FOREST DISTURBANCE AND THE IMPACTS ON MARITIME SNOW IN THE OREGON CASCADES

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ABSTRACT

The maritime mountain snowpack in Oregon's Cascades is a critically important source of flows for the Willamette River Basin. Recent warm winters have reduced snowpack due to precipitation falling as rain rather than snow. Furthermore, landscape-altering forest fires have altered the energy balance, affecting snowpack retention. This research investigates changes in snow water equivalent (SWE) due to warmer climate and fires in the McKenzie River Basin. The McKenzie River supplies water and hydropower to the city of Eugene Oregon and is a key tributary of the Willamette River. In 2003 the B&B Complex Fire (367 km^2) burned through Santiam Pass, at the headwaters of the MRB, severely burning the forest surrounding the Hogg Pass SNOTEL site. For this study, data were acquired from multiple SNOTEL and meteorological sites for the 20 years before and 15 years after the fire. We examined pre- and post-fire differences in SWE at the Hogg Pass SNOTEL site, in comparison with the nearby and unburned McKenzie SNOTEL site. We also modeled the changes in SWE, calibrating the model to the unchanged McKenzie SNOTEL and rerunning the model with a clear-cut forest cover to simulate disturbance. Next, we tested this model at the Hogg Pass SNOTEL for the years of pre- and post-fire. Results show that the measured SWE at the Hogg Pass SNOTEL it noticeably less in the years following the fire. Results from the modeled disturbance overestimate SWE at all times during the post-fire 2004 water year. From this, we conclude that the model's landcover doesn't fully represent the impacts on the snowpack following a forest fire. Further model development is needed to include these processes. This study is particularly relevant to water resource and forest managers who seek to understand how the declining seasonal snowpack will affect water availability and could increase the likelihood of more forest fires during the dry months. (KEYWORDS: maritime snowpacks, forest fires, climate change, McKenzie River Basin)

INTRODUCTION

The maritime mountain snowpack in Oregon's Cascades is a critically important source of water for the upland forest and the reservoirs of the Willamette Valley. Water stored in the snowpack accumulates in the colder, wetter months (November-March) and is released in the warmer, drier months (April-October). Sensitive to the warming climate, the snowpack in the Pacific Northwest (PNW) is declining faster than elsewhere in the western United States (Mote et al., 2005; Mote et al., 2018). In the winter months, temperatures generally at or above 0 °C, often allowing precipitation to fall as a mix of rain and snow (Sproles et al., 2013; Jennings et al., 2018). Warmer winter storms produce more rain and significantly affect the seasonal accumulation of the snowpack (Sproles et al., 2017). Warm spring temperatures are strongly associated with an early spring snowmelt, and result less snowpack water yield in the dry summer months (Stewart et al., 2005). This combination of less snow and earlier snowmelt impacts water availability for downstream users and increases moisture stress in mountain forests. Modeling of the Oregon Cascades show that under a warming climate, upland wildfires would increase 200-900% by 2090, followed by shifts in forest composition (Turner et al., 2016). Furthermore, landscape-altering forest fires can alter the snowpack water and energy balance (Harpold et al., 2013), and further affects the timing and availability of snowmelt.

The overarching goal of this project is to better understand how forest disturbance affects snowpack accumulation and retention of the snowpack in the PNW. This information will be useful for developing forest management practices to optimize snow accumulation and water yields for healthier forests and increased water availability. Specifically, we aim to better understand 1) how changes in forest structure affect snow accumulation and ablation, and 2) how forest disturbance impacts on snow water equivalent (SWE) compare with measured impacts in a burned area. We simulate forest disturbance using a process-based snow model and compare model output with daily SWE values from Snow Telemetry (SNOTEL) sites.

Paper presented Western Snow Conference 2019
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SITE DESCRIPTION

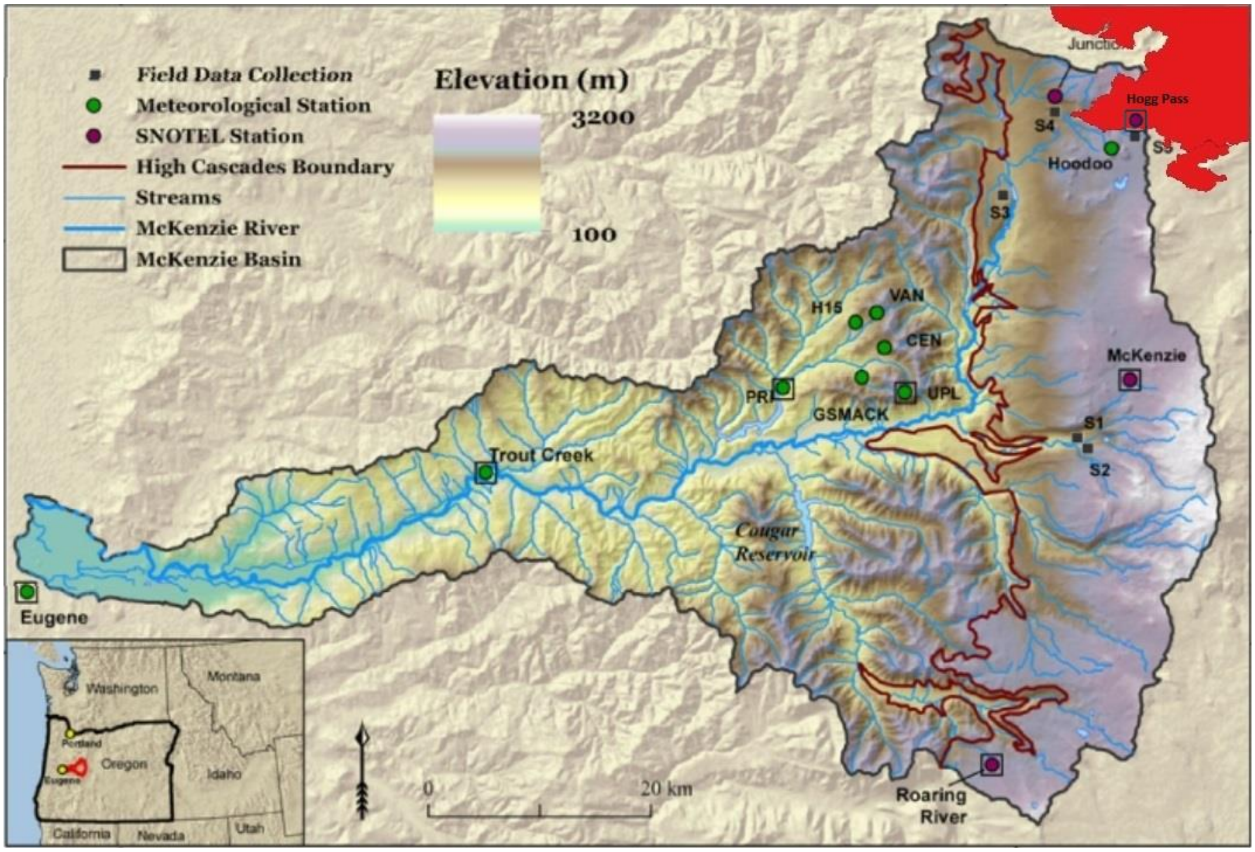

Figure 1. McKenzie River Basin, Oregon. Figure adapted from (Sproles et al., 2013). B&B Complex Fire burn area represented in red. Stations used in this project are represented with yellow squares.

The McKenzie River Basin (MRB; 3041 km^2) drains from the crest of the Oregon Cascades to its confluence with the Willamette River in the Eugene/Springfield metropolitan area of Oregon (Figure 1). The MRB has a series of reservoirs that provide flood risk reduction and also supply the greater Eugene area with water and hydroelectric electricity. Four SNOTEL stations are located in the upper basin, and information on the snowpack has been collected in the basin since 1978. In 2003, the B&B Complex Fire (367 km^2) burned through Santiam Pass, at the headwaters of the MRB. This fire severely burned the conifer forest surrounding the Hogg Pass SNOTEL site. The Hogg Pass SNOTEL site itself was not damaged in the fire, but the surrounding forest was completely altered.

METHODS

For this pilot study, we used SWE and meteorological data from water years 2003 and 2004. Station data for this study were selected following the previous work of Sproles et al. (2013). SWE data were acquired from the Hogg Pass SNOTEL and McKenzie SNOTEL Sites. These stations were selected because of their similar topographic position, elevation and forest type.

To simulate the daily evolution of the snowpack and specifically, SWE, we used SnowModel (Liston & Elder, 2006b), a spatially distributed process-based model for simulation the snowpack. SnowModel is composed of a series of sub-models. Micromet (Liston and Elder, 2006a) interpolates station-based meteorological data over the gridded model domain, including air temperature, humidity, precipitation, wind speed, and wind direction, surface pressure, incoming solar and longwave radiation. At each grid cell, EnBal calculates the energy exchange of the snowpack using the output from Micromet and snowpack information from the previous time step. SnowPack simulates the changing snowpack properties, canopy interception effects, and mass balance using data from both Micromet and EnBal. SnowTran3D simulates snow transport due to the wind. For this project, SnowTrans3D was not used because of the simplicity of running a single grid cell model.

In this research, we modified Micromet to include a linear rain-snow partition function for temperatures between -0.5 and 5 °C, which allows for mixed phase precipitation. The temperature at which it is raining (T_r) and the temperature at which it is snowing (T_s) are two new variables added to Micromet. It has previously been shown that including a rain-snow partition function is critical to accurately represent snow accumulation in maritime mountain regions (Sproles et al., 2013; Jennings et al., 2018). The second modification to the Micromet code is an improved temperature lapse rate, which better reflects the decrease in temperature with increasing elevation in the upper McKenzie River Basin (Cooper et al., 2016).

Model calibration was performed by comparing the measured SWE at the McKenzie SNOTEL with a modeled value for a single, co-located 100 m x 100 m grid cell. The Nash-Sutcliffe Efficiency (NSE) metric was used to assess the predictive power of the model for water years 2003 and 2004. Since snow is seasonally absent in the summer months, all time steps where both the simulated and measured values were zero were removed from NSE measure. The three model variables used to calibrate the model were the temperature at which it is raining (T_r), the temperature at which it is snowing (T_s), and the albedo of the snow in the forest (albedo_snow_forest). The use of T_r and T_s optimized the accumulation of SWE during winter storms. The snow forest albedo was used to match the melting rate of the snowpack after peak SWE.

To simulate forest disturbance, the model was rerun after changing the land cover from conifer forest to clear-cut forest. This reduces the leaf area index (LAI), which affects canopy interception and the energy balance of the snowpack in SnowModel. Incoming solar radiation is increased in the clear-cut forest and emitted longwave radiation is reduced. The turbulent fluxes, latent and sensible heat are increased in the clear-cut forest.

To compare our model results to measurements associated with real forest disturbance SnowModel was run for the Hogg Pass SNOTEL site, where the B&B fire had burned in August-September 2003. We ran SnowModel twice, once for a land cover type of undisturbed conifer forest and once for a forest clear-cut condition. The clear-cut condition is intended to somewhat simulate the effects of a wildfire on the subsequent year's SWE. Burn severity at that location is estimated at moderate to severe with much of the canopy removed by the wildfire. Specifically, we compared modeled and measured SWE for pre- and post-fire conditions.

RESULTS

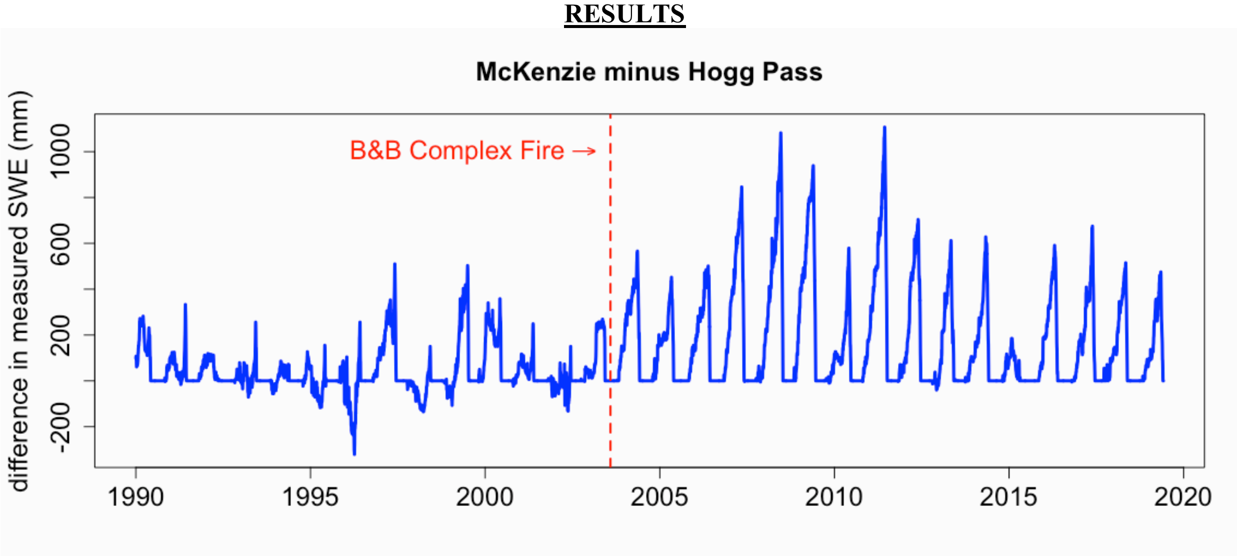

Figure 2. Difference between the measured SWE at the McKenzie and Hogg Pass SNOTEL sites

Before the B&B fire we see little difference in SWE for the two sites (Figure 2). This would be expected because of their similar elevation, location, and forest type. After the fire, we expect the differences between the two sites to be much greater than the pre-fire case. It can be assumed that little has changed at the McKenzie SNOTEL site so we would expect the change in SWE to be due to the forest disturbance at the Hogg Pass SNOTEL.

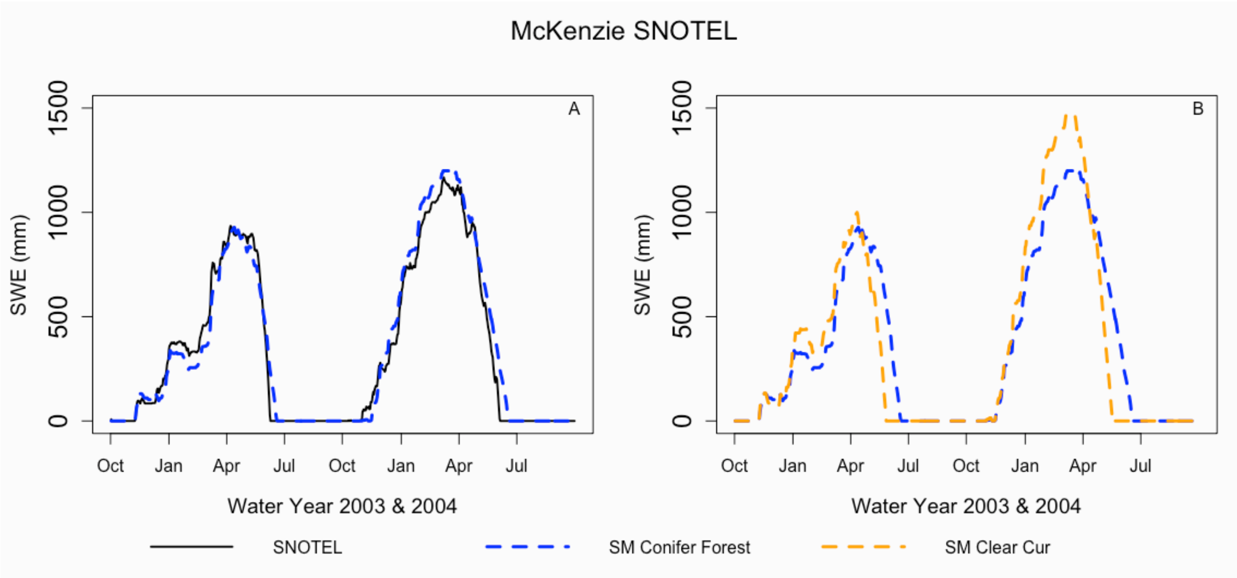

Figure 3. Measured and simulated SWE at the McKenzie SNOTEL for water years 2003 and 2004 (A). Simulated SWE for the calibrated conifer forest and the clear-cut forest for water year 2003 and 2004 (B)

Calibrating the model to the McKenzie SNOTEL produced a Nash-Sutcliffe value of 0.92. Visually inspecting the goodness of fit (Figure 3a) we see that the model accurately captures the accumulation rate, the magnitude and date of peak SWE, the rate snowmelt, and the snow disappearance date (SDD).

Running the model with a clear-cut forest (Figure 3b) we see an increase in SWE during the accumulation phase. We also see that the snow is melting off faster resulting in an earlier SDD. In the case of water year 2004, we note that the SDD occurs about a month earlier.

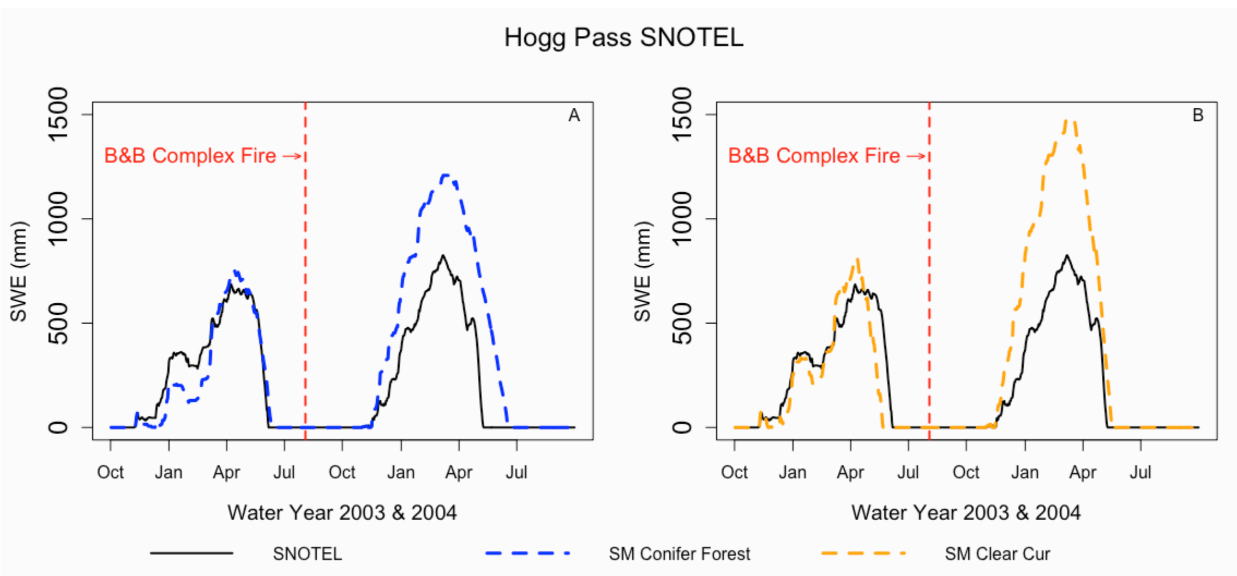

Figure 4. Measured SWE and simulated SWE for a conifer forest at the Hogg Pass SNOTEL for water years 2003 and 2004 (A). Measured SWE and simulated SWE for a clear-cut forest at Hogg Pass SNOTEL for water years 2003 and 2004 (B). The vertical line represents the stat day of the B&B complex fire.

The measured SWE at the Hogg Pass SNOTEL and the SnowModel runs for conifer, and clear-cut forest indicate several things about the model performance. Comparing the conifer forest model run to the measured SWE at Hogg Pass (Figure 4a) we see that the model effectively simulates the date of peak SWE and SDD. What the conifer forest model isn't capturing is the magnitude of some of the snow accumulation in the beginning of winter. The weather station data across the MRB show this to be a warm storm. We believe that further model calibration is needed to better include theses warm storms.

We see similar results with snowpack accumulation and retention when we run SnowModel for the conifer forest and the clear-cut forest (Figure 4a & 4b). The clear-cut forest model produces a higher peak SWE and an earlier SDD. For the conditions at Hogg Pass, SDD is more than a month earlier for water year 2004.

Comparing the clear-cut model to the Hogg Pass SNOTEL (Figure 4b) we see that simulated clear-cut disturbance significantly overestimates the accumulation of SWE for all times during the winter. In this case, we can conclude that this change in landcover doesn't fully represent the impacts on the snowpack following forest fire.

DISCUSSION

In this paper, we investigated the influence that forest disturbance has on the snowpack. Using a processed-based snow model, we modeled the change in SWE for two different land cover classes: coniferous forest and clear-cut forest. Model results show that removal of the forest allowed for more accumulation up until the time of peak SWE. After that point, we saw the snowpack melt out faster and an earlier SDD. In some cases, snow disappearance was over a month earlier than the forested model run.

Our model was calibrated using measured daily SWE at the McKenzie SNOTEL Station. Running this model at the Hogg Pass SNOTEL shows that future calibration of this model is still needed. Since SnowModel runs on a series of submodels, we feel it important to thoroughly investigate the calibration of Micromet before looking into snowpack properties. To do this additional meteorological stations data will be added for calibration and independent validation. After calibrating the metrological data, we will then go back to calibrating the snowpack.

Results comparing our simulated clear-cut disturbance to our measured fire disturbance show that SnowModel landcover does not fully represent the processes that are present during wildfires. Work investigating charred forests and their ability to accelerate snow albedo decay, decrease snow albedo, and subsequently drive faster snow ablation through increased post-fire radiative forcing on snow has been described by (Gleason et al., 2013) and (Gleason & Nolin, 2016). Both of these papers discuss the development of a post-fire snow albedo decay parameterization to quantify forest fire disturbance better. This code was developed in SnowModel, and it is likely to produce more accurate results than the clear-cut forest simulation.

Finally, we would like to look into using SnowModel's gap fraction parameter to better describe forest density. Gap fraction is the fraction of the snowpack surface that is not blocked by foliage. In SnowModel gap fraction is a single parameter that is applied over the entire spatial extent of the model. We will explore the effects of using a spatially-explicit gap fraction to better describe the forest structure.

CONCLUSION

This research provides a preliminary understanding of a model-based approach to simulation impacts of forest disturbance in the maritime snowpack of the Oregon Cascades. The modeling approach in this project was designed to be both a thought experiment and to test our model-based understanding of forest fire disturbance. In the next steps, we hope to address the model limitations and improve the model's sensitivity to wildfire disturbance.

We anticipate that future work from this study will be relevant to forest managers who seek to understand how forest disturbance and changing climate might alter water availability to the trees. In future work, we will examine forest management practices for the fire management and we seek to understand how snowmelt runoff is affected. We also expect this information to be relevant for water resource managers for the prediction of reservoir inflows. The development of a coupled human-natural systems model will help us better understand the tradeoffs in how we can manage resources for the future.

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