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USDA LTAR Common Experiment measurement: Snow

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ltar Common Experiment

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Abstract

Snow plays an important role in the hydrological and energy cycles. In agroecosystems, snow may be a beneficial source of plant-available water, a harmful source of flooding, a source of irrigation water supply (i.e., mountain snowpack filling reservoirs), and a determinant of seasonal timing, such as the onset of the planting or growing seasons. Key snow metrics include snowfall (precipitation amount), snow water equivalent (SWE), and snow depth. Depending on the application, we may be interested in the snowfall rate of a particular storm event (e.g., 60 mm of water equivalent fell overnight, and the weight damaged crop trees) or the total amount over a season (e.g., 400 mm of total winter snowfall will provide moist spring soil). Snowfall measurement is in some ways similar to rainfall measurement, to quantify the rate (e.g., per hour or day) of precipitation through a horizontal plane (opening of a precipitation gauge). However, it is usually necessary to melt the snow within the gauge. Snowfall measurement is also susceptible to the effects of wind, which can accelerate snow laterally past the gauge opening, resulting in “undercatch.” Snow depth is the most readily observable property, requiring only a graduated stake or other simple measurement devices. However, depth does not directly convey the water content. Snow depth may increase because of new snowfall or deposition by wind. Snow depth at a point may decrease because of settling over time (often within hours), compaction by overlying snow, melting, sublimation (evaporation of ice crystals), or scouring by wind. In addition to weather, these processes are regulated by local physiographic factors, including topography (slope and aspect with regard to sun and wind), and by trees, crops, or other vegetation. Since these factors may result in high variability of snow depth over short distances, snow depth measurements in many locations at a given time point are often desirable to assess conditions in a watershed, field, or plot. Snow water equivalent is usually considered the most important metric of snowpack since it represents the water available upon melting. SWE is the product of depth and density. Density is affected by similar factors as snow depth as well as age. Freshly fallen snow often has low density that increases with time on the ground as snow crystals lose their fine edges through friction, compaction, and partial melting.

This protocol describes the measurement of:
- Snow depth
- Snow water equivalent
- Snowfall
- Remote sensing and other long-term/large-scale snow products

Materials

Snow depth equipment

Snow depth can be measured using photographs of fixed snow stakes, manual surveys with handheld depth probes, and/or fixed automated ultrasonic sensors that concurrently measure air temperature (common brands include: Campbell Scientific, Judd Sensors, and Novalynx) with an associated data logger to store the data. For targeted, high-value applications, snow depth can be measured by airborne or terrestrially-based light detection and ranging (lidar).

Soil water equivalent equipment

The SWE of a snowpack on the ground is most commonly measured using:

- A snow tube, which consists of a metal or fiberglass tube with a cutter on one end to collect the snow core and a scale to weigh the tube containing the snow core.
- Typical snow tubes are the Federal, Mt. Rose, and Rosen snow samplers. These snow tubes can be expensive, but less-expensive plastic tubes may serve for shallow snowpacks, or a homemade tube is fabricable from a plastic pipe (Payton et al., 2021).
- Snow tubes require manual operation during a site visit.
- Continuous measurement of SWE requires using snow pillows or other weighing devices. Snow pillows require a large flat area and have considerable installation and permitting costs. Therefore, snow pillows are primarily applicable to long-term climate records at fixed locations and typically are unsuited for field plots.

Snowfall equipment

The following equipment is similar to that required for precipitation measurements, except for a mechanism to melt the snow and a shield to decrease or eliminate wind effects on the amount of snow caught in the gauge.

- Any weather weighing precipitation gauge with a high-precision load cell and processing capability that compensates for wind, temperature, and evaporation (e.g., Pluvio gauge, OTT HydroMet, Loveland, CO; AWP gauge, FTS, Blaine, WA)
- Windshield (e.g., Alter type)
- An orifice rim heater is optional, depending on snow conditions
- Alternatively, snow may be melted using nontoxic alcohol based antifreeze (e.g. water line antifreeze)
- Data logger
- Power source
- It is often useful to co-locate sensors for air temperature, humidity, and wind speed with the snowfall gauge

Troubleshooting

Snow depth

1 Snow depth is the total depth of snow, ice pellets, and ice on the ground during an observation and includes old and new snow layers.

2 **Measurements**

2.1 **Manual methods**

Graduated snow probes or a simple measuring stick are applicable to determining snowpack depth. A permanently fixed mounted snow stake may be viewed manually or photographed by an automated camera, or a measuring stick may be inserted at an observation point during field visits. When using a measuring stick or snow depth probe, place the stick in vertically and push through to the ground layer with particular attention to inserting through ice layers until reaching the ground. Be careful not to push the probe into the soil, which will inflate the measured snow depth.

2.2 **Semi-manual methods**

- Snow depth is measurable with a permanently mounted graduated snow stake or staff gauge in the field of view of an automated camera. For further details of this Snowtography method, see the Snowtography Handbook available from USDA-ARS at **https://www.ars.usda.gov/pacific-west-area/tucson-az/southwest-watershed-research-center/research/snowtography/** (Payton et al., 2021).
- Images can be analyzed at a certain time every 24 h to obtain daily snow depth.
- Camera images are manually retrievable during field visits or in some cases relayed via cell modem for remote monitoring.
- With supplemental site visits every one to two weeks to weigh snow samples for density, it is possible to develop a time series of SWE across the network of snow depth stakes.

2.3 **Automated methods**

- Sonic distance sensors measure snow depth by emitting an ultrasonic pulse (50 kHz) and measuring the time it takes for the emitted pulse to reach the ground or snow surface and reflect back to the sensor (i.e., return interval).
- Automated measurements are controlled by a data logger (may be solar-powered) at any desired frequency.
- With increased snow depth, the pulse has less distance to travel and thus a shorter return interval. Since ultrasonic sound pulses vary with air temperature, an air

temperature sensor is usually located within the sensor housing to correct for variations in the speed of sound in air.

- The emitted pulse is conical, and the dimensions of the circle on the ground surface are determined by sensor height. The conical shape should have a clear view of the ground uninfringed by vegetation, fence posts, or other objects.
- The sonic sensor should be perpendicular to the ground surface or to snowboards (i.e., boards mounted at the soil surface) and be mounted securely so the measurements are unaffected by wind moving the sensor.
- Ultrasonic depth sensors are standard equipment at **USDA SNOTEL** network sites.

3 **Site maintenance**

3.1 For manual measurements, keep the sampling points well-marked and free from foot traffic and other disturbances that might compact the snow.

3.2 For camera-based measurements, keep the field of view of the snow stake clear from objects that would obstruct reading the snow stake.

3.3

Note

Please refer to the "Placement and site maintenance" section in the *USDA LTAR Common Experiment measurement: Best practices for collection, handling, and analyses of water quantity measurements* protocol (Baffaut et al., 2024) for general equipment and siting considerations.

3.4 For automated sonic sensors, standard sensor calibrations and maintenance should follow the vendor guidelines; for example, the Campbell sensors require the user to change the desiccant packs regularly.

3.5 In addition, the user will need to check the distance measurement of the sensor to the bare ground surface or snowboard before the onset of winter to detect changes in the ground surface topography and account for these changes in the data logger program or with post-processing corrections.

3.6 For all methods, before the onset of winter, clear the ground surface within the conical projection of vegetation, litter, and rocks.

3.7 During site visits, observe and note frost heaving or other ground disturbances, which can change the reference point and cause variations in snow depth measurements.

4 **Data processing and quality control**

4.1 For ultrasonic sensors:

- If the sensor has an internal air temperature sensor, the temperature correction is usually done in the data logging program before being written out to data logger storage.
- If no internal air temperature sensor is included, post-processing for the temperature based on an external air temperature will need to be done (Ryan et al., 2008).

Standard quality assessment (QA) and quality control (QC) for erroneous values should check for extreme positive or negative values. Please refer to the data quality control section in Baffaut et al. (2024).

4.2 Unrealistic changes in snow depth may provide an additional constraint. Erroneous values (i.e., spikes) are producible because of extreme snowfall events, snow type, and blowing or drifting snow. Small negative values can be due to small amplitude variability around zero in the absence of a snowpack and are usually set to zero.

4.3 Snow photography produces image files typically read manually by observing the image and creating a spreadsheet of the snow depth; however, current research aims to develop a processing script to determine the snow depth from automated image analysis.

5 **Data file formats and metadata**

5.1 Manual data formats include text files or user-created spreadsheets and databases.

5.2 Semi-manual methods result in image files, text or .csv files of the snow depths read from the images, and sometimes field visit data consisting of depth checks with manual probes and/or density measurements.

5.3 Snow sonics connected to a data logger produce data files (.csv).

5.4 Metadata includes the type of snow depth measurement and location of sampling points (latitude, longitude). Optional metadata include a description of the location (e.g. open field, dense forest, 5 meters north of wind break).

Note

Other data listed in the metadata section in the *USDA LTAR Common Experiment measurement: Best practices for collection, handling, and analyses of water quantity measurements* protocol (Baffaut et al., 2024) apply, as well.

6 **Recommendations for data collection**

Table 1. Summary of recommendations for measuring snow depth.

	A	B	C	D
	Attribute	**Preferred**	**Minimum**	**Comments**
	Spatial scale	Plot and field	Point	Numerous point measurements apply to characterizing a plot or a field
	Frequency	Monthly snow surveys - field intensive and costly Daily scale - camera method Sonic sensors 15 min to hourly	Depends on study objectives	Daily is possible with camera methods. Manual methods will be less frequent. Ultrasonic methods are usually at 15-min intervals.
	Covariate metrics	Air temperature, wind speed, soil moisture	Hourly	

Snow water equivalent

7 The snow water equivalent (SWE) of a snowpack is the depth of liquid water resulting from melting snow. This snowpack measurement is crucial because it is the water available for infiltration and runoff upon snowmelt.

8 **Measurements**

8.1 Typically, measuring SWE with a snow tube involves establishing a snow course where repeated measurements can be collected at the same points. The number of sample points will vary depending on the spatial area of interest and the variability of snow depth over the site. These points should capture variability in snow depth and/or snow density across the field plot or basin that may result from wind drifting and/or differences in sun exposure.

8.2 To collect a snow core using the snow tube, force the sampler downward with a steady downward thrust until it reaches the ground. Minimize turning to reduce sampling error. If ice layers are encountered and turning/cutting is necessary, rotate the tube clockwise to engage the cutting teeth to cut through the ice layers.

8.3 The cutter normally should penetrate to the ground and collect a small amount of soil or ground litter to ensure that the full snowpack depth has been captured. The penetration depth is measured using marks on the outside of the tube before extracting the core; accurate snow depth is obtained by subtracting the depth of ground penetration observed upon core extraction.

8.4 After carefully scraping out the soil plug using a small spatula or pocket knife, immediately weigh the snow tube and core. Obtain snow weight by subtracting the tare weight of the tube. Density can be calculated as the ratio of snow mass to the internal volume of the sampler tube.

8.5 SWE can be estimated across large spatial scales by modeling combined with remote sensing. Gridded temperature and precipitation data are modeled via PRISM and assimilated with SWE information from SNOTEL and the NOAA COOP network to produce a daily gridded 4 km estimate of SWE, and this is available from NSIDC (**https://nsidc.org/data/nsidc-0719**) This estimation provides a useful national scale estimate of SWE applicable to extrapolating information from a common experiment to larger landscapes. A 40-year record is available for this extrapolation from 1981 to 2020.

9 **Site maintenance**

Clearly mark sampling points on the snow course so that measurements are repeatable near the same location, but take care not to sample directly upon spots sampled earlier in the same winter. It can be useful to develop a rule for sample locations on repeat visits such as "on the first sampling date, sample every 10 feet along the snow course. On the second trip, sample 1 foot to the West of each spot previously sampled, etc." Avoid foot traffic around the sampling points except as necessary during sampling.

10 **Data processing and quality control**

10.1 Snow scales provided with snow tubes often read out directly in units of SWE, which may be inches or centimeters, depending on the sampler.

10.2 Snow density is computed by dividing SWE by the observed snow depth.

Note

If possible, compute and review snow depth, SWE, and density data in the field to catch any obvious errors before leaving the field. It is good practice to occasionally take 3 or more replicate measurements in succession and nearby one another to help gauge the repeatability of the measurement.

11 **Data file formats and metadata**

Formats include text files or user-created spreadsheets and databases. Metadata include names of field personnel, time of day, type of snow tube, snow course layout, and location of sampling points (latitude, longitude, and possibly more precise local positional information).

12 **Recommendations for data collection**

Table 2. Summary of recommendations for measuring snow water equivalent.

	A	B	C	D
	Attribute	**Preferred**	**Minimum**	**Comments**
	Spatial scale	Plot and field	Point	Spatial measurements should capture SWE variability due to wind, sun exposure, topography, and vegetation
	Frequency	Weekly	Biweekly or after each snowfall event	
	Covariate metrics	Air temperature, wind speed	Snowfall; snow depth and density	

Snowfall

13 Solid precipitation such as snow is particularly vulnerable to undercatch resulting from wind-induced updrafts at the gauge orifice. A wind shield (i.e. wind fence) can reduce or

eliminate this effect. Solid precipitation must usually be melted within the gauge for accurate measurement, and gauges designed for rainfall may be inappropriate. Tipping bucket gauges are especially poor for measuring solid precipitation. Most studies suggest weighing gauges are more useful for recording snow, hail, and mixtures of snow and rain. A weighing gauge collects falling snow melted within the gauge via a heater or antifreeze solution before the snow is measured by weight differential. This overview is based on references Rasmussen et al., 2012; WMO, 2018; and Smith et al., 2020.

14 **Measurements**

The general guidance on "Data Quality Assurance" in Baffaut et al. (2024) will ensure that high-quality data are collected. In addition to these recommendations, the following instructions address specific needs for snowfall measurement.

14.1 Data collection frequency should be suited to the purpose, but usually varies from as often as 1 minute to as little as 1 day.

14.2 It is often of interest to aggregate high-frequency data to longer time intervals (e.g. hourly data aggregated to daily sums). These computations, as well as snowfall rate (intensity) can be calculated by a program on the datalogger or calculated later by the user.

14.3 Sample the following covariate metrics concurrently:

- Air temperature
- Humidity
- Wind speed
- Wind direction

15 **Site maintenance**

Recommendations on site maintenance follow the general recommendations for water quantity variables. Please refer to the "Quality assurance" and "Site maintenance" section in Baffaut et al., 2024. In addition, specific recommendations for the measurement of snow water equivalent include:

- Conduct weekly visits to check equipment and ensure the sensor is level and debris-free.
- Before the snow season, add oil and antifreeze solution to the reservoir of the gauge. Monitor the precipitation level in the reservoir and empty it when needed (usually every four months).

16 **Data processing and quality control**

Recommendations on data quality control follow the general recommendations for water quantity variables. Refer to the corresponding section in Baffaut et al., 2024. In addition, specific recommendations for snow water equivalent measurements include:

16.1 Temperature, humidity, and wind effect snowfall data, even with a windshield. Some gauges handle the necessary compensations internally. If manual compensations are necessary, see Rasmussen et al., 2012.

16.2 Some gauges screen data for error codes and out-of-range values, while other gauges do not and require user screening of raw data. Baffaut et al. (2024) provides a list of what to look for.

16.3 Use data from adjacent precipitation gauges for validation of the raw data.

16.4 If possible, fill data gaps with data from nearby gauges, interpolation, or other appropriate method.

16.5 Set a quality flag to “pass” if all quality control tests are passed.

16.6 Set a quality flag to “estimated” for model-filled data.

16.7 Set to “missing” if no valid method can fill the data gap.

16.8 Additional flags may apply to internal use of the data.

17 Data file formats and metadata

17.1 Metadata: unique site identifiers, spatial coordinates, a record of units, an indication of accuracy, sensor type, and data logger program reference. Data adjustments are recorded in the metadata.

17.2 Data format: site identifier, datetime stamp, and sensor values. Data stored for raw and production (corrected). Raw and production data are archived for permanent storage.

18 Recommendations for data collection

Table 3. Summary of recommendations for measuring snowfall.

	A	B	C
	Attribute	**Preferred**	**Minimum**
	Spatial scale	Plot and field	
	Frequency	One minute to hourly	Daily
	Covariate metrics		Air temperature, wind speed, wind direction

Remote sensing and other long-term/large-scale snow products

19 Long-term gridded datasets may provide important context for existing or planned site-level snow measurements. Gridded products are informed by ground measurements and/or satellite remote sensing, with intervening locations and time points estimated using interpolation or modeling.

19.1 Examples include:

- the **UA SWE** dataset (a daily 4 km gridded SWE and snow depth), and
- **SNODAS** (the snow data assimilation system).

Such datasets can provide context to the Common Experiment sites spatially and temporally.

20 Spatially, gridded snow data products inform the snow dynamics regionally or in places with hydrogeographic similarity to the experiment site. Temporal snow dynamics in the area of an experiment site can help in planning for equipment, personnel, and time resources for snow measurements. For example, the historical snow regime at a site provides the necessary information (e.g., likely maximum snow depth to be measured, typical date of peak snowpack and of snow disappearance) to select a site’s instruments/measurements, snow survey timing, etc.

21 Snow remote sensing can encompass several different products, depending on capability. These generally fall into two categories:

1. snow extent/fractional cover, and
2. SWE

21.1 Snow extent (SE) is valuable for energy cycle modeling and pertains to how much land surface has a snow cover of some minimal depth.

21.2 SE is usually estimated by visible or near infrared channels, and SWE is usually estimated from microwave imagers/radiometers.

21.3 SWE is concerned with the equivalent amount of water that a snowpack contains if melted to a liquid state.

21.4 Currently, SWE can be estimated with gamma sensors from aircraft. Another parameter of interest related to SE/SWE is the freeze–thaw state, usually estimated with microwave radiometers, such as SMAP.

21.5 Product List from CEOS: https://lpvs.gsfc.nasa.gov/producers2.php?topic=snow

22 Recommendations for data collection

Table 4. Summary of recommendations for measuring remotely sensed snow products.

	A	B	C
	Attribute	**Preferred**	**Minimum**
	Spatial scale	30 m	0.5 km
	Frequency	Daily	Daily
	Covariate metrics	Temperature	

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