Variability at Colorado Operational Snow Measurement Sites: Snowcourse Stations at Collocated Snow Telemetry Stations

S.R. FASSNACHT,[1] M.E. SKORDAHL,[1] AND J.E. DERRY[1]

ABSTRACT

The United States Department of Agriculture has been collecting snow data across the Western United States since the mid-1930s. These data were originally biweekly or monthly snowcourse measurements of snow depth and snow water equivalent (SWE) taken at 10 to 15 stations over a 100 to 300 meter transect. These data are reported as average snow depth, SWE, and density for a particular date, and have been used for various different analyses.

Individual snowcourse measurements for five stations of differing accumulation amounts have been used examine their intra-annual and inter-annual variability. The stations include the Tower site which receives on average 55% more snow than any other site in the state. The other sites had varying amounts of accumulation. Four years of weekly data at this site illustrated that the intra-annual variability was consistent. The exception was during early accumulation and once melt had initiated. The individual data for April 1st snow depth and SWE illustrated an inverse relationship between variability and quantity of snow.

Keywords: snowcourse; variability; consistency; NRCS

INTRODUCTION

The United States Department of Agriculture (USDA) has been collecting snow data since the mid-1930s. These data were originally biweekly or monthly snowcourse measurements of snow depth and snow water equivalent (SWE) taken at 10 to 15 stations over a 100 to 300 meter transect. These data (USDA, 2008) were reported as average snow depth, SWE, and density for a particular date. In the 1970s, numerous automated snow telemetry (SNOTEL) sites were established that report daily SWE. Over past five years, automated snow depth measurements have been added to many of the SNOTEL sites.

Snowcourse data collected on or about April 1st are used to represent peak accumulation across most of the Western U.S. These data have been used to understand annual trends related to climate and climate change (e.g., Cayan, 1996; Gutzler, 2000; Stewart *et al.*, 2005). However, few studies have used the 10 to 15 individual snowcourse station measurements to understand the variability associated with these data. Wells and Doyle (2004) examined long term measurements at specific snowcourse stations relative to forest growth and found no significant trend in peak SWE.

[1] Watershed Science Program, College of Natural Resources, Colorado State University, Fort Collins, Colorado 80523-1472 USA.

Recent research into the spatial distribution of snow data have used variograms (Deems *et al.*, 2006), power spectra (Trujillo *et al.*, 2007) and related analyses to understand the correlation structure of the data and the fractal characteristics. Various analyses that have been used in soil science to understand surface characteristics, in particular related to tillage practices, have been applied to understanding snow surface roughness (Fassnacht *et al.*, *in review*). Some of the metrics used to define roughness can also estimate spatial and temporal variability. The simplest of these is the coefficient of variation (COV), which disregards the relative location.

STUDY AREA AND METHODOLOGY

Focusing on the individual snowcourse measurements, this paper examines the variability at the transect scale for five snowcourses in Colorado (Table 1 and Figure 1). These stations are or were all co-located with SNOTEL stations. Different years of snow accumulation patterns were investigated for April 1 SWE at the snowcourses to determine the inter-annual variability for different snow years. The intra-annual variability in snowcourse data was determined using weekly measurements for four winters at one snowcourse: 23 dates during the winter of 1965, 27 dates during the winter of 1965-1966, and 17 dates during the winter of 1966-1967, and 17 dates during the winter of 1968-1969.

These snowcourses represent different snow accumulation stations, with the Tower site receiving the most snow recorded across the entire Colorado River Basin. The other stations are Berthoud Pass, Fremont Pass, Joe Wright, and Park Cone (Table 1 and Figure 1). They represent different accumulation patterns.

Table 1. Snowcourse stations used in this study with location and average April 1st SWE and depth. Rank is compared to all 147 snowcourse stations within the state of Colorado that have at least 20 years of April 1st measurements.

station		latitude	longitude	elevation	average April 1st SWE		average April 1st depth	
number	name	[N]	[W]	[m]	[mm]	rank	[m]	rank
05K03	Berthoud Pass	39°50'	105°15'	2957	414	40	1.372	34
06K08	Fremont Pass	39°23'	106°48'	3475	414	40	1.422	31
05J37	Joe Wright	40°32'	105°7'	3085	645	11	1.905	10
06L02	Park Cone	38°49'	106°25'	2926	269	82	0.965	81
06J29	Tower	40°32'	106°19'	3200	1278	1	3.353	1

RESULTS AND DISCUSSION

The intra-annual variability is presented by the coefficient of variability versus the standardized data to remove units associated with the data (Figure 2). Trends among the annual snow depth data (Figure 2a) were more evident than in the SWE data (Figure 2b). Overall, the COV was consistent once enough snow had accumulated but prior to substantial snowmelt.

Using the one annual set of measurements that is used for many analyses, i.e., April 1st, the variability was inversely and non-linearly related for both snow depth (Figure 3a) and SWE (Figure 3b), except at the Tower station that was consistent as with the intra-annual data.

Data from the other stations should be examined to determine any systematic variability. It is likely that other metrics (e.g., Fassnacht *et al.*, *in review*) would better explain the variability.

It should be noted that individual snow depth and SWE measurements are reported to the nearest 1.27 cm (0.5 inches), and for deeper snow (depth > 254 cm, SWE > 1270 mm) this is often rounded to the nearest 2.54 cm (1 inch). This yields precision of at least 1 to 2% (depth and SWE) for deeper snow, but only 5% for many measurements. Early in the snow season, depths are shallow and accumulation of SWE in relative terms is even less so precision is less. This could increase the estimated variability. Few measurements are made late in the melt season.

Fortunately the variability estimates discussed herein will mostly be used in temporal proximity to peak accumulation.

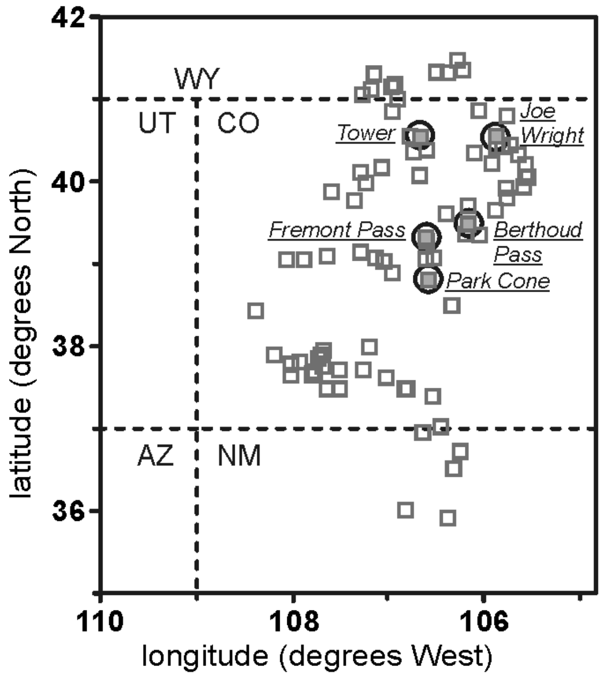

Figure 1. Location map for the five study snowcourse stations within the state of Colorado.

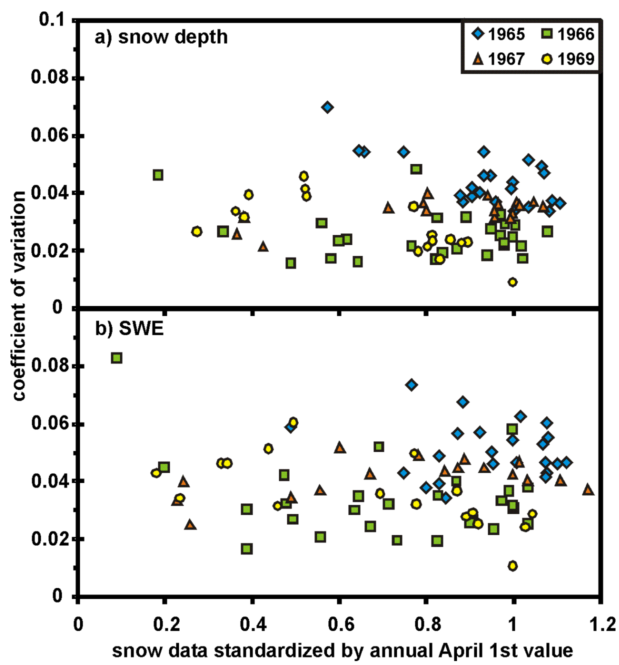

Figure 2. Plot of coefficient of variation versus annually standardized a) snow depth and b) SWE for four years of weekly data for the intra-annual evaluation from the Tower station.

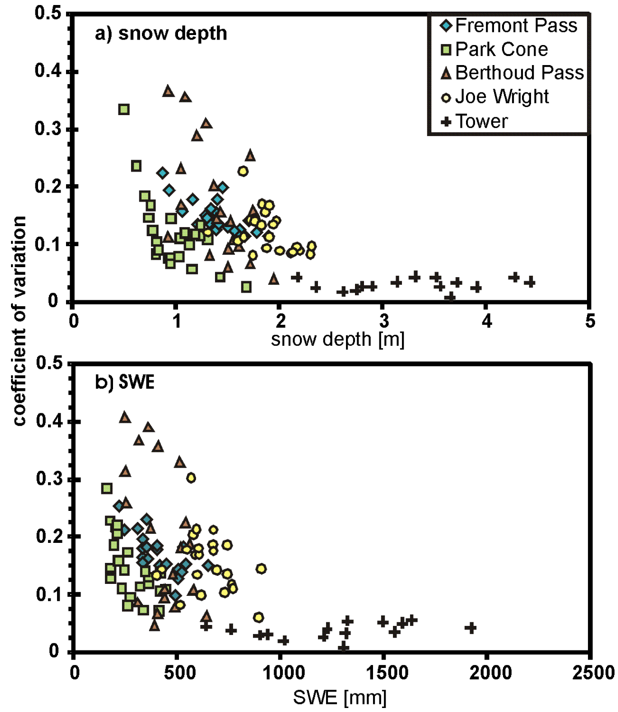

Figure 3. Plot derived from April 1st measurements of the coefficient of variation versus a) snow depth and b) SWE for the five snowcourse stations.

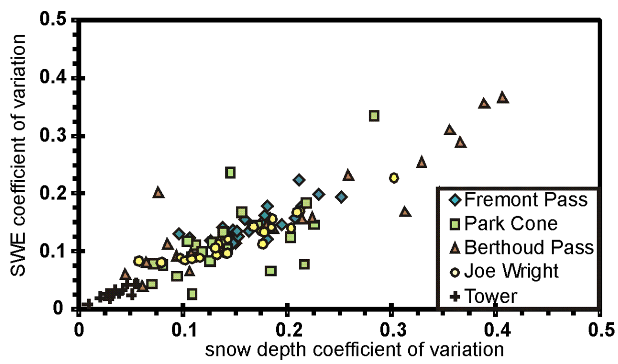

Figure 4. Plot of coefficient of variation for SWE versus snow depth for April 1st data.

Due to the strong consistency in snow density, the variability between SWE and snow depth is strongly related (Figure 4). However, this could change for times of the snow season other than April 1st, which is approaching peak accumulation at the five study stations.

Numerous snowcourse stations have been replaced by co-located USDA snow telemetry (SNOTEL) stations. The SNOTEL stations report daily (or shorter time) SWE, based on automated measurements representing approximately 10 m^2 (USDA, 2008). Snowcourse replacement by SNOTEL stations will remove the potential to assess snow variability at snowcourse stations. For snowcourses that have not been replaced, the data can be supplemented with the co-located SNOTEL SWE (and now snow depth) measurements since location does not change.

CONCLUSIONS

Four years of weekly data at the Tower site, the highest measured snow accumulation in the state, illustrated that the intra-annual variability was consistent for most of the winter. The except ion was during early accumulation and once melt had initiated. The individual data for April 1st snow depth and SWE illustrated an inverse relationship between variability and quantity of snow.

ACKNOWLEDGMENTS

Thanks are due to Doug Hultstrand, Molly Tedesche, and Marcos Roybal of CSU for their assistance with data entry. Mike Gillespie and his staff at the Colorado NRCS office provided access to the field notes. Partial funding was provided by the NOAA Office of Hydrologic Development.

REFERENCES

Cayan, D.R., 1996. Interannual climate variability and snowpack in the Western United States. *J. Climate*, 9, 928-947.

Deems, J.S., S.R. Fassnacht, and K.J. Elder, 2006. Fractal distribution of snow depth from LiDAR data. *J. Hydromet.*, 7, 285-297.

Fassnacht, S.R., J.D. Stednick, J.S. Deems, and M.V. Corrao, in review. Metrics for assessing snow surface roughness from digital imagery. Submitted to *Water Resources Research* (March 2008).

Gutzler, D.S., 2000. Covariability of spring snowpack and summer rainfall across the Southwest United States. *J. Climate*, 13(22), 4018-4027.

Stewart, I.T., D.R. Cayan, and M.D. Dettinger, 2005. Changes toward Earlier Streamflow Timing across Western North America. *J. Climate*, 18(8), 1136-1155.

Trujillo, E., J.A. Ramirez, and K.J. Elder, 2007. Topographic, meteorologic, and canopy controls on the scaling characteristics of the spatial distribution of snow depth fields. *Water Resources Research*, 43, W07409 (doi:10.1029/2006WR005317).

Wells, D.A., and R.F. Doyle, 2004. Forest growth impact on peak snow pack measurements at long term snowcourses. *J. American Water Resources Assoc.,* 40(2), 477-483.

USDA, 2008. *NRCS National Water and Climate Center*. URL: <http://www.wcc.nrcs.usda.gov>, accessed August 1, 2008.