How we know we're causing global warming in a single graphic

In 1859, physicist John Tyndall ran an experiment demonstrating the greenhouse effect. Visible sunlight easily passes through our atmosphere to warm the Earth. However, invisible heat rays rising from the Earth's surface, otherwise known as infrared radiation, don't easily escape back to space. What Tyndall showed by shining heat rays through tubes filled with different gases is that certain gases like water vapour and carbon dioxide block the heat rays. These became known as greenhouse gases.

Tyndall also made several predictions of what we should expect to see if greenhouse gases were causing warming (Tyndall 1861). In fact, we expect to see a number of distinctive greenhouse patterns in global warming. Observing these patterns strengthens the evidence that humans are causing global warming, as well as eliminates other possible natural causes. Let's have a look at the many human fingerprints on climate change:

Humans are raising CO2 levels

The first point to establish is that humans are the cause of the rise in atmospheric CO2 levels. This fact is common sense. The amount of CO2 in the atmosphere is going up by around 15 billion tonnes per year. Humans are emitting around twice that much! On top of this, there are a number of lines of evidence to confirm that we're the cause of rising CO2 levels.

When we measure the type of carbon accumulating in the atmosphere, we observe more of the type of carbon that comes from fossil fuels (Manning 2006). As you burn fossil fuels, you take oxygen out of the

atmosphere. Measured oxygen levels are falling in line with the amount of carbon dioxide rising (Manning 2006). There's been a sharp rise in "fossil fuel carbon" in corals (Pelejero 2005) and sea sponges (Swart 2010). Anthropogenic CO2 is penetrating even to the ocean depths (Murata 2010). Measurements of radiocarbon in tree-rings confirms human activity is the cause of rising CO2 (Levin 2000). Even the pages of ancient books trace the rising effects of fossil fuel pollution going back to beginnings of the industrial revolution (Yakir 2011).

So many independent lines of evidence (and common sense) confirm that yes, we are responsible for the recent rise in atmospheric CO2.

The extra CO2 is trapping heat

Our understanding of the greenhouse effect provides a number of verifiable predictions. If carbon dioxide is trapping more heat, we should see less heat escaping to space. Satellites measuring infrared radiation coming from Earth find less heat escaping to space over the last few decades, at those exact wavelengths that carbon dioxide absorbs energy (Harries 2001, Griggs 2004, Chen 2007). The researchers who analysed this data described this as:

> *"...direct experimental evidence for a significant increase in the Earth's greenhouse effect"*.
> Harries 2001

If less heat is escaping to space, there's only one place it can go - back to the Earth's surface. Scientists check this by measuring infrared heat coming down from the atmosphere. These measurements confirmed the satellite data - more heat is returning to the Earth's surface (Philipona 2004, Evans 2006, Wang 2009). This extra piece of evidence upon the existing body of evidence led scientists to conclude that*:*

> *"This experimental data should effectively end the argument by skeptics that no experimental evidence exists for the connection between greenhouse gas increases in the atmosphere and global warming."*
> Evans 2006

Unfortunately the scientists underestimated the human capacity to ignore evidence staring us in the face.

Global warming has a distinct greenhouse signature

As far back as the mid 1800s, Tyndall predicted that greenhouse warming should cause nights to warm faster than days. This is because at night, the Earth's surface cools by radiating heat out to space. Greenhouse gases trap some of this heat, slowing the night-time cooling. It took over 130 years before Tyndall's prediction was confirmed. Over the last few decades, surface measurements have observed nights warming faster than days (Braganza 2004, Alexander 2006, Zhou 2009).

Tyndall made another prediction of what greenhouse warming should look like. Just as greenhouse gases slow down nighttime cooling, they also slow down winter cooling. So Tyndall anticipated winters warming faster than summers. Again, recent analysis of temperature trends over the last few decades bear this out (Braganza et al 2003, Braganza et al 2004). Both thermometers and satellites find winters warming faster than summers.

And the evidence continues to build. Another distinctive greenhouse pattern can be found in the atmosphere. With heat being trapped, we expect to see the lower atmosphere to warm. But with less heat escaping to space and more carbon dioxide in the stratosphere, we also expect to see the upper atmosphere cool. Satellites and weather balloons both observe this curious contrast between upper cooling and lower warming

(Jones 2003).

With the lower atmosphere (the troposphere) warming and the upper atmosphere (the stratosphere) cooling, the boundary between the troposphere and stratosphere, otherwise known as the tropopause, should rise as a consequence of greenhouse warming. This has been observed (Santer 2003). An even higher layer of the atmosphere, the ionosphere, is expected to cool and contract in response to greenhouse warming. Satellites measure this effect (Laštovika 2006). We are changing the very structure of our atmosphere.

What's fascinating about all these greenhouse signatures is they also rule out a number of other potential causes of global warming. If the sun was causing global warming, it would cause summers to warm faster than winter, days to warm faster than nights and the upper atmosphere to warm. Observations rule out the sun.

Similarly, the pattern of ocean warming rules out ocean cycles as the driver of global warming. The world's oceans have been building up heat over the past half century. This isn't a case of heat shifting around due to ocean cycles but the entire global ocean system building up heat. The specific pattern of ocean warming, with heat penetrating from the surface, can only be explained by greenhouse warming (Barnett 2005).

If it walks like a duck and quacks like a duck...

Current global warming shows all the distinctive signatures of greenhouse warming. To be skeptical that humans are causing global warming, you must believe two things. Something unknown is causing warming that happens to mirror the greenhouse effect. And something unknown is somehow suppressing the well understood (and well observed) greenhouse effect. So we can accept what we know to be true (greenhouse warming) or we accept two unknowns.

The saying goes if it walks like a duck and quacks like a duck, then it must be a duck. But climate skeptics are trying to convince us it's some other, undefined animal impersonating a duck that's also mysteriously hiding the real duck.

H/T to James Powell, Scott Mandia and Lou Grinzo whose words inspired this post. The "How we know we're causing global warming" graphic has been added to the Climate Graphics resource and with a Creative Commons Licence, is free to be published elsewhere.

Posted by John Cook on Wednesday, 27 July, 2011