring the glaciers in the Altithermal, they may be able to provide weeks or months of warning about when some section is about to fail and melt rapidly, so there will be time to evacuate those in danger. Unfortunately, even in today's fossil fuel-driven economy, it takes years to decades to rebuild harbors and port cities, since this work involves complex politics, planning, and finding the resources to do the work. After a sudden jump in global sea level, all seaports will be competing with each other for resources. Even more unfortunately for us, there will be no high-energy fossil fuels available to make the work go faster once the glaciers really start melting, because the peak warmth comes about 100 to 200 years after we've emitted the vast majority of the terafart and run out of usable fossil fuels.

This is where our terafart sinks global civilization, or at least, whatever part of it has survived the population peak of our era, our exhaustion of so many resources, and the rapid heat-up. Global civilization, even the primitive global civilization pioneered by the Romans and later by the Muslim Indian Ocean trade, depends on shipping between ports, and those ports are going to be repeatedly destroyed by rising sea levels for centuries. For the next generation or two, possibly even for the next century, I have no doubt that every developed nation in the world will "Netherland up," building sea walls and surge gates to defend their critical ports. The problem is that the sea will keep rising in spurts for millennia, and it will stay high for much, much longer after that. Sooner or later, we're going to have to abandon the ports we have, and it will be at least 1,500 years before sea levels stabilize and we have stable oceanic access again across most of the planet. In the interim, we will be limited to whatever ports are available, and much of our shipping will be limited to smaller boats that we can pull up on beaches out of reach of the incoming tides.

What happens after the sea levels top out? After something like 10,000 years, mean sea level will start to very, very, very slowly fall, primarily through thermal contraction, the reverse of their previous thermal expansion. Until the ice sheets reform at the poles, average sea level will fall only some part of a meter. Major ice sheets aren't likely reappear at the poles for at least 100,000 years, until polar summers get cold enough that snow and ice can stay on the ground throughout the year. Even then, big ice sheets may be confined to Antarctica until temperatures return to today's levels or even below.

What are we thinking again? Let 'er rip? Or is it more like "Oh, the humanity?"

And these are just the averages

To keep this simple, I've been talking about global averages and general trends. One of the problems with this approach is that it disguises all the variability.

For example, sea level changes projected for this century vary between -1.8 centimeters per year to +2.1 centimeters per year at coasts across the globe (Center for Operational Oceanographic Products and Services 2013). Coasts rise and fall on their own due to continental drift, independent of what the ocean is doing. A few coasts are rising so fast they can stay ahead of the ocean's thermal expansion. Some are subsiding so fast that they'll be over a meter underwater in a century even without sea level rise. These are natural processes. It means that some places, like the subsiding Tacloban City in the Philippines, which was destroyed by super-typhoon Haiyan (Bower 2014), are even more at risk than the averages suggest. Being closer to the local sea-level means that it takes less of a storm surge to inundate the city.

The upshot is that not everyone will be affected equally by climate change at any given time. Some places, like Tacloban City, many Pacific atolls, and even parts of the US, are already subsiding underwater. Others won't be impacted for decades to come. This, of course, has both good and bad consequences: on the good side, there are refuges for refugees, places stable enough that they can help the world adapt. On the bad side, the politics of climate change are, shall we say, contentious, and I pessimistically believe that many people who are not badly affected will have trouble sharing with or even caring about climate refugees, even though we're the ones causing the mess.

But that's another chapter.

WANT MORE?
IT'S COMING
SOON.

Go to https://heteromeles.wordpress.com/
for current release news