Workshop Summary: Ensuring Quality Long-Term Monitoring with Precipitation Gauges

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Goals and Motivation

Obtaining accurate precipitation measurements is a problem that has plagued scientists for centuries, and many challenges remain. For example, collecting snow and other solid precipitation poses a different set of difficulties than those involved in collecting liquid precipitation. In the mid-1980s, this need for better solid precipitation measurements gave rise to a new style of precipitation monitoring using an automated weighing bucket type gauge. In this system, precipitation is collected in a bucket and accumulated amounts are determined as the bucket becomes heavier. Major improvements associated with this style of monitoring precipitation include the following:

- the sensors are considerably better at monitoring solid precipitation;
- the sensors are considerably better at measuring very light rates of precipitation;
- the sensors are capable of measuring very high rates of precipitation as long as the bucket does not overflow; and
- the sensors operate well in unmanned situations.

Weighing bucket type gauges are being used in a number of national networks, particularly in Canada and in the Scandinavian countries. The U.S. Climate Reference Network (USCRN), with 38 sites currently in operation, is also using a weighing bucket gauge. The automated weighing bucket style of monitoring is now accumulating its own substantial history and is expected to play an increasingly important role in the future of precipitation monitoring. As with all measurement systems, however, there remain some outstanding issues with regard to operating and obtaining quality data from the instruments.

The issues associated with long-term network operation of automated weighing bucket gauges led to the organization of a workshop, held in Boulder, Colorado, in May 2003. The workshop brought together scientists and engineers involved in precipitation measurement and analysis to discuss issues related to the long term operation and measurement quality of the weighing bucket gauges. Representatives from the Swedish Meteorological and Hydrological Institute (SMHI), Environment Canada, the U.S. Climate Reference Network (USCRN), the National Center for Atmospheric Research (NCAR), the University of Oklahoma, and the University of Alaska attended the workshop, along with data users from the National Snow and Ice Data Center (NSIDC) and the Colorado Climate Center. Technical personnel from Geonor and from Campbell Scientific also attended.

The workshop was organized based on discussions with the World Meteorological Organization (WMO) concerning challenges related to long-term climate monitoring. The goal of the workshop was to address several issues pertinent to the long-term network operation of precipitation gauges in the USCRN as well as in other national networks. The workshop included talks providing an overview of precipitation measurements and their applications, as well as overviews describing the weighing bucket approach used for precipitation measurements in networks in Sweden, Canada, and the U.S. An overview of the weighing bucket instrument used in these networks and individual studies focusing on aspects of the measurements and possible errors were also presented. Roundtable discussions helped to elucidate current needs and recommendations for issues pertinent to the long-term network operation of precipitation gauges. Topics discussed include the use of antifreeze and oil, sampling frequencies, snow-capping, wind undercatch, quality assessment, and other issues relevant to long-term, high-quality measurements.

Summary Reports

Importance of climate-quality measurements

Roger Barry (National Snow and Ice Data Center) made the important statement that although humans have spent centuries attempting to measure precipitation, the measurements are still not done well. Accuracy can be difficult to obtain, or even define, for precipitation measurements, but is extremely important for understanding climate variability and change. Betsy Weatherhead (CIRES/U. Colorado-NOAA) highlighted the importance of reducing measurement error, particularly in the face of general circulation model projections indicating a 5% increase in precipitation over land over the next 100 years. The magnitude of this change is small and will require extremely accurate long-term measurements for verification. Obtaining climate quality precipitation data will require overlap with existing measurements. As pointed out by Daqing Yang (University of Alaska at Fairbanks) and Roger Barry (National Snow and Ice Data Center), there is also a continuing need for intercomparisons and tests of various gauge-wind shield configurations.

Overview of the automated weighing bucket gauge

The workshop focused primarily on one type of automated weighing bucket gauge used in several national networks. This gauge, manufactured by Geonor, collects precipitation in a bucket suspended by wires. The wires vibrate at different frequencies as the bucket becomes heavier and these frequencies of vibration can be translated to an accumulation amount in the bucket. Two configurations of this gauge are currently used in national networks. Canada and Sweden use the traditional one-wire Geonor, in which one vibrating wire and two support chains are used to suspend the bucket. The USCRN has opted to replace the two support chains with additional vibrating wires. This three-wire system provides greater redundancy and is expected to aid significantly in evaluating the quality of the data. Both the Canadian and the Swedish groups were considering possible moves to the three-wire system, citing the improved accuracy as a key advantage.

Bucket contents

When collecting precipitation using a weighing bucket gauge, oil and antifreeze are added to the collection bucket to prevent evaporation and freezing. The oil and antifreeze amounts may vary by season and location, as is currently the case for Sweden's network. Removal and proper environmental disposal of the oil and antifreeze are an issue for everyone, and more environmentally friendly oil/antifreeze mixes need to be explored. Certain components of the mixtures can be environmentally toxic, but using an acceptable mixture is necessary to obtain accurate measurements that are not affected by evaporation or freezing of the bucket contents.

Other quality issues include unwanted additions to the buckets. For instance, birds can get into the collection bucket but are generally large enough to detect. Dust or other debris may fall into the bucket gradually and be difficult to detect. Multi-type precipitation measurements (for instance, an optical sensor) may be needed to address this problem.

Wind effects, wind shielding and undercatch

Wind can reduce the amount of precipitation collected by any type of precipitation gauge. Significant effort has been devoted to studying wind effects and the general undercatch of precipitation measurement instruments, but the problem is not yet solved. Ann-Christine Andersson and Sverker Hellström (both from the Swedish Meteorological and Hydrological Institute), Yves Durocher and Craig Smith (both from Environment Canada), and Daqing Yang (University of Alaska at Fairbanks) all report that there are a number of cases in which a shielded gauge has measured only 50 to 80% of the precipitation collected by an unshielded gauge (Figure 1). This problem is not uniform across networks because different wind shields are used. Canada and Sweden both currently use a single alter wind shield while the USCRN surrounds the raingauge with a single alter and a small double fence intercomparison reference (SDFIR) shield (Figure 2). SMHI has performed simulations showing that for the single alter configuration the air flow around the gauge is not uniform.

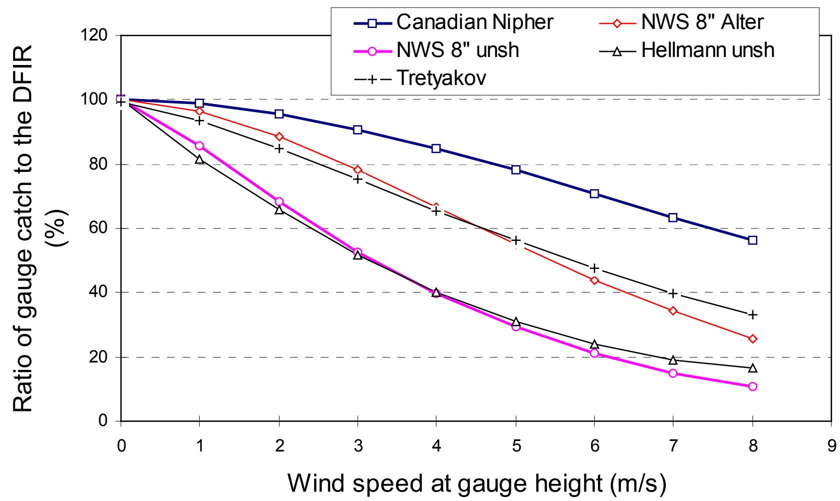

Figure 1. Wind undercatch for different gauge-wind shield set-ups relative to a gauge in a DFIR wind shield. (From Daqing Yang)

Correcting the wind undercatch effect is critical to both climatological understanding and real-time monitoring. There is an urgent need to develop appropriate adjustments for each of the wind shields in use. The corrections depend on the relationship between fall speed and wind speed, as well as on turbulence. These factors ultimately determine the angle at which precipitation approaches the gauge. The timescales of corrections are important, and at certain timescales it may be possible to improve the corrections by using real-time winds. Other factors that must be taken into account include snow-capping and contributions from snow build-up falling into the gauge.

Studies were reported on different wind shield configurations and set-ups, and included a comparison of six Geonor gauges in different wind shields undertaken at the National Center for Atmospheric Research (NCAR) by Claude Duchon at University of Oklahoma and Chuck Wade at NCAR. In these comparisons, the small double fence intercomparison reference (SDFIR) shield was found to perform very well. The USCRN program is currently conducting a precipitation bias study at the National Weather Service's Sterling, Virginia, and Johnstown, Pennsylvania, test facilities. The study includes most raingauge/shield configurations that have been used in the U.S. These studies need to be expanded to other locations and should perhaps involve U.S.-Canada co-locations.

Figure 2. UCSRN rain gauge with single alter and SDFIR wind shields. (From Bruce Baker)

Diurnal variations
One common problem for all of the networks is the unexplained diurnal variations in the data. At first, these variations may seem to be only a small detail, but they have direct impacts on the networks' ability to meet their goals of real-time precipitation reports. The magnitudes of the variations vary from sensor to sensor but are generally on the same order as trace amounts of precipitation. The variations are sometimes out of phase with temperature changes, so don't seem to be temperature related, and more work clearly needs to be done to understand the causes. Possible culprits include combined effects from wind or temperature, bending of the pedestal, balance of the bucket, solar radiation, deformation of the bucket, electronics, gravity, and dew or frost.

The Swedes have developed a simple algorithm to address the problem, but without understanding the cause of these variations it remains difficult to definitively discern precipitation accumulation in real time. Because these variations are somewhat repeatable from day to day with a given sensor, looking at the last few days of data allows an analyst to more easily determine whether or not the variations actually correspond to precipitation. Automation is more challenging, however, and when looking only at only the last few hours of data, it is difficult to determine whether an increase should be interpreted as precipitation or be disregarded as a diurnal fluctuation. The nature of the problem requires that the physics be better understand so that variations not due to wind pumping can be eliminated from the data. The three-wire configuration may be useful in diagnosing this problem by providing information on different parts of the bucket system. An adequate understanding of the phenomenon will assist in obtaining better real-time data and in identifying trace precipitation amounts.

Gauge Heating

Whether or not to heat precipitation gauges also remains an outstanding issue. Prior wisdom had cautioned against heating because of potential evaporative losses. Chuck Wade (NCAR) presented results suggesting that heating is necessary to prevent snow build-up that can interfere with precipitation collection. Claude Duchon (University of Oklahoma) reported some results comparing heated and unheated gauges in a double-alter windshield. The heated gauges seemed to report better precipitation values and there were no problems with snow build-up on the inlet or inside the gauge, as can happen with unheated instruments.

Mark Hall (NOAA ATDD) has also explored some options for heating the weighing bucket gauges, and these methods seem to have success for instruments in the field. Two aspects discussed by both Hall and Duchon involve using a controlled heating mechanism based on temperature or time to avoid any loss from evaporation (Figure 3). The heater used by Hall did not operate below a certain temperature at which precipitation build-ups would be unlikely, however Wade pointed out that snow could possibly stick to the gauge under high wind conditions at temps down to –20 ºC so there may be no threshold below which heating would be unnecessary.

Workshop discussions suggested that there is a need to revisit prior recommendations never to heat a precipitation gauge. It is not clearly understood whether or not the recommendations apply only to non-weighing bucket type gauges, but it is evident that heating is critical for solid precipitation measurements. Controlled and intermittent heating, which requires that the temperature of the sidewalls be carefully monitored, may be the best solution for reducing evaporative losses. Because not all sites have sufficient electricity, power and power availability are a concern. Further studies are needed to determine the potential benefits of gauge heating and to best balance the advantages for solid precipitation measurements against potential losses from evaporation.

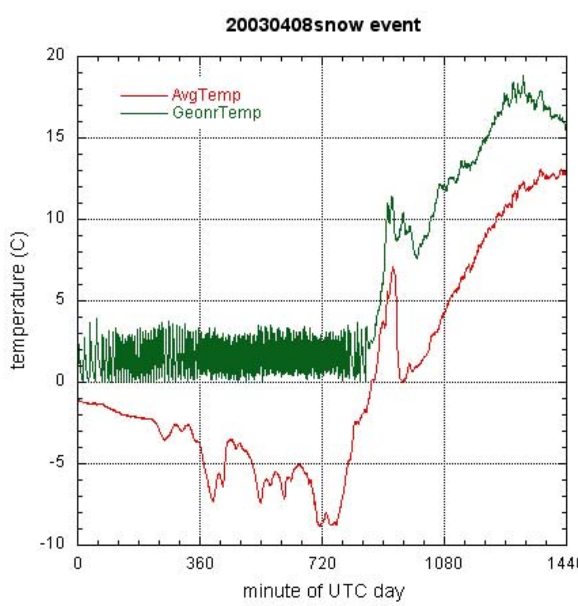

Figure 3. Gauge heating can help keep the sidewall temperatures above freezing to prevent snow build-up and capping. The figure shows the ambient temperature (red line) and the gauge temperature (green line) over the course of one day. When the ambient temperature was below 0 ºC, a heater turned on to warm the instrument and prevent snow capping on the top of the gauge. The heater was controlled so that the temperature of the instrument would never exceed approximately 4 ºC. (From Claude Duchon)

Instrument Failures

Both critical and non-critical types of instrument failures were discussed. In a non-critical failure, the data can still have value. Wire breakage is the most common failure observed. The wires used in the Geonor gauges were reported to be very stable and breaks have been infrequent. Ann-Christine Andersson and Sverker Hellström of SMHI have observed only five wire breaks on more than 100 Geonor gauges in seven years (7,052,000 network hours) of operation. All of the breakages were attributed to handling problems while emptying the bucket; no wires have broken during operation. Canada has had no failures thus far. The USCRN has had 6 wire breakages in 265,000 gauge hours.

For the one-wire Geonor system, a wire breakage is a critical failure. Soon after this workshop, modifications were developed to ensure that a wire breakage in the three-wire system will not be a critical failure. All possible failures should be understood to preserve the overall quality of the data. Failures that could still allow data to be reported must be identified so that the data can be corrected or flagged.

General Set-up and Maintenance

Set-up instructions are important for data quality and are detailed in the operating manuals for the gauges. Improper leveling, weak supports, or vibrations can result in bad or questionable data or in wire breakage. The magnitude of potential problems and options for improvement must be assessed. Options for improvement include wrapping the pedestal and measuring to verify that there is no tilt.

Maintenance routines remain an important component and vary among networks. Maintenance includes facilities work, requiring no technical expertise, as well as regular technical visits. Maintenance people must be adequately trained, and standardizing and thoroughly documenting procedures are necessary for ensuring the longevity of the network and data.

Data Quality Evaluation and Long-term Stability

Quality evaluation remains a critical aspect for data integrity and will require further research and cross-network communication. For the data to be most valuable to users, comprehensive documentation including meta-data must accompany all measurement information.

Long-term calibration stability is also an important issue. For the automated weighing bucket gauge used in their networks, Sverker Hellström (SMHI) and Mark Hall (NOAA ATDD) reported no major differences between the manufacturer and lab calibrations. The factory calibrations were reported to agree exceedingly well with the National Institute of Standards and Technology (NIST)-traceable calibrations. Although the Swedes have looked for calibration drifts, they have observed no calibration changes during the network's seven years of operation. The calibrations performed in the laboratory and field match the calibrations supplied by the manufacturer to within the uncertainty in the calibration standards. Mark Hall (NOAA ATDD) reported that the USCRN has systems in place to monitor for long-term drift. Chuck Wade (NCAR) reports no drifts with their instruments, finding changes of less than +/- 0.5% over 3 years. Stability tests do indicate an observable temperature dependence of the sensors, which are generally calibrated over a range of 85 ºC. Temperature effects on the actual measurements require further verification.

Conclusion

The workshop examined several issues related to the long-term operation and measurement quality of automated weighing bucket gauges for precipitation collection. Recommendations for future work and further exploration of some of these issues were discussed in detail and a complete report of the workshop proceedings is available from the authors.

In general, the benefits of the weighing bucket approach appeared to outweigh any problems, and the overall sentiment is that the automated weighing bucket gauges will greatly outperform more traditional collection methods for solid precipitation events. Solving the remaining issues regarding long-term gauge operation will require further research and will best proceed in collaboration with the international community.