RELATIONSHIP BETWEEN CLIMATIC CONDITIONS AND SOIL PROPERTIES AT SCAN AND SNOTEL SITES IN UTAH

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ABSTRACT

To improve our understanding of the influence of climatic conditions on soil properties, long-term in-situ monitoring is essential. The United States Department of Agriculture's Natural Resources Conservation Service's National Water and Climate Center has established a nationwide network of climate monitoring stations known as the Soil Climate Analysis Network (SCAN) and Snowpack Telemetry (SNOTEL) Network. Both SCAN and SNOTEL provide real-time soil moisture and temperature data coupled with additional climate information for use in natural resource planning, drought assessment, water resource management, and resource inventory. The stations are remotely located and collect hourly atmospheric and soils data that are available to the public online. Above and below ground climatic conditions are well documented in Utah with 35 SCAN and 97 SNOTEL stations. Research at high elevation sites (>2500 m) reveals that snow water equivalent and snow depth have profound effects on soil temperature patterns. Along an elevational gradient in the Uintah Mountains in northeastern Utah, soil temperature is not proportional to air temperature under snowpack due to differences in snow accumulation. Additional research at middle elevation sites (2000 m) explains how vegetation communities are impacted by differences in edaphic properties across short distances. Data collected at SCAN and SNOTEL stations are used primarily to forecast water supply in the west, improve irrigation efficiency, and indicate the presence of drought conditions, however, the collection of climatic data, such as these, is integral to managing the agricultural and environmental needs we face now and into the future. (KEYWORDS: Soil, climate, snow water deficit, soil temperature, soil moisture)

INTRODUCTION

The United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), National Water and Climate Center has established a nationwide network of climate monitoring stations known as the Soil Climate Analysis Network (SCAN) as well as a west-wide network of Snowpack Telemetry (SNOTEL) stations (fig. 1). The SCAN and SNOTEL networks provide real-time soil moisture and temperature data coupled with additional climate information for use in natural resource planning, drought assessment, water resource management, and resource inventory. The stations are remotely located and collect hourly atmospheric and soils data that are available to the public online. The standard SCAN site has a suite of sensors that measure air temperature, wind speed and direction, relative humidity, barometric pressure, precipitation, solar radiation, and soil moisture, temperature, and dielectric constant at 5, 10, 20, 50, and 100 cm. The standard Utah SNOTEL site measures, air temperature, relative humidity, snow depth, snow water equivalent (SWE), and soil moisture, temperature, and dielectric constant at 5, 20, and 50 cm.

Soil properties at SCAN and SNOTEL sites are directly influenced by the site-specific climatic conditions. The objectives of this research were to elucidate the complexity of the relationships between soil and climate by examining 1) the insulating effects of snowpack on soil temperature across an elevational gradient, 2) the role of vegetation in influencing the formation of soil morphological features and soil moisture patterns, and 3) how calculations of soil moisture deficit can improve runoff estimates in conjunction with water supply forecasting.

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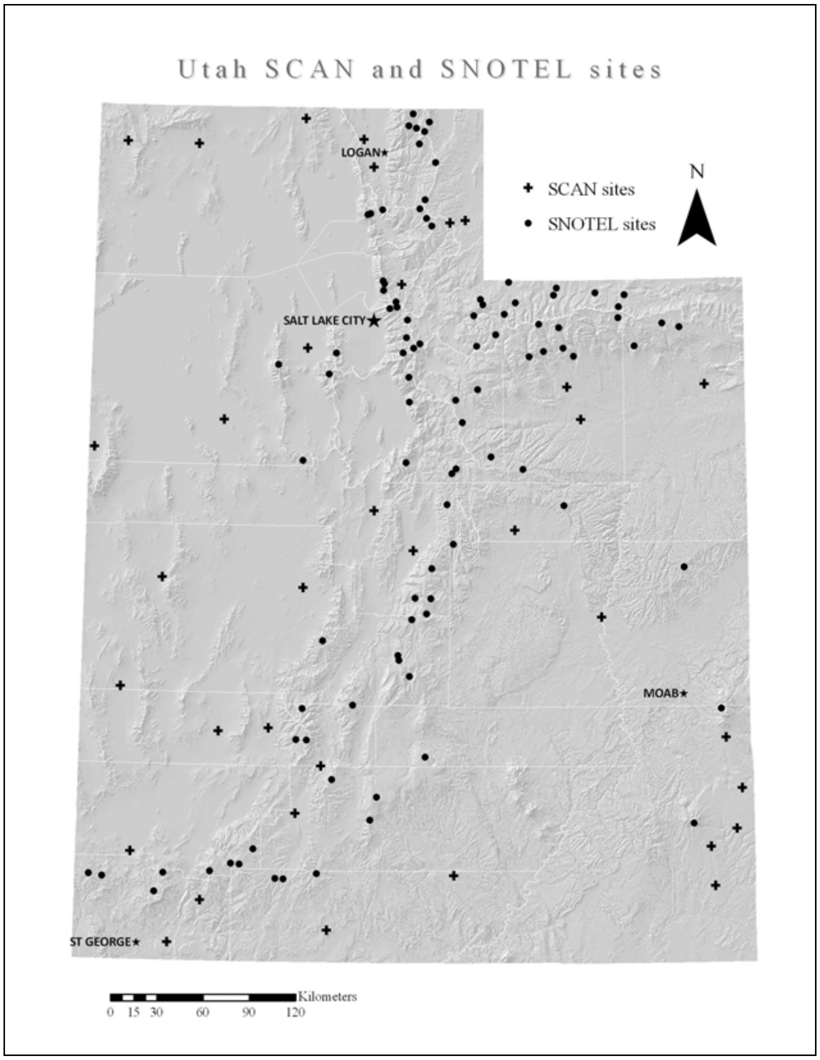

Figure 1. Location of Soil Climate Analysis (SCAN) and Snowpack Telemetry (SNOTEL) sites throughout Utah

INSULATING EFFECTS OF SNOWPACK ON SOIL TEMPERATURE

Methods

Three SNOTEL sites in the northern Uintah Mountains were selected for this study, Chepeta at 3200 m, Hewinta at 2900 m, and Hole in Rock at 2600 m. Soil temperature at 5, 20, and 50 cm were measured using Stevens Hydraprobes (Portland, OR) connected to CR10X dataloggers (Campbell Scientific Inc., Logan UT); air temperature and relative humidity were measured using HMP45 thermistors (Vaisala Inc., Helsinki, Finland); and snow depth was measured using ultrasonic depth sensors (Judd Communications, Salt Lake City, UT). Daily soil temperature, air temperature, and snow depth were analyzed from the 2006, 2007, 2008, and 2009 water years (October 1 through September 30). Snow depths were classified as less than 5 cm, 5 – 20 cm, or greater than 20 cm.

Results and Discussion

The mean annual air temperature (MAAT) is inversely proportional to elevation with mean values of 0.9°C at Chepeta, 2.3°C at Hewinta, and 3.2°C at Hole in Rock (table 1). Mean snowpack between November and April is proportional to elevation with greater snowpack at higher elevations, 78 cm at Chepeta, 52 cm at Hewinta, and 34 cm at Hole in Rock. Conversely, soil temperature does not follow a similar trend. SNOTEL sites that maintain deeper snowpack are typically at higher elevations and have lower air temperatures, however, these more consistent snow packs lead to higher soil temperatures. The mean annual soil temperature at 50 cm ($MAST_{50}$) at the highest elevation is nearly the same as at the lowest elevation. The greatest $MAST_{50}$ was observed at the middle elevation site. Based on these data, soil temperatures are moderated by the insulating effects of snowpack. Figure 1 displays the daily air temperature, daily soil temperature at 50 cm, and periods of snow cover at the three SNOTEL sites. A thicker, more consistent snowpack greatly influences the soil temperature throughout the snow covered period. As shown through data collected at three SNOTEL sites, soil temperatures remain warmer under greater snow packs (fig. 3).

Table 1. Summary of data from Chepeta, Hewinta, and Hole in Rock SNOTEL sites

Site name	Elevation	MAAT*	$MAST_{50}$#	Mean Nov-Apr snowpack^
	m	*°C*	*°C*	*cm*
Chepeta	3200	0.9	3.2	78
Hewinta	2900	2.3	4.3	52
Hole in Rock	2600	3.2	3.1	34

*mean annual air temperature
#mean annual soil temperature at 50 cm
^mean snow depth between April 1 and November 30

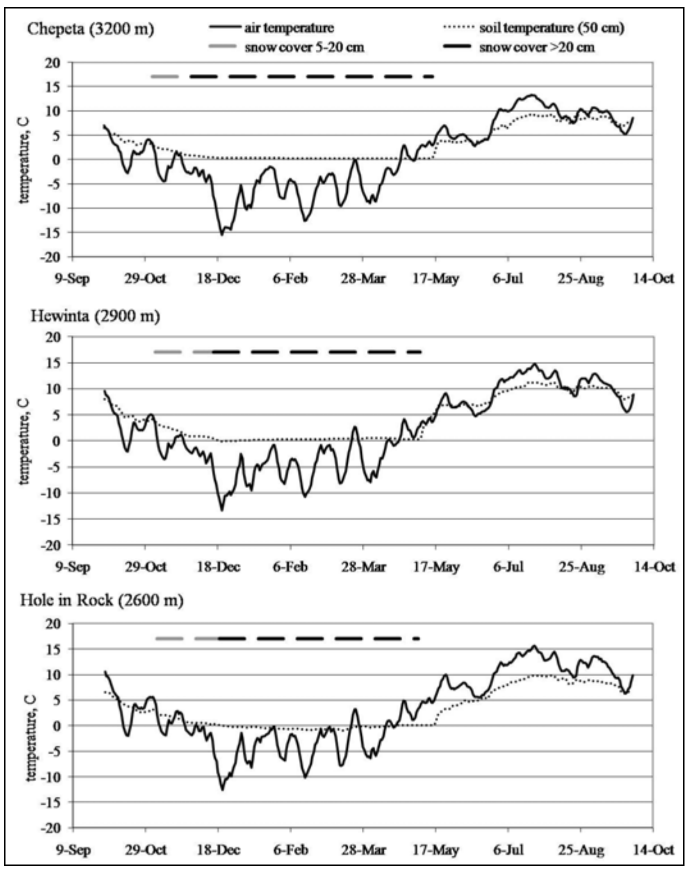

Figure 2. Air temperature, soil temperature at 50 cm, and snow cover throughout the 2009 water year at Chepeta, Hewinta, and Hole in Rock SNOTEL sites. Gray dashed line indicated snow cover between 5 and 20 cm while black dashed line indicates snowpack greater than 20 cm thickness.

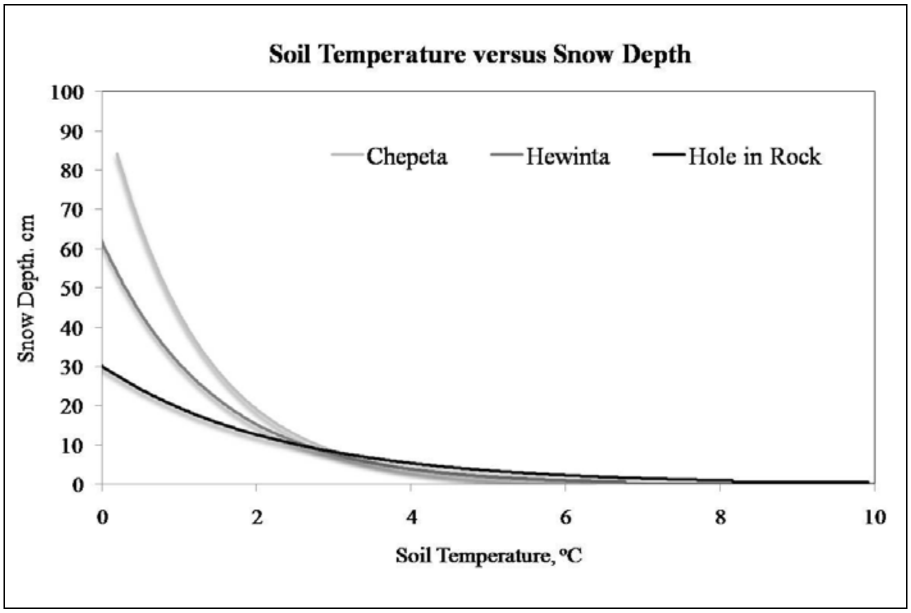

Figure 3. Soil temperature at 50 cm versus snow depth at Chepeta, Hewinta, and Hole in Rock SNOTEL sites. Solid lines indicate the best fit line for three years of data when snow depth was greater than 0 cm.

Changes in soil temperature influence decomposition rates, primary productivity, nutrient availability, carbon cycling, microbial diversity, and plant communities. If climatic conditions change and air temperatures increase, the rain/snow boundary will rise, leading to an increase in the length of snow-free season and as a result, the soil temperatures in some mountainous areas may decrease leading to reduction in microbial activity and a resultant decrease in carbon dioxide evolution. Alternatively, if air temperatures rise, soil temperatures at the lower elevations may increase resulting in a net gain in microbial activity and carbon dioxide evolution.

EDAPHIC FACTORS INFLUENCING VEGETATION COMMUNITIES

Methods

Two contrasting vegetation communities, rangeland and aspen, were identified within 100 m of one another along a hillside with a southern aspect in Morgan Count, Utah. Both soils were formed from colluvium over residuum. The rangeland site was instrumented with a standard Soil Climate Analysis Network suite of sensors, including, air temperature, relative humidity, precipitation, barometric pressure, wind speed and direction, solar radiation, and soil moisture and temperature at 5, 10, 20, 50, and 100 cm. The aspen site was instrumented with a snow depth sensor and soil moisture and temperature sensors at 5, 10, 20, 50, and 100 cm. Hourly data are transmitted via meteorburst radio communications. Soil profiles were described and sampled in August 2009 according to standard soil survey procedures (Schoeneberger et al. 2002; Soil Survey Staff, 2010).

Soil Morphology Discussion

The soil under rangeland vegetation is classified as fine-loamy mixed active Typic Argicryolls while under aspen, the soil is fine-loamy mixed active Pachic Palecryolls. The rangeland soil has a 28-cm thick mollic epipedon while the mollic epipedon in the aspen soil is 91-cm thick. A mollic epipedon is a means to classify a soil surface with high base saturation and accumulation of organic carbon (Soil Survey Staff, 2010). The thicker mollic epipedon under aspen vegetation indicates biomass productivity in excess of decomposition. The rangeland soil was slightly to violently effervescent throughout the profile while the aspen soil was non-effervescent to 128 cm and violently effervescent below. This indicates translocation of calcium carbonate through the aspen soil profile and less movement of calcium carbonate through the rangeland soil. Greater water movement through the aspen soil is likely responsible for the increased translocation.

Soil Climate Discussion

Soil moisture content at 5, 10, 20, 50, and 100 cm are generally greater under aspen vegetation than rangeland vegetation (Figure 4, 10-cm data not shown). The aspen dominated site likely receives greater effective precipitation due to drifting of snow as well as its location in a drainage pathway across the hill-slope. Aspen trees prefer a wetter environment than rangeland vegetation and therefore thrive in soil with higher water content. The topography of the aspen site likely led to the increase in drainage that may have initially favored aspen trees and other water tolerant vegetation. The wind break created by the large trees likely led to the snow barrier across the hill-slope, further increasing soil moisture. Because the monitoring station has been in only a short time, results concerning differences in soil climate will be forthcoming.

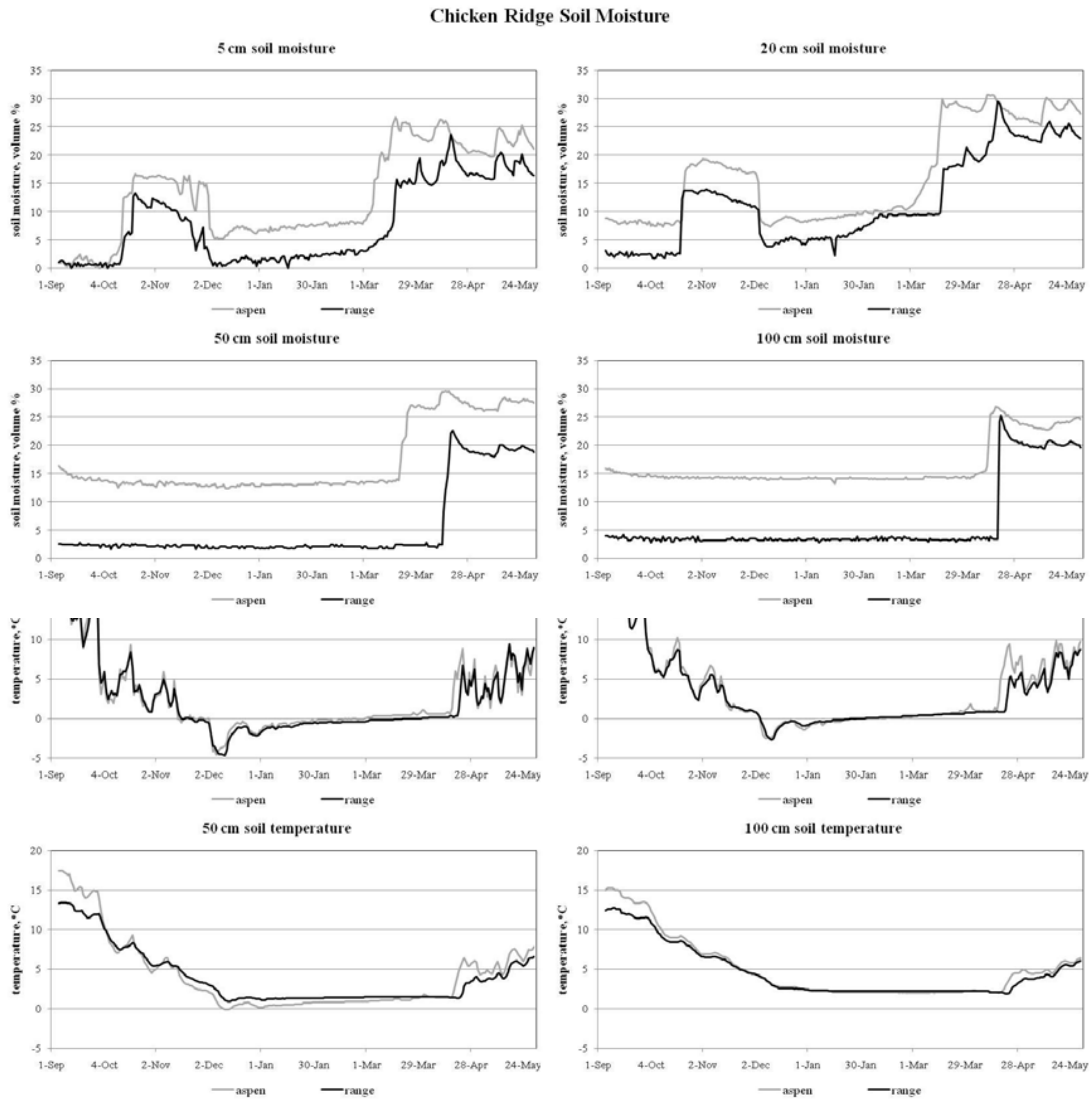

Figure 4. Soil moisture and soil temperature at Chicken Ridge station at various depths

Volumetric Water Content and Snow Water Equivalent

Hourly soil volumetric water content at 5, 20, and 50 cm were collected at SNOTEL sites in Utah using Stevens Hydraprobes (Portland, OR) connected to CR10X dataloggers (Campbell Scientific, Logan UT)(Table 2). Snow water equivalent was collected hourly using a pressure transducer (Sensotec, Columbus, OH). In order to generate percent saturation and water content in the soil profile, soil bulk density was assumed to be 1.2 g cm^{-3} for all horizons and particle density was assumed to be 2.65 g cm^{-3}. Percent saturation was calculated:

(eq.1) $$\frac{D_p - D_b}{D_p} = \%sat$$

where Dp is particle density (g cm^{-3}), Db is soil bulk density (g cm^{-3}), and %sat is the percent of water required to equal saturation. Percent of saturation was calculated:

(eq.2) $$\frac{\%sm}{\%sat} = \%ofsat$$

where %sm is measured volumetric water content (%) and %ofsat is the percent of saturation for that soil. Water in profile was calculated for a 76 cm (30-inch) profile:

(eq.3) $$(depth \times \%sat) \times \%ofsat = water\ in\ profile$$

where depth is the depth of the soil profile (cm) and water in profile is the amount of water (cm) in the corresponding profile depth. Soil water deficit (SWD) was calculated:

(eq.4) $$(depth \times \%sat) - water\ in\ profile = SWD$$

where depth is the depth of the soil profile (cm), water in profile is the amount of water (cm) in the corresponding profile depth, and SWD is the soil water deficit (cm) or amount of water that would be required to reach saturation. Minimum potential runoff was calculated:

(eq.5) $$SWE - SWD = MPR$$

where SWE is the measured snow water equivalent (cm), SWD is the soil water deficit (cm), and MPR is the minimum potential runoff (cm).

RESULTS AND DISCUSSION

Minimum potential runoff values were calculated for all SNOTEL sites in Utah. Select values are displayed in Table 2. The minimum potential runoff is the least amount of water expected to runoff after all pore space within the soil has filled with water. This assumes the rate of infiltration into the soil exceeds the rate of snow melt and does not account for water loss via sublimation. These values will be compared to previous years calculated values in order to develop a relative understanding of conditions for the current year. These values can be used by forecasters and hydrologists to advance our understanding of watershed dynamics with respect to climate change as well as improve streamflow forecasts and predict flood, debris flow, and drought conditions. Calculated minimum potential runoff should not be used as an absolute value due to the estimation and assumptions involved.

Table 2. Soil water content, percent of saturation, amount of water in profile, snow water equivalent, and minimum potential runoff for select SNOTEL sites.

Site Name	Soil moisture	Percent of saturation*	Water in profile*	Soil water deficit*	Snow water equivalent	Min. potential runoff*
	volume %	*%*	*cm*	*cm*	*cm*	*cm*
Snowbird	11.6	21.2	8.8	32.8	69.3	36.5
Temple Fork	10.3	18.8	7.8	33.8	28.7	0
Long Flat	9.0	16.4	6.8	34.8	39.4	4.6
Camp Jackson	30.4	55.6	23.1	18.5	56.4	37.9
Five Points Lake	9.7	17.7	7.4	34.2	34.3	0.1
Ben Lomond Trail	25.5	46.6	19.4	22.2	33.8	11.6
Burts Miller Ranch	39.0	71.2	29.6	32.5	32.8	0.3

*Assumptions: saturation = 1 – (bulk density / particle density); bulk density = 1.2 g cm^{-3}; particle density = 2.65 g cm^{-3}; infiltration rate exceeds rate of snowmelt.

SUMMARY

Climatic conditions aboveground directly influence conditions belowground. By examining the relationship between atmospheric and soil climatic conditions and soil properties, an improved understanding of their relationship will be achieved. Snowpack has profound impacts on soil temperature patterns and should therefore be used as an indication of biological activity coupled with large-scale climate change. High elevation, snowfall dominated ecosystems maintain similar soil temperatures in the winter to lower elevation sites that receive considerably less snow. Soils formed in similar parent material develop unique morphological features due to variations in climatic conditions, such as moisture and temperature. As a result, distinct vegetation communities may grow within close proximity to one another. The calculation of soil water deficit will be used to improve water supply forecasting in the western United States. Further investigation is required to examine these impacts.

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