# Climate change is happening, but how fast?
# This is what we really know

By Michael Le Page, published in *New Scientist* (weekly), print issue of Dec 15, 2018

*From past temperature change to future sea level rise, climate science is full of conflicting numbers. Here's our guide to the ones you can and can't trust*

Twelve years to save the planet. Warming of 3°C, or perhaps 5°C if we don't take drastic action now. Sea level rise of 0.3 metres by 2100 – or is it 3 metres?

Just about every article you'll read about climate change is full of numbers, starting with 1.5°C, the number that we are told represents the maximum temperature rise we can allow and still avoid the worst effects of global warming. Except it isn't – and that is just the beginning of the confusion. No two numbers from climate change studies ever seem to agree. Even climate scientists are often baffled by the figures other researchers come up with.

Climate change deniers seize on the uncertainty as evidence that the underlying science is wrong. It's not. It is just complex, as messy, real-world science is. The biggest uncertainty by far is us, namely what exactly we do over the next century. And the uncertainty cuts both ways: we could be underestimating how fast the world will warm and what the effects will be. So what numbers can and can't we be certain of? Read on for our potted guide.

**How much has the planet warmed already?**

As part of the Paris climate accord of December 2015, nearly every country in the world agreed to try to limit the increase in global average temperature to 1.5°C above pre-industrial levels.

To work out what that means, we must first know where we are now. The uncertainty starts here. We might have as much as 0.6°C still to go before we cross the threshold – or less than 0.3°C.

How can we not know how much the world has warmed? Well, the best way to measure global warming would be to look at the whole by examining land, sea and atmosphere. But our measurements focus on the thin layer we live in: mean global surface temperature usually refers to the heat of the air 2 metres above the surface.

We get an idea of how this temperature is changing from thousands of weather stations on land, and from ships and buoys at sea. Each reading is checked to see whether the temperature is lower or higher than the long-term average for that place at that time of year. They are then combined to work out how the average global surface temperature is changing relative to the long-term average, or baseline.

This isn't simple. For instance, although the weather stations on land measure the air 2 metres above the ground, marine observations are usually of sea surface temperature. And because you can't have fixed weather stations in an ocean full of shifting ice, we have few measurements from the Arctic. The HadCRUT temperature record, maintained by the UK's Met Office, simply leaves the Arctic out. NASA's GISTEMP record estimates Arctic temperatures based on surrounding stations. Because the Arctic is rapidly heating up, NASA's figures suggest there has been nearly 0.1°C more warming across the planet than the Met Office's do.

Further confusion surrounds the baseline question. Global temperature records go back no further than 1850, but the industrial age began a century earlier. Computer models suggest the world was already up to 0.2°C warmer before 1850.

Despite this, the average temperature between 1850 and 1900 has come to be regarded as the semi-official "pre-industrial level" because that is the earliest period for which we have direct measurements. "I don't think there's much appetite in the community for changing this," says Ed Hawkins at the University of Reading in the UK, who was involved in many of the relevant studies.

If you use the Met Office record and take 1850 to 1900 as the baseline, there has been around 0.9°C of warming so far. Go with NASA and the earlier, pre-industrial baseline, and there has been 1.2°C.

With the world on course to warm vastly more than 1.5°C, that difference is minor. But if we are serious about trying to limit warming to 1.5°C, it really matters. "With 1.5, a difference of 0.1 is a huge amount," says Hawkins.

**What is the safe limit for warming?**

Not 1.5°C. That was picked not because it is the right number, but because it was convenient. A 1990 report concluded that limiting global warming to 1°C would be safer than a 2°C cap. But in 1996, with 1°C already looking out of reach, 2°C was adopted as a target by the European Union's Council of ministers. This led to its 2010 adoption by the UN.

When the Paris climate agreement was being negotiated in 2015, island nations facing watery oblivion demanded a more ambitious target. Since the world was already around 1°C warmer by then, 1.5°C was chosen. But as an October report on this target by the Intergovernmental Panel on Climate Change (IPCC) makes clear, it is not a safe limit.

There is growing evidence that warming is fuelling record-breaking extremes. The devastating storms, incredible heatwaves and rampaging wildfires we are already seeing show that what is deemed safe is a matter of degree. As the world gets hotter, most of the downsides of global warming, from coral bleaching to more severe flooding, will grow ever greater.

Then there are potential tipping points such as the shutdown of the Atlantic current that warms northern Europe. But as we don't know for sure at what temperatures any of these will kick in, this doesn't help establish a "safe" limit.

And the dangers associated with any particular level of warming partly depend on us. If we stop building on coasts doomed to disappear under the waves and start adapting our homes to cope with far greater weather extremes, we will save many lives.

**When are we set to pass the 1.5°C limit?**

On current trends, the first year to exceed 1.5°C above the 1850 to 1900 average will probably occur in the 2020s. But as climate is weather averaged over many years, it would be premature to regard this as passing the limit. The threshold is likely to be crossed during an El Niño, a period in which warm waters spread across the Pacific and temporarily boost the global surface temperature. Temperatures will drop a little again when this passes.

A reasonable definition is that we will go over the limit when the average, long-term temperature rise exceeds 1.5°C. Following current trajectories this is likely to happen around 2040 – sufficiently close that many scientists and politicians have adopted a somewhat different definition of hitting 1.5°C. Almost all the scenarios considered in the IPCC report on the 1.5°C target involve getting the temperature rise back under this threshold by 2100 after exceeding it by the middle of this century (8 December, p 31).

That's a bit like lending someone a credit card with no spending limit. If you rack up a lot of debt, the only way to repay it – to get the temperature back down after an overshoot – is to reduce the level of carbon dioxide in the atmosphere by removing vast quantities of it. At present, we have lots of ways of capturing carbon on a small scale, but no technology that works on the stupendous scale required to reverse decades of fossil fuel burning.

Even if we can get the temperature back down, the impacts will be more serious if we go past 1.5°C because there will be faster warming over the next few decades. That could trigger tipping points that cannot be quickly reversed, such as the die-off of the Amazon rainforest. And once you start relying on science-fiction scenarios, you can justify a much vaster range of numbers.

**How much warming does CO2 cause?**

This is the perhaps the toughest question in all of climate science. Carbon dioxide directly warms the planet by trapping more of the sun's heat. That is the easy part.

But it also triggers all kinds of feedbacks that affect global temperature. Some kick in almost instantly: for instance, more warming means more water vapour, which is a powerful greenhouse gas. Cloud behaviour also changes immediately.

Other feedbacks take thousands of years. Warming will be amplified as vast, reflective ice sheets melt and are replaced by dark land and water that absorb most sunlight, for example. Adding to the confusion are all sorts of other pollutants that we are pumping into the atmosphere, some of which have a cooling effect. This not only makes it harder to determine how much warming $CO_2$ causes, but also to work out what we need to do to limit warming, because it depends on how levels of these pollutants change too.

A common measure of climate sensitivity is how much warming would occur in the decades and centuries after a doubling of $CO_2$ levels. Studies converge on the most likely value being 3°C, but with plausible values ranging from under 2°C to more than 5°C. If emissions keep increasing, it will be less than 50 years before $CO_2$ levels are double pre-industrial levels.

While we are increasingly confident that the low end of the plausible range can be ruled out, there is a long tail of high values that cannot. Earlier this year, some climate scientists warned that we could be greatly underestimating the risks, and that if the planet did warm by at least 2°C, it might be impossible to stop it warming several further degrees.

**How much more CO2 can we emit?**

Even if we are unsure of the exact value of the climate's sensitivity to carbon dioxide and other greenhouse gases, it is clear that what matters is how much is in the atmosphere. Less is definitely more. To try to simplify things, climate scientists have started talking in terms of carbon budgets: how much more $CO_2$ we can emit.

Because $CO_2$ stays in the atmosphere for many centuries, there is a fairly straightforward link between total, cumulative $CO_2$ emissions and its level in the atmosphere. So what is the budget for 1.5°C?

An IPCC report in 2013 estimated that, for a 66 per cent chance of limiting warming to 1.5°C, the carbon budget from 2018 was just 118 gigatonnes of $CO_2$. The seemingly equivalent figure in the latest report is 420 gigatonnes.

The higher budget is partly a result of some genuine good news. Earlier calculations had relied on estimated emissions over the past century, and were done using a subset of computer models that slightly overestimated temperature rise. More accurate figures and better models have resulted in an increase in the amount of $CO_2$ we can get away with emitting.

But the latest IPCC report acknowledges that budgets can vary widely for the reasons we have looked at already. For instance, using different temperature records can make the budget as low as 258 gigatonnes or as high as 570.

Even these numbers conceal huge uncertainty. The budgets could be 650 gigatonnes lower or higher, depending on climate sensitivity and the historical baseline, meaning we might already have exceeded even the biggest budget. In addition, the report says, if wetlands release more methane and melting permafrost releases more carbon than assumed, the budgets would be 100 gigatonnes lower.

Most carbon budgets are what Glen Peters of the Center for International Climate Research in Norway calls "exceedance budgets". These set out how much $CO_2$ we can emit up to the point the temperature rise passes 1.5°C. If you were doing a bungee jump, this would be equivalent to the length of rope with which you would exactly smash into the ground.

Ideally, you would work with a rope that is a little shorter: an "avoidance budget" with which you never actually hit 1.5°C. It is even more likely we have already busted such budgets.

The budgets in the IPCC's latest report are something different again. They are based on when emissions hit zero in those scenarios that assume we overshoot 1.5°C, but cool the planet back down by sucking carbon from the air. "Once you allow negative emissions, the carbon budget is an ill-defined concept," says Peters.

Confused? It's not just you. "Everyone is confused," says Peters.

**How high will the seas rise?**

During the warm period between ice ages about 120,000 years ago, temperatures were around 1°C warmer than from 1850 to 1900, and sea level was 6 to 9 metres higher. In other words, even if we limited warming to 1.5°C, much of the ice in Greenland and West Antarctica could still be lost, which would be enough to raise sea levels 5 metres or more.

Without a change of course, we are actually heading for a world that is 3 or 4°C warmer, which could lead to seas rising more than 20 metres. The huge unknown is how long this will take. Because the planet's temperature is increasing much faster now than it did in any recent warm periods, the past is not a good guide to our immediate future.

The prevailing view is that it will take many centuries or millennia. IPCC projections are for sea levels to go up by between 0.3 and 0.8 metres by 2100 in a world that is 1.5°C warmer, and by 0.5 to 1 metre by the end of the century if emissions keep increasing unchecked. If it stays warm, there will be bigger sea level rises in the 22nd century and beyond.

Some scientists regard these projections as conservative. Antarctica is already losing ice much faster than expected, and a 2016 study based on a computer model of its ice sheets suggests the seas could rise by up to 3 metres by 2100.

**How long do we have to turn things around?**

"Scientists Say We Have 12 Years to Save the World." That is the message many seem to have taken from the latest IPCC report – but that is not quite what the report says.

It is true that at the current rate of emissions we will exceed the report's "most likely" remaining carbon budget in roughly 12 years. But as we have seen, carbon budgets are at the midpoints of vast ranges, and the 1.5°C target itself is an arbitrary one.

We have also been here before. Climate change deniers have gleefully pointed out that we have been told several times before that there are just X years to save the planet. So focusing on arbitrary deadlines is probably not the best way to sum up the science.

"I personally don't like the 12 years," says Piers Forster at the University of Leeds in the UK, one author of the report. "We in fact have to act immediately in a larger way than ever before."

Amid the morass of confusing and conflicting numbers, two things remain crystal clear. First, we have to reduce net global emissions to zero, and the faster we do it the better off we will all be. Second, how bad things get partly depends on how much we do to prepare. We need to get serious about adapting to life on a warmer planet.

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**Hitting 1.5°C** This is the second of a series of four features in *New Scientist* over the coming two months looking at the 1.5°C climate target. In the next instalment in the New Year, we'll examine what a world warmed by 1.5°C will look like – and what happens if we miss the target. Follow the series here.