Simulating the Sierra Nevada snowpack: The impact of model resolution, snow albedo and multi-layer snow treatment

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1. Introduction

• The Sierra Nevada snowpack plays a crucial role in the water resources and hydropower generation in California.
• The high elevation snowpack serves as a natural reservoir which stores fresh water during the cold season and releases it gradually during the warm season.
• About 60% of the water supply for southern California comes from melting Sierra Nevada snowpack.
• Consequently, the impact of global warming on the Sierra Nevada snowpack has become one of the leading topics in the regional climate change studies for the California region.
• The calculation of the Sierra Nevada snowpack in climate models involves significant uncertainties.

2. Experimental Design

• The numerical experiments are performed using the Regional Earth System Model (RESM) being developed at the UCLA-JPL Joint Institute for Regional Earth System Science and Technology (JIFRESSE) on the basis of the WRF model, the regional ocean model (ROM), the Simplified SIB (SSiB) model, and the Community Multi-scale Air-Quality (CMAQ) model.
• For the investigation of the impact of RCM resolutions on simulating the Sierra Nevada snowpack, one-way, self-nested simulations in which a 12km resolution run is driven by the data from a 36km run (Figure 3a), is performed for the 10 winter seasons each for the late 20th century (1971-1980) and mid-21st century (2045-2054) periods.
• SWE simulations based on different snow layer treatments are performed over a North American domain at an 80km horizontal resolution (Figure 3b).

3.1 Snow simulations according to RCM resolutions

• The seasonal snowfall (mm) in the present-day climate simulated with the single- and three-layer snow model in the RESM-SSiB model are analyzed in terms of terrain elevation range for the 123/36km horizontal resolutions.
• The SWE climate change sensitivity in the 12km and 36km runs are analyzed in terms of terrain elevation range for the 123/36km horizontal resolutions.

3.2 The effects of snow albedo

• Snow albedo can change due to the presence of anthropogenic aerosols, especially black carbon (BC).
• The deposition of BC on the Sierra Nevada snowpack can be influenced by local emissions.
• This case study assumes two emission scenarios:
  - Control: The cold season October 2000 – April 2001 with the Nash-LSM default snow albedo values.
  - Increased emissions: Two runs in which the snow albedo value are of 75% and 50% of the control run.
• The changes in snow albedo affect run off in which the snow albedo treatment.
• The impact of the snow albedo alterations on the SWE in the Sierra Nevada region is investigated.

3.3 SWE in a multi-layer snow model simulation: A comparison against a single layer simulation

• A model framework in which snow physics are represented can also be an important source of uncertainties in simulating snowpack.
• In many snow models, for example, the amount of energy input to initiate snowmelt varies according to the thickness of a snow layer with snow temperature.
• In order to examine this concern, SWE in North America during May 1998 has been simulated using two different snow models:
  - A single layer representation in lieu of SIB-1 and SIB-3 models.
  - Three layer snow model with the SSB-3 model (Xue et al. 2002).
• The single layer model overestimates the observed SWE (Mote et al. 2005), most notably in Canada and the Rocky Mountains (Figure 4a).
• Much of the positive biases in the single layer snow model simulation could be alleviated by using the three-layer snow model (Figure 4b).
• Underestimation of SWE in the single layer model persists in the three layer simulation; perhaps due to the lack of terrain representation (80km).

Summary and conclusions

Projection of the Sierra Nevada SWE climate change signals can be significantly influenced by the spatial resolution.

(1) The differences in the projected SWE climate change signals are more directly related with the amount of snowfall than the climate change sensitivity of snowfall in the two simulations.
(2) The snowfall differences between the two simulations are amplified via snow albedo feedback to result in large differences in the SWE sensitivity despite the similar snowfall signals.
(3) Alterations in snow albedo possibly via the deposition of anthropogenic BC can exert large influences on high elevation snowpack and the associated surface hydrology.
(4) The deposition of BC on the Sierra Nevada snowpack can be influenced by local emissions.

More realistic treatment of snow physics within a multi-layer snow model framework can improve SWE simulations during the spring snowmelt season.

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