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Soil, snow, weather, and sub-surface storage data from a mountain catchment in the rain–snow transition zone

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Abstract

A comprehensive hydroclimatic data set is presented for the 2011 water year to improve understanding of hydrologic processes in the rain-snow transition zone. This type of dataset is extremely rare in scientific literature because of the quality and quantity of soil depth, soil texture, soil moisture, and soil temperature data. Standard meteorological and snow cover data for the entire 2011 water year are included, which include several rain-on-snow events. Surface soil textures and soil depths from 57 points are presented as well as soil texture profiles from 14 points. Meteorological data include continuous hourly shielded, unshielded, and wind corrected precipitation, wind speed, air temperature, relative humidity, dew point temperature, and incoming solar and thermal radiation data. Sub-surface data included are hourly soil moisture data from multiple depths from 7 soil profiles within the catchment, and soil temperatures from multiple depths from 2 soil profiles. Hydrologic response data include hourly stream discharge from the catchment outlet weir, continuous snow depths from one location, intermittent snow depths from 5 locations, and snow depth and density data from ten weekly snow surveys. Though it represents only a single water year, the presentation of both above and below ground hydrologic condition makes it one of the most detailed and complete hydro-climatic datasets from the climatically sensitive rain-snow transition zone for a wide range of modeling and descriptive studies. Data are available at doi:10.1594/PANGAEA.819837.

1 Introduction

Detailed weather, soils, and hydrologic response data are presented that provide a whole-catchment view of the dynamic hydrology that occurs in the mountain rain-snow transition zone. The rain-snow transition zone is the elevation band in temperate mountains where winter precipitation is predominately rain below and snow above this region. Rain or snow can fall anywhere within this zone. Precipitation can transition between phases during storms, but the snowline exists within the rain-snow transition zone. It may approach sea level at high latitudes (Feiccabrino et al., 2012), but can frequently extend above 2000 m at lower latitudes (Cayan et al., 2001). In the interior Pacific Northwestern US, where this data collection effort was conducted, the rain-snow transition typically occurs in mid-elevations ranging from 1500–1800 m (Nayak et al., 2010). Nolin and Daily (2006) estimated that currently the rain-snow transition zone covers approximately 9200 km^2 in the Pacific Northwest. This is a region where warming trends are expected to shift the current precipitation regime toward being rain-dominated and move the rain-snow transition to higher elevations.

The mountain rain-snow transition region is an important area for study because it is sensitive to warming trend effects on the snow cover (Mote, 2003) and ecosystems (Cayan et al., 2001; Cuo et al., 2011). The snow cover in this zone is sensitive to climate warming trends because it is generally warm and ephemeral. The presence or absence of snow impacts the energy and mass balance because it dictates whether incoming solar radiation is reflected or absorbed. Since precipitation can be deposited as either rain that is rapidly transmitted to the soil, or snow that delays the delivery of liquid water to the soil, changes in the precipitation phase translate directly to changes in the timing of water inputs to catchment soils. Weather and soil data sets have been published from rain-dominated (Western and Grayson, 1998) and snow-dominated areas (Reba et al., 2012; Seyfried et al., 2001a, b; Morin et al., 2012), but there is a general lack of data from the rain-snow transition zone.

Seven significant ROS events, which are known to create large amounts of runoff from the combined volume of rain and rapid melt, were recorded in the data presented in this paper. ROS events often contribute to record floods (Surfleet and Tullos, 2013; Marks et al., 1998; Kattelmann, 1996; McCabe et al., 2007; Harr, 1986; Sui and Koehler, 2001) and can cause major avalanche cycles (e.g. Conway and Raymond, 1993). One of the ROS events presented here caused the peak measured stream discharge (1998–2013) for this study catchment. ROS events in this region are common, but having them occur over a specific site under optimal measurement conditions is a matter of timing and luck. For example, Marks et al. (2013) established a transect of measurement sites every 50 m across 380 m of elevation (1488–1868 m) to monitor the transition between rain and snow. Though there were many precipitation occurrences, only a few significant mixed phase events were directly measured during the ten years that the transect was operated (2004–2013).

Catchment data are presented for the Treeline (TL) experimental catchment for the 2011 water year (WY2011: 1 October 2010–30 September 2011) (Fig. 1). The study area is unique because it is located at both a climatic transition between rain and snow, and a vegetation transition between shrub lands and forests. The catchment is instrumented specifically to quantify the distribution of precipitation, snow cover, and soil moisture. Table 1 summarizes the hydro-meteorological parameters presented and Fig. 1 locates catchment instrumentation. Table 2 summarizes the distributed watershed data presented.

The dataset provides a high-resolution, fine-scale set of observations that offer a broad spectrum of researchers the opportunity to study a host of topics associated with water storage and flux in a small catchment. Model developers can use distributed soil and topographic data to obtain state variables, weather data to drive, and snow, soil moisture, and streamflow data to evaluate model performance. Detailed topographic data combined with soil moisture measurements can be used to evaluate topographic indices common to many empirical streamflow modeling approaches (O'Loughlin, 1981, 1986; Beven and Kirkby, 1979). Soil moisture redistribution algorithms that account for diffuse and preferential flow can be tested to evaluate the timing of soil moisture responses at depth. Traditional watershed hydrology methods, such as annual water balances, can be used to make generalizations on geographic regions and watershed classifications (Wagener et al., 2007).

2 Catchment description

TL is a 1.5 ha catchment of the Dry Creek Experimental Watershed (DCEW) established in 1999 to study hydrologic processes in semiarid mountains. The extent of TL is defined by the location of a v-notch weir where catchment streamflow is measured (Fig. 1). The elevation ranges from 1600 to 1645 m a.s.l. and the mean slope is 21°. Vegetation is typical of a transition between lower elevation grasslands and higher elevation forests, with steep slopes and stark differences between aspects (Williams et al., 2009). The northeast facing slope is typified by sagebrush, *ceanothus* shrubs, *prunus* ssp., forbs, and grasses with a mean canopy height of 0.7 m. Southwest facing slopes have similar but sparser vegetation with a mean height of 0.3 m. There are 8 mature conifer trees in the catchment. Soils are thin (20–125 cm), range from loam to sandy-loam, and overlie fractured granitic bedrock (Gribb et al., 2009; Yenko, 2003). Basins with ephemeral streams such as TL are important sources of groundwater recharge (Aishlin and McNamara, 2011). Several studies have shown aspect differences on soil properties (Geroy et al., 2011; Tesfa et al., 2009; Smith et al., 2011).

3 Weather data

Weather data represent typical hydrological model forcing data, and include precipitation, solar and thermal radiation, air temperature and humidity, wind speed and direction, and soil temperature. All weather data are hourly and serially complete for the entire WY2011. Data gaps have been filled using the most appropriate of either linear interpolation, or linear regression to nearby measurements of the same variable.

Precipitation. Shielded and unshielded precipitation were measured at TL using Belfort-type gauges (Hanson et al., 2001), filtered following Nayak et al. (2008), and wind corrected using the protocol of Hanson et al. (2004). Precipitation and the stream hydrograph from the outlet weir are shown in Fig. 2a. The phase of cumulative wind-corrected precipitation based on dew point temperatures is shown in Fig. 2b (Marks et al., 2013).

Incoming radiation. Solar radiation was measured by two pyranometers at the TL weather station. A continuous hourly data record was generated using data from the two instruments, but favoring the more recently calibrated Huxeflux NR01 (Table 1). Incoming thermal radiation was measured by the four-component radiometer. Gaps in the measured thermal radiation record were substantial (48 %) and were filled by directly substituting data from a pyrgeometer at 1720 m a.s.l. 3.8 km away within DCEW. For the few times when incoming thermal data from both DCEW pyrgeometers were missing (59 hourly observations between 1 December 2010 to 1 March 2011), a regression between TL data and data from Reynolds Mountain East (see Reba et al., 2011) in the Reynolds Creek Experimental Watershed was used ($r^2 = 0.73$). Reynolds Mountain East is a mountain catchment at a similar elevation and is within a similar hydro-climatic environment, approximately 60 km to the west. Figure 3a presents the water year time-series of incoming solar and thermal irradiance.

Air temperature and humidity. Air temperature (T_a) and relative humidity (RH) were measured at the TL weather station. T_a and RH were converted to dew point temperature (T_d) using methods developed by Marks et al. (1999), as applied and described by Reba et al. (2011). Figure 3b presents weekly minimum, maximum, and mean T_a and T_d for WY2011, which was a cooler year than average. The mean T_a was 7.9 °C compared to the period of record mean, which was 9.3 °C. The maximum T_a of 31.8 °C was reached in late August while the minimum air T_a of −18.1 °C was reached in late November. WY2011 was wetter than average with a mean T_d of −1.67 °C compared to the period of record mean of −2.24 °C. The maximum T_d of 14.1 °C was reached in July, while the minimum T_d of −23.8 °C was reached in November. The dew point temperature was close to zero for much of the winter, demonstrating the sensitivity of the precipitation phase at this study location to changes in humidity and temperature.

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Wind speed and direction. Wind speed (u) and direction (v) were measured at the TL weather station. Hourly u and v data are serially complete for WY2011. u ranges from 0 to 13.5 $\mathrm{m\,s^{-1}}$. Figure 3c presents daily u_{max}, u_{min}, and u_{avg} for WY2011. Wind speeds for WY2011 do not show a pronounced difference between storm and non storm time periods. Both have median values of approximately 1.5 $\mathrm{m\,s^{-1}}$. Storm v is typically out of the southwest and ranges from 175° to 250° during winter storms, which agrees with work in nearby areas (Winstral et al., 2013).

Soil temperature. Soil temperature profiles are measured at all profile depths from Pit_3 and Pit_4 (Fig. 1, Table 3). Figure 4a and b present mean daily soil temperature profile data from Pit_3 and mean daily snow depth respectively.

4 Spatial characterization data

Characterization data are used to define the structure, composition, land cover, soil structure and hydrologic properties of the TL catchment. These data provide the fine-scale detail required for modeling and hydrologic assessment.

4.1 Soil data

Soil depth and soil texture from the top 30 cm were obtained at 57 points across TL, representing the full range of exposures, slopes, and elevations in the catchment. Soil depths were measured by pounding a steel rod to refusal and soil texture was acquired by sieving core samples (mean sample size of 4.7 g) as described by Williams et al. (2009). In addition, soil texture data from several depths at 14 locations are presented. Soil moisture data is presented that is collocated with texture profiles at locations SD5, SU5, SU10, SU20, and SU30 as described in the hydrologic response section of this paper.

4.2 GIS data

Terrain elevation and structure are derived from an aerial LiDAR dataset acquired in 2009 and processed using Idaho State University's publicly available LiDAR processing tools (http://bcal.geology.isu.edu/tools/lidar) as described in Streutker and Glen (2006). The processed TL GIS data includes four components: (1) a 2.5 m bare earth digital elevation model (DEM), from which (2) the catchment boundary is derived, GIS layers of (3) vegetation height, and (4) instrument and soil measurement locations. Figure 5 presents a shaded relief image of the TL catchment, with overlying vegetation height.

5 Snow and hydrologic response data

5.1 Snow depth

Hourly snow depth was recorded by a depth sensor located mid-slope on the north-east facing slope (Fig. 1). These data were processed and cleaned, and are serially complete for WY2011. Figure 4b presents mean daily values for these data. Five additional ultrasonic snow depth sensors are located in a transect that covers the two dominant basin aspects (Fig. 1). Due to instrument malfunctions, only intermittent snow depth data from these 5 sensors are available from 19 January 2011 through melt-out (Fig. 4b).

5.2 Snow survey data

A series of ten weekly snow surveys was completed from 21 January to 24 March 2011. Surveys were designed to capture snow depth and snow water equivalent differences within the catchment (Winstral and Marks, 2013) based on LiDAR derived depth similarity classes (Shallcross, 2011). Between five and nine snow density samples were collected across the two predominant aspects on each survey day and were used to convert snow depth to SWE. Density measurements were taken with a federal-type tube, density cutter, or new snow tube depending on conditions (Judson and Doesken, 2000; Conger and McClung, 2009). Density measurements are depth-integrated values and vary greatly on days where new snow is deposited on both bare ground and on the preexisting snowpack. A minimum of 105 depths were recorded in five transects each week, and the use of a *Magnaprobe* (SnowHydro, http://www.snowhydro.com) for seven out of the ten surveys enabled the collection of an average of 250 depths. Table 4 presents the number and method of measurements for each survey. Snow depth is presented as gridded average data (Fig. 6). Gridded data also include the number of depth measurements and standard deviation at each grid cell.

5.3 Stream discharge

Stream discharge is derived from stage recorded with a pressure transducer in a V-notch weir at the catchment outlet. The stream that drains TL is intermittent and initiates in the fall when snow cover is established and dries out in early to mid summer. Due to equipment malfunctions, continuous stage measurements begin on 16 December and continue through the cessation of streamflow. Discharge was estimated for the period prior to 16 December from a series of manual measurements and by developing a relationship between stage at the TL weir and data from other nearby weirs within DCEW over the ten years of record. The average WY2011 stream discharge at the TL weir is 9.3 $\mathrm{L\,min^{-1}}$. The streamflow peak of record was caused by a ROS event on 16 January 2011, which resulted in a high flow of 449.3 $\mathrm{L\,min^{-1}}$. Figure 2a presents streamflow from the TL catchment.

5.4 Soil moisture

Soil moisture is recorded at 2 depths at 5 southwest facing soil moisture profiles and at 4 and 5 depths at 2 northeast facing soil pits (Fig. 1, Table 3). TL soil moisture dynamics is described by McNamara et al. (2005). The coarse texture of TL soils leads to relatively rapid drainage when field capacity is exceeded. The semi-arid plant community draws soil moisture down quickly during spring green-up, but is slowed by spring rain events. Data from Pit_3 and Pit_4 are hourly and serially complete. Figure 4c and d presents soil moisture data from Pit_3 on the northeast facing slope and profiles SD5, SU10, and SU20 on the southwest-facing slope. Shallow probes may be influenced by evaporation from the soil surface. Deepest sensors at all profiles were placed at the soil bedrock interface, and may measure soil moisture increased due to the collection of water at the soil–bedrock interface, or the influence of lateral flow from upslope contributing areas.

6 Data availability

All data presented in this paper are available from the PANGAEA® website (doi:10.1594/PANGAEA.819837). Included are readme files in each directory listing the data contents, a detailed description of data, and contact information for additional details.

7 Summary

Data presented in this paper are unique because (1) they capture complicated snow-soil-streamflow dynamics from the climatically sensitive rain-snow transition zone, and (2) they present a complete representation of the data required to characterize the hydrologic processes in this catchment. Spatial GIS data are derived from a LiDAR data set and represent the TL catchment topography and vegetation at a 2.5 m resolution. 57 surface soil texture data points and 14 soil texture profiles are presented. Hourly weather data have been gap-filled and are continuous. Snow cover data are extensive and include continuous snow depths from 6 locations and 10 detailed weekly snow surveys. Catchment response data include stream discharge at the basin outlet and soil moisture from multiple depths at seven locations in the basin.

Supplementary material related to this article is available online at http://www.earth-syst-sci-data-discuss.net/6/811/2013/essdd-6-811-2013-supplement.zip.

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Table 1. Hydro-meteorological parameters, type of instruments, and instrument heights from the Treeline experimental catchment in WY2011. Locations are denoted by WS – weather station, 4CR – four component radiometer, Npit3 – north soil pit 3, OF – outlet flume.

hydro-meteorological parameter	method/instrument	sensor height (m)
shielded precipitation (WS)	8 inch Belfort-type gauge with Alter Shield	2
unshielded precipitation (WS)	8 inch Belfort-type gauge	2
wind corrected precipitation	(Hanson, 2004)	2
wind speed (WS)	Met One WS 013	2
wind direction (WS)	Met One WD 023	2
air temperature (WS)	Vaisala HMP45AC	2
Humidity (WS)	Vaisala HMP45AC	2
incoming solar (WS)	Matrix Mk 1-G	2
incoming and outgoing solar (4CR)	Hukseflux NR01	2
incoming and outgoing thermal (4CR)	Hukseflux NR01	2
soil temperature (Npit3)	CS 107 thermistor	−0.05
stream discharge (OF)	Druck PDCR1830 in v-notch flume	na

Table 2. Distributed watershed data, number of sensors, type of instruments, and instrument heights from the Treeline experimental catchment for WY2011.

number	variable	measurement method	heights (m)
2 profiles	soil temperature	CS 107 thermistor	−0.05 to −1.00
2 profiles	soil moisture	CS 615 soil moisture probe	−0.05 to −1.00
5 profiles	soil moisture	CS TDR100 soil moisture probe	−0.09 to −1.01
1 sensor	snow depth	Judd depth sensor	2
5 sensors	snow depth	MaxBotix XL-MaxSonar EZ2 (self-made)	2
10 surveys	snow depth	various	na
10 surveys	snow density	various	na
57 points	soil depth	steel rod pounded to refusal	−0.24 to −1.25
57 points	soil texture	sieve and hydromoter	0.00 to −0.30
14 profiles	soil texture	sieve and hydromoter	0.00 to −0.81

Table 3. Soil profile names, aspects, and sensor depths.

profile name	aspect	sensor depths (cm)
Pit_3	N	5, 15, 60, 100
Pit_4	N	5, 15, 30, 45, 65
SD5	S	15, 101
SU5	S	9, 27
SU10	S	15, 52
SU20	S	12, 34
SU30	S	18, 70

Table 4. Summary of snow survey data including the date, and number and method of snow depth and density measurements.

survey date	number of snow depth measurements	method	number of snow density measurements	method
21 Jan 2011	108	manual probe	7	federal tube
28 Jan 2011	248	Magnaprobe	9	federal tube
4 Feb 2011	262	Magnaprobe	9	federal tube/new snow tube
11 Feb 2011	395	Magnaprobe	9	density cutter/new snow tube
18 Feb 2011	377	Magnaprobe	9	density cutter
25 Feb 2011	155	Magnaprobe	9	federal tube
4 Mar 2011	349	Magnaprobe	7	federal tube
11 Mar 2011	105	manual probe	8	federal tube/density cutter
17 Mar 2011	300	Magnaprobe	6	federal tube
24 Mar 2011	245	Magnaprobe	5	federal tube

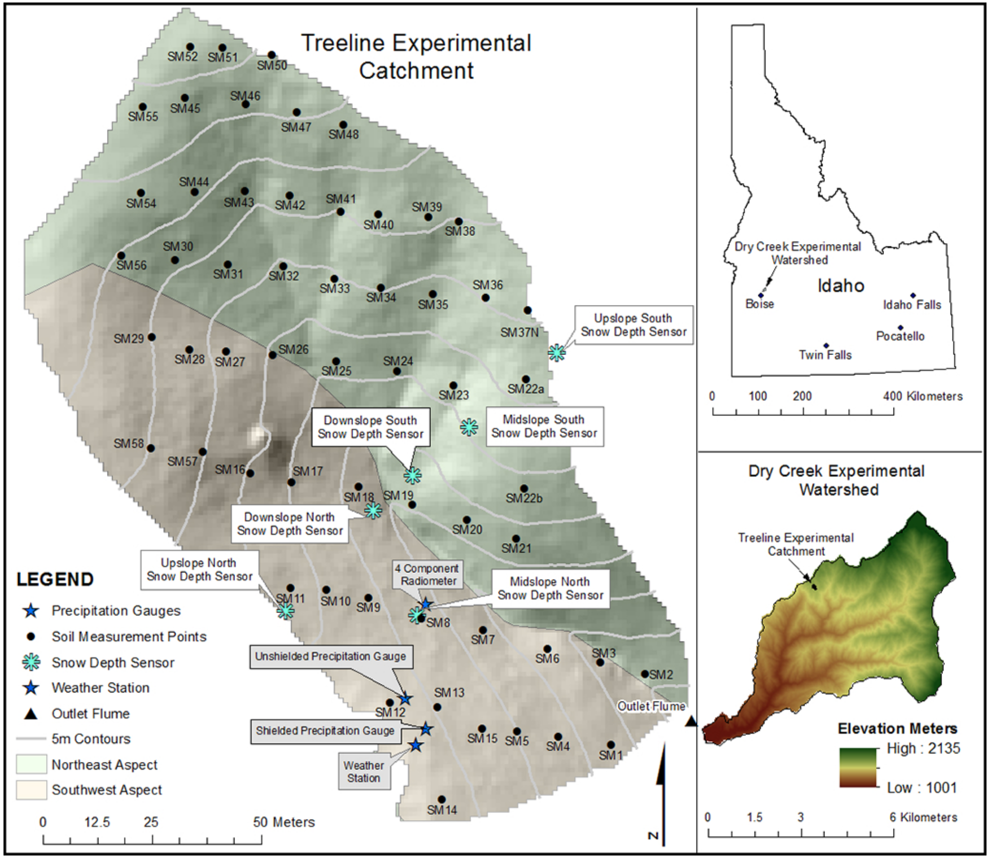

Fig. 1. Location map of the Treeline experimental catchment in the Dry Creek Experimental Watershed and the location of instruments and measurement points.

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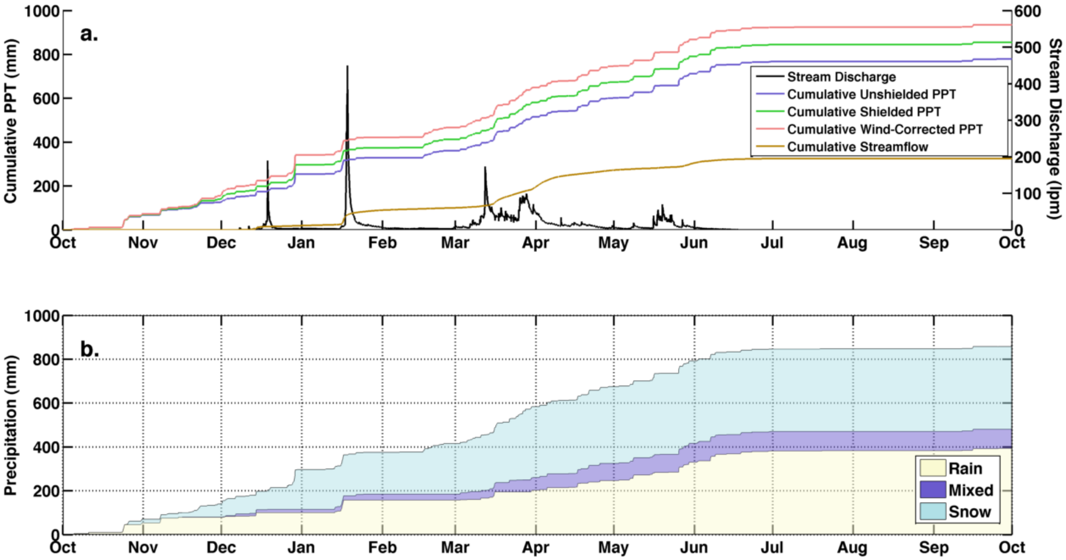

Fig. 2. Precipitation and streamflow from the Treeline experimental catchment for WY2011. Cumulative shielded, unshielded, and wind-corrected precipitation with cumulative streamflow and the hydrograph are presented in **(a)**. The phase of cumulative wind-corrected precipitation based on dew point temperature is presented in **(b)**.

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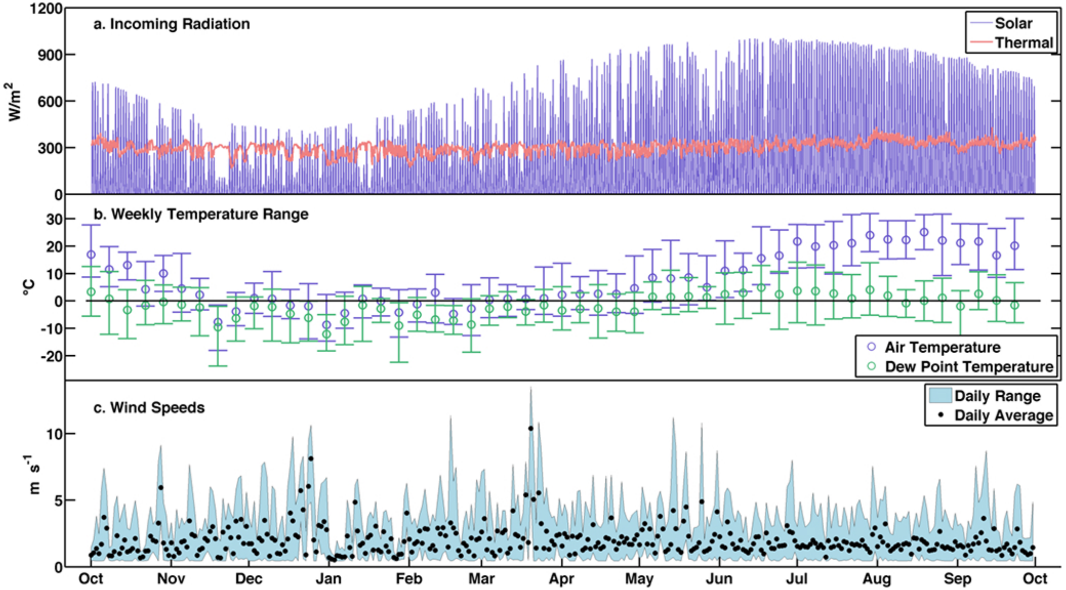

Fig. 3. Weather Data measured at the Treeline experimental catchment for WY2011. **(a)** Presents incoming measured and gapfilled solar and thermal radiation. **(b)** Presents weekly average, minimum, and maximum air and dew point temperatures. **(c)** Presents measured daily average, minimum, and maximum wind speeds.

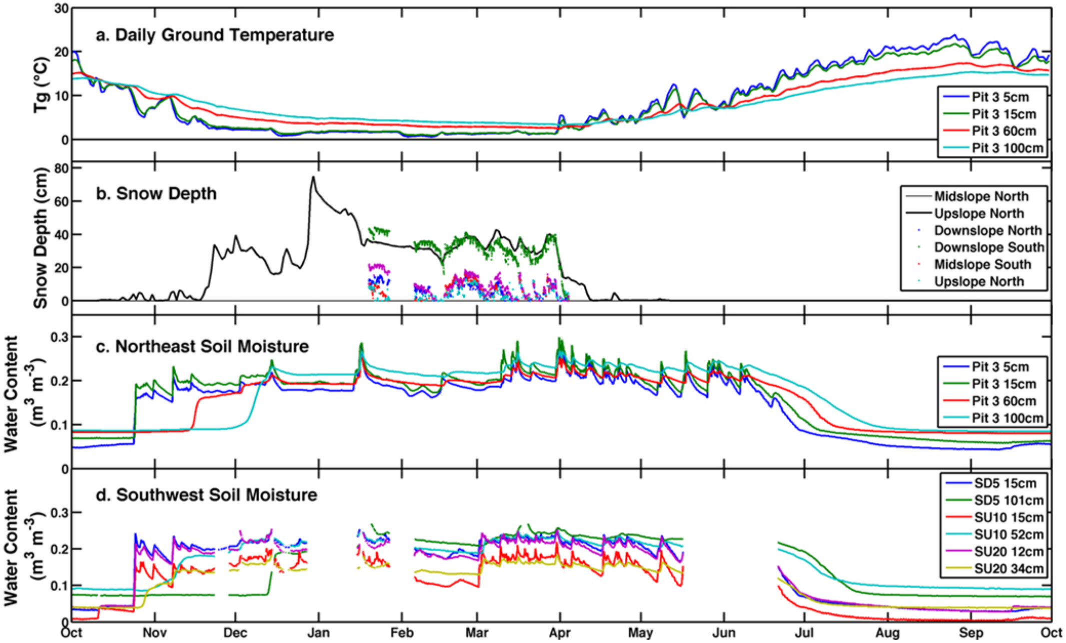

Fig. 4. Soil and snow data from the Treeline experimental catchment for WY2011. Daily average soil temperature **(a)** and moisture **(c)** from pit 3 on the northeast facing slope, and soil moisture from several pits from the southwest facing slope **(d)** are presented. Snow depths from six locations are presented in **(b)**.

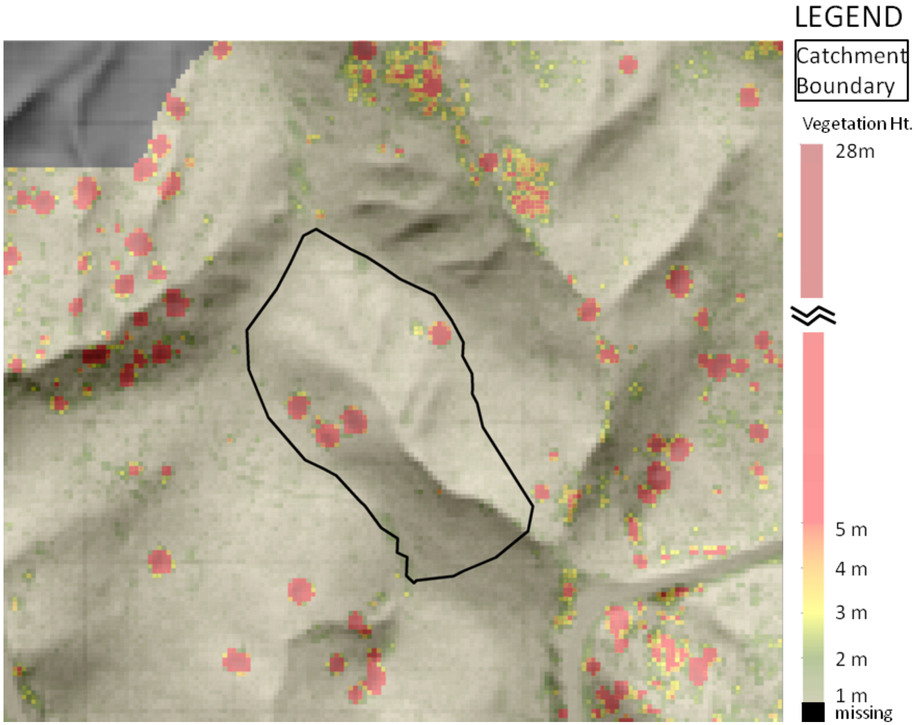

Fig. 5. Aerial LiDAR-derived vegetation height over shaded topographic relief map.

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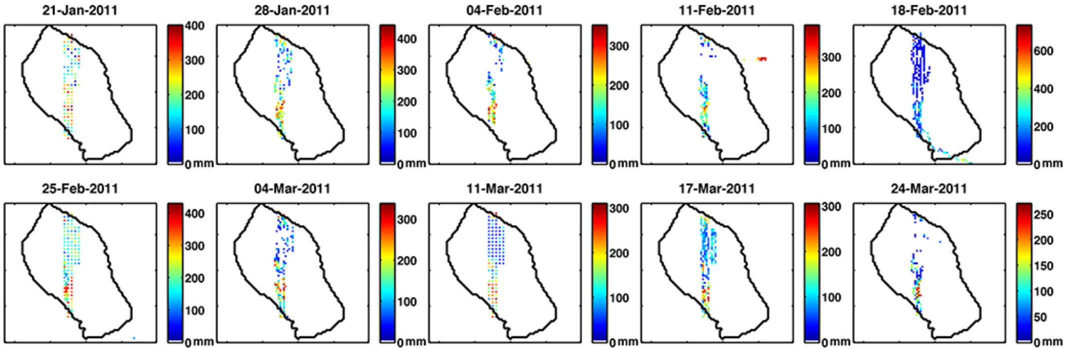

Fig. 6. Mean gridded snow depth from 10 snow surveys. Multiple depth measurements within the same 2.5 m^2 pixel were averaged.