How much hotter is the planet going to get?

- 18:00 09 March 2014 by **Michael Le Page**
- For similar stories, visit the **Climate Change** Topic Guide

The climate is highly sensitive to carbon dioxide, according to several new studies, which means that our greenhouse gas emissions will lead to strong warming. The finding suggests we need to cut emissions fast if we are to avoid dangerous climate change.

This may seem surprising given that the slower warming in the past decade has led some to conclude that the sensitivity of the climate is low. But the latest findings show that the cooling effect of aerosol pollution from factories and fires has been underestimated. This means warming will resume with a vengeance if countries in Asia clean up their skies.

It's a complicated story. So *New Scientist* has broken it down.

What is this climate sensitivity business about anyway?
If you kicked your best friend in the teeth, how would they react? Would they shrug it off, burst into tears, or stalk off to plot your murder?

Climate sensitivity is a measure of how strongly the planet will react to the kicking we are giving it. It is how much surface warming we can expect if we double the amount of carbon dioxide into the atmosphere.

Is that as simple as it seems?
If only. There has long been uncertainty about the climate's sensitivity. Very low values have been ruled out, but it is far from settled. The most recent report of the Intergovernmental Panel on Climate Change (IPCC) says the climate sensitivity is between 1.5°C and 4.5°C.

Even if sensitivity is low, if we fail to curb emissions soon the world will warm by 3°C by 2100, taking us above the agreed "danger" threshold. On the other hand, if sensitivity is high and emissions remain large, parts of Earth could become uninhabitable.

Thanks, that's very cheering. Why has there been so much uncertainty?
The immediate warming effect of greenhouse gases is well understood. But as the planet warms, all kinds of feedbacks are kicking in.

The lower atmosphere is becoming moister as it warms, trapping more heat. Clouds, sea ice extent and snow coverage are all changing. Permafrost is melting, allowing dark vegetation to grow in regions that were once too cold. The ocean is soaking up heat, and the great ice sheets are starting to melt.

At the same time, people have been cutting down forests, building cities and pumping pollutants into the atmosphere and oceans. Some pollutants, such as sulphur aerosols, have a cooling effect.

To pin down the sensitivity, we need to disentangle all these effects. That is hard.

So what's new?
A series of recent studies have resolved many of the discrepancies between different studies. They all suggest that sensitivity is on the high side.

"All the lines of evidence now point to the high end," says Drew Shindell of the NASA Goddard Institute for Space Studies in New York. "They're all telling us the exact same thing."

Hold on. I thought recent studies pointed to lower climate sensitivity?
This was the story in 2013. Last year, several studies came out with lower estimates for sensitivity. These studies were based on how much the world has warmed over the past few decades. Since the world warmed more slowly in the 2000s than it did in the 1990s – sometimes known as the "pause" in global warming – this method is yielding lower estimates than it used to.

But other approaches, such as looking at what Earth's climate was like thousands of years ago, have continued to point to higher values.

But if CO_2 levels are higher now than in the 1990s, and yet the world is warming more slowly, doesn't that mean climate sensitivity is low?
Good question. Most climate models predicted more warming in the 2000s than we have seen. In theory, that could mean the models are overestimating sensitivity.

But there are plenty of other possible reasons. The models assumed that volcanic activity, levels of aerosol pollution and solar output would continue at similar levels to those in the 1990s. But solar output fell while volcanic activity and aerosol levels increased. These changes had a cooling effect.

Shindell and his colleague Gavin Schmidt recently re-ran the models, using updated data on aerosol levels and solar output. Most of the discrepancy vanished (*Nature Geoscience*, DOI: 10.1038/ngeo2105). The remaining difference between models and observations is probably due to increased heat uptake by the oceans.

But that doesn't mean sensitivity is higher, does it?
It means we can no longer dismiss models with high sensitivity on the basis that their projections don't match reality. On the contrary, the most sensitive models may be the most realistic.

For instance, Steven Sherwood of the University of New South Wales in Sydney, Australia and his colleagues looked at why different models produce different estimates of sensitivity. The team found that the way clouds behave in these models explains half of the differences. What's more, the models that come closest to getting clouds right are the ones predicting higher sensitivity (*Nature*, DOI: 10.1038/nature12829).

If Sherwood is right, the equilibrium climate sensitivity must be more than 3°C. That is much higher than the minimum value of 1.5°C given in the IPCC report last year.

Wait, what's "equilibrium climate sensitivity"?
This is where it gets fiddly. There are lots of ways of defining climate sensitivity.

One is to ask how much warming there will be at the moment CO_2 levels hit double their original value. This is known as the transient climate response. It is called transient because, even if CO_2 levels stabilised right then, surface temperatures would keep rising for decades, and sea levels would rise for centuries.

The equilibrium climate sensitivity looks further ahead and asks how much warming there will be a few decades after CO_2 doubles, once a few feedbacks have played out. This is the figure the IPCC says is between 1.5°C and 4.5°C, and Sherwood says is above 3°C.

Finally, there is the long-term response to a doubling of CO_2. This is sometimes called the earth-system sensitivity, and includes very slow feedbacks like changes in vegetation and the great ice sheets of Greenland and Antarctica. It may be as much as double the equilibrium sensitivity. So if the equilibrium sensitivity is 3°C, the earth-system sensitivity could be 4.5°C to 6°C.

That is just confusing.

Think of it this way. The transient climate response is what we need to worry about now, because it will determine how much warming occurs in our lifetimes (alongside how much CO_2 we emit, of course). The equilibrium climate sensitivity matters more to our children and grandchildren. And the earth-system sensitivity will determine the fate of our more distant descendants.

Never mind my distant descendants, it's my own skin I'm worried about. How big is the transient climate response?

A study last year concluded that it is between 0.9°C and 2°C, and is most likely to be 1.3°C (*Nature Geoscience*, DOI: 10.1038/ngeo1836). That is a surprisingly low value, and got a lot of attention. The study used a very simple method, totting up the various factors that are causing warming or cooling, and estimating how much heat the planet has absorbed.

Shindell, who was one of the authors of the 2013 paper, has now shown that this kind of calculation greatly underestimates the cooling effect of aerosol pollution from factories and cars, because it ignores the localised distribution of the pollutants. Most of this pollution is in the northern hemisphere, with China a particular hotspot.

Once the patchy distribution of aerosols is taken into account, Shindell calculates that the transient climate response is between 1.3°C and 3.2°C, probably about 1.7°C. He has not calculated the equilibrium sensitivity but says his findings are entirely consistent with Sherwood's results, suggesting it is more than 3°C.

Shindell's finding does not mean that climate models are underestimating future warming, as general climate models already take the spatial distribution of aerosols into account. What it is does do is resolve the discrepancies between the different methods of calculating sensitivity.

"It is not down at the low end," Shindell says. "We can't take any solace from warming being slower of late."

That means we need to get our act together and cut emissions now, says Shindell. If we don't, warming could accelerate rapidly in 20 or 30 years as countries in Asia cut aerosol emissions. A combination of low aerosols, high sensitivity and high CO_2 emissions could lead to global temperatures rising by as much as 5°C or 6°C by 2100.

Journal reference: *Nature Climate Change*, DOI: 10.1038/nclimate2136