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Simulation of seasonal snowfall over Colorado

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ABSTRACT

This paper presents results of four high resolution simulations of annual snowfall over Colorado, U.S.A. The results are verified using SNOTEL data. Sensitivity to model resolution is also explored. The results show that proper spatial and temporal depictions of snowfall adequate for water resource and climate change purposes can be achieved with the appropriate choice of model resolution and physical parameterizations.

1. Introduction

Water is a key global resource that is essential to the development and sustainability of human civilization. Egyptian and Mesopotamian societies, for instance, were developed along the Nile and Tigris and Euphrates river systems to be close to a reliable water source. These river systems, in turn, are driven by precipitation in upstream mountains, such as the Ethiopian Highlands. Modern societies, such as the Western U.S., remain largely dependent on river flows driven by orographic precipitation. The Colorado River is one such system that is critical for a significant fraction of Western U.S. water needs.

Despite the critical importance of water in the Western U.S., current modeling systems do not accurately simulate seasonal snowfall or snowpack. For instance, Leung et al. (2003) show that current regional climate models typically underestimate precipitation by ~25% in the Western U.S. The headwaters region of the Colorado River (Upper Colorado River Basin) seems to be a particularly difficult area for climate models to properly handle, with inconsistent snowfall trends in this region from both the 3rd and 4th IPCC reports (2001, 2007, respectively), despite consistent predictions of temperature increases in this region from all climate models. With the increasing recognition of global and regional climate warming, water managers are rightly concerned about the potential impact of climate change on water in the Western U.S., especially given that recent studies suggest that global warming may lead to unprecedented drought conditions in the Southwest U.S. (4th IPCC Assessment). The Colorado Headwaters region is particularly important, since ~85% of the stream flow for the Colorado River comes from snowmelt in this region. A recent analysis of the 2007 IPCC Fourth Assessment global models by Hoerling and Eischeid (2006) indicates that the combination of increased temperature and weak to no trend in snowfall will produce unprecedented drought conditions over the next 50 years in the

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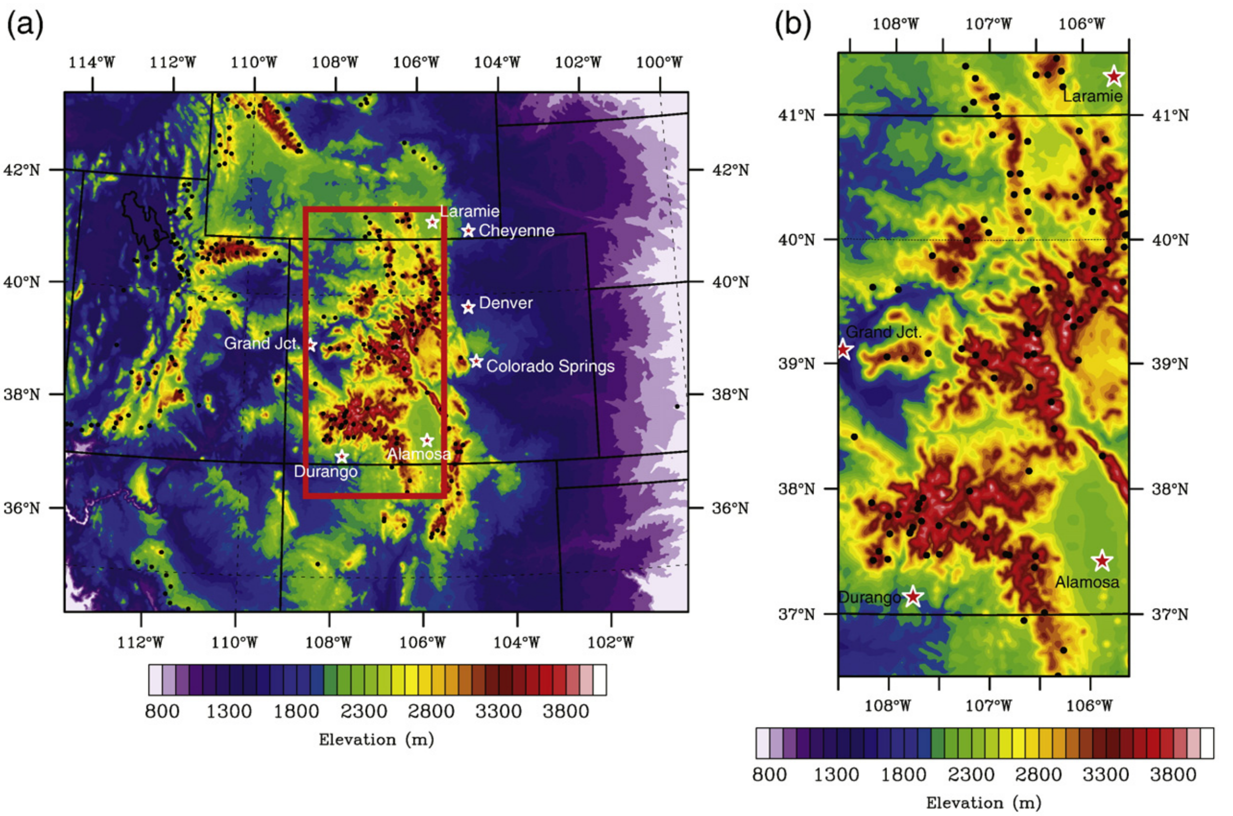

Fig. 1. Retrospective model domain and location of SNOTEL sites (black dots). Shown in (a) is the full model domain, and (b) a sub-domain focused on the Colorado Headwaters region. Locations of some towns and cities in and near the sub-domain are indicated by stars.

Southwest U.S. Seager et al. (2007) come to similar conclusions regarding future runoff in the Southwest through an independent analysis of the IPCC Fourth Assessment global models. While the above predictions from the global model runs from the 4th IPCC Assessment indicate dire consequences for the Southwest U.S., it also must be noted that the assessment indicated that global models typically perform poorly in regions of complex terrain. The Upper Colorado Region is, in particular, driven by high altitude snow melt, so climate assessments in this region using global models are uncertain. It is therefore critical to examine climate impacts in this region using higher resolution models in order to more realistically simulate orographic precipitation and evaporation processes.

Key aspects of snowfall, snowpack, evapotransporation and runoff potentially improved by high resolution climate runs with adequately resolved topography are:

1. Proper depiction of vertical motions leading to increased intensity of clouds and snowfall.
2. Formation of an isothermal layer at 0°C from melting snow leading to additional snowpack.
3. Improved simulation of airflow blocking effects on the flow and associated snowfall.
4. Proper depiction of terrain-induced embedded convection.
5. Improved spatial depiction of the local snow accumulation, accounting for local ridge shadowing reduction of snowmelt and sublimation.
6. Improved depiction of evapotransporation and runoff.

In this study, we perform simulations of winter precipitation between 1 November and 1 May for four retrospective years at various resolutions using various parameterizations and compare the model results to SNOTEL (SNOwpack TELemetry) observations. The current paper will attempt to address the following questions:

1. Can a properly configured high resolution regional model adequately simulate seasonal snowfall over the Colorado Headwaters region?

Table 1
List of simulations performed in the current study. The rightmost column indicates the number of SNOTEL sites that were operational during the respective years in the sub-domain (Fig. 1b). The SNOTEL data were used for model verification.

Water year	Simulation period	Model resolution		Number of SNOTEL sites
2001–2002	1 Nov.–1 May	2 km	Dry	95
2003–2004	1 Nov.–1 May	2 km	Average	102
2005–2006	1 Nov.–1 May	2 km	Average	108
2007–2008	1 Nov.–31 Oct.	2 km	Wet	112
2007–2008	1 Nov.–1 May	6, 18, and 36 km	Wet	112