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THE UNIVERSITY COURSE IN SNOW DYNAMICS—A STEPPING-STONE TO CAREER INTERESTS IN AVALANCHE HAZARDS

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Abstract. The principles of snow dynamics, including practical field work, constitute a feasible university-level course where seasonal snowfall and terrane of varying steepness are accessible. Two to three lectures or discussions per week are combined with one full afternoon in the field to provide a workable course format. We have successfully used the *U.S. Department of Agriculture Forest Service Agriculture Handbook* 489 (Avalanche handbook) as a text but also assign readings in diverse world literature.

Field work has centered on standard techniques for snow study in a realistic alpine setting but could easily be adapted to more simple "roadside" conditions if necessary. Student interest during and following the course usually leads to spontaneous and practical research that tends to develop life-long skill and application in the subject.

Our experience indicates that one instructor can manage a maximum of 25 students in the field, considering proper logistics, safety, and necessary adaptibility of field procedures to changing weather conditions.

Résumé. *Les cours universitaires de dynamique de la neige—un marchepied vers les carrières de prévision du risque d'avalanche.* Les principes de la dynamique de la neige, y compris les travaux pratiques, font l'objet de cours universitaires dans les régions où se trouvent une chute annuelle de neige d'une certaine importance et un terrain accidenté. Un bon format pour un tel cours consisterait en deux ou trois conférences par semaine suivies d'un après-midi sur le terrain. Comme texte, nous nous sommes servis avec succès *United States Department of Agriculture Forest Service Agriculture Handbook* 489 (Avalanche handbook) mais nous exigeons aussi des lectures de toutes sortes dans la littérature mondiale.

Les travaux pratiques se basent sur les techniques classiques des études de la neige dans un site alpin réaliste mais ils pourraient facilement s'adapter à des conditions plus simples "au bord de la route" si nécessaire. L'intérêt des étudiants pendant et après le cours souvent les mène à faire des recherches spontanées et pratiques, ce qui peut leur donner une habilité et une application dans ce domaine qui dureront toute la vie.

D'après nos expériences, le nombre maximal d'étudiants ne doit pas dépasser vingt-cinq pour des raisons de logistique, de sécurité et de possibilité de s'adapter aux changements météorologiques.

Zusammenfassung. *Der Universitätskurs in Schneedynamik — eine Stufe zur Ausbildung in der Lawinenforschung.* Die Grundlagen der Schneedynamik, einschliesslich praktischer Feldarbeit, behandelt ein Kurs auf Universitätsebene, wobei jahreszeitlicher Schneefall sowie Gelände verschiedener Steilheit zur Verfügung stehen. Zwei bis drei Vorlesungen oder Diskussionen pro Woche sind mit einem Nachmittag im Gelände kombiniert, um ein brauchbares Kursprogramm zu bieten. Als Grundlage wurde das *U.S. Department of Agriculture Forest Service Agriculture Handbook* 489 (Avalanche handbook) erfolgreich benutzt, ebenso aber verwandte Texte der internationalen Literatur.

Die Feldarbeit hat sich auf bestimmte Techniken des Schneestudiums in natürlicher alpiner Umgebung konzentriert, kann aber, falls notwendig, ebenso einfacheren lokalen Bedingungen angepasst werden. Studentisches Interesse während des Kurses und danach führt gewöhnlich zu spontaner und praktischer Forschungsarbeit, die dahin tendiert, Kenntnisse und Erfahrungen für eine lebenslange Tätigkeit auf diesem Gebiet zu entwickeln.

Die Erfahrung zeigt, dass ein Dozent mit höchstens 25 Studenten im Gelände arbeiten kann, unter Berücksichtigung angemessener Unterbringung, Sicherheit und notwendiger Anpassung der Feldarbeit an die wechselnden Wetterverhältnisse.

Introduction

For the past 17 years, Montana State University in Bozeman has offered an elementary four-credit course in snow dynamics conducted during the winter university quarter. Its purpose is to provide a thorough background in snow-hazard and management procedures, and to acquaint students with local and international scientific snow research. The course received its initial impetus from college students serving on local ski patrols who desired more depth of knowledge than could be gained through voluntary evening and week-end work sessions. Initially, the course was centered on purely scientific aspects of snow but excluded safety, rescue, and snow hazards. More recently, some disaster and safety subjects have been incorporated, improving the practical and applied aspects of the course, and therefore sharpening the interest in it. The course meets for 2 hours per week in lecture and discussion, and involves one complete afternoon laboratory per week in on-snow field work.

The course is limited to 25 upper-class students of diverse curricula who can demonstrate that snow dynamics has a practical application in their future and who have the ability to negotiate steep alpine terrane, usually by means of down-hill skis. Lately, the down-hill skills of cross-country skiers have improved and cross-country skis have been allowed. There is usually a waiting list for the course, indicating the general interest in snow dynamics in this part of North America. Although academic preparation in physics, chemistry, and geology is of help, there are no prerequisite courses.

The proximity of the Bridger Range, where excellent avalanche terrane can be experienced 30 km from Bozeman, enhances and expedites the necessary field work.

Course materials and procedures

The subject matter for the course more or less follows the sequence of the new *U.S. Department of Agriculture Forest Service Agriculture Handbook* 489 (Avalanche handbook) by Perla and Martinelli (1976). This text serves as an authoritative reference with excellent illustrations. Supplemental readings are assigned from many well-known publications including those of CRREL, U.S. Forest Service, the International Glaciological Society, and standard research works from Switzerland, Austria, France, Canada, and Japan. Of particular interest are those articles published in conjunction with various meetings of the International Association of Scientific Hydrology.

The lecture sequence is developed around the following outline:

World literature on snow.
Several approaches to snow analysis: "internal" *vs* "external" to the snow-pack.
Snow crystallography: the influence of weather and other environmental factors on snow metamorphism.
The response of snow to gravitational stress: creep, glide, fracture, avalanche phenomena.
Critical factors in stability evaluation; storm case histories.
Instruments and measurements.
Passive and active methods of control of snow movement and accumulation.
Special effects of wind: drifts, slabs, cornices.
Avalanche zoning for highways, development, and recreational activities.
Snow management for recreational areas and highways; grooming machinery and procedures.
Research in progress: local, national, world-wide.
Avalanche safety and rescue.

The field sequence is approximately as follows (note: flexibility is advised for this phase in order to accommodate observation of avalanches, and take advantage of chance visits of visiting scientists. Varying snow-touring conditions should also be co-ordinated with field exercises):

First week: terrane analysis in the central Bridger Range area with emphasis on snow accumulation and movements, vegetative scars and patterns, and slope angles.
Second week: terrane analysis in the northern Bridger Range area; demonstration of ram penetrometer, resistograph, snow-pit techniques; first snow-pit analysis.
Third week: terrane analysis in the south Bridger Range area; the study of snow conditions with respect to the directional aspect of slopes.
Fourth week: the effects of wind on snow; inspection of snow-cornice sites, drifts and changing snow depths, cornice- and drift-control devices.

Fifth week: snow-management procedures; the problems of machinery; crowd control under hazardous conditions at large ski areas; trail systems and slope routing for most efficient use of up-hill transportation.

Sixth week: revisit snow-pits and make comparative observations; snow-photography demonstration; snow-safety procedures; rescue beacons; special field experiments.

Seventh week: use of instruments and snow-pit in making stability evaluation for the day; the "snow-column isolation" experiment (see description below).

Eighth week: research in progress; work on individual research projects; special field experiments.

Ninth week: exploration and evaluation of selected avalanche terrane in adjacent mountain areas; the effects of spring weather conditions on snow in general.

Special field demonstrations and research developed during course

Snow-column isolation experiment

One of the most useful experiments during the field phase of this course follows a procedure suggested by E. R. LaChapelle and developed by C. C. Bradley for testing the snow resistograph (Bradley, 1968). The procedure was designed to gain confidence in obtaining the ratio of snow strength to snow load above the weakest layer in a mature snow-pack as measured by

Fig. 1. Isolated snow column ready to be undercut along its weakest strata by saw (shown).

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the snow resistograph (Bradley and Bowles, 1967). Students can determine the profile for compressive strength of the snow column using either the resistograph or the ram penetrometer. Following this, the load above the indicated weak layer is determined by means of the Mount Rose snow sampler. The research team then isolates a column of snow 1 m square using shovels (Fig. 1). The predetermined weak layer is located in the column and undercut by sawing from two sides on the column toward its center. (A crude large-toothed home-made wooden saw is used for this.)

Finally, careful manipulation will nearly always demonstrate that the column will collapse in the weak layer when the weight of the column per unit area is somewhat less than twice the indicated strength per unit area. The dynamic nature of this experiment and the clear demonstration that it is possible to measure snow strength quantitatively with instruments contributes a fascination that always attracts students' interest and attention.

In addition to demonstrating the validity of this instrument, the experiment is directed towards the ultimate use of the resistograph as a means for predicting slab avalanches originating from load collapse. In spite of difficulties (Perla, 1977), the shear frame has been suggested as a valid way for determining the most "unstable" layer in the snow-pack (Quervain, 1950; Roch, 1966) and could well be incorporated in this teaching situation.

Cornice dirt-band exercise

Dirt bands and textural changes in the snow can be used to demonstrate the history of snow deformation and cornice accretion (Fig. 2) in transects perpendicular to the long side of a cornice. Dirt bands tend to diverge towards the leading edge of the deformed cornice wedge, indicating that cornice accretion is accompanied by continual down bending, and that hollows can be perpetuated within the leeward areas of cornices as each successive cornice wedge bends downwards. Stakes planted vertically in the growing cornice wedge tend to lean down-hill in time as a result of this distortion.

Jet-roof experiment

Miniature or full-sized jet roofs can be erected up-wind from cornices to deflect and accelerate the wind and thus reduce the cornice.

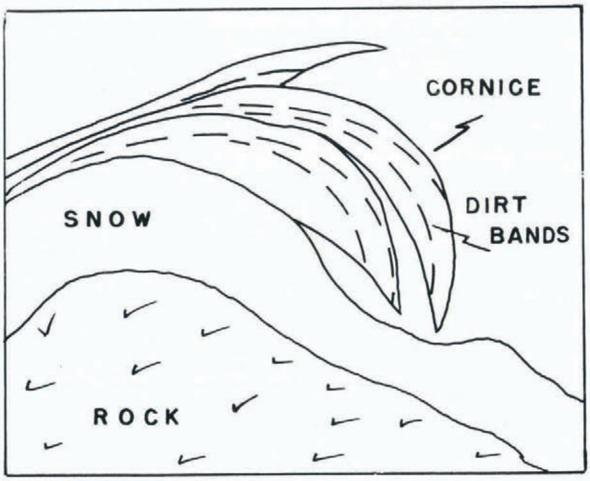

Fig. 2. Typical ridge-top cornice with various generations of deformed wedges. Dirt bands (dashed) diverge towards the leading edge, indicating that deformation was concurrent with accretion of wedges.

Standard snow-pit exercise

Well-known techniques for the study of snow-pit data are always basic to field work. Temperature variations, densities, textural and crystallographic changes, weak and strong layers are among the usual observations. In addition, by isolating a column 0.5 m square and by placing body pressure against this column, the column usually breaks along the bedding of a weak layer. The strength of the weak layer can be quantitatively measured by means of a shear frame as described by the Schleiss brothers in Canada (Schleiss and Schleiss, 1970).

Stability evaluation exercise

Standard instruments for measuring wind speed and wind direction through time, temperature and barometric trends, and snow depth and load are observed by students. Coupled with on-site inspection of snow conditions, a stability evaluation is possible, and practical experience in standard avalanche prediction has proven to be a completely workable and interesting phase of the field work. An instrument array is usually available at first-class ski areas, and if not, the necessary instruments can be purchased for less than $800.

The number of interesting illustrations of natural snow phenomena in a given area is only limited by the scope of the imagination. In fact, an alpine setting is not absolutely necessary for applicable examples. The creep of snow down an automobile windshield with resultant folds and tensional gaps is a worthwhile simulation of glide on snow slopes. Also, simple stakes or plexiglass tubes planted in sloping snow can demonstrate creep and glide through time. Rills formed in new snow during warm conditions are always interesting and tend to become inverse with time. Complex dune fields develop on local snow-fields, and a variety of forms that simulate mountain-top conditions can be seen in most road "borrow pits". It is not necessary to have a wealth of equipment to design a course around such interesting simple natural occurrences as these.

Research outgrowth

Interest generated in many diverse phases of snow study during the course has led in some cases to fruitful research either during or following the course experience. In many cases, such activities have stemmed from the imperfections in the state-of-the-art instruments and systems used during the course. One good example may suffice to illustrate that an initial course experience may be the seed that brings about further important scientific accomplishment.

Three students, T. Rayne, A. Satterlee, and G. Findell, found that multiple temperature readings could not be efficiently obtained in deep snow using common methods without digging a snow-pit for each set of readings. While granting the necessity for initial stratigraphic–temperature observations in a local snow-pit, obtaining multiple temperature readings in this way was so slow that it increased the odds for becoming involved with dangerous snow-slides on steep slopes. They, therefore, designed an instrument for rapid determination of snow temperature. With a small grant they built a wood-supported platinum tipped probe and wired it to a Wahl digital meter designed for accuracy to the nearest 0.1 deg. They have found that a 10 cm interval heat curve can be obtained in 10 ft (3 m) of snow in less than 3 min without digging, and the prototype of the instrument, which is very field portable, is a success. In concept, the temperature probe is not new. Thams (1945) reported using one over 30 years ago. However, the rechargeable digital read-out machine plus the sensitivity of the platinum probe make this latest model worth mentioning.

Other typical student research includes such subjects as a comparison of plant communities and substrates of avalanche and non-avalanche areas in south-central Montana (Eversman, unpublished), a snow-engineering handbook (Burroughs, unpublished), the effects of trees on the snow-temperature profile (personal communication from A. Satterlee, 1978), the use of dyes to bring out the stratigraphy of the snow-pack (personal communication from R. Lang, 1979), or the comparison of effects of compacted snow with non-compacted snow.

The creative activity described here may duplicate lesser known inventions and procedures developed previously in other locations, but the experience of discovery and development of ideas by individuals in a pedagogical situation justifies the activity in this context.

Logistics and special aspects of teaching

Obviously, the dangers inherent in negotiating alpine terrane in winter, coupled with the related physical exertion and sometimes uncomfortable conditions, dictate that an instructor be aware of these particular contingencies when teaching this course. Extensive experience with alpine or sub-alpine conditions and in handling people in those environments are necessary prerequisites for any teacher in this kind of pedagogy. One must build the intuition that dictates whether to "cut the class loose" and let them find their own way to the successive flagged instruction stations, or whether to have the class remain close behind a leader in a controlled mode of ski-ing. The "semi-controlled" traverse is probably the most common approach here.

The hazards involved with providing first-hand experience in avalanche terrane must also be carefully appraised. Conservative safety standards should be employed. This is not always popular with those who do not share the responsibility for the welfare of the group.

Quite aside from safety considerations, the morale and data retention of a class may depend upon many special considerations. For instance, it would make little sense to lecture standing on the crest of a ridge during a high wind if a more sheltered location were available. However, the experience of high wind is valuable. Likewise, to require a class to remain still for hours under very cold conditions is unnecessary and frustrates learning. A teacher needs the intuition to know when to move a class off to allow restoration of body circulation.

One may choose certain projects to fit the particular weather of the day. It would be fitting to schedule long cross-country trips during cold days with unbreakable crusts. Cross-country trips in soft wet snow should be avoided. Snow-pit crystallography is best observed under moderate conditions.

From the equipment standpoint, the few students who come unprepared to stand and work in the snow, in spite of forewarning, may in fact demoralize the entire class. This emphasizes the necessity to insist that cold-weather apparel suitable for sedentary observation be worn or available.

So far, aside from discussing the various aspects of the use of high explosives for control work, it has not been advisable to demonstrate such in the field. It has been policy, however, to recommend that students take week-end time to observe professional snow-testing crews in action. We have likewise made good use of visiting and local scientists in giving lectures on the nature of their work on the forefront of snow science. The past review of work in progress by St Lawrence (seismic and acoustical aspects of snow), Lang (modeling avalanche flow and run-out), Brown (strength dynamics related to snow crystallography and texture), and Bradley (1968) have added authority to the course in general and inspired students to move ahead into the field of snow dynamics.

At a time when environmental and hazard-impact statements are increasingly required, the avalanche hazard should be included in any geomorphological investigation in which snow-covered slopes are involved. Any university within reasonable commuting distance of hills or terrane with seasonal snow cover could justifiably consider such a course among its science offerings.

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