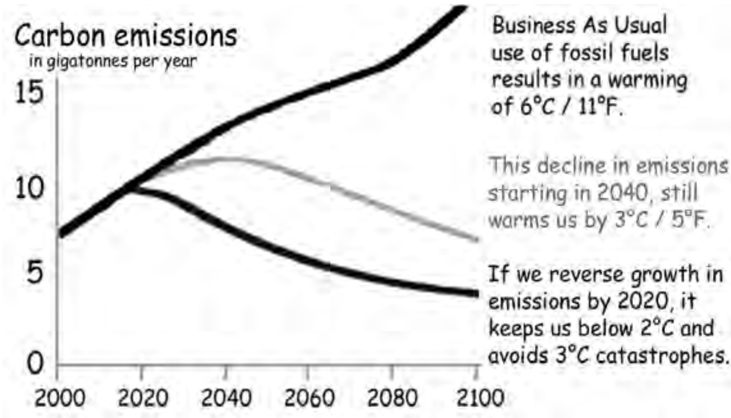


The emission of greenhouse gases ... is causing global warming at a rate that began as significant, has become alarming and is simply unsustainable in the long term. And by long term I do not mean centuries ahead. I mean within the lifetime of my children certainly; and possibly within my own. And by unsustainable, I do not mean a phenomenon causing problems of adjustment. I mean a challenge so far-reaching in its impact and irreversible in its destructive power, that it alters radically human existence.... There is no doubt that the time to act is now.

—British Prime Minister Tony Blair, 2005

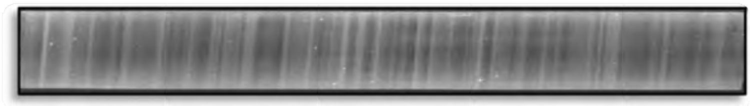
15

The Extended Forecast

> For I dipped into the future,
> far as human eye could see,
> saw the vision of the world,
> and all the wonders there would be.
> —Alfred Tennyson, 1842

Everyone loves to complain about the weather. And, of course, about weather forecasts that aren't perfect. This long tradition of authority-bashing for weather forecasts can carry over to the public's opinion of whether climate forecasts should be taken seriously. If this were about, say, the prospects for an influenza pandemic, there would be far less second-guessing of the experts.

Climate is the longer-term overview of weather. It consists of the averages and the extremes of hot and cold, wet and dry, snowpack and snowmelt, winds and storm tracks, ocean currents and upwellings—and the long and short of it, their patterns in space and time. The paleo-climate records from long cores of ocean bottoms, ice sheets, and bogs have been very useful for telling us what can happen and how fast.



About 38 years of Greenland ice layers from 16,250 years ago, a time when the dust storms in Asia left their mark in Greenland (darker bands).

What will happen if the earth's fever climbs even more? The simplest way of judging is to consult past history for analogous situations. For example, were the earth to warm up several degrees more, is there data from a past warming to suggest what could happen?

Yes. The last time that the earth warmed up more than present was only 125,000 years ago, during the warm interglacial before our most recent ice age. It warmed Greenland by $3^{\circ\mathrm{C}}$, what a general global warming of $1.6^{\circ\mathrm{C}}$ would do this century. As I mentioned earlier, this melted a lot of ice in Greenland and Antarctica, enough so that the oceans rose more than 6 m / 20 ft above today's sea level (see the figure on page 120).

So there's your first-order estimate: if it works like it did last time, just the untreated fever expected before midcentury will be enough to set in motion a large rise in sea level.

Besides the history of temperature change, you can use working models to project the Earth's current fever into the future—models run on a computer, rather than in a lab mockup. Scientists like to run experiments where you change something and see things play out differently.

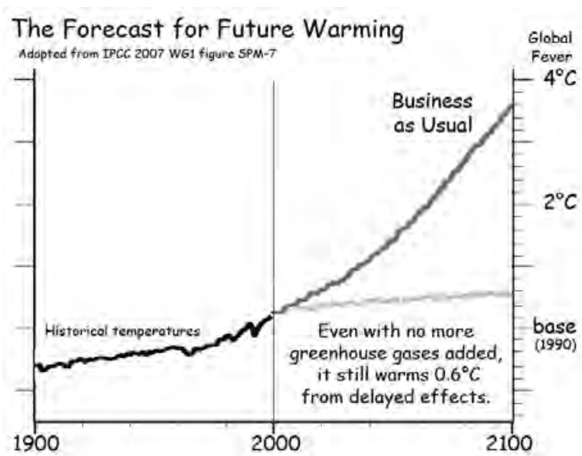
To forecast changes in annual rainfall does not require forecasting the rain each day for a year (remember that for the next time you hear "Why, they can't even get the weather forecast right for the weekend—why should we believe them about the year 2050?"). These models are not the weather forecast models which try to predict the next few days. Changes in annual precipitation only requires knowing the basic physics of temperature and pressure, then making a working model of the winds that should occur, then of the dew point where water vapor turns into fog or clouds.

Climate scientists have been making global-circulation models for both the ocean and the atmosphere. Dozens of labs around the world are competing to discover mistakes and have improved the state of the art over the last three decades. These global-climate models have been a great success.

A model will generate trade winds and westerlies, with dry zones between them, without being told to do so. If something like a volcanic eruption comes along, the model shows the expected cooling for several years. Such a model is not detailed enough to separately represent every cubic meter of the air or ocean, and so they cannot be used to model hurricanes in any detail. Most do not slice up time finely enough to do day after day weather forecasts.

The initial modeling focus is on the known past. If the model's CO_2 concentration is forced to match the Keeling curve, does the resulting temperature and rainfall follow what was actually observed? The models have gotten pretty good at it.

It's only at this point when the model is taken seriously as showing us what future climate might be. The best of these models are used for the IPCC reports. Typically the models are run many times, using the world weather on different days to start up the run.



The forecast for future air temperature, °C averaged globally. Double it for the interior of continents or higher latitudes; almost double again for °F. For scale,warming up from an ice age is a 5°C shift over nine centuries—but we may produce a similar shift within one century. For some processes, the rate of warming may matter more than the temperature itself.

These climate models predict unusually strong hurricanes like Katrina, fiercer heat waves, harsher droughts, heavier rains, and rising sea levels as global warming intensifies. And, of course, the models give you the degrees of fever to be expected.

The climate model forecast for twenty-first century warming depends on what happens with future fossil-fuel use. The hottest scenario typically graphed, Business as Usual, should not be considered an extreme case. It's for world economic expansion much like today's pace except that population growth is assumed to peak at midcentury.

Our interference with climate is already at dangerous levels in terms of floods, droughts, wildfires, species loss, and melting ice, just from our 0.8°C fever at the end of the twentieth century. Carrying on as usual carries enormous risks, condemning today's students to a world of constant insecurity and frequent catastrophes.

And we're already "committed" to a higher fever, just from the delayed effects of twentieth-century carbon emissions. That lowest curve assumes that greenhouse gases remain at their values for the year 1990 (in other words, that fossil-fuel use simply stopped or was cancelled by new carbon sinks) and it still shows a 0.6°C rise in the fever.

This much fever is not inevitable, of course, as we could increase sinks enough to counter the "commitment" if we tried hard enough to remove CO_2 from the air and sink it.

Climate change has a very high procrastination penalty that just grows and grows with each passing year of inaction—rather like what happens if you don't pay off your credit card. But for climate, there is no such thing as a fresh start from bankruptcy.

"Climate sensitivity" measures how strongly the Earth's climate system responds to a given perturbation—say, a volcanic eruption—and is often expressed as the equilibrium rise in global temperature resulting from doubling the pre-industrial CO_2 concentration (275x2=550).

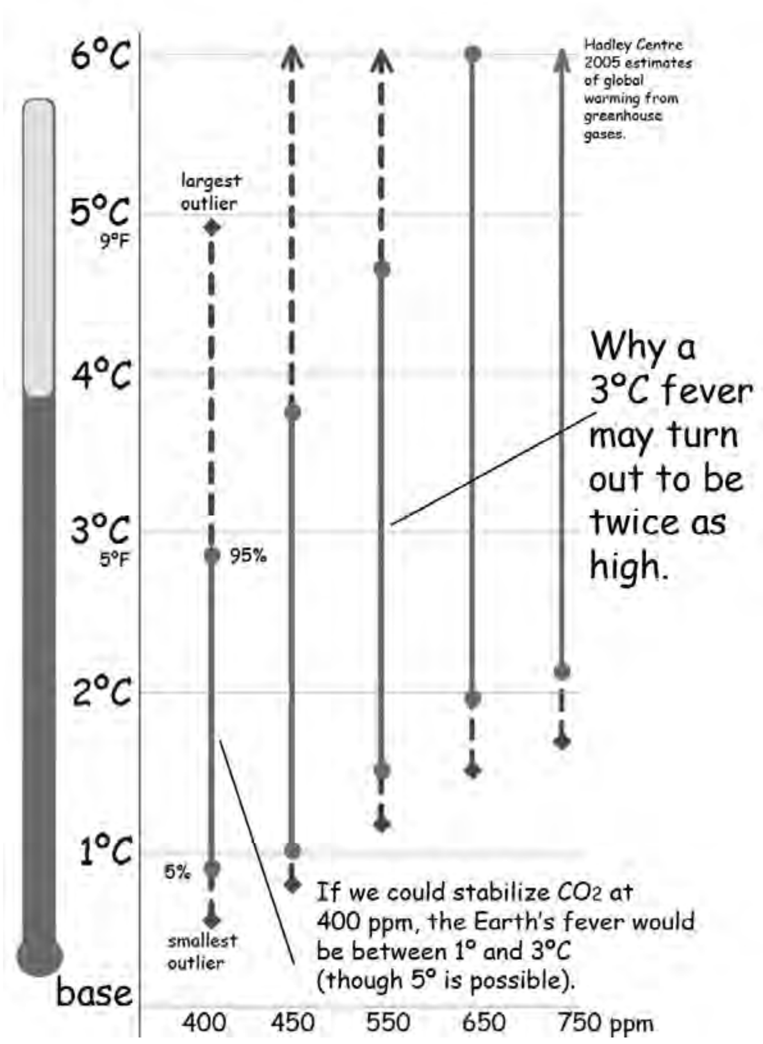
The baseline for temperature (no "fever") is simply the 1990 global mean temperature. There's also nothing special about doubling; it's just a convenient benchmark.

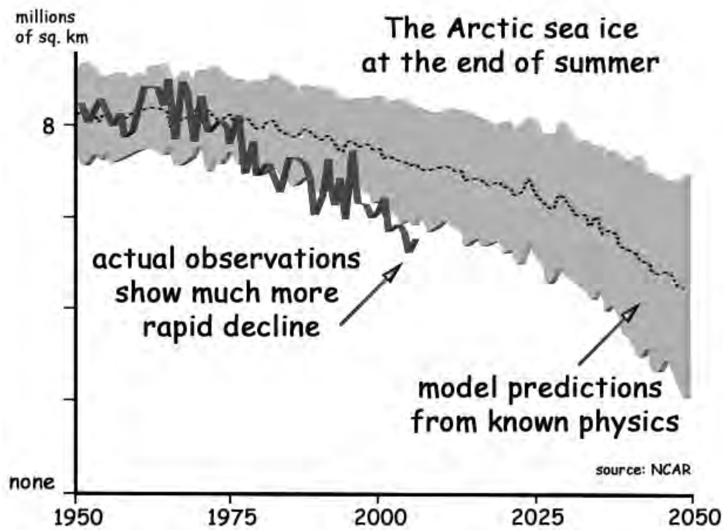
The conventional value for sensitivity is about $3^{\circ C}$, but it might be twice as great—warm a degree, get one free. So permit me a brief digression about how we know that. The graph at right shows the fever which results for five different values of the peak atmospheric CO_2 concentration. The center bar, whose indicated midpoint is the oft-quoted $3^{\circ C}$ fever, is produced by model runs that all end up settling down at 550 ppm of CO_2.

But that's only the most common result. About 95 percent were cooler than $6^{\circ C}$ ($11^{\circ F}$) average global fever; 95 percent were higher than a $2.4^{\circ C}$ fever. The reason for a range of sensitivities is that the model is re-run many times with slightly different starting values for, in effect, the weather conditions on the first day of the simulation. Ninety percent of the results lie between 1.6° and 4.7° with the average being a $3^{\circ C}$ fever.

Nature, however, doesn't do this averaging to get $3.0^{\circ C}$ and the actual sensitivity might be one of the outliers that yields a $6^{\circ C}$ fever—merely because Mother Nature got started on the wrong foot.

There are some ways to study the ice cores that ought to yield an independent estimate of climate sensitivity. By the time of the next big IPCC report, climate scientists might be able to narrow down the uncertainty in climate sensitivity.


6°C
5°C
9°F
4°C
3°C
5°F
2°C
1°C
base
400
450
550
650
750 ppm
Hadley Centre 2005 estimates of global warming from greenhouse gases.
largest outlier
95%
5%
smallest outlier
Why a 3°C fever may turn out to be twice as high.
If we could stabilize CO2 at 400 ppm, the Earth's fever would be between 1° and 3°C (though 5° is possible).



The actual decline in Arctic sea ice was about three times faster than the IPCC models would have predicted. One possibility is that soot was underestimated. Another possibility is that the 2007 IPCC sensitivity (3°C rise for a CO_2 doubling) may underestimate the fever track that we're on.

Since there is sure to be a lot of quibbling about "alarmist" climate forecasts, let me outline why scientists have come to view the matter so seriously. It's no longer a matter of one theoretical line of argument, as it was in 1898. It's no longer a matter of two correlated lines of data, CO_2 and global temperature, the way it was in the half century that followed.

Dozens of things have gone wrong with climate over the last fifty years that fit the theoretical framework for fossil-fuel climate change. Even if there were an alternative explanation for several of those—say, land use changes proving more important for the fifty-year trends in wildfires and floods than global warming—it wouldn't change things in the other areas. Nor would it change the forecasts for the future.

So let me explain where the climate change conclusions come from. Major scientific and medical conclusions start with the individual investigators, usually working on one piece of the puzzle. They submit their data and conclusions to peer review. An editor selects two to five other experienced investigators in the same field to read the manuscript, not only to "grade the paper" but to write a report on it. This often results in conclusions being toned down; sometimes it forces more data to be collected to fill the holes identified by the reviewers, whereupon the rewritten manuscript is resubmitted for more peer review.

Once published in a peer-reviewed journal, any important conclusion will not stand alone for very long because other researchers will be attracted to the subject and soon there will be a whole cloud of peer-reviewed papers on the subject. Usually, the original conclusions will be qualified or extended.

Important topics will soon require a scientific assessment, where an expert panel of scientists takes a careful look at all the evidence and writes an evaluation. This meta assessment is itself peer-reviewed, then published. For example, the entire literature on weight-loss dieting was recently evaluated in this manner. (Diets fail on four out of five tries, and the health hazards of a medically unsupervised diet may well swamp whatever benefit remains. This will, of course, alarm the profitable $35-billion diet-foods industry.)

Climate science does scientific assessments (themselves peer-reviewed) every few years. However, the major international scientific assessments of climate change and its impacts have an additional twist or two, as the science historian Spencer Weart explains:

> The Intergovernmental Panel on Climate Change . . . was created by conservatives [in the early 1990s] to forestall "alarmist" declarations from self-appointed committees of scientists. Governments committed the IPCC to repeated rounds of study and debate, forbidding any announcement except by unanimous consensus. It seemed a sure formula for paralysis.
>
> However, the power of democratic methods, combined with rational argument, overcame all obstacles. The IPCC has evolved into a robust transnational institution that provides authoritative conclusions of grave significance.

So for the physical science portion of the 2007 IPCC report, thousands of scientific findings were reviewed, 600 climate scientists were involved in writing the report, then it went out to peer reviewers, then to additional national reviewers like me—so thousands of reviewers (making a total of 30,000 comments) were involved before it ever landed in the laps of hundreds of government representatives gathered in Paris—who proceeded to tone down some well-established scientific conclusions. Fortunately, someone will always compare the draft report with the finished one to show the changes, put up the comparison on the web, and the countries that pushed the changes then become publicly identified with trying to rewrite the scientists.

To call something "alarmist" that survives such a winnowing process is to risk one's own credibility. It is more likely that the IPCC reports understate the case, that the alarm has been somewhat muffled by the cumbersome process.

As mentioned earlier, the sea-level rise for the twenty-first century in the IPCC report is mostly thermal expansion because they were uncertain how much to add for accelerated iceberg production. The models used for the 2001 IPCC report predicted CO_2 rise correctly but were on the low side for both temperature and sea-level rise.

Remember also that the IPCC estimates leave out anything that can't be assigned a reliable number—and so they leave out quite a lot, including history. A big part of IPCC's problem is its strict adherence to the use of physical models. By IPCC standards, "if it's not in a model, it's speculation," says Stefan Rahmstorf, one of the leading modelers. By ignoring factors that can't yet be modeled, he says, IPCC came up with deceptively reassuring numbers.

The other omission is the whole class of sudden episodes of damage, as when the Amazon burns in a prolonged El Niño.

The culture of science (in contrast to medicine) downplays the possibility of things going badly wrong. Mumbled British understatement is a style not confined to UK scientists. Jim Hansen calls it "scientific reticence." As the physicist Mark Bowen said, "Scientists have an annoying habit of backing off when they're asked to make a plain statement, and climatologists tend to be worse than most." Graduate students will witness enough examples of someone being shot down for "overstating the case" that they will become cautious, adopting their professors' style of understatement. Except in a few areas such as engineering and medicine, risk assessment usually isn't part of the scientific culture. It's one of the reasons why we've been getting "climate lite" reports for so long.

As we decide what to do about climate change, it is well to remember the standards in other areas for making "expensive" decisions. A U.S. jury in a criminal case uses the standard of "beyond a reasonable doubt" because we, as a society, have decided that convicting an innocent person by mistake is unacceptable. In a civil case, where only money and reputation is at risk, the standard is relaxed to "a preponderance of the evidence." As I learned serving as a jury foreman in both civil and criminal cases, it is much easier for a jury to agree in a civil case.

People also take sensible precautions when the risk is high. Ask a roomful of people if they have fire insurance. Almost all will raise a hand. Ask how many have had a fire in the last ten years, and almost none will respond. Yet people pay for insurance because, should a fire happen, they could lose everything—and still have to pay off the mortgage.

The 2006 Stern Report estimates the annual cost of climate insurance at below 5 percent of GDP (though the economy would take an annual 20 percent hit if action is delayed). Furthermore, much of the carbon-free ("C-free") remake is soon going to be needed anyway because both oil and natural gas production will decline. This means that much of the makeover's expense is a cost we will soon bear anyway, even if a miracle prevented further global warming.

We need to innovate in a hurry and, considering our reputation for technological innovation, it's odd that the U.S. has fallen behind.

Many U.S. geothermal installations are imported from Israel. Though the Hot Rock Energy concept was invented in 1972 at Los Alamos, the action is now in Europe and Australia.

The U.S. hasn't started a nuclear plant since 1978. The French and Japanese are now the most experienced. The French electricial utility will help build, and is a major investor in, the U.S. nuclear plants in the pipeline.

The Germans have become the innovators in "green" buildings.

The Japanese and the Germans have more experience with solar power panels, though innovative thin-film photovoltaic from the U.S. is starting to make a difference.

Think of wind turbine innovations and Spain, Denmark, and Germany will come to mind.

To my surprise, there are now Italian

windmills back home in Kansas! The largest Italian utility company is building a big wind farm near Hayes, Kansas to sell clean electricity to the coal-dependent American Midwest.

Countries that innovate early get the new jobs, developing an economic edge over the C-free laggards that end up having to later import the technology.

> I spent a day discussing climate change at No. 10 Downing Street [in 1989, Prime Minister Margaret Thatcher gave her Cabinet a seminar on global warming], and sitting next to me was Mr. James Lovelock, the author of the Gaia theory. When we went down to the street afterward there were lots of journalists waiting, and they all thrust microphones into our faces. They asked Lovelock, "What do you expect to happen after today?" He just said, "Surprises."
>
> —British diplomat Sir Crispin Tickell, 2002

Speaking of surprises, the 2002 National Research Council report on abrupt climate change had the subtitle: *Inevitable Surprises*. One reason we have a standing army is in case we are surprised. Now we must provide something similar for climate surprises. We need the resilience to bounce back when something unexpected hits.

We also must have a good safety margin. We routinely have safety margins in support strength or fire resistance. No architect would design a stadium without calculating the weight of the fans packing those bleachers—and then, for safety, doubling the number. Actually, it's the noncritical components that have a safety factor of two. For components whose failure could result in substantial financial loss, serious injury, or death, a safety factor of four or higher is common. Yes, that's more expensive, one reason why building collapses are common in countries where building inspectors can be bribed to ignore skimping on the materials.

For climate protection, we need a safety margin in schedule. Our response needs to make a lot of progress up front, just as insurance against something as unexpected as, say, a fire in a rain forest.

We've only got one habitable planet and we dare not shave our margins.

> It is now entirely plausible that about a rise of 1.5°C globally will mean the end of coral reefs and polar bears. That about 2°C will mean catastrophic melting of Greenland and Antarctic ice, with commitment to multi-meter rises in sea level. That about 2.5°C will sharply reduce global crop yields.
>
> Thus stopping at twice the pre-industrial CO_2 (550 ppm corresponding to about 3°C, once thought a reasonable target by many) may not be good enough.
>
> Many analysts and groups now conclude that prudence requires aiming not to exceed 2°C.
>
> —climate scientist John Holdren, 2006

GLOBAL
How to Treat Climate Change
FEVER

William H. Calvin

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