Snowmelt, infiltration, and soil moisture in Red Fir forest ecosystems of the Sierra Nevada

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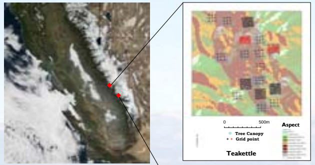
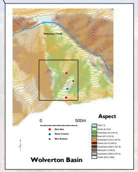
Introduction

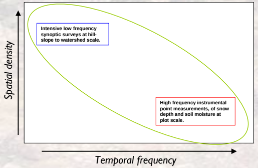




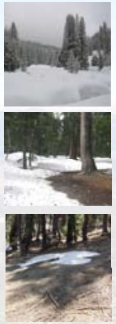
Location, aspect and contour maps of Teakettle and Wolverton basin study areas.

Snowmelt and soil moisture

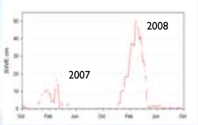
Measurements from the Wolverton basin in Sequoia National Park and the Teakettle Experimental Forest in the Red Fir zone of the southern Sierra Nevada (2,300-2,600 m elevation) evaluate our hypothesis that topography and vegetation cover are the most important variables affecting snowmelt and soil moisture. The global variables of slope, aspect, and topography influence large scale patterns of snow and soil moisture but vegetation also has a significant influence on the small scale distribution of both. The forest canopy has multiple effects on the accumulation and ablation of snow resulting in a heterogeneous snow cover and the subsequent soil moisture. Snow, as opposed to rain, represents > 90% of the annual precipitation received by these ecosystems and demonstrates a clear seasonal signal in vadose-zone recharge. Our strategy is to combine synoptic surveys and instrumental data from both sites to describe these processes across broad temporal and spatial scales.



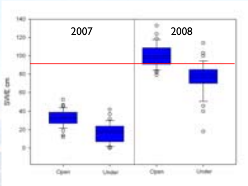
Snow melt



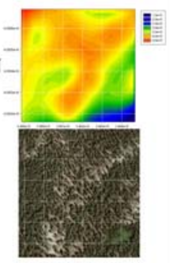
Snow distribution heterogeneity is influenced by tree canopies differently depending on the stage of accumulation or ablation.



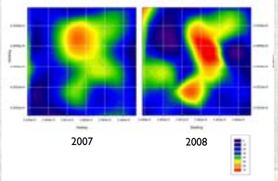
Interannual variability of SWE between 2007 and 2008. From Giant Forest snow pillow.



Box-plots of 496 measurements of open and under canopy SWE, at 36 locations for 2007 and 2008. Red line is 30 year snow course mean.



Top panel is clear-sky insolation in total Wh/m² was modeled using a transmittivity of 0.7, to account for reduced air mass attenuation at higher altitudes, at ½ hour time steps. Bottom panel is an areal photograph with grid for reference showing rock, soil and canopy cover.



Percent differences between open and under canopy SWE measurements for April 1st (± 2 days) in 2007 and 2008 show consistent patterns between years despite the large differences in total precipitation.

Snow surveys

Synoptic snow surveys of a 0.6 sq km area in the Wolverton Basin were conducted in April 2007 and 2008. Annual precipitation was below average in 2007 and above in 2008. Depth and density were measured at 36 grid points, four times under the canopy of the nearest mature Red Fir tree and four times in the closest canopy gap. The mean snow water equivalent (SWE) for all measurements was 24.8 cm in 2007 and 88.4 cm in 2008 with a 14 and 32 percent difference, respectively, between the under canopy and open measurements.

Spatial heterogeneity in SWE, snowmelt, and soil moisture timing are all influenced by orientation to and proximity with tree canopies. Differences between the open and under canopy are most prominent in locations that have high solar incidence during ablation. Conversely snow lingers in forest gaps that are shaded by large canopies.

Interpolation of the percent difference between open and under canopy SWE measurements show the largest variations are found in locations with the highest solar insolation following the last major storm of the accumulation period. However, modeled clear-sky irradiance does not fully explain the distribution since the lowest SWE is found under canopies (Fu and Rich 2002). This illustrates the importance of vegetation in the process of snowmelt infiltration and subsequent soil moisture in the early summer.

Despite the difference in melt stage and total precipitation between 2007 and 2008 the spatial influence of tree cover on SWE demonstrates some stationarity between years.

Fu, P. and P. M. Rich (2002). "A geometric solar radiation model with applications in agriculture and forestry." Computers and Electronics in Agriculture **37**(1-3): 25-35.

Infiltration

Plot scale measurements

The Southern Sierra Critical Zone Observatory consists of distributed sensor networks recording multiple variables at a catchment scale, capturing end members of abiotic factors such as aspect and elevation. Instruments located in the Wolverton basin, Southern Sierra Critical Zone Hydrologic Observatory, recorded hourly average snow depth and soil moisture integrated for the top 20 cm of mineral soil. The 2008 water year data is presented here.

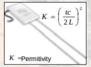
Infiltration from snowmelt occurred over a three month period starting in mid March and ending in late June. At these locations snow melt-out occurred over a 4 week period depending on the relationship to the forest canopy with south facing under canopy sites melting out first and open canopy shaded sites melting out last.

Soil moisture tracked the snowmelt pattern closely with diel fluctuations in saturated conditions, while the snow pack was melting. After melt-out saturated conditions ceased and there was an exponential dry-down to field capacity. This was followed by a prolonged summer drought punctuated by rain events that contributed less than 5% of total annual precipitation.

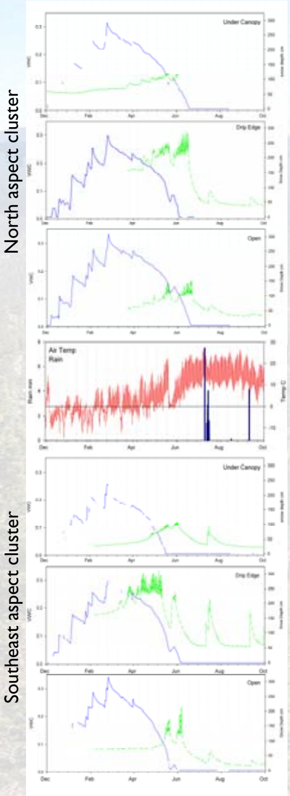
The differences in soil moisture amplitude are a function of heterogeneity in soil characteristics and litter depth. Rain events are also detectable at all sites but those with deep litter, which becomes hydrophobic as it dries out, show a muted response and are more prone to preferential flow paths.

Instrument cluster and met station with snow depth sensors visible on masts.

30 cm TDR's were inserted diagonally for measuring the top 20 cm of soil moisture.



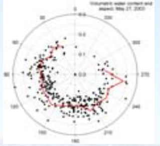
$$K = \left(\frac{tc}{2L}\right)^2$$



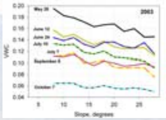
Soil moisture

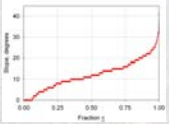
Soil moisture surveys

Synoptic surveys of soil moisture were carried out in the Teakettle Experimental forest as part of a comprehensive study on forest management. Soil moisture was measured at buried probes at multiple locations seven times over the water year using time domain reflectometry.

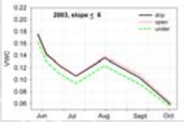


Volumetric water content by aspect, red line is mean (15 degree increments). Analysis of soil moisture data by aspect showed no patterns. This may be in part because there were no north aspects in the study area, which is largely southwest facing.





Soil moisture was consistently lower on steeper slopes than those with less slope in each survey, and decreased consistently through the water year with the exception of those conducted following a summer rain events.



Soil moisture was consistently lower under canopy than in the open, with values converging in late season after dry- down.

Conclusion

Synoptic snow surveys of at peak accumulation demonstrate consistent ablation patterns between above and below average years and significant differences between open and under canopy locations. The timing of infiltration from snowmelt in a forest is largely determined by the distance from and shading by tree canopies. Soil moisture prior to dry-down is consistently higher under canopies than in open locations and converges at the wilting point. While incoming radiation, slope aspect and soil conditions all play a role in these processes the spatial relationship to tree canopies is significant driver in the vadose zone hydrology.

Acknowledgements

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