Avalanche!

High in the Swiss Alps, a multidisciplinary group of researchers is developing a feeling for snow. Quirin Schiermeier meets the avalanche forecasters.

Many of those who lost their lives in Galtür on 23 February 1999 never knew what hit them. Until that afternoon, hundreds of thousands of tonnes of snow lay banked on the high ridges that flank the small ski resort in the Austrian Alps. Then the banks suddenly collapsed, unleashing an avalanche that swept away buildings and killed more than 30 people. Similar tragedies struck across the mountain valleys of Austria, Switzerland and France, where five metres of snow had fallen in the preceding weeks. In total, more than 100 people were killed, and the economic damage topped €1 billion (US$1.1 billion).

The death toll for this disaster was exceptional, but avalanches kill every year. Only last month, 14 skiers and hikers died near Rogers Pass in British Columbia, Canada. A similar number have so far been killed in the Alps this winter. To counter the threat, studies of the layers of snow and the dynamics of avalanches have intensified in recent years. Researchers cannot eliminate the hazard but, by mapping the most dangerous areas and understanding the physics involved, they can issue timely warnings that could save lives.

Avalanches are a common phenomenon: each year about a million thunder down the slopes of snow-covered mountains around the world, from the Himalayas to the Andes. The vast majority do little harm. In fact, by clearing patches of mountain forest they can provide space and light for new vegetation, and play an important role in maintaining the biodiversity of mountainous regions[1]. But in the densely populated Alps, the events pose a threat to skiers, property and the tourism industry.

Lofty ambitions

The Swiss Federal Institute for Snow and Avalanche Research (SLF) in Davos is at the heart of the efforts to understand avalanches. Founded in 1936, the SLF is the oldest institute of its kind, and it is also the scientific backbone of Switzerland's avalanche-forecasting system. The SLF's staff love mountains. Many are semi-professional climbers with impressive expedition records. Summit photographs decorate most of the institute's offices and the talk is of recent climbs. The 125 scientists who try to make the Swiss mountains a safe place to live and relax also come from many different fields — geology, forestry, geophysics, soil science, meteorology and climatology. "There is no fixed way of becoming an avalanche scientist," says Paul Föhn, a geophysicist and the SLF's chief senior scientist. "They'll only learn what they need once they've joined us."

The Galtür avalanche killed more than 30 people.

F. COFFRINI/AP

M. LEUKEL/REUTERS

For researchers such as Föhn, understanding the behaviour of snow and avalanches is as great a challenge as the climbing expeditions they have undertaken. Most avalanches begin on slopes inclined at between 30° and 60° to the horizontal, when snowfalls produce 'snowpacks' that are about 0.5–1.5 metres high. But sometimes these packs reach 2–5 metres high, and when these collapse, they do so with devastating effects. The big question is how these snowpacks manage to remain stable for so long, allowing so much snow to build up.

The answer lies in the structure of the snow — crystals of ice that have air and water interspersed in the pores between them. The detail of this structure is far from straightforward, and it changes with time. The beautiful jagged crystals that make up fresh snow slowly become rounded, changing the way in which the snow is packed. Temperature also affects the structure. Banks of snow are warmer than the surrounding air, even warmer at their base, and all levels can be close to melting. "If you want to know how avalanches behave, you need to understand these complex physical properties," says Föhn.

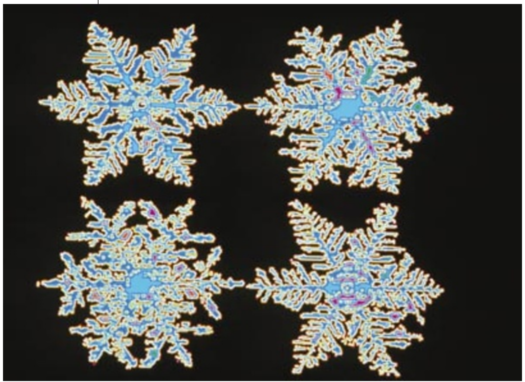
Of all the factors involved, perhaps the most important for avalanche researchers are the interfaces between the various layers of snow that have fallen at different times. The top of a snowpack can form an icy crust known as hoar-frost, which forms a weak interface with any snow that falls on top of it. Under strain — the weight of the snow on top, a disturbance caused by skiers or snowboarders, or a sonic boom from a jet plane — the jagged crystals on the surface of the hoar, which mesh with the snow layer above, can suddenly collapse like a house of cards, sending the snow slipping away[2].

Catching the drift

But predicting when and where this will happen is extremely difficult. Perry Bartelt, head of the SLF's department of avalanche dynamics and simulation, has developed equations that describe the conservation of mass, energy and momentum in the snowpack[3–5]. These have been combined with meteorological data, such as measurements of relative humidity and wind speed, collected by the 50 or so observation stations in the Swiss Alps to produce a model known as SNOWPACK. This tracks the height of the different layers formed by successive snowfalls, as well as the nature of the interfaces between them.

On his computer screen, Bartelt shows how his model tracks the build-up of the snowpack in the Swiss Alps during the catastrophic winter of 1999 — it corresponds well with observations. But such simulations are plagued by the small-scale variations that are present in every bank of snow. An abrupt change in steepness in the middle of a slope may make the snowpack above it less stable, and SNOWPACK and other models cannot take account of such infinitely variable details. Avalanche forecasters make use of the model's prediction for the height of the snowpack, but local knowledge is still essential. "Human observation and experience remain the most reliable components in any avalanche warning system," says Föhn.

Engineers working on avalanche defences and planning building projects would also benefit from a better understanding of snow. To calculate where an avalanche will come to a halt, and so prepare hazard maps, researchers use data on the frequency of avalanches in the area and on where the snow usually stops. This is combined with numerical models that describe how the mass of the avalanche changes as it falls — avalanches tend to pick up snow as they progress. To test the result of these calculations, researchers need to study avalanches under controlled conditions.


S. CAMAZINE/SPL

Crystal balls: the physical structure of snow is key to predicting the behaviour of avalanches.


K. NISHIMURA

Rolling, rolling, rolling: thousands of ping-pong balls simulate an avalanche on a ski jump.

This isn't as contradictory as it seems. On 31 January, after a three-year break caused by lack of snow, SLF researchers used a small dynamite charge to release a powerful avalanche at a test site in the Vallée de la Sionne in Switzerland. Such experiments can prove hairy for the scientists involved. "Even in our small observation bunker at the foot of the slope we felt the enormous shock wave," says Felix Tiefenbacher, a physicist who studies avalanche dynamics. During a similar experiment four years ago, the 20-metre-high measurement pylon erected in the avalanche lane was torn down — although this time it withstood the pressure.

Data from sensors on the pylon and elsewhere yielded measurements of velocity, friction between the snow and the ground, and the pressure exerted by the avalanche. The researchers also measured the mass of snow that arrived at the base of the slope — for comparison with the mass used to trigger the avalanche — and how far the snow spread. In the long term, says Tiefenbacher, they hope to use such data to generate a law to describe the flow of snow, similar to the fluid-dynamics equations that are used to describe the movement of water. Such a law could then be used to decide which areas are suitable for building, and how to protect existing property in danger areas. It may also aid research into similar processes, such as rock falls, landslides and mudflows.

Sharp chutes

Adverse weather conditions, and the risk of uncontrolled avalanches, mean that the large-scale experiments needed for this effort are not performed very often. In the meantime, researchers have to make do with substitutes. Tiefenbacher, for example, uses a 34-metre-long snow chute on the Weissfluhjoch, a mountain near Davos, to simulate avalanches and test the architecture of catching or deflecting dams. It is a painstaking business. "It takes hours to shovel into the chute the ten tonnes of snow you need for a two-second experiment," he says.

To estimate the balance of forces in an avalanche, researchers have even tried using ping-pong balls. In several experiments since 1995, researchers at Hokkaido University in Japan have released up to 550,000 balls from close to the top of the landing slope of the Miyanomori ski jump in Sapporo[6]. Video cameras measured individual ball velocities, and air-pressure sensors were mounted at different heights. Avalanches are much more complex events than such simulations, but the results helped to confirm assumptions, based on laboratory experiments, about the frictional forces and turbulence involved in such granular flows.

Despite the difficulties involved in their field, researchers at the SLF and elsewhere can point to a steady reduction in avalanche casualties. More than 100 people suffocated in their homes in the winter of 1950–51, trapped by avalanches. But apart from exceptional incidents such as Galtür, the main threat is to tourists who ignore warnings. The Davos scientists nevertheless remain alert to the constant winter threat. But they also get the chance to indulge in more glamorous work — the runs for this month's Alpine World Ski Championships, held in St Moritz in Switzerland, were prepared with the help of SLF expertise. ■

Quirin Schiermeier is *Nature*'s German correspondent.

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