Climate change and snowmelt—turn up the heat, but what about humidity?

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It's said on sticky summer days: "It's not the heat, it's the humidity." That

holds true in the winter too, and could hold the key to the future of snowpack and water resources in the American West.

In a new study published today in *Proceedings of the National Academy of Sciences*, University of Utah professor Paul Brooks and University of Nevada Reno professor Adrian Harpold show that changes in humidity may determine how the contribution of snowpack to streams, lakes and groundwater changes as the climate warms. Surprisingly, cloudy, gray and humid winter days can actually cause the snowpack to warm faster, increasing the likelihood of melt during winter months when the snowpack should be growing, the authors report. In contrast, under clear skies and low humidity the snow can become colder than the air, preserving the snowpack until spring.

Climate change, they say, can tweak winter humidity up in some regions and down in others.

"It means that trends and patterns in humidity will be very important to the future of snow," Harpold says.

Where did the snow go?

Brooks says that researchers have known that a changing climate could have major impacts on snowmelt-derived water resources. "But it has been unclear up to this point," he says, "why some areas seem to be much more sensitive to change while other locations seem resilient."

Researchers have evaluated different mechanisms that could account for declining snowpack in a warming world: earlier onset of snowmelt, a change in melt rates and shifts from snow to rain under certain conditions. But even these explanations didn't apply broadly to environments throughout the West, leading Harpold and Brooks to look at more basic principles of how snow melts.

Go with the heat flow

Scientists know that there are various forms of energy, including sensible heat (which we measure as temperature), radiant energy (like what we feel from the sun), and latent heat. Latent heat is stealthier - it's released and absorbed as water changes phase, for example between ice and liquid water. You experience the power of latent heat on a sweaty summer day. As the sweat on your skin evaporates, it absorbs heat in the transition from liquid water to water vapor, cooling you off in the process.

So how does this apply to snow melting? Snow's brilliant white results from snow crystals reflecting incoming solar radiation. This minimizes energy input to the snow, and also leads to the sunburn so common when skiing on sunny winter days. The molecular structure of snow crystals also emits energy back into the sky on clear nights - which serves to cool the snowpack. Also, snow on dry days can "sublimate," or change directly from a solid to vapor. This process, just like evaporation, absorbs heat and further cools the snow.

"That is one of the reasons skiing in Utah, Colorado, New Mexico or the Eastern Sierra can be so fun!" Brooks says. "The snow stays cold and dry and powdery, while the sun warms us as we ski or sit on a deck and admire the view—especially if we wear dark colors."

Cloudy, humid days reverse the cooling from both radiation and sublimation - cloud cover prevents snow from emitting energy, and condensation of water vapor on the snow releases latent heat, warming the snow. That is why a couple of humid days with temperatures right around freezing result in large melt events and even minor flooding. An extreme case of this can come on foggy days, Brooks says. "We often say 'fog eats snow.'"

Snow in the West

Brooks and Harpold looked at snowpack data from more than 400 locations around the West, from the humid Pacific Northwest to the arid desert southwest. Across that range of environments, they found that both dry and humid environments responded to climate warming with episodes of snowpack loss. In humid areas, though, the episodes were primarily snowmelt, while in dry areas the episodes were dominated by sublimation - direct loss of snow to the atmosphere. And these effects are likely to become more intense with more warming, Harpold says. "We found that relative humidity generally has been both increasing in the Pacific Northwest and decreasing in the desert southwest over the last 30 years, reinforcing the patterns of winter melt in the Pacific Northwest and sublimation in the southwest."

"What we don't know," Brooks says, "is how humidity will change in the areas in between - including the Rocky Mountains and Great Basin."

Up to now, future trends in winter humidity have not been a focus of prediction, Harpold says. "Our work shows this will be a key variable that we will have to predict under climate change." If humidity increases, water managers may be faced with the challenge of storing water for longer periods while mitigating mid-winter flooding. In contrast, a decrease in humidity will further stress already limited water supplies.

"Long-term planning for reservoirs, water storage and water supply systems is also key for water managers," Harpold says. "For example, in the Sierra and Lake Tahoe you may see a yearly pattern of humid air masses moving over the region, so plans should be made with these regional patterns in mind.

"As we reach a tipping point and see our customary water storage system, the snowpack, melting more and earlier in the winter, systems

that rely on snowmelt will need to be reevaluated and modified."

So, watch the snow around town for the remainder of the winter. Watch for the snow that remains in shadows even on warm sunny days. And watch what happens to that same snow during gray days and nights - quickly, though, before it's all gone.

More information: Adrian A. Harpold el al., "Humidity determines snowpack ablation under a warming climate," *PNAS* (2018). www.pnas.org/cgi/doi/10.1073/pnas.1716789115

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