Snowcloud: Development of a Distributed In Situ Instrument for Snowpack Monitoring

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Project Summary

Snowcloud: a Distributed *In-Situ* Snow-Depth Sensing System

Snow depth (SD) and snow water equivalence (SWE) information from dedicated stations and field surveys is critical for assessing water availability. The SNOTEL network, established, operated and maintained by the Natural Resources Conservation Service (NRCS), consists of over 730 sites in 11 states. Each site is equipped with a range of instruments that measure SD and SWE.

SNOTEL sites are long-term installations. NRCS field investigations sometimes extend information from SNOTEL sensors by carrying out manual snow course measurements. However, data are from a single set of instruments installed at a fixed location, which can limit quantifying the highly variable temporal and spatial nature of SWE and SD due to factors including weather, vegetation cover, and topography. Wireless sensing networks can be used to extend SNOTEL data to estimate areal distribution of SD and SWE on small- and intermediate-scales. The *Snowcloud* system, deployed at the University of California's Sagehen Creek field station, is a stand-alone system that can be used to augment data collected from permanent weather stations.

Snowcloud Description

Snowcloud: Costs and Characteristics

The *Snowcloud* system is:

- Low cost (~$500 per node)
- Easy to transport (on foot) and install
- Robust, with respect to climate and terrain extremes
- Non-invasive and non-destructive to site
- Easy to query for real time data retrieval

The *Snowcloud* system, comprised of multiple *sensor nodes* (*Figure 1)* and a *base station,* collects and communicates SD data using a low frequency mesh network and a base station that can be remotely accessed via cell or radio modem. Each node has a radio range of 50-100 meters; 802.15.4 mesh networking allows multi-hop communication between nodes and flexible distribution of nodes throughout an area of interest, The base station allows network control and data retrieval from long distances. Both sensor nodes and base station feature reprogrammable embedded processors running algorithms for network communication and control.

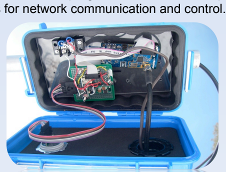


Figure 1: The "brain box" of a Snowcloud node. The brain box includes a sonar emitter/receiver, sensor control board and a connection to an external antenna for data transmission.

Data Reliability and Remote Control

The low cost, low power characteristics of *Snowcloud* may result in increased network volatility, which could threaten the reliability of data retrieval. *Snowcloud* anticipates network failure by using backup logs on-node with 1MB non-volatile flash storage. The logs are remotely retrievable, or accessible via data muling in the absence of remote connectivity. Work-in-progress seeks to achieve even greater levels of reliability via massive storage on the gateway, and by in-network data replication. In addition to backlog retrieval, *Snowcloud* networks are remotely controllable in real time, including sampling rates.

Sensor Network Details

The support structure of *Snowcloud* nodes is lightweight aluminum (Figure 2). It consists of a vertical support shaft terminating in a solar and antenna support frame, an elevated horizontal sensor arm, and a buried anchor system. It is modular and designed to be easily transported into remote areas. The solar panel support structure is adjustable in 3-dimensions to allow optimal solar panel and sensor arm placement simultaneously.

Total materials cost for support structure: ~$160

The Brain Box and SD Measurement

The *brain box (Figure 1),* situated on the end of the sensor arm, contains:

- Crossbow TelosB mote, comprising microprocessor running TinyOS, 1MB non-volatile flash storage, and 802.15.4 radio connected to external antenna.
- Ruggedized sonar sensor and temperature sensor, individually calibrated in lab and field settings.
- Sensor control board, allowing the microprocessor to control sensor power for energy savings.

Sensor suite allows accurate SD computation via standard means.

Total materials cost for brain box: ~$170

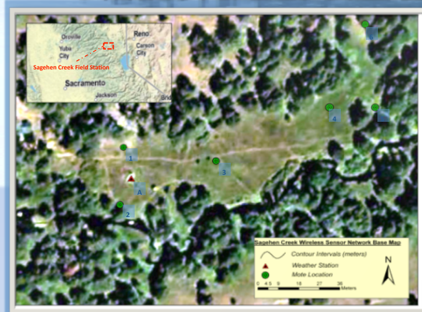
Power and Electrical Sytem

The power system consists of a 12V, 12Ah lead-acid battery with a -40C operational rating as the main power source, and a 12W solar panel for recharging. The solar panel aspect is fully adjustable, while the battery and solar control are housed in a waterproof box at ground level. A switch at the top of each node allows power to be turned off for maintenance during winter.

Total materials cost for power and electrical system: ~$170

Total materials cost per sensor node: $500

Figure 2: Snowcloud nodes are highly portable and easily deployed in remote locations. The aluminum tube support structure is mounted on the soil using metal stakes with internal threading to accommodate bolts.



Sensor Locations	Canopy Cover	Aspect
(A) Full weather station	Near Canopy	West
(1) Node one	Near canopy	Northwest
(2) Node two	Mid Canopy	Southwest
(3) Node three	No Canopy	Central
(4) Node four	No Canopy	East
(5) Node Five	Inner canopy	Southeast
(6) Node Six	Inner Canopy	Northeast

Figure 3: Locations and characteristics of a prototype 6 node Snowcloud network in the Sagehen Creek Field Station, operated by University of California at Berkely, near Truckee, California.

Field Trials – Sagehen Creek, CA

Snowcloud Prototype Deployment

A 6-node *Snowcloud* network deployed in the central Sierra mountains (Figure 3) has three purposes:

- To develop techniques to extrapolate SWE from SD in a spatially and temporally heterogeneous system to small and intermediate scales using weather data collected at a permanent weather station, topographic features and vegetation characteristics as predictors,
- To verify predictions of SD and SWE using data collected from *Snowcloud* nodes and manual snow courses, and
- To field test hardware and software in a real-world setting.

The Sagehen deployment directly measures snow depth and air temperature and the network is linked to a fixed location station that conforms to SNOTEL station design. Snow depths and extrapolated SWE data are interpreted using ArcGIS by kriging analysis. 95% confidence intervals of estimated accuracy are created on each kriged surface, which provide a range of interpolated SWE and snow depth values. Spatial scales of the raster output can range from centimeter^2 to kilometer^2.

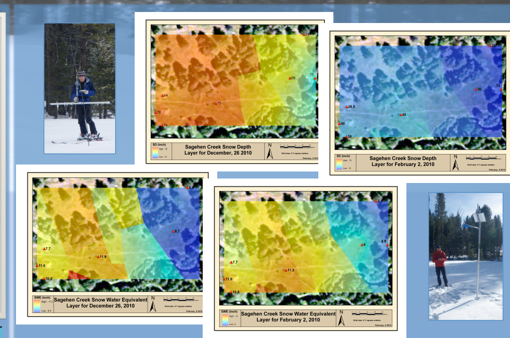


Figure 4: Snowcloud measurements are used with information from the meteorological station (Figure 3) and spatial data analysis techniques to provide areal estimates of snow depth (upper illustrations) and snow water equivalence (lower illustrations). Snowcloud measurements are also supplemented with manual snow courses (upper left corner) to develop and verify statistical models of the relationship between snow depth, snow water equivalence and other site characteristics.

Data Interpolation and Visualization

Time series analysis

In order to properly forecast spatially and temporally variable SWE and snow depth, it is important to interpolate between points, and between time intervals. Arc GIS is being used to interpolate in near real time, all data inputted at each time interval requested. Sample time intervals can range from seconds to days.

Animation output of interpolated and observed data

To facilitate visualization and analysis, animations are created with a variable time scale for the total desired time interval. SWE and snow depth variations are seen as color scale gradations on an aerial photo, while the observed data is represented as line graphs animated in time with the interpolated data.

Extrapolation Verification

Direct SD and SWE measurements are made weekly in a grid that spans the study area (0.33 ha) and includes each *Snowcloud* node.

The recommended NRCS snow course procedure using a Mt. Rose Federal Snow Sampler (Figure 4, 5) is used to collect 116 measurements from four east - west transects within the field area. Snow depth measurements are made with a snow probe with centimeter increments.

Figure 5: SD and SWE sampling with Federal snow corer

Acknowledgements

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