AN ANALYSIS OF THE TIMING OF SNOW COURSE MEASUREMENT AND THE POTENTIAL ERROR COMPARED TO APRIL 1 MEASUREMENT IN UTAH

Randall P. Julander[1]

ABSTRACT

Snowpack data collection began in an organized fashion in Utah during the late 1920's. The April 1 measurement soon proved to be one of the most important surveys with regard to water supply forecasting. These snow survey data, used historically as April 1 data were seldom actual April 1 measurements rather they were normally sampled at some time prior to April 1, in the latter part of March. In the way that Snow Survey Data were being used, principally in linear regression applications versus accumulated streamflow, this present little error in the forecasting scheme. However, with the advent of telemetered snowpack information, there exist now two sets of data - those manual sites still measured during the end of March and the SNOTEL or electronic data which are actual April 1 values. The snow course data would underestimate the actual April 1 snowpack compared to the SNOTEL data set, however the magnitude of the error has not been determined. The applications of snowpack data are rapidly changing as well. Climate change is being characterized by impacts seen in snowpack. For this type of analysis, the longer the data set, typically the better and more substantial and conclusive the findings. SNOTEL has a relatively short record being installed in the late 70's and early 80's but the snow course data reach back into the 20's, making the analysis far more long term. SNOTEL replaced many of the long term snow courses, thus reducing the pool of available long term data for analysis. This analysis compares the potential error associated with actual measurement timing to April 1 and provides an average correction factor for adjusting long term snow course data to observed SNOTEL data in Utah. This would allow comparative research of both data sets for climate change analysis or other purposes. Another method would be to use regression techniques to back estimate SNOTEL data from snow course data.

INTRODUCTION

The Natural Resources Conservation Service, United States Department of Agriculture is charged with the task of measuring high elevation hydroclimatic data in the western United States. Snowpack snow water equivalent is the data parameter of primary interest with precipitation, temperature and other parameters also being measured. Snowpacks in Utah have been measured to some extent since the mid-1920's and has one of the best long-term databases of snow water equivalent (Soil Conservation Service, 1979). These data provide a wealth of climate and runoff correlation data. The quantification of an average climatological condition as well as the associated extremes has long had relevance in the categorization and characterization of various geographic regions. Recent events compared to both the historical observed data records as well as the inferred or synthetically generated geological climate record have led to a general conclusion of accelerated global climate change and a generally heightened interest in how climate at the local level may be impacted Snow courses measured in the early days often took a major trip and involved travel by motor vehicle, horses, foot, snowshoe and/or ski travel all to accomplish a single snow course. Compared to the mechanisms of today, such as helicopter and snowmobile it would seem that large discrepancies in snow course measurement would be the result. This whole analysis is based on average conditions and at times when there was no snow between the actual measurement and April 1, there would have been no error at all. At other times, there could have been far greater error than what an average condition would reflect, thus applying a correction to individual years has no meaning. Using this analysis to generally adjust an overall dataset for comparative purposes would be appropriate.

METHODS

The sites selected for Snow Water Equivalent analysis, were determined based on the station period of record, the record continuity and whether the station is still currently measured. Given these criteria, 13 snow

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Paper presented Western Snow Conference 2005
[1] Natural Resources Conservation Service, U.S. Department of Agriculture, 245 North Jimmy Doolittle Rd Salt Lake City, UT 84116. (randy.julander@ut.usda.gov)

course stations were selected, all of which were initiated in the late 1920's or early 1930's. These sites were systematically measured on or near April 1 for each year. These early sites were systematically laid out to geographically cover the entire state and they reflect an excellent elevation distribution as well. The primary purpose of these sites was to provide water supply forecasts based on site-specific snow water equivalent. Table 1 gives the elevation in meters and location of the snow courses used in this study, geographically from north to south.

Table 1. Snow courses used in the study.

Station	Elevation	Latitude	Longitude
Garden City Summit	2315	41.92	111.47
Burts Miller Ranch	2410	41.00	110.87
Parleys Summit	2285	40.77	111.62
Trial Lake	3035	40.68	110.95
Redden Mine	2590	40.68	111.22
Mill D South Fork	2255	40.65	111.65
Hobble Creek	2260	40.65	111.38
GBRC Meadows	3050	39.30	111.45
Huntington Horseshoe	2990	39.61	111.30
Gooseberry	2560	38.78	111.68
Fish Lake	2650	38.50	111.77
Buckboard Flat	2745	37.87	109.45
Panguitch Lake	2490	37.70	112.65

The actual Julian date of measure for each site and each year was subtracted from April 1 Julian to quantify the days of measurement error. The number of days from April 1 divided by 31, the number of days in March, then multiplied by the average snow water equivalent accumulation for March gives the average potential snow water equivalent error for that site in centimeters for each year. Note that this is not the actual observed SWE error rather an average potential error that in the aggregate holds true but for any given year is meaningless. The total potential error for that year, divided by the average April 1 snow water equivalent (1971-2000) gives the percent error of the total snowpack. Total average error for each site was calculated as well as an average for all sites combined. A ten-year moving average was also calculated to see if there were any discernible differences between measurement timing today and that of earlier in the century. An F-test was run on each record comparing pre-1980 and post 1980 records to see if any variability in the measurement date had been eliminated by changing transportation modes from individual access to centralized helicopter surveys.

RESULTS

Table 2 presents the average number of days prior to April 1 each course is measured along with the range, the average error in snow water equivalent as well as the overall percentage of total peak April 1 snowpack error. In general, most snow courses are measured an average of 3.8 days prior to the posting date of April 1. This is about a 13% error with specific reference to March snowpack accumulation. It results in a statewide average snowpack underestimation of 0.7 centimeters of snow water equivalent when compared to observed April 1 snowpack values which is a -1.7% of total snowpack error. The minimum day's error refers to the greatest deviation prior to April 1 and the maximum day's error refers to the greatest deviation post April 1. Each snow course is extremely variable compared to the next. When snow accumulation in March is very low, so is the overall error. A case in point is Panguitch Lake which has zero net accumulation of snowpack during March. That is to say, Panguitch is relatively low elevation site in extreme southern Utah and what snow does accumulate in March is also melted or lost, (March 1 SWE average is equal to April 1 SWE average) thus the overall error due to sample timing is zero. Other sites, further north such as Garden City Summit which has a larger March snowpack SWE accumulation with less tendency for March melting has an overall error of -1.6 centimeters of SWE which is -3.9% of the total April 1 SWE value. Thus the magnitude of the error is directly dependent on the average March accumulation and the Percent of April 1 error is based on the relationship between that accumulation as well as the total average snowpack at that site. As an extrapolation, one would expect greater error at higher elevations as well as more northern latitudes because March would normally have higher SWE accumulations. Conversely, lower elevations and more southern latitudes might be more appropriately examined for March 1 snowpack instead of the typical April 1 values.

Table 2. Average, range and percent days of error and average SWE error.

	Avg Days Error	Average SWE Error - Centimeters	Percent April 1 Error	Minimum Days Error	Maximum Days Error
Garden City	-4	-1.6	-3.9	-9	1
Burts Miller Ranch	-4.3	-0.7	-0.6	-12	5
Parleys Summit	-3	-0.5	-1.1	-8	1
Trial Lake	-3.2	-1.1	-1.7	-15	4
Redden Mine	-3.5	-0.8	-1.8	-9	8
Mill D	-2.3	-0.4	-0.9	-7	7
Hobble Creek	-3.7	-0.2	-0.7	-8	4
GBRC Meadows	-2.4	-1	-1.7	-7	6
Huntington Horseshoe	-2.8	-1.1	-1.8	-7	4
Gooseberry	-3.3	-0.6	-1.9	-10	19
Fish Lake	-5.3	-0.6	-2.8	-12	4
Buckboard Flat	-4.3	-0.5	-1.7	-14	7
Panguitch Lake	-4.4	0	0	-18	2
State Avg	-3.8	-0.7	-1.7	-18	19

The range of error is also interesting as most sites have at least one measurement date that is significantly out of bounds. The earliest a site has been measured pre-April 1 is 18 days and the maximum post-April 1 is 19 days. Most of these large anomalies came fairly early in the record. Clearly, these kinds of measures reflect mid-month conditions and not the first of the month. The worst offenders in this category appear to be those that required significant travel. In the early days of snow survey activity, it was not uncommon for a single snow survey to take several days, starting with a vehicle, then horseback, then on foot or over snow devices (Julander, 2001). In those days, often the survey was fit in by volunteer surveyors around their other work. With the tremendous advantage of today's technology in travel one would think that the overall timing error associated with snow surveys would decrease and that the actual date of measure would more closely approach April 1. And that assumption would be wrong. In Figure 1, we see the average days of error for all 13 snow courses from 1937 through 2000 as well as a 10-year moving average. Note that although there are fairly wild deviations year to year, that the 10-year average consistently swings between -3 and a little over -4 days.

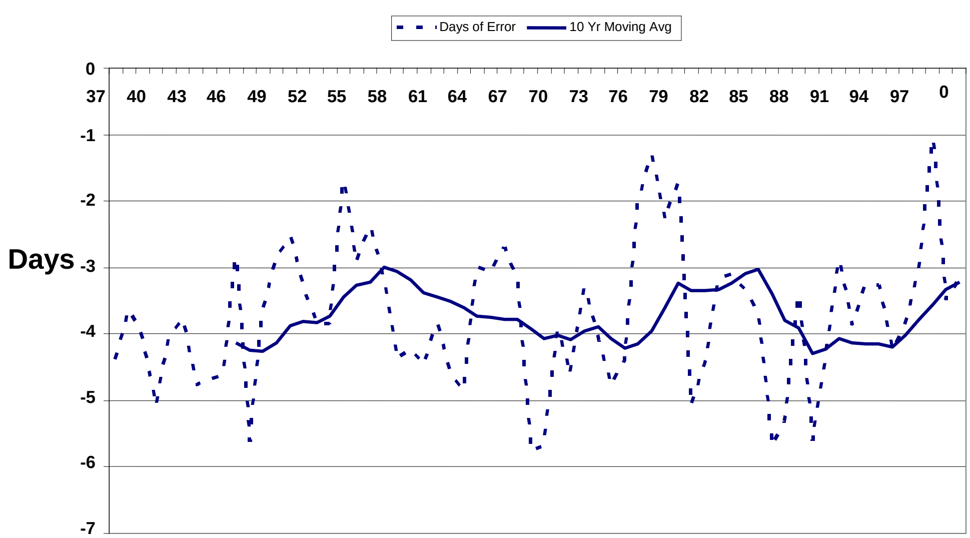

Figure 1. Utah average potential time of measurement error – days from April 1 and a 10-yr moving average.

Even though individual stations may have a positive sample date, the average of all 13 courses is consistently biased to a pre-April 1 condition and in fact, the closest the actual days of error gets to the zero line is one full day. In Utah, since the early 1980's, snow courses were to be measured within the last 7 days of the month. And at this time, the measurement duties were centralized to the main snow survey office and the use of a helicopter employed as opposed to many individuals in various locations using snowmobiles and foot travel. This is the time frame in which SNOTEL was installed and ground truth readings were also taken at all SNOTEL sites while measuring the snow courses, many of which were co-located. In the early 90's, these ground truth readings were discontinued and the time frame of snow course measurements was shortened to begin on the last 5 days of March. This could explain the steady decrease over the past few years, going from and average of 4 days to an average of about 3 days. Without the ground truth, the helicopter survey has decreased in time from an average of about 5 days of measurements to between 2 and 3 days of actual measurement. The start date of 5 days previous to the beginning of April is to give some leeway for stormy days. The object being that on the first of April, all data should be collected, quality controlled, posted to the database and ready for use in water supply forecast models. There are sites that appear to be getting closer to an actual April 1 reading, others that have been consistent over time and others that show relatively large discrepancies over the historical record. These discrepancies would reflect the individual snow surveyors and their ability to get the job done as close to April 1 as possible. Figure 2 shows the Burts Miller Ranch snow course. Note that from the 50's to the 70's, there was a tendency to measure 5 to 8 days previous to April 1. After the advent of the helicopter survey, things improved to and average of 3 to 4 days.

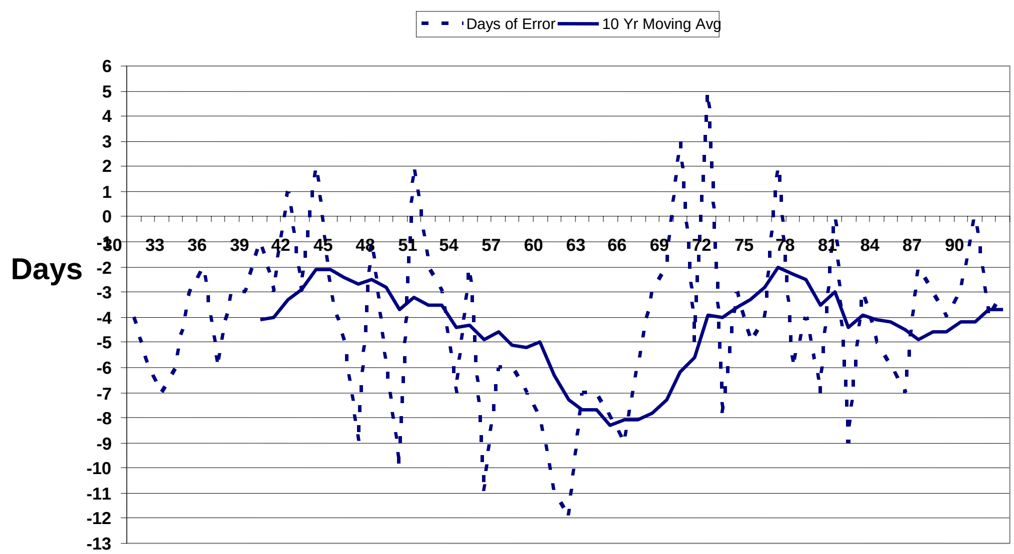

Figure 2. Burts Miller Ranch potential time of measurement error – days from April 1 and a 10-yr moving average.

Figure 3 shows the same graph for the GBRC Meadows snow course, which had a very close to April 1 measurement date from the early 50's through the early 80's when the helicopter surveys began, at which time, it went from between -1 and -2 to a -3 to -4 days, a obvious degradation in the error.

Switching gears, in Figure 4, we see the Garden City Summit snow course potential snow water equivalent error along with the potential percent error in total April 1 SWE. Note that at Garden City, there are many times when the potential SWE error is between 2 and 3 centimeters. The value of 2.5 centimeters of snow water equivalent can be significant and an error of this magnitude could have serious impacts on model output. Also of note is the fact that this error is up to a 9% underestimation of the total April 1 snow water equivalent at this particular site.

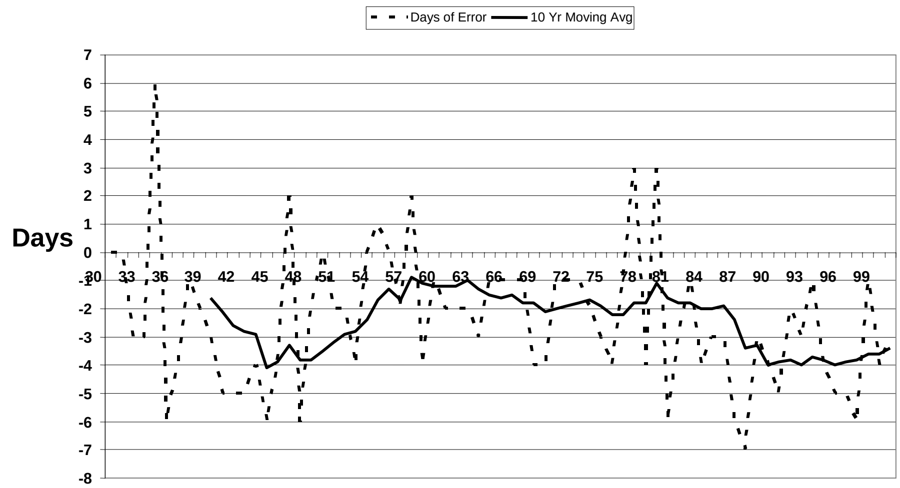

Figure 3. GBRC Meadows potential time of measurement error – days from April 1 and 10-yr moving average.

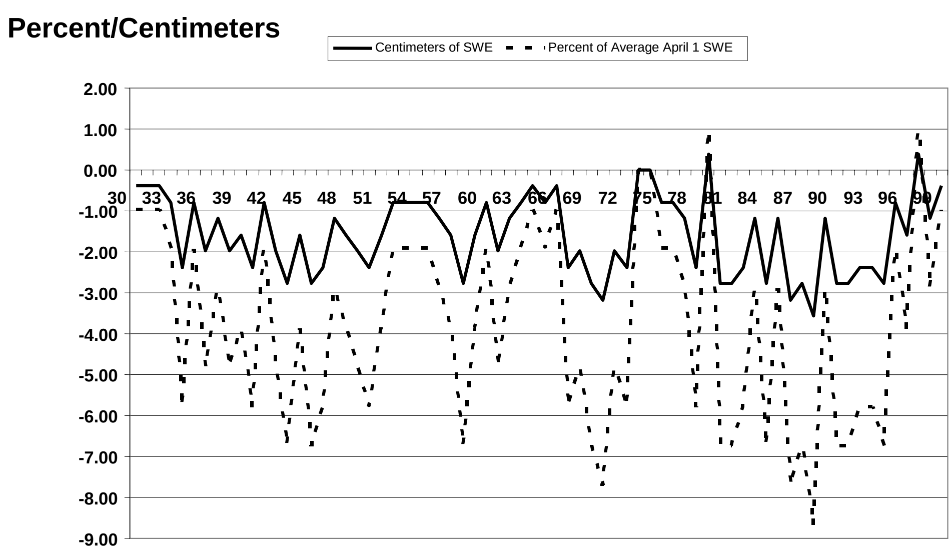

Figure 4. Garden City potential time of measurement error – centimeters of SWE and percent of April 1 SWE error.

Figure 5 shows the average of all 13 snow courses statewide regarding the potential centimeters of SWE error as well as the potential percent of April 1 total SWE error. The statewide average is about 1 centimeter of SWE error which in turns relates to about an overall 2% error in April 1 SWE.

An F-test was employed to determine if some of the variability in the date of actual snow course measure had been eliminated by centralizing the surveys to the Natural Resources Conservation Service Data Collection Office and using a helicopter instead of ground based transportation. The time period tested was the beginning of the record to 1980 compared to 1981 to 2000. Ten of the thirteen courses are measured by helicopter. The three that are not measured by air are: Parleys Summit, Mill D and Buckboard Flat. Of these three ground survey courses, Mill D and Buckboard Flat show both significantly reduced variability as well as means that were closer to an actual April 1 measure. The results of the helicopter measured sites tested were that five of the ten snow courses

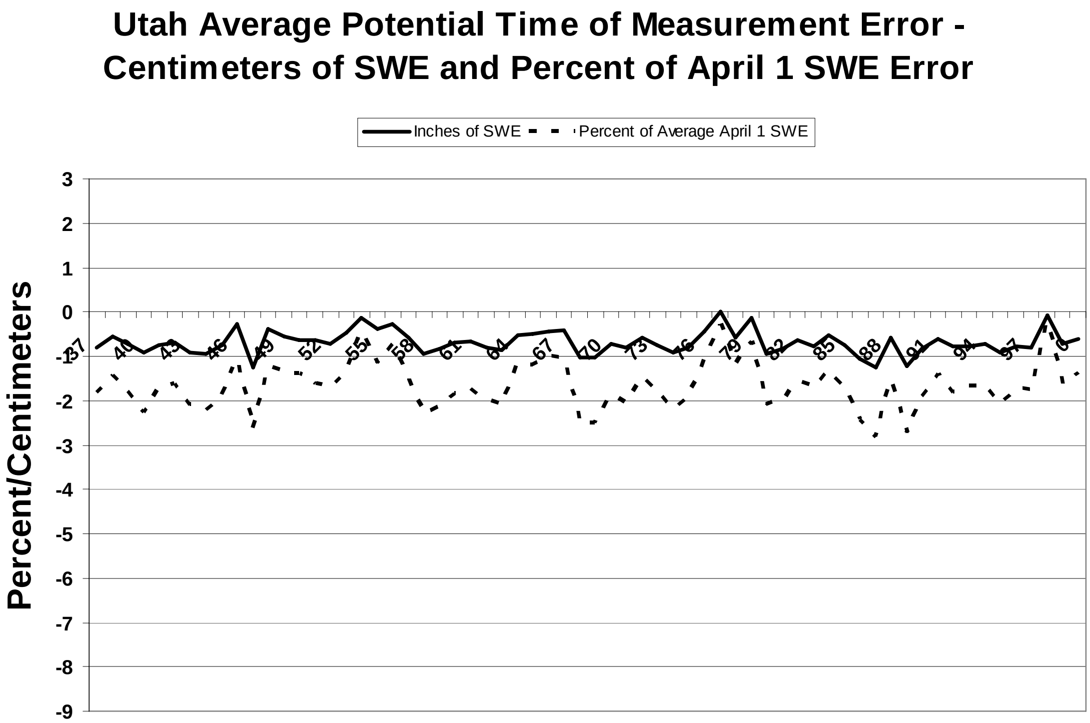

Figure 5. Utah average potential time of measurement error – centimeters of SWE and percent of April 1 SWE error.

had significantly less variability in the date of measure in the 1981 to 2000 compared to the early portion of the record. The sites that did not show significance are: Trial Lake, Redden Mine and Huntington Horseshoe. The significance level at Huntington Horseshoe was within 0.001 of being significant, so extremely close. The other two courses, Trial Lake and Redden Mine were also close to significantly less variability being short 0.2 to 0.3 points. There were two courses that showed significantly greater variability and these were Garden City Summit, Hobble Creek. With regard to Garden City and Hobble Creek, in the early portion of the record, they seem to have been measured consistently close to the same day. Having less variability does not necessarily mean that the actual date of measure is closer to April 1, and in fact Table 3 shows that at most sites, the average date of measure is slightly earlier than in pre-1980 record, going from -3.5 days to -3.8 overall. Since the early 90's, the beginning date of the helicopter surveys was reduced from 7 days previous to April 1 to 5 days. When comparing just this

Table 3. Average number of days of measurement before April 1.

Snow Course	Avg Days Pre 1980	Avg Days Post-1980
Garden City	-3.6	-5.1
Burts Miller Ranch	-4.6	-3.8
Parleys Summit	-3	-3.1
Trial Lake	-3	-3.6
Redden Mine	-3.3	-4.2
Mill D	-2.5	-2
Hobble Creek	-3.6	-3.8
GBRC Meadows	-2	-3.6
Huntington Horseshoe	-2.4	-3.8
Gooseberry	-3	-4
Fish Lake	-5.7	-4.2
Buckboard Flat	-4.9	-2.9
Panguitch Lake	-4.3	-5
State	-3.5	-3.8

time frame to the early record, the results were split down the middle with the northern stations being much closer to April 1 and the southern stations farther from April 1 on average. The propensity is to fly the southern loop first since it is the longest, takes the most time, covers the most distance and often requires an overnight stay thus the average measure date for those stations is moving closer to the 5 day previous to April 1. The northern stations are more likely to be measured on days -1 to -3 previous to April 1 than at the start of the helicopter survey at -5 days.

CONCLUSIONS

Thirteen long-term snow courses in Utah representing complete elevational and geographic coverage of the dominant snowpacks within state were analyzed for error and bias associated with sample timing. It was found that on average, Utah snow courses are measured 3.8 days prior to April 1, that the overall average SWE error was about 0.7 centimeter and that translates to about a 1.7% overall error in total April 1 SWE. It was further found that, on average, there was no improvement in this overall error based on modes of transportation. There is far less variability in the measurement date since the advent of helicopter surveys in Utah with almost all sample dates coming between 5 days prior to and actual April 1 survey dates. An F test on variability for all thirteen sites was conducted to see if using a helicopter significantly reduced the variability of the measurement date. The results of that test were that 7 of the 10 helicopter-measured sites had significantly reduced variability, 3 did not show significance. Two sites showed greater variability in the overall measurement date. Most sites showed a slight increase in the average days measured prior to April 1.

REFERENCES

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