

# STATISTICAL ANALYSIS OF SPATIAL AND TEMPORAL VARIATIONS OF SNOWPACK DENSITY USING SNOTEL DATA

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## ABSTRACT

In this study, we examined the spatial and temporal characteristics of snowpack density, and developed climatological maps of average monthly snow density for the contiguous western United States. Monthly averages were computed from SNOTEL daily measurements of snow depth and snow water equivalent available from 1999 through 2004. Our analysis indicated significant evolution of average snowpack densities from November to April, but only small inter-annual variability, regardless of the geographic location. The inverse-distance technique was used to create gridded maps of average monthly snow depth estimates, showing modest large-scale variability of monthly snowpack density.

## INTRODUCTION

Snowpack density is an important physical property of snowpack. It allows conversion between snow depth and snow water equivalent (SWE) where snowpack measurements are lacking of either type of data. Snow density varies in space and time, but in many applications it is assumed to be time and space invariant. For example, the current passive microwave snow depth retrieval algorithm was developed assuming a constant ratio of SWE to snow depth of 0.3 (e.g. Chang et al., 1987).

Daily snow depth data has been available from the Natural Resource Conservation Service (NRCS), Snowpack Telemetry (SNOTEL) in the western U.S. since the mid 1990s. Most SWE data has been available since the early 1980s. With both daily snow depth and SWE datasets, estimation of the bulk snowpack density was made at individual sites on a daily basis. The goal of this study was to examine the spatial and temporal characteristics of snowpack density estimated at SNOTEL sites.

## DATASET

The SWE and snow depth data used in this study were obtained solely from the NRCS, SNOTEL database. Snow depth measurements started in 1995-96 winter season, and the number of the sites that report snow depth measurements increases every year. Currently, nearly 500 SNOTEL sites provide both, daily SWE and snow depth data across the western U.S. (Figure 1). Snowpack density is estimated as a ratio of SWE and snow depth. It is usually given as a percentage of 0° Celsius water density. This study analyzed daily SNOTEL data from November through April for 5 winter seasons (1998/1999 through 2003/2004).

Quality control measures for both datasets were performed to eliminate erroneous values. This study followed similar procedures described by Serreze et al (1999) to remove erroneous SWE daily values. Erroneous values for daily snow depth were identified using the following steps. The negative depth values (cumulative values from October 1st) removed from the original data set. If the ratio of SWE and snow depth was greater than 1.0 or less than 0.05, depth values were removed. If the daily increment of snow depth/SWE was more than 120 cm, that value was also removed.

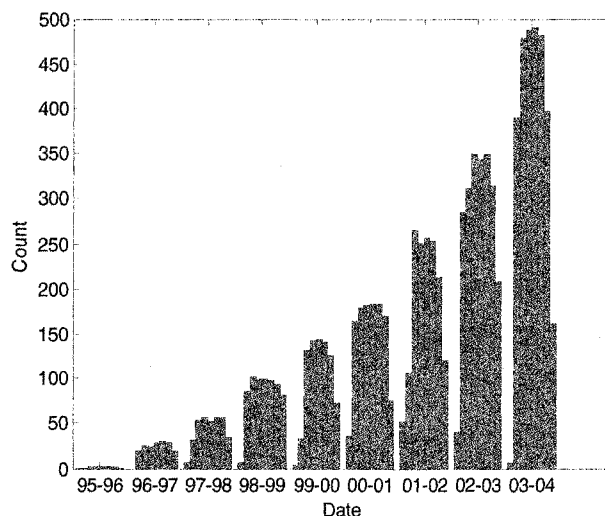


Figure 1. The number of SNOTEL sites per month and per year that had both, snow depth and snow water equivalent daily measurements.

## DATA ANALYSIS

### Snowpack Density at Single Site

Figure 2 shows a scatter plot of SWE versus depth from a 6 year daily dataset. Fairly good linear relationships appear for most of individual months except in March and April. However, a hysteresis loop is evident throughout the winter months, implying temporal change in physical snowpack characteristics. As can be seen in Figure 3, there is an obvious time evolution in snow density, but not much variability from one year to another. Snow density gradually increases, on average, from 0.18 to 0.25 from early November to mid February. The increase is much more drastic from March to May, from 0.25 to 0.45 respectively.

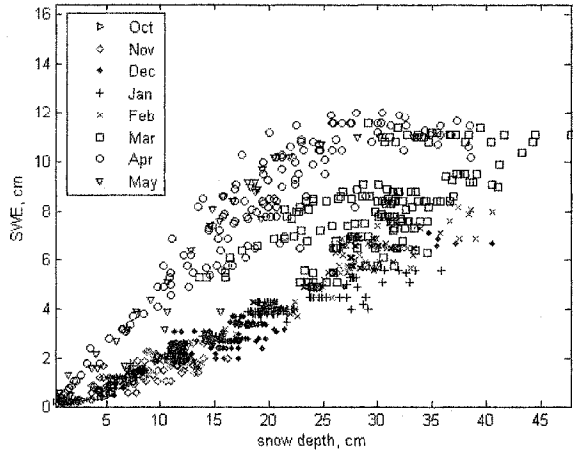


Figure 2. Scatter plot of daily SWE and depth values for KING'S CABIN in Utah during 1999-2004 period.

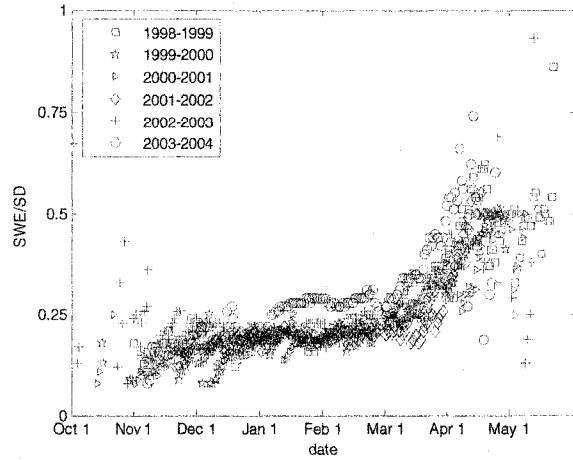


Figure 3. Time series of daily snow density values at KING'S CABIN, UT

### Interannual Variability

The coefficient of variation (CV) of monthly snowpack density was computed for each of the SNOTEL sites. As can be seen from Figure 4, CV was less than 0.2 for majority of sites except in November when the CV values on average ranges between 0.3 and 0.5. Relatively small CV indicates that monthly average snowpack density is fairly consistent in the mountain regions over the western U.S. from one year to another.

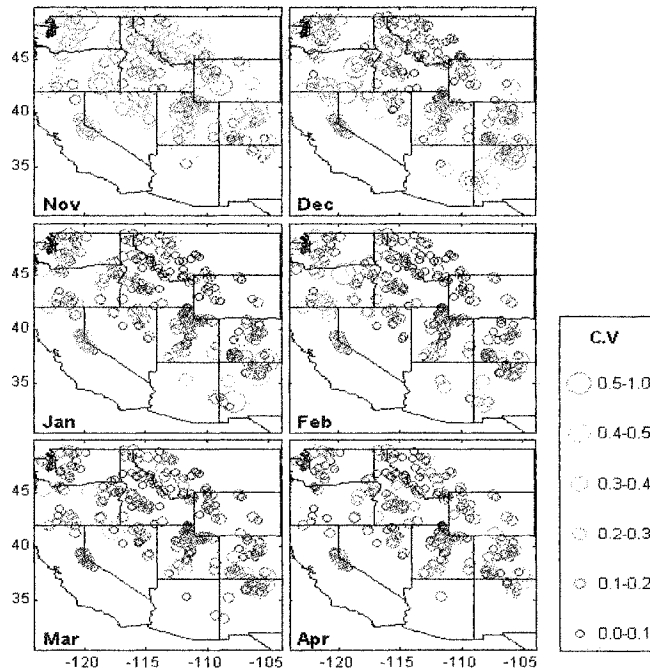


Figure 4. Coefficient of variation for monthly snowpack density

### Monthly Climate Map of Snowpack Density

Inverse-distance weighting with square power was used to interpolate monthly snowpack density at a 25 km grid interval. Interpolation was made only at grids that have more than two SNOTEL sites within 100 km search radius from the center of grid. Monthly climate maps of snow density, shown in Figure 5, reveal modest regional variability as well as significant seasonal effects. In general, snowpack density in coastal mountain regions is considerably higher than in continental areas throughout the winter season. However there exists smaller scale variability within each mountain region.

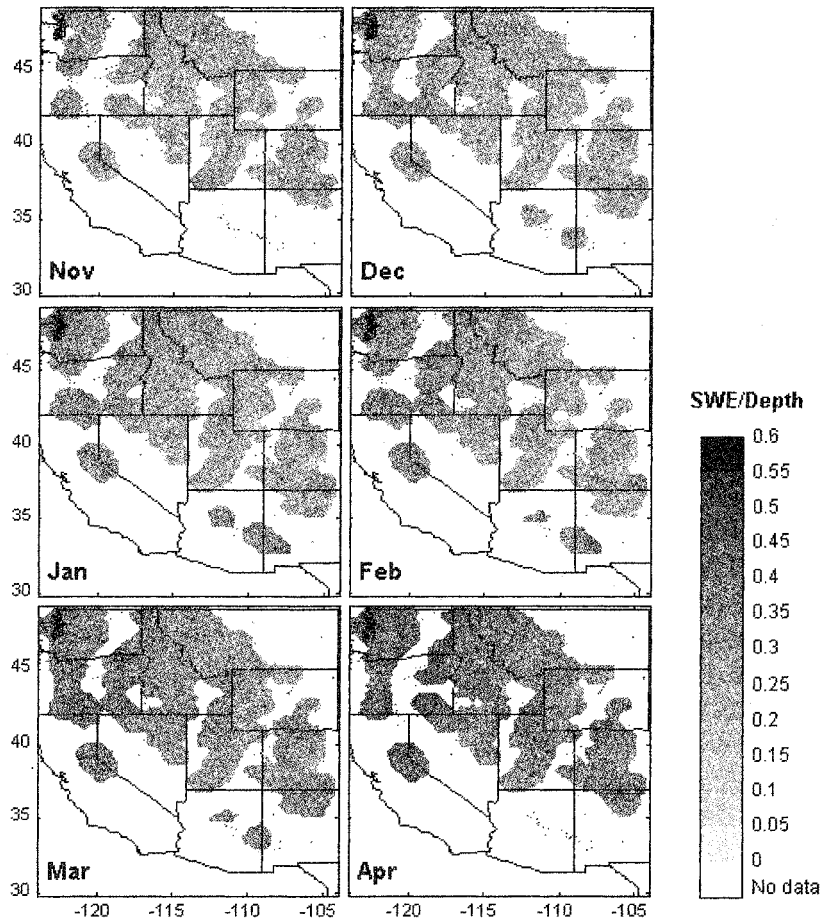


Figure 5. Monthly climate maps of snowpack density for November through April.

### SUMMARY AND FUTURE STUDY

Climatology of snowpack density was investigated using a 6 year snow depth and SWE dataset from the NRCS, SNOTEL network. Snowpack density increases slowly from early to mid winter months. However, density of early spring snow changes is significant in a relatively short period of time. In the western United States, interannual variability of monthly average snowpack density is small, except during early winter. The spatial map of monthly snowpack density shows that the snowpack density has a modest regional variability with smaller scale variability within the mountain regions. Future study includes quantification of spatial variability of snowpack density and exploring other interpolation techniques such as multiple linear regression with geographical and terrain variables for snow density climate mapping.

### ACKNOWLEDGEMENTS

We would like to thank Mr. Randy Julander, USDA NRCS, for providing daily snow depth dataset.

## REFERENCES

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