CHALLENGES TO AN AVALANCHE CENTER IN A TIME OF SEASONAL CLIMATE VARIABILITY: A CASE STUDY

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Abstract: Kachina Peaks (San Francisco Peaks) rising to nearly 13,000 ft. in northern Arizona represent an exception to the commonly held perception that snow avalanches are unimportant in the arid Southwest. On this prominent sky island, obvious, and often sizable, open swaths intrude mature stands of mixed conifers and aspens illustrating the power of sliding snow. Dramatic increases in winter backcountry recreation, combined with users that are often poorly informed of hazards, constitute the ingredients for disaster. This became evident during the 1994-1995 season when a very large hard slab event claimed Arizona's first avalanche victim. The 2004-2005 winter season, with its near record-breaking snowfall, produced numerous significant natural avalanche cycles. During these cycles, several close calls occurred as a result of skier and snowboarder triggered slides. These events prompted the rebirth of an old idea with a new name, format and momentum, the Kachina Peaks Avalanche Center, Inc. Then, as fast as impetus was gained, it became threatened by a near-record drought during the subsequent winter. The 2005-2006 season was marked largely by bare slopes with the first significant snowstorm delayed until March 11th, providing a vivid reminder of continued erratic seasonal weather that has historically besieged the region. The questions become: how can an avalanche center meet public needs under such conditions? How can we adapt to this level of irregularity? How can we provide information and training during times of need, yet sustain ourselves in dormancy during periods of droughts? This poster presentation and companion paper will characterize the history and nature of our problem, and attempt to further the discussion on strategies for meeting future challenges. Perhaps lessons learned in Arizona will have application in other regions as climate change increases seasonal variability on a broader scale.

Keywords: snow, avalanche forecasting, San Francisco Peaks, KPAC, backcountry skiing

1. INTRODUCTION

1.1 Geographical setting

Often visible from over 100 miles in any direction, San Francisco Peaks dominates the skyline in the southwest quadrant of the Colorado Plateau. Located within ten miles of Flagstaff; "The Peaks", as this dormant stratovolcano is commonly referred, is Arizona's highest feature, and arguably the only alpine mountain. Renowned Biologist, C. Hart Merriam, who spent considerable time exploring Arizona's high country in the 1880s, recognized this fact in his characterization of its highest reaches as "arctic/alpine" in his life zone theory, which correlated altitude and latitude with respect to climate and resulting plant communities.

This mountain complex rises from a base elevation of 2256m to a high point of 3854m. The approximate land area encompasses 105 sq. kilometers, which are managed by the Coconino National Forest. Most of the land at higher elevations is part of the Kachina Peaks Wilderness. The general

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topography of the mountain is thought to have resulted from the collapse of a caldera ring on what was previously a single large composite volcano. During the half million years since this occurrence, the subsiding area eroded into an interior valley, now known as “the Inner Basin”. Today, this feature is encircled from southeast to north by six summits: Doyle Peak 3494m, Fremont Peak 3649m, Agassiz Peak 3766m, Humphrey’s Peak 3854m, Aubineau Peak 3607m and Rees Peak 3497m. These peaks are joined by a single high ridgeline (with shallow intervening saddles and minor peaklets) forming an elongated horseshoe shaped rim around the Inner Basin. Two pronounced craggy spur ridges extend from the main ridge into this basin, the most notable of which in named Core Ridge. This ridge was in part a medial moraine from cirque and valley glaciation that adorned the mountain during Pleistocene times. The broad Inner Basin terminates at beautiful Locket Meadow (2597m) at the base of Sugarloaf Mountain (2830m) to the northeast. Ridges radiating exterior to the main rim are less pronounced and descend with relatively even gradient. Slope steepness in the upper basins is variable, but generally between angles of 28 and 38 degrees, with steeper chutes on several of the mountain faces, and on the flanks of the interior spur ridges. Craggy outcrops of moderate height give evidence of successive eruptions. These appear in the upper slopes, and along ridge crests. Poorly sorted, weakly consolidated sediments blanket intermediate and lower slopes surfaces (Pewe and Updike 1976).

Drainages are typically shallow and radiate from the main ridgeline. The exception is the interior valley (Inner Basin), which was subjected to broad gouging and rounding by glaciers. Vegetation distribution is variable by aspect, elevation and circumstance, with temperature, wind exposure, moisture availability, past wild fires and avalanches providing the primary controls. Most areas above 3500m exceed the tree limit, except for sparse islands of prostrate krummholz.

1.2 Weather and climate

Weather records for Flagstaff, Arizona document over 100 years. The Arizona Snow Bowl Resort maintains records of basic meteorological data dating back to 1980. In 1997 a SnoTel site was installed in Snowslide Canyon at 2965 m. This site provides an array of weather instrumentation allowing accessible and reliable near real-time data retrieval from the internet.

Winter storms are northern forming synoptic scale short wave troughs that move across Arizona by one of several identified storm tracks (Dexter, 1981). The configuration of long wave high-pressure ridges (Rossby waves) and the semi permanent Pacific anticline largely determine jet stream path and therefore storm track preference. During the fall a long wave crest is often located over western United States and atmospheric subsidence dominates Arizona, giving us clear weather. A seasonal shift in the residential position of the high pressure ridge to the eastern Pacific Ocean alters prevailing circulation, jet stream location and ultimately influences the storm tracks taken by short wave cyclonic storms in their migration west to east across the continent.

Variability in northern Arizona’s winter weather results from persistence, delays in shift and configuration of high pressure. If high pressure hangs over the West, the jet stream stays north of Arizona, diverting short wave cyclones from the region. The absence of high pressure shielding opens up the storm door allowing their southward migration. Generally, the track followed by a given storm determines precipitation quantity, snow density and temperatures. Storms that track across the Great Basin are colder and dryer, accounting for approximately 10% of northern Arizona’s winter precipitation (Staudenmaier et al., 2005). Those that follow the Pacific coast south and come onshore in southern California are our biggest events since they accumulate additional moisture, and encounter fewer mountain barriers en route. These storms account for 80% of our most productive storms – those with snowfall of over 50 cm. Some storms track south of California before moving onshore near the Mexico border. If these cross northern Arizona they deposit variable quantities of dense, wet snow and can result in high elevation rain. Storms following this track have accounted for some dramatic avalanches due to rapid loading (Dexter, 1981).

In general, El Niño years favor higher winter precipitation in the Southwest and La Niña years is associated with dryer conditions. During El Niño southern oscillation positive

(ENSO+) winters, the southern jet stream is energized causing warm moist air to become added to the mix. Table 1 illustrates a clear correlation between El Niño years and high seasonal snowfall, and La Niña years with drought at the Snow Bowl resort. Ongoing research on interactions of El Niño southern oscillation with the Pacific decadal oscillation may prove fruitful in helping to explain some of our more mysterious feasts and famines.

As a prominent and relatively isolated mountain feature, San Francisco Peaks is an active player in terrain-forced flow and orographic lifting. The result is enhanced precipitation and lots of wind. A clear example is the seasonal snowfall on the San Francisco Peaks, which averages 239 % of that recorded by the city of Flagstaff. The average snowfall per year at the Arizona Snow Bowl Resort is 660 centimeters. Storm winds typically come from the south and southwest and shift to the north and northeast as the storm passes. Winds maximums in excess of 25 m/s are common above 3350 m. Wind dynamics significantly affect snow accumulation patterns, loading lee slopes on north, northeast and east aspects during precipitation, and to a lesser degree, south, southwest and west facing slopes during post storm wind events (Dexter, 1981). Rapid and substantial snowpack loss from terrain above tree limit can be attributed to evapo-sublimation, particularly during high wind events.

Flat faced ridge-top cornicing occurs, but classically overhanging cornices are rare. This may be attributed to the frequency at which ridge top winds exceed optimal rates for cornice development, >25 m/s (McClung and Schaerer, 93). Wind riming at high elevation on windward aspects is a San Francisco Peaks hallmark, occurring with great regularity, particularly during warmer storms.

The interplay of continentality, latitude, and altitude creates an interesting interplay with regard to temperature ranges and extremes. Extremely cold conditions are rare, but can occur, usually after the passing of a storm or when frigid continental Polar (cP) air pools into the region. The record low for the city of Flagstaff is -37.2 °C. Temperature readings of below -18 °C are common at high elevations on the Peaks, as well as, diurnal variations that exceed 23 °Celsius. However, during periods of high pressure, temperature inversions often result in warmer morning temperatures on the Peaks than in town. Storm temperatures, snowfall, and snow densities vary radically as discussed earlier. Our most productive years tend to have relatively warm temperatures, big storms, and higher density snow, while during average years; storms tend to have cooler temperatures with modest snowfall, and lower density snow.

Table 1. Seasonal snowfall totals at Snow Bowl Ski Resort compared to ENSO (+/-) conditions

Season	Total snowfall (cm)	Above/below avg. (cm)*	ENSO (+/-)
1988-89	431	- 229	La Niña
1989-90	610	- 50	Normal
1990-91	592	- 68	Normal
1991-92	914	+ 254	El Niño
1992-93	1168	+ 508	El Niño
1993-94	559	- 101	Normal
1994-95	658	- 2	El Niño
1995-96	287	- 373	La Niña
1996-97	686	+ 26	Normal
1997-98	838	+ 178	El Niño
1998-99	381	- 279	La Niña
1999-00	457	- 203	La Niña
2000-01	495	- 165	Normal
2001-02	221	- 439	Normal
2002-03	523	- 137	El Niño
2003-04	411	- 249	Normal
2004-05	1168	+ 508	El Niño
2005-06	338	- 322	La Niña

* Based on average snowfall of 660 cm/year

1.3 Snow climate and metamorphism

Categorizing snow climate on San Francisco Peaks is difficult for reasons of variability already discussed. During relatively dry years it responds similarly to a continental snowpack, and during wet years it is comparable to intermountain conditions. Radiation input during any year is a dominant factor due to latitude and average high percentage of days with clear sky. Ed LaChapelle identified this condition by writing "The combination of high altitude, low latitude, and predominantly continental climate produces what we now define as a radiation snow climate" (Dexter, 1981). This is illustrated by the fact that the Peaks on average display 12 clear days in January as opposed to 2-9 days for other mountains in the West (Dexter, 1981).

Radiation intensity on sunny aspects (SE, S and SW) generally produces melt-freeze crusts from diurnal temperature variation during inter-storm periods (Dexter, 1981). Fine faceted grains are often found sandwiched with these crusts produced by melt layer recrystallization. Although natural slides on these surfaces are rare, observers have reported unstable snowpack condition on these warm aspects (Dexter, 1981).

On years of shallow snowpack, cold aspects (N, NE and NW) demonstrate deep-seated temperature gradients and resulting basal faceting. Long dry spells can result in faceting of more than 50% of moderately thick (<1.5 m) snowpack via kinetic metamorphism. At high elevation, early season snow is frequently completely converted to facets before being subsequently buried as new storms arrive.

Except during drought years, weakening temperature gradient as the snowpack increases thickness curbs kinetic processes deep in the snowpack. After the end of January (and earlier on moist years), weaknesses are typically found in the upper snowpack. These are often simply poor interface bonds between old snow and new wind-loaded snow. Persistent graupel layers in the upper snowpack and other rimed forms have been identified as weak layers (Dexter, 1981). Near surface facets have also been linked with weak layer formation. Surface hoar development in the high starting zones is rare, or quickly obliterated by winds before being buried. Buried surface hoar may play a greater role in creating instability on, or below tree limit pockets in the Inner Basin.

A wet spring avalanche cycle, as well as rain on snow avalanching has been observed (Dexter, 1981). However, wet slides occur with surprising infrequency even on south aspects during warm weather. This may be a function of the permeable bed surface, often composed of cinders, which allow the melt water to infiltrate rather than flow. High moisture losses due to evapo-sublimation could also be a factor.

Research on avalanche reoccurrences based on dendrochronology of avalanche events determined that at least 15 avalanches occur annually; and this is probably an under estimation since high frequency channel avalanches are not always reflected in vegetation disturbance (Dexter, 1981). Most natural avalanches occur before the end of January when rapid loading on weakened (faceted) early season snow is the scenario for release (Dexter 1981). The spring wet snow cycle is usually delayed until late May and early June, with a period of relative quiescence during April and early May. Inner Basin slides display greater event disturbance similarity with each other than with paths on the outside portion of the mountain complex (Dexter 1981).

2. DISCUSSION

2.1 Patterns of winter recreational use

Up until 1960 skiing in Northern Arizona was pretty much synonymous with the Snowbowl Ski Resort. Then in 1960, "state of the art" wooden cross-country skis were brought to Flagstaff from Gunnison, Colorado by university professor Roger Thweatt. His enthusiasm for the freedom of travel outside of the busy and costly ski resorts had a certain appeal. Others took notice and the seed of backcountry recreation was planted (Bremner, 1987). By the 1970's, Northern Arizona joined the rapid growth in popularity of cross-country and alpine skiing and other adventure sports that were taking place nationwide. Soon after, the Alpineer shop opened in Flagstaff, as the first full service climbing and Nordic skiing equipment store, and in subsequent years provided guiding and backcountry skiing instruction. In 1973, the first Arizona Citizen's Cup Cross-country ski race was held (Bremner, 1987). Winter recreation grew to the extent that by 1980, the San Francisco Mountain Avalanche Project in combination with Coconino National Forest created an avalanche advisory warning plan. In 1987, Dougald Bremner's guidebook Ski Touring Arizona: Plateaus of Snow was published. This was the first guide to backcountry skiing in Arizona, which went beyond covering skiing on San Francisco Peaks, however virtually all the "most difficult" tours described are in the Kachina Peak Wilderness. The publication represented a coming of age in Arizona backcountry skiing. The book highlighted avalanche hazards on San Francisco Peaks and gave useful information on identifying signs of instability, however recommendations did not include carrying transceivers, illustrating prevailing practices in Arizona in 1987.

2.2 History of avalanche awareness

In 1978, Dr. Lee Dexter and Art Pundt created a non-profit research organization called the San Francisco Peaks Avalanche Project (SFMAP). It was an outgrowth of their interest in monitoring and researching avalanches in the area. Soon, others of similar interests and backgrounds joined their ranks, including Ken Walters, Bruce Grubbs and Richard Hughes (U.S.F.S. Snow Ranger). Dr. Chuck Avery, a professor in the Forestry Department at Northern Arizona University (NAU), and an avalanche expert, added his guidance and support. In addition to research, this group conducted avalanche clinics for the public. Many of today's well-informed local winter recreational skiers, senior Snow Bowl ski patrol members, and board members of the newly formed KPAC got their initial avalanche training through these clinics back in the late 1970's.

The SFMAP personnel analyzed weather data from the National Weather Service and from several local stations (including their own remote weather station on Fremont Peak), and collected snowpack data from the project's study plot in the Inner Basin and from test pits. The amalgamation of this information was then used to develop forecasts of avalanche activity. If warranted, contact was made with a Forest Service representative who would ultimately issue an avalanche advisory. Unfortunately, a lack of financial commitment to this work proved the project unsustainable.

Remarkably, to date only one recorded avalanche fatality has occurred on the San Francisco Peaks. Although the circumstances were relatively unusual, it was understandable given the snowpack and weather conditions leading up to it. The accident took place January of 1995. It involved two NAU students, who were snowboarding out of bounds from the Arizona Snow Bowl Ski Resort on the south face of Agassiz Peak, in a slide path named Monte Vista. One of the individuals triggered the slide and alerted his companion before being swept away. His partner was able to find shelter behind a tree. Although the victim was not buried, he was critically injured and died of massive internal injuries. Both were accomplished backcountry snowboarders, and somewhat knowledgeable of avalanche hazards, but were under the impression that avalanches only occurred in powder snow conditions, not in the bullet-proof hard slab they had encountered. The weather and snowpack condition leading up to the accident is noteworthy. It had not snowed in several days, but strong continuous winds had blown out of the north building a thick slab on the slope that is typically windward during storms.

Documenting past natural avalanches, near misses, skier triggered slides, and minor injuries from avalanches since the SFMAP ended has proven impractical. There are many stories, but most of these are second or third hand, and no individual or group has taken the responsibility of accurate record keeping. Avalanches do occur in Arizona, but probably not as frequently as in the neighboring mountains to the north in Utah and Colorado. As a result, complacency and lack of awareness play a role in human behavior on the San Francisco Peaks.

2.3 The emergence of KPAC

The winter of 2004-2005 was exceptional, the ski resort opened for business on November 26 with the sixth deepest snowpack in the world (a settled base of 170 cm at 3292 m elevation). It maintained its position in the top dozen throughout the season. This seemed astonishing, since this particular season followed a string of drought years that had started to feel like the new norm.

Not only were ski area attendance records broken that season, but backcountry, and out of bounds skiers and snowboarders showed up in surprising numbers. The number of backcountry permits issued more than doubled any previous year. This was a new phenomenon in Arizona where backcountry skiing was considered a sport for those who wanted to get away form the crowds. Many of the prominent slide paths ran at various times during the winter including Dunnam Canyon, Telemark, and Snowslide. Crossfire ran so big (class 5) it took out the Aubineau Canyon trail and redefined the path by removing a substantial amount of old growth timber. A number of skier and snowboarder triggered slides were reported, and there were unsubstantiated stories of more. An avalanche awareness clinic at one of the local sports shops (offered annually by the ski patrol) attracted a record of over 50 participants; and the corresponding field session attracted people who had not even attended the clinic. People were requesting more information and more educational opportunities. The need to respond by reinvigorating an old idea with a revised approach became apparent. Kachina Peak Avalanche Center, Inc. was born on Saint Patrick's Day 2005.

2.4 Winter backcountry user survey

Dr. Kevin Tatsugawa developed a survey instrument in an effort to gain insight into user profiles and avalanche awareness/training. This was available at local (Flagstaff) outdoor sports shops and on the Kachina Peaks website. Since filling out the survey was completely voluntary and a majority of the respondents accessed the survey form on our website, it should be recognized that this group is by nature filtered and therefore not necessarily representative backcountry users. A total of 50 individuals completed the survey, 86% of whom did so from the website. Even though the sample is small, it was useful in informing us about out target audience. The survey questions pertained to: respondent's age, gender, frequency of backcountry use, mode of travel, avalanche training, years of experience, safety equipment regularly carried, and most frequent backcountry area accessed.

All except two respondents were male, with 70% in the 20 to 39-age range. Forty percent of frequent visitors fell in the 20-29 year old group, while 42% of the infrequent visitors in the 30 to 39-age bracket. In terms of avalanche training (figure 1), the largest group (38%) had been introduced to avalanche hazards in a group avalanche awareness workshop. The second largest group (28%) had no avalanche training at all. The total of those with level 1, level 2 and advanced training was surprisingly high with a combined total of 34 percent. This was surprising since (to our knowledge) no level 1 or 2 courses have ever been taught to the general public in Arizona. As expected, a majority of backcountry users access the backcountry from the Snow Bowl to the tune of at least 60%, compared to the second most accessed location, Inner Basin at 10%. Twenty percent of respondents listed "other" as a preferred access location, but 8% of the localities described are most easily accessed through either the Snow Bowl or Inner Basin. Just over half (54%) of respondents carry avalanche transceivers when they go backcountry touring (figure 2). The frequency of visits was highest at a few days per month, but followed closely by those who visited twice or three times per week (figure 3). Skiers dominated the group of respondent (figure 4). There were no snowmobile users who took the survey.

When compared with a survey developed by the Colorado Avalanche Information Center (accessed through SurveyMonkey.com), our sample was younger, with a higher percentage of males who have less backcountry experience and significantly less formal avalanche training. Also, fewer of them carry avalanche safety equipment, particularly beacons. In Colorado 87.7% carry them compared to 54% of Arizona respondents.

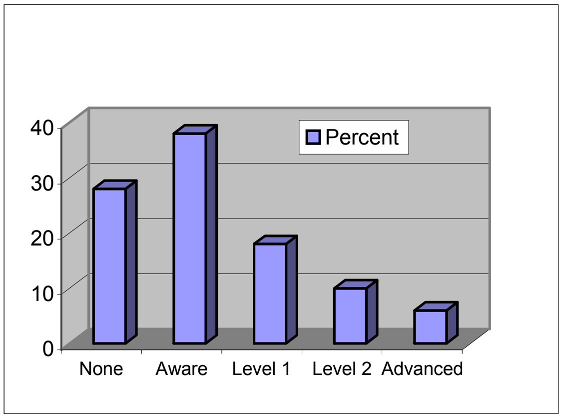

Figure 1: Avalanche training

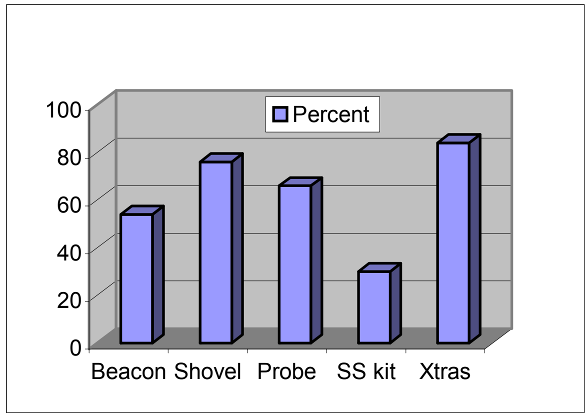

Figure 2: Safety equipment carried

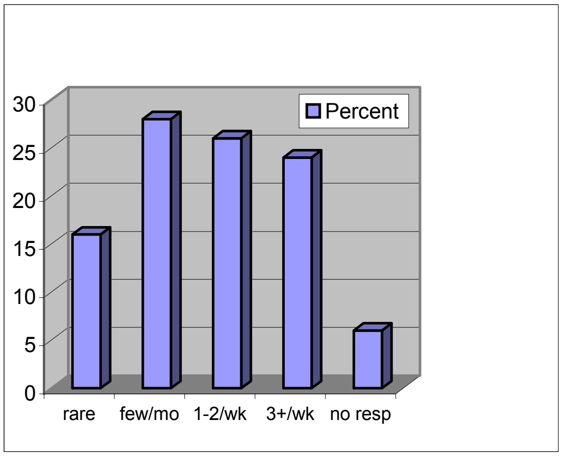

Figure 3: Frequency of visit

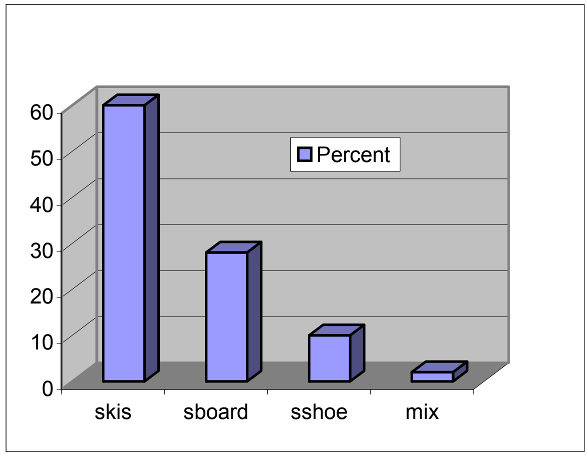

Figure 4: Travel mode

3. CONCLUSIONS

3.1 Strategies for Success

The discussion on how to sustain and hopefully develop Kachina Peaks Avalanche Center, Inc. is ongoing. Our struggles are responding to erratic winter seasons and associated levels of backcountry use, combined with financial constraints. Up to this point, our thrust has been two pronged, to educate and share field observations through our website **www.kachinapeaks.org**

In 2005-06 we scheduled four free avalanche awareness clinics at local sport shops. The first was well attended, and the second less so due to the dry season, and the rest were cancelled. Also during this season we attempted to run a level 1 avalanche course (using AAA curriculum) through a memorandum of understanding with Prescott College. This was cancelled due to no snow. Sharing snowpack stability observations is the main objective of the website; however, it has been developed as an educational and fundraising tool as well. We have been impressed with the website activity and look forward to expanding its utility in a number of ways.

Our opportunities have appeared through local support. Flagstaff residents and businesses welcomed us, which was very encouraging. Backcountry enthusiasts have also expressed their support, not only locally, but also from the region at large (Prescott, Phoenix and Tucson). Since Arizona and particularly the ‘Valley of the Sun’ (Phoenix Basin) is the fastest growing area nationwide, we believe there is a great deal of future need and potential for our vision.

We have a committed Board of Directors and a group of friends who are long-term residents of the area and highly dedicated to our goals. This is critical if we are to keep the dream alive

Ideally, we aspire to forecast, or at least issue avalanche hazard warnings. Doing so requires affiliation with a government agency for liability reasons. Some of our discussions have involved creating an association with the Coconino National Forest that avoids impacting their operating budget. Although this idea has potential, it needs to be fully considered, since such an arrangement would put a great deal of pressure on our private fundraising efforts. At the moment we are considering the following initiatives:

1. Train high-caliber volunteers, and avalanche instructors who can work with us on a contractual basis.

2. Further develop relationships with local, regional, and national corporations to enhance our support base.

3. Investigate opportunities for grants and fellowships.

4. Utilize innovative and low cost means of getting our message out (internet, email).

5. Develop a working relationship with the Coconino National Forest to mutually assist each other in improving snow safety using creative low cost strategies.

6. Create course schedules (and other activities) that can be easily cancelled due to drought, with tuition refunds fairly administered.

7. Maintain a core of directors committed and engaged even through drought stricken seasons.

8. Avoid commitments to full-time employees by endorsing contracts and piecework at reasonable pay rates.

9. Retain and manage the website during drought years by providing clear information on our dormant status, while promoting future possibilities and opportunities.

10. Develop relationships with government agencies that will allow the potential for forecasting through an official office; but attempt to cover salaries or contract work through grants and private contributions

11. Keep a sense of humor throughout all of it

4. ACKNOWLEDGEMENTS

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