Sources of variability in winter soil temperature moderation by mountain snowpacks

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Abstract: The insulation provided by seasonal snowpacks is an important controller of temperature in mountain soils, but the inter-annual variability of this effect and its significance across the landscape are not well understood. We analyzed recent records of snowpack and soil temperature from the NRCS SNOTEL network, a network of automated snow monitoring stations in the Rocky Mountains, to determine seasonal and topographic patterns in soil temperature, and their relationship to mountain snowpacks. These stations range in elevation between 1700m to almost 3500m and receive a mean peak snow water equivalent between 200 and 1200mm. Among these sites, we found that mean surface soil temperature during winter months are several degrees warmer than mean air temperatures, and that winter soil temperature declines less with elevation than the air temperature lapse rate. At individual sites, a late onset of persistent snowcover was associated with low-temperature events in the fall, and lower soil temperature during subsequent winter months. Across all sites, low December snowpacks were associated with lower soil temperature. At most sites, winter soil temperature at 5 and 20cm depths averaged between -2°C and 2° C, a temperature range at which below-snow organisms have shown great sensitivity. This analysis suggests that the moderating effect of seasonal snowpacks on winter soil temperatures varies significantly with elevation and across inter-annual timescales. This may have important implications for ecosystem processes that take place below the snowpack.

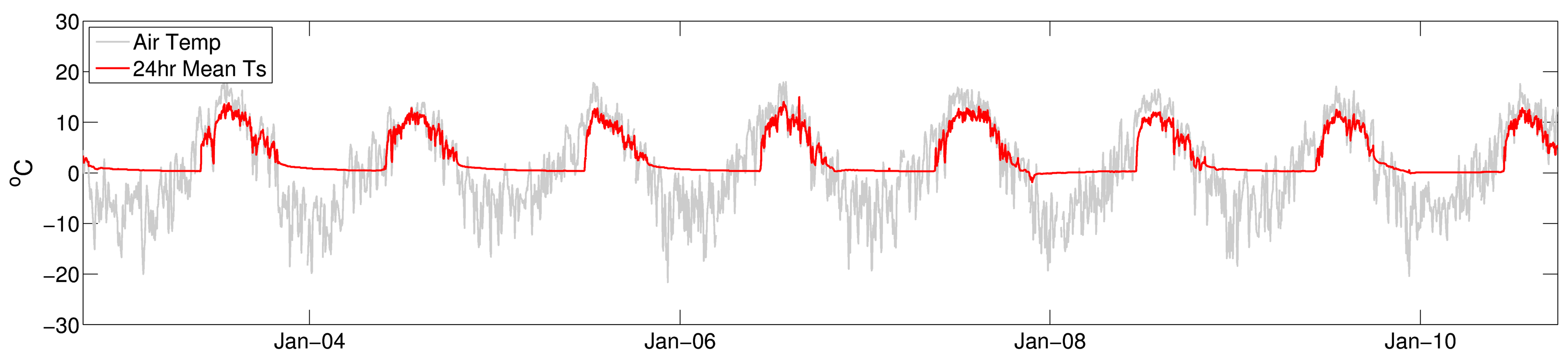


Figure 1. A multi-year timeseries from a typical SNOTEL site (Trial Lake, Uinta Mtns., UT). Soil temperature (red) follows the seasonal pattern of air temperature during summer, but winter soil tempatures are decoupled from atmospheric temperatures.

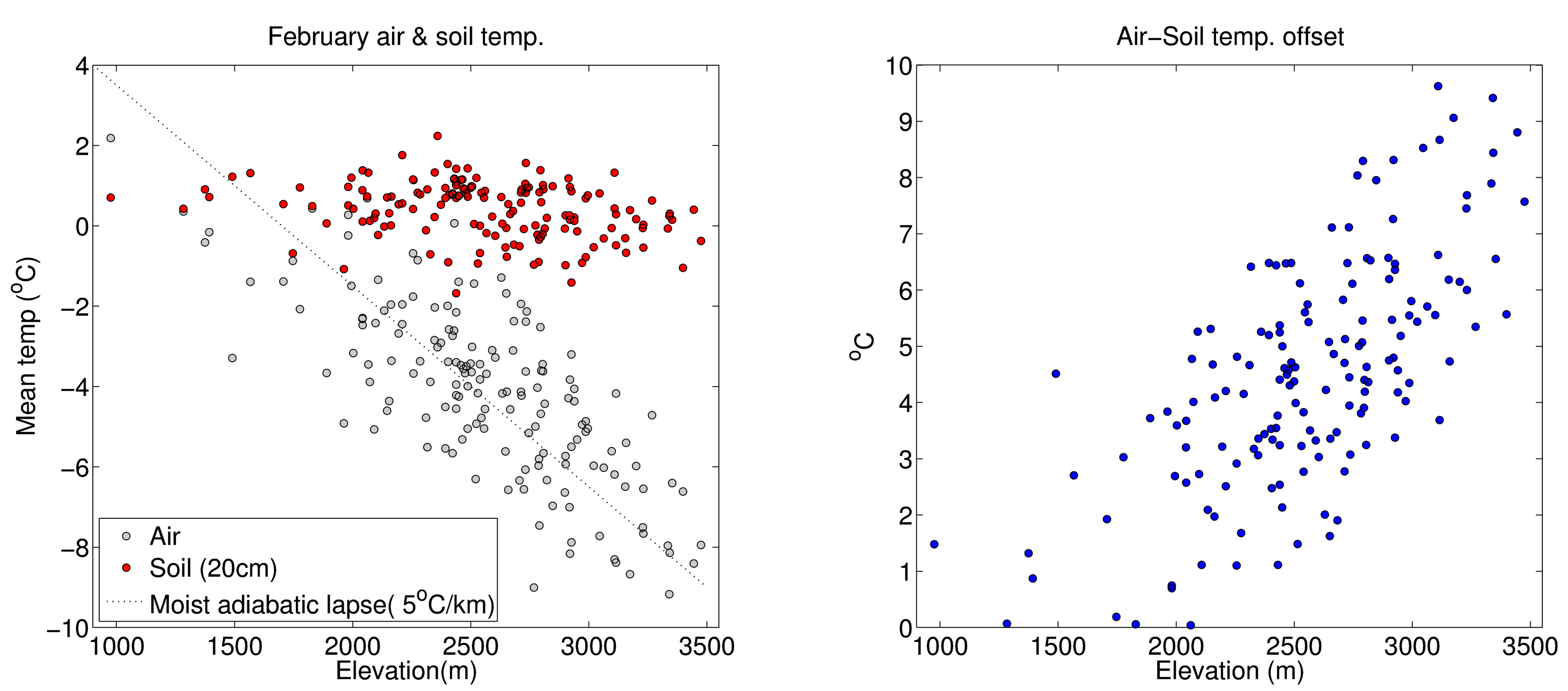


Figure 2. Soil temperature is much warmer than air temperature above the snowpack during winter and it averages between -2 and 2º C in February. The amount of temperature offset between mid-winter air and soil temperature increases with elevation. Multi-year February averages shown for CO, ID, NV, UT, WY SNOTEL sites.

Conclusions and significance: We found decoupling between surface soil temperature and air temperature in the presence of a snowpack, and considerable year-to-year soil temperature variability that depends on the accumulation of seasonal snowpacks. Numerous studies have demonstrated high rates of winter soil organic matter decomposition and soil respiration in montane and sub-alpine forests in this region, and high temperature sensitivity in the near-zero ºC range among the microbial communities responsible for these ecosystem processes[1,2]. We hypothesize that seasonal and inter-annual variability in winter soil temperature has significant effects on the rate of biological activity below snow, and that this influences annual ecosystem carbon balance at a site.

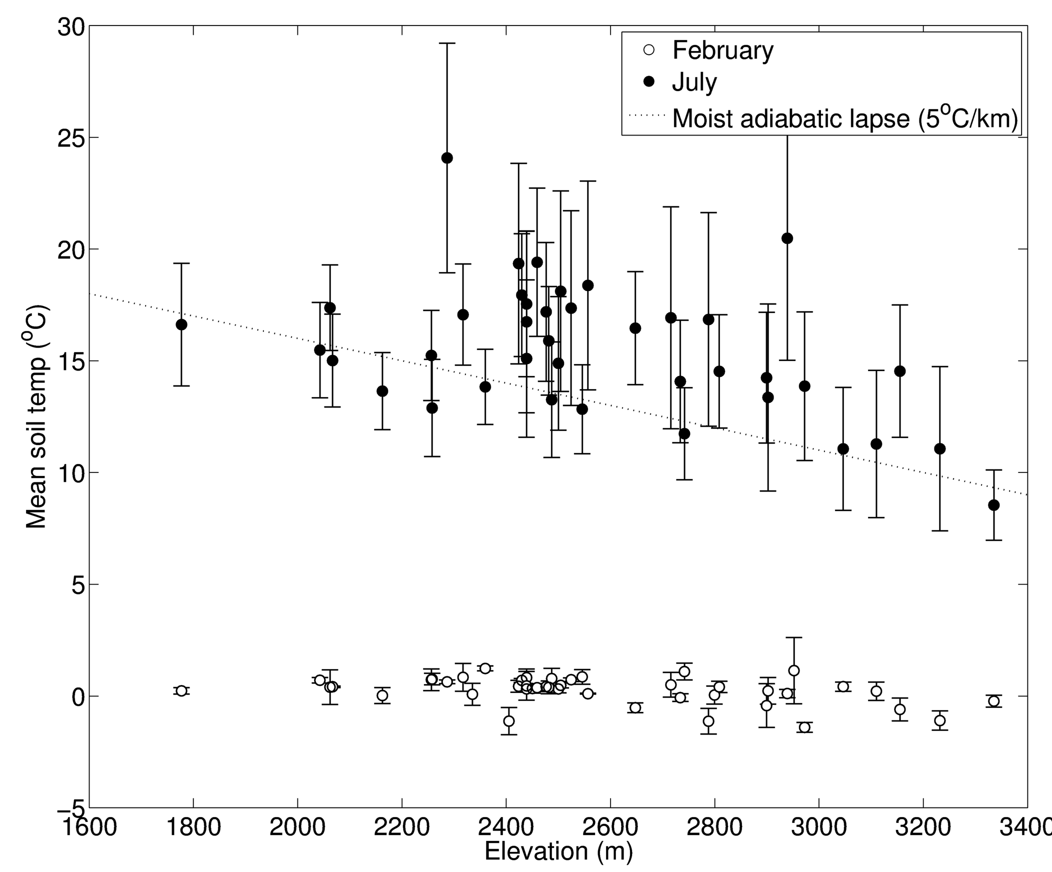
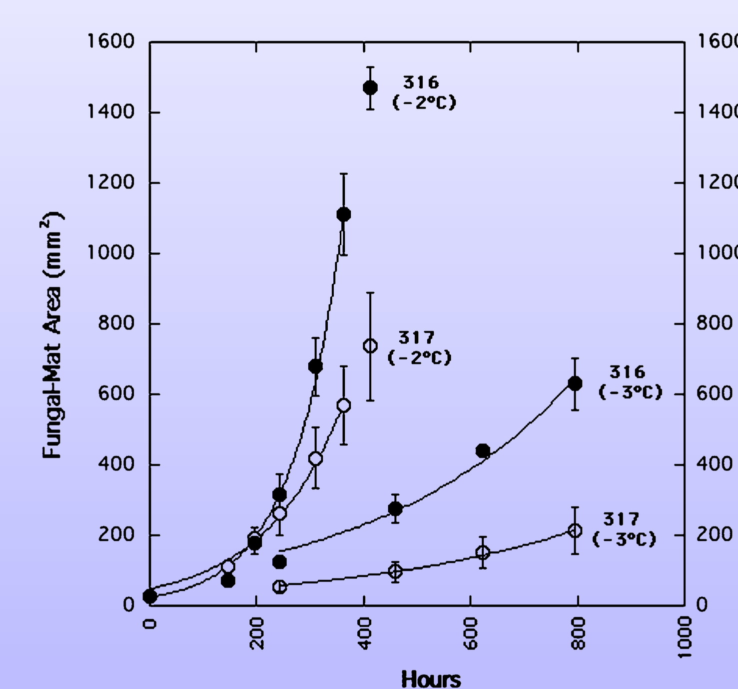
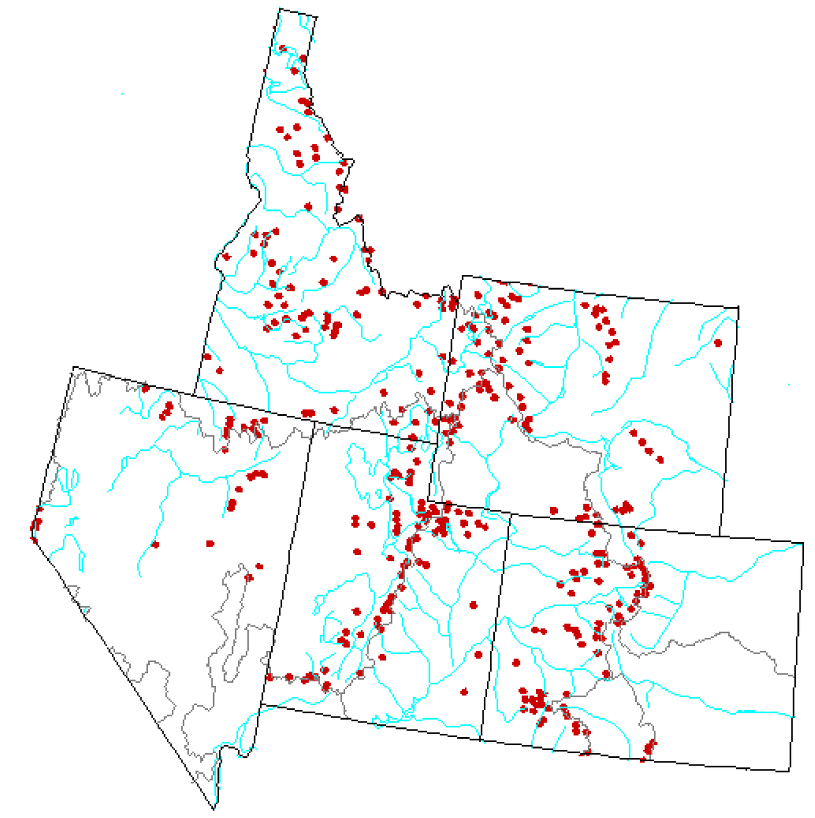


Figure 3. Because soils are decoupled from the atmosphere below snowcover, soil temperature is similar at sites along an elevation gradient. This is in contrast to the same sites during snow-free periods, when soil temperature roughly follows the adiabatic lapse rate (as does air temp). Each datapoint represents the mean and std. deviation of all July or February measurements in a multi-year site timeseries. Only Utah SNOTEL sites shown.

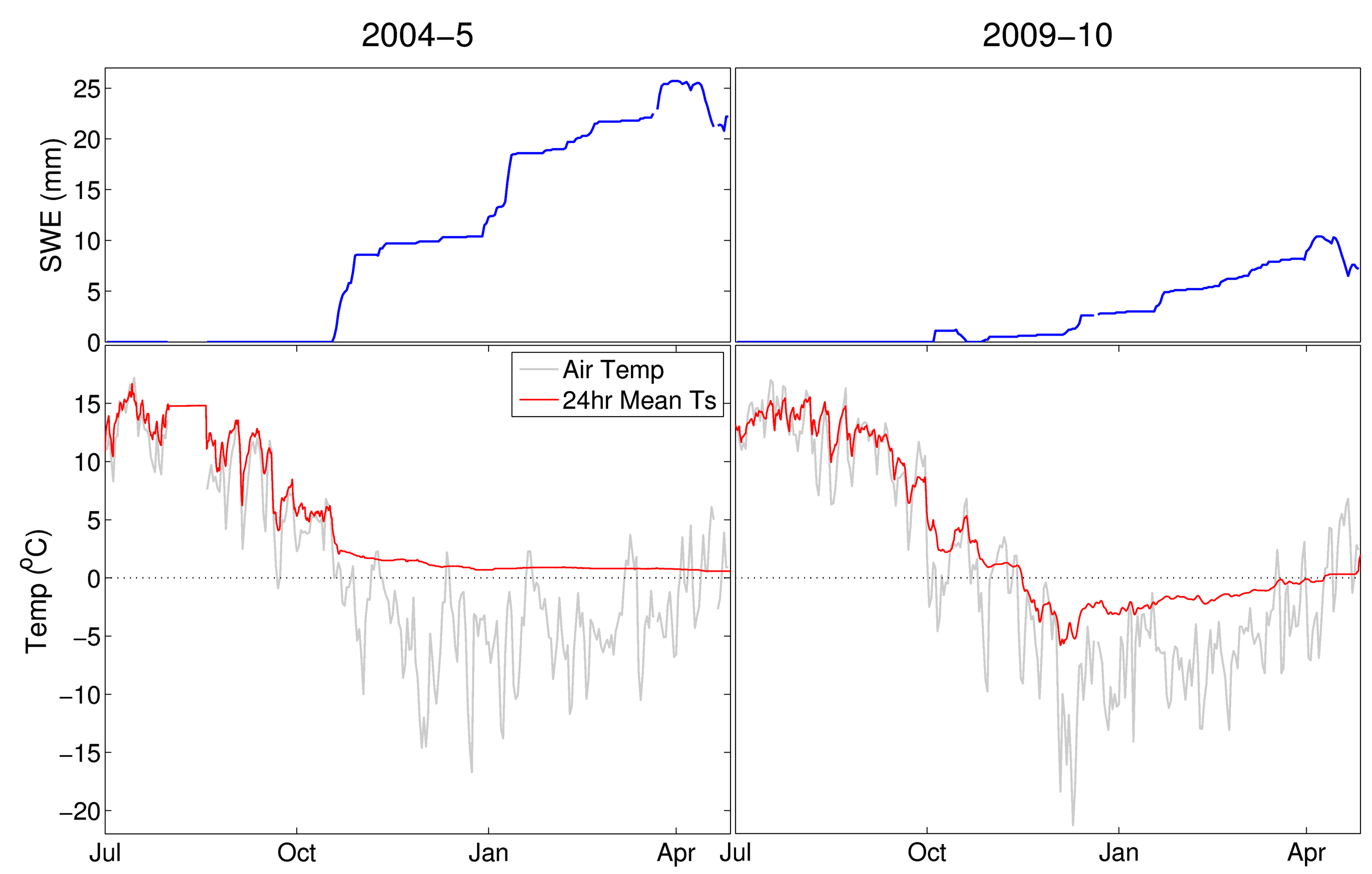
Figure 6. Below-snow microbial communities are active at low temperatures and are highly sensitive to changes in soil temperature. The figure at right shows exponential growth rates in two fungal isolates at both -3 and -2º C. Growth rate for both isolates increases significantly with a 1ºC temperature increase. This figure is from a study of fungal isolates collected below a spring snowpack at Niwot Ridge LTER[2].





Methods: This study was conducted using data from the NRCS SNOTEL Network, a network of environmental monitoring stations in the mountains of the western U.S. In addition to standard meteorological measurements, these stations make continuous measurements of snow water equivalent (SWE) using a snow pillow, snow depth using an ultrasonic depth sensor, soil temperature, and soil water content at multiple depths (Stevens HydraProbe). Data from sites at elevations between 1560 and 3487m in Utah, Idaho, Colorado, Wyoming, and Nevada were used in this analysis. Datasets were obtained directly from the National Resources Conservation Service Snow Survey website (http://www.wcc.nrcs.usda.gov/snow/).

Figure 4. Low early-winter snowpack accumulation can lead to soil frost and low soil temperature for much of the winter. At this site, soil temperature was decoupled from air temperature due to heavy snowfall by mid-October 2005. In 2009, decoupling did not occur until late December, resulting in early season soil low-temperature events, and colder than average temps for much of the remaining season. Mosby Mountain SNOTEL, 2899m, Uinta Mtns., Utah.



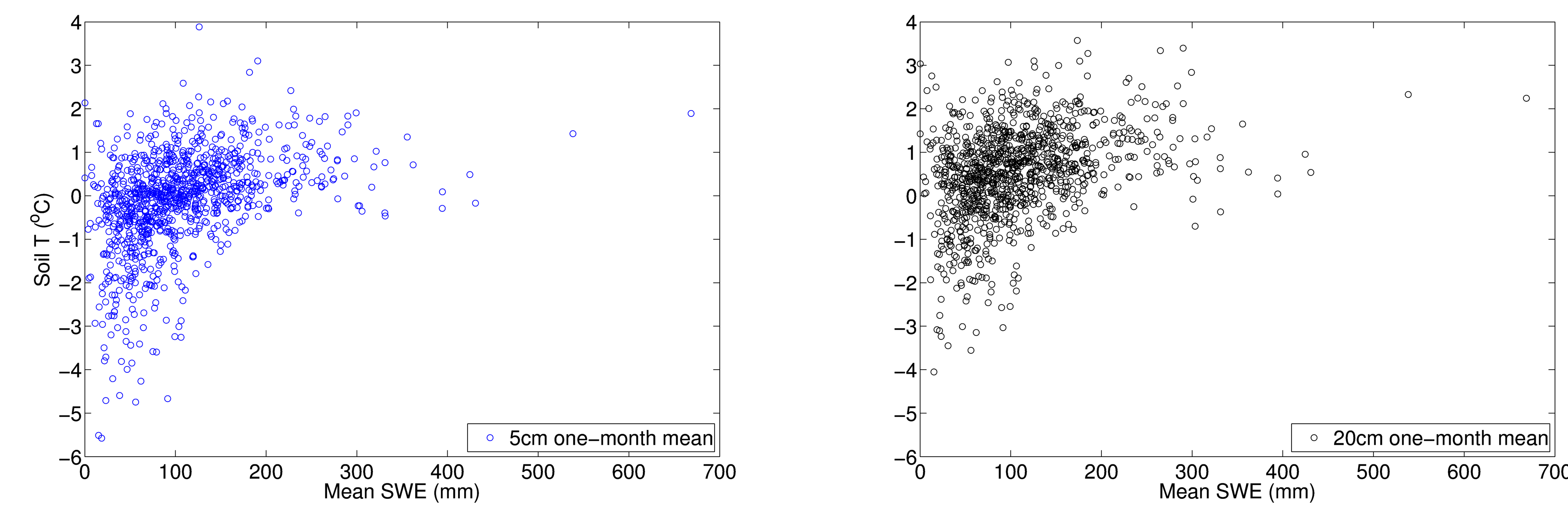


Figure 5. Late development of seasonal snowpacks can lead to low winter soil temperature. Each datapoint represents mean December soil temperature at a site during an individual year (sites appear multiple times). December soil temperature tends to be lower in low-snow years.

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References:

1. Monson, R.K. et al. Winter forest soil respiration controlled by climate and microbial community composition. Nature 439, 711-714 (2006).
2. Schmidt, S.K., Wilson, K.L., Monson, R.K. & Lipson, D.A. Exponential growth of "snow molds" at sub-zero temperatures: An explanation for high beneath-snow respiration rates and Q 10 values. Biogeochemistry 95, 13-21 (2009).