Excerpted *from How to Change Minds About Our Changing Climate* by Seth B. Darling and Douglas L. Sisterson. Reprinted with permission of The Experiment and available wherever books are sold. http://bit.ly/1pLYcsk

Climate is too complex to model or predict

NIELS HENRIK DAVID BOHR was a brilliant Danish physicist (awarded with a Nobel Prize in 1922) born at the tail end of the nineteenth century. His contributions to science were monumental in the areas of atomic structure and quantum mechanics, but it's some of his other contributions that we're interested in. You see, Niels was something of a scientific Yogi Berra: a guy who reached the pinnacle of his profession but who's known by many as much for his wonderful quotes as for his professional accomplishments. Among the most delightful is that "prediction is very difficult, especially about the future."*

There are some things that we can predict with near-absolute certainty. Like that the sun will rise in the east next morning, or that the Chicago Cubs will not win the World Series this season. Lots of things, of course, are less certain. In particular, really complex stuff is far more difficult to predict with high certainty, and so our skeptic Brad is, well, skeptical that climatologists have even a slight chance of predicting what will happen to something as complicated as the Earth's climate . . . as Bohr would say, especially in the future.

A common incarnation of this skeptic argument says, "Even with state-of-the-art computer models, scientists can't even accurately predict the weather two weeks from now, so how can they possibly tell us what's going to happen twenty years from now?" Here we have

*It turns out that there's a dispute about who actually said this first, but being big Niels Bohr fans, we're giving him the credit.

one of those classic climate-skeptic mistakes. (Nope, not cherry-picking this time, but we're glad you've picked up on that common skeptic mistake.) This mistake is confusing weather with climate. As we explained back in the Prologue, weather is what you get day to day, which is something that can vary considerably based on all sorts of influences. It's chaotic, in the scientific sense of the word. Chaos theory looks at the behavior of dynamical systems that are highly sensitive to initial conditions, and people have applied it to everything from data-encryption systems to models that try to predict epileptic seizures. It is because of the extreme sensitivity to initial conditions that weather predictions are such a challenge. Even a tiny change in these initial conditions can have a dramatic effect on how things unfold, something known as the "butterfly effect."*

Climate isn't the same as weather. Climate is the average of weather over a long time—years or even decades. Think of it in terms of a slot machine at a casino. Predicting weather would be like trying to predict whether you're going to win on the next pull of the lever, which, despite some folks' belief that they can do this, is not going to be successful very often. Predicting climate, on the other hand, would be like predicting whether you'll win or lose money averaged out over thousands of pulls of the lever. As casino balance sheets will tell you, the odds are pretty darn high that you're gonna lose.

Bringing it back to weather and climate: Consider when the temperature one day to the next differs by, say, five degrees Celsius (nine degrees Fahrenheit). You might not even notice such a change. It is an entirely different story if the *climate* changes by those same five degrees Celsius, because a climate change means that the average global temperature has changed. We're no longer looking at a brief, local fluctuation.

What would it look like if Earth were five degrees colder on average than it is now? We would be in a glacial period. Sea levels would

*A marvelous 1952 science fiction short story by Ray Bradbury called "A Sound of Thunder" is based on this effect.

be perhaps 100 meters (over 320 feet) lower than they are today.* Places like Chicago, London, and Manhattan would be buried under ice. Some places that are now deserts, like in the American Southwest or Afghanistan, would be wetter, while other deserts would expand. All in all, our planet would be a very different place. What about five degrees in the other direction (warming)? Ice would likely disappear completely from both poles, sending sea level about 20 meters (more than 65 feet) higher than it is today. Oxygen levels in the oceans would drop dramatically, suffocating many higher forms of life in the seas. Oceanic methane eruptions coupled with ignition sources such as lightning could unleash unimaginable destruction. The tropics and sub-tropics would be essentially uninhabitable. Super-hurricanes would wreak havoc on those who managed to survive. Basically, you've got something approaching the biblical apocalypse.

Clearly, five degrees is a pretty serious thing in terms of climate (and just so we're clear about where things stand: five degrees of warming is within the range of possibility this century if we don't start changing our behavior as a society). Weather and climate are really quite different beasts. The real question, then, is not if scientists can model and predict weather, it's if they can model and predict climate.

Brad tells you that climate models are riddled with fudge factors to fit our current climate, and that this explains why they agree with observations today, but that these ad hoc insertions are unlikely to be appropriate for modeling a future climate with different atmospheric chemistry. The point he's trying to make is that climate models' dire predictions of future global catastrophes (see Chapter 3) are melodramatic. This leads to another question: How do you test the accuracy of a model that is projecting trends many years into the future?

*The last time this sort of thing happened, the drop in sea level aided human movement from Asia into North America because the land now under Alaska's Bering Strait surfaced to provide something of a bridge.

It's important to keep in mind that we're talking about climate here, not weather. The object is not to predict what temperature it will be in Delhi on, say, March 5, 2023, or exactly when the next hurricane will hit New Orleans. Instead, we want to predict the trend in the climate over the coming decades. Like modeling weather, this, too, is no easy task. Climate models have to account for interactions between the land surface, ice, oceans, the sun, and the atmosphere, among other factors. What's remarkable is that despite their complexity, climate models do an impressively good job, as we'll explain, and are improving all the time.

There are two basic approaches to testing the accuracy of a climate model. You can wait and see what happens in the future and compare it with the predictions of your model, or, if you don't have the luxury of waiting for years and years, you can do what's called "hindcasting." This process involves picking a starting point somewhere in the past, feeding those (known) climatic conditions into your model, and letting 'er rip. If the model projects trends that match what actually occurred from that starting point, you can have reasonably high confidence that it will also do a good job projecting what will happen years from today. It is standard practice for climate modelers to first test their models with hindcasting before using them to project future climate trends, and good models routinely pass this test. Of course, modelers design their models such that they would be expected to match the observational data (a little like knowing the questions on the pop quiz ahead of time), but nonetheless, if they failed to capture historical changes, you wouldn't have much faith in their predictive capabilities.

In fact, hindcasting like this has shown that, unless you incorporate human CO_2 emissions and their associated greenhouse effect, you cannot properly simulate recent climate changes. Other, natural factors are sufficient to explain temperature variations prior to the relatively recent warming period, but models without anthropogenic influence fail to reproduce the warming observed since the middle of the last century. This is among the strongest pieces of evidence that global warming is in large part caused by human activity.

There are some models, however, that have been around long enough for us to check in on how they've been doing with their challenge of predicting the future. One such model was launched back in 1988 by a team of NASA and MIT scientists led by James Hansen. The Hansen model predicted a trend of rising global temperatures that does a very good job of tracking the trend that has actually taken place in the decades since it was published. Hats off to Hansen and his team for working on this issue before most of us had ever heard of global warming. (Al Gore, for one, who was a US Senator at the time and busy running for the Democratic nomination for president, was certainly trumpeting environmental issues like the growing ozone hole over the Antarctic,* but he hadn't yet assumed his role as one of climate change's most visible activists.)

It turns out that Mother Nature provided a convenient opportunity on June 15, 1991, to test the Hansen model as well as other climate models. Mount Pinatubo, a volcano located in the Philippines, experienced a massive eruption that day—one of the largest of the twentieth century. This event launched about twenty million tons of sulfur dioxide into the atmosphere. The resulting sulfate aerosols in the stratosphere had a gigantic influence on global temperatures—about 0.5 degrees Celsius (0.9 degees Fahrenheit) of cooling—that lasted about three years. How did climate models do in predicting the effects of the Pinatubo eruption? Strikingly well. Not only did they predict the temperature drop correctly, but they also predicted feedback related to water vapor and radiative effects that quantitatively matched what actually happened.

Climate modeling may be hard, but these guys are good. Brad may not believe in their models, but as Niels Bohr once replied when he was asked by a visitor to his home in Tisvilde if he really

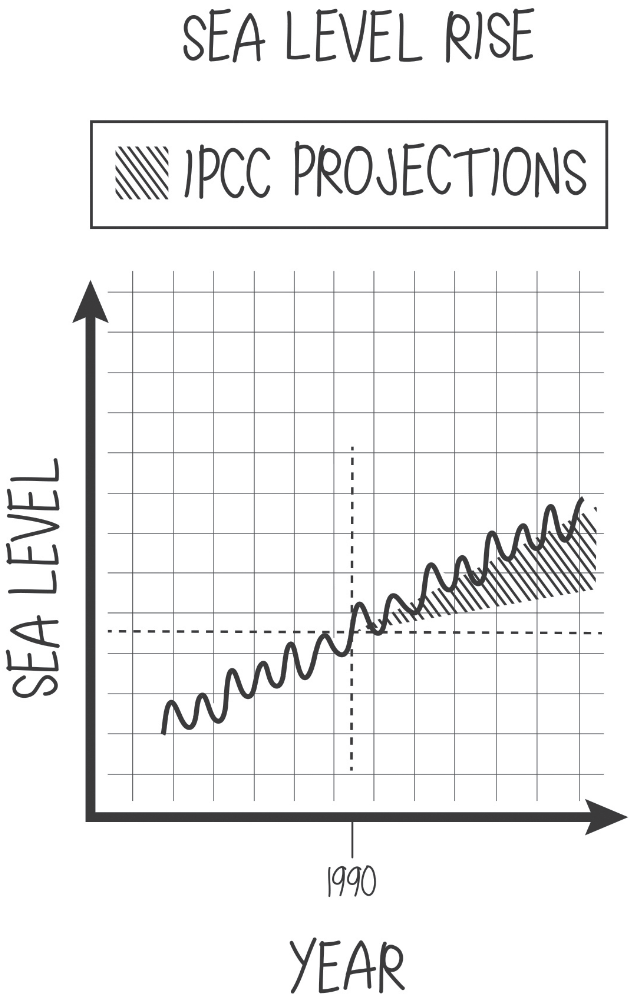
*Refer back to Chapter 8 for an interesting connection between the ozone hole and climate change.

believed a horseshoe above his door would bring him good luck, "Of course not . . . but I am told it works even if you don't believe in it."

Probably in part because the projected consequences of climate disruption are so scary, skeptics seem to find welcome ears for their claims that climate models exaggerate the threats posed by our greenhouse-gas emissions. It sure would be nice if that were true. Let's take a look at some model projections and see how they've panned out.

The IPCC's first assessment report was released in 1990. One of the landmark predictions from that report involved sea-level rise. As we've discussed in Chapters 3 and 8, heating of the oceans and melting of ice sheets and glaciers results in the sea level climbing progressively higher. Pulling from a variety of climate models, in 1990 the IPCC predicted a range of possible rises in sea level, with the most probable value being 1.9 millimeters per year. Today, researchers have a great set of data from tide gauges and satellite observations, and they not only agree with each other extremely well, but they also show a trend of rising sea level from the early 1990s through the present time. What do these data show regarding the pace of that rise? Did the IPCC embellish the potential effect? It turns out that the actual rate of sea-level rise during this period was 3.4 millimeters per year. Interestingly, this value aligns with the worst-case scenario from the IPCC report in 1990. In other words, the IPCC didn't exaggerate the situation at all. Quite the opposite. It appears that the IPCC underestimated the scale of the change.

Ice melting is another major indicator of climate change, and so climate models project the pace of things like melting of the Arctic sea ice. When you compare actual observations of this melting with the model projections reported by the IPCC, you find an alarming result. As with the sea-level-rise projections, the IPCC models produce a range of possible rates of sea-ice melting. The sea ice, however, doesn't read IPCC reports. The actual rate of ice melting has been a full 40 percent faster than the average of the IPCC model predictions. In fact, the actual melting rate is faster than the worst-case scenario coming out of those models. The bad news is that the models have failed to quantitatively capture some impor-



Schematic of sea-level rise showing how the IPCC's projection in 1990 underestimated the effect

tant effects. The really bad news is that things are even worse than our worst expectations. The IPCC has also underestimated how fast emissions of carbon dioxide would rise, and they've even underestimated the degree of confidence that climate scientists have in the fact that human activity is the primary driver for climate disruption (see Chapter 1). What's the good news? Well, perhaps this sort of thing will make Brad stop saying that the IPCC is exaggerating the problem. The models don't get some things right, but where they get it wrong, it is almost always in the direction of underestimating the scale and pace of the problem.*

We've pointed out the ways in which climate models have gotten things right, and ways in which they've gotten it wrong in precisely the opposite way claimed by the skeptics. There are things that climate models are really good at, but there are also things that give them what could very well be an insurmountable challenge.

In an effort to make climate models more useful, climatologists have worked hard to increase their spatial resolution; that is, to provide predictions for how climates will change on a more regional scale. This is important because, while the planet is warming on a global scale, local changes will vary quite a lot from one region to the next. The problem is that the higher the spatial resolution of your model, the more uncertainty there will be in the projections. Things like the amount and timing of precipitation in a particular area are highly variable. Basically, the models are starting to encroach on something more akin to weather forecasting, which we've already explained is far more difficult than long-term global climate forecasting.

Let's take as an example the Mekong River Basin, a system in

*A rare counterexample would be the surface-air-temperature trends in the past decade or so, which have risen more slowly than the vast majority of models had projected (see Chapter 7). Climate scientists are beginning to understand the reasons for this error (volcanic eruptions, unexpectedly low solar output, and so on), but this reminds us that climate models are not necessarily accurate over short timescales.

Southeast Asia that plays a central role in agriculture and trade in the region. A leading climate model projects that the monthly water discharge from this basin could decrease by 16 percent . . . or it could increase by 55 percent. So much for being useful! What's a policy maker or a rice farmer supposed to do with that information? The idea is to feed the results of these regional climate models into so-called impact models that project how the quality of human lives will be changed by variations in the local climate. Not only is the input information uncertain, but it's daunting to try to model the resilience of a particular culture to these environmental changes. This sort of modeling is not really climate science at all. Socioeconomics is perhaps even more complex than climate.

Another way that socioeconomic complexity finds its way into climate modeling is through the one factor that plays the biggest role in changes to our future climate—our own greenhouse-gas and aerosol emissions. As we've already said, the IPCC has badly underestimated the growth in carbon dioxide emissions. This aspect of climate modeling is really economic modeling. Researchers have to be able to predict how we will be using fossil fuels over the course of many decades in the future. How do you model how quickly societies will shift to alternative energy sources? Or even the health of the global economy on that timescale, which has a direct impact on the amount of emissions? If the recent Great Recession taught us anything, it's that economic prediction is a perilous task. Climate models will always get better over time, but that doesn't mean that the uncertainty in their projections will decrease, because human behavior is impossible to predict with certainty.

Another critical area in which climate models are especially challenged is in capturing the effects of tipping points. These are potentially lightning-fast changes such as the much-talked-about melting of the Greenland Ice Sheet, which, if it were to completely and rapidly melt, would raise the seas to a frighteningly high level. The problem is that climate models are designed to be stable. You wouldn't want your simulation running off into oblivion—that is, unless running off into oblivion is what's actually going to happen! These rapid changes are not well understood, and thus they're not well integrated into models. When climate models are tested against past abrupt changes in climate using hindcasting, they generally don't do a good job of reproducing these cataclysmic events. What this means is that climate models will generally get the right answer, it's just a question of the timing. Models can tell us with very high certainty that specific levels of global warming will occur . . . they just can't tell us, with an equally high certainty, *when* those levels will be reached.

All right, so we have a sense now for what climate models can and can't do well. Where do we go from here? What are policy makers—and the rest of us—supposed to do? Brad wants us to wait until scientists have proved that it's our activity that's causing climate change. Check (see Chapters 1, 10, and 11). Then he says, "We need to wait until the modelers can tell us exactly what's going to happen and when." No, Brad. We can't wait for that, because the models will never do that and we'll still be waiting while catastrophic effects begin to destroy our society. There is enough certainty now to act. We've created an awful mess for ourselves as a species, but there are things we can do to prevent the worst consequences from taking place. This will require public support and government action, and the skeptics are doing their best to stymie both of those things.

The gravity of the predicament we've gotten ourselves into as a species is so grim that, at times, we feel guilty about poking fun at the most audacious and absurd of Brad's claims. At times like these, we return to our old friend Niels Bohr for some solace. He once sagely declared, "Some subjects are so serious that one can only joke about them."