LIFE AFTER ASOS (AUTOMATED SURFACE OBSERVING SYSTEM)--
PROGRESS IN NATIONAL WEATHER SERVICE SNOW MEASUREMENT

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ABSTRACT

The National Weather Service is the primary source for snow measurements for areas of our country where most people live and work. Through its networks of first-order and cooperative stations, snowfall data are available for nearly every county of our country dating back many decades.

Important changes have occurred in NWS weather observations that are affecting the continuity of snowfall data. The single greatest change was the deployment of the Automated Surface Observing System (ASOS) at hundreds of airport weather stations across the country during the 1990s. ASOS does not measure snowfall or snow depth. It utilizes a heated tipping bucket rain gauge for measuring both rain and the water content of snow. This type of gauge tends to under measure the water content of precipitation that falls as snow, especially at temperatures well below the freezing point.

New snow measurement guidelines were implemented in 1996 to expand the use and consistency of snow data from cooperative observers. These guidelines allow snowfall measurements at intervals of no less than once daily to no more than once every six hours. Data were collected for two winters at volunteer locations in several states to assess the impact of measurement interval on measured snowfall. Results show that the time interval between measurements does affect the reported snowfall totals. Measurements taken every six hours produced snowfall totals 19% greater than measurements taken once each day. Similarly, measurements taken every hour produced snowfall totals 15% greater than if measured only once at the end of each 6-hour period. This suggests that data users must beware of this characteristic before analyzing time series or spatial snowfall patterns from different types of weather stations.

INTRODUCTION

This paper, on the subject of National Weather Service snow measurements, is written by someone outside of the National Weather Service as a direct result of the Climate Data Continuity Project (CDCP). The CDCP is a NOAA (National Oceanic and Atmospheric Administration) project funded since the early 1990s through NOAA's Environmental Services Data and Information Management program. The Climate Data Continuity Project was established to help provide collectors and users of NOAA climate data with information to help understand changes that may have been introduced during the 1990s. The National Weather Service deployed the Automated Surface Observing System (ASOS) beginning in 1992 as a part of their nationwide modernization program. Airport weather stations that previously had been staffed with professional round-the-clock weather observers turned over the function of surface weather observations to an array of electronic instruments.

The Colorado Climate Center has been a major contributor to the CDCP. The Center has conducted national evaluations of ASOS temperature and precipitation measurements. Comparisons of other basic climate elements have also been investigated. This paper looks at the impacts that ASOS has had on precipitation measurements across the country and on the measurement of snow in particular.

ASOS WINTER PRECIPITATION MEASUREMENTS

ASOS measures precipitation using a twelve-inch diameter heated tipping bucket (HTB) gauge. From the time of its initial deployment at a few stations on the Central Great Plains, this gauge was found to measure significantly less precipitation during the winter season than the conventional gauges that it replaced (McKee et al, 1994). ASOS gauge catch also decreased drastically as a function of temperature below 32 degrees Fahrenheit as shown in Figure 1.

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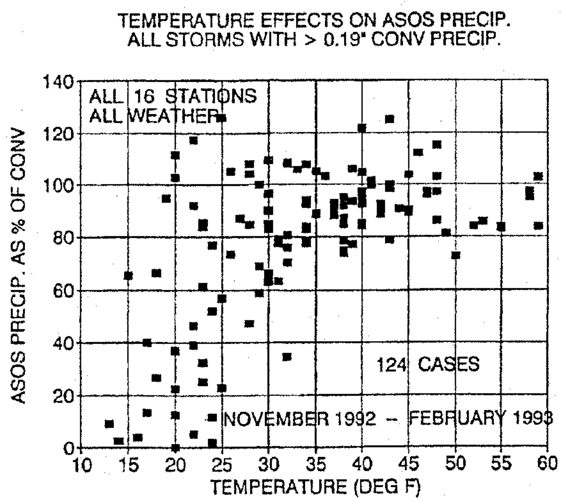

Figure 1. ASOS precipitation as a percent of Conventional measurements plotted as a function of temperature for each significant precipitation event (only events with greater than 0.19 inches from the conventional gauge were included), November 1992 through February 1993, from 16 stations (both commissioned and uncommissioned) ASOS comparison sites in the Central U.S. Temperature for each event was defined as a the mean ASOS temperatures, determined from hourly observations, for the 6-hour period with heaviest precipitation (from McKee et al, 1994).

Since initial deployment, some modifications have been made that improved the overall performance of the ASOS precipitation gauge for measuring rainfall (McKee et al, 1996). However, for the measurement of the water content of snowfall, it remains ineffective. Efforts are underway in the National Weather Service to replace the ASOS gauge with a better all-weather gauge for portions of the U.S. where snow accounts for a significant fraction of annual precipitation. Implementation could begin as early as 2002. However, many years of data from the HTB are already in the climatological archives meaning that data users will have to deal with years where winter precipitation readings are lower than they should have been for some stations.

Prior to the deployment of ASOS, snowfall and snow depth were measured by trained human observers following (hopefully) regulations established many years earlier for airways weather observations. A series of National Weather Service handbooks lays out the rules and regulations for these observations. Airport weather observers were directed to measure changes in snow depth every hour and report, by means of special remarks, snow depth increases if they equaled (when rounded) or exceeded one inch per hour. Actual snowfall was recorded every six hours at staffed weather stations. With the deployment of ASOS came a large and fundamental change. ***Snowfall was no longer measured.*** ASOS employed an electronic sensor for measuring the type and intensity of precipitation (rain or snow) but did not measure snowfall accumulations, total snow depth, or the snow water equivalent. ASOS was designed to serve the requirements of aviation as established by the Federal Aviation Administration. No specific requirements existed for snowfall measurement. This came as a surprise when the public and media realized snow observations at some major cities were no longer being taken by the National Weather Service. The winter of 1995-1996 really forced this issue as record snows fell over many eastern U.S. cities. The National Weather Service came face to face with a snow measurement crisis.

NWS SNOW MEASUREMENT GUIDELINES

At the same time, Doesken and Judson (1996) completed a book about snow and its measurement. Interest and use of snowfall data continued to grow greatly in the U.S. during the 1980s and 1990s. Snow is a major factor in the U.S. economy in both positive and negative ways. Snow is also a critical part of the global climate system. More and more research projects have sought out historic snowfall data. The primary sources for snow data in the U.S. for the locations where most people live and work are the National Weather Service first order stations (typically major airport weather stations) and thousands of cooperative stations that belong to the NWS Cooperative Program. Unfortunately, even from these official sources, snowfall data don't always stand up well to close scrutiny. The quality and continuity of historic snowfall data are sometimes questionable (Robinson, 1989).

The emerging snow measurement crisis led to a national snow measurement workshop sponsored by the National Weather Service and the Colorado Climate Center and held in Boulder, Colorado in September 1996. The results of this workshop were a new set of snow measurement guidelines for all National Weather Service weather stations (NOAA, 1996). No fundamental changes were made in how to measure snowfall. However, snowfall was more clearly defined as the greatest accumulation of new snow since the previous observation on a measurement surface prior to reduction by melting, compaction or other disturbance. The guidelines also attempted to achieve more uniformity between first order and cooperative observations. Through time, aviation observations had evolved such that some stations were measuring and clearing snow every hour while others measured every six hours. Most cooperative stations measure snowfall only once per day, either when snow ends or at a preset scheduled observation time. The new guidelines stated "This measurement should be taken minimally once-a-day (but can be taken up to four times a day).... Never sum more than four 6-hourly observations to determine your 24-hour total."

Findings by Doesken and Judson (1996) suggested that the frequency and timing of measurements of fresh snow accumulation could significantly affect data continuity. Since the new guidelines allowed a range of observational frequencies from a minimum of once per day to a maximum of once every six hours, some method of quantifying the effects was needed. Then, on January 11-12, 1997, extremely heavy snow fell in a narrow "lake-effect" band downwind of Lake Ontario. Subsequent reports from a snow spotter for the National Weather Service on the Tug Hill Plateau appeared to set a new national 24-hour snowfall record. With the new guidelines in place, the observation of 77 inches in 24-hours was not accepted as a new national record since it was the sum of six measurements from variable time increments, some of which were less than 6 hours (NOAA, 1997).

DOES THE MEASUREMENT INTERVAL AFFECT SNOWFALL TOTALS?

Unlike rain that lands in rain gauges and retains a constant volume after falling to the ground, snowfall is much trickier to measure. Snow melts, settles and may be redistributed by wind. Common sense tells us that the more frequently we measure and sum the accumulation of new deposits of snowfall, the more snow we will measure. Avalanche scientists have been aware of this for years (U.S. Dept. of Agriculture, 1961) but this has not been examined carefully when applied to National Weather Service data.

In the fall of 1997, a cooperative effort between the National Weather Service and the Colorado Climate Center was initiated to better document the effect of snow measurement interval on reported snow accumulations. Steve McLaughlin of the Buffalo, NY Weather Forecast Office and John Quinlan of the Albany, NY Weather Forecast Office each had a strong interest in this study and already had networks of trained snow spotters willing to help. Individual volunteers were identified from other states such as Colorado, Ohio, New Jersey, Maryland and North Carolina.

Participating snow spotters were asked to set up a series of snow boards for measuring snow accumulations for each of several different measurement intervals. During each snow event, snowfall was measured and then cleared from the appropriate board at intervals of one hour, three hours (at some stations), six hours, twelve hours (at some stations) and once daily. Observers also maintained a precipitation gauge for measuring snow water content. Additional information was recorded at the discretion of the observer including wind, temperatures and snow crystal type.

Despite a large number of participating volunteers, only 64 event data sets were obtained for the winters of 1997-1998, 1998-1999 and 1999-2000. Snow was nearly non-existent in the eastern U.S. for the winter of 1997-1998. Other potential storms could not be used if they included rain, freezing rain, ice pellets, or other conditions interfering with measurement interval comparisons. More than half of the candidate snow events from stations east of the Mississippi River were omitted due to rain and ice effects. We also learned how difficult it is for individual volunteers to maintain snow interval measurements for all intervals for the duration of a storm. Job and family responsibilities, plus the reality of sleep requirements, resulted in very few complete samples from storm beginning to end for all measurement intervals. Therefore, the data set is composed of some complete storm samples and many partial-storm segments.

Examples of snowfall measurements for different measurement intervals are shown in Figure 2 for three selected storms. For the majority of events, observed snowfall decreased as the interval between observations increased similar to the examples shown here.

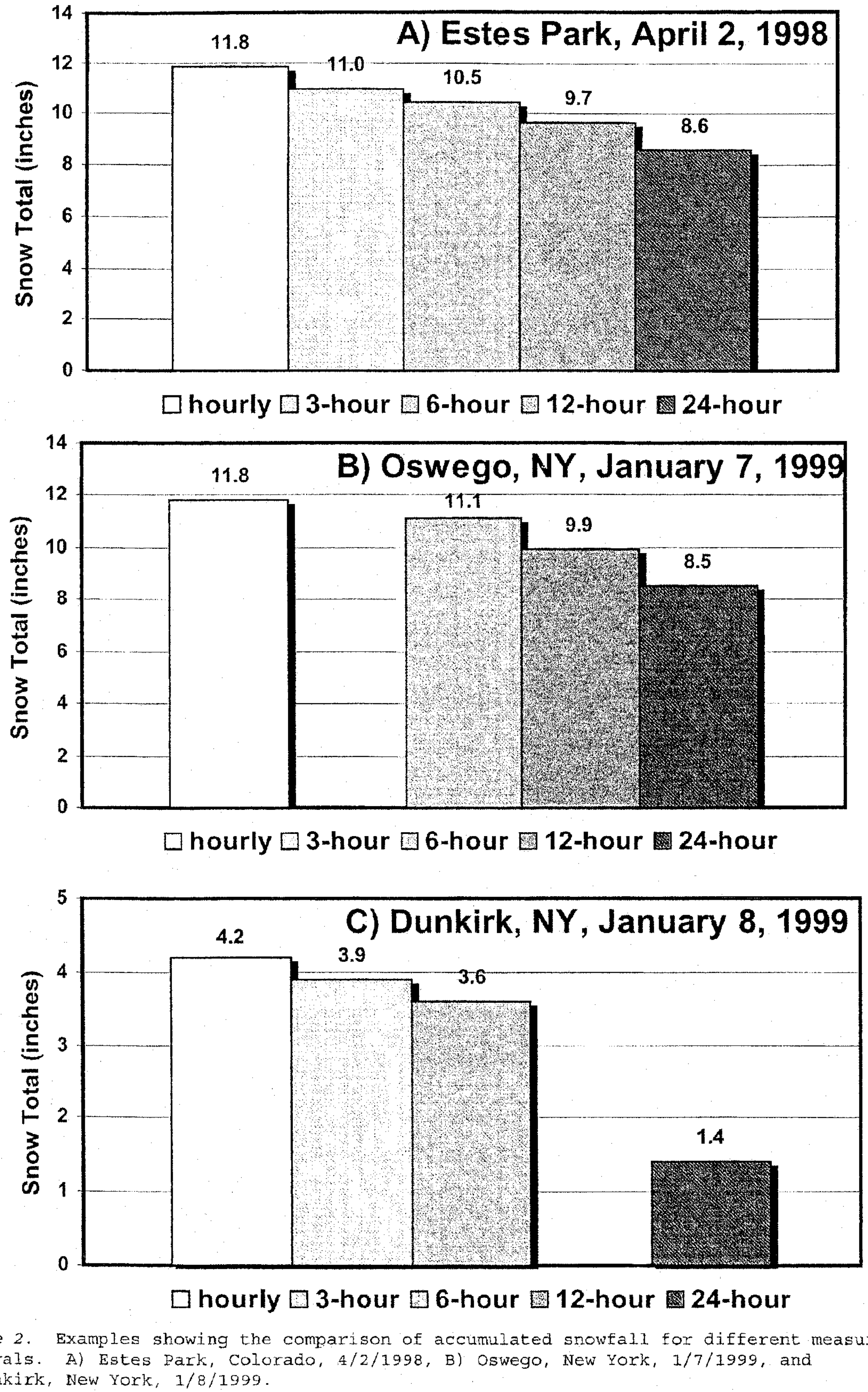

Figure 2. Examples showing the comparison of accumulated snowfall for different measurement intervals. A) Estes Park, Colorado, 4/2/1998, B) Oswego, New York, 1/7/1999, and C) Dunkirk, New York, 1/8/1999.

To quantify the relationship between measurement interval and accumulated snowfall, snowfall was summed for each measurement interval and compared to appropriate accumulations for coincident intervals. For example, if a storm (snow event) lasted 12 hours and all interval measurements were successfully taken, hourly measurements would be summed into four 3-hour totals, two 6-hour totals, one 12-hour total, and one 24-hour total. Likewise, each 3-hour interval measurement would be summed to form two 6-hour totals, one 12-hour total and one 24-hour total. The two six-hour interval measurements would be summed to form one 12-hour and one 24-hour total, and so on. Each sum would then be compared with the appropriate snow board accumulation for the matching period.

A summary of snowfall comparisons for different measurement intervals is shown in Table 1. Keep in mind that due to the volunteer nature of this effort the same storms may not be included in each sample. As a result, the measured snowfall and number of snow events vary from one category to the next. Despite these variations, it is very clear that the measurement interval does have a significant impact on snowfall totals. For the 28 snow events where measurements taken every six hours were summed and compared to the once-daily snowboard reading, the six-hour samples summed to 164.4 inches, 19% greater than the 138.4-inch total from once-daily observations. This is very relevant for the comparison of traditional first order station snow observations with that of surrounding cooperative stations. It clearly indicates that first order stations will likely report more snowfall than a nearby cooperative station for the same amount of new snow. Similarly, measurements taken every hour and summed into six-hour totals (327.9 inches) exceeded the six-hour measurements by 43.3 inches (15%) based on 45 events. Some professionally staffed weather stations have been measuring snowfall at hourly increments for many years. Such sites will report significantly more snow accumulation for the same actual snowfall than a station measuring less frequently. The largest differences were observed when measurements taken every hour and summed to form 24-hour totals were compared directly to once-daily readings. For 17 events, daily snowfall totals formed by summing hourly measurements equaled 118.6 inches, 30% greater than the 91.2 inches accumulation from coincident once-daily readings. Results are shown graphically in Figure 3.

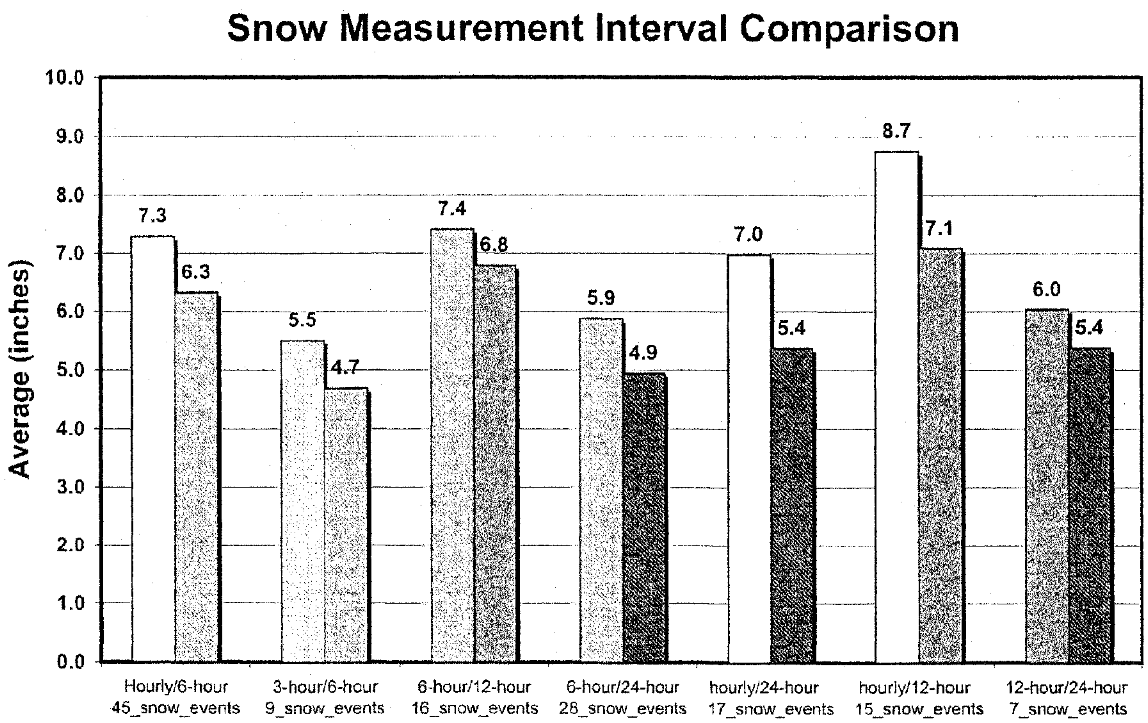

Figure 3. Snowfall comparisons for different measurement intervals. Values were normalized by dividing the total accumulated snowfall in each category by the number of events sampled.

Observed snowfall totals are a function of the measurement interval. While this may surprise some people, it is a logical outcome since snow changes over time. Measuring snowfall is similar to shooting at a moving target. While the accumulated totals appear to show systematic biases that are interval dependent, considerable variations were observed.

The small sample size for this study does not lend itself to meaningful discussions of variability, but more data will hopefully be gathered in the future. National Weather Service Offices in New York and Virginia continue to gather data from volunteer snow enthusiasts to extend this study.

Settling rates are nonlinear functions of time of day, temperature, wind, crystal structure, snow density, age of snow and other variables. Melting can obviously also contribute. In most subfreezing situations, snowfall totals obtained by summing short interval measurements (hourly or three-hourly) exceeded longer interval measurements. However, in some instances when snow fell at temperatures near the freezing point and especially during midday, snow accumulations on the one and three-hour interval snowboards were actually lower than for longer intervals. Melting occurred more quickly under these circumstances on the boards that were cleared the most often.

Table 1. Comparison of accumulated snowfall totals for specified measurement intervals for 64 snow events. This is a composite of all observations for all participating stations. Only periods with matching coincident measurements are included. The number of events in each comparison category is less than 64 since not all intervals were compared for each storm.

Snow Measurement Intervals Compared	**Number of Snow Events**	**Accumulated Snowfall in Inches**
6 Hours to 1 Hour	45	6: 284.6, 1: 327.9
6 Hours to 3 Hours	9	6: 42.2, 3: 49.5
6 Hours to 12 Hours	16	6: 118.5, 12: 108.6
6 Hours to 24 Hours	28	6: 164.4, 24: 138.4
1 Hour to 12 Hours	15	1: 131.2, 12: 106.3
1 Hour to 24 Hours	17	1: 118.6, 24: 91.2
12 Hours to 24 Hours	7	12: 42.2, 24: 37.6

DISCUSSION AND CONCLUSIONS

For snow experts accustomed to the deep snowpacks of the western mountains, this comparison of snowfall for different measurement intervals may seem trivial and irrelevant. However, for the millions of people who live and work in the cities, forests and agricultural lands of the valleys and plains of our country and whose lives are impacted briefly but dramatically by occasional snows, this project is far from trivial. Thousand of snow removal contracts are written each year based on official snowfall measurements. Urban snow removal budgets are set and adjusted according to snowfall measurements. Winter precipitation data from major cities across the country continue to be used in countless business applications. Teachers, students, researchers, businesses and the media routinely compare snowfall from one location to another and one year to another. Can the data truly be compared? It depends on how it is measured.

ASOS continues to under-measure winter precipitation at many stations across the country. This will continue until an all-weather precipitation gauge is deployed. Despite greater efforts during the past five years to standardize measurement procedures for snowfall, inconsistency is still a problem. As this study shows, even the best weather observers may report differences in accumulation per storm or for entire seasons by 15% to 30% simply due to differences in the time interval between measurements.

Snow data can be improved and should be. Understanding problems and data discontinuities has been accomplished with the help of NOAA's Climate Data Continuity Project. The 1996 National Weather Service Snow Measurement Guidelines were a large step in the right direction. However, by specifically allowing different measurement intervals, inconsistencies become inevitable. It is not easy to employ a single standard for measurement frequency, especially in a network that relies so heavily upon volunteers. Some volunteers are lucky to be home long enough to make a single measurement while others will eagerly measure as frequently as possible. There are still a few manual snowfall observations at first-order stations where most observers are measuring every six hours but some are measuring hourly. We hope that the information presented here will open people's eyes to the effects of observational differences. It is not trivial. With this knowledge in hand, improvements can be made leading to higher-quality long-term climate data.

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