Extremes in wet, dry spells increasing for South Asian monsoons

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Hervey clouds formed during storm from north-west to south-east, at monsoon, over Salt Lake, Calcutta. Credit: Biswarup Ganguly/Wikipedia

Stanford scientists have identified significant changes in the patterns of extreme wet and dry events that are increasing the risk of drought and flood in central India, one of the most densely populated regions on Earth.

The discoveries, detailed in the April 28 issue of the journal *Nature Climate Change*, are the result of a new collaboration between climate scientists and statisticians that focused on utilizing statistical methods for analyzing rare geophysical events. These new approaches reveal that the intensity of extremely wet spells and the number of extremely dry spells during the South Asian monsoon season have both been increasing in recent decades.

"We are looking at rainfall extremes that only occur at most a few times a year, but can have very large impact," said senior author Noah Diffenbaugh, associate professor of environmental Earth system science and a senior fellow at the Stanford Woods Institute for the Environment. "Having these advanced statistical tests is a huge step forward, and has enabled the discovery of important changes in the observed record."

For the new study, Diffenbaugh and graduate student Deepti Singh collaborated with Bala Rajaratnam, assistant professor of statistics and of environmental Earth system science, and Michael Tsiang, a graduate student in Rajaratnam's research group.

Vital for Indian agriculture

The South Asian summer monsoon is an annual wind-driven weather pattern that is responsible for 85 percent of India's annual precipitation and is vital for the country's agricultural sector. The monsoon season starts in June and lasts through September.

"The monsoon typically starts in southern India and moves across the subcontinent. By mid-July, it's established over the entire subcontinent," said Singh, who is the lead author of the new study.

Singh said that rainfall extremes during the months of the monsoon season can be as important as how much total water is received. For

example, during critical crop growth stages, too many days without rain can reduce yields or lead to crop failure, which can reverberate through India's agriculture-dependent economy. At the same time, short periods of very heavy rainfall can create humanitarian disasters, such as in 2005, when massive flooding killed thousands of people in Mumbai.

Because such extreme events are rare, it can be difficult to study them objectively. For the new study, Diffenbaugh and his team wanted to test whether the pattern of extreme wet and dry "spells" during the monsoon season had changed in recent decades. Wet and dry spells were defined as three or more consecutive days of extremely high or low rainfall, respectively.

The team compared rainfall data gathered by the Indian Meteorological Department and other sources over a 60-year period. They used rigorous statistical methods to compare peak monsoon rainfall patterns during two time periods: from 1951 to 1980, and from 1981 to 2011. The team looked specifically at rainfall during the months of July and August, which is the peak of the South Asian summer monsoon. The analysis focused on central India, which is the core of the monsoon region and has extremely high population densities.

Appropriate statistical tools

The team analyzed the Indian monsoon data using statistical tools that account for so-called spatial and temporal relationships, which are typically ignored in "classical" or "off-the-shelf" statistical tools that were originally designed for use in the fields of biology, medicine and agriculture.

Such "spatial-temporal dependencies" are particularly important when studying temperature, rainfall and other geophysical phenomena that can change over a daily scale, Rajaratnam said. For example, if it rains

today, there's a higher chance that it will rain tomorrow because a storm system is already in place.

"I was intrigued when Noah approached us with the idea of a collaboration, because many studies published on this topic don't use statistical methods that account for spatial-temporal dependencies," said Rajaratnam, who is also an affiliated faculty member at the Stanford Woods Institute for the Environment.

Changing rainfall patterns

When the team members analyzed the Indian monsoon data using their statistical methods, they discovered that although the average total rainfall during the monsoon season has declined, the variability of rainfall during the peak monsoon months has increased. In particular, the researchers observed increases in the intensity of wet spells and in the frequency of dry spells.

"The statistical techniques show that the changes in these characteristics are robust and that these changes are unlikely to happen purely by chance," Singh said.

The team's findings match stories told by Indian farmers in recent decades, said Singh, whose family lives in the region of the country affected by the monsoon.

"My grandfather grew up in a village that is primarily dependent on agriculture, and the farmers that live there say that the monsoon rainfall pattern has changed," she said. "They've noticed over the last decade that rainfall occurs in heavy bursts and comes earlier in the monsoon season, and that the dry spells last longer."

The team also found changes in the atmosphere – such as winds and

moisture –that are likely responsible for the changes in wet and dry spells. Diffenbaugh said that the next step is to investigate what might be causing the changes in the atmosphere.

"There are many predictions that global warming should cause heavier downpours and more frequent dry spells," Diffenbaugh said. "That's what we've found here, but India is a complex region, so we want to be sure before we point the finger at global warming or any other cause."

More information: Paper: dx.doi.org/10.1038/nclimate2208

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