SUBLIMATION OF SNOW--THE BASICS

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ABSTRACT

Understanding the process by which snow vaporizes without melting helps explain many interesting phenomena. This paper reviews the sublimation mechanism, examining the transfer of heat to the snow, and the water vapor transfer from snow to the surrounding air. As examples, sublimation from a snowpack, from snow on trees, and from drifting snow, each involves this same balance of heat and water vapor transfer between snow and air.

INTRODUCTION

Ice, the solid phase of water, is almost always within 100 °C of its melting point in Earth's atmosphere. Changes in the crystal structure of ice occur more rapidly as temperatures approach melting. This makes ice and snow especially interesting to scientists. However, it also makes ice and snow especially difficult for snow safety specialists and others who must forecast properties of the material.

Most scientists prefer mathematics as the language to describe their understanding of this physical phenomena. While this preference may improve their communication among scientists and others trained in mathematics, it certainly strains communication with those who earn their living by more honest means.

This paper attempts to convey, in English (with drawings), the basics of a process that almost always accompanies ice in the atmosphere. Called sublimation, it is the mechanism by which molecules leave the ice crystal surface and become water vapor in the atmosphere, without becoming water first. It is similar to evaporation, the process by which water molecules become vapor from the liquid state. (Some scientists even use evaporation to mean sublimation.)

Part of its fascination for scientists is that sublimation is invisible to the human eye. We see no water streaming from a snowpack, as we do with melting, the phase change from solid to liquid. Human ears cannot detect sublimation of snow, as they can the drip of water as snow melts. To detect sublimation, scientists use instruments, which they love to do. In what follows, we'll discuss what those instruments may have taught them. Some examples of snow sublimation at work show how scientists presently interpret these findings.

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WHAT'S HAPPENIN'--TO THE STATE OF ICE

It all comes down to the individual, in this case, the ice molecule. Ice molecules look just like water molecules--two little hydrogen parts hanging on a big oxygen part--remember? In ice crystals, these 'hummers' are all lined up in rows, mostly nice and neat. We call the ice molecules hummers because they're vibrating--something to do with internal bonding. It's like they're sitting in rows in the ice crystal, shivering. What's peculiar (about this analogy) is that the molecules shiver harder as the ice gets warmer.

By another analogy (in keeping with a U.S. election year), what happens to the state of ice depends on individuals at the extremes--the far left and right, so to speak. Some of these molecules way out on the edge of the crystal get to shaking so hard they break out of the structure, and gain the 'freedom of vapors.' Surely there must be some micromicro "hurrah" when this occurs.

But most of the ice molecules that gain the freedom of vapors are helped into that state by the pushing and shoving of other vapor molecules, those that we call air. These are always humming around the fringe of shivering ice. The faster they hum, the warmer the air is, and the more ice molecules they bump over into the vapor state.

All this 'bumping into vapor' is a lot of work for the army of air molecules, and a constant supply of energetic hummers must be brought to the front, the air-ice interface for the scientist. Ice molecules just bumped into 'vapor land' are not shakin' nearly as fast as the air army. They keep getting bumped away from the front, until they finally get 'up to speed.'

These conflicts of state and individual freedoms balance in a condition called equilibrium. Scientists dance with glee when they recognize equilibrium, which means two sides are equal--an equation! For sublimation of snow, the equation says, in mathematics of course, that the rate at which ice molecules are bumped from the crystal surface is in balance with the rate heat moves toward the interface (Fig. 1).

Backing away from our microscopic view of an ice crystal edge, we see that zillions of molecules must be freed to make much change in the size of the ice crystal. The more crystal edges exposed, the more molecules get bumped or jump off.

But what really gets the little hummers bumpin' and jumpin' is when a warm wind's ablowin'. Now the air hordes descend in waves. The new water vapor molecules don't hang around getting in the way, but are swept off.

Though they still can't see or hear the process, scientists have abstracted sublimation of snow into something they can measure--temperature gradients, humidity gradients, surface areas, wind speeds. Out come the toys--the instruments. The next section also includes references, which are missing from this first part--for good reasons.

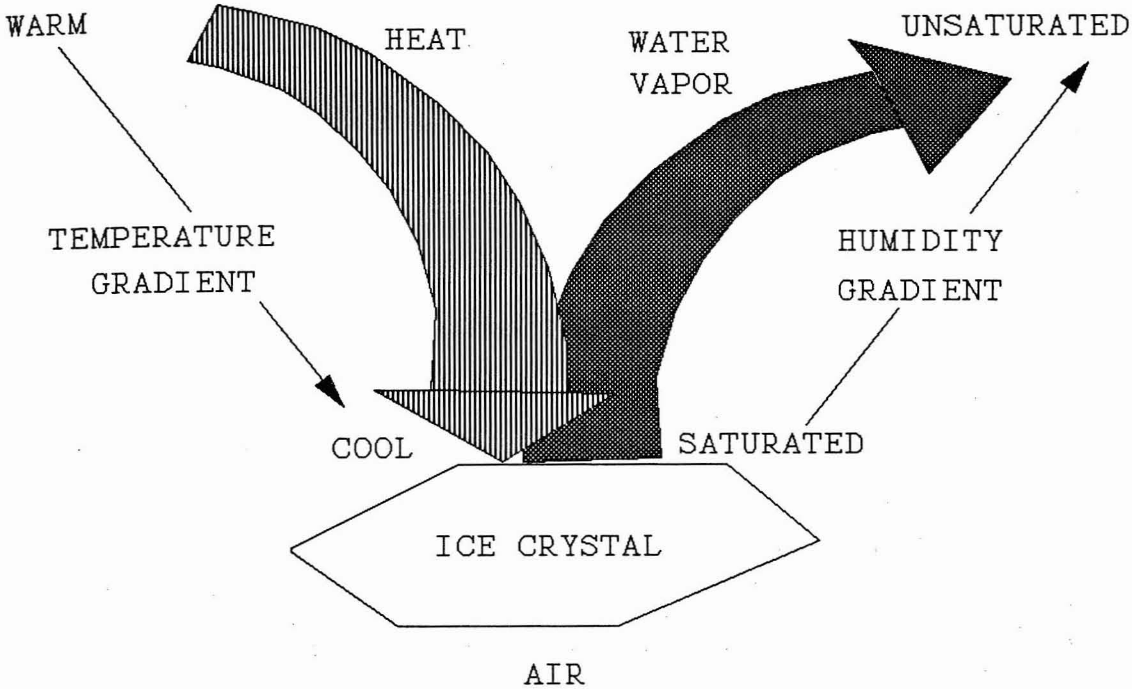

Figure 1. Equating the rate that ice molecules leave the crystal surface to the rate of heat transfer to the surface from surrounding air is the basis for an equation predicting snow sublimation rate.

MEASURING WHAT'S MISSING

To test their equation for what was happening to the state of ice, two British scientists put a vacuum cleaner in a refrigerator and sucked cold air past a tiny ice sphere while they watched through a microscope. The apparatus was crude but they were careful, measuring, checking, adjusting--playing. Finally, they reported yes, it worked like their equation said (Thorpe and Mason, 1966). What was really important, they said, was just how the sublimation process increased with wind speed (Fig. 2).

Soon after, two scientists playing in Wyoming blizzards read the British paper. "If they're right," yells one, trying to hold the paper in the wind.... What else he said could not be heard, but what he wrote was an equation--for the sublimation of snow in blizzards (Schmidt, 1972). A little ice particle whingin' along in a blizzard doesn't last long, according to that equation (Fig.3).

After days and nights of playing with sling psychrometers (talk about a crude apparatus), anemometers, and thermometers, finally the two in Wyoming agreed. "Yup, looks like it works that way" (Tabler and Schmidt, 1972). Lots of Wyoming snow never gets to melt--it just disappears (Fig. 4). Of course they said "sublimates," not "disappears."

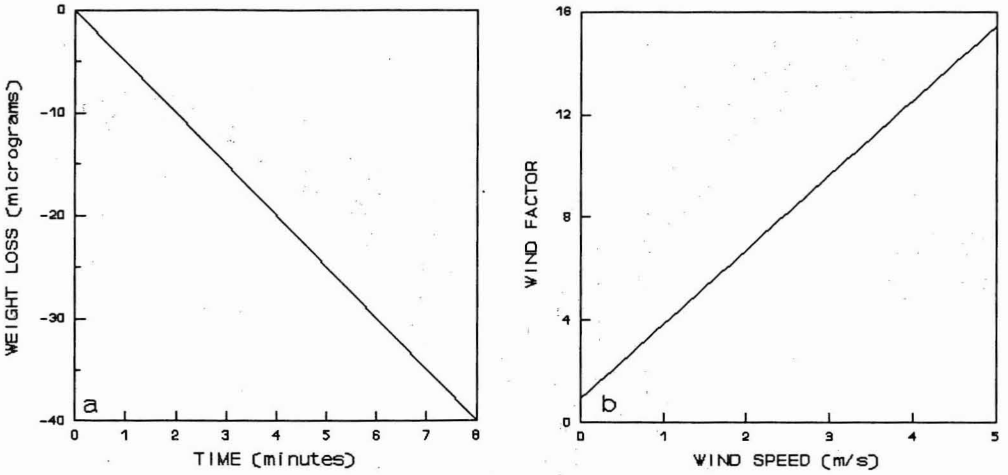

Figure 2. A laboratory experiment (Thorpe and Mason, 1966) showed that the basic sublimation equation was correct if a factor was included to describe the increase in sublimation rate with ventilation (wind). Figure 2a shows the weight loss of a small ice sphere when temperature, humidity and ventilation are constant, and the radius is changing slowly (after Thorpe and Mason, 1966, their figure 3). In 2b, ventilation increases the sublimation rate of an ice sphere by a factor proportional to wind speed. For example, air velocity of just 5 m/s increases the sublimation rate of a small ice sphere almost 16 times.

About then, an interstate highway (I-80) was being built through Wyoming. It was hard to convince the builders that any snow disappeared. They were sure it all drifted--right onto their highway. So, to simplify, and convince these non-believers about sublimation, the equation was refined. This new equation (yes--another one) said that if you knew how much snow fell, it knew how much would sublimate, and you could keep the rest off the road with a snow fence (Tabler, 1975). Figure 5 shows how it all added up.

Other things began to add up while snow fences were being built along Wyoming highways. Pomeroy (1988) expanded the concept to show why some farming practices saved snow from sublimation on the Canadian prairies--tall wheat stubble for example. Schmidt and Hartman (1986) showed that almost 20% of snow sublimated during redistribution from a 600 m fetch upwind of an avalanche catchment. Snow sublimation also explained why more snowmelt came from mountain basins after timber cuts (Troendle and King, 1985). Snowfall intercepted on branches had lots of crystal surface area exposed to air moving through the tree crowns--more equations, more instruments (Schmidt, 1991). Add it up over a winter, over a forest, over a continent, and we're talking lots of water moving back to the atmosphere without ever running down a river (Schmidt and Troendle, 1992). With interception by conifers, as much as a third of winter's snowfall sublimates. Cut down the trees, and now the snow builds in a pack, with much less surface area exposed, much less sublimation. Even then, the same sublimation equation applies (Fig. 6), but amounts are much smaller because snow surface area is so reduced.

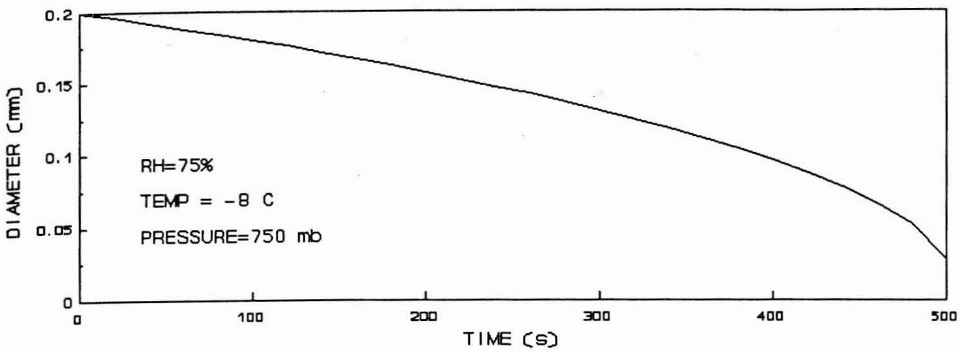

Figure 3. Applying the equation to an ice sphere (0.2 mm diameter) moving in a blizzard showed that the particle was soon vaporized under average conditions (Schmidt, 1972; Tabler and Schmidt, 1972).

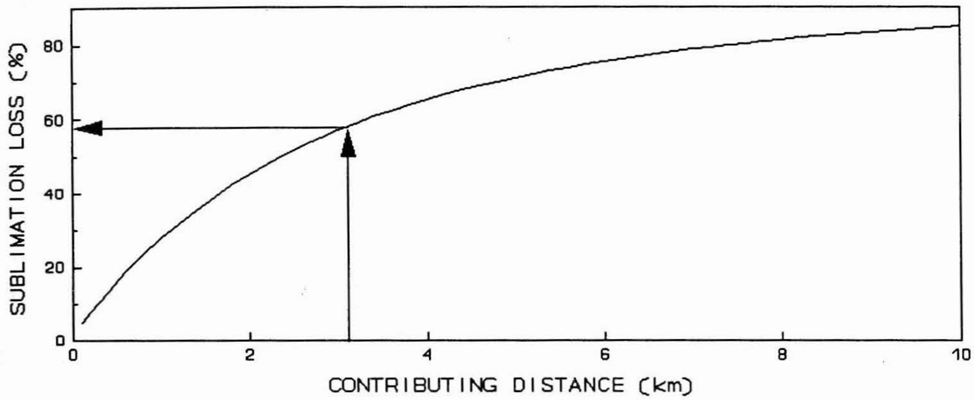

Figure 4. In a winter with average Wyoming blizzard conditions, over half of winter snowfall sublimates if it is relocated more than 2 miles (3.2 km) by wind (after Tabler 1975).

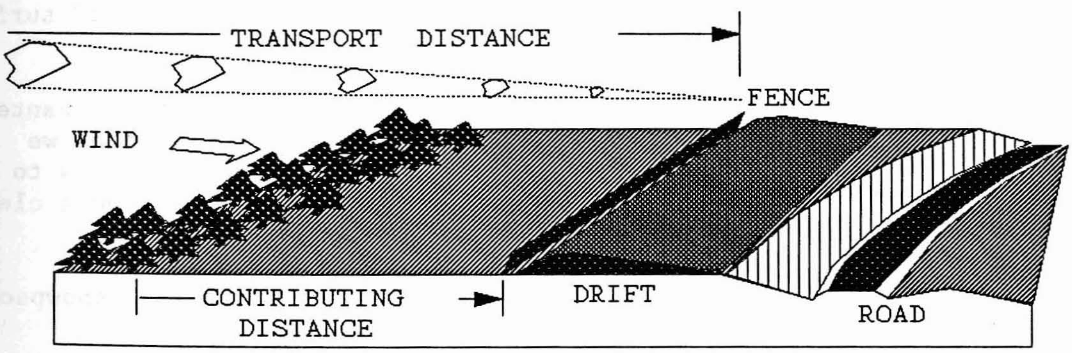

Figure 5. Simplifying the sublimation equation led to a logical procedure for designing snow fence systems. The concept is that, because snow sublimates during relocation by wind, only a predictable fraction of snowfall must be stored by the fence to protect the downwind area from drifting (after Tabler, 1975).

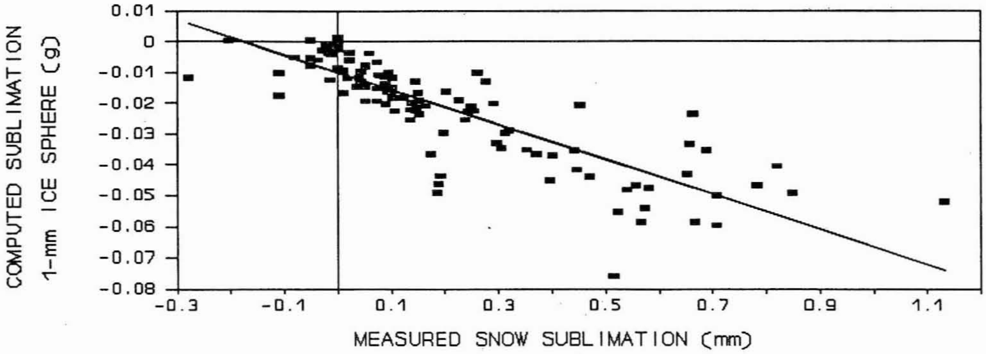

Figure 6. Snow sublimating from plastic pans set flush with the snow surface shows the same dependence on temperature, humidity, windspeed, and solar radiation that determine loss from a single ice sphere. Measurements, by the second author, were in 1988-89, at Fraser Experimental Forest headquarters, near Fraser, Colorado, USA. Units are millimeters of water equivalent and measurement periods were 8 to 14 h.

TO WRAP IT

By assuming a balance between heat flowing toward a snow surface, and the rate water vapor molecules leave the surface, scientists wrote an equation to describe sublimation of snow. It proved a good guess. With it, they predict the rate of sublimation quite well by measuring air temperature, humidity, wind speed, and solar radiation.

Their measurements show that large amounts of snowfall return directly to the atmosphere when snow is dispersed, exposing large surface areas. In blizzards on the Wyoming plains, half of snowfall relocated by wind sublimates, if it blows an average distance of two miles. In the Colorado mountains, as much as a third of snowfall sublimates from the dense conifer canopies. The process even takes a share from the snowpack surface, but without the expanded surface area, amounts are much smaller.

Well, that's not the whole story, but we're betting its more than you wanted. We left out all the equations, and lots of little details, but nothin' we think is important. One of the easiest ways to "see" snow sublimate is to set a camera on a tripod and take photographs of a snow-covered branch on a clear, cold day--make a time-lapse record.

Sublimation is one of the processes that produces metamorphism in a snowpack. The same equations--but really, we've already gone too far.

ACKNOWLEDGEMENTS

It was Dr. Richard Armstrong, ISSW'92 Papers Committee Chairman, who suggested that a paper with this topic might fit the ISSW goal of merging theory and practice. Though we may have fumbled the assignment, we feel it was an excellent suggestion, for which we thank him.

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