AVATECH: THE FIRST PORTABLE, WEB CONNECTED SNOW PENETROMETER FOR PROFESSIONALS

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ABSTRACT: Understanding snowpack stratigraphy and stability, its spatial and temporal variability, and the associated avalanche risks is inherently difficult, time consuming and one of the greatest challenges snow professionals face. For decades, snow professionals have recognized the need to develop field tools that can gather fast, quantitative, and accurate stratigraphic information about the snowpack which, in combination with other observations, provides invaluable information about slope stability. Current tools like the SnowMicroPen (SMP) and Ram Penetrometer have done wonders for the snow science community, but have not been broadly adopted by professionals due to high costs, difficulty of use, or other constraints. At AvaTech, we have developed the first portable, web-connected, and affordable snow penetrometer, the “SP1”, designed to quickly and accurately sample, record, and evaluate snow-pack structure and other critical snowpack characteristics. AvaTech measurement data is automatically synched via bluetooth to a smartphone application and then to the cloud, creating a unique crowd-sourced database of geographically based, snow conditions. Sharing this data across a broad network has the potential to create one of the largest sets of spatial and temporal snowpack information in the world, a potential high value resource for avalanche forecasting, snow hydrology, snow ecology, glaciology, and remote sensing applications. In our paper, we share qualitative and quantitative results from a rigorous scientific testing program with over 50 professional partner organizations across the US (CO, UT, CA, MT, WY, ID, AK, NH, VT), Canada, Norway, Iceland, Chile, Greenland and Switzerland. Specifically, we highlight high correlations between probe data and professional manual snowpit assessments as well as key learnings from testing.

KEYWORDS: Snow penetrometers, spatial variability, avalanche forecasting

1. INTRODUCTION

AvaTech builds proactive systems that quickly analyze the snow pack and facilitate the sharing of this information real-time in order for individuals and groups to make better decisions. Over the past two years, AvaTech has developed several new snow safety technologies including: the SP1, a high precision, portable, lightweight, and web-connected penetrometer that measures snow structure and other critical snowpack information; AvaNet, a global snowpack data platform that crowdsources information from the SP1; and a new easy to use manual snow profile tool.

AvaTech was born out of MIT in September 2012. With much of today’s attention focused on how to survive an avalanche, AvaTech focuses on developing technologies that address the proactive, avalanche avoidance side of snow safety. Working with the guidance and feedback of some of the top industry practitioners and scientists who joined our advisory board we conducted a rigorous winter testing program soliciting the feedback from this professional network. In this paper, we will focus primarily on the results from this winter testing

Fig. 1: An AvaTech SP1 prototype from the testing program

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program and our key learnings that went into our production development.

2. METHODS

2.1 Summary of testing partners and goals

From January to May of 2014, AvaTech and a team of 50+ partners rigorously tested 25 prototype SP1 units as well as version 1.0 of our web platform. The testing program included both lab and field-testing, with snow professionals across six different countries around the world. We selected testing partners with a wide variety of avalanche experience as well as geographic diversity to ensure testing in every type of snowpack possible.

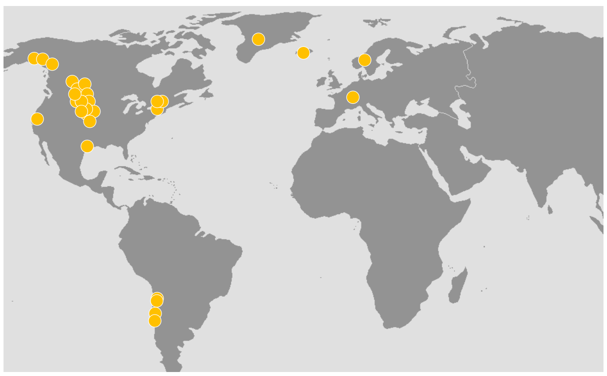

Fig. 2: Map of testing partner locations.

Our testing program included 20 ski resorts, 7 avalanche education providers, 9 avalanche forecast centers, 8 guiding companies, 5 heli-ski / cat operations, 3 universities, military special forces, departments of transportation, professional athletes and others.

Fig. 3: These organizations took part in AvaTech's testing program.

Feedback from this broad set of professional users helped us focus on the solutions that the professional community valued most.

The development of the SP1 benefited from the following goals of AvaTech's 2014 testing program:

- To present professionals with a functional prototype device, and understand the perception of the product as a whole.
- To evaluate the effectiveness, accuracy, and repeatability of the measurement capabilities of the device.
- To rigorously test the durability and robustness of the product through extreme use conditions and backcountry environments.

This report summarizes the key learnings from the testing program, including feedback directly from the field as well as a summary of the feedback from the beta testing program wrap-up survey. Beta tester feedback has resulted in direct actions and improvements have been implemented into the production units.

2.2 Testing program approach & methodology

During our testing period, we asked testers to use the SP1 regularly in daily operations and record their experiences and feedback both qualitatively and quantitatively. The program consisted of three distinct types of testing:

1. **Functionality**
   Functionality was by far the most important part of our program. We wanted to understand how well the device and web application worked in real professional situations.

   Key example questions:
   - How well does the SP1 compare to your side-by-side professional snowpit evaluations?
   - Do you trust the device to gather accurate, reliable information in a repeatable way?
   - Are snow structure measurements affected by speed or angle of the probe?
   - Are slope angle and GPS measurements consistent with your expectations?
   - Is battery life sufficient?
   - Are you able to resolve the thinnest weak layers of concern?

2. **Durability**
   We needed to understand how durable the prototypes were and where issues could come up. We encouraged users to use the prototypes in all kinds of conditions, varying temperature, wind, snowpack, etc. across extreme climates.

   Key example questions:
   - Are there any issues with breakage / durability that concern you?
   - Do you encounter any challenges with durability of the sensors?

3. **UI / Design**
   We wanted to understand how intuitive users found the interface, what they did and didn't like about the design, and what alterations we could make to improve the product according to their needs.

   Key example questions:
   - Is the UI intuitive and easy to use? What elements do you like / not like?
   - Are there any parts of the UI you find confusing or particularly challenging?
   - Is the screen size and data resolution sufficient?
   - What are your impressions of the handle design, comfort, overall weight / size of the product, etc.

The most critical part of our testing program was comparing the SP1 snow structure results to professional snowpit assessments. In order to do this, we developed a simple software platform which allowed testers to upload data directly to our website, as well as easily input their manual profile results.

Because we were collecting so much data from testers on a daily basis across the globe, we designed a simple, standardized snowpit and SP1 data collection procedure as follows:

1) Testers would first dig their own snowpit and record standard evaluations (location, time, structure, grain size/type, temps, etc.). In particular, they would note any major layers of concern (e.g. layers with concerning results from CT/ECT tests, buried surface hoar, depth hoar, facets, etc.)

2) Once the full snowpit assessment was complete, we asked testers to complete 18 standard measurements with the SP1 prototype right behind or next to the snowpit wall where the hand hardness test was completed. The first 9 measurements were oriented vertically (3 medium speed, 3 fast speed, 3 slow speed) and the second 9 measurements were oriented normal to the snowpack in relation to the slope angle (3 medium speed, 3 fast speed, 3 slow speed). Gathering data at different speeds helped us build the appropriate algorithms to eliminate speed as a variable when we graphed snow profiles. Gathering data at different angles also helped us understand device performance for different angles of entry.

Below are two examples of snow pit comparisons with our testing partners:

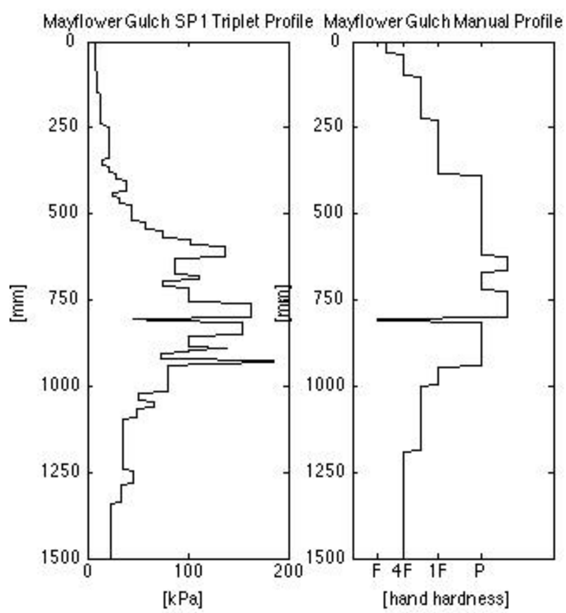

Fig. 4: Side-by-side AvaTech SP1 and professional hand-hardness profiles from Mayflower Gulch, CO, March 21st, 2014.

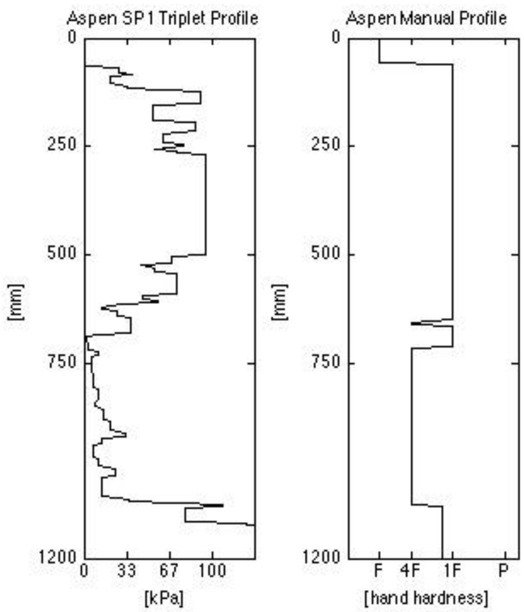

Fig. 5: Side-by-side AvaTech SP1 and professional hand-hardness profiles from Aspen, CO, Spring 2014.

3. DISCUSSION

3.1 Summary of results

Overall, we received very positive feedback from many testers:

"Your device will be a game changer at understanding the snowpack"

"Once professionals learn about the AvaTech SP1, they'll never want to go into the backcountry without one. This is a great device to gather more information and make better decisions. Sharing the information is also extremely valuable"

"I've been able to your device alongside our regular snowpack data collection procedures and the probe fits in seamlessly. It's nice to have empirical data to confirm our hand hardness tests. We had been using the Ram penetrometer for this purpose for many years. Your probe does the same task in seconds not an hour, which is nice."

Feedback was formally collecting along several important dimensions including data collection speed, penetration speed, data visualization, size & weight, durability and mechanics, sensing tip, electrical hardware and software, and data transfer.

3.2 Measurement quality

The "SP1 Triplet Profiles" shown above were generated by aligning and averaging together three consecutive SP1 tests taken at the snowpit comparison site. This method of combining three tests results in a more representative profile, due to the penetrometer's high sensitivity to local variability that is not important when considering overall structure. We found that this results in an SP1 output more similar to that of the coarser, manual profiles.

The average correlation between the 3 profiles averaged together for the triplet profile from Mayflower Gulch is 88%. The average correlation between the 3 Mayflower Gulch profiles and the professional hand hardness assessment is 73%. While the correlation between the SP1 profiles and the manual profile is not statistically significant, we believe the SP1's ability to catch major hardness changes accurately represents many stratigraphic features important for avalanche risk (in this case, buried surface hoar at about 800mm depth). Since penetrometers quantify snowpack in a fundamentally different way than the hand hardness procedure, a significant correlation is not necessarily expected. Consequently, the repeatability of SP1 profiles is a better metric assessing the quality of SP1 data.

3.3 Data collection speed

One of our primary goals with the SP1 was to dramatically improve the speed at which we collect snowpack information. The responses from our testing program supported this. Below are some responses from testers when asked to list the promising value of the product:

- "The ease of use and the speed at which I can form opinions based on the data."
- "Ease of use. Immediacy of read out."
- "Efficiency of data collection."
- "The ability to quickly generate multiple observations of snow structure on a given slope(s)"
- "The most useful aspect of the device for an organization like mine is its instant translation from observation to documentation."

Further hardware and software development after these tests further improved data processing and more immediate data sharing.

3.4 Hard Layers and Penetration Speed

Some users expressed concerns with extremely hard layers at certain measurement speeds. As sharp as the tip was, at times it was difficult to push the device through some thicker ice layers.

After careful consideration of the data collected in the testing program, we believe that faster penetration speeds (approximately .75 m/s – 1.5 m/s) result in more accurate measurement results, and coincidentally fewer challenges with hard layers. With this feedback in mind, we have built in audible feedback that will suggest the optimal beginning and end to a test. This will support not only increased accuracy of the readout but also improved ease-of-use.

3.5 Data visualization

After completing a test, the SP1 automatically runs the raw data through a series of algorithms to create a plot of snow hardness over depth. This is how the device communicates what it sees to the user. The goal with the SP1 is to visualize the measurement data as simply, objectively, and accurately as possible.

Overall, beta testers were pleased with the simplicity and clarity of the data visualization, but many testers communicated a desire for even simpler and/or “blockier” graphics. Here are some example quotes:

- “The graphic is easy to read. I like it, nothing too fancy.”
- “I actually really liked the device tests once I got used to reading them. They showed a lot of different layers and if you could go at a fast speed it seemed to be better…”
- “Too much detail for the "average" user - need to smooth the results, and highlight weak layer - e.g. Here is the SH / DH / ice crust of concern.”
- “I would like to see the data read out more like a professional profile.”

With the feedback of our testers in mind, we developed several new algorithms for our production units which allow the user to decide how to visualize the data in the settings menu (e.g. a higher resolution more ‘scientific view’ and a summarized view of the snowpack in line with a professional profile). In addition, we have built a three test average function which allows the user to view an average of three consecutive tests to account for subtle snowpack variations and improved confidence.

3.6 Size and weight

Size and weight are absolutely critical considerations when traveling into backcountry terrain. The goal with the SP1 was to develop a design that was uncompromising in its functionality while as lightweight and portable as possible. Below are some quotes from users of the beta prototypes:

- “Would always be nice to make it a little smaller but overall it was an ok size and weight.”
- “It's impressive that the technology you built fits in such a small package. In a perfect world, I would like to see a lighter, smaller version. If it shrunk, I would be more likely to carry it in the field.”

Following the testing program, we took several steps to continue reducing size and weight:

1. Reduction in cross-sectional area, and thus volume, making it easier to slip into a narrow pack.
2. Addition of a flexible strap to cinch up the poles in a tight package when collapsed
3. External pack mounting features to provide users with accessibility alternatives.

3.7 Durability and mechanics

The SP1 must be able to withstand abuse in the backcountry. We asked our testers to push the prototype devices to their limits, to help us understand weak points and mechanical failures in the design. Our testers identified the following challenges, to which we now have confident solutions:

- Slider poles seizing up and locking the device in either a collapsed or extended form due to oxidation in wet environments. The production pole segment materials and geometry have already been changed to avoid such reactions and binding situations.
- Inconvenient access to the battery door via small screws. We’ve developed a new easy-access battery door.
- Separation of the clear plastic display window. Better manufacturing techniques have improved the material quality and durability of the handle materials and durability.

3.8 *Sensing tip*

A critical part of the SP1 is the sensing tip of the device. While most users didn't have any issues, there was some feedback during the program regarding ice build-up in the tip under harsh weather conditions.

Following the testing program, we added a few features to the tip to resist ice or dirt build-up and improve the accuracy of the sensor.

3.9 *Electrical hardware and software*

During the testing program, prototype units were optimized for data collection, but not battery life or processing speed. In the production version, batteries (AA x2) are targeted to last several weeks under normal use. Processing times target ~1-10 seconds a test.

3.10 *Data transfer*

During the testing program, beta testers transferred data from the device to the cloud via USB connection. The purpose of gathering this data from testers was to help our team compare the AvaTech data to professional snow profile assessments, which has allowed us to quickly iterate and improve our algorithms and graphical output. In general, data transfer worked well but we did have some issues with compatibility on all types of different operating systems. In our production units we built in Bluetooth low energy to transfer data seamlessly to a smartphone application and then onwards to the cloud. As a backup USB connectivity will allow non-wireless functionality.

3.11 *Firmware upgradeability*

All units are firmware upgradeable via our website with a USB connection.

4. CONCLUSIONS

Overall, the opportunity to engage in rapid dialogue and feedback with experts in the field and our technical advisors was successful. We were able to gather feedback from a significant cross section of users and geographically unique snowpacks. This design feedback loop has been invaluable to the final development of the SP1 which delivers this winter. Results clearly demonstrated the SP1's ability to gather rapid information about the snowpack in a reliable and repeatable manner. Quantitative results demonstrate a strong repeatability between SP1 tests and potential for the SP1 to even pick up layers that might be easily missed in manual assessments. Qualitative feedback supported the theory and practice of this new technology and that real solutions were being addressed.

5. ADDITIONAL INFORMATION

5.1 *Conflict of interest statement*

The authors of this paper are employees of AvaTech, Inc. and are involved in the development and sales of the SP1 and AvaNet web portal.

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