International Snow Science Workshop, 2023
Summaries of 15 Interesting Papers

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During October 8-13, 2023, over a thousand avalanche specialists and experts met in Bend, Oregon, for the International Snow Science Workshop (ISSW). This event, normally held every other year but interrupted during the Covid-19 pandemic, draws ski patrollers, academic researchers, mountain guides, snow-safety officials, and government scientists from around the world to share the latest developments in snow science and avalanche safety. The week-long conference included over 100 presentations, numerous posters, and booths showcasing the latest in avalanche rescue technology, guidebooks, and equipment for winter mountaineering.

I'd like to share summaries of 15 presentations, selected purely according to personal taste. I also learned a lot from many of the other presenteations, including a poster presentation on the ongoing work of NSP's Nordic ski patrols to promote avalanche safety.

A striking recent development in avalanche science is the use of mathematical models. Statistician George Box once admonished that "all models are wrong; some are useful." My own (biased) opinion, as a mathematician who studies porous-media flows, is that we do not have a science until we have useful models. They identify the dominant mechanisms and tell us what to measure. ISSW 2023 revealed many great strides in this direction, but snow science still has a lot of work to do.

All papers—from this and previous workshops—are available for free download from the Montana State University's International Snow Science Workshop Proceedings, https://arc.lib.montana.edu/snow-science/.

1. Grégoire Bobolieri et al., SUPERSHEAR CRACK PROPAGATION IN SNOW SLAB AVALANCHE RELEASE: NEW INSIGHTS FROM NUMERICAL SIMULATIONS AND FIELD MEASUREMENTS (ISSW2023_O2.01).

Dry-slab avalanche size depends on the speed of crack propagation in weak layers. Numerical models and field measurements of the propagation saw test indicate that propagation speed depends on slope angle.

- On low-angle terrain (0°-20°), weak-layer collapse causes compressive failure at the crack tip. The crack propagates at speeds lower than the slab's shear-wave speed ("sub-Rayleigh speeds"), depending on the weak-layer microstructure and slab stiffness.
- On steep terrain (25°-50°), cracks greater than a critical length—about 5 meters—propagate at speeds approximately 1.6 times the slab's shear-wave speed ("supershear speeds"). This propagation is driven mainly by gravity-induced tension and shear stresses on the slab and is less dependent on weak layer mechanical properties and slab stiffness.

The second bullet suggests that a shear-based model may suffice to predict the sizes of large dry-slab avalanches.

2. Francis Meloche et al., INFLUENCE OF SLAB DEPTH SPATIAL VARIABILITY ON THE PROBABILITY AND RELEASE SIZE OF SKIER-TRIGGERED AVALANCHES (ISSW2023.O2.04).

Spatial variability in slab depth influences (1) the probability of a skier triggering an avalanche and (2) the size of the avalanche. Mechanical-statistical simulations indicate that probability of triggering:

- Decreases with mean slab depth, since deep weak layers are harder to trigger;
- Increases with slab-depth variance, since larger variances allow for more shallow (weak) spots;

- Decreases with slab-depth correlation length, since a large correlation length results in fewer weak spots.

Skier and rider trajectories also influence the probability of triggering. Trajectories with small cross-slope amplitudes, such as freeride trajectories, have a smaller probability of finding weak spots. Conversely, trajectories with large cross-slope trajectories, such as typical uphill skin-track trajectories, are more likely to hit weak spots.

3. Karl Birkeland et al., COMPARING STABILITY TESTS AND UNDERSTANDING THEIR LIMITATIONS (ISSW2023_O2.05).

Although explosives provide the most effective method for testing the avalanche potential
of a slope, they are not always practical. In these cases, small-block tests offer alternatives. Although these tests provide information at scales much smaller than a typical slope, they help indicate whether (1) there is a slab overlying a weak layer, (2) it is possible to trigger weak-layer failure, and (3) the resulting crack will propagate. The four most common tests are the Rutschblock Test (RB), the Compression Test (CT), the Extended Column Test (ECT), and the Propagation Saw Test (PST).

The following table summarizes the types of information that each of the four tests can provide for dry-snow slabs.

Test	Slab Over Weak Layer	Weak Layer Failure	Crack Propagation
RB (with release type)	Yes	Yes	Yes
CT (with shear quality)	Yes	Yes	Partly
ECT	Yes	Yes	Yes
PST	No	Partly	Yes

Other observations include the following.

- The ECT is a good general-purpose test, since it (1) can be conducted quickly, (2) gives representative results on low-angle slopes, and (3) yields information about layering, failure initiation, and crack propagation.
- The RB requires more time but samples a larger area than the other tests. It also requires that the weak layer of interest be deeper than the ski penetration depth. RB test results depend on slope angle, so tests on slopes less than 30° require cautious interpretation.
- The CT is fast and useful for identifying potential weak layers, especially within the top meter. It focuses on weak layer failure and yields useful results on low-angle slopes.
- The PST requires prior knowledge of the critical weak layer. It focuses primarily on crack propagation in that layer. PSTs are useful when the critical weak layer is too deep to test using other methods.

All four tests sometimes yield false-stable results. All four have the virtue of slowing a travel party's decision-making process, allowing time for better group communication and more focus on snowpack stability.

4. Ron Simenhois et al., SLOPE SCALE ESTIMATES OF CRACK PROPAGATION SPEEDS FROM AVALANCHE VIDEOS (ISSW2023_O9.01).

Snow-surface movements observed in avalanche videos allow estimates of crack propagation speed, a key factor in determining dry-slab avalanche size. Changes in pixel intensity reveal the location of the crack in the weak layer before slab fractures appear on the snow surface. This technique measures crack speed at the slope scale, in contrast to small-block tests such as the propagation saw test.

In the videos analyzed, crack propagation speeds within about 15 m of the initiation point—about 27±2 m/s—were comparable to previously reported speeds observed in propagation saw tests, in both the up- and down-slope directions and the cross-slope directions. However, beyond 15 m from the initiation point, speeds were 150±11 m/s in the up- and down-slope directions and averaged 34 m/s in the cross-slope directions. These results support other researchers' proposals that cracks propagate at sub-Rayleigh speeds near initiation points, later transitioning to supershear speeds in slope-wise directions.

5. Jason Konigsberg et al., THE RELATIONSHIP BETWEEN WHUMPF OBSERVATIONS AND AVALANCHE ACTIVITY IN COLORADO, USA (ISSW2023_O9.03)

Backcountry travelers have long associated whumpfs—caused by the collapse of basal weak layers in the snowpack—with avalanche danger. Analysis of data from Colorado's Front Range and San Juan Mountains confirms this association at snow depths less than 1 m. Later in the season, when basal weak layers lie deeper than 1 m, whumpfs are less common, even when avalanche activity increases. In these circumstances, often associated with the largest avalanches of the season, the absence of whumpfs is unreliable as an indicator of safe avalanche conditions.

6. Alex Marienthal, COMPARING THE EFFECTIVENESS OF THE ECT, PST AND CT FOR ASSESSING SNOW STABILITY (ISSW2023_O9.04)

Two data sets—561 stability tests conducted by professional backcountry avalanche forecasters and 3,313 tests reported in the SnowPilot.org database—yield information about the effectiveness of the extended column test (ECT), propagation saw test (PST), and compression test (CT). The following table summarizes false-stable and false-unstable rates for these tests.

Test	False-Stable Rate	False-Unstable Rate
ECT	16-31%	23-44%
PST	19-36%	34-37%
CT	39-86%	39-86%

The relatively high false-stable rates shown here may reflect the mismatch between scale of small-block tests and the scale of actual avalanches.

7. Amelie Fees et al., GLIDE-SNOW AVALANCHES: THE INFLUENCE OF SPATIAL VARIATION IN INTERFACIAL FRICTION AND SNOW COVER ON AVALANCHE RELEASE (ISSW2023_O9.05)

Glide avalanches occur when liquid water at the ground-snow interface results in a loss of friction. Because the spatial distribution of liquid water is unknown, glide avalanches are difficult to predict. A mathematical model based on hypothetical snow columns having hexagonal cross-section and interacting through compression, shear, and tension helps explore the mechanics of glide avalanches and the effects of spatial variability.

The model shows that glide-avalanche release area obeys a power-law distribution, in agreement with 14 years of field site observations. Sensitivity analysis indicates that the probability of glide avalanches increases with homogeneity of the basal friction but is only weakly dependent on snow density and other snow-cover properties.

8. Spencer Logan et al., ASSESSING THE COLORADO AVALANCHE INFORMATION CENTER'S BACKCOUNTRY AVALANCHE FORECASTS (ISSW2023_O5.02)

The Colorado Avalanche Information Center (CAIC) selected a set of public backcountry avalanche forecasts between November 2017 and April 2022 to compare the forecast avalanche problems and danger ratings with a posteriori assessments and an avalanche activity index (AAI) based on observed avalanches. The forecast avalanche danger rating agreed with the assessed avalanche danger rating on 84% of the days studied.

The following observations help describe the cases where the forecast and a posteriori assessments differed.

- The percentages of days of under- and over-forecast danger levels were similar—about 8% in each case.
- Differences between the forecast and observed weather explains many of the differences between forecast avalanche danger and the assessed danger.
- Below timberline, the forecast danger was one level or more higher than the assessed danger in 10% of the cases, suggesting that avalanche observations and danger ratings are more difficult below timberline.
- Some evidence suggests that discrepancies between forecast and assessed danger levels are more frequent during the temporal tail ends of avalanche cycles.

Over-forecast danger ratings—when the forecast danger rating is higher than the assessed danger rating—may be acceptable from the perspective of public safety.

9. Erich Peitzch et al., BIG AVALANCHES IN A CHANGING CLIMATE: USING TREE-RING DERIVED AVALANCHE CHRONOLOGIES TO EXAMINE AVALANCHE FREQUENCY ACROSS MULTIPLE CLIMATE TYPES (ISSW2023_O6.01).

Tree-ring analysis (dendrochronology) helps identify long-term, large-magnitude avalanche (LMA) chronologies for regions in three climate types: a high-latitude maritime zone in southeast Alaska, an intermountain zone in Montana, and a continental zone in Colorado. Of special interest were tree rings associated with reaction wood, where an LMA bent the tree and subsequent tree growth tried to straighten it, altering the tree rings.

The analysis yielded the following conclusions:

- In southeast Alaska, precipitation in February and March is the main driver of LMA activity. Shifts in the Oceanic Niño Index—an indicator of ocean temperature effects—can change the precipitation type during this late-winter period. Warmer temperatures associated with El Niño tend to reduce the frequency of LMA activity.
- In Montana, LMA activity has historically been associated with above-average snowfall, but in recent decades warmer temperatures and shallower snowpacks have driven LMA activity.
- In Colorado, LMA winters tend to occur in years with more precipitation and deeper snowpacks, but the relationship is more complex. Cold early winters tend to produce persistent weak layers that can lead to LMA activity independently of total winter snowfall.

10. Erich Peitzch et al., USING TREE RINGS TO COMPARE COLORADO'S 2019 AVALANCHE CYCLE TO PREVIOUS LARGE AVALANCHE CYCLES (ISSW2023_O7.01).

In March 2019, Colorado experienced a historic large-magnitude avalanche (LMA) cycle, with over 1000 avalanches—many size D4 or larger—reported in a two-week period. In many cases, the avalanches lengthened and widened existing paths. Downed trees from these avalanches provided an unusual opportunity to study avalanche history using tree-ring analysis (dendrochronology). Tree rings and historical records indicate that the most recent LMA cycle comparable to that of 2019 occurred in 1899.

11. Paul Baugher et al., CHARACTERISTICS OF INBOUNDS AVALANCHE FATALITIES AT UNITED STATES SKI AREAS (ISSW2023_O14.05).

The risk of dying in an in-bounds avalanche is less than one death in 60 million skier visits. In the U.S. during the past two decades, 17 people died in 14 in-bounds avalanches. Many of these events shared one or more of the following characteristics:

- They occurred when the terrain was opened for the first time of the season.
- They involved post-mitigation releases (PMR).
- The fracture occurred on a persistent weak layer.
- Multiple people were on the slope.

Two events occurred in closed terrain. All occurred early in the season (10 December – 23 January). In all cases where slope aspect is known, the events occurred on NW-N-NE aspects. Among events where slope angles are known, 83% occurred on slope angles 39° or steeper. Over 40% of the deaths were attributable to trauma.

Recommendations for minimizing risks associated with in-bounds avalanches include the following:

1. Make terrain closures as clear as possible.
2. Use caution when opening terrain for the first time of the season, especially if persistent weak layers exist.
3. To minimize the risk of early-season PMR, place shots in a wide variety of locations, to increase the probability of finding trigger spots. Where feasible, air shots (detonating explosives above the snow surface) can reach more trigger spots.
4. Where possible, introduce artificial spatial variability to inhibit crack propagation. Techniques such as skier compaction and boot packing can increase small-scale spatial variability.

12. Michael Ferrari, AVALANCHE FATALITY IN THE CHUTES AT MT. ROSE FROM THE ACCIDENT THROUGH THE TRIAL (ISSW2023_O15.01).

On 10 December 2016 a customer died in an avalanche that occurred in a closed area at Mount Rose Ski-Tahoe. The event led to a wrongful-death lawsuit against the ski area. After a three-week civil trial, the jury delivered a verdict in favor of the ski area. This paper reviews the details of the accident, rescue, and recovery and examines the key factors that led to the jury's verdict.

13. Andy Moderow and John Sykes, STABILITY TEST CRAFTSMANSHIP: DOES IT MATTER? (ISSW2023_O16.01).

Avalanche experts place a great deal of emphasis on craftsmanship in extended column tests (ECT) and compression tests (CT). A study of 255 tests conducted at a single site with a weak layer 80 cm deep helps identify how irregularly shaped columns can affect the results of small-block tests. Types of irregularity studied for the CT include:

- Columns tapering from 30 cm × 30 cm at the surface to 20 cm × 30 cm or 40 cm × 30 cm at the weak layer
- Undersized (20 cm × 30 cm) and oversized (40 cm × 30 cm) columns.

For the ECT, the irregularity studied included 30 cm × 90 cm columns that tapered to 20 cm × 90 cm at the weak layer.

For the CT, the difference in average scores between the tapering blocks and the standard blocks was 8.8 taps. The comparable difference for undersized and oversized blocks was 5.6 taps, with undersized blocks yielding lower scores and oversized blocks yielding higher scores. For the ECT, 100% of the undersized, irregular columns yielded weak-layer failure with propagation, with an average score of ECTP 22, while only 15% of the correctly sized columns failed.

14. Samuel Verplanck and Edward Adams, STRESS WAVES THROUGH SNOW COLUMNS (ISSW2023_O16.04).

Dry-slab avalanches commonly occur as a result of impact forces, which generate stress waves in the snow column. A comparison of one-dimensional mathematical models with laboratory experiments on 30 cm × 30 cm snow columns 60 cm tall shows that the damped wave equation (Maxwell viscoelastic model) captures the wave propagation more accurately than the standard wave equation (elastic model). Stress waves attenuate more rapidly in response to short-duration (impulsive) impacts than for longer-duration impacts, which are more representative of the hand-tap loading used in small-block snowpit tests. Stress waves also attenuate more rapidly in hard, dense snow than in soft, light snow. An interesting phenomenon that occurred in both the mathematical model and in the experiments is the reflection of waves when they hit a hard surface, such as granite. Positive interference between the incident and reflected waves can result in stresses at the bottom of the column that exceed the peak stress applied at the snow surface.

15. Brian Lazar et al., STRESS MITIGATION IN AVALANCHE WORK (ISSW2023_O15.02).

Avalanche workers experience both acute and chronic stress, which can lead to stress injuries. Using a framework developed by Laura McGladrey and the Responder Alliance, the Colorado Avalanche Information Center and Snowmass Ski Patrol implemented stress injury programs during the 2022-2023 seasons. The goals of the programs are as follows:

1. Identify stress injury as a common, predictable occupational workplace phenomenon in snow work and institute screening procedures.
2. Establish systems to treat predictable reactions of stress injury.
3. Prevent stress injury by promoting self-awareness and a culture that supports positive mental health choices.
4. Establish and implement support systems to encourage post-exposure risk identification and mitigation.

Younger employees tended to be more receptive than veterans to the concepts of stress management and stress resiliency. The programs provide tools for supervisors and managers to identify periods in which workplace stresses can reach critical levels that lead to stress injuries and for employees to recognize when other team members may be experiencing moderate or considerable stress levels.