Weather Instrumentation

for Avalanche & Snow Safety Programs

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Supported by The National Avalanche Center

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Special Note: **This document is a work in progress.** New sections are scheduled to be added in the future, and the overall presentation format may change as well. Also, due to rapid changes in weather and information technology, and the inclusion of new field information, frequently updated pages and data are likely. Please check for new revisions.
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Foreword

My outstanding mentor and recently passed faculty advisor at the University of Washington, Dr. Ed LaChapelle, had just edited the *USFS Snow Safety Guide #2* when I became one of his graduate students. One thing he impressed upon me was the need for the recording and availability of high quality data in the pursuit of any scientific endeavor. From the UW research into alternate methods of avalanche control as a graduate student and research assistant to my current avocation of avalanche and weather forecasting this requirement for accurate and reliable data has been manifested time and time again. In fact, much of my time nowadays is spent in installing, maintaining and troubleshooting remote weather systems, including sensors, land lines, and data transmission methods. Fortunately in the learning process it has been my good fortune to have many mentors and colleagues who have patiently listened to stories about a boggling array of data problems and then suggested either plausible explanations or a variety of excellent and innovative solutions or workarounds to such dilemmas. In particular, I am indebted to Phil Taylor of Taylor Scientific, Dan Judd of Judd Communications, and Austin McCue of Campbell Scientific, who have collectively spent an abundance of time and effort with me on behalf of the greater good of instrumentation knowledge. In formative years I have also had the pleasure of working with Rich Marriott and Dr. Sue Ferguson and current NWAC forecasters Garth Ferber and Kenny Kramer, who provided not only thoughtful discussions about unexplained weather sensor phenomena but also a healthy amount of humor—a necessary prerequisite when investigating potentially frustrating instrumentation problems. Thanks also to all the good technicians at Campbell Scientific Inc, as well as more local avalanche professionals Steve Breyfogel, Mike Stanford, Rob Gibson and John Stimberis of the Washington State Department of Transportation for their insights into the often mystical world of working weather stations.

1) Introduction

The USFS Snow Safety Guide #2, published in 1970 by the USDA Wasatch National Forest and edited by Dr. E.R. LaChapelle, was long considered an excellent resource for describing instrument specifications for standards of snow and avalanche observations in class A[1] ski areas. However, the state of the art in weather instrumentation is constantly evolving, and since the early 70's many notable advances have taken place in the measurement, transmission, display and access of snow and weather data for use in avalanche work. During this time the data needs and expectations of ski areas, highways, railways, weather and avalanche forecasters, and others tasked with public safety in the wintertime have increased significantly. Whether for transportation corridor maintenance, ski lift safety, forecasting, hydrological, or avalanche control programs—the necessity for more accurate and more reliable snow and weather instrumentation sites in an expanding variety of remote locations is taken for granted. Enhanced availability and access of high quality snow and weather data has also become a de facto requirement for most wintertime maintenance and avalanche mitigation programs. Access to such real-time weather information also appears to be an increasingly important commodity that helps maximize safe recreational use of the mountain environment.

It is hoped that this updated instrumentation guide will help meet some of the informational needs of this great variety of mountain data users. Where appropriate, past and proven weather equipment is described although most of the guide concentrates on the present and the future. While every attempt has been made to be as thorough as possible in describing the prevalent types of proven weather instrumentation systems currently in use by snow safety personnel in North America, some omissions and errors will undoubtedly

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[1] Class A ski areas on National Forest lands have extensive or frequent avalanche hazards that normally require extensive avalanche danger mitigation. Class B areas have few or infrequent avalanche hazards which do not warrant a continuous snow safety program, and Class C areas are free of avalanche hazard.

occur. These will be addressed and updates released as more information becomes available. Please address concerns, recommendations, additional data, etc. to either the National Avalanche Center (dabromeit@fs.fed.us) or the Northwest Weather and Avalanche Center (mark.moore@noaa.gov). Owing to its electronic format, such updated information can be quickly made available.
As mentioned above, technology is rapidly advancing and weather equipment is changing with it. Significant research efforts are being devoted by both governmental and private concerns toward development of improved sensors for measuring a wide variety of atmospheric properties. Agencies like the FAA (Federal Aviation Administration), NCAR (National Center for Atmospheric Research) and others are currently testing sensors for both precipitation and wind measurements. As the results of these tests become available, and as new products are proven in mountain environments, these will be included in updates of this guide. For now, some of the products visible "just over the horizon" or as prototypes will be mentioned where appropriate.

Finally, in the highly competitive realm of mountain weather sensors and data systems, a cautionary note is definitely in order. Potential users of mountain weather instrumentation systems are urged to very carefully read manufacturer's equipment specifications and with an open mind. While operational claims by manufacturers are as accurate as applicable laboratory or field testing allow, it has been the woeful experience of many dedicated mountain weather professionals that instrumentation claims may not be realistic if the product has not been adequately tested in a specific mountain regime. Always check around before you leap into the sensor graveyard—it is best to consult with experienced users of particular pieces of equipment and get their feedback before unknowingly jumping into what may be a major purchase of inappropriate or inoperative equipment that could eat up most of your annual weather equipment budget. Ask the manufacturer for references of satisfied users in your particular climate and for applications under conditions that you might expect. Although certain sensors are designed to operate in a variety of harsh weather conditions, some sensors may be more suited for use in particular climate regimes and less harsh or different conditions (maritime versus intermountain versus continental and vice versa). Such design characteristics may limit their usefulness in a extremely harsh or a differing environment (e.g., more or less riming, more or less snowfall, higher or lower humidities). Such sensor limitations or idiosyncrasies are noted wherever applicable, along with strengths of certain sensors or data systems. Hence while this publication should not be construed as an instrumentation manual per se, hopefully it can serve as a guide to the application, troubleshooting and maintenance of the ever increasing array of weather sensors, data loggers, transmission methods and displays available to avalanche and mountain weather professionals. To help in individual assessment of sensors and data application, a comprehensive list of links and addresses for many weather and snow equipment manufacturers is given in the Appendices.

Please note that any errors or omissions are the author's, and the opinions expressed are those of the author. Users should not construe the inclusion of any particular instrumentation as an endorsement of such products by the Forest Service.

2) Manual Study Plots

During the past few years, even the most technology challenged and down-to-earth avalanche professional has begun to allow the gradual incursion of high technology and increased computer power into his or her snow safety program. Yet despite considerable recent advances in a wide variety of remote weather and snowpack sensing equipment, some standard manual observations are still needed and are often critical—either as a check on automated sensor data or to provide unique snowpack and/or weather info that may be difficult if not impossible to obtain with sensors alone and without at least some human intervention. Such information might include 24-hour, interval, shot, storm and total snow stake measurements[2], current/changing sky conditions (sensors exist though very expensive), snow surface type, and the existence and quality of shear layers[3] and/or crusts. Other manually reported information that might be needed includes foot, ski or ram penetration, evidence of natural or other avalanche activity, size and structure of drifts, snow falling from trees or rocks, and propagating cracks within surface snow. See Table 1 for a list of standard manual observations performed at least daily by most avalanche forecasting & control operations in North America. Although the international standard of SI[4] is preferred for making and recording manual observations, common practice in many US snow safety operations still favors the English system and these units are listed in parenthesis where applicable. More detailed explanations of these measurements are available in McClung and Schaerer's *The Avalanche Handbook.*

Table 1. Common Snow and Weather Observations in North American snow safety programs

Observation	**Units of measure** **(Preferred units are SI)**	**Remarks**
Sky Condition	Symbol or description for percentage of cloud cover	Type and amount of cloud cover
Precipitation	Estimated rate and type	Type and intensity
Air Temperature	Degrees C (F)	Maximum, minimum and current (& trends)
Snow Temperature	Degrees C (F)	10 and/or 20cm snow temperature from calibrated thermometer/probe
Relative Humidity	%RH	Taken from hygrograph
Total snow depth	Cm (inches)	From suitable base or ancillary study plot
New Snowfall	Cm (inches)	Includes 24-hr, interval, storm, shoot stakes
Weight of new snow	Grams	Taken from weighing core sample
Water equivalent of new snow	Mm (inches)	Divide weight by cross section area of sampling tube and multiply by 10
New snow density[#]	Kg/m^3 (gm/cm^3)	Weight of new snow divided by sample volume
Rain	Mm (.01 inches)	Taken from rain gage, either manually or automatically
Total precipitation	Mm (.01 inches)	Total of both snow and rain for the specified period
Surface penetrability[#]	Cm (inches)	Foot, ram, ski penetration
Snow surface condition[#]	Symbol for snow surface type	E.g., wind crust, surface hoar, etc
Wind	Direction and general speed category (calm, light, moderate, strong)	Estimates of wind effects near study plot
Barometric pressure	Hectopascals, kilopascals, millibars, millimeters or inches	Reading and trend of barograph
Blowing snow*	Symbol and description of transport	Extend of snow transport
Shear layers[#]	Cm (inches) below surface, type and quality of shear (easy-smooth, moderate-irregular, etc)	Location, quantity and quality of weak layers
Avalanche activity[#]	Type, size and distribution of slides	Best indication of snow stability
Moisture content of (near surface) snow[#]	Estimated liquid water content (LWC) of layer(s) (dry, moist, wet, etc)	Used to estimate potential snow strength and location of liquid water
Hardness profile[#]	Fist, 4 finger, 1 finger, pencil, knife	Relative hardness of near surface snow layers
[#] Automated data sensors not yet available for such data *Sensors under development		

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[2] Even though such snowfall data are now amenable to automated observations—at least during most situations, some snowfall measurements are also taken manually as part of standard observation programs,

[3] Many types of shear tests exist, including shovel shear, tilt board, weighted column, stuff sack, and rutschblock, among others. Tensile strength analyses such as the cantilever or "bridgeblock" test may also be critical for helping assess avalanche danger in depth hoar climates.

[4] Metric system of units known as Systėme International d'Unitės—abbreviated as SI.

The Canadian Avalanche Association (CAA) has also compiled an extensive manual[5] for taking standard weather and avalanche observations in Canada. This guideline is available to interested avalanche professionals through the Canadian Avalanche Association for $20 Canadian (P.O. Box 2759, Revelstoke, B.C. V0E 2S0 Tel: 250-837-2435 Fax: 250-837-4624). It may also be available through the CAA website. More recently, the American Avalanche Association compiled and published its own observation guidelines for US avalanche workers: **Snow, Weather, and Avalanches: Observational Guidelines for Avalanche Programs in the United States.** Printable versions of the manual are available in the research section of the AAA (American Avalanche Association), with a bound manual available through the AAA on-line store.

A variety of additional and important snow structure information is available from shear tests and other snowpit derived data taken in base area study plots. Techniques for taking and recording such snowpack information are addressed extensively in both the CAA *Guidelines, AAA Guidelines* and in *The Avalanche Handbook*. It is beyond the scope of this current document to include detailed descriptions of these snowpack derived stability tests.

In recent years, research efforts in several European countries (Swiss—nearest neighbor computer models and computer aided avalanche forecasting, Nivilog, French—CROCUS and others) have resulted in rather sophisticated computer programs that attempt to meteorologically reconstruct the current snowpack structure as well as related snow stability from the weather history of a site—which is commonly supplied by an extensive array of selected weather sensors. Input data normally needed includes hourly precipitation, temperature, relative humidity, solar radiation, cloud cover, snowfall, wind speed, and wind direction. Other recent research efforts have concentrated on automatic sensing of snow transport by wind, (e.g., FlowCapt). Such computer based modeling may greatly aid snow safety programs by providing forecasters with general and/or supplemental information about snowpack structure, wind effects and snow stability, especially when combined with GIS (geographical information systems). In fact, in conjunction with The Swiss Institute of Avalanche Research, the National Avalanche Center, the Salt Lake Organizing Committee, the Utah Highway Department and others, the Utah Avalanche Forecast Center is in the process of planned testing of a Swiss Snowpack Evolution Model so that forecasters can ultimately graphically see the evolution of the snowpack in a remote location. However, it is unlikely that such computer based efforts will soon replace human forecasters or direct human sensing of snowpack properties via shovel, ski, explosive or other shear tests, and in any case it is beyond the scope of this guide to discuss the applicability of such modeling for operational programs. Rather it is left to the individual forecaster, forecast program, or agency to assess the usefulness of computer models for integration into their operational avalanche programs.

a) Location & Standard observations

Base study plot location is very worthy of discussion, since without a good and representative location much of the data derived from the plot may be both inaccurate and misleading. A baseline of standard parameters measured at most study plots includes hourly precipitation, temperature (24-hour minimum, 24-hr maximum, and current), relative humidity, snowfall and snowdepth, although other parameters may also be measured (density, pressure, clouds, snow surface, etc—see Table 1 above). Wind sensors are commonly not installed immediately adjacent to precipitation gages for obvious reasons, as a good site for precipitation data is not normally conducive to good wind info, and vice versa. However, nearby wind data from a more exposed site may be meaningful for assessing lower elevation wind transport and for estimating potential precipitation gage blow over that may occur at only partially sheltered precipitation sites.

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[5] *Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches*. 1995. Canadian Avalanche Association.

In short, a good precipitation measuring site will have reasonably good 360 degree tree protection that shelters the gage from wind effects as much as possible while still not encroaching on the site at more than a 45 degree angle measured out from the gage or tower top (an inverted 45^o cone centered on the gage). This site configuration encourages vertical snowfall while still limiting snow accumulations on nearby conifer branches from falling into the gage during windy but non-precipitating events (and thereby producing misleading water amounts). While a variety of precipitation gage wind shields have been developed (Alter, Nipher, Wyoming shield, snow fence, wind baffles, etc)—with the Nipher reportedly working the best in several applications[6], none of the shields normally work as well as natural tree protection that might be available from a well situated study plot. Also, in heavy snowfall areas wind shields or baffles may produce snow deposits that can negatively and significantly impact reliable precipitation measurements. See the Precipitation Gage section for a more in-depth discussion of wind shields.

Study plot locations should also be chosen to be as representative of the weather in nearby terrain as possible. For example, avoid sites directly to the lee or in front of knobs or other terrain obstacles, as such terrain barriers may result in turbulent winds and highly site specific precipitation effects. Study plots should be relatively easy to access in all conditions—nothing is as useless as a primary study plot that can only be accessed in good weather and stable snow conditions. Considerations should also be given to the very large and real effects of creep and glide on instrument towers, and for this reason nearly flat surrounding terrain in the immediate area of the plot is almost a necessity if longevity of the tower is to be expected—especially in a deep maritime snowpack region. Snow settlement pressure is another important consideration if guy wires are deemed necessary, as a deep snowpack will exert unbelievable vertical forces on guys and easily bend or snap attached towers. While many weather site locations are normally determined through a series of compromises between meteorological, aesthetic, construction and environmental concerns, considerable effort should nevertheless go into selection of the best site for the intended purpose. To help ensure that the best possible plot location is chosen, a weather site checklist is provided in Table 2 below.

Table 2. Partial checklist for installation of weather and snow study plot

Factor	Discussion
Site Planning	Choose best site meteorologically for the parameters to be measured. Then check environmental concerns and consider location aspects below, reassessing location as appropriate. Obtain all necessary environmental approvals, including cultural/archaeological, biological/ecological, fisheries, & wildlife. In sensitive areas, installation may require services of a botanist, plant ecologist, cultural technician and/or archaeologist. Plan for site inspection/analysis in June and construction to begin in July or August, depending on environmental sensitivity of site.
Location	Meteorologically representative of surrounding terrain; accessible in all conditions; adjacent to power and phone lines; flat or wind-scoured area to minimize creep and glide. In deep winter snowpack locations, eliminate use of guy wires to ground and be sure to meet or exceed manufacture guidelines for size of concrete tower base. May sometimes put horizontal guys to surrounding trees above expected maximum snow depth, or use near vertical guys, I-beams or other structural members for tower support (like vertical stays on a sailboat mast).
Power	Ensure that power, if required, is available and can be laid to site (check environmental concerns with digging trench if required). Do sensors require 120 or 240 VAC and are appropriate circuit breakers available? Use direct burial 600 volt rated power cable (normally 12AWG or larger), & place in flex or rigid conduit as necessary.
Telemetry cable or other data transmission methods	If extensive land lines from sensor site to inside data logger are necessary, install telemetry cables outside of conduit-enclosed power line to minimize induced AC or DC in telemetry cables.

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[6] *Handbook of Snow*, pp. 192-194, & pp. 203-210.

	Use high quality direct burial, shielded telemetry cable and be sure to include many extra pairs to accommodate problems and/or future expansion. If site is to be VHF/UHF radio, cell-phone, satellite, or meteor burst telemetered site, be sure to check for proper signal reception before acquiring equipment and beginning installation.
Tower	Ensure that tower base installation or tower brackets (if next to building) are adequate for planned tower height. Provide proper training for all maintenance personnel—utilize climbing harnesses and proper protection. Make sure that the tower can be safely climbed during all weather conditions. Check and tighten all bolts and nuts at tower section interfaces (inspect all tower components at least annually). Properly ground tower, all AC connections and data logger. Install lightning rod and proper grounding cable and ground rod if appropriate at exposed sites.
Sensors and junction box	Provide for proper placement and secure attachment of all sensors to tower. Use properly galvanized nuts and bolts for attachment. Use cable ties or high quality electrical tape to fasten cables to tower legs. Install proper lightning or power surge protection for sensors (e.g., fuse and tranzorb for each sensor wire in water-tight junction box), and phone modem lines.

It should be noted that even in current *manual* base study plots, increasing usage of automated sensors and data retrieval systems has already replaced some of the traditionally human-measured and recorded data. In-glass mercury thermometers and instrument shelters have gradually been replaced by thermistors in naturally or fan-aspirated radiation shields, and manual snow stakes and snow cores have been supplanted by acoustic depth sensors and heated tipping bucket or cumulative precipitation gages. Although transition-type (from manual to automated measurements) sensors used in telemetering temperature and precipitation data from the outside study plot to inside recording devices such as recording thermograph, and other drum or chart recorders are still in use, it is becoming difficult and expensive to have such systems repaired. And while locally recorded weather information from such systems has been available for continuous local data readout since the 1950-1970 era, relatively recent integration of such data into phone modem or LAN connected data loggers has made this previously only local data more available at more locations than ever before. Hourly base study plot precipitation, snowdepth, new snow, temperature, relative humidity, and solar radiation data are now commonly telemetered to dataloggers or computers that are accessed through a variety of methods at any time of the day or night. Nevertheless, as Table 1 shows there are still some observations that just aren't immediately amenable to automated measurements. And even with the most sophisticated and reliable automated instrumentation systems currently available, a great variety of problems can and do occur—AC power is interrupted for whatever reason, land lines get chewed or damaged, sensors get struck by lightning or unhappy animals. Hence a real need remains for at least some human observations to always measure *ground-truth* data and augment and supplement such automated information. Of course, both sides of the human/automated data acquisition loop needs to be considered. Since observers need rest and can oversleep and intense snowstorms or avalanche problems can render study plot access slow and uncertain, automated data systems have assumed an increasingly important role in most snow safety programs, for they can measure data even when any number of other constraints (extended avalanche control, highway opening or closing, budget, accidents, etc) relegate manual observations to the back-burner for the time being.

3) Automated Weather Stations

Recent advances in technology have allowed a significant expansion in remote weather sensing capabilities, especially during the past 10 years. Sensors have improved, measurement techniques have expanded, and storage, transmission and display of snow and weather data have experienced quantum leaps of progress owing to computers and related technology. As a result, addressable sensors now exist that utilize far fewer land lines when properly set up, acoustic depth gages remotely and reliably measure snow depths—even in the midst of storm episodes, RV batteries and solar panels allow for much greater power and flexibility in truly remote sensor operation, and transmission of weather data from the remote site to the base station now ranges the gamut from satellite to meteor burst to cel-phone to RF link, with near instantaneous data available world-wide through the Internet. In short information technology has reached the avalanche business in a very major way.

Since so much has happened since the 1970 guide was written and since the applications of weather technology have evolved in different ways in varying climatic regimes, the author has attempted to gain a broad perspective on proven automated remote weather sensor technology for snow and weather observations by soliciting input from a diverse group of avalanche and snow safety programs in the US and Canada. As a result, this guide incorporates instrumentation experience from remote weather stations and data networks in maritime weather sites in Alaska, British Columbia, Washington, Oregon and California as well as expertise garnered in more continental or intermountain environments like Utah, Colorado, Montana and Wyoming. From this synthesis, a rather extensive variety of useful hardware and software emerges to help the interested avalanche professional measure, store, transmit and display weather and snow parameters of interest in support of avalanche forecasting and snow safety programs. Although the information presented here attempts to summarize and explain the application and usage of the more prevalent kinds of equipment along with known advantages and disadvantages (if they exist), it's chief function should be to educate the user on the many possible methods of weather sensing that currently exist—and to help determine what kind of equipment or systems may be most appropriate for a certain area or a particular application. Once again, although specific manufacturers and items are listed, their inclusion should not be construed as an endorsement of particular products by the Forest Service. Rather they should be viewed more as working examples of proven and reliable mainstream weather applications currently in use in North American snow safety programs. Most weather sensors or systems are not unique but are nevertheless currently considered to be among the best at what they do. Certainly the equipment listed here will not be static in the months and years ahead, especially since sensor, communication and information technology are changing so rapidly. As other equivalent, or comparable/improved but less expensive equipment becomes available, an on-going effort will be made to reference it here.

a) Location & Standard observations

Standard daily or more often base study plot observations are still taken in most areas, although much of what used to be relegated to purely manual observations has now been largely supplanted by automated sensing techniques. Instead of pulling out and looking at lengthy runs of strip or drum chart data, spinning maximum-minimum in-glass thermometers, etc, modern snow safety programs are increasingly relying on graphical, spreadsheet or tabular displays of weather provided by computers. Nevertheless, human observations are still necessary and form an important link in most snow safety programs—either to supplement or augment automated data, provide information that current technology does not easily provide or check the reliability of automated systems. While the lack of a suitable AC power source still restricts deployment of some of the more power hungry sensors like heated precipitation gages and heated wind sensors, previous restrictions on other less power intensive data site locations have been reduced significantly by a judicious use of RV batteries and more efficient solar panels—except for some valley sites in Alaska during winter when sun angles are low or non-existent or on exposed ridges in northwestern locations where the solar panels may be heavily coated in rime ice for weeks on end. However, in most instances it is now possible to install a battery/solar panel powered remote weather site and have it effectively and reliably measure such parameters as temperature, snowdepth, wind speed and direction (unheated), relative humidity, barometric pressure and precipitation (unheated cumulative storage gage with an anti-freeze,ethanol or ethelyne-glycol charge) for months on end, along with automatically telemetering of the data via phone/cel modem, RF link or satellite/meteor burst to office-based computers or satellite/back scatter earth stations.

i) Power requirements

The power requirements for a particular instrumentation site are influenced by the types of weather parameters to be measured, the location, climate, and to a lesser degree the type of data transmission method. In short, although most data loggers, sensors, and data transmission methods can run fairly reliably off a well designed 12 VDC supply system if sensor heating is not required, almost any type of sensor heating (heated precipitation gage, wind sensors, ceilometer, visibility, etc) requires a reliable source of electricity (generally 120-240 VAC, but 24-36 VDC in some cases) to be available at the site. This is normally obtained through appropriate power lines (minimum 3 conductor with ground, 600-volt rated, direct burial, conduit as necessary) run to the site, although a generator may also supply power or back-up power, or it may be possible to convert to 120 VAC from 24 VDC systems if power consumption is relatively low. Although most electrical power systems in ski areas have extensive back-up generator systems to ensure almost continuous power supply to sensitive public operations (like chairlifts, lighting, lodges, restaurants, etc.), fuses or breakers controlling power distribution to remote weather sites may be tripped and need resetting, etc, and this may require manual intervention and time. To get through such intermittent loss of power at AC-required locations and still have data loggers and unheated sensors providing automated measurements, back up DC power sources are common in most remote applications. These DC systems typically include up to several deep-cycle RV batteries wired in parallel along with a 10-20 watt or larger solar panel. When AC is available, the batteries are trickle charged from the AC, and when AC is interrupted, the solar panel supplies daytime charging. In any case, when AC power is interrupted, heating ceases and previously heated sensors will gradually freeze, fill with snow, or rime if adverse weather conditions are occurring. However, if sufficient DC is still available, parameters like temperatures, snowdepths, pressure and other low power consumption measurements should still be available via remote access of the weather system data logger.

ii) Tower considerations

While a large percentage of existing mountain data sites have been created around the 12-inch equilateral Rohn 25G tower, the new USDA-Forest Service/OSHA tower safety guidelines now specify a Rohn 45G tower7 (18-inch equilateral) or its equivalent as the minimum acceptable tower standard for safety, since tests on the welded 5/16 inch cross arms of the old 25G indicated that they could break if certain forces were applied (e.g., forces exerted by a potential fall of maintenance personnel). These same safety standards also specify several other regulations for individuals involved in climbing such towers for servicing equipment (a list of these standards is given in list address of FS tower safety website). Unfortunately, when these guidelines were adopted, no additional funding was provided to help data network managers conform to these regulations.

Although fold-down sensor towers are also considered as practical safety alternatives in the new guidelines for free standing towers in fire weather programs, the fold down is not practical or durable for high elevation/heavy snowfall locations as a potentially long snow trench excavation would be required to lay the tower over for sensor access. Also, owing to their normally lighter weight and weaker construction, as well as weaker attachment between sections and at the fold-over joint, fold-over towers are much more subject to snow pressure damage and typically need guy wires for support. In the author's experience, such guy wires have collapsed several significantly more robust towers—both Rohn and otherwise. As a result, planning of most new or repaired/refurbished study plots or sensor sites should factor these new regulation specifications into construction costs—especially for the Rohn 45G or equivalent, as much of the mountain instrumentation either currently in existence or in the planning stages lies on governmental land in one form or the other (i.e.,

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[7] The 45G is an 18 inch face triangular design tower using 1-1/4 inch tube steel legs and continuous 7/16 inch steel rod bracing in the ROHN Zig-Zag pattern. Each section is joined to the next with a swaged steel double bolted connection for extra strength. The tower is completely hot dip galvanized after fabrication and is available in 10 foot sections, with all required hardware for installation.

Forest Service, National Park Service etc—Provincial Park installations should consult applicable provincial or other governmental safety standards).

In addition to safety and meteorological considerations (most representative site weather-wise for the parameters to be measured) for tower placement, the effects of creep, glide and snowpack settlement pressure on the tower and supporting structures are crucial concerns for placement and longevity of weather towers. As a result tower height and type becomes both a weather-snowpack dilemma as well as an engineering problem, and often some degree of compromise is necessary to most effectively balance all of the concerns, especially if funding is tight and suitable sites limited. Adequate consideration must be given to the type of tower utilized—cutting corners by adding a wind system to an old telephone pole that may be either marginally accessible or downright dangerous for sensor maintenance during high wind or heavy icing conditions is not an acceptable option.

For most wind exposed locations experiencing any degree of riming, towers higher than 10 feet dictate either guy wires or near vertical braces in order to outlast more than one windstorm. In wind scoured ridgetop locations where surrounding snowpacks are shallow and snow settlement pressure is limited, guy wires of 3/16 inch or heavier steel aircraft cable/wire rope should be installed from turnbuckles near the tower top at 30-45 degree angles to anchor bolts in rock or cement. However, in sheltered locations where snowpacks may be deep, towers of 30 feet or less are best left unguyed with structural support coming from large concrete bases and strong section-to-section bolts. Otherwise, guys if used should be horizontal to surrounding trees above the expected maximum snowdepth, or near vertical braces of angle iron or I-beam installed to substantive ground anchors near the tower base. If braces or wires extend more than 5 to 10 degrees off vertical, snow settlement pressure can easily grab the structural supports and bend or snap attached tower legs through the tremendous forces exerted (see Figures 1 and 2).

Figure 1. The weight of snow on the guy wires for this tower at Hurricane Ridge in the Olympic Mountains of Washington State bent the legs of this tower, resulting in an expensive replacement. Mark Moore photo.

Figure 2. The overburden pressure of a very deep snowpack on this tower's guy wires pulled it off vertical over the course of a month or two. Photo courtesy Mark Moore.

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iii) Removal and Storage

Mountain weather systems used for winter data measurement and retrieval will last much longer if sensors and data loggers are removed and repaired during the last spring, summer and early fall. This removal prevents damage from potential hazards such as summer thunderstorms, vandals, hunters, and limits wear and tear on any mechanical parts, heating systems, or measuring systems. However, with an increasing ease of automating data retrieval and transfer making it possible to routinely send mountain weather datasets onto the Internet, there is often increasing pressure from both private and governmental concerns to make the data available on a year-round basis. This desire for expanded remote weather data may originate from the public, Weather Service offices, private meteorologists, television stations, etc and may provide information ultimately beneficial for all concerned. In some cases emote weather systems left in to operate year-round normally lessens the time and staffing normally involved in removal and then reinstallation of the sensors and related data systems. Unfortunately, it may not always be cost effective. Sensor and/or system damage from whatever reason may significantly increase the annual operating costs of each system. In the end, data system managers must balance the need for year round data with the cost and consequences of providing it and make decisions accordingly.

Whatever operational time frame is selected, proper record keeping for all of the particulars about a weather station greatly facilitates system reinstallation and sensor replacement. Even during normal operating periods of less than one year, good record keeping about sensors, loggers, power supplies, modems, and the normal problems that crop up from time to time significantly reduces the time, effort and frustration levels encountered in troubleshooting weather stations. A master file that contains all of the accumulated information about a certain station is strongly recommended, Some sort of Rite-in-the-Rain or other log book that holds up in marginal weather conditions is also highly desirable as a Master Book for each weather station.

b) Sensor types and measurement techniques

A very large variety of possible sensor types and measurement techniques exist for measuring weather and snowpack parameters of interest. The majority of operating mountain weather stations that support avalanche forecasting and snow safety programs stations known to this author currently utilize standard analog sensor output via land lines or RF link to base station data loggers or computers. However, an increasing percentage of snow safety programs either employ digital and perhaps addressable sensors and sensor output or are considering a change to different systems to limit data downtime. To minimize potentially negative effects of long land lines, some systems use current (4-20 mA circuits) rather than voltage sampling, and others convert to digital signals at the sensor before transmitting the data over what may be very noisy land lines.

i) Analog versus digital, current versus voltage

Analog voltage outputs are the traditional and perhaps simplest method of getting weather information from remote sensors. In most instances a known voltage is applied across a sensor whose resistance changes with the parameter of interest (i.e., temperature, wind direction, etc). This change in resistance translates to a change in voltage that is input and recorded by the data logger. Unfortunately, the normally low DC voltages that are typical with analog sensors are very subject to distortion or modification by a variety of landline related problems. These include variable ground potential from place to place, improper sensor or system grounding, induced DC and/or AC from nearby power sources (typically ski area or other commercial power sources/lines), insulation resistance shorts (partial wire breaks brought about by a myriad of sources including animals or hunters chewing or shooting the wire, abrasion, tension, bad splices, etc). Whatever the source, such stray voltages may wreak havoc with what otherwise might be the very best of systems. Potential solutions to land line problems include cable replacement, re-splicing, or changing the data transmission method. Such data transmission changes may involve shifting from voltage to current measurements, digital data conversion before the signal hits the line (less susceptible to noise), or abandoning land lines and switching to radio links from the remote to the base station. Other possibilities include conversion to current (4-20mA) based telemetry, as well as installation of new data loggers to locally sample sensors at the remote site. In the latter case, only the phone line signal would then need to be run over the landline or if this is not possible, then providing for cell phone, meteor burst, satellite or other access of the new data logger would eliminate the noisy or broken line problem. Although an initially more expensive alternative (the cost of an additional data logger, phone line and phone modem must be considered), the lack of frustration and availability of high quality, reliable data may be worth it.

In theory, current rather than voltage based telemetering of weather sensor signals appears to offer better signal quality over marginal cables. Several 4-20 milliamp-based systems have been installed in ski area applications and these have provided relatively reliable operation. The starting threshold of 4 mA (rather than 0 volts normal in voltage based systems) eliminates problems encountered near the low end of sensor operation while the "smart" operation of the signal conditioner (it adjusts the current flow to whatever impedance the data lines create) makes overall system performance more impervious to problem land lines. However, these commonly require some signal conditioning at the sensor location before sending the signal over the line.

In most instances, phone telemetry access of remote weather systems provides for the most economical and easiest interface between a local computer and the remote site. In general RF, meteor burst, cellular phone or satellite systems are often more complex, require more power at the remote, and in general may have their own set of different considerations (e.g., radio interference, antenna riming, greater expense). In most instances the appropriate transmission system is largely dependent on the infrastructure which may already exist, such as the quality and quantity of existing land lines, proximity to power sources, cooperation with other agencies or entities that may already have established data transmission methods, and availability of proper radio frequencies (one newly developing radio frequency potential is that of spread spectrum radio data transmission—which is discussed at more length in the Transmission section below).

ii) Addressable sensors

The recently introduced addressable sensor concept (SDI—serial data interface) appears outwardly to have considerable merit as it uses digital communication between datalogger and remote sensors to both establish the data link and provide for the subsequent transfer of data. Weather data that is encoded digitally (as either a 1 or 0) at the sensor before transmission over questionable landlines is much less susceptible to degradation due to line noise (error checking protocol eliminates most problems). Such sensor addressability is also possible through RS-232 or the new RS-485 serial interface protocol, both of which may help limit the impact and interference that noisy lines might otherwise produce. Meanwhile, in theory the unique addressability of each sensor allows an almost endless number of sensors to be installed or removed at any point along a pair of conductors without impacting any of the other sensors. If properly programmed an SDI enabled datalogger can readily recognize and initialize any new SDI sensor, much like the "plug and play" concept of PC computer peripherals. Also, any sensor may be "taken off line" for repair without affecting overall system operation. Despite the obvious advantages of the SDI system however, there are some drawbacks, mainly cost and complexity. While SDI sensor interfacing may ultimately allow for better and more reliable communication between sensor and data logger over long line runs, unless SDI is really needed for encoding and transmission of complex sensor data, its expense and complexity may not justify its integration into most normal data gathering programs.

4) Remote Weather Sensors

As mentioned earlier, this guide makes no claim to be *the definitive reference* for remote weather and snow sensors as applied to avalanche forecasting or avalanche danger mitigation. It will undoubtedly fail to mention some instrumentation and data systems that are considered important and essential by their respective users or manufacturers. For this the author apologizes and will be pleased to add them to a future update of the electronic version or this guide if the users will notify me at the listed email. It should be noted that an expanding multitude of sensors exists and this makes a complete discussion of each and every sensor type almost impossible. However, this guide does attempt to describe the more common and more robust sensors and related data systems that have been proven to be generally reliable in harsh mountain environments in support of snow safety programs. Sensors discussed have run the gamut of winter operation from continental to maritime weather regimes, and from heavy riming and deep snow pack situations to interior and more continental mountains characterized by low humidities, limited rime episodes and shallow snow packs.

While many sensors and data systems may operate reliably and accurately for months or years on end, problems with some sensors develop immediately upon installation and others invariably develop over time with even the most durable and well-maintained systems. Whether the problems result from induced DC or AC voltages, land line breaks, lightning, vandalism, system power variations, fuses, ground wires, or a host of other potentially frustrating dilemmas, they will need to be addressed as soon and as efficiently as possible. Hence many of the common problems that afflict remote weather sensors are detailed and possible solutions offered. Also, to facilitate initial installations, some of the more normal sensor conditioning circuits are outlined for ease of input into the attached data loggers. Finally, some sample data logger programs are presented as examples of operating data systems, and several visual display methods are shown.

a) Wind

Over the years, many different types and manufacturers of wind systems have been tried in a great variety of weather conditions. Some have been discarded due to breakage, lack of sensitivity or durability, poor performance during rime events or significant maintenance problems; others have worked relatively reliably, even admirably under the most adverse of weather conditions. Although current wind systems can be divided into four types of sensors, mechanical (like cups or rotors) sensors have long been the traditional choice and three cup anemometers have been used at most locations at one time or another. However, in recent years several alternatives have developed, including hot wire anemometers, (ultra)sonic sensors and differential pressure devices. Although initially relegated mostly to research applications, these alternate wind sensing devices have been increasingly integrated into more main-stream applications.

i) Mechanical sensors

Despite a growing number of non-mechanical alternatives, mechanical wind speed and direction sensors currently remain the preferred choice among most snow safety programs. Many variations of the standard three cup anemometer and split tale direction vane have evolved since 1980, and these newer iterations of the mechanical solution remain in widespread usage throughout the US and Canada. Most mechanical sensors respond to the force of wind on their exposed surfaces, with the wind force resulting in rotation of either cups or other exposed surfaces for speed and orientation of the vane into the wind for direction.

Mechanical wind speed sensors either generate a voltage proportional to their rate of rotation (by using a tachometer/DC generator) or they output pulses proportional to the rotating speed of the cups (typically one or two photo-choppers/revolution). The Electric Speed Indicator Wind Speed Transmitter F420C-1—is one of the more well-known three-cup speed sensors which generates its own voltage and it enjoyed widespread usage in the 1960's into the 1980's. It was discussed and recommended in the 1970 *Snow Safety Guide #2*, and along with its Wind Direction Transmitter F420C-2 sibling which uses a circular potentiometer and brush for analog voltage output, it still remains as an integral part of mountain top weather systems in several regions. Combined with a dual channel Esterline-Angus Chart Recorder, this wind system has served as the backbone for many snow safety programs in determining amount and slope aspect of wind transport and snow loading. However, in heavy riming environments, the externally mounted rime lights that have been traditionally used for heating and de-icing the sensors simply do not supply enough heat to keep the units rime free, and once rime-ice begins to accumulate, a feedback process starts that soon renders the units useless (rime reflects the incident heat which allows more rime to accumulate which reflects more of the radiation and so on….). To combat this problem, newer internally heated speed and direction units arriving in the 1980's seemed to solve many of the riming and related durability problems. Extremely hardy and proven successful in a variety of harsh mountain conditions, speed and direction sensors from Taylor Scientific can either be heated or unheated, and offer pulse or analog output. Their robustness adds weight and cost however, and their increased mass has contributed to wind reporting problems such as: a higher starting threshold for speed than other lighter (and typically less durable) designs; a delayed response to and under reporting of wind gusts (response time of ~7seconds); and a slight off-axis response (increase) in wind speed for winds impinging on the sensor at more than about a 10-degree off horizontal angle (due to their shape most mechanical wind speed sensors suffer from this effect to some degree). Also, the momentum of the wind direction sensor may result in a slight over reporting of direction variability. Although many of these negative effects can be minimized or mostly overcome by reducing the sensor mass, this comes at the cost of less durability. Nonetheless, for most snow safety operations utilizing the heavy duty heated or unheated sensors, such reporting problems have a limited impact on operational programs and are relatively minor inconveniences. In general these modified cup and vane sensors offer a significant increase in reliable operation in almost all conditions—primarily due to ultra heavy bearings in the transmitter and up to 1000 watt internal heating coils.

It should be noted that other less heavy-duty mechanical sensors with either lower wattage or no heaters have been used relatively successfully in light or minimal riming locations. These sensors include the older standards from Electric Speed Indicator as well as newer units from Vaisala/Handar, RM Young, Met One, Climatronics, Qualimetrics, FTS and Coastal Environmental. Primary wind sensors in use and their attributes are outlined in the table below. In propeller type combined wind speed and direction sensors there are some torque effects generated by the spinning propeller that can reduce the responsiveness and accuracy of the sensor, both for speed and direction; however, in most situations these effects appear to be relatively minor.

Table 3. Wind system summary—(under construction)

Manufacturer	Sensor type	Sensor output	Sensor input Power	Telemetry cables needed	Remarks
Climatronics	Mechanical wind speed & direction sensor				
Coastal Environmental	Mechanical wind speed				
Electric Speed Indicator	Mechanical wind speed	Analog voltage	None—self generating for output	Two conductors	Durable; unheated
Electric Speed Indicator	Mechanical wind direction	Analog voltage	2.5-5 VDC for sensor output	Three conductors	Durable; unheated
FTS	Mechanical wind speed & direction sensor				
Innovative Dynamics	Drag/force sensor				
RM Young	Mechanical wind speed & direction sensor	Analog voltage	5 V DC for wind direction		Durable for non heavy riming applications
RM Young	Ultrasonic wind speed & direction sensor				
Sutron	Ultrasonic wind speed & direction sensor				
Taylor Scientific	Mechanical wind speed	Analog voltage or pulse output	120 V AC for heat—1500 watt;	Two conductors	Durable; Reliable in extreme riming conditions
Taylor Scientific	Mechanical wind direction	Analog voltage (5K ohm pot)	120 V AC for heat—1500 watt; 2.5-5 V DC for sensor output	Three conductors	Durable; Reliable in extreme riming conditions
Vaisala (Handar)	Mechanical wind speed				
Vaisala (Handar)	Mechanical wind direction				
Vaisala	Ultrasonic wind speed & direction	Variety of available outputs			Unproven in heavy rime environments

	sensor				

Unfortunately, as well built as the newer mechanical sensors are, they do have moving parts and their performance does degrade with wear. Some of the alternatives discussed below have fewer or no moving parts and suffer no mass or inertia related effects of their mechanical cousins. However, they are also relatively new and as yet unproven in most harsh mountain regimes. They are also generally more complex and can be more costly.

ii) Hot wire, hot film anemometers

Operation of hot-wire anemometers is based on measurement of convective heat loss from a heated wire to the surrounding atmosphere. In general, the heat loss from the wire increases as the wind increases, with the rate of heat loss proportional to the speed of the wind around the wire. As the wind speed increases (decreases), more (less) current is required to maintain a given temperature of the heated wire, and from this current increase (decrease) the wind speed can be deduced. Although this sensor has no moving parts, to date it has been used primarily in special (research) applications. The associated temperature maintenance circuitry and calibration measurements may be too complex for general use, a situation that is complicated by rain or snow accretion, melt and evaporation or other contamination of the wire or other exposed film surface.

iii) Differential pressure sensors, Drag sensors

The differences between upstream and downstream air pressure as it flows around an obstacle—in this case a pitot or pressure tube—form the basis for measuring wind speed and direction using differential pressure sensors. However, the differential pressure is normally quite small, the associated pressure transducer very sensitive and expensive, and the resulting measurement may be quite sensitive to contamination of the tube by dirt, ice, and water. Hence its incorporation into the mainstream of snow safety or avalanche forecasting programs has been relatively limited.

Force or drag sensors typically utilize a three-axis force transducer to detect 3-dimensional aerodynamic drag on a particular sensor surface (normally a cylindrical metal tube that encloses the transducer, heaters and other electronics). Instantaneous force information output from the transducer is fed into either a data logger or logic circuit that determines the air-velocity vector (speed and direction) over the interested range of measurements.

iv) Sonic (acoustic) anemometers, Doppler anemometers

An increasing variety of sonic anemometers have been developed and marketed during the past 5-10 years, and they show promise in overcoming some of the limitations of mechanical or other sensors. Based on time-of-transit measurements for sound impulses transmitted back and forth along either three or four axes aligned at some angle to the wind flow, the sonic anemometer utilizes algebraic computations to determine speed and direction of the wind. This determination is possible due to the fact that the speed of the sound impulses generated and measured by the sensors increase when aligned with the wind, and decrease if they are moving against the wind. Since the sonic anemometer has no moving parts, it is not subject to wear and potential contamination from salt, dust and sand. Also the relatively small surface area that is has exposed to the air flow limits both turbulent effects on the measurements, and results in lower power requirements for keeping the elements rime and ice free. Several recent changes in the design and heating of the sonic anemometer may soon allow for its introduction into the mainstream of mountain weather and snow safety programs.

The acoustic Doppler anemometer relies on the wind speed to change the frequency and timing of a pressure pulse, and it combines time-of-flight information with frequency shifts of returned pulses to determine three-dimensional wind trajectories.

b) Temperature

As temperatures rise and fall, metal's ability to conduct electricity varies in a known way. This temperature-induced change in resistance to current flow forms the basis of measurement for most current air temperature sensors, or thermistors—which are basically a semiconductor device with a resistance that is very sensitive to temperature, resistance decreasing as the temperature increases. Such thermistors typically have a relatively high resistance (on the order of several thousand to tens of thousand ohms). With a known voltage (e.g., 2.5 or 5 VDC) applied across the sensor, the voltage drop across the thermistor relative to a known ground provides the information necessary to determine the temperature. Although the resistance response to temperature changes is often not linear, most data loggers can relatively easily be programmed with some sort of n^{th} order polynomial fit that defines the temperature/resistance relationship.

i) Air Temperature

Thermistors are used in both air temperature and snow temperature applications throughout North America. Air temperature (AT) sensors are also often combined with relative humidity (RH) chips to serve as integrated ATRH sensors, since RH sensors need temperature anyway to make their measurements. A useful by-product of measured air temperature and humidity information is the dew point—which is needed for helping plan snowmaking operations.

Thermistors by themselves are relatively fragile, and are typically enclosed in some sort of silicone gel or protective housing. Since direct solar radiation strongly affects sensor temperature, these encapsulated sensors are normally mounted within some sort of natural or fan aspirated radiation shield, which provide some of the same solar shielding that the older instrument shelters in the 1970 Snow Safety Guide gave to the in-glass mercury thermometers which they housed. Many different designs of radiation shields are in use currently, ranging from the Gill Radiation shield to double walled radiation shields of various dimensions and designs. Of greatest importance in the design is to allow for relatively unrestricted airflow out the top (for heated air to vent) while still preventing wind driven snow from clogging the vents and/or reaching the sensor. In sheltered locations where wind transported snow is not a significant problem, it can be helpful to provide as much additional shade for sensors as possible (mounting on the north side of a vertical white shield, north side of a chair tower pole, unheated building, etc). For while the temperature may track very accurately during stormy winter days, the strong sunshine of spring may quickly result in erroneously high values if both proper air ventilation and shelter from direct radiation are not provided.

ii) Snow Temperature

Thermocouples rather than thermistors are most often used to measure snowpack temperatures due to their significantly lower cost (typically on the order of 10-100 times cheaper than thermistors). However, thermocouple measurements may be complex to initiate (due to the very small EMF they generate, they are very sensitive to all connections and wires leading to and from the thermocouple), they need to be protected from water and they require a reference thermocouple for proper calibration. For these reasons, thermistors may be a better choice if budgets are not too tight. Whatever sensor is used, it is important to mount the sensors on a non-conducting pole (fiberglass wind surfing masts have been used in New Zealand, and PVC pipe in the US) to minimize induced changes of the substance you're trying to measure—i.e., to limit any temperature transfer through the snowpack by the pole. Once the system is in place, care must be taken to limit the effects of creep and glide on the pole. To sample the various snow temperature sensors, multiplexors are commonly used to automatically step through the data signals and input them to the data logger.

c) Precipitation

Avalanche professionals often consider accurate precipitation measurements one of the most important weather parameters for operational forecasting and control—yet reliable data can be very difficult to obtain.

As mentioned above, proper siting of precipitation gages can be critical for obtaining meaningful data. However, even if the best possible locations are utilized, a host of potential problems may limit reliability and usefulness of such data. Such problems include but are not limited to: blow over or blow into, heating or power problems, evaporation, gage capping, broken switches, and plugging of the orifice. These and other problems and potential solutions and troubleshooting methods are discussed at more length in the troubleshooting section.

i) Water Equivalent

Hourly water equivalent measurements—the sum of both liquid and frozen precipitation reaching the site in question during the past hour—form the backbone of most snow safety programs. Such data directly relates to both overall loading and rates of loading of weak layers, and combined with wind and temperature trends provides critical information for determining which slopes are loading and at what rate, thus directly impacting both avalanche danger levels and related control decisions. Currently such data is obtained primarily through the use of either heated tipping bucket gages or cumulative/storage gages, although other methods are also used (vibrating wire, snow pillow). Unfortunately until just recently, resolution and other internal problems associated with the cumulative/storage gages had relegated their usefulness to relatively long term forecasting efforts like flood forecasting or water supply outlooks. Better and more reliable pressure transducers and automatic charging systems currently being offered appear to be expanding the storage gage solution to operational real-time forecast efforts, possibly even in deep snow climates.

(1) Tipping bucket—

During the past 20 years, the most widely used precipitation gages for most mountain weather programs have been either the heated tipping bucket gage or the cumulative weighing gage. The tipping bucket gage utilizes either an 8 or 12-inch funnel to catch precipitation that is then funneled into a small orifice that channels the liquid precipitation into one side of a pivoting bucket mechanism. When one side is filled, the weight of the liquid causes the filled bucket to fall, much like a teeter-totter. This rocking of the tipping bucket results in closure of a low level DC circuit—typically induced by a magnetic or mercury switch attached to the bucket and/or bucket post—with each closure representing .01 inches or 1 mm of accumulated precipitation.

In most operations where 120VAC power is available, tipping bucket precipitation gages like this normally have any number of either molded heaters or power resistors that are used to supply heat for both the funnel and inside bucket mechanism. These heaters typically supply a thermostatically controlled source of from 2-500+ watts of heat to the gage—which is generally sufficient to melt incoming frozen precipitation during most normal precipitation events. Unfortunately, while such heaters normally keep the gage ice-free and allow for unattended remote operation, they have been shown to cause some evaporation of the liquid, especially during precipitation events characterized by low humidities and low precipitation rates that may be common in more continental climates.

If AC power is not available, propane powered heat sources (mostly using catalytic heater beads) for tipping bucket gages have been the primary solution to-date. However, even with relatively large supplies of propane (180 pounds), propane consumption rates of the catalytic converters used to provide heat in a heavy precipitation maritime climate have normally been such that unattended operation is generally only possible for a month or two at a time before the propane supply is exhausted. This situation has occurred repeatedly with two 90# bottles joined together at the tower base with a T fitting; a pressure regulator installed at the T to drop line pressures on the tower supply hose to around 10 psi; and a final pressure regulator inside the gage to drop operating pressures into the catalytic converter to the ~2-3 psi required for continuous operation. If mid-winter access of such remote sites is possible, re-charging the propane supply is a viable alternative. However, for sites that are difficult or impossible to reach without helicopter or snow machine support, re-charging of the propane supply may be a highly problematic, time-consuming or expensive proposition. When this re-supply dilemma is combined with internal condensation problems within the gage (water/vapor is a significant by-product of burning propane) and resultant inaccurate or misleading precipitation readout, the usage of currently designed propane heated becomes rather questionable. Additionally, in relatively cold and dry environments, excessive heating of the funnel has led to significant evaporation of precipitation prior to measurement, and the catalytic converters have been known to just "go out" or stop functioning—presumably due to water or other contaminant in the supply line. Such a sequence of consistent problems has plagued this equipment, and it has resulted in the withdrawal of most propane-heated gages from the market. Currently no vendors that the author is aware of still offer either the propane gages or replacement parts for earlier models. (The author readily welcomes any information on new or updated gages that address the problems described)

It is possible that a future redesign of the gage will allow for availability of a condensation free, limited evaporation and lower propane (or other suitable fuel) consumption model that can be reliably used for heating and measuring frozen precipitation in remote mountain environments having no electricity. Until this occurs, the best alternatives appear to be the automatically charging (new anti-freeze solution) cumulative storage gages described below.

(2) Cumulative/storage gage

For years the Natural Resources Conservation Service (NRCS—formerly SCS) has relatively successfully used a cumulative stand-pipe precipitation gage/pressure transducer combination for measuring long-term/annual precipitation at a variety of remote mountain locations. Due to the height required for such a gage in very wet locations, the resolution of the pressure transducer output has been restricted to increments of .10 inches WE (most forecasting operations rely on .01 inch resolution output). Also due to its lack of heating the gage is often plagued by capping around the orifice, and misleading data when frozen precipitation accumulates along the side of the gage and then subsequently falls into the gage during non-precipitating warming events.

(3) Snow Pillow

NRCS has also successfully used snow pillows—fluid filled bags that measure the overburden of snow by the use of high resolution pressure transducers—to measure total water equivalent of the overlying snowpack. These can provide meaningful general WE information in a non-layered medium, but they can suffer from significant short term reading fluctuations during warming events and bridging over the sensor by ice layers may limit or delay the recording of new snowfall arriving on the snow surface. In the warming scenario, it has been thought that the erroneous increases in overall snowpack weight could be attributed to an overall warming driven settlement of the upper layers of the snowpack. However, McClung (personal communication) argues that such surface temperature variations will take some time to affect deeper layers and hence some other mechanism may be at work to influence such temperature related variability. In any case, most current snow pillow output is normally not of sufficient resolution or timeliness to use for operational weather and avalanche forecasting programs, except in a relatively gross fashion or as supplementary information in data-sparse regions. However, they do provide excellent snow storage information for longer term programs like flood or water supply forecasts.

ii) Total Snowdepth

Automation of snowdepth information has

        iii) **24-hour/Interval Snowfall**

d) **Relative Humidity**

e) **Solar radiation**

f) **Precipitation Identification**

5) Abbreviations

AC—in electricity, alternating current
DC—direct current
DVM—digital voltmeter or multi-meter tester for electrical component testing
RF—radio frequency
VOM—voltage-ohm meter

6) Vendor Addresses and Internet Links

a) Weather and Snow Instrumentation

Belfort Intrument Company

http://www.belfort-inst.com/

Belfort Instument Company offers a wide range of meteorological and environmental instruments for both research and repetitive observations.

727 South Wolfe Street, Baltimore, MD 21231 USA
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Campbell Scientific Inc.

http://www.campbellsci.com

Campbell Scientific, Inc—manufacturers dataloggers, data acquisition systems, and measurement and control products used worldwide in research and industry.

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Climatronics Corporation Home Page

http://www.climatronics.com/

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Coastal Environmental Systems

http://www.coastalenvironmental.com

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Ph# (206)682-6048, (800)488-8291 or Fax (206)682-5658;
email:pkelly@coastalenvironmental.com

ESI Environmental Sensors Inc

http://www.envsens.com/products/moisture/irrigat/aquaweat.html
Environmental Sensors, Inc. Weather stations with AquaStation Weather Model enables up to 7 weather parameters to be monitored, including wind speed and direction, air temperature and relative humidity.

300 Enterprise Street, Suite A, Escondido, CA 92029
Toll Free (in North America):1-800-553-3818; International: (250) 479-6588; Fax: (250) 479-1412
Email: sales@envsens.com

Electric Speed Indicator Company

http://www.electricspeedindicator.com
Electric Speed Indicator Company has been designing and manufacturing meteorological instruments since 1934.
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PHONE: (216) 251-2540; FAX: (216) 251-2641; email: info@electricspeedindicator.com

FTS (Forest Technology Systems) - complete environmental monitoring solutions

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FTS manufactures automated weather stations, water monitoring stations and monitoring software. Systems consist of a datalogger, sensors, communication telemetry and data management software including fire code calculation. Specializing in remote applications.

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Novalynx Corporation

http://www.novalynx.com/
Nova-Lynx Corporation—Weather, Wind & Water Monitoring Instruments.

P.O. Box 240, Grass Valley, CA 95945
FAX: (530) 823-8997 Telephone: (530) 823-7185 USA Toll Free: 1-800-321-3577;Email: nova@novalynx.com

Qualimetrics Weather Equipment—Weather Sensors and Weather Systems

http://www.qualimetrics.com/
Qualimetrics is an established meteorological equipment engineering and manufacturing company that has been designing and building weather sensors and monitoring systems for almost 20 years.
1165 National Drive, Sacramento, CA 95834, USA
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email:qual@qualimetrics.com

R M Young Company - Meteorological Instruments

http://www.traverse.com/commerce/rmyoung/rmyhome1.htm
For over 30 years, YOUNG meteorological sensors and displays have served successfully in settings as varied as tropical ocean buoys and frigid mountain observatories.

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Phone: 231-946-3980 FAX: 231-946-4772 email:met.sales@youngusa.com

Scientific Technology, Inc. - weather environmental software

http://www.scti.com/
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http://www.texas-weather.com/
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http://www.vaisala.com/
Vaisala, Inc develops and manufactures electronic measurement systems and equipment for meteorology and the environmental sciences, traffic safety and industry.
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5 Buttonwood, Irvine, CA 92614 USA
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Handar Business Unit; 1288 Reamwood Ave. Sunnyvale, CA 94089-2233 USA
Phone: (408) 734 9640 Fax: (408) 734 0655

Vector Instruments Website - Wind and Weather Sensors
http://www.windspeed.co.uk/
Vector Instruments - manufacture quality, robust, professional wind speed and wind direction measuring equipment (anemometers and wind vanes) together with other weather sensors.
115 Marsh Road, Rhyl, Denbighshire, North Wales, LL18 2AB, United Kingdom.
Tel: +44 (0)1745 350700 Fax: +44 (0)1745 344206 Email: sales@windspeed.co.uk

b) Data loggers

Campbell Scientific Inc.
http://www.campbellsci.com
Campbell Scientific, Inc—manufacturers dataloggers, data acquisition systems, and measurement and control products used worldwide in research and industry.
815 West 1800 North, Logan, Utah 84321-1784 USA
Phone: 435.753.2342; Fax: 435.750.9540; email: info@campbellsci.com

Coastal Environmental Systems
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820 First Avenue So., Seattle, WA 98134-1202
Ph# (206)682-6048, (800)488-8291 or Fax (206)682-5658;
email:pkelly@coastalenvironmental.com

Vaisala, Measuring the Environment
http://www.vaisala.com/
Vaisala, Inc develops and manufactures electronic measurement systems and equipment for meteorology and the environmental sciences, traffic safety and industry.
8401 Baseline Road, Boulder, CO 80303 USA
Phone: (303) 499 1701; Fax: (303) 499 1767; email:hannu.patrikainen@vaisala.com

5 Buttonwood, Irvine, CA 92614 USA
Phone (nat): (949) 651 0407; Fax (nat): (949) 651 9743; e-mail: antti.korhonen@vaisala.com

Handar Business Unit; 1288 Reamwood Ave. Sunnyvale, CA 94089-2233 USA
Phone: (408) 734 9640 Fax: (408) 734 0655

c) Towers

ROHN Industries Inc

http://www.rohnnet.com/

Rohn Industries Inc. A complete line of towers, poles, cabinets, shelters, antenna mounts and much more

6718 West Plank Road, Peoria, Illinois 61604 USA
Telephone 309-697-4400; FAX 309-697-5612; E-Mail Address: mail@rohnnet.com;

d) Data Display

Campbell Scientific Inc.

http://www.campbellsci.com

Campbell Scientific, Inc—manufacturers dataloggers, data acquisition systems, and measurement and control products used worldwide in research and industry.

815 West 1800 North, Logan, Utah 84321-1784 USA
Phone: 435.753.2342; Fax: 435.750.9540; email: info@campbellsci.com

Judd Communications

http://www.juddcomm.com

Judd Communications—offers products and services for datalogger users and the Snow Safety community, including acoustic snowdepth sensors and the *Visualog* data display program.

2248 E. Lauri Kay Drive ,Salt Lake City, Utah 84124 USA
Voice: (801)424-2889 Fax: (801)424-1528; email: dan@juddcom.com

Gasman Industries, Ltd

http://www.gasman.com

Gasman Industries Ltd. provides computing and programming solutions to business and government agencies and develops commercial software in various disciplines

3318 Wascana Street, Victoria, B.C., Canada V8Z 3T8
Phone: 250-881-4117; Fax: 250-727-2695; Email: info@gasman.com

NoHow Inc

http://www.nowhowinc.com

NoHow Inc provides a wide array of Remote Environmental Monitoring services, including software and hardware solutions.

P.O. Box 936, Polson, MT 59860-0936 USA
Voice: 406.883.5881; Fax: 406.883.1679 ; email:howie@nohowinc.com

e) Troubleshooting Equipment—Test Meters, etc

Fluke Corporation

http://www.fluke.com/

Fluke Corporation manufacturers a variety of instruments (VOM, DVM, etc) for testing a wide range of electrical and electronic equipment.

PO Box 9090, Everett, WA USA 98206
Phone: (425) 347-6100; Fax: (425) 356-5116

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