MONITORING SNOWPACK ABLATION USING LYSIMETRY
or, Sublimation - a forgotten concept in the snow managers' toolbox

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INTRODUCTION

As long ago as 1972, George Peak, who was the SCS Snow Survey Supervisor for Wyoming, observed that the seasonal snowpack related very poorly to the region's Spring runoff and attributed the deficit to an overlooked factor, theft by sublimation.

It is time to give this element another round of investigation! Recently we reported that sublimation, as tracked by simple devices and indices, can result in a loss of the majority of the annual snowfall in Flagstaff, Arizona. This means that, under the right conditions, little of the snowpack could result in runoff and, therefore, in water supplies. Obviously the continual tracking of the snowpack by repeated snow surveys accounts for this depletion indirectly, but an appreciation for the significance and variability of this "thief" is commonly lacking, and early-season snowpack enhancement is often given the same economic value as late-season enhancement activities - an entirely unwarranted valuation in the authors' opinion.

Moreover, skiing conditions at high elevations are subject to rapid change not only because of the normal ripening process but also because of the often quick, but highly unpredictable, disappearance of surface snow crystals. Again, sublimation is at work!

WHAT IS SUBLIMATION

Simply defined, sublimation is the transfer of a material directly from the solid phase to the vapor phase. Under the usually observed scenario, water first melts - a phenomenon that takes about 80 calories per gram, the "heat of fusion." The meltwater can, and often does, subsequently evaporate, a phenomenon that takes an energy input known as the "heat of vaporization" (about 597 calories per gram at 0°C). While the meltwater may disappear from the snow and show up later as streamflow, when the sublimation phenomenon occurs meltwater is not produced and the snowpack is vaporized immediately (*i.e.*, evapo-sublimation), with the result that the global water balance is enhanced by an increase in the atmospheric vapor content. As has been estimated by Schmidt and Troendle (1992), the Canadian boreal ecosystem probably loses 40% of its snowpack via sublimation.

Whether or not snow melts or sublimates is a matter of chance - the chance assemblage of those factors that permit water to move directly across the phase boundary. While temperature and pressure are the two major factors, we are convinced that conditions immediately above the snow play a dominant role in this transfer process: if there is no "potential" for sublimation, none will occur despite any availability of energy, and consequently, only more meltwater will be produced. The fact that sublimation is not treated in the same way as precipitation, as a variable subject to statistical description, is due to a lack of appreciation of its significance and its observability.

For these reasons we have begun the development of a "Sublimation Opportunity Index."

AN INDEX OF SUBLIMATION

Our first attempt has combined either surrogates for, or observations of, the following factors into an index model:

- net solar radiation
- wind
- vapor pressure gradient
- advected heat energy

and the combination we presented (Avery *et al.*, 1992) has been applied to a 21-year climate record, producing a record that is not only interesting but intriguing. Our present efforts include updating this index through 1993. We have also field tested our

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basic hypothesis, *that sublimation can be measured*. We did so by using the mass balance approach and constructing a simple lysimeter.

FIELD METHODS

A dual-chamber sublimimeter was constructed from sheet Thermax brand closed cell foam insulation 2.5 cm thick assembled into a 13,000 cm^3 open box. The floor of the foam box was perforated with a grid of drain holes fitted with short tension tubes to remove melt water by gravity. The melt water was retained in a Teflon coated metal pan which was bolted to the overlying foam chamber and sealed with a soft foam weather-strip to minimize evaporative loss from the melt water.

At a typical site, one of the lysimeters was supported at 1 meter height and shielded from open sky conditions by a dual-roofed shelter. This roof is 1.5 meters above the ground and supported by wooden legs. The "field life" of the sample was longer under shielded conditions so if site maintenance could not be performed in a timely manner or if accumulating precipitation affected the site, the covered lysimeter typically provided more reliable results. A second elevated lysimeter was left exposed to ambient sky conditions. In addition to the covered and exposed elevated lysimeters, a third lysimeter was kept even with the snow surface and left exposed. For two snow seasons (1990-91 and 1991-92) daily evapo-sublimation and melt measurements were obtained.

FIELD RESULTS & DISCUSSION

Field measurements support the results obtained through the author's previously developed Sublimation Opportunity Index (S.O.I.). The field data yield a corrected r^2 of 0.62, a time series cross-correlation value of 0.89 and a non-parametric cross association value of 79% with the Sublimation Opportunity Index computed for the same time period.

A mean loss of 1.56 millimeters of snow water equivalent (S.W.E.) as evapo-sublimation was recorded at Flagstaff, Arizona (latitude - 35°N, elevation - 2135 m). A maximum evapo-sublimation loss of 8.52 mm day^{-1} was recorded under clear, dry and windy conditions.

Sites that were sheltered from clear sky exposure appear to lose more snow water equivalent to evapo-sublimation and exposed sites transform more snow water equivalent to meltwater. Using mean value ratios for evapo-sublimation to melt (based on lysimetry alone), approximately 20 percent of the snow water equivalent was lost to evapo-sublimation (and 80% was transformed to meltwater) for this period. By assuming a "worst-case" scenario, where the snow pack accumulates early in the season, we estimate a majority of an average season's snow water equivalent could be lost to evapo-sublimation.

LYSIMETRY IN A CONTROLLED ENVIRONMENT

We are now trying to understand better how these several elements interact so we can refine this simple model, and our efforts are focused on the development and testing of a sublimation chamber, utilizing (a refined) mass balance approach which may produce some insights into this phenomenon.

Our first attempts have resulted in the finding displayed in Figure 1. Wind, even when slight, appears to have a strong effect on sublimation. In this trial, there was no significant radiant energy applied, nor was there effort to modify the atmospheric conditions from the ambient conditions found in the cold room where the experiment was conducted. The apparatus functioned as intended and the results show a pronounced alteration in the sublimation rate once a 2.2 m/sec airflow was initiated.

Our chamber is constructed in a modular fashion on a 50 cm x 50 cm x 100 cm welded 2.54 cm angle-aluminum frame as shown by Figure 2. The exterior is fabricated from plexiglass and the device permits not only the positioning of all necessary instruments but also a means of (relatively) making the airflow laminar.

This latter undertaking is accomplished by installing, both on the fore and aft of the snow box, 2.54 cm diameter tubing segments that cause the intake and exhaust air to flow in a horizontal manner through the chamber. The exhaust fan used in the initial prototype will be replaced with another design, as its capacity has proved to be too small, and the platform configuration will also be altered to permit more airflow.

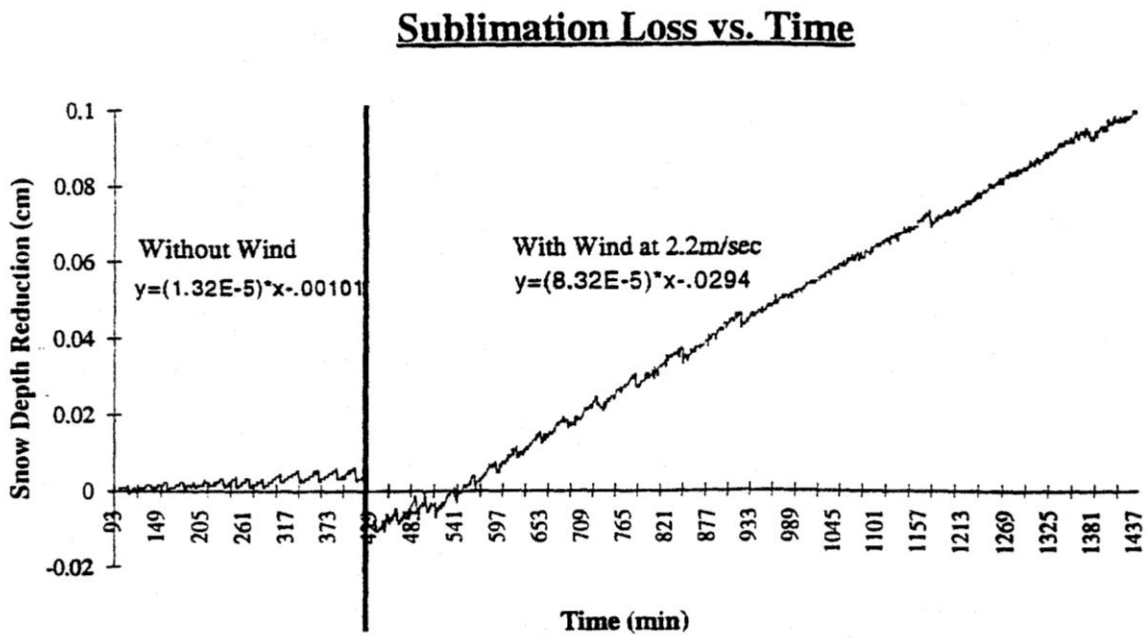

Figure 1

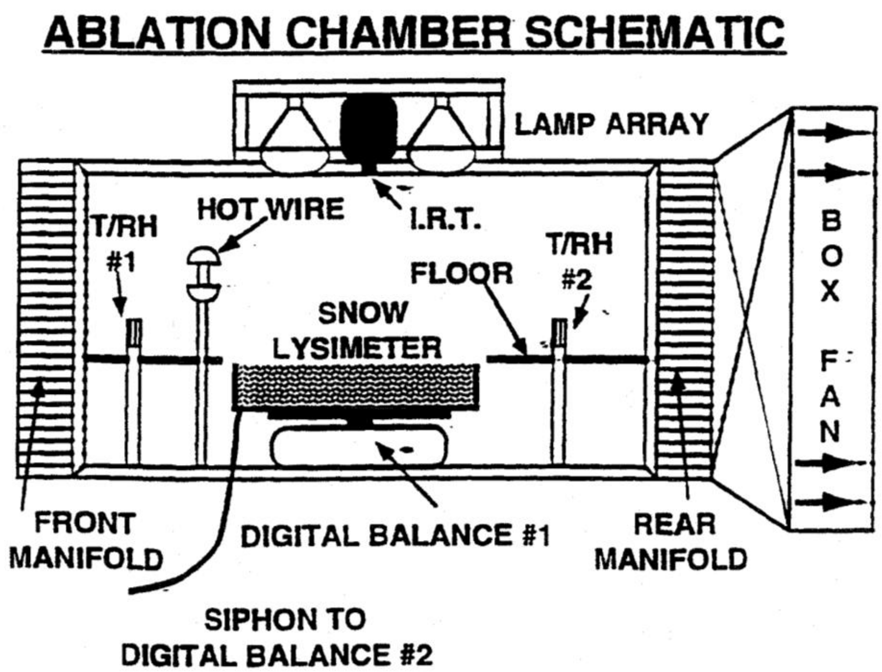

Figure 2

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