Western U.S. forests show substantial vulnerability to drought, with declines in productivity and increases in mortality and disturbance in drought years (Allen et al., 2010; Hicke et al., 2012; Williams et al., 2013). Understanding these ecosystems' responses to primary climate drivers is of particular concern given recent warming trends (Sterl et al., 2008) and multi-year droughts (Cook et al, 2004; Dai, 2004). The region is climatically characterized by warm summers that receive little precipitation and the general role of winter precipitation and snowmelt as a driver of forest water use and productivity has been well established (Boisvenue & Running, 2006, Hanson and Weltzin, 2000). Warmer temperatures are already shifting seasonal water availability in the western US through reductions in snowpack accumulation (Knowles et al, 2006) and earlier occurrence of peak snowpack (Mote et al, 2005) and this is evident in shifts in streamflow timing (Stewart et al, 2005). Increased temperatures also effect plant phenology, leading to earlier spring onset of plant water use and productivity (Cayan et al, 2001). However increases in early season water use, combined with higher atmospheric moisture demand, may lead to increased soil water deficit later in the season. These changes in water and energy demand are expected to intensify (Ashfaq et al., 2013).

Soil and snowpack store water for forests in much of the western US. Recently, field and modeling studies have shown that the years with greater snowpack accumulation can be a strong predictor of vegetation water use and productivity for sites in the California Sierra (Tague & Peng, 2013; Trujillo et al, 2012). Though this recent work emphasizes the relationship between snowpack storage and forest water use, there has been little analysis of how shifts in the storage of precipitation as snow will interact with soil moisture storage characteristics. Like snowpack, soil has the potential to act as a water reservoir, storing winter precipitation into the growing season (Geroy et al., 2011). The amount of water stored by a soil varies substantially in space with topography, soil properties, and antecedent moisture conditions (Famiglietti et al, 2008; McNamara et al, 2005). Soil characterization remains a key uncertainty in hydrologic modeling and, in the western US, soil moisture availability is a major limitation of forest water use and productivity (Hamlet et al, 2007; Zhao & Running, 2010). Subsurface drainage can provide moisture to points on the landscape (i.e., riparian zones and swales) during seasonal summer drought, contributing to vegetation presence and enhancing ET (Hamlet et al., 2007; Hwang et al., 2011; Voepel et al., 2011). However, field studies have also shown that shallow soils may not be able to capture all of the annual snowmelt (Kampf et al, 2014; Smith et al., 2011), limiting the role of soil in providing snowmelt for use during the summer. The relative and interacting roles of snowpack and soil storage will vary geographically with regional climate patterns and thus differ in supporting ET.

This manuscript's primary research objective is to address the interaction between soil characteristics and key climate metrics that influence forest water availability in Mediterranean environments that receive a significant amount of precipitation as snow. To our knowledge, little research has compared soil-climate interactions across multiple watersheds in this geographic niche due, in part, to the extensive fieldwork required to characterize these relationships and the difficulty in modeling these environments with empirical models. A spatially distributed, process-based model driven at a sub-seasonal time step can explore watershed response to these climate drivers and changes in their seasonality. We use a process-based model in three case study watersheds of differing precipitation regimes to investigate how climate and soil combine to control inter-annual variation in ET. This work has implications for better estimating a major component of the hydrologic budget.

We apply our model at a daily time step to three watersheds located in the western Oregon Cascades (OR-CAS), central Colorado Rocky Mountains (CO-ROC) and central California Sierras (CA-SIER). These watersheds receive a substantial fraction of precipitation as snowfall, but vary in their precipitation and temperature regimes and magnitude of snowpack relative to precipitation. We use these case studies to provide a range of precipitation/temperature conditions and use these to examine how soil moisture storage can interact with a combination of inter-annual variation in precipitation timing and magnitude and shifts in snowpack storage. We first focus on how differences in three primary climate metrics that strongly influence seasonal snowpack--precipitation, temperature, and soil moisture recharge—vary in their correlation with annual ET. We then explore the interaction effects between climate and soil in changing ET, showing that spatial heterogeneity in soils varies the strength of climatic drivers within and across watersheds.

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