New study shows vegetation controls the future of the water cycle

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View from Guanica Biosphere Preserve, Puerto Rico. Credit: Kevin Krajick/Earth Institute

Predicting how increasing atmospheric CO_2 will affect the hydrologic cycle, from extreme weather forecasts to long-term projections on agriculture and water resources, is critical both to daily life and to the future of the planet. It is commonly thought that hydrologic change is driven by precipitation and radiation changes caused by climate change, and that as the land surface adjusts, rising temperatures and lower precipitation will make the planet drier.

Columbia Engineering researchers have found that, to the contrary, vegetation plays a dominant role in Earth's water cycle and that plants will regulate and dominate the increasing stress placed on continental water resources in the future. The study, led by Pierre Gentine, associate professor of earth and environmental engineering at Columbia Engineering and at the Earth Institute, is published today in the *Proceedings of the National Academy of Sciences*.

"Our finding that vegetation plays a key role future in terrestrial hydrologic response and water stress is of utmost importance to properly predict future dryness and water resources," says Gentine, whose research focuses on the relationship between hydrology and atmospheric science, land/atmosphere interaction, and its impact on climate change. "This could be a real game-changer for understanding changes in continental water stress going into the future."

Gentine's team is the first to isolate the response of vegetation from the global warming total complex response, which includes such variables for the water cycle as evapotranspiration (the water evaporated from the surface, both from plants and bare soil) soil moisture, and runoff. By disentangling the vegetation response to the global rise of CO2 from the atmospheric (greenhouse gas) response, they were able to quantify it and found that the vegetation actually is the dominant factor explaining future water stress.

"Plants are really the thermostat of the world," says Léo Lemordant, Gentine's PhD student and lead author of the paper. "They're at the center of the water, energy, and carbon cycles. As they take up carbon from the atmosphere to thrive, they release water that they take from the soils. Doing that, they also cool off the surface, controlling the temperature that we all feel. Now we know that mainly plants?not simply precipitation or temperature?will tell us whether we will live a drier or wetter world."

For the study, Gentine and Lemordant took Earth system models with decoupled surface (vegetation physiology) and atmospheric (radiative) CO_2 responses and used a multi-model statistical analysis from CMIP5, the most current set of coordinated climate model experiments set up as an international cooperation project for the International Panel on Climate Change. They used three runs: a control run with CO_2 at the leaf level and in the atmosphere, a run where only the vegetation responds to a rise in CO_2, and a run where only the atmosphere responds to the CO_2 increase.

Their results showed that changes in key water-stress variables are strongly modified by vegetation physiological effects in response to increased CO_2 at the leaf level, illustrating how deeply the physiological effects due to increasing atmospheric CO_2 impact the water cycle. The CO_2 physiological response has a dominant role in evapotranspiration and has a major effect on long-term runoff and soil moisture compared to radiative or precipitation changes due to increased atmospheric CO_2.

This study highlights the key role of vegetation in controlling future terrestrial hydrologic response and emphasizes that the continental carbon and water cycles are intimately coupled over land and must be studied as an interconnected system. It also emphasizes that hydrologists should collaborate with ecologists and climate scientists to better predict future water resources.

"The biosphere physiological effects and related biosphere-atmosphere interactions are key to predicting future continental water stress as represented by evapotranspiration, long-term runoff, soil moisture, or leaf area index," Gentine says. "In turn, vegetation water stress largely regulates land carbon uptake, further emphasizing how tightly the future carbon and water cycles are coupled so that they cannot be evaluated in isolation."

Gentine and Lemordant plan to further untangle the various physiological effects. "The vegetation response is itself indeed complex," Gentine says, "and we want to decompose the impact of biomass growth vs. stomatal response. There are also implications for extreme heatwave events we are currently working on."

"This work highlights an important need to further study how plants will respond to rising atmospheric carbon dioxide," says James Randerson, professor of earth system science, University of California, Irvine, who was not involved with the study. "Plants can have a big effect on the climate of land, and we need to better understand the ways that they will respond to carbon dioxide, warming, and other forms of global change."

More information: Léo Lemordant el al., "Critical impact of vegetation physiology on the continental hydrologic cycle in response to increasing CO2," *PNAS* (2018). www.pnas.org/cgi/doi/10.1073/pnas.1720712115

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