New feedback phenomenon found to drive increasing drought and aridity

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A new Columbia Engineering study indicates that the world will experience more frequent and more extreme drought and aridity than currently experienced in the coming century, exacerbated by both climate change and land-atmosphere processes. The researchers demonstrate that concurrent soil drought and atmospheric aridity are largely driven by a series of land-atmosphere processes and feedback loops. They also found that land-atmosphere feedbacks would further intensify concurrent soil drought and atmospheric aridity in a warmer climate. The study was published today in *Proceedings of the National Academy of Sciences (PNAS)*.

While earlier studies have looked at how atmospheric and oceanic processes drive climate extremes, the Columbia Engineering team has focused on examining and modeling land-atmosphere processes, especially in setting up concurrent extremes that can be very destructive. Soil drought, represented by very low soil moisture, and atmospheric aridity, represented by very high vapor pressure deficit, a combination of high temperature and low atmospheric humidity, are the two main stressors that drive widespread vegetation mortality and reduced terrestrial carbon uptake. Concurrent soil drought and atmospheric aridity is a time period when soil moisture is extremely low and vapor pressure deficit is extremely high.

"Concurrent soil drought and atmospheric aridity have dramatic impacts on natural vegetation, agriculture, industry, and public health," says Pierre Gentine, associate professor of earth and environmental engineering and affiliated with the Earth Institute. "Future intensification of concurrent soil drought and atmospheric aridity would be disastrous for ecosystems and greatly impact all aspects of our lives."

The researchers combined reanalysis datasets and model experiments to identify the main land-atmosphere processes leading to concurrent soil drought and atmospheric aridity, and used climate models and statistical methods to assess how land-atmosphere processes would impact the frequency and intensity of concurrent soil drought and atmospheric aridity in future climate. The challenge they faced was how to isolate the impact of land-atmosphere feedbacks on concurrent drought and aridity. After trying many different methods, they worked with the GLACE-CMIP5 (Global Land Atmosphere Coupling Experiment—Coupled Model Intercomparison Project) scientists at ETH Zurich's Institute for Atmospheric and Climate Science and used their model experiments.

Gentine's group is the first to isolate this phenomenon and were surprised their work produced such dramatic findings.

"Most groups have been focused on assessing concurrent drought and heatwaves, but we are finding stronger coupling between drought and aridity than between drought and heatwaves," says Sha Zhou, the study's lead author and a postdoc working with Gentine. "Concurrent drought and aridity also have a stronger impact on the carbon cycle and so we felt this was a critical point to study."

The team discovered that the feedback of soil drought on the atmosphere is largely responsible for increasing the frequency and intensity of atmospheric aridity. In addition, the soil moisture-precipitation feedback contributes to more frequent extreme low precipitation and soil moisture conditions in most regions. These feedback loops lead to a high probability of concurrent soil drought and extreme aridity. The CMIP5 simulations suggest that land-atmosphere feedbacks will further increase the frequency and intensity of concurrent drought and aridity in the 21st century, with potentially large human and ecological impacts.

The *PNAS* study highlights the importance of soil moisture variability in enabling a series of processes and feedback loops affecting the Earth's near-surface climate.

Says Gentine, "It's critical that we better quantify and evaluate the representation of these processes in our climate models. Accurate model representation of both soil moisture variability and the associated feedbacks is crucial if we are to provide reliable simulations of the frequency, duration, and intensity of compound drought and aridity events and of their changes in a warmer climate. Ultimately, this will help us mitigate future risks associated with these events."

More information: Sha Zhou el al., "Land–atmosphere feedbacks exacerbate concurrent soil drought and atmospheric aridity," *PNAS* (2019). www.pnas.org/cgi/doi/10.1073/pnas.1904955116

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