AVALANCHE FREQUENCY AND MAGNITUDE DETERMINATION FOR SKI TOURING OPERATIONS [1]

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Abstract. Simple methods for estimating avalanche frequency and magnitude have been in use for several years. Three methods are suggested: 1) direct observation, 2) historical records and 3) tree-ring analysis. These methods may be used by commercial ski touring operations to improve aspects of safety and planning.

INTRODUCTION

For many years, various avalanche research projects, independent avalanche consultants and land use planning agencies have employed a variety of techniques for estimating avalanche path event frequency and magnitude characteristics. These methods are generally considered to be best suited for fixed installation site planning and to be of relatively little use for the winter traveler. However, because commercial backcountry ski touring operations quite often make repeated use of standard routes, exposure to the same hazard may make some of these ideas worth investigating. This paper reviews several simple and cost effective techniques which can be used to extract path-specific avalanche frequency/magnitude relations at three different time scales. The results thus obtained can be compiled into one detailed map (as in figure 3), or in a more comprehensive atlas, thus assuring their availability and continued use by persons other than the original investigators.

Most ski touring guide services, which hold a special use permit covering terrain where avalanches are a recognized hazard, monitor and record snowpack and weather information to some degree. Some keep track of directly observed avalanche events and have several years of this information on file. While these data are obviously of great importance, two problems often limit their utility; 1) the length of record is quite short and; 2) the data are usually buried in files and are not available for immediate use by the guides. A map styled presentation of this data along with longer term event histories, can greatly increase the usefulness of such information.

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DIRECTLY OBSERVED EVENTS

For the first stratum of frequency /magnitude analysis presented here, the physical dimensions of directly observed events are recorded by persons in the field whenever possible. Information noted should include fracture line depth and enough spatial information (perhaps obtained via photography) to allow plotting on a base map. Additional notes concerning depositional characteristics of the event may be of use in development of the rescue plan and in rescue training. Weather and/or snowpack data may also be keyed with the event data and concise summaries of these conditions may be noted on the path map as illustrated in figure 3. One of these working maps is maintained for paths of interest each season. At the end of the season the information is summarized and transferred to a permanent base map which has already been prepared and coded with event information from the historical record and tree ring analysis methods as described later. During subsequent seasons, the master map is reviewed at the end of the season and any additions or corrections are made. These changes will usually involve re-aligning the high frequency event margins, including a unique event or adding depositional characteristics etc. Copies of the master path maps are then made available to guides at the beginning of the following season.

HISTORICAL EVENTS

The second stratum of the suggested frequency and magnitude analysis involves plotting events observed or reported by persons other than the avalanche trained staff. This may include researching sources such as libraries, newspaper archives and interviews with long-time residents etc. This stratum may be used to fill in the direct observation record and extend the record back several years depending on the resources available in your area.

In North America, the historical record exists in many areas because of mining activity. In the 19th century, mining attracted increasing numbers of people into many areas of the mountainous west. Population centers and extensive transportation systems rapidly developed to support the mining industry. The year-round habitation brought people and their property into direct contact with avalanches, resulting in hundreds of fatalities and millions of dollars worth of property destroyed. The best source of information on these historical avalanche accidents is the newspaper record, which in some areas covers over a hundred years. Many local and regional libraries and historical societies maintain microfilmed copies of these newspapers, as well as diaries and other related material.

The length and quality of the historic record will determine how accurate and detailed the evaluation of avalanche frequency and magnitude can be from this source. The ideal and most accurate record is a combination of several sources: newspaper accounts, interviews and photographic collections. Photos are especially useful to document exact event boundaries. Time-series photographs or past and present photos are extremely useful in documenting changing vegetation patterns. However, photos alone can mislead and it is essential to determine if these changes resulted from human impact (e.g. deforestation), natural but non-avalanche events (e.g. fire) or from actual avalanche events.

Searching the record for the mention of avalanche accidents is a slow and tedious process and is only the first step in reconstructing the avalanche history of a specific area. The next step requires in-field confirmation that the geographic location mentioned is actually in an area that could be reached by an avalanche event.

A good example of multi-source reconstruction of avalanche events is from the Camp Bird Mine area near Ouray, Colorado (B. Armstrong, 1977). Documentation of damaging avalanche events in the form of newspaper accounts, mine records and photographs begins in 1897 and continues to the present.

In the Camp Bird Mine example, the third stratum for determining avalanche frequency and magnitude, tree-ring analysis (described below) was also used (Burrows and Burrows, 1976). This method verified the the date and extent of the destructive avalanche of 1906, which not only removed a portion of the forest cover, but also destroyed a large mill, a portion of the boarding house and the aerial tramway. Documentation of this event thus involved all three methods: direct observation, historical records and old photographs,and tree-ring analysis.

EVENTS INFERRED FROM TREE RING ANALYSIS

The third, and most complex, stratum of the suggested methods involves the use of tree rings to date undocumented avalanche events and to confirm the date and extent of those events which were indirectly observed. Tree rings can resolve avalanche events only to the nearest year, but have the potential to extend the event record back several hundred years. Excellent detail is usually found in the most recent 100 years of the ring record. Event magnitude information can also be obtained from observing the general condition of the vegetation (Martinelli, 1974). If event dates can be obtained from specimens which are known to be in-situ and if the location of the tree can be accurately mapped, then a spatial analysis of the events can be made (figure 1). In addition, overall damage to the tree can be used to imply some of the flow dynamics (Mears, 1976).

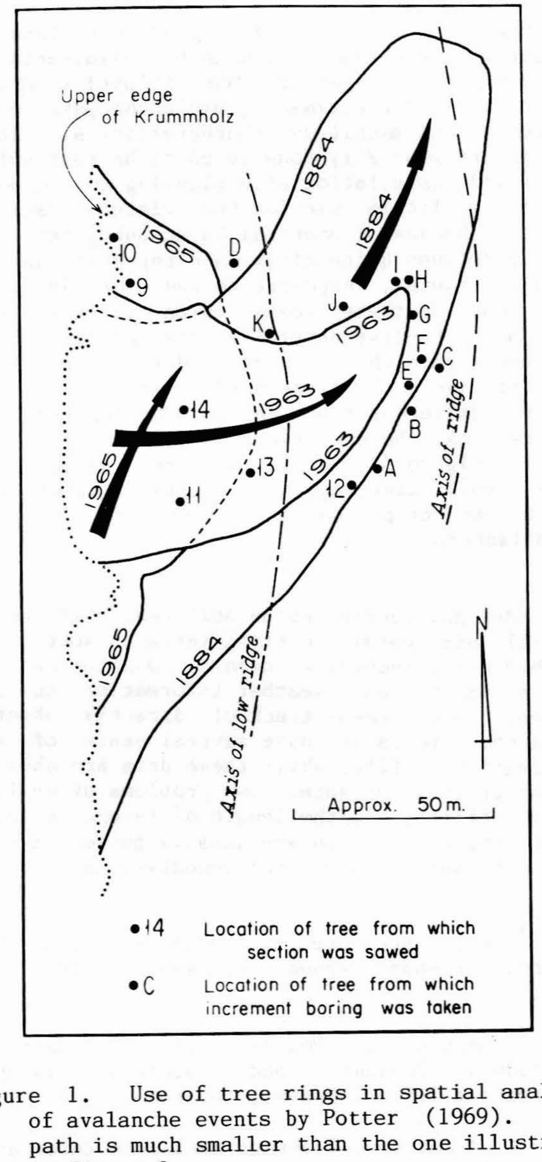

Figure 1. Use of tree rings in spatial analysis of avalanche events by Potter (1969). This path is much smaller than the one illustrated in figure 3.

The application of tree ring dating methods to avalanche event reconstruction is relatively straightforward. The process involves counting the annual growth rings back in time to various "indicators" of past avalanche activity which can be seen in the ring pattern. This type of tree ring work does not necessarily involve complicated statistical evaluations usually associated with dendroclimatology for example. Useful conclusions can be drawn with a minimal amount of data processing, as in Potter's study (1969).

Sampling

Two sample types are commonly used; the "disk" sample, which is a full cross-sectional slab taken from a downed tree and the "core" sample, which is a thin plug which can be taken from either living or downed trees using an "increment borer". Disk samples usually give more information per sample but, because they should be taken from dead trees whenever possible, one must know when the tree in question was killed in order to anchor the chronology. This is not a major problem for the purpose at hand. One can simply observe and tag winter-kills over the course of normal operations and sample these trees during the following summer. The terminal year of downed trees can also be estimated by decay rates. Needles seldom remain green beyond one year and brown needles seldom remain attached the tree beyond two or three years for totally severed trees.

Another complication which is common in some areas of tree ring work is the "missing" or "dropped" ring and its opposite the "double" ring. These complications invalidate the assumption of one growth ring per year and thus introduce errors into the count. It is the experience of the authors and of other workers (Glenn, 1974) that such complications are rare for most species used in avalanche dating of sites in the western U.S. Spruce is a very good species for this kind of work. Fir and pine will also do but they tend to suffer greater amounts of heart rot. Aspen can be used but its "diffuse porous" ring structure becomes increasingly hard to count as the wood drys so special stain techniques are usually applied (Burrows and Burrows, 1976).

Once a tree is selected, surface damage on the upslope exposure can indicate where to remove the specimen. If no damage is evident on the surface then approximate breast height is a good choice. Disk specimens are taken with either a bow saw or light weight chain saw, labeled with a specimen number and orientation arrows (fall line and north). Core samples are usually taken parallel to the fall line on both the upslope and downslope side of the tree or at scar locations. The wood associated with avalanche indicators is difficult to core and the increment borer is easily damaged. Use a gel handsoap to lubricate the borer and make frequent use of special honing stones to keep the cutting edge free from nicks which produce ragged cores. Large plastic drinking straws can be used to transport the cores. Carefully locate the map position of the tree noting whether it is in-situ or transported.

Disk samples can be surfaced for counting by using a belt sander or hand sanding block with successively finer grits of paper. Core samples are glued to a grooved slat of wood and hand sanded or shaved with a sharp blade. Extremely well polished surfaces are possible if several grades of paper are used but generally this detail is not required unless the rings are hard to count under about 10 to 20 X. A dissecting needle will aid in counting and it is customary to code the decadal rings with pin holes (1 hole at each decadal ring, two holes at the 50 yr. ring and 3 holes at the century ring)(Stokes and Smiley, 1968).

A master chronology is needed for some of the methods described below. Several core samples should be taken from undamaged trees growing in the vicinity. Cores are usually taken from opposing sides of each tree at about breast height. In rigorous dendrochronological work, each annual ring width is carefully measured and the whole ring width sequence is de-trended (corrected for declining growth rates) and standardized around a mean ring width index (RWI) of 100 (sometimes 0.100). For purposes here, it may be sufficient to simply compare the ring widths visually and note years of abnormally narrow or wide rings and especially the years of rapid ring width change. A more quantified approach, which is not much more difficult, involves the construction of a "skeleton plot". The horizontal axis is incremented in years and the vertical axis is incremented in some estimate of relative ring width. A vertical line is drawn in proportion to ring width (i.e. a narrower ring yields a longer line). Typically, only the narrow rings are compared and average or wide ring years are left blank. For avalanche work, however, it may be useful to plot the wide rings in a similar fashion extending in the opposite direction from the axis. For a more detailed explanation of this type of plot, see Stokes and Smiley (1968).

Analysis

Avalanche event dating methods make use of various types of damage or other alterations within the ring pattern. These "indicators" fall into one of three broad accuracy classes (table 1). The direct indicator generally dates the exact year of the event. The conditionally direct indicator may display a lag in response but these indicators usually do date the event accurately. Indirect indicators almost always display a lag or give only an approximation of the event timing.

Scars are wounds on the upslope side of the tree resulting from damage to the cambium inflicted by debris carried in the avalanche flow. It is assumed that the ring immediately outside of the scar represents subsequent spring growth. If the damage to the tree is severe, a narrowing of the ring pattern or even missing rings can result. Scars can also result from rockfall, lightning, fire, animals and sun scald (Burrows and Burrows, 1976).

Table 1. Catagories of avalanche indicators based on potential accuracy (Dexter, 1981).

DIRECT	CONDITIONALLY DIRECT	INDIRECT
Scars	Epicormic releases	Re-colonization
Reaction wood	Ring width changes	Decay rates
Terminal year		Absolute age

Trees with apical dominance maintain vertical growth with respect to gravity. The mechanisim for maintaining this vertical growth is manifested in the xylem. In gymnosperms, tilting results in the modification of trachied cells on the downslope side of the tree (with respect to gravity) which appears as a dark red wood called reaction wood. Specifically this type of reaction wood is termed compression wood as it forms in eccentric growth rings which exert preferential compressional forces along the downslope side of the trunk, slowly returning the apical leader to a vertical position. It is assumed that the first indication of reaction wood marks the spring growth following the tilting event. Windthrow, soil creep and snow creep can also induce tilting. Massive windthrow usually does not display the same terrain control as does avalanche flow and windsnap higher up in adjacent trees is often present. Snow and soil creep are harder to deal with, adjacent timber should be inspected for signs of non-avalanche tilting. Branches should not be used for this method as they continually produce reaction wood in response to gravity (Burrows and Burrows, 1976).

Terminal year dating is one case in which the date of the outer ring is not known prior to sampling. In this situation a tree which is believed to have been killed by an avalanche is sampled. The width sequence of the sample is compared ring by ring with the master chronology established beforehand from several nearby undisturbed living trees. A match in the ring width pattern then establishes the terminal year of the unknown specimen and hence the date of the event (Stokes and Smiley, 1968). This method can become complicated and is probably best omitted for our purposes here.

Epicormic growth results when an apically dominant tree loses its main leader. Supressed buds can be released which resume the vertical growth of the tree. Dating the epicormic branch will closely approximate the date of the snapping event (Burrows and Burrows, 1976)). It has been pointed out (Ronco, 1981) that epicormic buds may not release immediately. For this reason epicormic indicators have been treated here as conditionally direct and are assumed to give a minimum age for the event. Work by Dexter (1981) indicates that the actual error due to latent release was zero out of seven epicormic samples used to date a confirmed 1973 event.

Changes in ring width can sometimes be used to date avalanche events, especially if the sample comes from a tree growing at the edge of a trimline or from a tree which has been isolated by avalanches. Relative ring widths are usually controlled by environmental conditions, a fact which has served as the cornerstone of dendrochronology and dendroclimatology. Localized events can influence the ring widths as well. Removal of competition by avalanches, for instance, can improve the growing conditions for a surviving tree which will show increased ring width (Burrows and Burrows, 1976). Conversely, a tree which has been severely damaged may show a decrease in overall ring width for a period of years (Potter, 1969). Changes in ring width which may be attributable to avalanches should be compared to the master chronology established from samples taken from undisturbed sites well away from possible avalanche influence. Also, trees typically grow more rapidly when they are young. Avoid using any "width sensitive" indicator from very young trees or from the centers of older trees.

Absolute age can be used to estimate a minimum recurrence interval for large events which penetrate previously undisturbed timber. When applying this method the core should reach the center of the tree. Standard cores obtained for this purpose are taken at breast height but many avalanche workers core at the base of the tree. The maximum ring counts can then be used as the minimum recurrence interval value for the event.

Closely associated with absolute age is the colonization age method. Here a full depth event has removed all sizable trees from a given area. Subsequent colonization will produce a stand of even sized individuals from which several cores can be taken. Some small individuals may have survived the event and will yield dates which are too old while other individuals may not have germinated until several years after the event so this method is considered indirect.

Decay rates can be used to give various levels of estimates. The presence or absence of green needles, brown needles, bark, branches or the degree of wood rot etc. may be correlated to known events in a specific area (e.g. old logging operations, road construction etc.) and applied to debris within the avalanche path to give rough estimates when other more precise methods are not feasible (Burrows and Burrows, 1976).

Reduction of the Data

The simplest approach to analyzing tree ring data is to plot it as a type of time - series histogram with sample number on the vertical axis and year on the horizontal axis. A one-letter coding scheme is used to identify the type of damage from a given sample for a given year (figure 2). After a few samples have been logged the event years will become apparent. Some workers have suggested that one or two of the damage types are more reliable as avalanche indicators than the others. While this may be true, the present authors feel the strongest confirmation of avalanche activity comes from several indicator types converging on one date. Fire may produce a scar but it is highly unlikely that fire would yield an epicormic release of the same age. It is thus best to assume that we are looking at an assemblage of damage types which is characteristic of avalanche activity. The more we must rely on just one type of indicator the greater the chance that we may be dating some other kind of event. As illustrated in figure 2, a number of questionable indicators may also occur. Work by Dexter (1981) suggested between 5 and 10 % of the indicators from avalanche paths in his area may have been produced by non-avalanche causes. This figure assumes the path of interest is free of major complicating events such as fire, massive windthrow etc. Well documented "control events" should be used to evaluate the accuracy of tree-ring techniques wherever possible.

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Sample No.

001   +    R               S       R     W
002   +    R               R             S
003   +             R      R             R
004   +    E               W             S
005   +                    S              E
006   +                    S      S      R
007   +                    E             R
008   +    S               S             S
009   +                      C
010   +                  C
      +----+----+----+----+----+----+----+----+

      1    1    1    1    1    1    1    1    1
      9    9    9    9    9    9    9    9    9
      0    0    1    1    2    2    3    3    4
      0    5    0    5    0    5    0    5    0

                     Year
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Figure 2. An indicator histogram for a hypothetical path where R = reaction wood, S = scar, W = width change, E = epicormic, and C = colonization. Note the late biologic response and random nature of some of the indicators.

COMPILING AND PRESENTING THE RESULTS

Tables of data are hard to assimilate at best and at worst will not be used at all. To prevent this from happening, the authors suggest maintaining the combined frequency / magnitude information in map or atlas format. The format could include the following:

1) A general hazard map of the area (1:24,000 scale).

2) Detailed path maps with identifiable events outlined (1:10,000 to 1:2,000).

3) A path data sheet.

4) A photo of the path.

Generally the 1:24,000 scale U.S.G.S. topo sheets are suitable only for general path outlines. If time and enthusiasm permit, a comprehensive avalanche map for all routes in the permit area could be constructed on 1:24,000 base maps along the lines of the various atlases prepared for the San Juans (Armstrong and Armstrong, 1977; Miller, et. al., 1976). For paths of special interest, greater detail will be required. Scales of 1:10,000 to about 1:2,000 will be much more useful as individual path maps (figure 3). The simplest way to obtain maps at such scales is to photographically enlarge U.S.G.S. topo sheets using ordinary 35 mm cameras fitted with tubes, bellows or close-up lenses. Kodalith film may be used to obtain sharp, high-contrast negatives from which base maps of varying scale can be printed and subsequently photo-copied. Always include a graphic scale with each shot as the representative fraction scale can easily be rendered useless by careless enlarging or reduction. This method of detail mapping is <u>not recommended</u> for siting permanent facilities (Mears, 1976) as it simply magnifies the error of the original map (U.S.G.S. maps are usually better than +/- 0.5 contour interval in the vertical and +/- 0.02 inch map distance in the horizontal). Considering the cost/benefit ratio of custom mapping services, the enlargement method becomes more attractive when the primary use is only for route analysis over large areas.

CONCLUSIONS

Via the application of inexpensive research and graphics methods, the ski touring service operators who are forced to deal with the avalanche hazard may gain a better understanding of the problem as it applies directly to their operation. Immediate benefits include:

1) Providing the manager with information useful in long term planning.

2) Providing the guide with quickly assimilated information about the potential extent of hazards along routes.

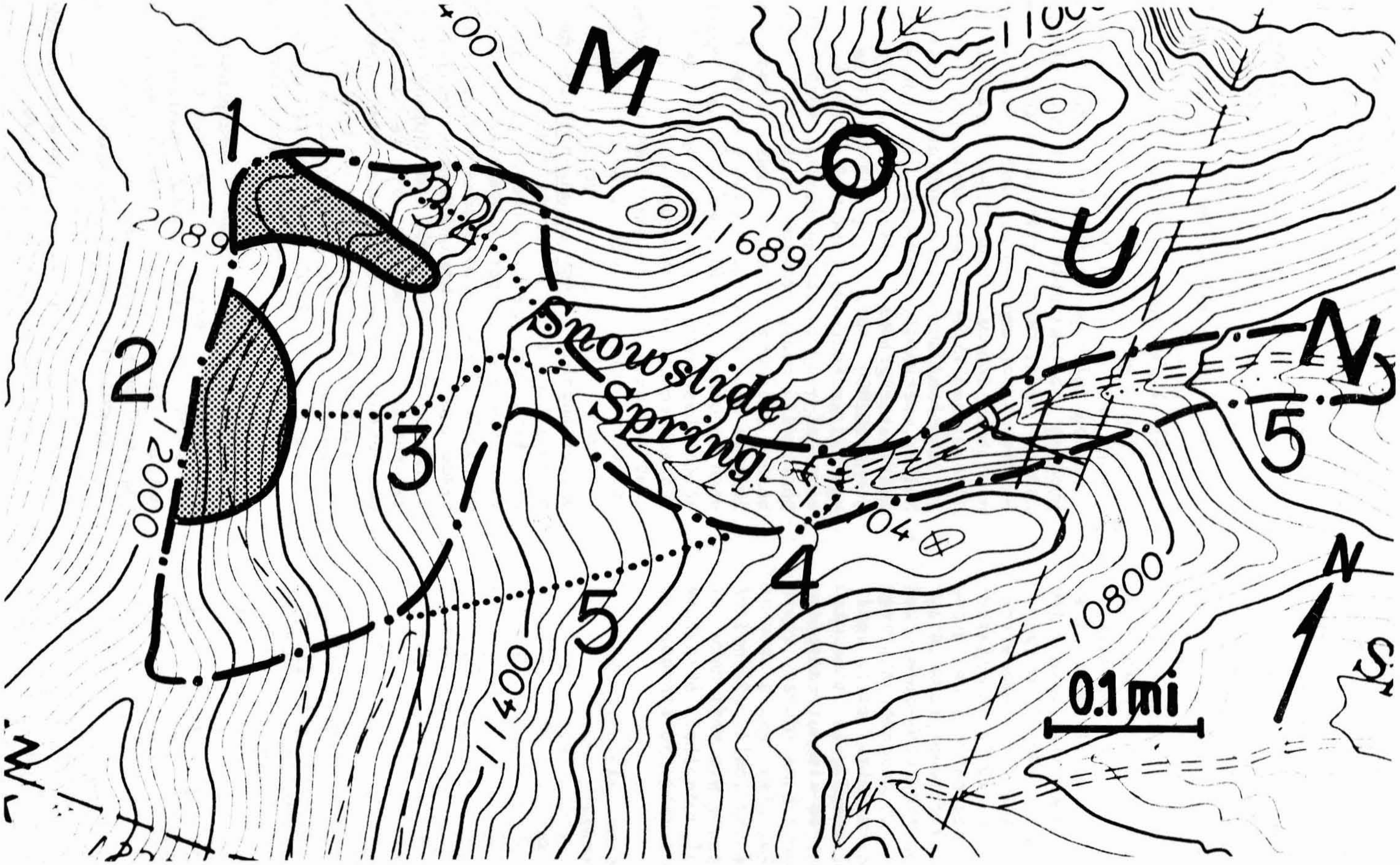

Figure 3. SNOWSLIDE SPRINGS CANYON EVENT MAP

(1) Northern gully - very frequent, runs under almost any load over 20 mm. water / day.
(2) Main Bowl - frequent, runs at about 30 - 40 mm. water / day with westerly winds.
(3) 1981 Northern gullies and half of main bowl ran 1-2 meters. Crown fracture extended into S. half of main bowl but did not release (observed on tour, 1/8/81).
(4) 1973 event reaches at least to the springs (based on rings).
(5) 1932 event takes out most trees on lower bowl bench (some were over 150 yrs. old) and runs full extent of path (based on rings).

3) Providing rescue personnel with detailed accident site information.

4) Providing a statement, along with the rescue plan, of the operations commitment to client safety.

The potential user of these procedures should examine several of the references listed to become more familiar with the techniques and to see examples of conclusions reached with such methods. The publications listed with an "*" indicate technique-oriented references. The others generally are application studies.

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