SLOPE MEASUREMENT FOR HUMANS: INCLINOMETER ERROR AND RISK COMMUNICATION

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ABSTRACT: Inclinometers are key tools for assessing risk in avalanche terrain, and a wide variety of devices and methods are in use across the avalanche community. But how accurately can this community actually measure slope steepness? This study found that, under ideal conditions, currently available inclinometers have a profile measurement accuracy of about ± 4°. This measurement uncertainty, when combined with start zone avalanche frequency and slab extension effects, can result in significant unintended exposure to avalanche risk. Exposure amplification can be four-fold or greater on critical slopes around 30° and above. These effects can be partially mitigated by making multiple independent measurements of a subject slope in order to reduce, but not eliminate, risk errors. More robust risk mitigation can be obtained by de-emphasizing precise slope angles in favor of communicating color-coded slope angle ranges and associated action standards for those ranges. A specific construct with boundaries at 20° and 30° is shown to quantitatively align with decision strategies most likely employed by individuals who seek out particular ranges of slope angles, and guide users to more robust, error-tolerant management of backcountry avalanche risks.

KEYWORDS: Slope measurement, slope angle, inclinometer, error, start zone, risk communication.

1. INTRODUCTION

It was day two of a hut-based avalanche course, and our small group was ascending a sparsely wooded ridgeline. As we entered a small glade the open slope to our left came into view, perfectly framed between two aspens. Seeing an opportunity to practice inclinometer skills, I asked the students to measure the angle of the slope profile and I showed them where I wanted them to stand when they made their measurement.

But I added a twist to this exercise. Instead of verbalizing their measurement, I asked the students to write it on a scrap of paper. Once everyone had a turn, I tucked the paper scraps into my parka, and we went on to have a fine day of terrain selection and great snow.

Back at the hut that evening I unfolded the scraps of paper. After arranging them in order, this is what I saw in the lantern light:

30°, 32°, 32°, 32°, 33°, 34°, 34°, 36°, 38°.

Two students saw me with the paper scraps and came over to the table. Now it was their turn to ask me how steep the slope was. By way of an answer, I showed them the results. They weren't impressed. They wanted to know what the slope angle really was. Just a single number so they could judge the slope as safe, potentially dangerous, or somewhere in between. Just like their instructors had taught them.

I realized that if I was being totally honest, I didn't know the answer to their question. Was it the measurement I had made as the instructor? Was it the average of all our measurements? They wouldn't have instructors or multiple inclinometers on their post-course tours, so how realistic were those answers?

Like many folks I had assumed that people could translate advice like "avoid slopes steeper than 35 degrees" into good avalanche terrain choices. But now I wasn't so sure. If measurements were off by three, four or more degrees, then what did this mean for good decision making in avalanche terrain, especially around critical slope angles?

This study examines three aspects of this slope measurement problem: 1) a preliminary analysis of how well people measure slopes under ideal conditions, 2) a fresh look at the relationship between slope angle and avalanche frequency and how measurement error might translate into unintended risk taking, and 3) how these unintended risks combine with decision strategies likely used by backcountry travelers. The paper concludes by suggesting an error tolerant red-yellow-green scheme for assessing slope angle.

2. INCLINOMETER ERROR

In the classic skills manual *Mountaineering Art* (1920), Harold Raeburn describes the inclinometer as "the handiest and most easily read instrument" for measuring snow slopes. But he cautions that single measurements may not be reliable and he advises "a number of measurements must be taken and an average made," (p. 40).

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Raeburn's advice has been validated by numerous studies during the ensuing century. For example, Gerrard and Robinson (1971) identified direct slope measurement variability as a significant source of error in geomorphological studies. Gilg (1973) and Gerrard, Cox and Parsons (1978) discuss the problem of variability in direct slope measurements. More recently, Isaak, Hubert and Krueger (1999) report significant intra-tool variability among inclinometers, and Keogh and others (2019) report significant angle measurement variation in smartphone applications. These studies underscore the measurement uncertainty that concerned Raeburn over one hundred years ago but they don't provide many insights into what these errors mean for avalanche slopes.

2.1 *Assessing avalanche inclinometers*

In the seasons following my avalanche course in Idaho, I wanted to find out how well people measured slope profiles under ideal conditions: in a warm classroom, with an unambiguous image projected on large screen and measured with their own inclinometer. I minimized parallax errors by ensuring measurements were made perpendicular to the center of the screen. I also asked participants not to share results until after their measurement forms were handed in.

Along with their measurements, participants recorded their inclinometer type and in some cases their number of seasons measuring slope angles. Some participants were also asked to estimate their own measurement error.

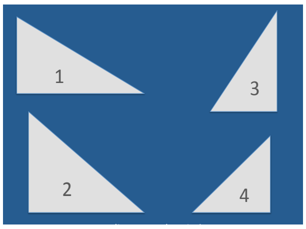


Figure 1. Images presented to participants for on-axis slope profile measurement. Images were projected full-size on a classroom screen.

At first, I used photos of actual slopes but later switched to simple shapes against a blue background (Fig. 1) to eliminate distracting elements. Measurement errors of the two presentation formats were not significantly different ($p_{\text{t-test}} = 0.486$; $p_{\text{f-test}} = 0.128$). I collected data between 2002 and 2019 at avalanche courses and workshops, with skill levels ranging from novice recreationists to professional guides, avalanche educators, rescue personnel and ski area professionals.

I analyzed profile measurements from each session as four subgroups, and for each measurement calculated its deviation from the subgroup mean for that slope image (Taylor, 1997: p. 98). This approach eliminated any effects from intragroup image tilt or keystoning. I computed statistics using the computer language R and Microsoft Excel™.

2.2 *Inclinometer error results*

I obtained 561 measurements from 248 participants. Inclinometer types fell into six broad categories: 1) **Ball-in-track**: ball bearing enclosed in a calibrated curved channel; 2) **Compass**: plumb-finding indicator enclosed in a compass capsule; 3) **Digital**: smartphone app, avalanche transceiver function, or other solid-state device; 4) **LLSM** (Life-Link Slope Meter): weighted disk with off-center pivot and indicating needle; 5) **String**: flat card with an angle scale and weighted string; and 6) **Other**: devices with fewer than 10 samples and illegible or blank entries.

All devices exhibited significant dispersion around their subgroup mean (Figure 2). Analysis revealed three types of error (Table 1):

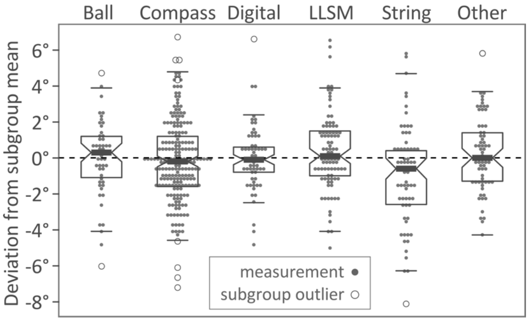


Figure 2. Beeswarm-box plot of slope profile measurements by device type. Boxes indicate central 50% of data and whiskers extend to 1.5 times the interquartile range. Large outliers for compass, string & other devices are not shown for clarity.

Gross errors appeared as outliers to the central distribution. These measurements were likely the result of either a) user error such as improper calibration or errors in alignment, reading or transcription, or b) device manufacturing variation. I used the Chauvenet criterion (Taylor, 1997: p. 166) to identify gross errors and avoid bias introduced by different subgroup sizes. Gross errors were not observed in LLSM measurements, but ranged from 1.6% for digital to 4.4% for string inclinometers (Table 1).

Random error, or measurement uncertainty**,** is the natural variation of repeated measurements around a central value. Random error typically follows a gaussian distribution, here verified by the Shapiro-Wilk's test ($p_{(\text{S-W})} > 0.05$). After excluding gross errors, I calculated the standard deviation for each inclinometer type and expressed its measurement uncertainty with a coverage factor

Inclinometer type	*n*	*Outlier rate*	*Normality $p_{(s\text{-}w)}$**	*Bias $p_{(1STT)}$**	*Measurement uncertainty*†*	*Underestimate by ≥ 3°**
Ball	51	3.9%	0.782	0.848	±4.1°	1 in 14 people
Compass	222	4.1%	0.065	0.383	±4.5°	1 in 11 people
Digital	63	1.6%	0.136	0.548	±3.2°	1 in 31 people
LLSM	90	0.0%	0.134	0.139	±4.3°	1 in 12 people
String	68	4.4%	0.737	***0.012***	±5.7°	1 in 7 people
Other	67	3.0%	0.317	0.674	±3.9°	1 in 16 people
Estimate††	179	-	-	-	±3.1°††	1 in 37 people
Error model	-	3.2%	-	-	±4.2°	1 in 13 people

*outliers removed †k=2 coverage factor ††Self-assessed accuracy by participants

Table 1. Results of classroom inclinometer measurements by participants showing gross measurement errors (outlier rate), apparent bias in string type inclinometers, and measurement uncertainty by device type.

$k = 2$ (approximately 95% confidence) common in health and safety applications (Taylor and Kuyatt, 1994). Device-specific uncertainties ranged from ±3.2°(digital) to ±5.7°(string) allowing me to estimate the number of people who would underestimate a slope by 3° or more as a comparative metric between device types.

Systematic error affects all measurements of a device type in the same way, and appears as a bias away from the subgroup mean as determined by the one-sample student's *t*-test ($p_{(1STT)} < 0.05$). I observed this type of error only in string inclinometers (underestimation of 0.9°).

Responses to two additional questions gave further insight into the slope measurement problem: One hundred seventy-eight participants provided written responses to the question "*How accurate do you expect your measurements with your inclinometer to be: Accuracy ±_____ degrees?*" Estimates ranged from ±0.5° to ±10° with a mean of ±3.1°, which translates into 1 out of 37 people underestimating a slope by 3° or more. Only 11 respondents (6%) estimated slope measurement accuracy to be ±1° or less.

Two hundred forty-seven participants responded to the question "*How many seasons have you been measuring slope angles in avalanche terrain?*" Responses ranged from 0 to 30 seasons, with an average of 10.1 seasons. Interestingly, there was no meaningful correlation between the number of seasons reported and subgroup measurement error ($R = 0.010$). This result suggests that measurement accuracy does not improve with experience, at least in a classroom setting.

2.3 A slope measurement error model

Avalanche forecasts routinely convey travel recommendations based on slope angle. But how accurately the user community will be able to apply these recommendations depends greatly on how well users can measure slope angle.

Measurement error in a contemporary backcountry community can be approximated by first excluding two device types. The once-ubiquitous LLSM is no longer produced and its usage is becoming rare. Also, string-based devices seem to enjoy only brief use by novices before being exchanged for more robust devices. Therefore, it seems reasonable to construct our model based on equal weighting of the remaining three inclinometer types (digital, ball-in-track, compass).

After excluding outliers from these device error distributions (Table 1), the pooled standard deviation of the combined error can be found from (Harris, 2019):

$$\sigma_{\mathrm{p}} = \sqrt{\sum(n_{\mathrm{i}}\text{-}1)\,\sigma_{\mathrm{i}} \Big/ \sum(n_{\mathrm{i}}\text{-}1)}\,, \qquad (1)$$

where n_i and σ_i represent sample sizes and standard deviations respectively for ball-in-track, compass, and digital inclinometers. This yields a standard deviation for the (gaussian) community error model of 2.12° and a mean of 0.0° (Table 1).

Figure 3 illustrates the cumulative performance of the proposed community error model (heavy black curve) simulated across a population of users (Monte Carlo $n = 5000$) for slopes 10° to 45°. As expected, the percentage of measurements (or probability of being within an accuracy window) increases as the accuracy window expands. In this model, the mean self-assessed accuracy by participants lies at roughly 85% certainty of a single measurement being within a 6.2° window.

Multiple independent measurements of the same slope can improve steepness estimation for the backcountry user. Averaging 2, 3, 4 and 5 independent measurements of the same slope (dotted curves in Fig. 3) will improve accuracy, and two field expedient methods (median of 3 and 5 measurements) also compare favorably. However, most backcountry users will likely find more than 3 independent measurements of the same slope impractical, and so it appears unrealistic to

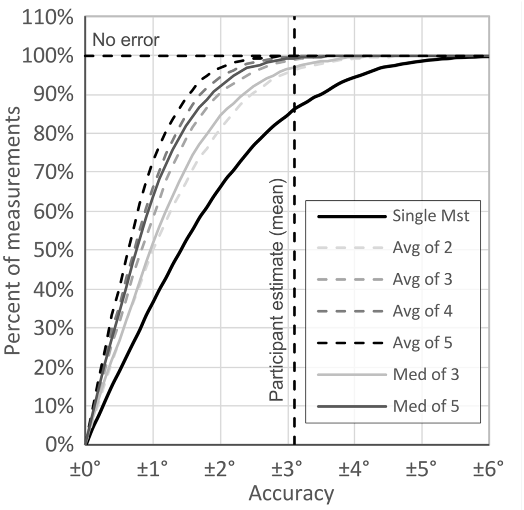


Figure 3. Accuracy of the community slope error model, showing the mean accuracy estimated by participants. Multiple measurements can improve accuracy, but achieving robust (95%) accuracy better than about ±2° appears impractical for most backcountry users.

assume that parties can reliably measure a slope with less than ±2° accuracy, or a 4° window.

In general, an approximately 95% (k = 2) accuracy window (A_{2k}) of a number of measurements (n) with standard deviation σ_p can be found from (van Belle, 2002: p. 33):

$$A_{2k} = \pm\, k\sigma_p/\sqrt{n}\ . \qquad (2)$$

So, for my course in Idaho, the accuracy of the students' nine measurements works out to ±1.4° around a mean of 33.4°. In other words, our best estimate of the slope angle, with nine measurements, was somewhere between 32° and 35°. Not exactly the precision we were conveying in our lectures!

As a unit of measurement, the degree appears to be over-precise for the task of measuring (and specifying) slope steepness with the inclinometers currently used by the backcountry community. But what unit would be better? Ideally, this improved larger unit would ensure that many users would arrive at the same result after measuring the same slope. Table 1 indicates that this property exists only when this unit of measure spans at least ±4.2° or an interval greater than 8°.

But recall that the community model is based on *ideal* conditions. In actual avalanche terrain where unseen breakovers, foreshortening, and obscured slope profiles are common, the accuracy interval for a robust measurement unit will be even larger.

What does this mean for decision making in avalanche terrain? To understand this, we have to first consider how avalanche risk changes with slope angle.

3. SLOPE ANGLES AND AVALANCHE FREQUENCY

In 1977 Ron Perla published the now-familiar chart of avalanche frequency versus start zone steepness. His bell-shaped histogram of 194 avalanches had 5° intervals and peaked at 38.3° with a standard deviation of 4.79°. Many subsequent studies have replicated Perla's findings (mean slope angle ≈ 38°) with the result that the relationship between slope angle and avalanche likelihood has become a cornerstone of avalanche risk management.

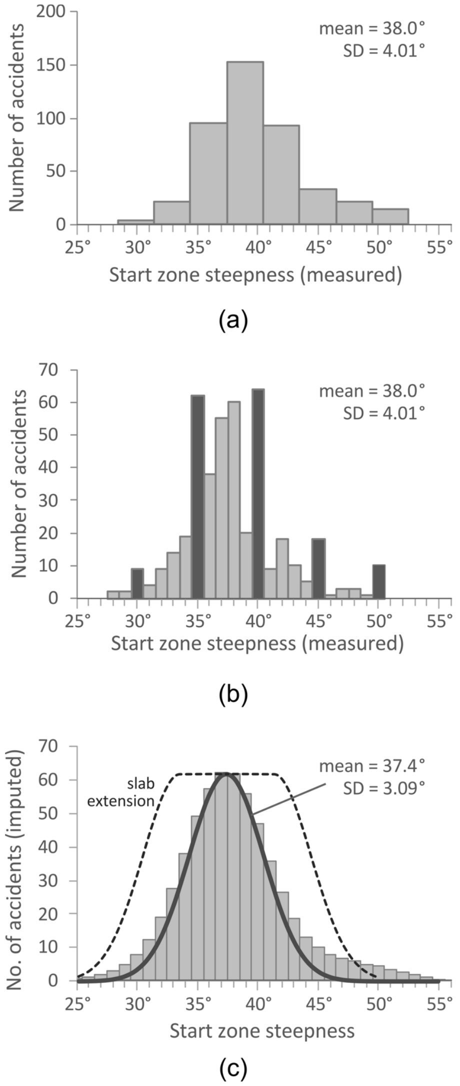
As a first step in developing a more precise slope angle-frequency model, I reviewed 50 years of U.S. avalanche accident reports (1970-2020) where the start zone was reported as *measured in the field* by accident investigators (n = 436). When displayed with histogram bins spanning 3°, a common format for such diagrams, we see the familiar bell-shaped distribution with mean 38.0° and standard deviation 4.01° (Fig. 4a).

However, when histogram bins span 1° the data appears to be quite irregular (Fig 4b), with prominent spikes at 30°, 35°, 40°, 45°, and 50°. This phenomenon is known as heaping, and is common at preferred digits when the property being measured is coarser than the unit of measurement (Heitjan and Rubin, 1991). Heaping metrics for this data show p-values <0.001 ($H1_{S(\text{neighbor})}$ = 0.870; $H2_{S(mode)}$ >0.999) (Roberts and Brewer, 2001), indicating that these heaps cannot be reasonably attributed to random variation.

Because heaped data can bias data parameters like means and standard deviations, de-heaping methods have been developed that minimize such bias. Here, I applied the method described by Beaman and others (2015). I used the community measurement error model as a de-heaping prototype and then regressed the distribution to a gaussian function, iterating the process until the mean and standard deviation became stable within 5% (4 cycles). The de-heaped result appears in Fig 4c, where the mean of the estimated distribution is now 37.4° and the standard deviation has narrowed by almost a full degree.

While the right-hand tail of the deheaped function is a poor fit at slope angles above 43°, the area of interest for this study is the rising left-hand portion of the curve where the majority of travelers will be choosing to enter an avalanche path. In this region, the gaussian approximation represents a reasonably good fit for avalanche frequency by start zone steepness (μ = 37.4°; σ = 3.09°).

In order to complete the model, we have to account for entrainment of connected slopes when the slab extends into lower-angle terrain.



(a)

(b)

(c)

Figure 4. Field-measured start zone steepness from 436 U.S. avalanche accidents. Displayed with (a) 3° bins and (b) 1° bins with heaps at preferred digits highlighted. (c) De-heaped approximation using the method of Beaman et al. (2015).

Of the 50 years of avalanche data described above, there were 203 cases where the range of adjacent slope angles that were entrained in the avalanche were reported as measured. Since there was no evidence of proportionality in the distribution of ranges (*R* = 0.004; mean = 6.9°; Manchuk et al., 2009), I approximated slab extension with a triangular distribution where the mean corresponds a probability of 0.5. The result is that the rising edge of the slope-frequency model will extend to lower angles by approximately 6.9° at the furthest edge of the slab extension distribution (Fig. 4c).

While this result is supported by available data, hard slabs and persistent slabs do, in my experience, entrain slopes of even shallower angles. Thus, these slab extension results should be viewed as provisional pending further analysis.

4. SLOPE MEASUREMENT ERROR AND AVALANCHE RISK

Exposure to avalanche risk depends on a large number of factors. But all things being equal, steeper slopes up to about 38° represent a higher likelihood of triggering an avalanche. Therefore, undermeasurement of slope angle can correspond to an unintended increase of avalanche risk, as shown in Fig. 5.

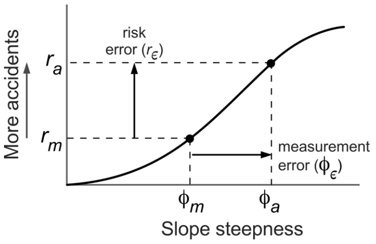


Figure 5. Slope measurement error translates to risk perception error via accident frequency.

Here, a backcountry traveler measures a slope with angle ϕ_a that corresponds to an accident proportion (risk) r_a. But due to error in their measurement (ϕ_ε) the slope appears to have lesser steepness ϕ_m with corresponding lesser risk r_m. We can define a risk ratio to describe the relative risk posed by mismeasurement ϕ_m:

$$R(\phi_m) = {}^{(r_a - r_m)}/_{r_m}\,, \tag{3}$$

where the relationships between ϕ and r can be found from the gaussian probability density function specified in Fig 4c. The relevance of the risk ratio will depend greatly on the point on the slope-accident curve where the error occurs. We can ensure utility of R as a risk metric by transforming the function to emphasize the region where the risk is changing rapidly, which is found via the derivative of the gaussian function $g(\phi)$:

$$\Delta_R(\phi) = \frac{\delta}{\delta\phi} g(\phi) = \frac{\delta}{\delta\phi}\left[\frac{1}{\sigma\sqrt{2\pi}} exp\left(\frac{-(\phi-\mu)^2}{2\sigma^2}\right)\right]$$
$$= g(\phi)\,\tfrac{\mu-\phi}{\sigma^2}, \tag{4}$$

where μ and σ are the mean and standard deviation shown in Fig 4c. In order to ensure that units of risk are relative to the percentage of accidents for the non-error case, the result is scaled by the factor:

$$S = \frac{R_{(\emptyset_m)}|_{(max)}}{1+R_{(\emptyset_m)}\Delta_{(\emptyset_{mp})}|_{(max)}\times 100}\,, \tag{5}$$

where the mid-point gradient $\Delta(\phi_{\mathrm{mp}})$ and $R(\phi_{\mathrm{m}})$ are evaluated at their maximum values.

The risk multiplier M that results from the transformation expresses the risk multiple that arises from a particular measurement error relative to a measurement with no error:

$$M = SR_{(\emptyset_m)}\Delta_{(\emptyset_{mp})}\ . \qquad (6)$$

Figure 6 illustrates the impact of measurement error for several probabilities within the community error model. When no measurement error is present (dotted line), risk is accurately reflected in the measurement (M = 1). But when a measurement error of -2.7° occurs (about 1 in 10 people in the community error model) the user will experience more than a four-fold increase in avalanche risk on a slope (erroneously) measured to be 30°. On my course in Idaho, the student measuring our slope as 30° was unknowingly subject to a 6.1-fold increase in risk through their measurement error of -3.4°.

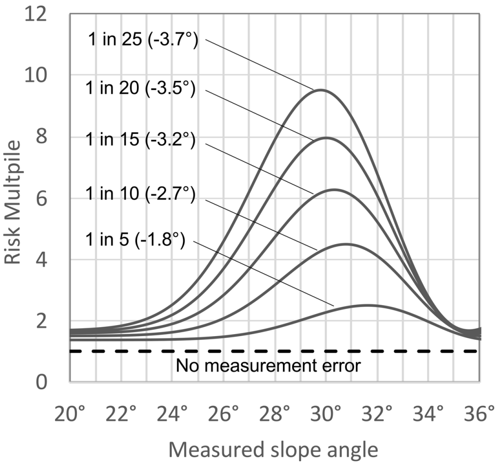


Figure 6. Impact of slope measurement error on unintended risk. Risk multiple (*M*) indicates the increase in unintentional risk exposure relative a no-error measurement.

These estimates of risk are further compounded by slab extension effects and are necessarily approximate. But it is clear that the error inherent in current slope measurement methods can produce significant unintentional exposure to avalanche risk, particularly around 30° slope steepness. Unfortunately, avalanches are triggered less frequently on slopes below 35° so these increased risks may easily go unnoticed until an accident occurs.

These results are of little value if they cannot be effectively communicated and applied. The final step in this analysis is to identify a construct that facilitates informed decisions about entering or avoiding avalanche terrain.

5. DECISIONS BASED ON SLOPE ANGLE

Doug Fesler and Jill Fredston (1988) were among the first to promote a red-yellow-green (RYG) scale for identifying hazardous avalanche slopes, and various color-coding schemes now appear in digital maps, safety diagrams, smartphone apps and even on some inclinometers.

Unfortunately, precise definitions of color-code boundaries have been elusive and conflicting scales endure in the wild. For example, a 30° slope can appear as red (NAC, 2023), orange (Iterum LLC, 2016), yellow (Tremper, 2013), or green (Caltopo, 2023).

Ideally, risk scales should align with the decision strategies and desired actions of users (e.g. Baker, 1995) while being tolerant of user errors. Scales based on avalanche slope angle boundaries in particular can and do leverage preferred digits in slope measurement (Figure 4b).

5.1 Slopes of negligible risk (green)

Many who travel and recreate in the winter mountains wish to do so with near-zero avalanche risk. Examples include scout, church, or school groups, young families and those who simply seek to have an avalanche risk free experience. These users desire terrain that is effectively free of avalanche hazard, exemplified by Class 0 or Class 1 (simple) terrain in the Avalanche Terrain Exposure Scale (ATES; Statham and Campbell, 2023).

At the most basic level, decision strategies of these individuals will likely correspond to novice level risk mitigation (Dreyfus and Dreyfus, 2005, Persky and Robinson, 2017) and will typically involve single-criterion, context-free rules for action and avoidance. An example rule might be to "avoid all slopes steeper than X°," where X° is determined by a single slope measurement. To be effective for this user group, X° must be tolerant of measurement error while still ensuring near-categorical exclusion of start zone and slab extension risk.

Figure 7 shows slab extension risk and measurement error as functions of slope angle. Dashed curves correspond to 2*k* minima of the community error model. At 25°, risk levels are > 1% (1 chance in 100 of entrainment if an avalanche occurs on an adjacent slope) and single measurements are sensitive to risk amplification. At the next lower preferred digit (20°), start zone risk is negligible and slab extension risk is less than 0.1%, or 1 chance in 1,000 should an avalanche occur on an adjacent slope. Thus, slopes under 20° can be provisionally viewed as having negligible entrainment (not runout) risk providing risk averse users with a single, error-robust decision criterion.

5.2 Slopes of critical risk (red)

At the opposite end of the risk appetite spectrum are individuals who actively manage avalanche risk in order to access steeper terrain. These individuals necessarily engage in real-time prioritization of myriad terrain, snowpack and weather factors that contribute to avalanche risk. Ideally, decision strategies will correspond to competent, proficient, and expert stages in the expertise development model. Tremper (2018) argues cogently that longevity in terrain above 30° requires a keen awareness of patterns (schemas) and their exceptions – both of which are hallmarks of expertise (Persky and Robinson, 2017).

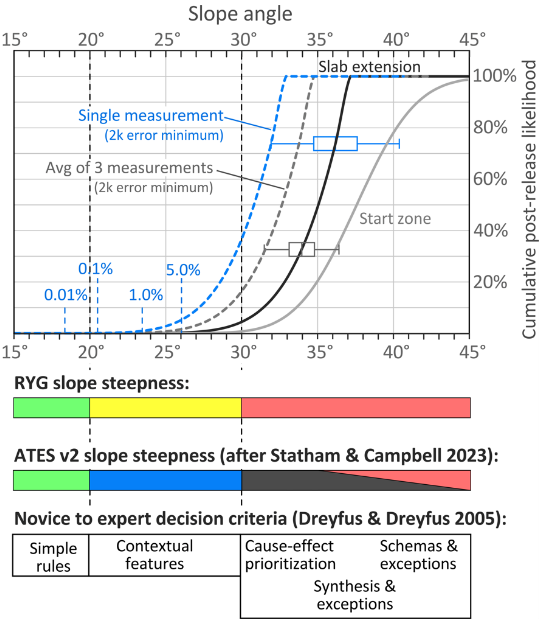


Figure 7. Cumulative post-release likelihood of entrainment by slope angle, showing two steepness color schemes and decision criteria by user stage of avalanche risk management expertise.

Figure 7 illustrates the problem with risk management by slope angle alone above 30°; both start zone and slab extension risks rise rapidly within the approximately 95% span of measurement errors, as shown by (50%, 4*k*) box-whiskers for single and 3-sample slope measurements. Staples (2022) argues persuasively that 30° represents the “door to avalanche terrain” beyond which decisions are complex processes which go well beyond simply measuring slope angle.

5.2 Slopes of transitional risk (yellow)

Between the two extremes of risk appetite lies a 10° region (20° - 30°) where risk grows from near-zero to almost 40% for 2*k* measurement error of slab extension. Consequently, avalanche risk management in this region necessarily progresses from the single-criterion, context-free strategy of the novice to multicriteria, context-dependent strategies. Dreyfus and Dreyfus (2005) identify an advanced beginner stage in expertise development where local and temporal features form the basis of mitigation decisions. This strategy represents a minimum for managing risk in this transitional region, and involves important contextual information such as the current danger rating, avalanche problems including hard slab and persistent slab conditions, terrain variation, and consequences of being caught. Attention to these cues has increasing importance as slope angles approach 30° (Tremper, 2018).

Worth noting is that a 10° span represents a near minimum size for a color scale interval. Section 2.3 showed that the 2*k* accuracy of a single slope measurement under ideal conditions spans 8.4°. Smaller spans result in > 5% of users mis-classifying a mid-yellow slope as green or red.

As slope angles approach 30° and entrainment risk increases, averaging multiple measurements can reduce risk error. In Figure 7, averaging three measurements reduces risk error to about 20%. Even so, significant risk error remains, providing further proof that managing avalanche risk by slope angle alone is unwise.

6. CONLCUSIONS AND IMPLICATIONS

The preliminary analysis presented in Section 2 indicates that inclinometers exhibit significant measurement uncertainty even under ideal conditions. Sections 3 and 4 showed that this uncertainty can lead to critical errors in assessing avalanche risk, and Section 5 showed that these errors can be minimized (but not eliminated) by using a 3-element color-coding scale. These results suggest the following:

Inclinometer measurements are approximate – Despite some devices displaying measurements in 1° increments, true profile measurement accuracy is probably around ±4° (ideal conditions). Averaging 2 or 3 independent measurements can reduce but will not eliminate error (Fig. 3).

Improving slope angle measurement – Slope measurement accuracy does not appear to improve with experience (Section 2.2). Avalanche courses offer an excellent opportunity for error correction for personal devices or methods against a group average of many measurements.

Communicating action rather than uncertainty – Simply pointing out slope measurement uncertainty has little practical value, especially for novices seeking simple decision criteria. Instead, emphasizing an action standard for a given color range of slope angles gives novices concrete steps they can take in the face of measurement uncertainty.

Avoiding the Illusion of precise risk management – Characterizing avalanche slopes as having a single slope angle may contribute to the illusion that precise avalanche risk management is possible via slope angle measurement. Non-events are notorious for nurturing bias. So, when no avalanche occurs, those who that believe they are precisely managing their risk by parsing slope angles may be learning the wrong lesson. Not that they got lucky, but that they have the ability to precisely manage their risk in avalanche terrain.

With all of this in mind, I think I finally have an answer for my students on that avalanche course in Idaho so many years ago. Today, after scanning their scraps of paper, my answer might go something like this: "Our measurements seem be clustering in the low- to mid-thirties, which is a red slope. Rather than expending our energy on more precisely measuring the slope angle, let's focus on what we need to know about the snowpack and the consequences of being caught."

Investor Warren Buffett is often credited with saying "It's better to be approximately right than precisely wrong." While it may be tempting to manage avalanche risk by precisely parsing slope angles, a deeper gaze into the uncertain heart of the avalanche dragon may be the key to longer life in avalanche terrain.

7. LIMITATIONS

This study has been largely exploratory and its results should be considered preliminary. Much follow-on research is needed, including: 1) robust study of real-world slope measurement errors, 2) grounding of the community error model in a device use survey, 3) deeper analysis of start zone frequency and slab extension with improved data, 4) validation of these results by post-accident mismeasurement investigations, and 5) extension of these results to include avalanche runout.

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