Explaining how the water vapor greenhouse effect works

What The Science Says:
Increased CO_2 makes more water vapor, a greenhouse gas which amplifies warming

Climate Myth: Water vapor is the most powerful greenhouse gas
"Water vapour is the most important greenhouse gas. This is part of the difficulty with the public and the media in understanding that 95% of greenhouse gases are water vapour. The public understand it, in that if you get a fall evening or spring evening and the sky is clear the heat will escape and the temperature will drop and you get frost. If there is a cloud cover, the heat is trapped by water vapour as a greenhouse gas and the temperature stays quite warm. If you go to In Salah in southern Algeria, they recorded at one point a daytime or noon high of 52 degrees Celsius – by midnight that night it was -3.6 degree Celsius. […] That was caused because there is no, or very little, water vapour in the atmosphere and it is a demonstration of water vapour as the most important greenhouse gas." (Tim Ball)

At a glance

If you hang a load of wet washing on the line on a warm, sunny day and come back later, you can expect it to be dryer. What has happened? The water has changed its form from a liquid to a gas. It has left your jeans and T-shirts for the air surrounding them. The term for this gas is water vapour.

Water vapour is a common if minor part of the atmosphere. Unlike CO_2 though, the amount varies an awful lot from one part of the globe to another and through time. Let's introduce two related terms here: 'non-condensable' and 'condensable'. They set out a critical difference between the two greenhouse gases, CO_2 and water vapour.

Carbon dioxide boils at -78.5o C, thankfully an uncommon temperature on Earth. That means it's always present in the air as a gas. Water is in comparison multitalented: it can exist as vapour, liquid and solid. Condensed liquid water forms the tiny droplets that make up clouds at low and mid-levels. At height, where it is colder, the place of liquid droplets is taken by tiny ice-crystals. If either droplets or crystals clump together enough, then rain, snow or hail fall back to the surface. This process is constantly going on all around the planet all of the time. That's because, unlike CO_2, water vapour is condensable.

CO_2 is non-condensable and that means its concentration is remarkably similar throughout the atmosphere. It has a regular seasonal wobble thanks to photosynthetic plants - and it has an upward slope caused by our emissions, but it doesn't take part in weather as such.

Although water vapour is a greenhouse gas, its influence on temperature varies all the time, because it's always coming and going. That's why deserts get very hot by day thanks to the Sun's heat with a bit of help from the greenhouse effect but can go sub-zero at night. Deserts are dry places, so the water vapour contribution to the greenhouse effect is minimal. Because clear nights are common in dry desert areas, the ground can radiate heat freely to the atmosphere and cool quickly after dark.

On the other hand, the warming oceans are a colossal source of water vapour. You may have heard the term, 'atmospheric river' on the news. Moist air blows in off the ocean like a high altitude conveyor-belt, meets the land and rises over the hills. It's colder at height so the air cools as it rises.

Now for the important bit: for every degree Celsius increase in air temperature, that air can carry another 7% of water vapour. This arrangement works both ways so if air is cooled it sheds moisture as rain. Atmospheric

rivers make the news when such moisture-conveyors remain in place for long enough to dump flooding rainfalls. The floods spread down river systems, causing variable havoc on their way back into the sea.

Atmospheric rivers are a good if damaging illustration of how quickly water is cycled in and out of our atmosphere. Carbon dioxide on the other hand just stays up there, inhibiting the flow of heat energy from Earth's surface to space. The more CO_2, the stronger that effect.

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Further details

When those who deny human-caused global warming use this argument, they are trying to imply that an increase in CO_2 isn't a major problem. If CO_2 isn't as potent a greenhouse gas as water vapour, which there's already a lot of, adding a little more CO_2 couldn't be that bad, they insist.

What this argument misses is the critical fact that water vapour in air creates what scientists call a 'positive feedback loop'. That means it amplifies temperature increases, making them significantly larger than they would be otherwise.

How does this work? The amount of water vapour in the atmosphere has a direct relation to the temperature in any given region and the availability of water for evaporation. Heard the weather-saying, "it's too cold to snow"? There's more than a grain of truth in that; very cold air has a low capacity for moisture.

But if you increase the temperature of the air, more water is able to evaporate, becoming vapour. There's a formula for this, the figure being 7% more moisture capacity for every degree Celsius of warming. All you then need is a source of water for evaporation and they are widespread - the oceans, for example.

So when something else causes a temperature increase, such as extra CO_2 emissions from fossil fuel burning, more water can evaporate. Then, since water vapour is a greenhouse gas, this additional moisture causes the temperature to go up even further. That's the positive feedback loop.

How much does water vapour amplify warming? Studies show that water vapour feedback roughly doubles the amount of warming caused by CO_2. So if there is a 1°C upward temperature change caused by CO_2, the water vapour will cause the temperature to go up another 1°C. When other demonstrable feedback loops are included, and there are quite a few of them, the total warming from a 1°C change caused by CO_2 is as much as 3°C.

The other factor to consider is that water evaporates from the land and sea and falls as rain, hail or snow all the time, with run-off or meltwater returning to the sea. Thus the amount of water vapour held in the atmosphere varies greatly in just hours and days. It's constantly cycling in and out through the prevailing weather in any given location. So even though water vapour is the dominant greenhouse gas in terms of quantity, it has what we call a short 'atmospheric residence time' due to that constant cycling in and out.

On the other hand, CO_2 doesn't take an active part in the weather. It does hitch a lift on it by being slowly removed from the air as weak solutions of carbonic acid in rainwater. These solutions are key weathering agents, affecting rocks on geological time-scales. Weathering is a key part of the slow carbon cycle, with the emphasis on slow: CO_2 thus stays in our atmosphere for years and even centuries. It has a long atmospheric residence time. Even a small additional amount of CO_2 thus has a greater long-term effect - and in our case that additional amount is far from small.

To summarize: what deniers are ignoring when they say that water vapour is the dominant greenhouse gas, is that the water vapour feedback loop actually amplifies temperature changes caused by CO_2.

When skeptics use this argument, they are trying to imply that an increase in CO_2 isn't a major problem. If CO_2 isn't as powerful as water vapor, which there's already a lot of, adding a little more CO_2 couldn't be that bad, right? What this argument misses is the fact that water vapor creates what scientists call a 'positive feedback loop' in the atmosphere — making any temperature changes larger than they would be otherwise.

How does this work? The amount of water vapor in the atmosphere exists in direct relation to the temperature. If you increase the temperature, more water evaporates and becomes vapor, and vice versa. So when something else causes a temperature increase (such as extra CO_2 from fossil fuels), more water evaporates. Then, since water vapor is a greenhouse gas, this additional water vapor causes the temperature to go up even further—a positive feedback.

How much does water vapor amplify CO_2 warming? Studies show that water vapor feedback roughly doubles the amount of warming caused by CO_2. So if there is a 1°C change caused by CO_2, the water vapor will cause the temperature to go up another 1°C. When other feedback loops are included, the total warming from a potential 1°C change caused by CO_2 is, in reality, as much as 3°C.

The other factor to consider is that water is evaporated from the land and sea and falls as rain or snow all the time. Thus the amount held in the atmosphere as water vapour varies greatly in just hours and days as result of the prevailing weather in any location. So even though water vapour is the greatest greenhouse gas, it is relatively short-lived. On the other hand, CO_2 is removed from the air by natural geological-scale processes and these take a long time to work. Consequently CO_2 stays in our atmosphere for years and even centuries. A small additional amount has a much more long-term effect.

So skeptics are right in saying that water vapor *is* the dominant greenhouse gas. What they don't mention is that the water vapor feedback loop actually makes temperature changes caused by CO_2 even bigger.

Skeptical Science explains the science of global warming and examines climate misinformation through the lens of peer-reviewed research. The website won the Australian Museum 2011 Eureka Prize for the Advancement of Climate Change Knowledge. Members of the Skeptical Science team have authored peer-reviewed papers, a college textbook on climate change and the book Climate Change Denial: Heads in the Sand. Skeptical Science content has been used in university courses, textbooks, government reports on climate change, television documentaries and numerous books.