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## Steamy Relationships: How Atmospheric Water Vapor Amplifies Earth's Greenhouse Effect

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Credit: John Fowler on Unsplash

Water vapor is Earth's most abundant greenhouse gas. It's responsible for about half of Earth's greenhouse effect — the process that occurs when gases in Earth's atmosphere trap the Sun's heat. Greenhouse gases keep our planet livable. Without them, Earth's surface temperature would be about 59 degrees Fahrenheit (33 degrees Celsius) colder. Water vapor is also a key part of Earth's water cycle: the path that all water follows as it moves around Earth's atmosphere, land, and ocean as liquid water, solid ice, and gaseous water vapor.



A simplified animation of the greenhouse effect.

Since the late 1800s, global average surface temperatures have increased by about 2 degrees Fahrenheit (1.1 degrees Celsius). Data from satellites, weather balloons, and ground measurements confirm the amount of atmospheric water vapor is increasing as the climate warms. (The United Nations' Intergovernmental Panel on Climate Change Sixth Assessment Report states total atmospheric water vapor is increasing 1 to 2% per decade.) For every degree Celsius

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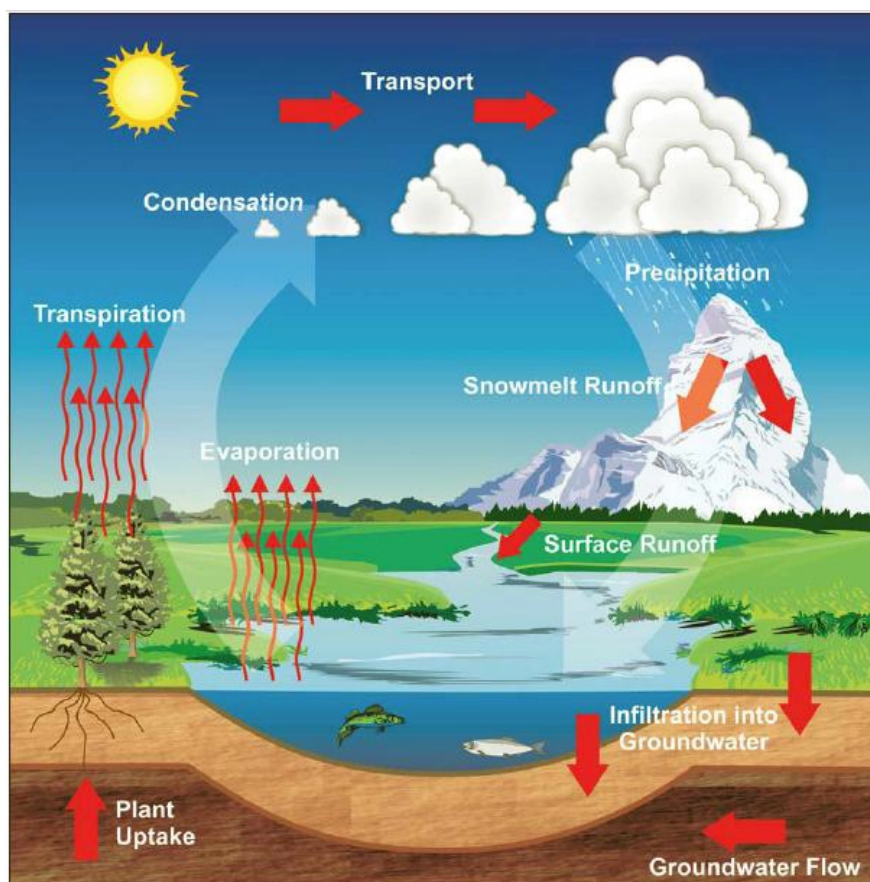
that Earth's atmospheric temperature rises, the amount of water vapor in the atmosphere can increase by about 7%, according to the laws of thermodynamics.

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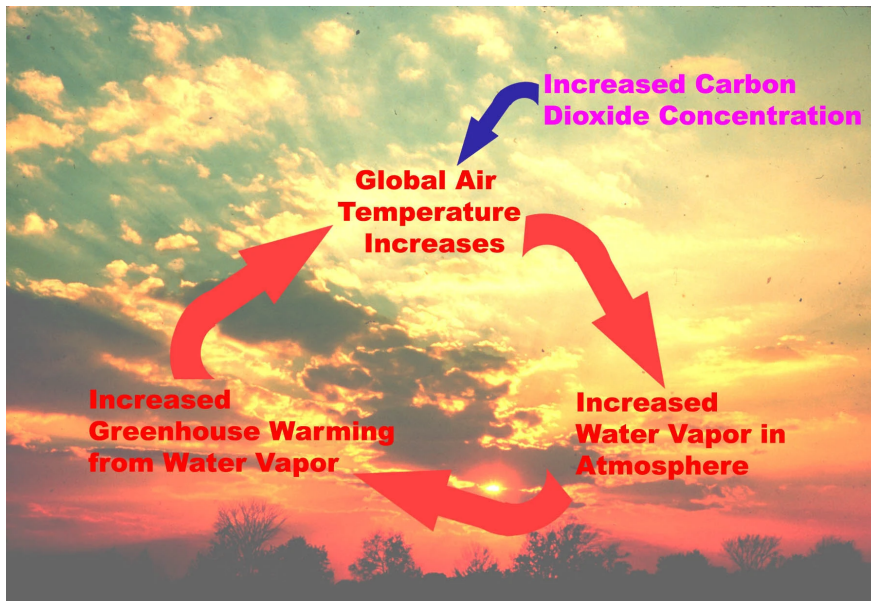
Some people mistakenly believe water vapor is the main driver of Earth's current warming. But increased water vapor doesn't *cause* global warming. Instead, it's a consequence of it. Increased water vapor in the atmosphere amplifies the warming caused by other greenhouse gases.



Earth's water cycle. Credit: NASA

It works like this: As greenhouse gases like carbon dioxide and methane increase, Earth's temperature rises in response. This increases evaporation from both water and land areas. Because warmer air holds more moisture, its concentration of water vapor increases. Specifically, this happens because water vapor does not condense and

precipitate out of the atmosphere as easily at higher temperatures. The water vapor then absorbs heat radiated from Earth and prevents it from escaping out to space. This further warms the atmosphere, resulting in even more water vapor in the atmosphere. This is what scientists call a "positive feedback loop." Scientists estimate this effect more than doubles the warming that would happen due to increasing carbon dioxide alone.



This diagram shows the mechanisms behind a positive water vapor feedback loop. Increases in carbon dioxide, a greenhouse gas, cause a rise in global air temperatures. Due to increased evaporation and since warmer air holds more water, water vapor levels in the atmosphere rise, which further increases greenhouse warming. The cycle reinforces itself. The background is a sunset through altocumulus clouds. Credit: NASA and NOAA Historic NWS Collection

## A Different Breed of Greenhouse Gas

The greenhouse gases in the dry air in Earth's atmosphere include carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbons. While making up around 0.05% of Earth's total atmosphere, they play major roles in trapping Earth's radiant heat from the Sun and keeping it from escaping into space. Each is driven directly by human activities.

All five of these greenhouse gases are **non-condensable**. Non-condensable gases can't be changed into liquid at the very cold temperatures present at the top of Earth's troposphere, where it meets the stratosphere. As atmospheric temperatures change, the concentration of non-condensable gases remains stable.



But water vapor is a different animal. It's **condensable** – it can be changed from a gas into a liquid. Its concentration depends on the temperature of the atmosphere. This makes water vapor the only greenhouse gas whose concentration increases *because* the atmosphere is warming, and causes it to warm even more.

If non-condensable gases weren't increasing, the amount of atmospheric water vapor would be unchanged from its pre-industrial revolution levels.

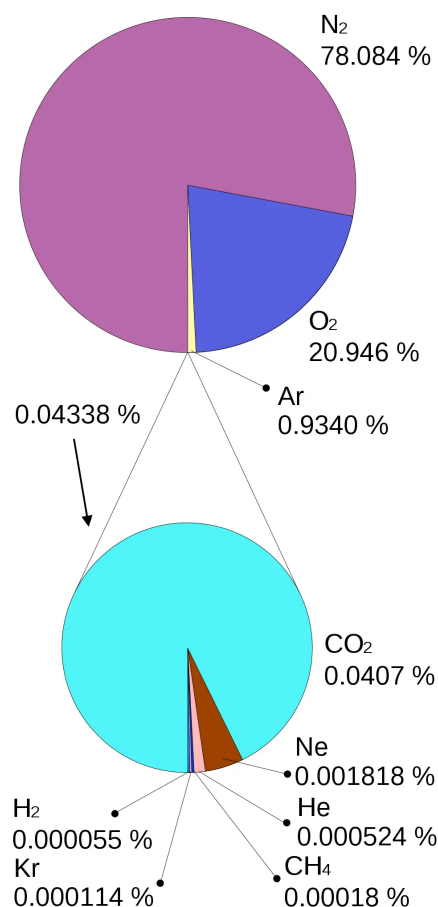
## Carbon Dioxide Is Still King

Carbon dioxide is responsible for a third of the total warming of

Earth's climate due to human-produced greenhouse gases.

Small increases in its concentration have major effects. A key reason is the length of time carbon dioxide remains in the atmosphere.

Methane, carbon dioxide, and chlorofluorocarbons don't condense, and they aren't particularly chemically reactive or easily broken down by light in the troposphere. For these reasons, they remain in the atmosphere for anywhere from years to centuries or even longer, depending on the gas.



Composition of Earth's atmosphere by molecular count, excluding water vapor. Lower pie represents trace gases that together compose about 0.0434% of the atmosphere (0.0442% at August 2021 concentrations). Numbers are mainly from 2000, with CO<sub>2</sub> and methane from 2019, and do not represent any single source. Credit: Public domain

## Major Long-Lived Greenhouse Gases and Their Characteristics

Greenhouse gas	How it's produced	Average lifetime in the atmosphere	100-year global warming potential
Carbon dioxide	Emitted primarily through the burning of fossil fuels (oil, natural gas, and coal), solid waste, and trees and wood products. Changes in land use also play a role. Deforestation and soil degradation add carbon dioxide to the atmosphere, while forest regrowth takes it out of the atmosphere.	see below*	1
Methane	Emitted during the production and transport of oil and natural gas as well as coal. Methane emissions also result from livestock and agricultural practices and from the anaerobic decay of organic waste in municipal solid waste landfills.	12.4 years**	28–36
Nitrous oxide	Emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.	121 years**	265–298
Fluorinated gases	A group of gases that contain fluorine, including hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride, among other chemicals. These gases are emitted from a variety of industrial processes and commercial and household uses and do not occur naturally. Sometimes used as substitutes for ozone-depleting substances such as chlorofluorocarbons.	A few weeks to thousands of years	Varies (the highest is sulfur hexafluoride at 23,500)

This table shows 100-year global warming potentials, which describe the effects that occur over a period of 100 years after a particular mass of a gas is emitted. Global warming potentials and lifetimes come from Table 8.A.1 of the Intergovernmental Panel on Climate Change’s Fifth Assessment Report, Working Group I contribution.

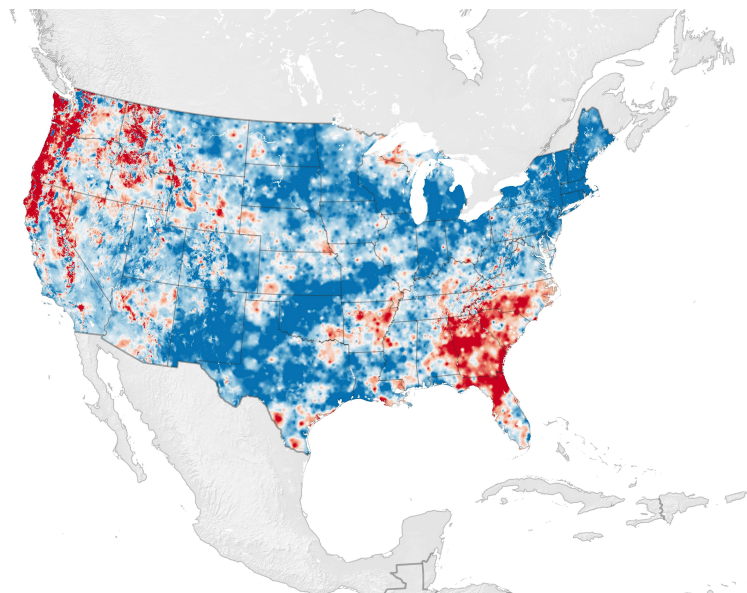
\* Carbon dioxide’s lifetime cannot be represented with a single value because the gas is not destroyed over time, but instead moves among different parts of the ocean–atmosphere–land system. Some of the excess carbon dioxide is absorbed quickly (for example, by the ocean surface), but some will remain in the atmosphere for thousands of years, due in part to the very slow process by which carbon is transferred to ocean sediments.

\*\* The lifetimes shown for methane and nitrous oxide are perturbation lifetimes, which have been used to calculate the global warming potentials shown here. Credit: EPA

In contrast, a molecule of water vapor stays in the atmosphere just nine days, on average. It then gets recycled as rain or snow. Its amounts don’t accumulate, despite its

much larger relative quantities.

“Carbon dioxide and other non-condensable greenhouse gases act as control knobs for the climate,” said Andrew Dessler, a professor of Atmospheric Sciences at Texas A&M University in College Station. “As humans add carbon dioxide to the atmosphere, small changes in climate are amplified by changes in water vapor. This makes carbon dioxide a much more potent greenhouse gas than it would be on a planet without water vapor.”



Scientists from the U.S. Geological Survey (USGS) showed that there has been an increase in the flow between the various stages of the water cycle over most the U.S. in the past seven decades. The rates of ocean evaporation, terrestrial evapotranspiration, and precipitation have been increasing. In other words, water has been moving more quickly and intensely through the various stages.

This map shows where the water cycle has been intensifying or weakening across the continental U.S. from 1945-1974 to 1985-2014. Areas in blue show where the water cycle has been speeding up—moving through the various stages faster or with more volume. Red areas have seen declines in precipitation and evapotranspiration and experienced less intense or slower cycles. Larger intensity values indicate more water was cycling in that region, primarily due to increased precipitation. Credit: NASA Earth Observatory image by Lauren Dauphin, using data from Huntington, Thomas, et al. (2018).

## Wreaking Havoc on the Global Water Cycle

Increases in atmospheric water vapor also amplify the global water cycle. They contribute to making wet regions wetter and dry regions drier. The more water vapor that air contains,

the more energy it holds. This energy fuels intense storms, particularly over land. This results in more extreme weather events.



Flooding in Roman Forest, Texas, on September 19, 2019, from Tropical Storm Imelda. Credit: Photo by Jill Carlson, used under Creative Commons license.

But more evaporation from the land also dries soils out. When water from intense storms falls on hard, dry ground, it runs off into rivers and streams instead of dampening soils. This increases the risk of drought.

In short, when atmospheric water vapor meets increased levels of other greenhouse gases, its impacts on Earth's climate are substantial.

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