# UNDISTURBED MEASUREMENT OF THE ENERGY AND MASS BALANCE OF A DEEP ALPINE SNOWCOVER

669-80

By

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## Introduction

To compute the melt rates and magnitudes from a snowpack using an energy balance approach we need accurate and reliable field measurements of the heat and mass transfer across the air-snow interface and, in some cases, across the soil-snow interface. These data are particularly valuable in regions with deep snow covers and where much of the annual precipitation falls as snow.

Over recent years modeling spring runoff has been attempted using the energy balance concept in point models by Outcalt et al. (1975), Anderson (1968, 1976), Price et al. (1976), McKay (1979) and others. Significant problems exist in extending an energy balance model over an area. One potentially useful approach for the application of an energy balance model to a large area is the use of calibrated satellite data to measure snow characteristics. For the past three years we at the University of California at Santa Barbara have been developing an energy balance snowmelt model to be driven by calibrated satellite data. Accurate experimental data for the testing and development of models such as this are not available as a result of inadequate instrumentation used for measuring comparatively small energy transfer values in extreme meteorological conditions (McKay, 1979).

As a step toward the implementation of an energy balance model for large mountainous watersheds, we have established a micrometeorological station in cooperation with the U.S.D.A. Forest Service on Mammoth Mountain in the southern Sierra Nevada of California.

## Theoretical Background

The energy balance for a snowcover can be expressed by the familiar equation:

$$R + H + LE + G = dQ$$

where R is the net radiation, H is the sensible heat transfer (this term includes the vertical turbulent component), LE is the latent heat exchange, G is the transfer of heat across the soil-snow interface, and dQ is the change in energy stored in the snowpack and/or utilized in the fusion and sublimation processes.

This equation has been found to be generally satisfactory for modeling melt at a point and has been applied with increasing sophistication. (U.S. Army Crop of Engineers, 1956; Muller and Keeler, 1969; Anderson, 1968, 1976; McKay, 1979). Before an energy balance model can be confidently extended over a large heterogeneous area, it must be validated to a significant degree at a point, particularly if the model is to be driven by a calibrated satellite data. This requires the measurement of the various energy balance components, snow mass balance, and snow and soil properties. Ideally, these data should be obtained without disturbing the natural state of the snowpack. While some of the energy balance components can be measured both remotely and without affecting the snow, some snow characteristics present special problems.

## Location

Mammoth Mountain is located on the eastern side of the southern Sierra Nevada, about 32 miles northwest of Bishop, California. The station lies on the north side of the mountain at an altitude of 2930 m. This site has an average winter snow depth of about 3 m and can be as deep as 8 m (this year's maximum is about 5 m). The station is located on open, gently sloping terrain with little vegetation. The instrument tower has approximately 200 m of fetch in the direction of the prevailing wind and about 50 m of

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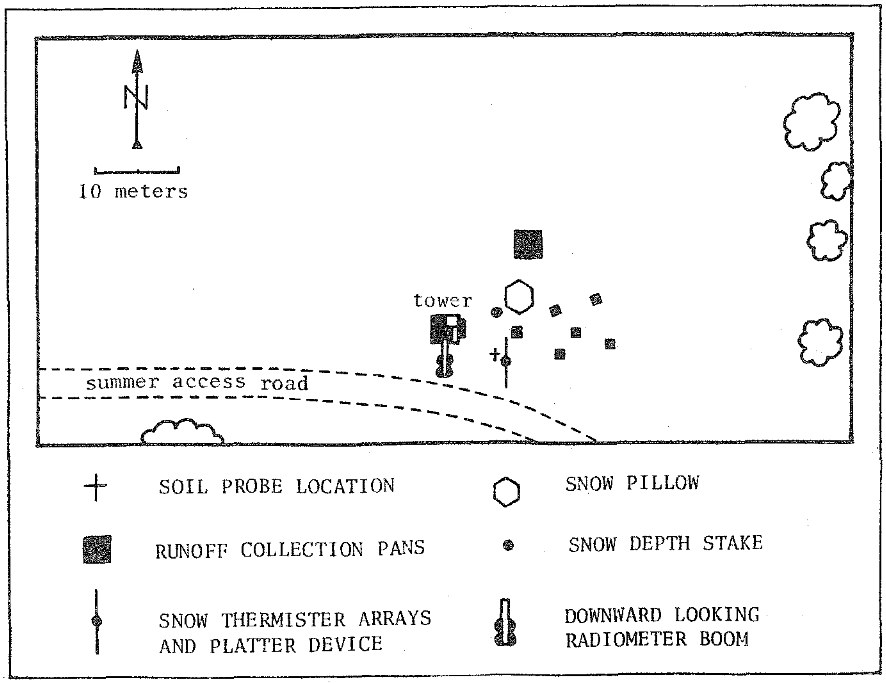

Figure 1. Schematic diagram of the Mammoth Mt. instrument site.

fetch in other directions. Wind speeds commonly gust over 30 m/sec (70 m.p.h.) during the frontal passage of winter storms. The site was chosen based on the ease of winter access for data retrieval and instrument maintenance and the coincidence of this site with a Forest Service meteorological station and a California Cooperative Snow Survey snow course and snow pillow. The focal point of the instrument outputs at the site is a "Santa Claus" tower, built as a modification to the Forest Service tower (see Figure 1). It is a sealed plywood enclosure about 5 m high and about 1.2 m on a side with a door in the top. The shack allows access to the outflow of the runoff collection system located below the base of the snowpack. The shack also contains the interfacing circuitry, instrumentation amplifiers, microprocessors, recorders and tools.

### Instruments

### Radiation

Two arrays of three precision radiometers (Epply) are used to measure the incoming and reflected solar radiation in two wavelength bands and the incoming and emitted thermal radiation in one wavelength band. The arrays are pointed upward and downward to obtain the incoming and outgoing radiation. The two solar wavelength bands are 280-2800 nm and 700-2800 nm and are detected by pyranomenters (model PSP). Two of these sensors have transparent protective hemispheres and two have RG-8 filters to provide the cutoff at 700 nm. The thermal band radiation (4-50 µm) is measured by pyrgeometers (model PIR).

Table 1

Energy Balance Parameters Measured at the Mammoth Micro-meteorological Station

| Parameter | Measured Value or Range | Instrument | Measurement Frequency |
|---|---|---|---|
| Radiation: | | | |
| Incoming and Reflected Solar Radiation | 280 to 2800 nm | 2 Epply Pyranometers | Continuous |
| Incoming and Reflected Near IR Radiation | 700 to 2800 nm | 2 Epply Pyranometers, (RG-8 filters) | Continuous |
| Incoming and Emitted Longwave Radiation | 4 to 50 μm | 2 Epply Pyrgeometers (Silicon dome) | Continuous |
| Temperature: | | | |
| Air Temperature and Dew Point Temperature | (°K) | EG&G Humidity Analyzer Model 911 | Continuous |
| Surface Temperature | (°K) | Teletemp Radiant Thermometer | Daily |
| Wind: | | | |
| Wind Speed and Direction | m/sec and Degrees | Weather Measure Sensors (USFS) | 4 Hour Averages |
| Heat and Mass Transfer: | | | |
| Snow Temperature Profiles | (°K) every 15 cm | Yellow Springs Thermistors | Daily |
| Precipitation | Depth and Mass | Snow Board and Gage (USFS) | Daily |
| Snow Density and Water Equivalent | Mass | Snow Pillow (L.A. DWP) | Continuous |
| Melt Runoff | Volume | 10 $m^2$ Collection Pans and Gage | Continuous |

The choice of the solar wavelength bands is a result of the tradeoff between the available filters and an ideal combination to best separate the aerosol and water vapor attenuation bands. All of the radiometers have an unmodified look angle of about 180°. Therefore, the upward looking sensors are mounted on the highest point of the station. The downward pointing sensors are suspended over the snow about 4 m from the tower on an aluminum boom. The downward pointing pyrgeometer has been modified to act as a radiant thermometer. It has a view angle of about 6 degrees with the addition of a polished aluminum tube over the filtering hemisphere. The aluminum used has a thermal emissivity of about 0.08 and is therefore highly reflective in the thermal wavelength band. The tube is assumed to be at the same temperature as the air. Surface temperature is calculated by inverting the Stefan-Boltzman equation and applying an empirical correction function for the effect of the aluminum tube to the output of the radiometer. This correction function has been calibrated for temperatures ranging from -20 to +20 °C. Within this range the measurements are accurate to within +/0.5 °C. The tube has a polystyrene foam exterior to reduce the likelihood of errors during high winds and bright sunlight. We assume that the portion of radiation contributed to the shorter wave sensors by the tower and the surrounding terrain is comparatively small. The radiometers have an analog output of millevolts.

The observations of the outgoing thermal radiation can be used to calculate the surface temperature. The modified downward pointing pyrgeometer has been calibrated using a portable radiant thermometer (Teletemp, modifed model 44). It has an expanded temperature range of -50 to +100 °C with an accuracy of +/0.1 degree. A view angle of three degrees and its portability allow the spatial averaging of surface temperature around the view area of the pyrgeometer.

## Sensible and Latent Heat

The fluxes of sensible and latent heat at the snow surface are calculated from measurements of the surface temperature, the dew point, and the wind velocity at two heights using the Businger-Dyer equations (Paulson, 1970).

For snow surface energy exchange calculations, the dew point temperature is one of the most important parameters because of the large energy transfer rates involved in vapor transport. At temperatures near freezing the dew point is difficult to measure with standard methods because the latent heat of fusion degrades the measurment accuracy. We have overcome this by using a direct measurement of dew point temperature. The dew point is obtained with a high degree of accuracy using a condensation-mirror device (EG&G Digital Humidity Analyzer, model 911). Dew point temperature is measured utilizing a Peltier-cooled, gold-surfaced mirror, automatically held at the dew point temperature by feedback from a photoelectric condensate detector to the thermoelectric cooler (Peltier device). As condensate forms on the mirror, an optically sensing bridge detects the change in light level and develops a proportional control signal to the power supply. The dew point is continuously tracked and changes of less than +/0.06 °C are detected.

Wind velocity is measured using anemometers with the standard three-cup assembly. Rotation is nearly frictionless and is sensed with optically isolated LED switches (contactless). They are set up to provide an integrated output or wind run with a low threshold velocity. The anemometers are placed at two heights on the tower above the surface of the snow. The greater height is fixed on the tower and the lower level is be periodically adjusted to maintain a relatively constant distance above the snow surface. The measurements of these devices can be periodically checked against a portable hot-wire anemometer whose output is also integrated.

## Snow and Soil Heat Flux

The soil and snow heat fluxes and exchange can be calculated with measurements of snow and soil temperature profiles and estimates of the appropriate transport coefficients (Davis, 1980). Soil conductivities and capacities have been derived from laboratory analysis. However, those of the snow are more transient in time and are estimated from periodic measurements of snow density.

Snow temperature profiles are obtained with three fixed-depth thermistor arrays. Each array has ten interchangeable thermistors (Yellow Springs Instrument) at 45 cm intervals. The three arrays are staggered with respect to each other so that between them, there is a sensor every 15 cm. This configuration allows for the failure of an entire array without the loss of a major portion of the profile, rather, with a loss of depth resolution. Each thermistor array is constructed of multiconductor wire with thermistors embedded in silicone gel. Each thermistor is connected to a unique conductor and a common ground. The sensing elements of the thermistors are encased with thin aluminum caps to insure good thermal contact with the snow. Each array is shielded from solar radiation with an outside layer of aluminum foil. In addition there is a smaller PVC enclosed array of five thermistors mounted directly over one of the runoff collection pans.

Soil temperature profiles are also measured using thermistor arrays. These arrays have been fabricated into probes consisting of PVC tubing and epoxy. The sensing elements of the thermistors protrude from the PVC shell and are protected with a thin layer of fiberglass and epoxy. One soil probe is installed beneath the snow temperature arrays and the other beneath one of the runoff collection pans. The installation of the thermistors above and below the runoff collection pan was made to aid in the evaluation of the effects of the pans on the soil-snow thermal regime.

### Snow Properties

With density measurements and temperature profiles the snow heat flux can be calculated (Anderson, 1976). The water equivalent of the snow is measured with a standard snow pillow. (Variations in the weight overlying the pillow result in changes in the level of a stilling well in the tower.) Changes in snow mass are recorded by a chart recorder. So far we have not electrically interfaced the chart recorder with either the analog or digital recorder due to the slow change of the snowpack water equivalent and the mechanical nature of the recorder. Combined with information from the nearby snow depth stake, the snow pillow data yields an average snow density for the pack.

In order to make relatively undistrubed measurements of snow settlement and track the temperature of particular snow layers, we have designed and built a sliding platter device similar to that developed by Swanson (1968). Thermistors are mounted on small platters designed to slide down a nichrome wire to the snow surface at periodic intervals. The platters are subsequently buried and are free to settle with the snow. The depth of a platter is obtained from the impedance or voltage drop across the section of nichrome wire between the platter and the end of the wire. This impedance is compared to the total impedance of the wire to determine the relative location of the platter. Electrical connection between the platter and the nichrome wire is maintained with a mercury contact.

Design differences from Swanson's device arise from the storage of many platters (typically 20), the long drop distance during the early part of the season, and the need to organize the wire leads from the platters to minimize wind resistance and still provide enough slack for the platters to drop. To accommodate the weight of several platters we use a double set of storage rods. This design feature provides extra stability with weight against the wind. The arms of the platters are solid strips of acrylic plastic to prevent excessive penetration of the platters into the snow upon release. A separate drop mechanism is used for the slack sensor leads.

### Snowmelt Runoff

A system of plastic pans and PVC plumbing is used to catch the snowmelt which reaches the soil-snow interface. The pans are constructed from polystyrene structural foam with a fiberglass skin. Six are about one meter square and one is four meters square. The pans are located so that the collected runoff flows to the tower where a tipping gauge and an event recorder are installed. The pipes are bured at a depth of about 1 m and contain low dissipation heat tape to prevent freezing. The plumbing system was initially filled to capacity and tested with a mixture of ethylene glycol and water.

## Data Acquisition

Measurements from the instruments which provide an active analog output (e.g., radiometers) are recorded with a 31 channel analog data logger (Sierra Misco, model 5070). This logger provides an analog to digital conversion and stores scaled signals along with time, date and channel information on standard tape cartridges. The scaled signals are stored as three digits which represent a fraction of the maximum output of the instrument. Presently, the thermistor arrays, snow pillow, and tipping bucket gauge are read manually as we have yet to build the multiplexing and interface circuits.

We are developing a microprocessor-based digital data logging system which will calibrate and convert raw analog signals and output from both passive devices (e.g., thermistors) and active devices into any desired units and store the information on tape cartridges. This system is based on the Motorola MEK6800D2 microprocessor evaluation kit. It has the flexibility to allow preliminary data transformation and analysis while retaining the raw values. The maximum number of channels to be monitored is restricted only by the interface multiplexing scheme and the frequency of instrument polls. The device can be interrogated for diagnostics directly via a keypad or remotely through a standard RS232 port. Firmware governing the basic operation is stored on UV erasable programmable-read-only memory which can be readily modified.

## Conclusion

The data requirements for energy balance simulation of snow properties and melting are extensive and not usually available for remote alpine areas. The instrument station described in this paper is designed to provide this data. The station is not complete and is continually being upgraded and modified to overcome technical and environmental problems. During January and February of 1980 extremely high winds (over 60 m/sec!!) destroyed the instrument mast and several of the anemometers. Riming is a continual problem which has yet to be adequately solved, and during January, 1980, five days of rain shorted much of the electronics in the measurement tower. It is our hope that through our continual efforts to solve these and other measurement and maintenance problems, we will be able to establish a reliable data collection system for monitoring the energy budget of a deep alpine snowcover.

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