MAN-MADE SNOW AVALANCHES IN THE EASTERN UNITED STATES

Roger H. Damon, Jr.
Tuckerman Ravine Ski Patrol
25 Spring Street
St. Johnsbury, VT 05819

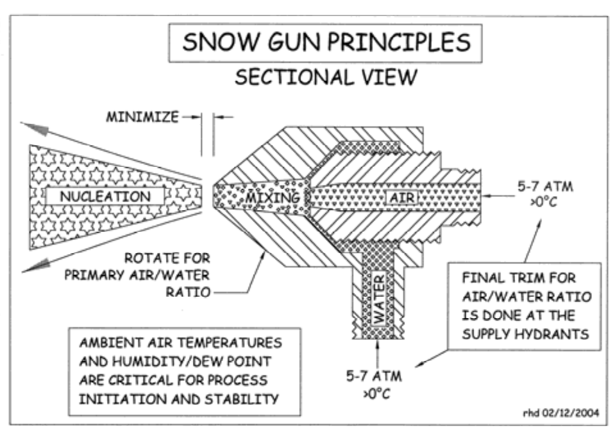
ABSTRACT: Avalanches of man-made snow occurring naturally, or triggered by skiers or snow-making personnel, have destroyed property and caused physical injury in the Eastern United States. Discussion with several well-known individuals at previous ISSW conferences revealed what appears to be a widespread disbelief that man-made snow can -- and does -- produce significant avalanches. Discussion of these phenomena includes a brief review of the snow-making process, a description of the product's nature and composition, how the product interacts with natural snow's metamorphism, and a review of the injuries, property damage, and the functional and economic losses that have resulted. An Olympic venue is included as a presentation example. Field analysis of several of these episodes has led to initial theories which may define the root causes of product failure. These theories, when merged with the practice of snow making, can be considered as a guide to mitigation of future episodes.

One of the earliest recorded avalanches involving man-made snow which came to my attention took place on Cannon Mountain, New Hampshire, early in the winter of 1973-74. At that time, operational practices were to create large mounds of man-made snow -- colloquially called "whales" -- in locations where grooming equipment could redistribute the material as required. One of these "whales," some twenty meters long, ten meters wide, and five meters high, was constructed at the top of a trail subsequently named "Avalanche." While one of the two snowmakers went to a nearby tree to retrieve his camera, the other climbed to the top of the mound. Without any warning, the whale headed for the ocean. The rider was uninjured, and managed to stay on top of what was a hard slab avalanche that ran for approximately two hundred meters.

Let us first take a look at man-made snow, or as it's called here in the West, "artificial snow." There isn't any crystalline structure, because there are neither the conditions nor the time for conventional crystals to form. Nor can it be described as small hail, because it isn't formed by raindrops that pass repetitively through freezing/wet conditions as they respond sequentially to convection and gravity. Rather, a hand lens will reveal irregular ice globules ranging in size from a few tenths up to a half-millimeter. "Very small sleet" might be apropos – but sleet as we know it is larger, because it is formed by raindrops falling through a freezing layer. Like sleet, however, individual particles of man-made snow can be surrounded by a layer of water. The presence -- or absence -- of this wet surface layer is controlled by the snowmaker, and depends on what needs to be achieved. There can also be water droplets that did not freeze.

A snow gun is a simple device. Typically, it consists of a chamber in which air, compressed to six or seven atmospheres, is released. An atomizing nozzle, or nozzles, sprays a mist of water into the chamber.

Freezing does not take place in the chamber; rather, there is a turbulent mixing of water droplets and air, which has just released its heat of compression.



This energy release cools the swirling mist, but it is not adequate to freeze the particles. If it did, the gun would quickly plug with ice. The start-up sequence is water first, then air.

As the high-velocity plume exits from the nozzle, it encounters and mixes with ambient air. Depending on the temperature and humidity, nucleation takes place, and the atomized droplets freeze and gravity takes over. The amount of airborne time the particles can achieve depends on the height of the nozzle above the snowpack, the wind, and the terrain.

There are also fan machines that do not require the installation of a compressed air system.

These are permanently mounted or portable. To operate its axial-flow air compressor, either a self-contained engine-generator set or nearby power outlets are required. Water droplets are injected into the resulting air stream and the product flow is directed at the target area. They require similar type of water pressure, but at a greater volume than air/water guns. The photo above shows the compressor blades where air is sucked into the machine.

At the other end of the scale are large tower units – mobile or fixed.

Their elevated nozzles are three to six meters above the surface, increasing time available for more complete nucleation, and improved product dispersion over a larger area. It is common to see lines of fan machines along each side of a trail, so that the left, right, or both sides may be activated, depending on wind conditions. This group is laying down man-made snow on bare ground.

In every case, nucleation -- freezing of water droplets -- occurs when the droplets mix with surrounding free air, which is below the freezing point. It is desirable to achieve nucleation as close to the gun as possible to maximize the airborne time. When the product comes to rest, it usually adheres to whatever it hits or lands on. Large trees will bow down in submission. Within a few seconds, even the driest of man-made particles will bond -- or freeze -- to the previous arrivals, leaving a smooth, creamy layer. Its density is usually in the vicinity of 240-280 kg/m^3.

Additives are frequently inserted into the water supply to assist nucleation. They are said to work by reducing droplet size, lessening the tendency of droplet aggregation, and accelerating mixing with air. These characteristics should allow the process to proceed at slightly higher ambient temperatures and humidity. Environmental impact studies continue at some ski areas. Further discussion is not a part of this paper.

Snowmaking is an expensive proposition. Initial capital costs vary from \$35,000 to \$150,000 per hectare (\$15,000 - \$60,000 per acre) depending on complexity, elevation, and water supply. For example, an installation at a typical small (590 hectare (240 acre) 3,500 skiers/hr capacity) Northern New England area in the 450cm (180") "snow belt" requires up to four kilometers of permanently installed piping ranging in sizes from 200 to 50 mm with eighty to one hundred hydrants.

The direct operating costs are significant. Pumping water against a five hundred meter hydrostatic head, while providing five to six atmospheres of air and water pressure at the summit, requires energy. Lots of it. Operating the system will account for at least seventeen to twenty percent of the area's direct operating cost. This does not include costs of slope grooming, which must follow completion of the previous night's snow-making, but must be finished before the area opens the next day. The Killington resort becomes Central Vermont Public Service's largest customer when snow-making is in full swing

Some areas lease diesel-powered engine-generator sets for pump and compressor motors; others are dependent on commercial power to create and maintain five to six atmospheres of air and water pressure in a system design to leak. Such an installation is not capable of simultaneous operation of every branch and every snow gun – perhaps only one or two trails can be treated at a time, while the snow-making crew attends to the system, usually at night when negotiated off-peak electric power rates are effective.

An area might restrict its snowmaking operations to the months of December and January, building up a base of man-made snow that will last through March or early April – if the weather cooperates. Thus, should a major trail produce a climax avalanche, it represents an immediate loss of labor hours and purchased energy that must be replaced before skiing can resume on that particular trail.

Snow-making during operating hours often requires trail closures, and can produce safety hazards to the skiing public. Should a client on a chair lift pass through a nucleation plume, the bottom of his skis can become covered with sandpaper, and he'll do a face-plant on the exit ramp. Should he ski through a plume, his goggles can ice up and cause him to run off the trail and into a tree. The downhill side of a whale can exceed fifty degrees of slope angle, causing injurious falls.

As with Mother Nature's avalanches, most man-made snow avalanches occur during or immediately after a precipitation event. One of Killington's largest avalanches occurred in the mid-eighties on its Devil's Fiddle trail. Skip King remembers that the slide path was well over 300m (980') long and left a crown that exceeded 3m (9'). It happened when all the guns were blowing snow during an overnight snowstorm that left nearly a meter of natural snow. "A lot of snow-making equipment was mangled and buried. They tried to shoot the remainder of it, but couldn't get any more snow to kick loose."

Again, it was man-made snow on top of an early-season layer of snow – which most likely became the failed weak layer of facets precipitating this climax episode.

What happens to man-made snow once it settles down with its neighbors? It depends on several factors. In cold temperatures, particles that are wet will quickly bond creating a hard, strong slab. If the particles are excessively wet, free water will drain out and either percolate or run on the supporting surface, then freeze as clear water ice. As the air/water ratio increases, the snow becomes drier. The snow-maker's test: what is happening on his coat sleeve? If the particles stick, they are wet. If the particles bounce off, they are dry. Sort of. Even the driest man-made particles, however, are nothing like Mother Nature's creation, because they bond quickly to their siblings. It results in a smooth, creamy surface that is reasonably quiet under your edges. Skis do not sink into it. An aggressive rider on a carving snowboard will cut only a fifty mm (2") notch in a newly groomed surface. Continual grinding by skis scrubs off the surface particles and plows them towards the sides of the trail, where they remain more or less "loose frozen granular" during the day. The rest of the trail is what Western skiers would call ice.

But -- and this is an important but – people come to slide downhill on it. They come by the thousands. Without it, they wouldn't.

In the meantime, what's going on below? Not very much, in the man-made layers. New man-made depositions bond to the old stuff. Every night, the "loose frozen granular" -- the particles that skiers have scrubbed off and plowed to the trail edges -- gets groomed back into corduroy. Every few nights, depending on traffic and erosion, more man-made snow is added and groomed.

It's in early December, however, that the stage is usually set for subsequent trouble. A few centimeters of natural snow covering the ground get a layer of man-made on top of it, while the trail remains closed due to thin cover. We have real cold in the far Northeast – nearly every winter, we have a week of days when the temperatures never rise above minus 20°C. Night-time temperatures of minus 35° - 40°C are not surprising. These cold, clear nights quickly turn Mother Nature's snow grains into faceted crystals, all the way up to the man-made/natural interface. There sits the man-made slab, poorly unsupported over much of its area. As more man-made is added; the thickness increases and the slab becomes stronger. Its weight may crush the underlying faceted crystals, but they do not provide any bonding – they remain as a weak layer. When there is enough man-made snow in place, the groomers attack it. Their weight may collapse the facets even more, but nobody knows it. If the slope angle is low to moderate, there is no problem.

On the steeper trails, though, it's different. The same metamorphic changes occur until the weight of the entire man-made slab exceeds the weak layer's load-carrying capability. Perhaps a cold snap causes a crack, and part of the slab settles in place. Or it slides.

This concept was clearly demonstrated to me one mid-January day in 1996. Peg Doheny, pro patrol director at Jay Peak in extreme northern Vermont, called me. She asked, "Roger, will you come up and listen to Can-Am with me? It's sounding like a bass drum again." Can-Am is a trail with a history of spontaneously climax avalanching its entire cover of man-made snow. I have looked down at large slabs piled up against the chair lift tower that is in the fall line below the steeper section.

The situation: Can-Am was lower in snow-making priority in the early part of the season. They had blown some man –made snow on it "to preserve the cover" but kept the trail closed. Again, they'd had a thin layer of natural snow, bitter cold nights, and an outer shell of man-made when they began to make snow on it in earnest.

Before the lifts opened the next morning, we stood at the top of the trail. It was steep and smooth. We skied the steep section about half-way. I measured the slope angle at an honest 42° for about fifty meters each way from where we stopped. Moving to the side, I began to dig. It did sound like a bass drum when you thumped the surface with a fist.

After cutting through about a meter (3'±) of very hard man-made snow, I reached the bottom layer of natural snow. Squares began to flow into the pit like dried corn. As fast as I shoveled them out, more flowed in. These faceted crystals measured up to 9mm (3/8".) They were as large as any I have ever seen here in the East. I looked up at Peg and said, "If this was all Mother Nature's snow, we'd be dead."

They were unable to use grooming machines on the slope due to its steepness. "Skier Stabilization" had been the method of choice. I recommended closure for the day, followed by blasting – a control measure that had not yet been used in the East to my knowledge.

Mother Nature smiled on us in the form of heavy rain which began mid-morning. The slab cracked in several spots and settled quietly in place, buttressed by the equally thick layer of man-made snow in the run-out area,

Another major avalanche took place on January 11, 1988. It was an important wake-up call. The newspaper in Stowe, Vermont, had some real news to report:


THE Stowe REPORTER

SERVING THE GREATER MT. MANSFIELD AREA

Stowe, Vermont | January 14, 1988 | Volume 30, Number 2 (USPS614-620) | 35 Cents

Avalanche damages National

The National is a FIS racing trail, and the priority for covering it may not have been as high as for less challenging (and more popular) trails. The end result, as seen in the deposition zone, was creation of a strong slab of reasonably uniform thickness Field observation recorded this as a hard slab climax avalanche with a 75 cm (30") crown 35M (115') wide -- the full width of the trail. It ran approximately 200M (650') down a slope averaging 35^o.

The 5,250M^3 (6700Yd^3) deposition zone, more than one and a half meters deep in places, completely covered a converging trail below the gondola lift line. While the newspaper account stated that the mountain's representative pointed at a layer of freezing rain as the culprit, it is more likely that faceted crystals at the snow-earth interface were the weak layer that failed. The trigger most likely was the snow-maker himself, as the entire slope fractured beneath him as he walked down the slope, wrestling with a snow gun and its trailing hoses. Working alone at night, without a radio, he was pinned against a tree. Half-buried and unable to extricate himself, his most serious injury was a fractured rib. Another maintenance party discovered the deposition zone, which led to his rescue.

The piping system supplying the trail with compressed air and water was ripped out, and three hydrants and guns were damaged, causing the system to be inoperative until repairs could be achieved. The mountain representative stated that "snow slides have occurred on Upper National before. They are not uncommon…"

The event allowed us to review weather and snowpack data. The most significant factor in this event was the small amount of natural snow cover in place before the onset of snow-making, and the temperature gradients that developed in the natural snowpack.[1]

Thin soil cover over bedrock, or a partially buried boulder, increases the efficiency of energy transfer into the snowpack, accelerating development of faceted crystals. As is the case with many higher Eastern trails, there is often a relatively thin layer of earth over glacier-polished bedrock. We assume there was no additional faceting after January 8 due to the additional man-made cover. There may have been some additional faceting above a rain crust that developed on December 25, when the natural snow cover was only about 10 cm.

The other common bed layer is grass. As we consider the ski areas in the East where natural snow may be limited, snow-making is initiated as soon as temperatures permit. Here is an early-season avalanche which slid on grass.

This ski area is called "Holiday Valley." It is located in Ellicottville, New York, forty-eight km from Lake Erie, and seventy-five km S-SE of Buffalo. With a summit elevation of 690 meters, and twelve lifts serving a vertical drop of 228 meters with fifty-two trails, it doesn't sound like an avalanche-prone site.

On December 13 and 14, 2002, its "Wall" trail, aptly named for its 37.5^o slope, produced large avalanches of exclusively man-made snow. It was unusual because there was <u>no</u> natural snow on the ground. Holiday Valley is definitely in the "lake effect" zone, receiving an average of 4.5 meters of natural snow in a typical season. That's why early season snow-making was underway -- to satisfy the hordes of skiers that were anticipating Christmas holidays and vacations.

Jane Eshbaugh, HV's spokesperson, wrote as follows:

[1] See Appendix 1.

“There was really no natural snow on the ground when we got a very long cold snap, but the ground was still very warm. We made snow (full-time) for a couple of days, let it cure, then it was groomed out. Next, we got rain which percolated down through the entire snow layer on to the relatively warm ground where it ran downhill and undermined the thick layer of manmade snow. I'm not sure, but I think there was a crack in the snow at some point earlier which had been filled in.

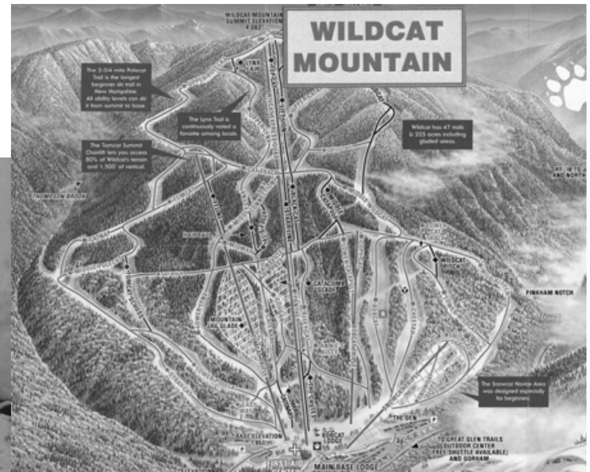
“The snow actually slid twice, Friday night and Saturday. The lower section, approximately 2/3 of the slide, broke off Friday night.

“(Early) the next morning, after some additional rain, another 30 M (100’) section came down. Our belief is that the slide was partly precipitated by the warm ground and lack of adhesion and that there was no snow at the base of the steep pitch. The lack of snow at the bottom to (anchor) the 2.1+M (7+ft) slab on the steep headwall was a key factor in the second slide. The end result was that we had 3M (10’) of snow at the bottom after the slide which helped stabilize the (subsequent) snowmaking.

“We have had cracks and fracture lines on this pitch every year, but never a snow slide until this season. We are very thankful that no people were injured or equipment was damaged!”

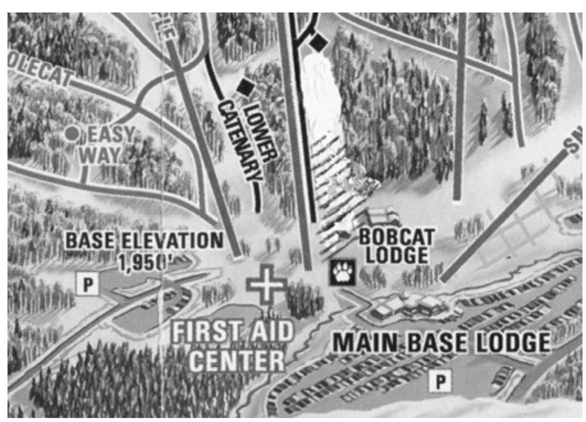
Sam Caldbeck has nicely explained why snow grains won’t stick to ice. His analysis [2] may apply to a slush flow avalanche that occurred last December 17 at Wildcat Mountain, Pinkham Notch, NH.

While firefighters were tracking down a false alarm in heavy rain at 11:30 PM, The Chutes – an old gondola lift line -- slid.



“The Chutes” -- 28^{o} to 30^{o} -- is close to the base of the mountain. It had received more than 120cm (4’) of new snow in the preceding 48 hours. This was deposited on 60cm (2’) of man-made snow than had been distributed from whales on a few centimeters of natural snow. Then, more than 50mm (2”) of rain fell in a few hours.

Beginning about 200M (600’+) above the bottom of the trail, the now water-soaked new snow slid off the lubricated icy surface of the man -made snow for 100M until its accumulating mass collapsed the man-made layer. It then turned into a climax avalanche for the second 100M, filling the former gondola building with slush, tree branches, and gravel.

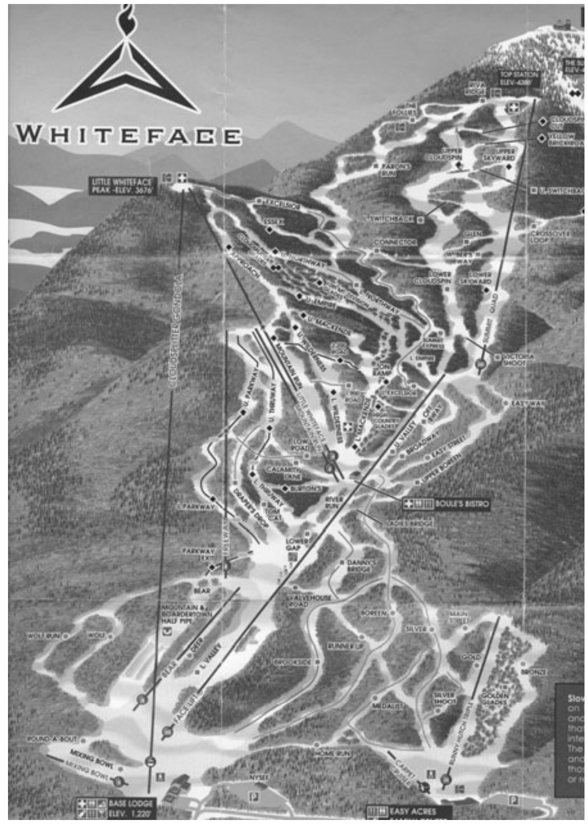


[2] - see Appendix 1

It half-buried the vehicle inside, totally buried a snow machine and ripped a power transformer off its mounting pad.

The resulting electrical outage affected about one-third of the entire complex, including lift motors and water pumps to the rest rooms. The next morning, there were about 2,000 people milling about, using the rest rooms, waiting for the lifts to start. Not a nice day.

The last avalanche on today's list dates back to 1980 at Whiteface Mountain, Lake Placid, NY. As a memory-jogger, the American ice hockey team beat the Soviets. Ingemar Stenmark's victories in the Slalom and GS really raised the bar. It was also a busy year for the snowmaking crew as they coped with a dearth of snow in the Adirondack's "High Peaks." It was the very first time that man-made snow was to be used in Olympic competition.



Whiteface has the greatest lift-served vertical drop in the East – 964M (3166'). Its summit elevation – 1483M (4687'), however modest by Western standards, creates a small sub-alpine zone that is mostly krummholz.[3]

Facing northeast through east, the higher elevations receive wind-deposited snow – augmented by extensive snow-making.

Outside the snow-making area, five separate landslides have left wide 35^o bedrock scars that create natural avalanche tracks. Closely monitored by the Ski Patrol, the avalanche hazard level is routinely publicized. Even though easy access from the Summit Quad is controlled, a dedicated tourist can enter the slides by skinning up the Auto Road to where they begin, fifty meters above the top of the Summit Quad.

It is all New York State Park; no control or closure measures are possible at present. We have found The Slides to be a superb venue for our Eastern Division's Level II courses.

[3] See Appendix 3

The Olympic men's downhill began near the top of the lift-served area and ran almost to the very bottom. The steepest section was on Upper Cloudspin. This is the area that proved troublesome.

Snowmaking began by depositing about a half-meter (18") on top of a thin layer of natural snow. It fractured as a hard slab and climaxed from Cloudspin Cut to below Upper Switchback, with most of the deposition running into the woods that make up the islands above Lower Switchback. (Last winter, I measured slope angles on this convex section and found them to vary between 35^{o} and 40^{o}.) The trail pitches down sharply just below the Upper Cut, which is where the initial avalanche's crown was left standing.

Quiet – but deep – panic set in. There was little or no natural snow in the forecasts. The opening of the 1980 Winter Games was days away, and the competitors needed to get in their practice runs.

The snowmakers replaced the damaged plumbing and went back to work. Temperatures held below freezing. As soon as a few centimeters accumulated, the ski patrol, ski school instructors, and volunteers went to work, boot-packing and jumping with skis in an effort to make the new man-made snow adhere to the ground – which was fortunately frozen. There was a valid concern that grooming vehicles would start another slide, and would be immobilized in the avalanche's deposition.

This time, it stayed in place.

<u>Recommendations</u>

There are a few things that I would offer for consideration <u>when it becomes necessary to make snow on slopes with angles that exceed 30^{o}</u>.

- Do not let snowmaking personnel work alone without an avalanche beacon and a trained watcher with a beacon, shovel, probe, and a means of communication.
- Avoid making snow on top of thin layers of early-season natural snow. Be aware of what temperature gradients can do. Build base layers on frozen ground whenever possible. If your ground never really freezes, and the area is grassed, good luck.
- See what test pits can reveal. They are far more useful than in the back country, because you can dig them on the suspect slope itself.
- If it is desirable to create whales, don't build them on convex slopes.

<u>In Conclusion:</u>

I have written down a few details of some of our avalanches involving man-made snow in New Hampshire, Vermont, and New York State. I have heard of others in other eastern states – and in Alberta. No doubt you know of more. Most of the observers had little, if any, training in avalanche hazard assessment, which makes this presentation mostly anecdotal. Causation judgment is mine, and it is based on what I have learned about the Eastern snowpack's characteristics.

It has not been possible to have qualified observers report on causative factors. In all cases where there was significant deposition, trail closure and aggressive grooming quickly redistributed the "evidence" to minimize operational interruptions.

Within the past three or four years, a story emerged from a very large ski area not too far from where I live. I have verified that the story is true.

The lifts had just opened. A first-run in-bounds skier with a valid lift ticket, skiing alone, went over a whale. There was some new overnight snow over extensive snowmaking (which was still in process.) The whale released, broke apart, and the ensuing hard slab avalanche carried the skier some 45 meters (150') down the 30^{o}+ slope, trundled him another 23 meters (75') into the woods, and buried him up to his neck, standing up, still on his skis. Eight inches deeper, and his survival would have been in question

Holiday Valley: Jane Eshbaugh

We have had our share of fatalities in natural snow avalanches here in the East. Most, if not all, were triggered by the victims. I shall not be surprised to learn of our first Eastern fatality in an avalanche of primarily man-made snow.

Date, 1988	Minimum temp, °C	Old snow depth, cm *	Temperature gradient =/>1 degree/cm	Added man made, cm	Total man made, cm **	Avalanche episode
Jan 3	-19	17	yes	None	None	None
Jan 4	-27	27	No	None	None	None
Jan 5	-27	27	No	None	None	None
Jan 6	-28	25	Yes	None	None	None
Jan 7	-30	27	Yes	None	None	None
Jan 8	-32	30	No	20	20	None
Jan 9	-29	30	No	20	40	None
Jan10	-18	27	No	20	60	None
Jan 11	-28	27	No	20	80	Climax

Thanks:
Scott Barthold
Peg Doheny, Pro Patrol Director, Jay Peak, VT
Dennis Duquette, Operations Manager, Wildcat Mountain, NH
Jane Eshbaugh, Public Relations, Hidden Valley, NY
Jay Rand, General Manager, Whiteface Mountain, NY
William Roy, General Manager, Cannon Mt, NH
Yaroslav Stanchak

Photos:
Snow guns: Timothy Grover and manufacturers
Cannon Mountain whales and Wildcat: Mike Pelchat

Appendix 1

Weather and natural snowpack* data for eight days preceding the January 11, 1988, man-made snow avalanche at Mount Mansfield, Stowe, Vermont.

Appendix 2

US Army Cold Regions Research and, NH
Paper presented at bi-annual conference of Eastern Division NSP Avalanche Instructors – March, 1999

Appendix 3

Krummholz -- literally, “crooked wood.” Created by prevailing winds, scrub evergreen and hardwood grows horizontally rather than upwards. The dense foliage mat creates good anchorage for the snowpack, until it is covered.