Incorporating snow albedo feedback into downscaled temperature and snow cover projections for the Sierra Nevada

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Summary prepared by the [UCLA Center for Climate Science](#)

Key points

- By 2081–2100, if nothing is done to curb greenhouse gas emissions, average temperatures in the Sierra Nevada are projected to increase by about 7–10 degrees F, depending on the month in question, compared with 1981–2000.
- Warming will be associated with decreases in snow cover in the Sierra Nevada by 2081–2100. For the typical month of April, snow-covered area shrinks by 48%, compared with the typical April in 1981–2000.
- Warming and snow cover loss are greatest under a "business as usual" scenario of greenhouse gas concentrations. Under a "mitigation" scenario, warming and snow cover loss still occur but are less severe.
- A key factor in the severity of warming and snow cover loss is *snow albedo feedback,* a feedback loop in which warming causes snow cover loss, and snow cover loss increases warming. The UCLA study is the most comprehensive study of future climate in the Sierra Nevada to date because it takes into account this feedback loop and considers multiple greenhouse gas scenarios.

Context

Sierra Nevada snowpack is an important source of freshwater for the state of California, acting as a natural reservoir that holds water in frozen form until it gradually melts over spring and summer and flows into manmade reservoirs and conveyance systems. Past studies have shown that in the future, warming due to human emissions of greenhouse gases is expected to shrink the Sierra snowpack. If California is to adapt to these changes, we need a better understanding of the specifics: How much warmer will it get, and just how much snow will we lose overall? How much earlier does snow melt and run off? Do soils dry out faster after snow has melted? Are all elevations and all watersheds affected to the same degree? If we act to reduce greenhouse gas emissions, can we prevent these changes?

Answering these questions requires the help of global climate models, powerful computing tools that simulate the climate system. Global climate models are the best tools we have for projecting future climate, but they are too low in spatial resolution to accurately simulate future climate in topographically complex areas like the Sierra Nevada, where different elevations experience different climatic conditions. There are several methods by which climate scientists can "downscale" global climate model information to create higher-resolution future climate projections. Some of these methods are *dynamical,* meaning they use a regional climate model, a high-resolution cousin of a global climate model, to simulate future climate. Dynamical downscaling is physically realistic but is very expensive, computationally speaking. Some downscaling methods are *statistical,* using mathematical shortcuts to produce higher-resolution projections. Statistical models are computationally cheap and quick to run, but they don't necessarily represent the physical dynamics of local climate.

A physical climate phenomenon that's especially important to represent when you're studying snow is called *snow albedo feedback.* Albedo is a measure of how much sunlight is reflected by a surface. Snow has a high albedo, meaning it reflects a lot more sunlight than it absorbs. Other land surfaces have lower

albedos, meaning they absorb more sunlight than snow. Snow albedo feedback occurs when warming causes snowpack to shrink at its margins. The ground that is uncovered absorbs more sunlight than snow would have, which enhances the warming at that location. The enhanced warming melts more snow, which exposes more sunlight-absorbing ground, which further enhances warming, and so on. In other words, snow albedo feedback is a feedback loop that leads to greater local warming than would be expected from atmospheric warming alone. If a study doesn't account for it, snow loss could be significantly underestimated.

In this study on warming and snow cover changes, UCLA researchers took the first step in answering key questions about the fate of Sierra snowpack, and they did so by using a method that explicitly accounts for snow albedo feedback.

Methods
The UCLA team has developed an innovative approach called *hybrid downscaling,* which combines the strengths of dynamical and statistical downscaling. First, the researchers run a limited number of dynamical simulations that represent the full span of global climate model outcomes, and then they build a statistical model that mimics the dynamical one. The result is set of future climate projections that is both comprehensive and physically credible. The team first used this approach in a first-of-its kind study of climate change in the greater Los Angeles region. Now they are applying it to project future climate in the Sierra Nevada.

In this study, the researchers first created a simulation of the historical climate from 1981 to 2000 at a spatial resolution of 3 kilometers, or about 1.9 miles. Then they projected future climate at 2081–2100 at the same resolution. Future projections represent the full ensemble of latest-generation global climate model output, which underlies the most recent climate change assessment report by the Intergovernmental Panel on Climate Change (IPCC). The team created projections for each of the four different greenhouse gas scenarios used in the latest IPCC assessment, including a scenario that roughly represents the present emissions-reductions goals of the recent Paris climate accord, which we call "mitigation," and a scenario that represents "business as usual."

Findings
The researchers found that by 2081–2100, both warming and loss of snow cover occur in all greenhouse gas scenarios, but to different degrees.

In the "business as usual" scenario, which sees the most severe changes, warming averaged across the entire Sierra ranges from about 7 degrees to more than 10 degrees Fahrenheit, depending on the month. Warming tends to increase as you go up in elevation, with more marked increases at elevations where snow albedo feedback is occurring. Snow albedo feedback's enhancement of warming is particularly severe in the months of May–July, and at some elevations it accounts for more than 3.6 degrees Fahrenheit of additional warming, on top of what would be expected from atmospheric warming alone.

Thanks to warming, snow cover decreases substantially by 2081–2100 under the "business as usual" scenario. For example, the total area covered by snow during the typical April decreases by 48%, compared with 1981–2000.

In the "mitigation" greenhouse gas scenario, warming and snow cover loss still occur but are less severe. For example, in the month of April, average warming ranges from 3.6 to 4.5 degrees Fahrenheit,

depending on the elevation. Snow cover losses under "mitigation" are about half the losses seen under "business as usual."
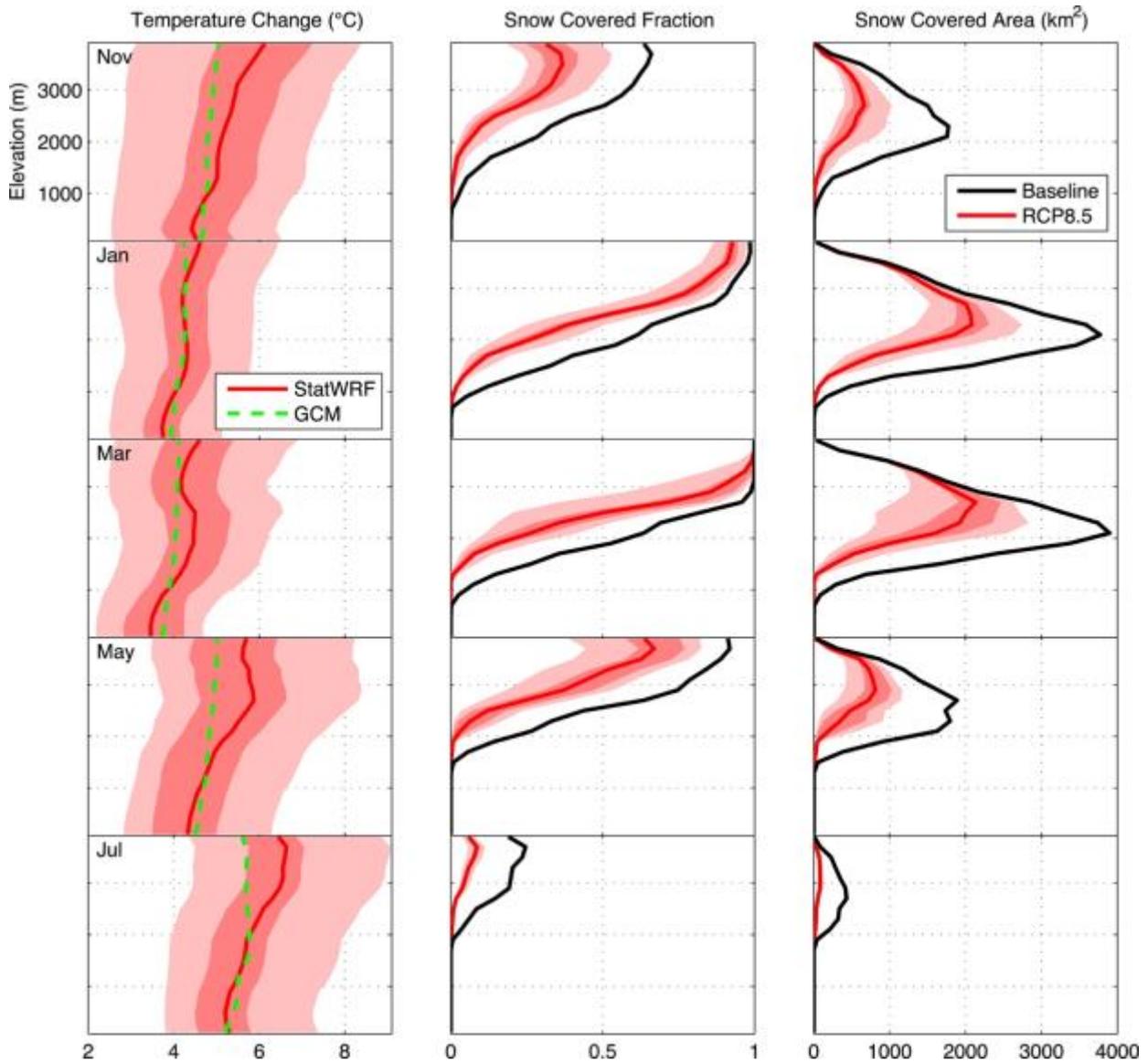
Key figures

Fig 12 shows projected warming (first column), percentage of domain covered by snow (middle column), and total area covered by snow (third column) for various months at 2081–2100, compared with 1981–2000, for the business-as-usual greenhouse gas scenario. Red lines represent the average warming for all global climate models downscaled. The warming "bulges" in the temperature column show where snow-albedo feedback is occurring.

Implications
The projected temperature and snow cover changes have implications for water resources. Snowpack acts as a natural reservoir that gradually melts and recharges manmade reservoirs throughout the

summer. A smaller snowpack would be expected to "run out" of water earlier in the year. (The researchers are currently analyzing snowpack changes in greater detail and will publish a separate study looking at different measures of snowpack health.) Warming and changes in snow also have implications for ecosystems in the Sierra, since species are adapted to cooler, snowier conditions. They could also affect the ski industry in the Sierra. These areas merit further study.

Why this study is different
Other studies have projected future climate and snow loss in the Sierra Nevada, but they were primarily based on statistical downscaling methods that don't incorporate snow albedo feedback. By accounting for this important process, the UCLA team's projections provide greater and more physically credible detail about warming and snow cover loss than ever before.

Next steps
This study is the first in a series investigating many aspects of future climate in the Sierra Nevada. The UCLA team is currently analyzing changes to snowpack, the timing of runoff from snowmelt, and soil moisture, and these studies are forthcoming. These investigations will provide insight into climate change impacts not only on water resources but also on wildfire, ecosystems, and recreation.

Study citation
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