SNOW DISAPPEARANCE TIMING IN WARM WINTER CLIMATES IS DOMINATED BY FOREST EFFECTS ON SNOW ACCUMULATION

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EXTENDED ABSTRACT

Forests modify snow processes and affect snow water storage as well as snow disappearance timing. However, forest influences on snow accumulation and ablation vary with climate and topography, and are therefore subject to substantial temporal and spatial variability. Prediction of where and how forest cover will accelerate versus delay snow disappearance timing has valuable forest management applications, particularly in regions of extensive forest cover and intensive timber harvest such as the Pacific Northwest (PNW), USA. However, an improved understanding of how different forest-snow processes combine to contribute to snow disappearance timing is needed before applying empirical models (Varhola *et al.*, 2010; Lundquist *et al.*, 2013), or physically-based hydrologic models (Ellis *et al.*, 2013; Du *et al.*, 2016) to management practices. We therefore utilize multiple years of snow observations from across the PNW to assess forest-snow interactions in the relatively warm winter conditions characteristic of maritime and transitional maritime-continental climates (Figure 1). We (1) quantify the difference in snow magnitude and disappearance timing between forests and open areas and (2) assess how forest modifications of snow accumulation and ablation combine to determine whether snow disappears later in the forest or in the open.

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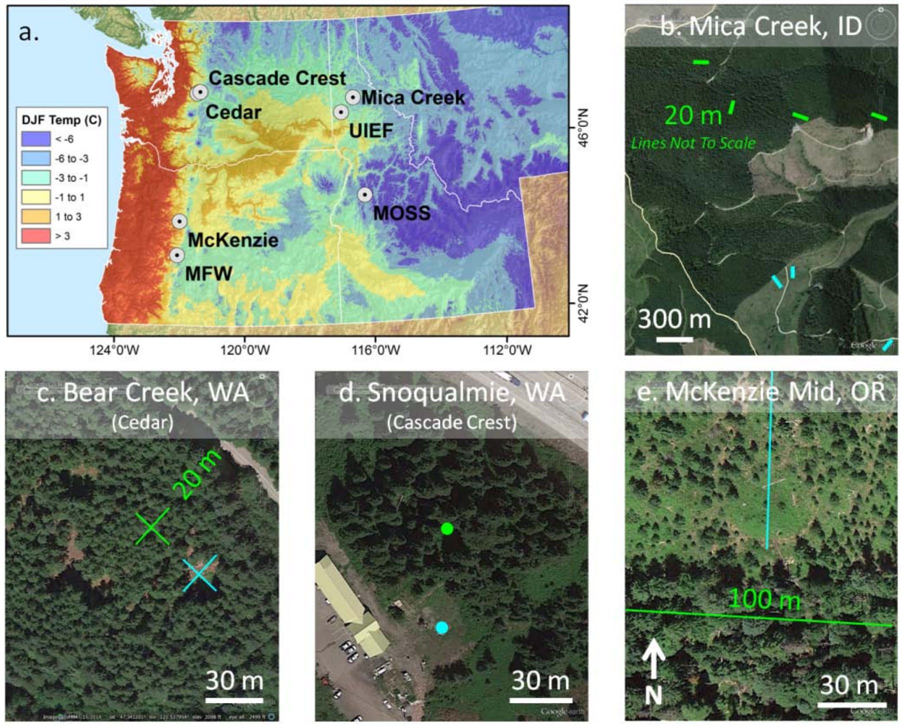

Figure 1. (a) Map of the PNW, showing average December-January-February (DJF) temperature from PRISM Climate Group (2012) and field locations and aerial photographs showing forested and open areas from representative snow observation sites. Approximate locations of snow depth transects are shown as green (forest) and blue (open) lines, with the length of the forest transect that is visible in the photograph indicated in green type. Approximate point observation locations are shown as green and blue dots. Photographs courtesy of Google Earth Imagery, © 2016 Google, with the following additional data sources: (b, c, d) Landsat and (e) Landsat, LDEO-Columbia, NSF, and NOAA.

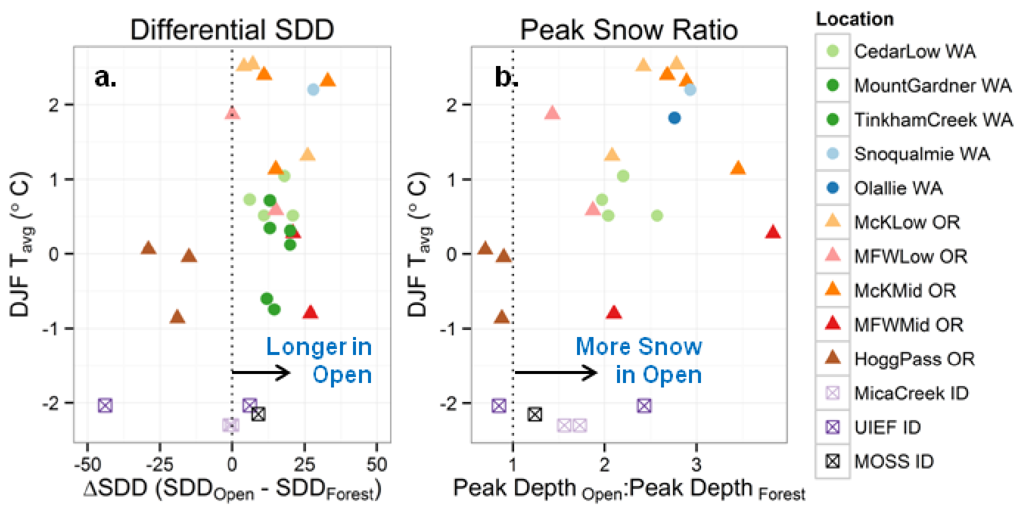

Figure 2. (a) Differential snow disappearance timing (ΔSDD) and (b) the ratio of peak snow depth in the open to the forest versus 4 km DJF average air temperature for the year of snow observations at each site. An outlier ΔSDD value of 96 days observed at Olallie has been removed from (a) for readability.

We find that snow disappearance timing at 12 (out of 14) sites ranges from synchronous in the forest and open, to snow persisting 0-4 weeks longer in the open (Figure 2a). However, at two windy sites (hourly average wind speeds ranging up to 8 and 17 m/s) differential snow disappearance timing is reversed: snow persists 2-5 weeks longer in the forest. The ratio of peak snow accumulation in the open to the forest at the Washington (WA) and Oregon (OR) sites is consistently high, ranging from 1.4 to 3.5 at all sites except Hogg Pass, OR, with a median ratio of 2.2 (Figure 2b). Ratios at Hogg Pass are below 1 (i.e., more snow in the forest than in the open). There are fewer data points for the colder sites in Idaho (ID), but the ratio ranges from 0.9 to 2.9 with a median of 1.9.

Analysis of daily snow depth observations indicates higher rates of snow gain and snow loss in the open as compared to the forest (Figure 3). This result is consistent with previous synthesis work by Varhola *et al.(* 2010) on the relation between forest presence and snow accumulation and ablation. However, when snow is present at both the open and the forest, there is more difference between open and forest sites in cumulative gain than in cumulative loss. Using gain and loss as a proxy for accumulation and ablation, the difference between accumulation rates up to the day when snow first disappears (i.e., the vertical dashed lines in Figure 3) is larger between the open and forest than the difference between ablation rates between the open and forest. Thus, canopy snow interception and subsequent loss, rather than ablation, sets up longer snow duration in the open at the majority of the sites. Reduced accumulation within the forest establishes the direction of differential snow disappearance timing, in that snow disappearance timing will range from synchronous to snow lasting longer in the open (Figure 2a). Even though cumulative loss in the open is consistently higher than in the forest, diminished rates of loss in the forest are not sufficient to balance out the diminished snow accumulation.

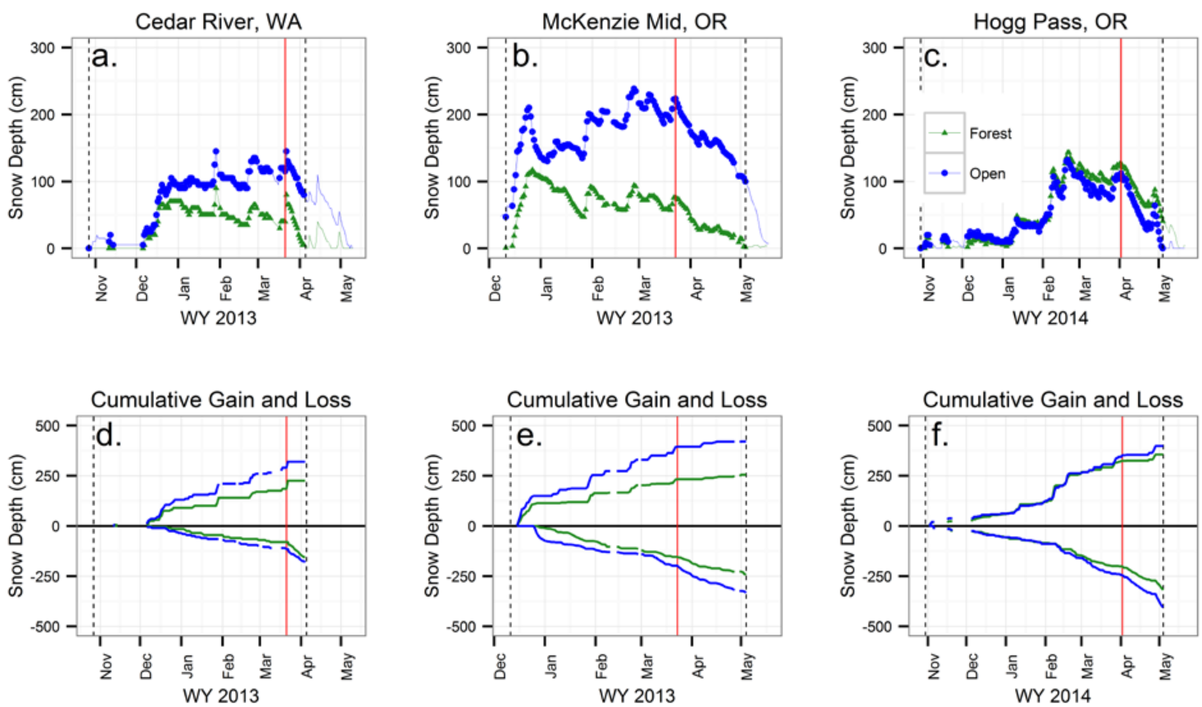

Figure 3. Examples of cumulative gain and loss analysis from three sites, including (a-c) time series of snow depth in the open (blue) and forest (green), and (d-f) time series of cumulative gain and loss. Temporal bounds on analysis are indicated as vertical black lines and the timing of peak snow magnitude indicated as a vertical red line. Analysis for Water Year (WY) 2013 at (d) Cedar River and (e) McKenzie Mid, where the difference in cumulative gain is larger than the difference in cumulative loss at both peak snow and first SDD, is typical of all the sites and years analyzed, with the exception of (f) Hogg Pass in WY 2014.

At the windy sites, such as Hogg Pass, OR, the peak snow ratio is close to 1, and accumulation rates in the forest and open are similar (Figures 2b and 3f). This suggests that accumulation processes that differ from the majority of sites drive the longer snow retention in the forest, rather than greatly enhanced ablation rates in the open. We speculate that the equivalent accumulation in the forest and open at this site is driven by preferential snow deposition (and thus accumulation) in the forest due to the transition to slower wind speeds (Hiemstra *et al.*, 2002; Geddes *et al.*, 2005) and possibly from the contribution of canopy-intercepted snow to the under-canopy snowpack due to wind unloading (Roesch *et al.*, 2001). Redistribution of snow from the open to forested area after a storm event ends is less likely due to relatively warm winter temperatures that support high snow cohesion (Li and Pomeroy, 1997). Therefore, longer snow retention in the forest at the sites with high observed wind speeds appears to be controlled by preferential snow deposition. While ablation rates are higher in the open, the difference between ablation rates in the forest and open is approximately equivalent to the difference at less-windy sites.

These observations provide evidence that forest modification of snow accumulation processes is the dominant factor in determining differential snow disappearance timing between forested and open areas in the PNW. Improved quantification of forest effects on snow accumulation processes is needed to predict the effect of forest canopy change via harvest or natural disturbance on snow water resources. (KEYWORDS: snow; forest; canopy interception; wind)

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