

CANADIAN SNOWFALL MEASUREMENTS: SOME IMPLICATIONS FOR 642-78
THE COLLECTION AND ANALYSIS OF DATA FROM REMOTE STATIONS 1/

By

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Introduction

Over the past few years there has been a significant effort within the Atmospheric Environment Service (AES) to investigate the adequacy of our present methods of measuring snowfall precipitation. AES operates a national network of about 2700 weather observing stations. The MSC Nipher shielded snow gauge is the standard instrument used to measure snowfall precipitation at more than 325 stations. At stations without a snow gauge the measured ruler depth of fresh snowfall is converted to water equivalent by dividing the depth by ten. Both methods of measurement require at least daily measurements by observers. In addition AES processes data from a network of over 110 Fischer and Porter recording precipitation gauges located at sites where regular observations are not feasible. The Universal gauge is used only in a few research and experimental basins. However, with increased automation and the demand for real-time acquisition of data from remote sites, automatic recording gauges, such as the Fischer and Porter, are becoming more important in the operational observation network. One then is faced with the problem of comparing data from different sites, while using different methods of measurement.

The problem of snowfall measurement, particularly as related to snow gauge measurements, has been recognized and investigated in other Northern countries. Members of both the Western and Eastern Snow Conferences have been concerned with this problem for many years (for example: Warner, 1966; Rechar and Larson, 1971; Larson, 1972; Hamon, 1973; Larson and Peck, 1974; Rechar et. al., 1974). Canadian field investigations to evaluate the accuracy and comparability of different methods of snowfall precipitation measurements were limited. Beginning in 1973, a series of projects were conducted by personnel from both the Hydrometeorology Research Division and the Atmospheric Instruments Branch aimed at evaluating and improving the accuracy of Canadian snowfall measurement methods.

Field investigations to assess the accuracy and comparability of different snow gauges have been conducted at the Cold Creek Hydrometeorological and Woodbridge Research Stations north of Toronto. Additional studies are being carried out at Peterborough and Monticello Ontario and Resolute N.W.T. to investigate the benefits of artificial shielding of gauges. Flow visualization experiments to study the airflow around shielded and unshielded gauges were conducted in the AES wind tunnel. Finally, research and development work was being carried out concurrently on the Fischer and Porter gauge to obtain increased resolution.

This paper will briefly review the accuracy of snow gauges as determined by field studies at the Cold Creek station, with particular emphasis on the accuracy of the Fischer and Porter gauge, since it is most suited to the remote telemetry of precipitation data. Methods being developed and tested by the Atmospheric Instruments Branch to increase the resolution of the Fischer and Porter and to incorporate a built-in processing facility to correct measured gauge catch for environmental parameters will be presented.

Accuracy of Snow Gauges Used in Canada

Long term observations have shown that, even at the same site, different gauges can provide significantly different precipitation totals (Allis et al., 1963; Harris and

1/ Presented at the Western Snow Conference, April 18-20, 1978, Otter Rock, Oregon. Mention of trade or company names in this paper is solely for the benefit of the reader.

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Carder, 1974). Wind has been shown to be a major cause of error in precipitation gauge measurements (Weiss and Wilson, 1957; Larson and Peck, 1974; Goodison, 1977a). Basically, the catch efficiency of precipitation gauges decreases with increasing wind speed, but siting in a natural "well-protected" location will minimize the effect of wind. In practice, however, in much of Canada it is often difficult, if not impossible, to find the ideal location. Consequently, gauges are necessarily placed in exposed windy locations. Determination of the relationship between the catch of different gauges used in Canada and environmental parameters was a necessary first step before new or improved methods of measurement could be developed or evaluated.

The field procedures used to assess the accuracy and comparability of snow gauges at the Cold Creek station are presented in detail in Goodison (1977a) and summarized in Goodison (1975; 1977b). Instruments evaluated included the Fischer and Porter, Universal (Belfort), and MSC Nipher shielded snow gauges. Gauges were located at two open and two sheltered sites in order to sample a wider range of wind speeds. Shielded and unshielded pairs of gauges were located at the open sites. An Alter shielded Fischer and Porter and MSC Nipher shielded snow gauge were installed at each site. Wind speed at gauge height (2m) was measured at all sites. "Ground true" precipitation was determined by weighing the storm snowfall which accumulated on snow boards located at the two sheltered sites. To minimize the effect of measurement errors or possible biases, only storm totals with a ground true value greater than 5 mm snow water equivalent were used in the final analysis. The contents of the Nipher gauge were both weighed and poured out in order to assess retention losses. The Universal gauges were operated in the normal manner, but to overcome the coarse 2.54 mm incremental weighing resolution of the Fischer and Porter gauge, weight-bags were attached under the orifice in place of the bucket to catch the snow. These bags were weighed after the storm to determine the snowfall water equivalent.

An example of an initial plot of results is given in Figure 1. It summarizes the relationship between the ratio of gauge catch to ground true snowfall as a function of wind speed for the Fischer and Porter gauge. The results are differentiated by site and storm total. Data from the four sites were quite consistent with the smaller storms falling within the range of the larger ones.

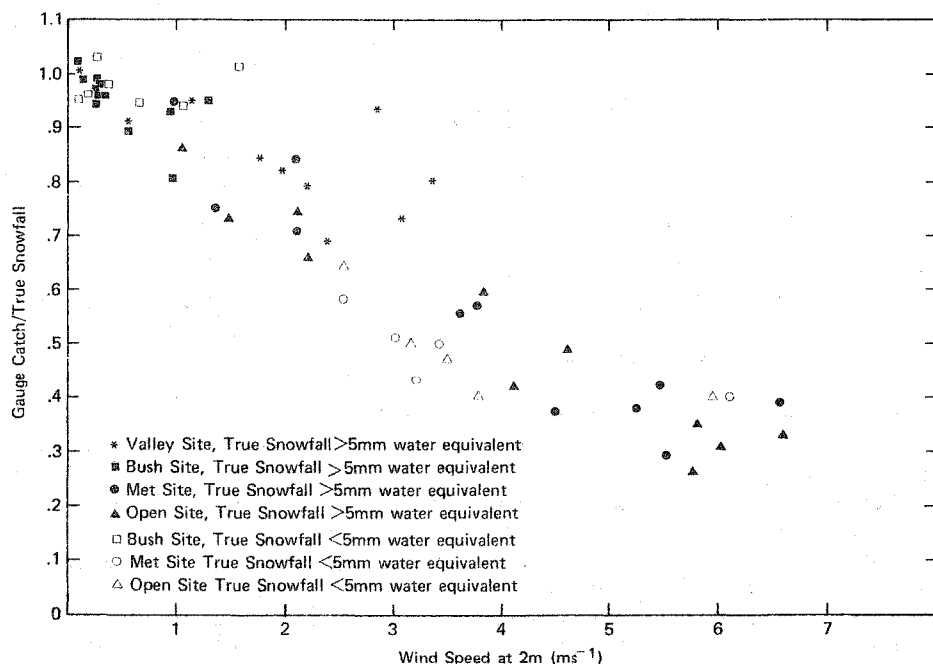


Figure 1: Observations of gauge catch versus wind speed for the Alter shielded Fischer and Porter precipitation gauge

To assess objectively the effect of environmental parameters on gauge catch, standard stepwise multiple regression procedures were used to analyze the ratio of gauge catch to ground true. Parameters assessed in the analysis included mean storm wind speed, screen air temperature, 700 mb and 850 mb temperature, and density of newly fallen snow. For all gauges tested wind speed was the dominant environmental parameter influencing gauge catch. For the Fischer and Porter and Universal gauges, screen air temperature was a statistically significant secondary parameter, although in the Cold Creek tests it added only a 2% and 1% increase in the explanation of variance of the respective models. In Figure 1, the three notable deviations of valley and bush site data occurred when the mean air temperature was near or above freezing, i.e. $\pm 1.0^\circ\text{C}$. Figure 2 shows the fitted curves of the gauge catch ratio as a function of wind speed and air temperature for the shielded Fischer and Porter gauge based on storm total greater than 5 mm. The exponential relation shown was typical for all gauges tested except the Nipher shielded gauge. For the Universal and Fischer and Porter gauges, screen air temperature was positively related to catch, i.e. the higher the temperature the higher the catch ratio. These results follow the relations suggested by previous American investigations (e.g. Hamon, 1973). For the same environmental conditions, the Fischer and Porter had a lower catch ratio than the Universal gauge.

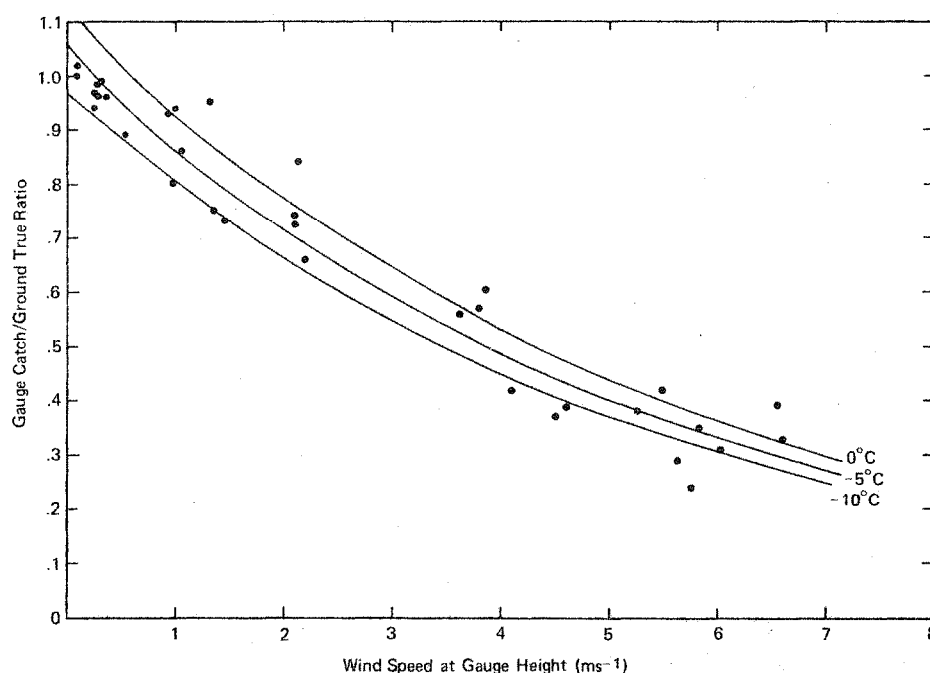


Figure 2: Gauge catch ratio as a function of wind speed and temperature for Alter shielded Fischer and Porter precipitation gauge

The results for the Canadian MSC Nipher shielded gauge were very different. Figure 3 compares the mean curves of gauge catch ratio with respect to wind speed for the three types of shielded gauges. For wind speeds up to 4 ms^{-1} the Nipher gauge overmeasured true snowfall, and for speeds up to 5.5 ms^{-1} the mean gauge catch is within 10% of true. Screen air temperature was inversely related to gauge catch, but it was not statistically significant. Instead the 700 mb temperature was a significant secondary parameter. The Nipher gauge also requires a correction for the retention of moisture in the collector when its contents are melted and poured out for measurement. The mean retention loss was $0.15 \pm 0.02 \text{ mm}$ for each observation. Since the gauge is non-recording, adjustment for trace observations is also necessary. A more complete discussion of these corrections and their significance, particularly in low snowfall regions such as the Prairies and Arctic, is given in Goodison (1978).

As found by other researchers, unshielded gauges caught less than their shielded counterparts. Preliminary results for these gauges are summarized in Goodison (1977b). Of

particular interest was the fact that the unshielded collector of the Nipher gauge displayed an exponential decrease in catch ratio with increasing wind speed similar to other shielded and unshielded gauges, but quite unlike its shielded counterpart. This suggests that the superior catch ratios of the Nipher gauge are a result of the solid shield design. It appears that "undercatch" associated with Nipher gauge measurements are related as much to the method of observation (i.e., the problem of trace amounts and retention losses) as the gauge design (Goodison, 1978).

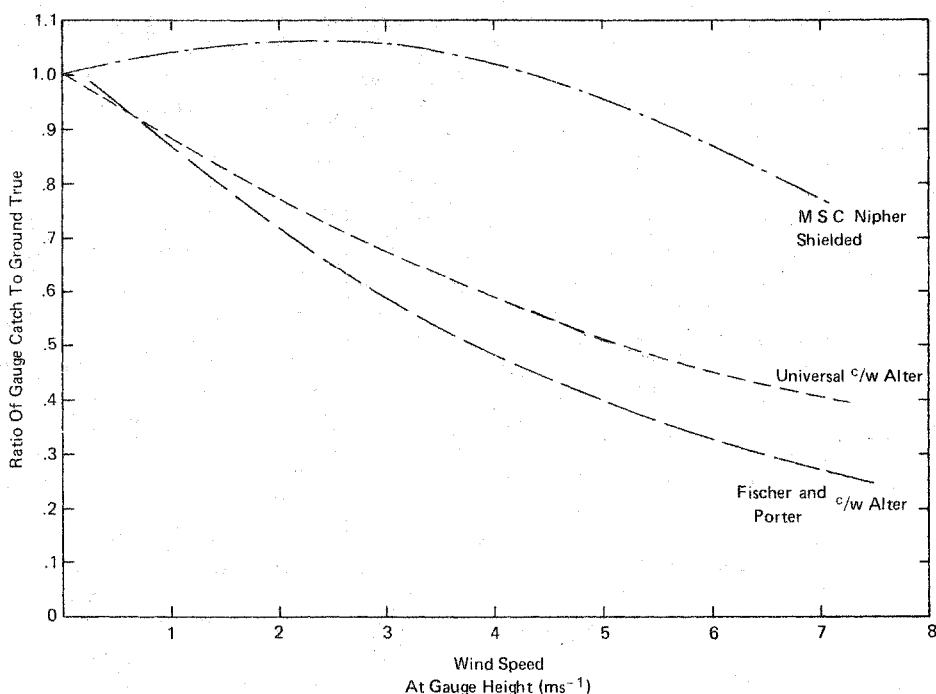


Figure 3: Gauge catch ratio as a function of wind speed for shielded precipitation gauges

Implications for the Collection and Analysis of Snowfall Data

The results emphasize that each type of gauge requires individual correction procedures to determine true precipitation at a point. It is clear that to obtain comparable precipitation data for either the same site or sites with different exposures, correction for environmental factors, notably wind speed, is required. In 1978, is it not time that we get away from using measured precipitation solely as an index and give some consideration to its use as an absolute quantity?

At last year's Western Snow Conference there were several papers related to hydrologic modelling which involved the use of snowfall data. Tangborn (1977, p. 39) in reference to the selection of precipitation stations in basin analyses stated that: "additional precipitation gages placed within or very near the drainage basin would likely improve the estimate of basin precipitation. It should be noted that high altitude stations are not necessarily the most representative. The reason for this is believed to be the difficulty in catching precipitation as snow at these exposed, windy sites".

There will certainly be a problem of measurement at high altitude sites and uncorrected gauge measurements certainly will not be representative of true precipitation. Would the correction of data from such sites provide more suitable input data for our hydrologic models?

Keyes (1977) discussed the need for the expansion of national climatic networks to include high elevation precipitation measuring stations to assess future weather modification activities. Sites would be required upwind, within and downwind of mountain target areas. Presumably for such a study exact absolute quantities would be necessary in order

to assess accurately the effect of weather modification schemes. The above results indicate that unless exposure, environmental conditions, and type of equipment are identical at all sites the measured precipitation statistics would not be comparable. Use of gauge catch correction curves would be one approach to achieving comparable snowfall data for the sites.

Then there was the evaluation by Baker et al (1977) of four snow models, two of which included a "precipitation adjustment factor" and two which did not. The conclusion was that the output of all models was quite sensitive to small adjustments in air temperature and precipitation, indicating the need for accurate daily records of these parameters if the models were to be used to simulate the snow regime on a particular site. If a continuous physically-based conceptual hydrologic model is to be used effectively, comparable and accurate precipitation data must be used. A change in the method of measurement at a station will affect a time series analysis of historic data. Any areal analysis of precipitation gauge data from sites with varying exposures can provide very misleading results unless corrections for variations in gauge catch are first made.

The problem becomes even more perplexing when considering the measurement and analysis of data from remote stations and their comparability with standard network stations in say an international drainage basin such as the Columbia or Saint John. The MSC Nipher shielded snow gauge and the Alter shielded Universal gauge are the national standard gauges for snowfall precipitation measurement in Canada and the United States, respectively. The analysis of gauge catch efficiency has shown that, under similar conditions, these gauges will provide very different snowfall water equivalent totals which could cause an artificial discontinuity in the precipitation pattern at the Canada-United States border. To avoid such a discrepancy in areal analyses, the measured precipitation should first be corrected to achieve comparable data sets.

If it is necessary to expand the regional or basin network, it is only reasonable to want data which can be readily compared to the longer term network station data. One way is to use similar equipment and install it at a site with a similar exposure. In Canada this would require installation of a Nipher gauge at a relatively exposed site. Although the Nipher gauge has a superior catch efficiency compared to the other gauges, it is non-recording and must be attended daily by an observer. Consequently, it is not presently suited to situations which require measurements from remote sites.

In Canada, the alternative choice has been the use of the Fischer and Porter gauge, an instrument with characteristics suited to the collection and, if necessary, real-time transmission of precipitation data from remote stations. There is a serious problem, however. The Fischer and Porter gauge had the poorest catch efficiency for snowfall of all gauges tested. Unless the gauges were well sheltered so as to minimize the effect of wind, the measured catch should be corrected for the effect of wind speed and temperature in order to be useful. Cold Creek tests showed that a well sheltered Fischer and Porter gauge could provide acceptable uncorrected measurements, i.e. within 5-7% of true. If gauges must be located at exposed or partially sheltered sites, then a record of wind speed at gauge height is necessary to correct the measured precipitation total. This creates a problem since wind speed is not normally measured at remote stations. Given the correction curves above this requirement should be given serious consideration if accurate data are really our aim. In Canada the Fischer and Porter gauge is currently being installed at the new automatic weather stations at a unit cost of \$5500. Should we not seriously ask what kind of data we will receive from this instrument? Will the data be only an indicator of when precipitation occurred? Will the data even do that?

A problem with the Fischer and Porter gauge and the application of its correction curves is its resolution of 2.54 mm. For example, for a snowfall with density of 0.08 gcm^{-3} , falling at a wind speed of 4 ms^{-1} and an air temperature of -5°C , more than 6 cm depth would be required before the event would even be recorded on the punch tape. It might take several small storm events before the gauge even recorded that precipitation had occurred. This resolution limits the accurate application of gauge catch correction procedures as it may be difficult to accurately define when the snowfall event had occurred. An example of the application of gauge catch corrections is given in Table 1.

The results were very encouraging, especially considering the magnitude of some of the corrections; however, the constraint of the 2.54 mm resolution is evident. Correction of Fischer and Porter data from sites where many small events occurred over varying wind

speeds has proven more frustrating. In heavy snowfall regions, particularly at sheltered sites, this problem is certainly less significant. In Canada, however, if the instrument is to be used at sites where in reality its use was not designed for, then improved resolution and the utilization of correction procedures may be a potential alternative.

Table 1

Calculation of True Snowfall Water Equivalent (mm)
for Individual Storms at Cold Creek, Ontario, 1972-1973

Date	Ruler ($\rho = .1$)	Nipher		Unshielded Universal		Alter shielded F&P	
		Uncorr.	Corr.	Uncorr.	Corr.	Uncorr.	Corr.
29/12	12.19	11.43	11.17	5.33	13.00	5.08	12.93
27-28/01	2.29	7.52	7.44	4.32	8.38	5.08	8.25
07/02	8.64	6.73	6.51	2.03	4.19	2.54	4.54
14-15/02	1.78	4.22	5.94	1.16	4.82	2.54	6.62
20-21/02	11.69	12.44	12.15	4.70	9.45	5.08	8.41
25/02	6.60	3.86	3.78	2.03	4.08	2.54	3.29
Totals	43.19	46.20	46.99	19.57	43.92	22.86	44.04

Increasing the Resolution of the Fischer and Porter

First let us assure you that you should not run to your local dealer and buy one of the units about to be described. The purpose of the instrument system developed for this test was to satisfy a specific requirement and to verify a concept. It is the concept which will be elaborated on here.

With the advent of microprocessors it is now possible to attempt to make measurements which were at best impractical using standard analog and digital circuits. They allow such things as algorithm linearization, numerical averaging and decision making to be accomplished at the sensor level.

In the case of precipitation sensors the Atmospheric Environment Service has had an automatic weather station requirement for a precipitation sensor with a high resolution to be used as an indication of the occurrence of precipitation. For summer operation a tipping bucket rain gauge with a resolution of 0.25 mm was satisfactory; however, for most of Canada using heated gauges during the winter gave totally unacceptable results for measuring snow. A weighing gauge provided acceptable totals, but available gauges do not have sufficient resolution. During our evaluations we noted that the Fischer and Porter Gauge had the potential for significantly higher resolution than allowed by its mechanical encoding disc (2.54 mm). Visual estimation of precipitation could be made to better than 0.51 mm.

By substituting a Baldwin optical absolute position encoder for the mechanical encoder we found that under laboratory conditions a resolution of 0.25 mm was easily obtainable. Outside, however, oscillations due to wind pumping were much more evident with the increased resolution, and although the damping fluid tended to minimize the magnitude of wind pumping, it did not eliminate it. It was also found that under calm wind conditions the damper could cause the gauge mechanism to stick if it was not very carefully adjusted. This tended to reduce the resolution to about 0.76 mm.

At this point in the development the microprocessor provided a possible solution. The Fischer and Porter gauge is a second order mechanical system that oscillates in a well prescribed fashion. The true weight of the accumulated precipitation could be determined by making frequent measurements of the weight (at a measuring frequency higher than the natural oscillation) over several cycles of oscillation and averaging the results. However, since the system has a sinusoidal oscillation with only a small amount of damping it is sufficient to measure the maximum and minimum indicated weight over several cycles and find the mean. These points are easy to measure because the time interval spent near the maximum and minimum points is relatively longer than at any other positions. The technique

of obtaining the average weight as the mean of the maximum and minimum indicated weights not only allows us to extract a meaningful measurement during wind pumping, it allows the possibility of obtaining a mean with twice the resolution of the individual measurements. This factor can be used to minimize digitizing errors. Figure 4 shows a simplified flow chart for the system. In the feasibility stage the system was programmed on an Intel 4004 to measure precipitation only and output the result on an LED display. While this proved that the concept was sound the microprocessor system used was not practical for operational use.

At about this stage of the investigation the results of the Canadian field experiments were becoming available. This represented a good opportunity for a joint project whereby we could combine a field test of a precipitation gauge with a built in processing facility and provide increased resolution for further snow studies.

In order to minimize the amount of development work it was decided to use commercially available equipment as much as possible. An Intel System 80/10 single board computing system was used to measure and process the precipitation gauge data, measure wind, temperature and dewpoint, and format an output message to an ASR33 Teletype machine. The analog voltage data from temperature and dewpoint sensors were measured using an Intel 723 A/D board which is designed for the 80/10 system. Non commercial design consisted of building the following:

- 1) the optoisolator interface between the Baldwin Shaft encoder, the wind sensor, and the System 80/10 I/O ports.
- 2) a 2Hz crystal controlled oscillator for the real time clock.
- 3) Resistance to voltage converters for the temperature and dewpoint sensor.
- 4) Software.

Items 1) and 3) were built on an auxillary development board which fits into the System 80/10 card frame. Software was written in PLM high level language on an Intel MDS development system. This allows very rapid turn around for changes in programming that may be necessary. This is a desirable feature in an experimental system because it allows easy correction of erroneous algorithms and it allows the system to be reconfigured when necessary. For instance, since we could not get delivery of the A/D board we were able to configure the software to produce dummy temperature and dewpoint data for testing purposes.

Figure 5 shows a sample of the output from the system. A printout is produced every 10 minutes and whenever an increment of precipitation occurs. The system samples the precipitation and wind sensor approximately 1300 times per second. It determines the maximum and minimum precipitation readout during a 4 second interval and calculates the average precipitation value. This is compared to the previously calculated value to determine if precipitation has occurred. Meanwhile the input from the wind sensor is accumulating the number of revolutions made by the cups. This data is updated at each 10 minute readout. Before each printout the temperature and dewpoint are read and the corrected precipitation is calculated using the algorithm based on the Cold Creek field tests. It is intended to use the dewpoint to determine when the precipitation is rain (dewpoint $>0^{\circ}\text{C}$) where no correction is made and snow (dewpoint $\leq 0^{\circ}\text{C}$) where the correction is calculated.

The printed output format is as follows:

DAY:HR:MN

Incremental amount of precipitation since last printout (x.01 inches).

Total accumulated precipitation (average) (x.01 inches).

Maximum indicated precipitation since last 10 minute readout (x.01 inches).

Minimum indicated precipitation since last 10 minute readout (x.01 inches).

Wind speed during last 10 minute interval (x.01 mph).

Temperature ($^{\circ}\text{C}$)

Dewpoint ($^{\circ}\text{C}$)

Corrected incremental precipitation since last printout (x.0001 inches).

FISCHER & PORTER PROCESSOR

DAY:MM:MN IS 020:14:41 IF CORRECT TYPE C

020:14:41	156	156	156	156	2	99	99	>976
020:14:50	0	156	157	156	475	99	99	0
020:15:00	0	156	157	156	580	99	99	0
020:15:10	0	156	157	156	627	99	99	0
020:15:20	0	156	157	156	582	99	99	0
020:15:23	1	157	157	156	169	99	99	156
020:15:30	0	157	157	156	600	99	99	0
020:15:40	0	157	157	156	584	99	99	0
020:15:50	0	157	158	156	588	99	99	0
020:16:00	0	157	157	156	565	99	99	0
020:16:10	0	157	158	156	569	99	99	0
020:16:20	0	157	157	157	543	99	99	0
020:16:30	0	157	158	157	602	99	99	0
020:16:31	1	158	159	156	99	99	99	156
020:16:40	0	158	159	156	578	99	99	0
020:16:50	0	158	158	157	488	99	99	0
020:17:00	0	158	158	157	552	99	99	0
020:17:10	0	158	158	157	534	99	99	0
020:17:20	0	158	159	157	543	99	99	0
020:17:30	0	158	159	158	553	99	99	0

Figure 5

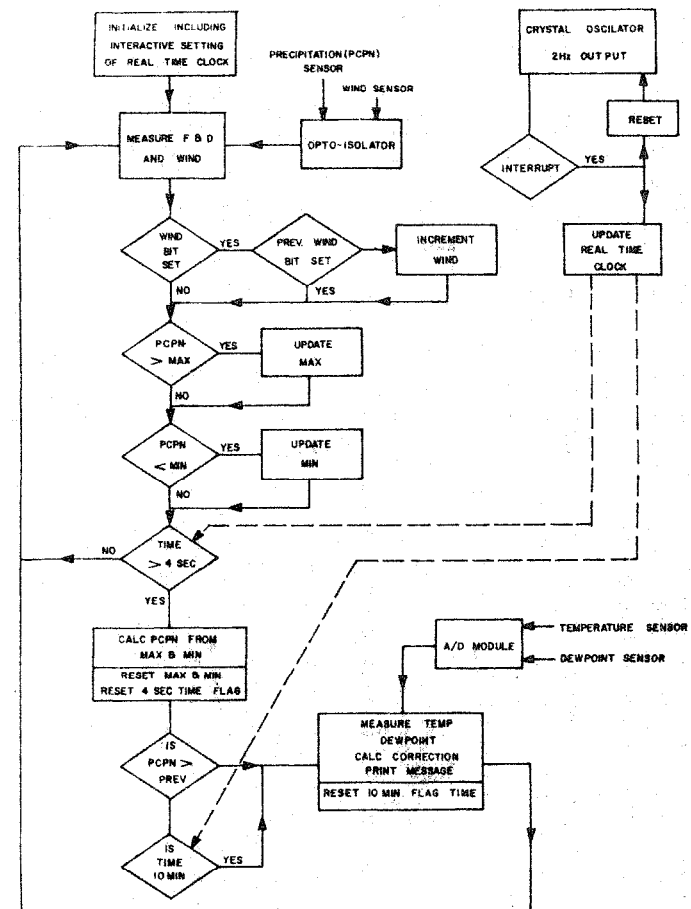


Figure 4

Note: The maximum and minimum values are included in this readout to indicate the magnitude of wind pumping. The difference of these two values was greater than 0.30 during one storm at our headquarters site this winter.

Unfortunately the system was not installed in the field until late in the snowfall year so that the amount of data obtained was limited. Testing will continue next year at which time temperature and dewpoint parameters will be included and a fuller assessment of the utility of the system will be possible.

On the practical side, this system could hardly be considered suitable for our network application. The cost of the system is about \$10,000, it requires 110 VAC power, and a multiconductor cable between the sensors and the heated shelter for the System 80/10.

However, we are now developing low power, low temperature microcomputer systems which can be combined with a meteorological sensor or group of sensors to provide a "smart" sensor. This "smart" sensor will be able to process the raw sensor signals, provide linearization, averaging, or corrections as required (or requested under software control), provide self evaluation, and enable communication of this data with a minimum of hardware. We hope the data from this test will put us a step closer to the introduction of smart precipitation gauges.

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