A technical overview of Ministry of Transport automatic weather stations and their data elements

Cameron G. Rawlinson *
MoT Snow Avalanche Programs, Victoria, British Columbia

Abstract: At 24 times the physical size of Switzerland, British Columbia contains a wide variety of Avalanche prone terrain in a number of different and often unpredictable climatic zones. For about 20 years, avalanche forecasters have used automatic weather stations in BC for synoptic observations of the weather and snowpack, often from very far away. Successful use of the technology has led the way for expanding their use into the field of road temperature and condition forecasting. In light of these factors the current suite of supported sensors is reviewed including some specific details on sensor operations. Some factors in geographic station siting are mentioned with examples. Sensor and derived data output formats are disclosed with subjective notes on sensor reliability. Some techniques and principles fundamental to reliable operations in winter are presented.

Keywords: snow sensing, methods of sampling , weather sensing, road weather, avalanche forecasting

1. Introduction

This paper gives a very brief technical overview of the Automatic Weather Stations used for avalanche and pavement condition forecasting at the BC Ministry of Transportation (MoT). As of July 2002 the network consists of 90 hourly reporting stations and associated support equipment to store and forward the real time data to points throughout BC and in part on the WWW. The network size is growing by about 10 stations per year.

All stations consist of equipment integrated from in and out of house sources (see Figure 1 and Table 1). Stations are based on the Campbell Scientific CR10X dataloggers and include sensors for measuring atmospheric conditions along with data pertinent to snowpack and pavement conditions, which are vital for forecasting in the aforementioned applications.

A staff of 5 regional Environmental Electronics Technicians (EET's) along with 20 other Avalanche program staff support the stations from November through till the end of May (or later if the winter threat persists). Avalanche staff undertake the work as part of an overall responsibility for avalanche safety programs, which operate out of 6 locations spread throughout BC. Additional support for services such as telemetry planning and parts warehousing are provided through other ministry programs which have greatly helped the growth of the network.

Growth of the network in recent years has been primarily due to the introduction of automated weather stations for use in winter road maintenance programs. Station locations for this application have been selected where the data, in combination with Road Temperature and Condition forecasts (RTC's), can be beneficial to planning for plowing and anti icing operations. Approximately one third of the stations in the network are presently used for this purpose and they are located at the roadside. Another third serve both forecasting clients with common and unique sensors relevant to each hazard being forecast. The remaining stations are installed for avalanche forecasting alone.

Designing and maintaining remote automatic stations for winter operation in harsh mountainous terrain is a challenge. To make the stations most useful, their locations must also be considered regardless of utility services such as electricity, communications or, in the case of Avalanche stations, road access. Solar power and radio telemetry is used throughout the network to keep remote stations online at all times. Support considerations must be taken into account from conception to final turn on for any of these weather stations to provide quality information.

The details discussed below are a snapshot of technical considerations for our standard stations as of July 2002. A number of changes are presently under consideration or presently in the design phase. For this reason some details are subject to change.

Author Address: BC Ministry of Transportation
4C 940 Blanshard St, Victoria, BC V8W 9T5
250-387-1150 cam.rawlinson@gems7.gov.bc.ca

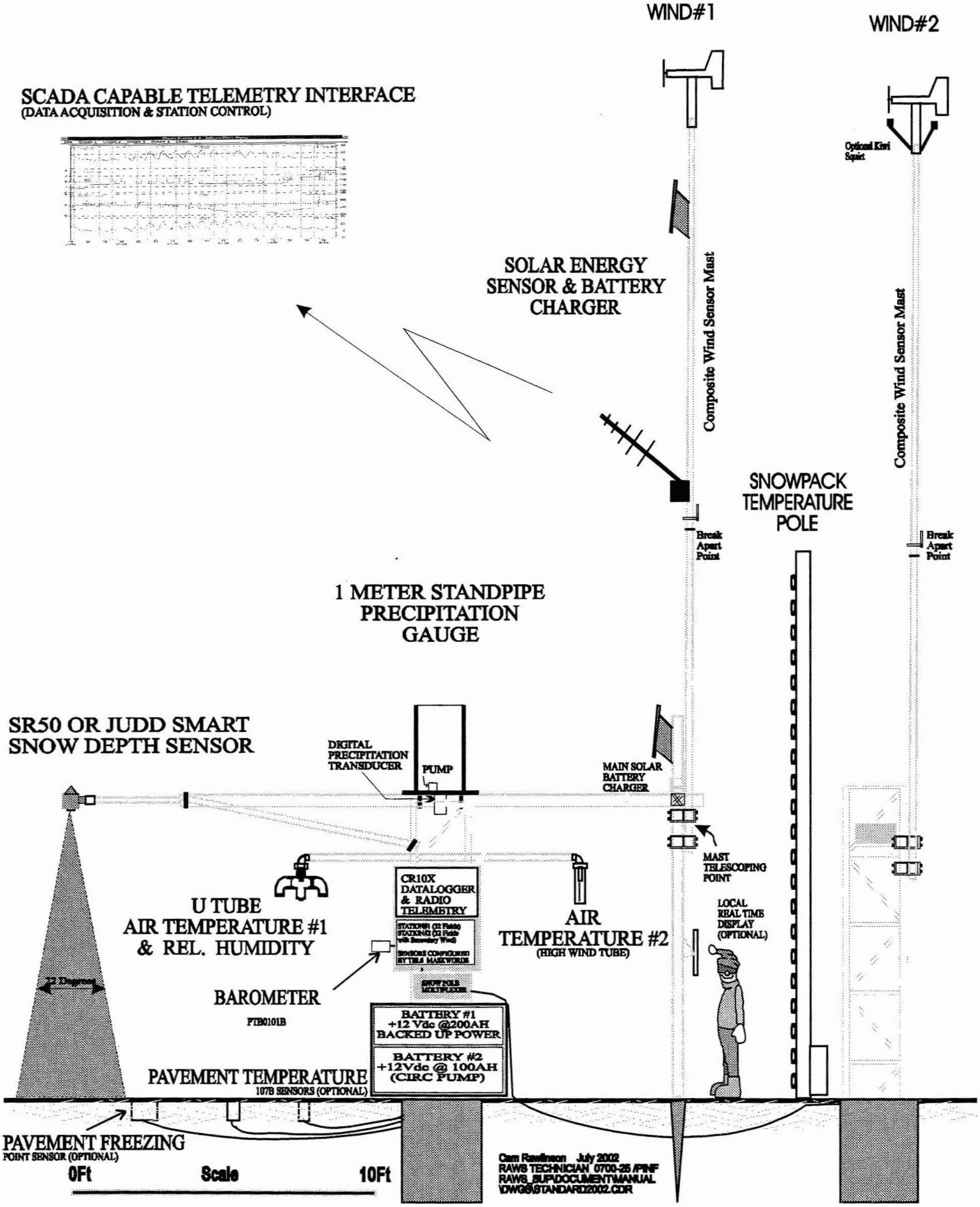

Figure 1. Sensing components of a standard RAWS weather station used at the BC Ministry of Transportation. Some components may be excluded as dictated by the hazard, site topology or the support burden associated with a given sensor. Stations often run unattended for months at a time.

2. Sensors

Sensors in MoT standard stations include legacy devices like the precipitation gauge developed under NRC avalanche research grants (Campbell 1988), industry standard devices such as the RMY 05103 Wind sensor, and in house designs like the Solar Energy sensor. Analog, Digital, Electro-mechanical and synthetic sensor design approaches are all being used to produce 80 unique environmental data outputs from about 14 sensors. The datalogger software is essential to producing and refining all sensor data outputs. Hourly and New Snowfall (12 hour total) are examples of synthesized data based on the snow depth sensor. The derivation of their values is flowcharted in figure 2.

Most standard sensors and associated support methodoogies are under constant review and refinement by staff at the Ministry to ensure the stations operate as best as possible in the harsh British Columbia winter environment. Examples are preemptive techniques and devices to prevent sensor icing (Benum), and offset mounts for sensors as well as portable stations (Heikkila). This years sensor software refinements included new datalogger routines to detect and report data quality issues caused by known phenomenon. Examples of such phenomenon are, intense sun combined with calm winds that are known to cause reductions in measured air temperature accuracy, and excessive signal deviations or constant outputs from sensors with known operating noise profiles.

The harsh environment and infrequent service visits dictate that all sensors include special features to resist failure in cold, precipitous and icy conditions. An example is the precipitation gauge, which is precharged with antifreeze and which contains a pump to mix in new precip. And also the "Bendy Wind Mast" developed at the Ministry, which naturally sheds ice & snow by way of flexing actions due to wind acting on it. To ensure their operation, sensors and electronics are also cold temperature specified and tested to -30 or -55 Degrees Celcius prior to deployment.

The sensor suite presently in use at the Ministry is with some exception based on established sensing techniques and on economies of scale. Data biases, failure modes and maintenance requirements are predictable and well known to the trained observer. They are refined, economical and effective "point of measurement" devices given the seasonal conditions.

PART	SUPPLIER	COMMENT
Air Temperature Sensor (207)	M.O.T.	Industry standard circuitry
Relative Humidity (EMD 2000)	General Eastern	Long life, low cost probe
Air & Humidity U Tube Housing	M.O.T.	Inverted U Tube Design
Barometer (PTB101B)	Vaisala	Relative Pressure Record
Precipitation Gauge	M.O.T.	Designers & Integrators
PPT Precipitation Sensor	Honeywell	Smart Sensor
Precipitation Standpipe Bucket	Allanco International	Plastics Specialists
Snow Depth Sensor (JCDG/SR50)	Judd Communications, Campbell Scientific Canada Inc	Smart Senor
Snowpack Temperature Pole	M.O.T.	Measures at 20 CM Intervals
Wind Sensor (05103)	RM Young Company	Wind Speed & Direction
Bendy Wind Mast	M.O.T.	Natural Derimer
Solar Panels (SX10)	BP Solar (BP Solarex)	20 Watts typical
Solar Regulator / Energy Sensor	M.O.T. / Microchip	New 2000
Pavement Temp & Condition	Under Review	
Pavement Temperature (107B)	Under Review / CSCI	107B is primarily a backup sensor
Datalogger (CR10X)	Campbell Scientific Inc	Reliable and efficently sized part
Datalogger Software (Silver)	M.O.T.	
Batteries	Trojan Battery Co.	200 – 400AH D.C. Lead Acid
Towers & Bases (LR20)	Radian Inc.	LR20 Model
RF & Telephone Telemetry	Campbell Scientific Inc	Modem Supplier
RF Telemetry Transciever	M.O.T. / Tekk Inc	EFJ DL3410 Compatible
Antennas	Sinclair / Scala / Larsen	
Cell Phone Telemetry (CDPD)	MoT /Sierra Wireless/Motorola	Formerly Motorolla SC725
Wiring & Control Hardware	M.O.T.	Aka "The Layout board"

Table 1. *List of Primary Sensor & component Suppliers*

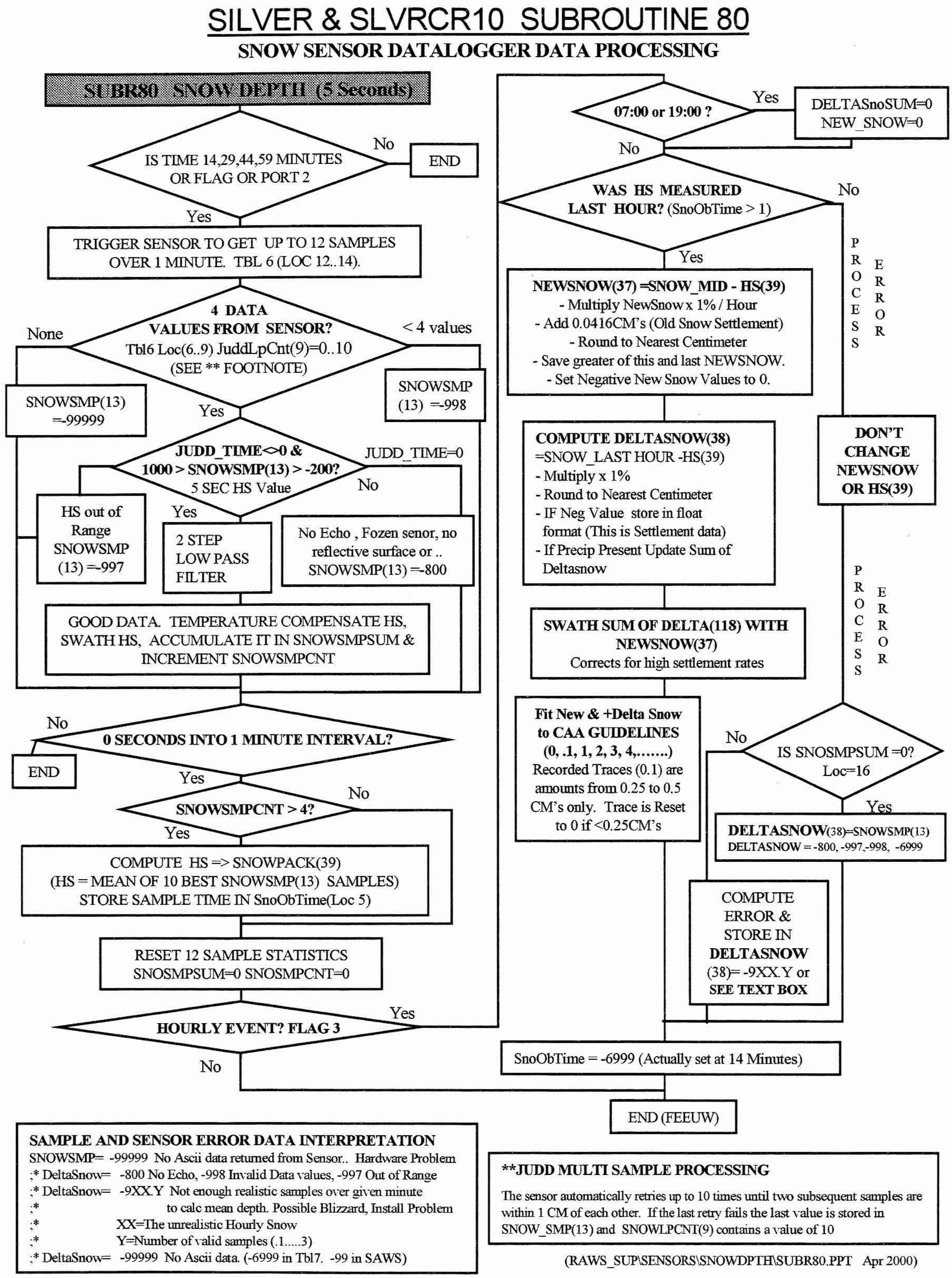

Figure 2. Low level sensor processing routine used to improve HS data quality and compute Hourly and New snowfall rates. This logic was used during the 2000-2001avalanche season.

3. Siting Considerations

Stations are deployed at either roadside, slope side or mountain top locations for various reasons. Siting factors include; the primary user needs, the sensors being deployed, climate regime of the area and the hazard being forecast. Wind transport of snow is a major contributor to snow avalanches. Stations deployed at or near mountain top locations make these measurements best. When combined with road or slope side stations they can also make differential measurements of phenomonom such as thermal inversions. They are excellent radio telemetry and solarization sites and normally provide data representative of a large area.

Figure 3. A typical Mountain Top Wind site used to measure the wind driven transport of snow.

Roadside sites are especially challenging to select at MoT. To measure the micro climates created by the road, a station should be located as close as possible to curbside. However several sensors require the protection of a wind block in order to make accurate measurements. For these reasons the roadside siting of stations involves a compromise. Technological changes may eventually allow more separation between sensors for more effective sensor sighting. An alternative is to use snow and liquid precipitation sensors that are designed to measure in free air provided they are energy compatible with solar powered stations. Some cost can be offset by elimination of the fenced compound.

3.1 Siting relevance with Examples

An intimate awareness of the local topopology and an awareness of cause and affect due to local phenomena are helpful in making judgements regarding weather observations at stations. Stations deployed to monitor local harzards may or may not produce data sets representative of the area as a whole. A picture and local knowledge greatly improve interpretation of remote weather data.

Figure 4. RWIS Station monitors hazard prone to gully due to its orientation, the road alignment, and potential for increased humidity from a creek at its base.

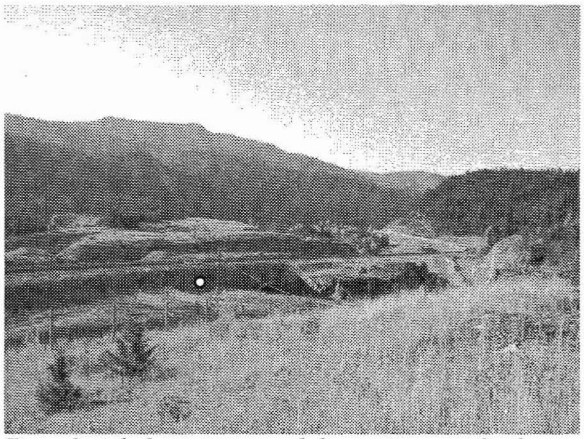

Figure 5. A dual-purpose station helps monitor an avalanche prone cutbank, pavement conditions, and also provides representative data of the area as a whole (that is provided wind affects don't bias precip entering the capture bucket).

Siting relevance could be reduced with geo-climatic modeling and this inspires a great vision for improving data interpretation, reducing station counts and their associated costs. Avalanche forecasters use intuitive models extensively combining their historic climate knowledge with the local station topology to interpolate snowpack conditions in start zones. Extensive knowledge of station and sensor siting is crucial to making the best use of the data in numerical or intuitive modeling situations.

4. Sensor operating and sampling rates

The base output rate for all weather station data passed to the outside world is one record per hour. This is facilitated via output to the CR10 datalogger Table 7 area for remote collection by a base station computer.

Additional longer duration accumulations of most measured parameters are stored locally and in the ministry's database. Accumulations are based on a MoT standard 12-hour observation period for New Snow, New Precip, as well as Min and Max Air Temperature. Resets occur at 6AM and 6 PM daily. Longer term rolling accumulations of 5 day total precipitation and 3 day snow accumulations are stored locally in the station to assist in data analysis when time profiling graphs are not easily obtained.

Faster observation rates are possible for sensors such as wind direction via a direct connection to the station and are described below.

Table 2 below shows the general lower level sampling rates for sensors. Low level integration is done on sensors which benefit from data smoothing. The standard low-level integration rate is 5 seconds. For support purposes a diagnostic mode is available which provides sensor updates in real time (every 5 seconds). This greatly helps the troubleshooting and servicing of problematic sensors.

Each sensor has driver software operating in the on site datalogger. The parameters measured do not depend on outside post processing for their derivation. As described earlier some parameters are derived entirely through software models running on the local datalogger. Dew point is also an example of a derived or synthesized parameter.

4.1 Station data availability

The strategy at the ministry has always been to store decision based data at both the station itself and in a remote ministry database. This ensures avalanche staff can interrogate a station's dataset either on the office workstation or when working in the field with minimal bias. A mobile test kit to remotely access weather data is a common tool in the avalanche forecaster's arsenal.

LOW LEVEL SENSOR SAMPLING & PERIPHERAL TIMING DETAILS

(Diagnostic Mode off)

SENSOR/DEVICE	(SUBR)	RATE & DETAILS
Temperature\Humidity	(79)	1 Minute (Checks Min & Max)
Air Temperature #2 **(1)**	(79)	1 Minute for 107Probe or Note#1
Precipitation **(2)**	(82)	4/ Per Hour at 14,29,44,59 Minutes (10 or 20 Point Average)
Snow Depth **(2,3)**	(80)	4/ Per Hour at 14,29,44,59 Minutes (10 Point Average)
Barometer	(81)	4/ Per Hour at 14,29,44,59 Minutes
Wind Speed/Direction	(85)	5 Seconds (for statistics such as gust speeds)
Solar Energy	(92)	2 Minutes
Pavement Data	(93)	1 Hour at 0:54 minutes & if Bad @0:56
Snow Temperatures **(5)**	(88)	1 Hour @0:57 (6HR Output)
CR10 Temperature	(95)	5 Seconds (Table 6 Only)
Precip Circ Pump **(4)**	(83)	1 Hour @ XX:36:00 for 15 Seconds. 25Secs when gauge total >400MM*
Kiwi Sqirt Deicing **(4)**	(86)	6 Hours for 15 seconds
Battery Voltage 1,2,3&4	(95)	5 Seconds (Output Hourly)
Timers	(95)	1 Minute (Table 6 Loc 110-2)
Local Display	(99)	1 Minute or User Triggered
Table7 (Data Output)	(84)	1 Hour

DIAGNOSTIC MODE CAN CAUSE ALL SENSORS (Except Pavement) TO SAMPLE EVERY 5 SECONDS

1. Output timing depends on the sensor configured for Temperature#2. Options are Snow Depth, Snow Temperatures. Or 107 Probe

2. GaugeTotal(Loc40) & Snowpack(39) updated every 15 Minutes. Hourly & New Totals Updated Hourly @ 00 Minutes. The values shown are the average of the best 10 of 12 samples taken over 1 minute.

3. Judd Sensor Only. One valid data point is established by 2 measurements taken 0.1 seconds apart that are within 1CM of each other. **Done internally in the sensor.** Also planned for SR50

4. Kiwi & Circ Pump duration is programmable by changing Table 6 locations 65 & 17

5. Starts @ 57 Minutes with 1 thermistor sampled every 5 seconds. A complete scan takes 105 Seconds. Temp#2 Storage is defined by Mask word 107. See Mask#7

Table 2. *List of Sensor Sampling rates and Timing details*

5. Sensor and derived data outputs with reliability comments

FIELD#	RAWS STANDARD PACKET (Table6 Location/Instruction)	FIELD#	RAWS + SNOW TEMPERATURE POLE	RAWS WINDSITE PACKET	RWIS PACKET
1	PREAMBLE= 115	1	PREAMBLE= 116	PREAMBLE= 117	PREAMBLE= 118
2	STATION Identifier	2......52	Same as 115	Same as 115	Same as 115
3	ELEVAT/ASPECT (Format EEEEA in Meters)	53	User Defined (UDF)#4	User Defined (UDF)#4	User Defined (UDF)#4
4	Year	54	UDF#5	UDF#5	UDF#5
5	Day	55	Snow Temperature_0CM	UDF#6	UDF#6
6	Hour/Minute	56	SnT_020CM	UDF#7	UDF#7
7	MaximumTemperature1(32)	57	SnT_040CM	UDF#8	UDF#8
8	TemperatureAct#1(33)	58	SnT_060CM	UDF#9	UDF#9
9	MinimumTemp1(34)	59	SnT_080CM	UDF#10	UDF#10
10	Temperature#1Quality	60	SnT_100CM	UDF#11	UDF#11
11	Temperature#2(35)	61	SnT_120CM	UDF#12	Pavement Temperature_Loc1
12	Temperature#2Quality	62	SnT_140CM	Wind#2_Elevation/Aspect	Alt Pavement Temperature_Loc1
13	RelHumidity(36)	63	SnT_160CM	12HrWindRoseMag#2	Pavement Conductivity_Loc1
14	Dew_Point(47)	64	SnT_180CM	12HrWindRosePeak#2	Pavement Freeze Pt_Loc1
15	Barometer(52)	65	SnT_200CM	MaxHrlyWindSpd#2 (168/P73)	PvmntCondition_Loc1
16	SnowSurfaceTemp	66	SnT_220CM	MeanHrlyWindSpd#2(172/P69)	Bed_Temp_Loc1
17	Snow_Pack_Height(39)	67	SnT_240CM	HrlyWindSpdQ#2	Pavement Temperature_Loc2
18	New_Snow(37)	68	SnT_260CM	MeanHrlyWindDir#2(173/P69)	Alt Pavement Temperature_Loc2
19	Hourly_Snow(38)	69	SnT_280CM	HrlyStdDevOfWindDir#2 (174/P69)	Pavement Conductivity_Loc2
20	Storm_Snow (Implemented as 3 Day total)	70	SnT_300CM	WndSpd#2Act(144)	Pavement Freeze Pt_Loc2
21	SnowSensorQuality	71	SnT_320CM	WndDir#2Act(145)	PvmntCondition_Loc2
22	Precipitation_Gauge_Total(40) .. (Precip Water Equivalent)	72	SnT_340CM	Wind#2Derime	BedTemp_Loc2
23	New_Precipitation (41)	73	SnT_360CM	PrecipDetector_PrecipType.Variance	PrecipDetector_PrecipType.Variance
24	Hourly_Precipitation(42)	74	SnT_380CM	PrecipDetector_HourlyRate	PrecipDetector_HourlyRate
25	PrecipGaugeQuality	75	SnT_400CM	PrecipDetectorQ	PrecipDetectorQ
26	12HrWindRoseMagnitude#1 Formatted as NESW.Deviation				
27	12HrWindRosePeak#1 NESW.Deviation				
28	MaxHrlyWindSpd#1 (68/P73)				
29	MeanHrlyWindSpd#1(72/P69)				
30	WindSpeed#1Actual(44)				
31	HourlyWindSpeedQ				
32	MeanHourlyWindDir#1(73/P69)				
33	HrlyStdDevOfWindDir#1 (74/P69)				
34	WindDirection#1Actual(45)				
35	Wind#1Derime				
36	MaxHourlySolarEnergy				
37	SolarEnergySince00Hrs				
38	HourlySolarEnergy(Avg)				
39	SolarEnergyQ				
40	Battery1 (Datalogger)				
41	Battery2 (Pump)				
42	Battery3				
43	Battery4				
44	Program_Rev				
45	CR10X_Signature(Ins19)				
46	RxSensitivity				
47	Engineer1 (Air_Col_Temp)				
48	Engineer2 (Intrusion/Visit)				
49	Eng3(Precip Fluid Temperature)				
50	User Defined (UDF)#1				
51	UDF#2				
52	UDF#3 (Last field in Packet)				

Sensor Output Uniits	Comments & Reliability Issues
All Temperature Fields in Degrees Celcius	Accuracy in optimum conditions is better than 1/2 Decree. Can rime up shut at Mountain Top Wind Sites. Can backfil with snow during exception precip events
Relative Humidity is in Percent	Better then 5% accuracy. Less above 90% & Below 25)
Barometric Presure in MM of Hg	Not elevation corrected. Accuracy is +/- 3 MM Hg. A trend indicator is available at Table 6 Loc 53
Actual & Hourly Windspeeds in Km/Hr 12 Hour Wind Roses are in Beautfort	Subject to bias or failure due to Rime & Ice. Alcohol and self shedding "Bendy Mast" deicing scemes are used which ensures better than 65% data return at rime & ice prone
Precipitation in Milimeters (1..2000MM) (Trace Preip is marked as 0.1MM)	Target winter time accuracy is 1 mm. Good for Avalanche Forecasting but data quality can vary. Trace precip is not always reliable. Problems are; capping of gauges, orifice wind dynamics, thermal stability, transducer reliability, subject to freezing. Sensor needs maintenance.
Snow is measured in CM's (Trace Snow is marked as 0.1 CM)	Data qualitiy varies. Limitations are; Snowfall rates > 7cm/hr, Drifting snow, Non Uniform snowpack surface, Snowpack Acoustics, Transducer failures, Settlement can be unpredictable.
Solar energy is in KiloWatts/Meter^2	Sensor is new. Some minor limits on Incedence angle in some applications.
Battery Voltages are in Volts	
Quality numbers are nominal values from -999 to +999. < 0 is deemed as	
Consult with MoT regarding units for other fields	

Table 3. Elements of four varieties of output arrays captured in the datalogger. Records are collected and stored using comma field separators on an hourly basis by base stations operating throughout BC. An average record can be collected in 30 seconds via a Scada telemetry system. Observations are then transferred as packets to the Ministry's Snow Avalanche Weather System (SAWS) Database.

Significant events involving rain, snow or rime can influence station reliability in general. It's affect will vary with air temperature, wind and with the frequency of visits to "dust off" stations. Staff availability, relevance of any data elements to forecasts in general, and QA intervals will all affect the final quality of a station's dataset. The packet formats shown above have been introduced in 2001 to help accommodate changes in station sensor standards. New sensors (eg Solar Energy), sample quality numbers, more engineering data, user definable fields and space for redundant sensors have been added to the traditional elements.

6. Conclusions and Acknowledgements

The automated weather station network of the BC Ministry of Transportation provides the primary source of synoptic weather information relevant to the British Columbia highway system. The data and program as a whole is primarily intended for use by Avalanche forecasters and Road maintenance contractors along with their associated support workers.

The observations also provide a significant component of the forecast verification process performed by agencies that provide highway and community weather forecasting services in BC. When forecasts prove inaccurate, remote stations also provide data on de facto conditions which often support the operational decision making process in lieu of the forecasts.

The record of weather collected is becoming large and at some stations is exceeding 2 decades. It is a potentially valuable tool for managing and planning aspects highways maintenance programs that are directly affected by weather.

The data seems to be somewhat in demand for public purposes also. A properly staffed and funded service to oversee data and associated systems for public dissemination could be of service to the winter traveler especially when planning routes through High Mountain passes. The present unsupervised system of public dissemination provides a service but a potential exists for conflict between station data quality and weather forecast quality.

Automatic weather station design and operations are an evolving combination of Technology, Art and Science. An awareness of sensor operations theory as well as current and past conditions at the station can greatly influence interpretation of data by users. This paper is a small attempt to help bridge the gap between station technology and the resulting datasets which people periodically work with. The importance of station and telemetry system maintenance as a means of ensuring data availability and quality can also not be under stressed.

The datasets have also been used for applications ranging from accident litigation to wind power suitability modeling. Modernization of processes for rendering, visualization and model confirmation could span a whole new era of value for this data. That is assuming numerical and computational processes remain at the forefront of applied meteorology.

Many thanks to all BC MoT Snow Avalanche Program staff for supporting MoT Weather Stations. Special thanks to Brant Benum EET Revelstoke (Deicing) and Paul Heikkila EET Nelson (Mounts) mentioned in the paper as well as Ted Weick SAP Victoria, Art Mcclean SAP Victoria Paul Hadfield EET Terrace, Bill Golley EET Hope, Nic Seaton and Steve Portman SAP Penticton, Doug Tuck SAP Pemberton. All for whom weather station work is a part of daily life in the winter. Final thanks to Jack Bennetto for confidently believing BC MoT's weather station technology is of a quality that merits an expanded network.

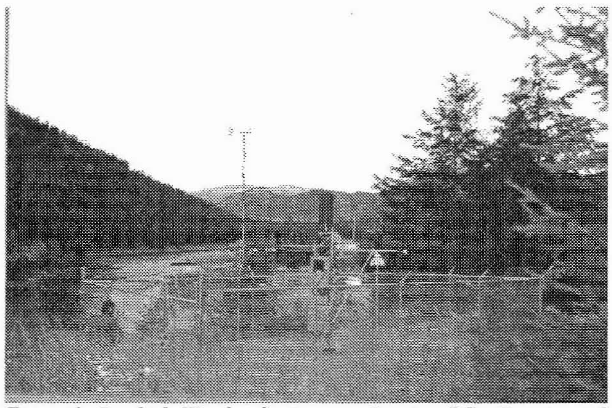

Figure 6. Roadside Weather Station near Barriere BC. Data is used for both Avalanche and Road Temperature and condition forecasting.

References:

Campbell, E. 1988 Standpipe Precipitation Gauge. ISSW Proceedings 146-148

Related Documents:

Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches
By Canadian Avalanche Association, May 1995

Road Weather Information for Winter Maintenance
By Art McClean, MoT. Snow Avalanche Programs, June 1996