AN INNOVATIVE PROTOCOL FOR CONDUCTING AND EXPLOITING SNOW TESTS: THE OUTCOME OF A RELIABLE FIELD EXPERIMENT AND THE DEVELOPMENT OF DIGITAL TOOLS ON SMARTPHONE

Frédéric Pourraz *[1,4], Alain Duclos[2,4], and François Louchet[3,4]

[1] *LISTIC - University Savoie Mont Blanc - Annecy - France*
[2] *ALEA - Avalanches: Localisation, Etudes, Actions - Aussois - France*
[3] *Grenoble University - Grenoble - France*
[4] *data-avalanche association - Aussois - France*

ABSTRACT: The avalanche risk estimation, performed by a forecaster as well as a practitioner, is based on a limited number of parameters which are now subject to a consensus. Their measurement, processing, and dissemination are fundamental, as it is the preliminary step towards the complex forecasting task. The experiences and skills of experts from various cultures have been brought together to combine and refine the commonly used snow tests (CT, ECT, and PST) and thus formalize a complete measurement protocol. This protocol has been framed thanks to a Smartphone application that guides the user in order to guarantee measurements' homogeneity. It also facilitates result recording, whatever the weather conditions might be, but also their real-time sharing. With 543 tests carried out over three winter seasons, the protocol we propose, as well as the tools supporting it, are now robust. Their validity is assessed by conducting a certain number of them in areas where avalanches have just been triggered, or in their immediate vicinity. This dataset thus highlights multiple questions that contribute to refining our understanding of the slab-triggering mechanism. All these measurements are used as an input for the *CRISTAL* approach and are disseminated online thanks to *SYNTHESIS*, an innovative tool that provides an overview of all the useful information for decision support.

KEYWORDS: Avalanche forecasting, snow tests, measurement protocol, propagation propensity, real-time sharing.

1. INTRODUCTION

The aim of this approach is not to create a new protocol for snow measurements, but rather to better address the needs of avalanche risk assessment, for both practitioners and forecasters. Although the value of snow tests is indisputable, they still come up against obvious difficulties of interpretation, which we have tried to reduce. They are used as a complement to other major information, such as observed avalanche activity and snow-meteorological measurements [van Herwijnen and Birkeland, 2014]. The danger level index from the bulletin may possibly be considered as an output rather than an input data, within this process.

The inherent uncertainty of spatial variability is reduced by choosing the locations for snow testing according to a well-defined process. The intention is not to repeat tests throughout the season at predetermined sites, but rather choosing the test site expertly. It must correspond to the place where the stratigraphy seems, *a priori*, the most unstable, at both the sector level (exposure, altitude, etc.) and the slope level (topography, etc.). It requires travel in the mountains, multiple exploratory soundings with a ski pole (looking for stratigraphy of varying hardness) and then soundings with a probe before digging (is the total snow depth appropriate?).

The inherent uncertainty of snow tests significance is also reduced by prioritizing a PST test [Gauthier and Jamieson, 2006, Sigrist and Schweizer, 2007]. Our goal is to evaluate crack propagation in a buried weak layer, which is the key phase of slab avalanche release processes [Louchet and Duclos, 2006], avoiding as far as possible bias due to failure initiation phase. This PST is carried out with an increased length, and performed after preliminary tests have been carried out to detect the weak layer to be characterized.

The objectives of this new testing process are manifold, including:

1. Detect the presence of one or more weak layers within the snowpack.

2. Assess snowpack heterogeneity.

* *Corresponding author address:*

Frédéric Pourraz

LISTIC - University Savoie Mont Blanc
5 chemin de bellevue
74944 Annecy-le-Vieux
FRANCE

tel: +33 450 666 002,
email: frederic.pourraz@univ-smb.fr

3. Characterize the propensity of a local crack to propagate in the identified weak layer.

4. Characterize the different layers of the snowpack throughout its entire thickness.

All these steps will be formalized in Section 2. We will discuss the first statistics from the first three winters of data collection in Section 3. We will also outline how these data are disseminated and used on a daily basis in Section 4. We will end with a discussion of the interests and limitations of the approach in Section 5, and conclude in Section 6.

2. MEASUREMENT PROTOCOL

2.1 Snow test location and trench template

The significance of any snow test depends on location choice. Our stated aim is to identify and characterize the most unstable spots in the explored area, which requires systematically probing the snowpack with a ski pole to detect any potential heterogeneity (layers of different hardness). As the aim is also to characterize the snowpack over its entire depth, we use the avalanche probe to find an area not exceeding, or slightly exceeding, a depth of 150 cm. This is an important prerequisite, given the almost systematic variability of snowpack thickness. For instance, a weak layer detected at a depth of 120 cm during a test might be buried only 30 cm deep a few meters away. It is therefore important to systematize trench clearing down to the ground, and therefore to limit its depth, so that the test can be carried out without wasting too much time and energy.

Although [Gauthier and Jamieson, 2008] and [Heierli et al., 2011] have considered that the slope inclination has little impact on snow tests results, we find it important to account for its influence on test representativeness. This is why our tests are primarily conducted on slopes with a steepness close to 30° (always prioritizing the safety of observers), in order to avoid any unexpected influence of slanting. At least two reasons guided this choice: (i) the influence of slope angle on stratigraphy (at the start of the winter season, for instance, the grazing sun light maintains cold temperatures at the surface of shallow slopes, unlike steeper sun-exposed slopes), and (ii) the influence of steepness on the stress shear component.

To make our protocol as reproducible as possible, we formalized the trench excavation process (see Figure 1). The trench is systematically dug perpendicular to the slope line, using a new 240 cm-long template. Once again, we use our avalanche probe and ski poles to outline the perimeter of the digging area. Beforehand, we systematically check that the depth of the snowpack can be exploited over the entire length of the trench, by conducting a minimum of four probings spread over the 240 cm length. The aim is to ensure that no rocks or sudden terrain shifts are encountered during trench excavation. This notable modification compared to conventionally conducted tests allows us to optimize our template to combine several test types, as we shall see now.

Figure 1: Protocol trench template and tests combination

2.2 Snow test significance and combination

One of the distinctive aspects of our approach is the combination of different tests and the consideration of their individual significance. Figure 1 illustrates the distribution of these tests along the trench.

Snow tests combination is formalized as follows. A first CT of 30 cm by 30 cm, as proposed by [Jamieson, 1999], is carried out on the left side of the trench (CT1), followed by another one on the right side (CT2). Each of these CTs serves our first two objectives, i.e. (i) detecting the presence of one or more weak layers, revealed by a local crack resulting from dynamic overpressures, and (ii) assessing the heterogeneity of the snowpack by comparing the results of both tests, conducted 180 cm apart. As mentioned in Section 3, this heterogeneity may be significant, even for such a close spacing. Due to this reason, we have chosen not to follow the conventional CT protocol (10 wrist taps, 10 elbow taps and 10 shoulder taps [Jamieson, 1999]), opting instead for shoulder taps only. Given the intrinsic variability between

CT1 and CT2, we believe that measurements as precise as wrist or elbow taps cannot be considered accurate. Lastly, as also mentioned in section 3, local collapsing does not necessarily ensure effective propagation within the weak layer. However, this propagation is a fundamental premise for slab avalanche release. Hence, this initial test stage involving two CTs is no more than an intermediate and indicative stage before carrying out a PST, which remains a pivotal component in assessing avalanche danger.

In the very small minority of cases where several weak layers are highlighted by the two preliminary CTs, we supplement the protocol with an ECT [Simenhois and Birkeland, 2006]. In all other cases, we prioritize conducting a PST to address our third objective, i.e. to characterize the propensity of a local crack to propagate within the identified weak layer. Whatever the number of identified weak layers, we also conduct a PST when the top layers of the snowpack have quite a reduced hardness as the shovel edge tends to cut those layers and sink through [Simenhois and Birkeland, 2006]. [van Herwijnen and Birkeland, 2014] have shown that, irrespective of the failure initiation test (PST or ECT), the weak layer collapses to a similar extent, and the same holds true for the propagation speed of the crack. According to [Ross and Jamieson, 2012], PSTs also provide an comparable accuracy to other snow tests, and, unlike ECTs, PSTs can also test deeply buried weak layers [Ross and Jamieson, 2008]. Moreover, the PST makes it possible to circumvent the influence of all the intermediate hard layers of varying thicknesses above the weak layer, allowing the least ambiguous and most comparable measurements.

Traditionally, a PST is conducted on a parallelepidedic snow block *"with a length of 1 m or equal to the slab thickness (measured vertically), whichever is greater"* [Gauthier and Jamieson, 2008]. However, we have chosen to carry out the PST on the remaining 180 cm between both CTs. This corresponds to the upper limit of the protocol proposed by [Sigrist and Schweizer, 2007] and is also in agreement with [Bair et al., 2014]. We justify this choice by the fact that, in the case of incomplete propagation, most propagations stop close to or beyond one meter, as shown in Section 3. Based on our dataset, a shorter column would not have adequately characterized the arrest condition of the crack propagation within the weak layer, a condition which is nevertheless another important parameter along with the critical cut length [Gauthier and Jamieson, 2012].

After these tests have been carried out, a temperature and stratigraphic profile (using the usual procedure) enables us to meet the fourth objective, i.e. characterizing the various layers of the snowpack throughout its entire thickness. Therefore, this protocol leverages the strengths of each of the traditionally employed tests while making an effort to minimize the remaining limitations as much as possible.

2.3 Snow test guiding and recording App

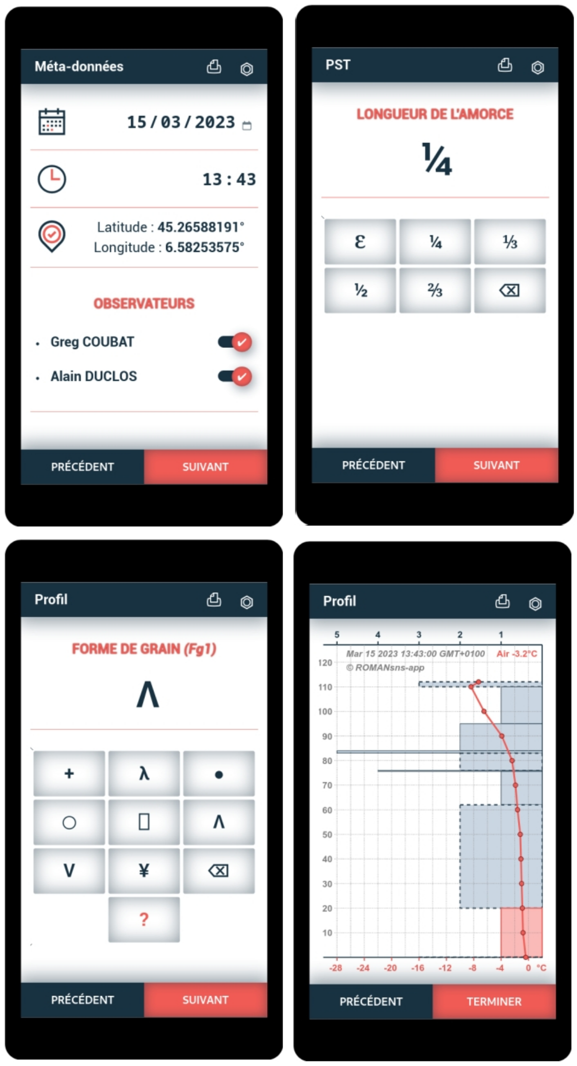

Figure 2: Smartphone App

Formalizing the various stages of the protocol we have just described is a necessary but not sufficient step to ensure the reproductibility, recording, dissemination and interpretation of our snow tests. Therefore, we have developed a dedicated smartphone application for this purpose (see Figure 2).

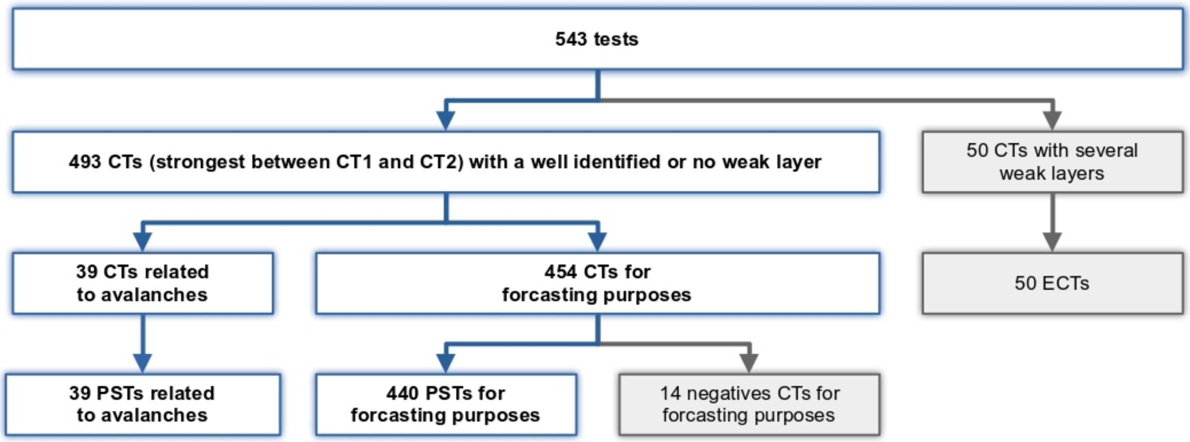

Figure 3: Sample of tests constituting our database

Firstly, in terms of reproducibility, our application guides the user throughout the different process stages. Recognizing that this process is more complex than traditional tests, we believe that this assistance is essential to maintain protocol uniformity, thus rendering the data usable and comparable.

Secondly, in terms of data recording, our application significantly simplifies data input with a user-friendly and intuitive interface. The application is fully functional offline, in all weather conditions, and it also enables automatic GPS coordinates collection for each test as well as a timestamp. Once all the information has been entered, and as soon as a network access is available, the test data is uploaded to the data-avalanche association's server, where it is stored and subsequently shared freely with the entire practitioner community (see Section 4).

3. STATISTICAL INTERPRETATIONS

After over 10 years of informal experimentation, test recording through the application started in 2020/2021 early winter. Three winter seasons later, **543** tests, all compliant with the previously outlined protocol, have been collected, constituting our database (see Figure 3). Among them, **50** tests identified multiple weak layers during the CTs, leading to the execution of an ECT. This subset will not be discussed in this article, as our focus will be on the **493** tests that revealed either a single weak layer or none at all.

In the subsequent sections of this article, the results of conducted CTs and PSTs will be categorized into four incremental classes, to simplify the interpretation of measurements. While acknowledging that this classification introduces a degree of imprecision, it's important to bear in mind that these tests are merely an imperfect simulation of the real phenomenon. Consequently, employing a classification with a finer granularity would be overly presumptuous.

3.1 CTs measurements

Within the considered subset, **39** CTs were conducted in areas of recent avalanche release or in their immediate vicinity, either on the same day or the day following the observed avalanche. Initially, it's from this subset of tests that we will extract the initial statistics to demonstrate the validity of our protocol. The four classes characterizing the results of the conducted CTs aim to classify the local crack following the failure initiation (shoulder tap(s) - see Table 1).

	Failure initiation
Strong$_{(CT)}$	Spontaneous upon block isolation **or** 1 to 3 taps
Moderate$_{(CT)}$	4 to 6 taps
Slight$_{(CT)}$	7 to 9 taps
Negative$_{(CT)}$	10 or more taps **or** no crack

Table 1: CT local crack classification

Considering the more effective CT (between CT1 and CT2), we obtained the following results (see Table 2):

Strong$_{(CT)}$	**Moderate$_{(CT)}$**	**Slight$_{(CT)}$**	**Negative$_{(CT)}$**
92.31 %	**5.13 %**	**2.56 %**	**0.00 %**

Table 2: Classification of **39** CTs related to recent avalanches (with a single weak layer)

The CT was classified as **Strong$_{(CT)}$** in **92,31%** of cases. Only **5.13%** of cases were classified as **Moderate$_{(CT)}$**, corresponding to 2 tests. In the first one, a very thin temporary weak layer

(5 mm thick) was present, that probably evolved between the avalanche event and the test itself, conducted the following day. In the second one a persistent weak layer was deeply buried at a depth of 179 cm, and propagated completely during the PST within the initial centimeters of cutting. Finally, only one test was classified as **Slight$_{(CT)}$**, corresponding to **2.56%** of cases. Here again, we note the presence of a very thin temporary weak layer (2 mm thick) coupled with a test conducted the day after the avalanche was triggered. Additionally, we observe that no test was classified as **Negative$_{(CT)}$**. These statistics thus reaffirm the value of conducting a CT to detect the presence of a weak layer within the snowpack, as it corresponds with observations made during tests on proven avalanche releases.

In a conventional statistical study, these data would ideally be compared to those derived from a random sample of tests. However, in the context of avalanches, obtaining such a sample without jeopardizing the safety of observers would be utopian (it would require considering all slopes steeper than 30°, for instance). As a result, this sample cannot be entirely random. To supplement this statistical study, we extended the analysis to the **454** CTs that, once again, differentiated a single weak layer or none at all. However, this time, these tests were conducted for avalanche danger forecasting purposes (see Figure 3). The obtained results are as follows (see Table 3):

Strong$_{(CT)}$	Moderate$_{(CT)}$	Slight$_{(CT)}$	Negative$_{(CT)}$
85.46 %	**9.25 %**	**1.54 %**	**3.74 %**

Table 3: Classification of **454** CTs made for forcasting purposes (with a single weak layer)

It is worth noting that these results are fairly similar to those for the **39** cases mentioned above, but nevertheless show a small but significant decrease of **Strong$_{(CT)}$** cases, and an emergence of several **Negative$_{(CT)}$** ones. These results are consistent with our explicit intention to systematize the characterization of the most unstable spot within the frequented area and indeed confirm the sought-after heterogeneity within the snowpack prior to conducting each test.

Not represented in the previous tables, which consider the more effective CT, we also extracted statistics regarding the heterogeneity of results between CT1 and CT2. Notable differences were observed in **63.49%** of cases. These differences pertained to either the slab thickness, the weak layer thickness, the number of taps performed, or a combination of these metrics.

3.2 PSTs measurements

We followed the same statistical approach to analyze the results of the PSTs. Thus, the four classes characterizing their outcomes aim to classify the crack propagation within the weak layer. This classification intersects two components: (i) the critical cut length with the saw and (ii) the arrest condition of the propagation [Gauthier and Jamieson, 2012] (see Table 4). Regarding the critical cut length, note that the term *"Epsilon"* corresponds to a very small critical length (a few centimeters). Regarding the arrest condition, note that the term *"Takeover"* implies that propagation is at first incomplete, but then resumes if a new failure is initiated on the remaining block. However, this is not always the case, and the term *"Incomplete"* is used in such instances.

	Critical cut length		**Arrest condition**
Strong$_{(PST)}$	Spontaneous upon block isolation **or** Epsilon **or** 1/4	**and**	None (complete propagation)
Moderate$_{(PST)}$	Spontaneous upon block isolation **or** Epsilon **or** 1/4	**and**	Takeover
Moderate$_{(PST)}$	1/3 **or** 1/2	**and**	None (complete propagation)
Slight$_{(PST)}$	Spontaneous upon block isolation **or** Epsilon **or** 1/4	**and**	Incomplete
Slight$_{(PST)}$	1/3 **or** 1/2	**and**	Takeover
Slight$_{(PST)}$	2/3	**and**	None (complete propagation)
Negative$_{(PST)}$	1/3 **or** 1/2	**and**	Incomplete
Negative$_{(PST)}$	2/3	**and**	Takeover **or** Incomplete
Negative$_{(PST)}$	Full	**and**	/

Table 4: PST crack propagation classification

As shown in Figure 3, the first subset considered corresponds to the **39** tests conducted in areas of recent avalanche release (see Table 5), and the second subset consists of **440** PSTs conducted for avalanche danger forecasting purposes (see Table 6 - **14** CTs out of the **454** didn't reveal any weak layer).

Strong$_{(PST)}$	Moderate$_{(PST)}$	Slight$_{(PST)}$	Negative$_{(PST)}$
53.85 %	**28.21 %**	**10.26 %**	**7.69 %**

Table 5: Classification of **39** PSTs related to recent avalanches (with a single weak layer)

Strong$_{(PST)}$	Moderate$_{(PST)}$	Slight$_{(PST)}$	Negative$_{(PST)}$
41.36 %	**26.14 %**	**11.82 %**	**20.68 %**

Table 6: Classification of **440** PSTs made for forcasting purposes (with a single weak layer)

In Table 5, propagation is predominantly characterized as **Strong$_{(PST)}$**, even though it's less pronounced compared to the CTs (see Table 2). It's worth noting that all tests not classified as **Strong$_{(PST)}$** were conducted at least one day after the avalanche release, suggesting that the weak layer might have evolved, explaining this difference.

In Table 6, we observe a significant decrease in **Strong$_{(PST)}$** cases, even though they remain in the majority, in favor of **Negative$_{(PST)}$** cases, and this shift is much more prominent than in the case of the CTs (see Table 3). In agreement with the above statistics, local crack is no guarantee for an efficient propagation in the weak layer, since collapse sizes may be smaller than critical propagation crack sizes [Louchet, 2020]. This clearly demonstrates that the execution of a CT must be complemented by a propagation test, as it remains one of the critical aspects in avalanche danger forecasting.

Figure 4: PST with incomplete propagation

To conclude this statistical study, let's now revisit the relationship between the arrest condition of the propagation and the chosen PST block size (see Section 2.2). In the case of an incomplete propagation (see Figure 4), whether with or without takeover, **70%** of the recorded tests demonstrated a propagation arrest beyond the midpoint of the column, i.e. more than 90 cm. This observation validates the extension of our test column to 180 cm to better characterize this phenomenon.

4. DISSEMINATION AND EXPLOITATION OF RESULTS

Although largely funded by certain *"departments"* in the French Alps, these tests are intended to be public and are thus disseminated as soon as they are uploaded from the Smartphone application, through *https://www.data-avalanche.org/romansns*.

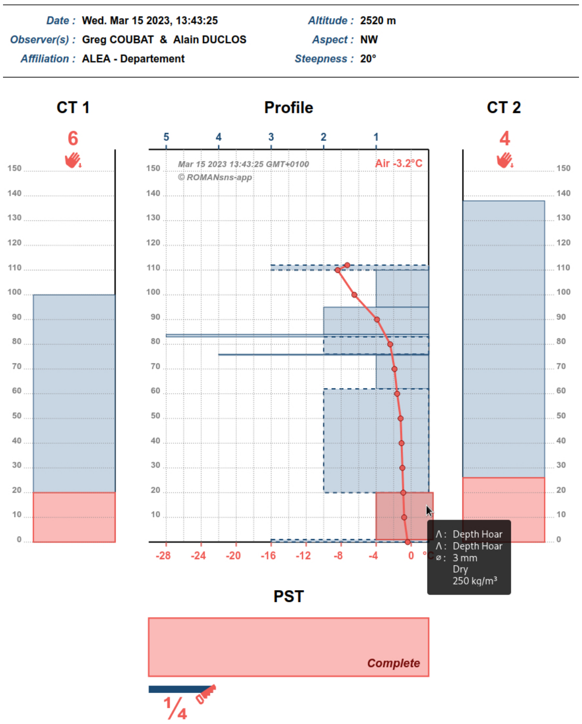

Figure 5: Graphical test's results

To enhance interpretability, we have designed a graphical representations for each of the results (see Figure 5). In addition to the test's metadata, all stages of the protocol are visualized in relation to the same layout as our template. CT1 and CT2 are depicted on either side of the graph. The height of the test column, slab thickness, weak layer thickness (in red), and substrate thickness (if any) are shown, along with the number of applied taps. The temperature and stratigraphic profiles are centered, as well as the result from the propagation test. This can take various forms to represent the critical saw-cut length and the propagation arrest condition (see Figure 6):

1. Spontaneous propagation upon block isolation (cable cut).
2. Complete propagation after a given length of saw cutting.
3. Incomplete propagation with propagation resumption after a new saw cut.
4. Incomplete propagation without resumption.
5. No propagation.

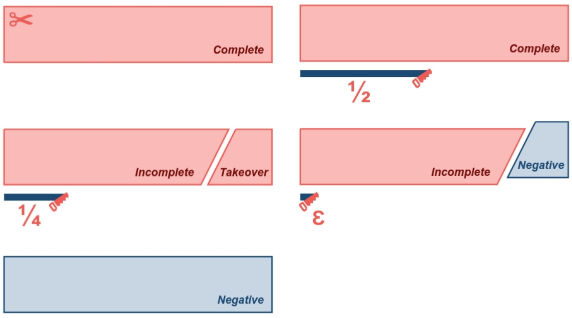

Figure 6: Graphical PST representations

All these results are used daily by numerous practitioners, both professionals and amateurs, and are now an integral part of the information system used by three French *"departments"* (Savoie, Isère, Hautes-Alpes) for securing road access and reopening major Alpine passes at the end of the season. In a broader context, these outcomes provide a solid foundation for estimating one of the six criteria of the *CRISTAL* approach, namely *"a possible buried weak layer"* criteria. They are thus disseminated via our online tool *SYNTHESIS*, which enables easy access and systematic cross-checking of all information essential for avalanche danger assessment. Both *CRISTAL* and *SYNTHESIS* are the focus of two additional articles in this ISSW issue.

5. DISCUSSION

Whether in the applied perspective of avalanche danger forecasting or in the broader analysis of the snowpack and its stability, our protocol still suffers from an insufficient number of tests, both in terms of spatial distribution and over time (543 tests over three seasons). Many of these tests are integrated into activities funded by local authorities and are necessarily limited. The required expertise and time are a drawback compared to conducting a CT, which despite its acknowledged limitations, remains the test predominantly conducted by French institutions. Additionally, it's worth noting that our application (see Section 2) is currently compatible only with Android smartphones. The challenge of interpreting test results by non-experts also likely hinders the method's adoption, despite our efforts at simplification (clear graphical representation - see Section 4) and characterization (see Table 4) disseminated through the *SYNTHESIS* tool.

The tests conducted following avalanches are a strong point of our database, but they are still too few in number (44). Conducting such tests after accidental avalanches has often been done in the context of legal investigations. Opportunities to conduct tests on spontaneous avalanches might be more frequent within the scope of currently funded missions, but they present an additional constraint for already busy observers. Nonetheless, the information obtained from these real avalanche events is of major interest.

From a methodological standpoint, conducting tests outside of predefined permanent sites allows for addressing questions about stratigraphy and stability with a high degree of freedom in relation to current and forecasted snow and weather conditions. However, this approach faces challenges in terms of selecting appropriate locations and interpreting the results. The involvement of guides from the SNGM (National Union of Mountain Guides - France) in the 2020-2021 period demonstrated that a strong training program and ongoing support throughout the season are necessary to produce comprehensive and relevant data, even for professionals.

The arbitrary definition of seven critical cut measures (see Table 4) is practical for field data collection and subsequent statistical analysis, but it can suffer from inaccurate estimation and can mask a more complex reality.

6. CONCLUSION & PERSPECTIVES

Our protocol, now formalized and fully equipped, is being used in a formal and sustainable manner. For example, it is applied in the context of ongoing risk management for avalanche hazard on roads in three French Alpine *"departments"*. Its effectiveness has been recognized in crisis management as well as in decisions to conduct (or not) preventive avalanche control operations. The protocol is also integrated into the training of professionals such as French ski instructors, both as field practice and as an examination topic.

The formalized protocol is designed to improve avalanche danger assessment through four objectives: (i) detect the presence of one or more weak layers, by conducting CTs; (ii) assess the heterogeneity of the snowpack, by comparing CT1 and CT2, located on either side of the trench; (iii) characterize the propensity of a local crack to propagate in the identified weak layer by conducting a PST using a modified template of 180 cm, in order to better characterize arrest condition; (iv) characterize the different snowpack layers throughout its thickness, by systematically producing a stratigraphic profile. For this purpose, the trench design was defined according to a precise template, ensuring protocol reproducibility. The location of each test trench is expertly determined to choose the spot where stratigraphy seems to be the most unstable. All these steps are facilitated by a Smartphone application that guides users through the protocol, streamlines data entry, and ensures the long-term storage of results on the data-avalanche association's server. Our efforts have also led us to develop a novel graphical representation of test results, making them easier to analyze, comprehend, and share.

A statistical analysis of the results initially demonstrated the consistency of the protocol when applied to recent avalanches. It also highlighted points that still suffer uncertainties. For instance, it becomes evident that an easy local crack after the failure initiation (CT) is not consistently linked to a complete propagation within the weak layer (positive PST or ECT). From a perspective of avalanche risk estimation, it appears that relying only on a CT is insufficient.

One of the limitations still inherent in our protocol is the relatively small number of tests conducted (543 over three seasons). For this reason, we started working on the spatial extrapolation of each test. The goal is to determine their geographic significance (altitude and exposure range, topography, etc.) and their scale (slope, sector, mountain range, department, etc.). This probabilistic extrapolation should ultimately enable better avalanche hazard prediction, even with a small number of tests.

REFERENCES

[Bair et al., 2014] Bair, E., Simenhois, R., van Herwijnen, A., and Birkeland, K. (2014). The influence of edge effects on crack propagation in snow stability tests. *The Cryosphere*, 8.

[Gauthier and Jamieson, 2006] Gauthier, D. and Jamieson, B. (2006). Evaluating a prototype field test for weak layer fracture and failure propagation. *Proc. 2006 Int. Snow Sci. W., Telluride, CO, USA*.

[Gauthier and Jamieson, 2008] Gauthier, D. and Jamieson, B. (2008). Evaluation of a prototype field test for fracture and failure propagation propensity in weak snowpack layers. *Cold Regions Science and Technology*, 51(2):87–97.

[Gauthier and Jamieson, 2012] Gauthier, D. and Jamieson, B. (2012). The Propagation Saw Test (PST): A Review of its Development, Applications, and Recent Research. *Proceedings, 2012 International Snow Science Workshop, Anchorage, Alaska*, pages 1047–1053.

[Heierli et al., 2011] Heierli, J., Birkeland, K., Simenhois, R., and Gumbsch, P. (2011). Anticrack model for skier triggering of slab avalanches. *Cold Regions Science and Technology*, 65(3):372–381.

[Jamieson, 1999] Jamieson, B. (1999). The compression test - after 25 years. *Avalanche Rev.*, 18.

[Louchet, 2020] Louchet, F. (2020). *Snow Avalanches: Beliefs, Facts, and ScienceBeliefs, Facts, and Science*. Publisher: OXFORD University Press. ISBN: 9780198866930.

[Louchet and Duclos, 2006] Louchet, F. and Duclos, A. (2006). Insight into Slab-Avalanche Triggering: A Combination of Four Phenomena in Series. *The Avalanche Review*, 24(3):13–19.

[Ross and Jamieson, 2008] Ross, C. and Jamieson, B. (2008). Comparing fracture propagation tests and relating test results to snowpack characteristics. *Proceedings Whistler 2008 International Snow Science Workshop September 21-27, 2008*, page 376.

[Ross and Jamieson, 2012] Ross, C. K. H. and Jamieson, B. (2012). The propagation saw test: slope scale validation and alternative test methods. *Journal of Glaciology*, 58(208):407–416.

[Sigrist and Schweizer, 2007] Sigrist, C. and Schweizer, J. (2007). Critical energy release rates of weak snowpack layers determined in field experiments. *Geophysical Research Letters*, 34(3).

[Simenhois and Birkeland, 2006] Simenhois, R. and Birkeland, K. (2006). The extended column test: a field test for fracture initiation and propagation. *Proceedings of the International Snow Science Workshop*.

[van Herwijnen and Birkeland, 2014] van Herwijnen, A. and Birkeland, K. (2014). Measurements of snow slab displacement in extended column tests and comparison with propagation saw tests. *Cold Regions Science and Technology*, 97:97–103.