The Water Vapor Feedback

Zeke Hausfather

Water vapor is one of the most important elements of the climate system. A greenhouse gas, like carbon dioxide, it represents around 80 percent of total greenhouse gas mass in the atmosphere and 90 percent of greenhouse gas volume.

Water vapor and clouds account for 66 to 85 percent of the greenhouse effect, compared to a range of 9 to 26 percent for CO_2. So why all the attention on carbon dioxide and its ilk? Is water vapor the real culprit causing global warming?

The answer is that water vapor is indeed responsible for a major portion of Earth's warming over the past century and for projected future warming. However, water vapor is not the cause of this warming. This is a critical, if subtle, distinction between the role of greenhouse gases as either forcings or feedbacks. In this case, anthropogenic emissions of CO_2, methane, and other gases are warming the Earth. This rising average temperature increases evaporation rates and atmospheric water vapor concentrations. Those, in turn, result in additional warming.

The primary reasons why water vapor cannot be a cause of climate change are its short atmospheric residence time and a basic physical limitation on the quantity of water vapor in the atmosphere for any given temperature (its saturation vapor pressure). The addition of a large amount of water vapor to the troposphere would have little effect on global temperatures in the short term due to the thermal inertia of the climate system. The Earth's thermal inertia, largely due to the enormous amount of water covering two thirds the planet's surface, is the primary reason why half the Earth does not freeze over every night and bake every day. As a result, different areas warm over the course of years (for land surface temperatures), decades (for ocean surface temperatures), and even centuries (for deep ocean temperatures and ice sheets).

For the troposphere to sustain higher absolute humidity requires an increase in air temperature. Water vapor cannot itself catalyze temperature increases in the short time (estimated at around 10 days) that a discrete water vapor influx would remain before precipitating out. A sustained increase in tropospheric water vapor requires a strong external forcing to provide the initial temperature increase.

In general, the amount of water vapor in the troposphere does not vary significantly over time so long as temperatures remain stable. However, if some external forcing causes tropospheric temperatures to increase, there will be a water vapor feedback. Warmer air can sustain a higher absolute humidity than cooler air. Furthermore, warmer temperatures tend to (but do not always) increase evaporation rates, leading to a higher concentration of atmospheric water vapor. This feedback acts in a number of different and at times contradictory ways.

Water vapor is a greenhouse gas, and sustained additional water vapor concentrations (resulting from higher average temperatures) will trap additional heat and result in additional warming. Increasing temperatures also influence cloud formation, though the relationship is complex and humidity is but one of many contributing factors. Clouds both trap heat below them, heating the Earth, and increase the reflectivity of the Earth (the albedo) by reflecting light off their white surfaces, cooling the Earth. There remains considerable uncertainty regarding the magnitude of cloud feedbacks, though many researchers believe that the net radiative forcing is either neutral or slightly positive.

Image

Range of estimated magnitudes of major climate feedbacks from the most recent IPCC report and Colman 2003. Figure taken from Soden and Held 2006 (pdf) via Realclimate.

Unlike water vapor, carbon dioxide, methane, and nitrous oxide are long-lived greenhouse gases. Carbon dioxide remains in the atmosphere for about 100 years (though this is somewhat of a simplification, as some is removed quickly, some stays for around a century, and some remains almost indefinitely). Methane stays in the atmosphere for a dozen years on average before decomposing into carbon dioxide and water vapor. Nitrous oxide remains around for over a century.

These long-lived greenhouse gases produce sustained warming, which drives the water vapor feedback. If concentrations of greenhouse gases are reduced, the planet will cool and the water vapor feedback will work the opposite way: lower temperatures lead to lower atmospheric water vapor concentrations, further cooling the Earth. The short residence time and relatively constant magnitude of evaporation as a function of temperature mean that water vapor will always follow, not lead, changes in long-lived greenhouse gases.

Climate scientists can quantify the effect of the water vapor feedback on the climate system, as shown by frequently modeled effects of doubling CO_2. In the absence of a water vapor feedback, doubled CO_2 would increase global temperatures by around 1 to 1.2 degrees C (1.8 to 2.2 degrees F). However, the additional water vapor in the atmosphere triggered by this initial warming will result in roughly 1.6 degrees C (2.9 degrees F) more warming, and positive feedbacks caused by changes in cloud formation add around 0.7 degrees C more (1.3 degrees F). This cloud feedback varies significantly between models, ranging from 0.3 to 1.1 degrees C (0.5 to 2 degrees F). See the IPCC AR4 WG1 chapter 8.6.3 (pdf) for a more detailed discussion on uncertainties regarding cloud forcings.

Climate scientists can also verify the effects of the water vapor feedback by examining the response of water vapor to a global decrease in temperatures after a major volcanic eruption. After Mount Pinatubo erupted in 1992, for example, water vapor concentrations decreased within the range predicted by the model and amplified the cooling by 60 percent more than would have occurred as a result of the sulphate aerosol emissions alone.

Claims that water vapor is the “dominant” driver of recently observed climate change are spurious at best. While uncertainties in the magnitude of water vapor feedbacks are one of the key areas concerning climate change, none of this research casts any doubt on the role of carbon dioxide and other anthropogenic greenhouse gases as the initial forcings behind our current climate perturbation.

Understanding Forcing and Feedback

Understanding the different factors that affect the earth’s climate requires distinguishing between those that are forcings, which create an initial change in the climate, and those which are feedbacks, acting to amplify initial forcings.

For example, warming temperatures can increase the rate of sea ice melt. When sea ice melts, it exposes the darker waters beneath. Dark seawater absorbs more incoming solar radiation than sea ice, further warming the water and speeding ice melt. It is clear in this case that ice-albedo interactions are a feedback, rather than a forcing, and respond to an initial perturbation of increased temperatures.

Similarly, water vapor serves as a feedback to temperature changes catalyzed by anthropogenic greenhouse gas emissions. Water vapor itself cannot force changes in the climate, due to its short atmospheric lifetime, but atmospheric water vapor concentrations respond to and amplify temperature changes. Even carbon dioxide and methane have acted as feedbacks to changes in temperature caused by shifts in the Earth's orbit, as discussed in our earlier article on CO2 as a feedback and forcing.

Editor's Note: This posting revises a posting on this subject initially posted on January 31, 2008, as a result of expert input provided by a handful of highly respected climate scientists who identified shortcomings in the original piece. We are grateful for their input.

Filed under: climate change, clouds, feedbacks, forcings, greenhouse gases, water vapor, Zeke Hausfather