MICROMETEOROLOGICAL MEASUREMENTS AND INSTRUMENTATION[1] IN SUPPORT OF REMOTE SENSING OBSERVATIONS OF AN ALPINE SNOW COVER

760-84

Robert Davis, Jeff Dozier, and Danny Marks[2]

INTRODUCTION

Remote sensing measurements from satellites and aircraft provide radiometric information about spatial distribution of snow properties. This information can then be combined with models of snowpack thermodynamics to estimate melt rates over a drainage basin. To calibrate remote sensing data we must first determine the energy and mass balance of the snow at an experimental site, measure those physical properties that affect snow's radiometric properties, and compare these to reflectance and emittance data. To satisfy these needs we have maintained a snow research and experiment site at Mammoth Mountain, California for the past six years.

In this paper we describe instrumentation and techniques used to monitor the energy and mass balance, and to measure critical snow properties such as liquid water content, temperature and density profiles, and crystal properties. These measurements have been made concurrently with radiometric measurements in the visible, near-infrared, thermal infrared, and microwave spectral regions.

ENERGY AND MASS BUDGET OF AN ALPINE SNOW COVER

For the past six years we have developed components of an energy balance snowmelt model for mountainous drainage basins, and we have explored methods to determine snow surface properties from satellite data (see bibliography). Adverse environmental conditions and difficulties in directly measuring critical snow properties have hindered the testing of these techniques against measured values.

The energy and mass budget components of the snow cover energy balance -- net radiation, sensible and latent heat transfer, heat exchange across soil-snow interface, advected heat from rain or snow -- are measured at a small plot (0.5ha) at 2930m on Mammoth Mountain, California. The energy exchange variables are measured at point locations within the study plot and assumed conservative, while the mass balance of the snowpack is averaged over the area.

Radiation

Because radiation is the most important component of the energy budget of an alpine snow cover (Marks, 1982) and is the most directly related to remote sensing data, it is the most carefully monitored parameter at the Mammoth snow study plot. Two arrays, each of three Eppley Precision Spectral Pyranometers, measure total (.3-2.8μm) and near-infrared (.7-2.8μm) incident and reflected solar radiation and incident and emitted thermal (4-50μm) radiation. The upward pointing sensors are mounted on the highest part of the instrument tower. The downward pointing sensors are suspended over the snow about 4m from the instrument tower on an aluminum boom with a mount that has a variable angle to adjust the view factor. The downward pointing pyrgeometer (4-50μm) measures snow surface radiant temperature. It has a view angle of 45^o, restricted by a polished aluminum tube of known emissivity.

Sensible and Latent Heat Exchange

Because energy transfer by turbulent exchange is second in importance to radiation (Male and Granger, 1981) we also give it considerable attention. The fluxes of sensible and latent heat at the snow surface are calculated from measurements of surface temperature, dew point at one height, and air temperature and wind speed at two heights. The vapor pressure at the air-snow interface is calculated from the snow surface temperature. Surface roughness is estimated by extrapolating the wind speed profile to the surface.

---

[1] Western Snow Conference, April 17-19, 1984, Sun Valley, ID.

[2] University of California, Santa Barbara, CA 93106.

The dew point temperature and related vapor pressure gradient is important because of the large energy transfers associated with phase change. At temperatures near freezing, psychrometric measurement of humidity is difficult because release of the latent heat of fusion raises the wet-bulb temperature. To avoid this we measure the dew point directly using a condensation-mirror device.

Wind speed is measured with standard three-cup anemometers. While riming can be a problem at the study plot, heated anemometers do not have enough sensitivity at low velocities for our purposes. Our anemometers have been modified to measure the high wind speeds at the site. The anemometers are placed at two heights above the surface of the snow, 2m and 5m. The lower anemometer and air temperature sensor are mounted on a snow board that is moved when changes in the snow surface elevation take place. The upper anemometer is also adjustable to maintain a constant 5m height above the snow surface, but in a deep snowpack this is not possible, and adjustments in the calculated turbulence must be made.

Snow and Soil Heat Fluxes

Davis (1980) showed that energy transfer from soil is small for a deep alpine snow cover. While it is monitored at the snow study plot, we pay more attention to the snow temperature profile in the top 1m. The soil and snow heat fluxes from heat conduction and vapor transport can be calculated with measurements of snow and soil temperature profiles and estimates of the appropriate transport coefficients (Davis, 1980). Snow thermal properties are computed from empirical relationships with density. Soil thermal properties are determined by laboratory analysis.

Snow temperature profiles are measured with two cable-mounted arrays of thermistors and a portable multi-sensor probe. The two main problems with measuring snow temperatures over long intervals are maintaining good thermal contact and minimizing the absorption of solar radiation in near-surface layers. The cable arrays are monitored weekly to assess the general thermal state of the snow cover, but are not more frequently recorded because of the problems mentioned above. The output of the portable probe (currently 5 temperatures in the upper 1m) is recorded at half hour intervals. The sensing elements of this probe are surrounded with polished silver bands to insure good thermal contact with the snow and reduce the absorption of solar radiation penetrating the snow. It is moved periodically to reduce effects of sun, accumulation, and scouring. Soil temperature profiles are measured using thermistor arrays, which have been fabricated into probes of PVC tubing and epoxy.

Snow Mass Balance

The total water equivalent of the snow is obtained from snow density measurements at 10 points in the plot. Snow depths are recorded from depth stakes, and periodic random samples of depth are obtained between existing stakes. Density profiles of the entire thickness of the snowpack are measured about once per month and profiles for the top 1m are measured weekly.

The settlement of snow layers in the pack is measured with a sliding platter device (Swanson, 1968). Small platters slide down a nichrome wire to the snow surface at intervals. The platters are subsequently buried and are free to settle with the snow. Settlement measurements are normally made weekly; unfortunately rime and wind have repeatedly destroyed the nichrome wire during winter storms.

A system of plastic snowmelt lysimeters intercepts snowmelt that reaches the soil-snow interface. The pans are of polystyrene structural foam with a fiberglass skin. Six are 1m^2 and one is 4m^2, so runoff rates and volumes are averaged over a 10m^2 area. Practical aspects of snowmelt lysimetry are surveyed by Kattelmann (1984).

CORRELATIVE SNOW PROPERTY MEASUREMENTS FOR REMOTE SENSING

Snow reflectance in the visible wavelengths is almost insensitive to crystal size but sensitive to contamination from dust, atmospheric aerosols, pine pollen, etc., because ice is so transparent in these wavelengths that increasing the size of a snow crystal does not significantly change the probability that a photon impinging on the crystal will be absorbed. The possible contaminants are much more absorptive than ice (Warren and Wiscombe, 1980). In the near-infrared snow reflectance is sensitive to grain size but not sensitive to contamination, because in these wavelengths ice is slightly absorptive. An incident photon is more likely to be absorbed if the crystal is larger. Impurities are not so important because their absorption coefficients are not much larger than those of ice (Wiscombe and Warren, 1980). In the infrared snow emissivity is independent of snow properties, because ice is so absorptive. The emissivity does, however, vary with viewing angle (Dozier and Warren, 1982). In microwave wavelengths snow reflectance and emissivity vary with snow density, grain size, and liquid water content. The microwave signal from snow covered terrain results from the electromagnetic interaction with a volume rather than a surface. Microwave emission and backscattering consist of contributions from the snow surface, snow layers, and often the ground. The presence of liquid water in snow, even in small amounts, can drastically change the microwave properties. Therefore initial work has concentrated on measuring the liquid water fraction in snow.

There is a disparity between theoretical parameters describing snow as a medium for radiative transfer and the physical parameters describing measurable snow properties. In part this is because of the difficulties in obtaining reliable measurements of some snow properties, most notably liquid water content and ice grain geometry. A new and rapid field technique for measuring liquid water content of snow measures dilution with a fluorescing dye solution (Davis and Dozier, 1984; Perla and LaChapelle, 1984). The advantages are that samples for analysis can be obtained rapidly and easily; the main disadvantage is that on-site data analysis is difficult.

Snow ice grain properties are recorded photomicroscopically by preparing section planes in snow cores (Perla, 1982). The important microscopic snow properties are grain size, shape and orientation, volume fractions of the phases, specific surface of the phases, mean random spacing between the ice grains, grain contiguity, and parameters describing the spatial variance and correlation of the phase properties. The volume fraction of a phase, the mean random particle spacing, and the interface area per unit volume (of which specific surface is a subset) are quantities directly measurable from a single section plane. These are independent of shape and size distribution of the phases, assuming isotropy of phase location and orientation. The spatial variance and correlation of phase properties can be calculated by digital analysis of a classified subimage and reference image of a section plane (Vallese and Kong, 1981). Other parameters must be calculated by making some assumptions about the shape of a particular phase and its size distribution (e.g. Kry, 1975; Gubler, 1978), or by using more than one section plane. This can be achieved by successively sectioning a snow sample for photography.

CONCLUSION

With its increasingly sophisticated instrumentation, the Mammoth Mountain site promises to yield useful data on snow physical properties, especially those related to snow electromagnetic properties.

REFERENCES

Davis, R., 1980. Simulation of an alpine soil thermal regime beneath a snowpack. M.A. Thesis, Univ. Calif. Santa Barbara, 82 pp.

Davis, R., and J. Dozier, 1984. Snow wetness measurements by fluorescent dye dilution. J. Glaciol., in press.

Dozier, J., and S.G. Warren, 1982. Effect of viewing angle on the infrared brightness temperature of snow. Water Resour. Res., 18, 1424-1434.

Gubler, H., 1978. Determination of the mean number of grain bonds per snow grain and of the dependence of the tensile strength of snow on stereological parameters. J. Glaciol., 20, 329-341.

Kattlemann, R.C., 1984. Theory and practice of snowmelt lysimetry. Proc. 1984 Western Snow Conf., in press.

Kry, P.R., 1975. Quantitative stereological analysis of grain bonds in snow. J. Glaciol., 14, 467-477.

Male, D.H., and R.J. Granger, 1981. Snow surface energy exchange. Water Resour. Res., 17, 609-627.

Marks, D., 1982. Net all-wave radiation as an index to snowmelt runoff. Eos, 63, 927.

Perla, R., 1982. Preparation of section planes in snow specimens. J. Glaciol., 28, 199-204.

Perla, R., and E.R. LaChapelle, 1984. Dilution method for measuring liquid water in snow. Proc. 1984 Western Snow Conf., in press.

Swanson, R.H., 1968. A system for making remote and undisturbed measurements of snow settlement and temperature. Proc. 1968 Western Snow Conf., 1-5.

Vallese, F., and J.A. Kong, 1981. Correlation function studies for snow and ice. J. Appl. Phys., 52, 4921-4925.

Warren, S.G., and W.J. Wiscombe, 1980. A model for the spectral albedo of snow, 2, Snow containing atmospheric aerosols. J. Atmos. Sci., 37, 2734-2745.

Wiscombe, W.J., and S.G. Warren, 1980. A model for the spectral albedo of snow, 1, Pure snow. J. Atmos. Sci., 37, 2712-2733.