The Uneven Response of Different Snow Measures to Human-Induced Climate Warming

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ABSTRACT

The effect of human-induced climate warming on different snow measures in the western United States is compared by calculating the time required to achieve a statistically significant linear trend in the different measures, using time series derived from regionally downscaled global climate models. The measures examined include the water content of the spring snowpack, total cold-season snowfall, fraction of winter precipitation that falls as snow, length of the snow season, and fraction of cold-season precipitation retained in the spring snowpack, as well as temperature and precipitation. Various stakeholders may be interested in different sets of these variables. It is found that temperature and the fraction of winter precipitation that falls as snow exhibit significant trends first, followed in 5–10 years by the fraction of cold-season precipitation retained in the spring snowpack, and later still by the water content of the spring snowpack. Change in total cold-season snowfall is least detectable of all the measures, since it is strongly linked to precipitation, which has large natural variability and only a weak anthropogenic trend in the western United States. Averaging over increasingly wider areas monotonically increases the signal-to-noise ratio of the 1950–2025 linear trend from 0.15 to 0.37, depending on the snow measure.

1. Introduction

Climate change will affect most of the world’s snowpack, imposing important impacts on people’s livelihood and living conditions considering that more than one-sixth of Earth’s population relies on melting snow for part of their water supply (Barnett et al. 2005). Snow responds to both temperature and precipitation, as well as other factors such as dust deposition on the surface and net absorbed solar radiation. Temperature has risen across the globe because of human activity (i.e., Solomon et al. 2007), a trend that is likely to accelerate in coming decades and which tends to reduce snowpack. Precipitation changes are more regional and uncertain, with increases likely in higher latitudes but declines in already-dry midlatitudes (Solomon et al. 2007), so precipitation changes can have conflicting effects on snowpack (Brown and Mote 2009). Future changes in snowpack are also likely to be elevation dependent, since high elevations tend to be colder, and therefore require more warming to reach the melting point.

Although these factors come into play in all snowy regions of the world, in this work we analyze in detail one region where the population relies on snowpack as a natural reservoir to capture and store precipitation from intense winter storms, the western United States (e.g., Palmer 1988; Mote et al. 2005). Numerous works have examined changes in snow over the western United States from observations and projected human-induced climate change (e.g., Groisman and Easterling 1994; Cayan 1996; Hayhoe et al. 2004; Mote et al. 2005; Hamlet et al. 2005; Regonda et al. 2005; Mote 2006; Knowles et al. 2006; Mauzer et al. 2007; Das et al. 2009). Formal detection and attribution studies have shown that anthropogenic climate change has already increased winter