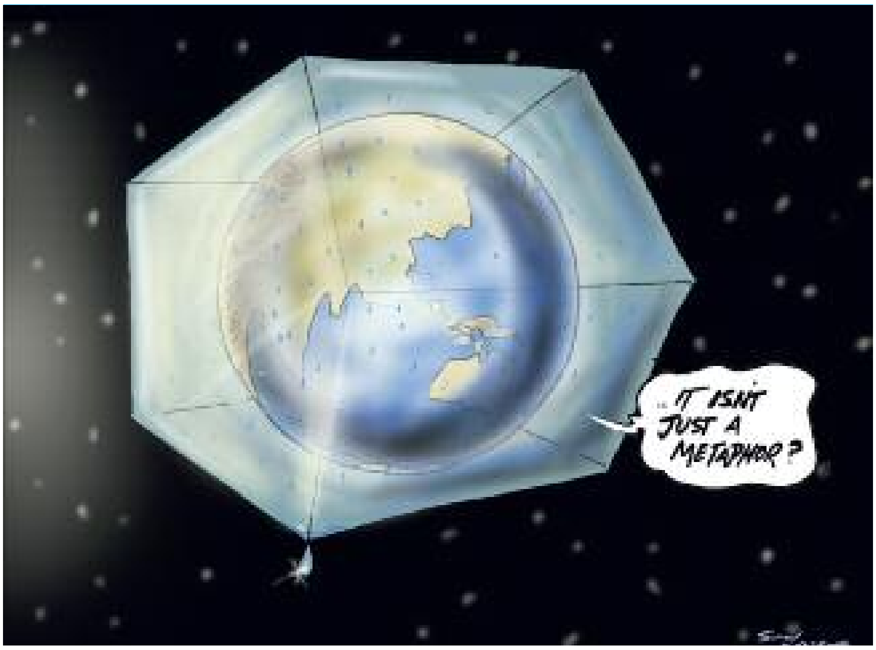


Humidity Doubles Global Warming

BY STEVEN SHERWOOD

CO_2 is not the most important "greenhouse gas" in our atmosphere.

We are hearing a lot these days about carbon emissions and efforts to address the problem of climate change or global warming. The basic problem, we are told, is the carbon dioxide that is released into the atmosphere every time we burn something like petrol or coal.

Carbon dioxide is a "greenhouse gas" that causes warming of the planet. But is it really the most important one?

It turns out that simple and naturally occurring water vapour, not carbon dioxide, is actually the strongest greenhouse gas in our atmosphere. Does that mean all the hype about carbon emissions is overblown? To answer that we need to understand what are called climate forcings and climate feedbacks.

First, what exactly is a "greenhouse gas"? The way a greenhouse works is that the glass panes allow sunlight to come in and warm the plants and the air, but then prevent this heat from escaping to the free atmosphere. The panes do this mainly by physically holding the air in; putting all that solar energy into a relatively small volume can raise its temperature quite a bit, even on a cold day. Without glass panes, winds would carry the air away before it had warmed much.

The way a greenhouse gas in the atmosphere works is a little like this, in that these gases are transparent to sunlight (like glass panes) and trap heat that would otherwise escape. But the way the heat would normally escape the entire Earth is not by winds but by infrared radiation emitted from the Earth. Infrared is what you feel if you sit near a fire – it is completely harmless and you are even radiating some of it yourself right now.

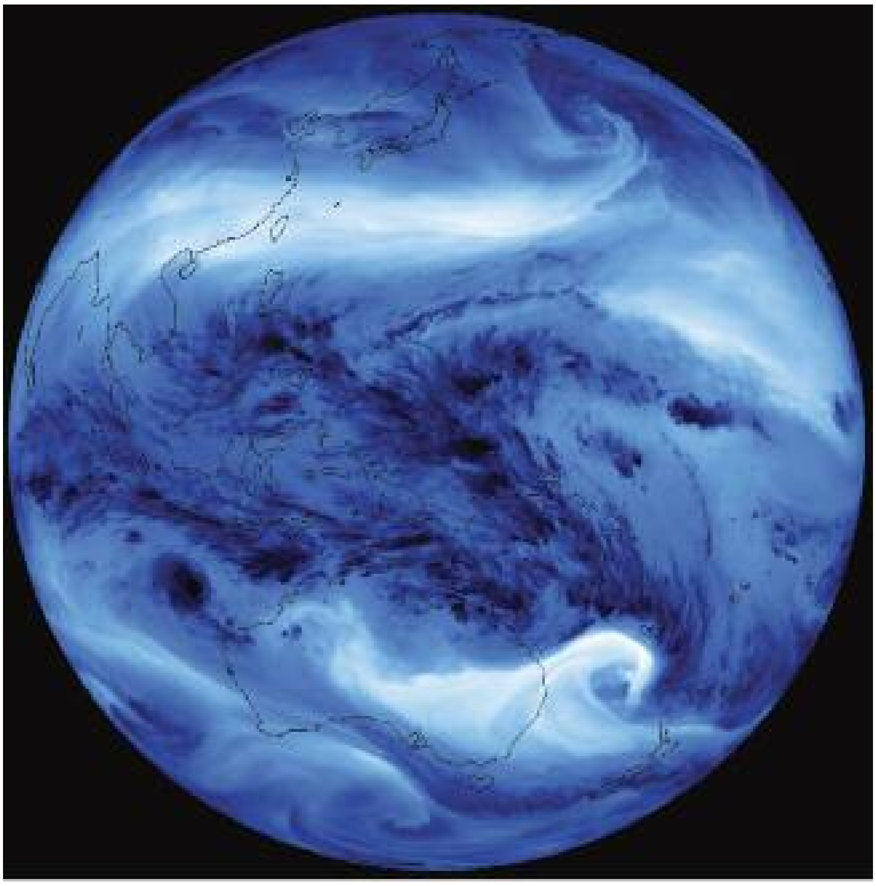
A greenhouse gas is one that absorbs infrared, meaning it won't escape to space. The gas also radiates infrared of its own, but not as much as would have been emitted in its absence. The net result of this is that less energy escapes to space than otherwise would have done, which we call a climate forcing.

If greenhouse gas amounts increase, then a deficit develops between the energy coming in and going out, and the planet must warm up. By the 1950s we knew enough about the details of how carbon dioxide absorbs radiation, and how the planet emits it, to make a fairly precise calculation of its effects, such as how much the Earth's surface would have to warm if the amount of carbon dioxide doubled. The answer was 1.1°C – not a whole lot.

This is where climate feedbacks enter the picture; 1.1°C might not sound like much of a change but it is enough to set in motion changes – perhaps imperceptible but global in scope – to the world's atmosphere and land surfaces. For example, snowlines would retreat slightly, exposing more of the Earth's dark surface and enabling more sunlight to be absorbed, pushing the warming beyond the 1.1°C that we initially calculated.

This is an example of a positive feedback on climate. People sometimes think that positive feedback must lead to a runaway or "snowball" effect, but in fact this does not occur unless the feedback is very strong. In the snowline example, warming will eventually stop when the extra emission of infrared radiation has overtaken the extra absorbed sunlight – a warming in the neighbourhood of 1.3°C or so.

Many other feedbacks are possible, and some remain impossible to calculate



An image showing the infrared energy emitted to space by water vapour in the atmosphere, taken by the Geostationary Meteorological Satellite (GMS) on 7 February 2009, near the time of the Victorian bushfires. Dark areas show regions of thick high cloud cover and high water vapour where little infrared energy is emitted to space; light areas show the opposite. Note the very dry air that has recently passed over south-eastern Australia associated with a weather system over the Tasman Sea. Data for this image courtesy of J. McGregor/MetVUW

based on current science. There is one feedback, however, that we think we can calculate and is stronger than all others known. It is due to water vapour.

The word "vapour" means a condensible gas. Gaseous water condenses out of the air when it is cooled sufficiently; the more the air is cooled, the more condensation is formed and the less vapour is left. On a humid summer day in Queensland, the air can be as much as 2% water vapour by weight, but on a Tasmanian winter night humidity could not get anywhere near that high without most of the vapour immediately condensing out.

Unfortunately, carbon dioxide is not a vapour. It does not condense, at least not at temperatures you'll find on Earth outside of a cryogenic laboratory. Essentially all the carbon dioxide we emit either stays in the atmosphere or seeps into soils, oceans or plants for tens of thousands of years until chemical reactions gradually lock the carbon up in newly formed minerals at the bottom of the ocean.

The fact that gaseous water is a vapour means two things. First, human emissions of the stuff (which are at least as prodigious as our emissions of carbon) hardly have any effect on the humidity of the atmosphere because the extra water vapour rains out so soon.

The best one could try to do is emit the moisture in a desert (this actually is happening in regions of heavy agricultural irrigation and does produce measurable increases in humidity near the irrigation). But even then, winds carry the air within a week or so to some place where it is raining.

Even more importantly, it is impossible for the humidity to get lofted more than a couple of kilometres above the Earth's surface without the condensation process resetting the humidity to an amount determined entirely by the temperature, totally independent of its initial humidity.

It turns out that nearly all of water vapour's greenhouse effect comes from vapour at high altitudes. Emitting it near the ground is a bit like pouring water into a bathtub that is already overflowing at one end; the water level may rise slightly but the main result is to increase the rate of overflowing onto the floor (analogous to rainfall). By contrast, carbon emissions go into a bathtub with sides that are miles high.

The second implication of water's vapoury nature is that the bathtub walls, to continue with this analogy, grow taller with rising temperature. Warmer temperatures allow more vapour to accumulate before condensation begins.

This is no small thing: the amount of water vapour increases by 6–18% per degree Celcius (depending on the temperature to start with). This means that a warming of less than 10°C can double the amount of water vapour in the air.

If water vapour amounts increase with rising temperatures at the rate expected from this simple argument, the positive feedback from this would change our global warming to nearly 3°C for a putative doubling of carbon dioxide. That means that over half of global warming is not due to carbon dioxide directly, but to water vapour! Of course, the carbon dioxide is what sets the whole process off, but the same feedback would occur if something else drove a climate change.

Some of the other climate forcings to consider are changes in solar luminosity or radius, the orientation of the Earth's axis of rotation, the land surface (due, for example, to forest clearing), air pollution, and changes in the amounts of other greenhouse gases like methane. All of these have played some role in driving past climate changes but none appear to be on the move now at anything like the pace of forcing by carbon dioxide.

Whether water vapour feedback will really occur in the expected way has been questioned occasionally over the years. For example, one hypothesis that was put forward was that in a warmer climate the increased height of storms would take water vapour further from key dry regions and reduce the feedback. Another proposal was that increased water vapour near the ground – where it exerts little greenhouse effect – would lead to larger cloud and rain droplets and that this, paradoxically, would ease the rainout of water and actually reduce the delivery of vapour to the key regions further aloft.

If these proposals sound a bit unconvincing, they didn't convince most scientists either – but they still attracted a great deal of attention. Most places in our atmosphere are not raining, so water added there won't immediately rain out. As I've already argued, it doesn't seem possible for human emissions to get into these nooks and crannies, but a certain amount of water vapour is naturally delivered there by atmospheric motions. If, somehow, this natural delivery were to decrease in a warmer climate, as in the above hypotheses, this would weaken the feedback (or the reverse if delivery increased).

It is not possible to absolutely prove one way or the other whether these sorts of things might happen, or exactly how water vapour will change in a warmer climate, until we learn the hard way and experience much more warming. Environmental sciences do not permit true "controlled experiments" where we warm a planet in the laboratory, keeping everything else constant, and see what happens. All we can do is observe the one planet we have.

It turns out that nearly all of water vapour's greenhouse effect comes from vapour at high altitudes.

However, a lot of work (some by this author) has gone into understanding the principles that determine how water vapour is cycled through the atmosphere. This understanding now leaves very little room for hypotheses like those suggested above: the global transport just isn't affected much by things such as changes in storm height and rain formation.

Furthermore, we have now observed many natural temperature fluctuations, including seasonal changes in humidity, changes after volcanic eruptions, trends over the past 30 years, and changes during El Niño events. So far, all of these show water vapour changing at more or less the rate we always expected. This has led nearly all scientists to accept that this feedback is real and will accelerate global warming the same way it behaves for all the other wiggles and wobbles of the climate system that we see happening, unless some evidence emerges to the contrary.

There are, of course, all sorts of other questions about climate change. How will it affect rainfall, especially in southern parts of Australia? How strong are other feedbacks besides the ones due to water vapour and snow? How quickly will sea levels rise? How easily could people adapt to all of these changes?

These are the questions to which climate scientists must devote their attention if we are to anticipate what the 21st and 22nd centuries on Earth would look like based on current trends before it is too late to change them. The answers will, to a large extent, determine how hard the nations of the world are willing to work to reduce today's emissions and tomorrow's warming.

Steven Sherwood is Professor of Climate Sciences at the University of New South Wales.