Summary of
"Anthropogenic Warming Impacts on California Snowpack During Drought"
by Neil Berg and Alex Hall

Prepared by the UCLA IoES Center for Climate Science

Key points

- In the "snow years" (November–June) of 2011–2012 through 2014–2015, human-caused warming to date reduced average Sierra Nevada snowpack levels by 25%, compared with a climate model simulation without human-caused warming.
- Middle and low elevations (up to about 8,000 feet) saw even greater reductions, ranging from 26% to 43%.
- In a model simulation of the recent drought under the warming conditions expected at 2081–2100 under a "business as usual" scenario of greenhouse gas emissions, average snowpack was reduced by 85%, compared with what actually occurred in winters of 2011–2012 through 2014–2015. Nearly all snow is lost at elevations below 8,000 feet.
- Loss of snow in drought years will be made worse by climate change no matter which greenhouse gas emissions pathway the world follows.

Context

In recent years, California experienced a severe drought that was by some measures unprecedented in the modern historical record. The severity caused many to wonder whether climate change was at play. Researchers at UCLA and elsewhere have found human-caused climate change was probably not a significant factor in the low precipitation levels the state received. However, researchers have found that human-caused warming does explain why soils were so dry. That's because hotter temperatures increase the rate at which water evaporates from soils and transpires from plants.

Neil Berg and Alex Hall at the UCLA IoES Center for Climate Science wondered whether human-caused warming affected the snowpack in the Sierra Nevada during the drought. Because warming causes a greater share of precipitation to fall as rain instead of snow and snow to melt faster, the authors hypothesized the Sierra Nevada snowpack in the winters of 2011–2012 through 2014–2015 was smaller than it would have been if there were no human-caused climate change. They also hypothesized that future warming would cause even greater reductions in snowpack.

Methods

To investigate these hypotheses, the authors fed data from a high-resolution regional climate model into a land surface model called Noah-MP. First, they simulated the snowpack that actually occurred throughout the snow years (November – June) of 2011–2012 through 2014–2015. This created the "reference" simulation that other simulations could be compared with. The researchers checked this simulation against observational measurements of snowpack to ensure its accuracy.

Next, the researchers simulated how the snowpack would have evolved if there were no such thing as human-caused climate change. They calculated the human-caused warming that occurred between the periods of 1880–1914 and 1981–2015, and then lowered temperatures in the simulation by that amount. The researchers nicknamed this the "natural" simulation.

Finally, the researchers created a series of four future simulations representing different scenarios of climate change at the end of this century (2081–2100). These scenarios are based on the warming projected to occur under four different pathways of greenhouse gas concentrations. (Greenhouse gases are those that trap heat in the atmosphere and cause climate change.) These so-called "Representative Concentration Pathways," or RCPs, were created in 2005 and used in the Intergovernmental Panel on Climate Change's latest scientific assessment. The future simulations show how the snowpack would evolve if the same precipitation patterns were to occur at the end of the century under warmer temperatures.

Findings

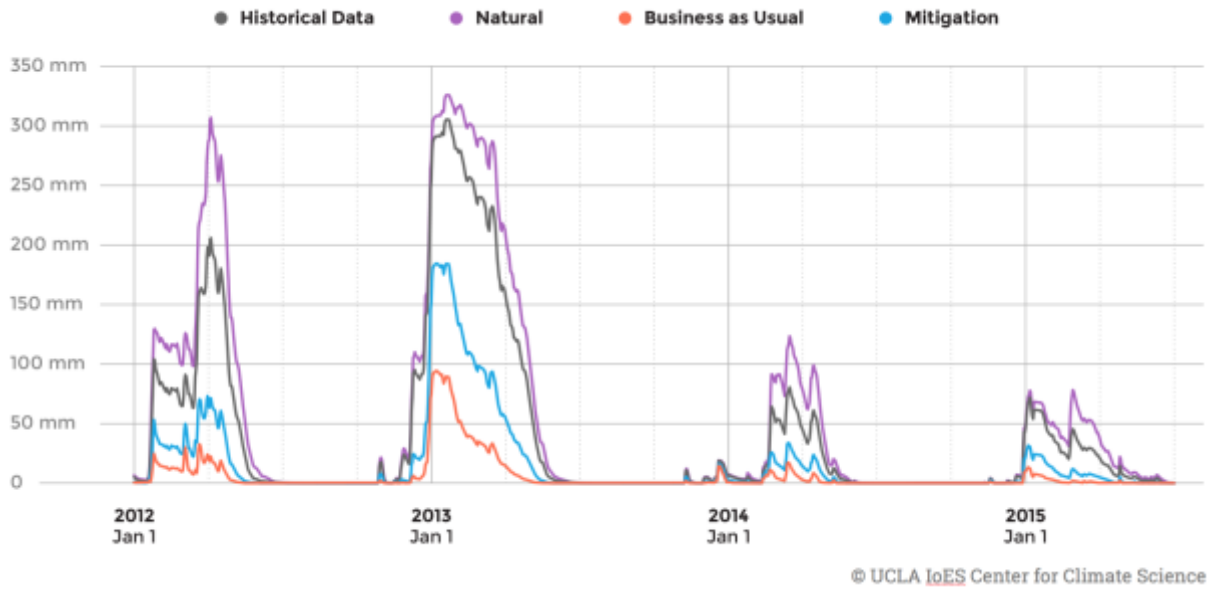
When the authors compared the "natural" simulation (with no human-caused warming) to the "reference" simulation (what actually occurred), they found less snow in the reference simulation. Average Sierra Nevada snowpack levels in the reference simulation were 25% lower than in the natural simulation. Snow loss varied by elevation: Middle and low elevations (up to about 8,000 feet) saw reductions ranging from 26% to 43%.

The future simulations revealed even greater snow loss:

- In the "RCP8.5" future simulation, average Sierra snowpack was reduced by 85%, compared with the reference simulation. At elevations below 8,000 feet, nearly all snow was lost. The RCP8.5 scenario represents global greenhouse gas emissions that continue to rise over the course of this century, and it is the scenario the world is currently tracking. For this reason, the researchers refer to it as "business as usual."

- Average snowpack was also reduced in the other three future simulations, but to a lesser degree. The other three RCPs represent different scenarios of global greenhouse gas emissions cuts. The "RCP4.5" scenario, nicknamed "mitigation" by the researchers, is roughly equivalent to what would occur if the world follows through with obligations agreed to in the 2015 Paris Climate Accord. In this simulation, average Sierra snowpack is 60% lower than in the reference simulation.

Key figure



This image is adapted from Fig. 3 in the paper. On the x-axis is time, and on the y-axis is snow water equivalent* in millimeters, averaged over the entire Sierra Nevada study domain. The "reference" simulation (here labeled "Historical Data") is shown in gray, and the "Natural" simulation (with no human-caused warming) is shown in purple. The "Business as Usual" future simulation (representing warming at 2081–2100 with no abatement in greenhouse gas emissions) is shown in red, and the "Mitigation" simulation (representing warming at 2081–2100 with cuts in greenhouse gas emissions similar to those expected with implementation of the 2015 Paris Accord), is shown in blue.

**Snow water equivalent is a measurement used by researchers and water managers. Because snow can vary in density, snow depth is not a useful way to measure the water contained in snow. Instead, snow water equivalent (SWE) is used. SWE is typically measured in millimeters and represents the depth of water that would occur if all the snow in a given area were instantaneously melted.*

Implications

Snowpack is important for ecosystems in the Sierra Nevada, and for water resources throughout California. In terms of water resources, snow acts as a natural reservoir, holding mountain precipitation in frozen form until spring snowmelt sends it gradually into streams and reservoirs. When snowpack is reduced, so is reservoir recharge.

This study shows that California is already being affected by climate change. If there were no such thing as human-caused global warming, the Sierra Nevada would have had a larger snowpack in the winters of 2011–2012 through 2014–2015 than the one it did have.

In their future climate change simulations, the authors did not consider whether precipitation patterns would change, or whether droughts would become more common. Instead, they re-created the recent drought's precipitation patterns under different scenarios of warming, so that they could isolate the effects of warming on snowpack. Their findings indicate that warming will reduce snowpack during droughts in the future, even if greenhouse gas emissions are curbed in coming years. California will need to manage its water resources carefully to be prepared for droughts of the future.

Next steps

This study was made possible by a grant from the Metabolic Studio in association with the Annenberg Foundation, as well as by UCLA's Luskin Center for Innovation and Sustainable LA Grand Challenge. It is the second in a series investigating many aspects of future climate in the Sierra Nevada. The UCLA team recently analyzed warming in the Sierra and is currently analyzing changes to snowpack, the timing of runoff from snowmelt, and soil moisture. These studies are forthcoming, and will provide insight into climate change impacts not only on water resources but also on wildfire, ecosystems, and recreation. Visit our website to learn more about the Climate Change in the Sierra Nevada project. To stay updated, sign up for our mailing list.

Study citation

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