Novel Snotel Data Uses: Detecting Change in Snowpack Development Controls, and Remote Basin Snow Depth Modeling

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OVERVIEW

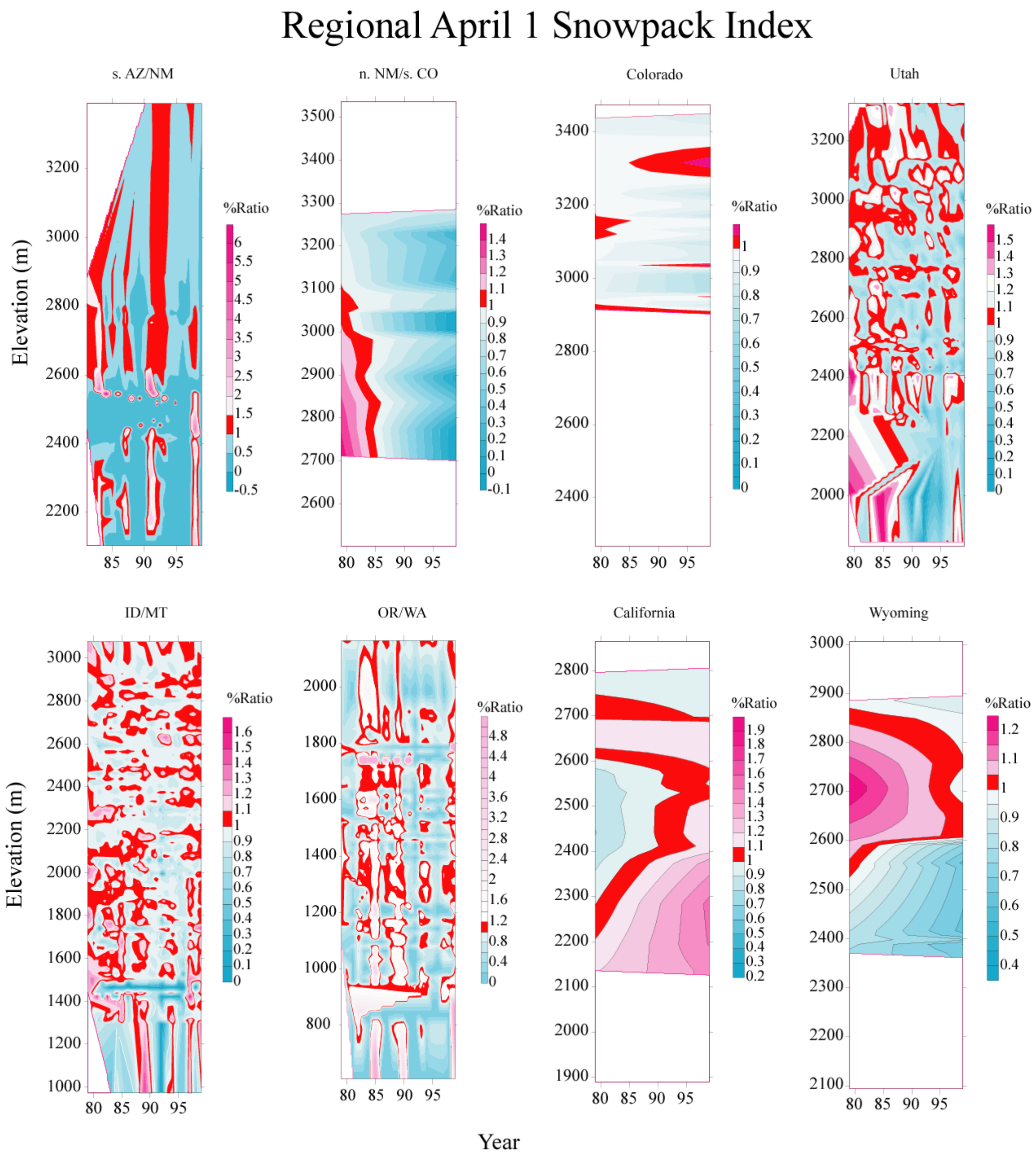
We present two uses of Snotel data beyond streamflow forecasting:

- Detecting non-precipitation changes in climatic controls on snowpack development through use of the Snowpack Index (SI).

- Modeling the spatial distribution of snowpack depth in alpine basins normally higher than Snotel installations.

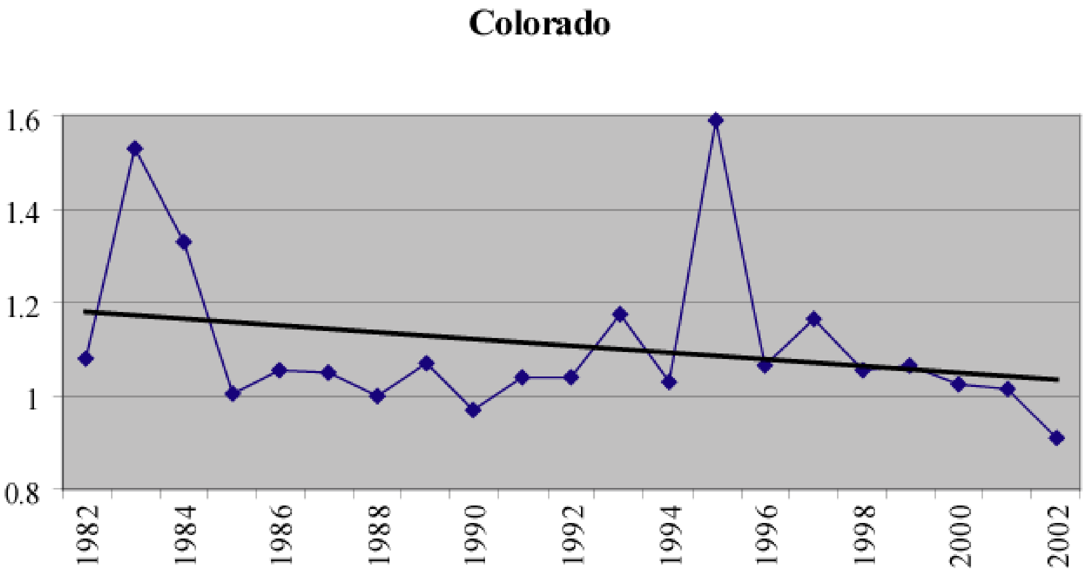
The SI normalizes for precipitation variability by ratioing the percent of average snow water equivalent divided by the percent of average cummulative winter precipitation. Both values are Snotel products. A SI of one indicates normality; less than one indicates less winter precipitation is sequestered as snowpack than average; greater than one indicates a greater snowpack than expected for the given precipitation.

Remote, windswept alpine basins are significant contributors to later season runoff which is important to fire vulnerability, and increasingly as a water source. However, alpine basins are often logistically challenging to instrument or manually survey for snow depth. The spatial distribution of snow in alpine basins can be accurately modeled using a complex mean geostatistical (CMG) approach. Parameters of this model are typically parameterized from intensive sampling within the basin. However, many of the model parameters have been found to be strongly correlated to the maximum Snotel SWE measurements for a site outside the basin. Once trained on actual data, it has been shown that a CMG model can be parameterized from data from a SINGLE Snotel site to accurately model snow depths in a remote basin. An example using the University Camp Snotel site to model the upper Green Lakes Valley in the City of Boulder Watershed is presented.

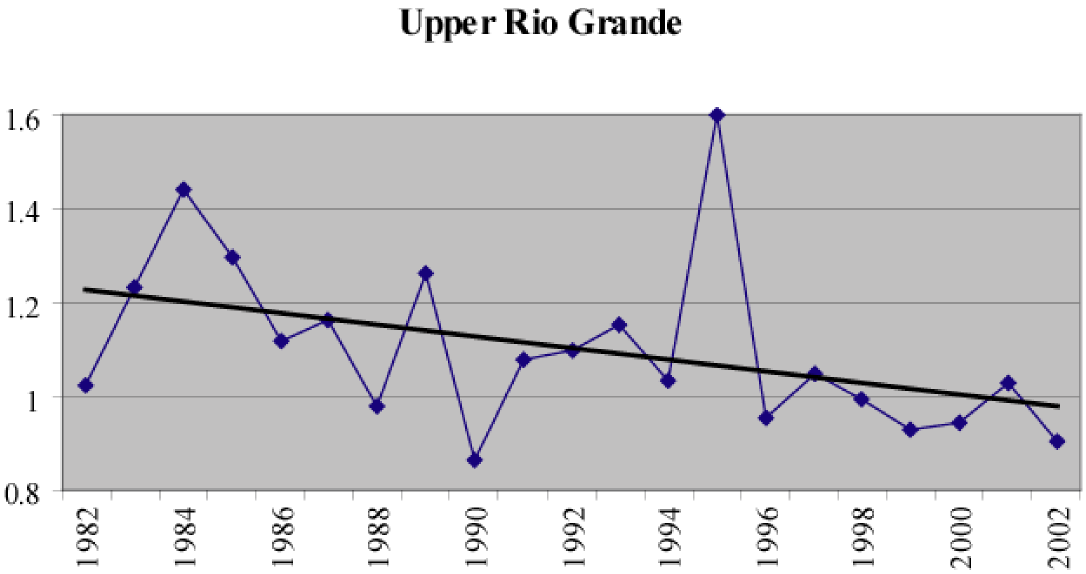


Snowpack Index (SI) in eight mountain areas of the West as a function of elevation and time. Color changes moving up or down indicate more SI variability by elevation. Changes moving left to right indicate more temporal variability.

The Snowpack Index trend for Colorado is slightly negative (-0.0074 SI/Yr), however this trend is not significant; the trend for the Upper Rio Grande River (-0.0124 SI/Yr) is significant. The Colorado snowpack is melting out 0.47 days per year earlier



(significance is at the 99.5% confidence) while the cummulative winter precipitation is decreasing by 0.30 inches per year (significance is at the 100% confidence). There is no trend in meltout date for the Upper Rio Grande, however the cummulative winter precipitation is decreasing by 0.52 inches per year (significance is at the 95% confidence).



Using SNOTEL data to model the spatial distribution of snow depth

SNOTEL data can be used to make predictions about the spatial variation of snow depth in an alpine basin. To illustrate this concept, we illustrate the estimation the spatial distribution of snow in the Green Lakes Valley (Figure 0) for 1999 using three different methods.

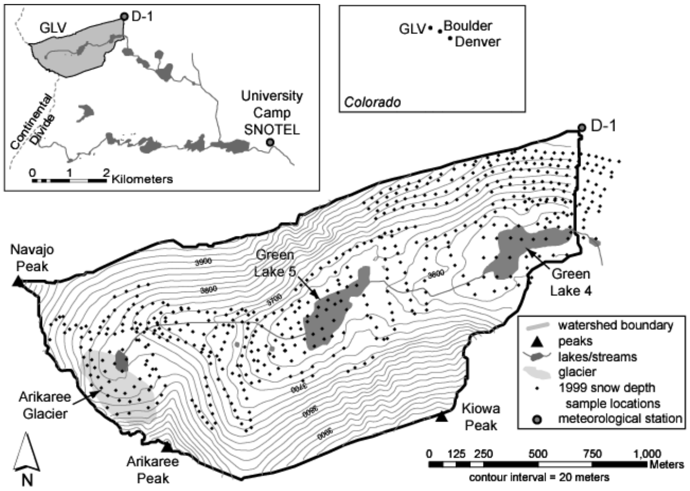


Figure 0 - Map of the Green Lakes Valley and surrounding meteorological stations.

The first method utilizes a non-linear trend model optimized for snow depth measurements taken in 1999 (Figure 1). The optimized trend model is based on five terrain parameters derived from a 10-m digital elevation model and knowledge of the dominant wind direction. The terrain parameters include elevation, slope, potential radiation, an index of wind shelter, and a binary index of wind drift formation. This first method represents the 'best' estimate of snow depth distribution, but is based on snow survey data that is not commonly available.

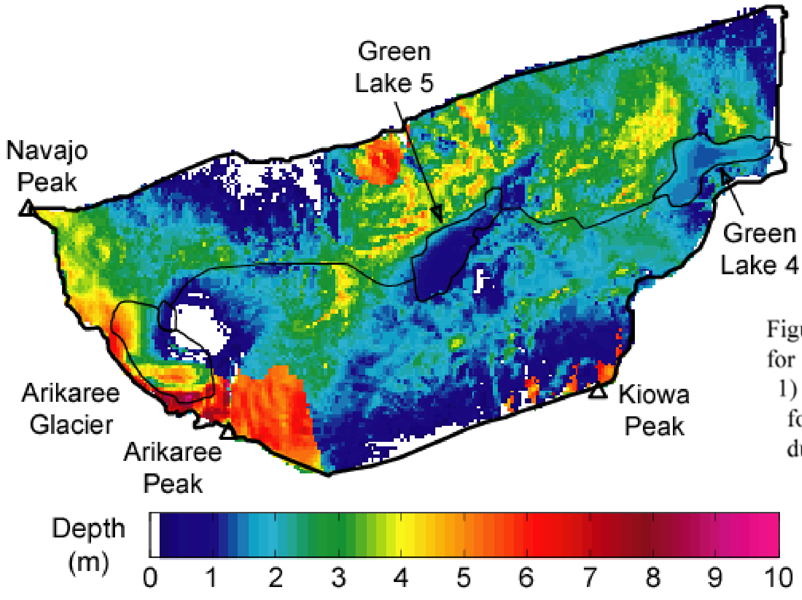


Figure 1: Best estimate of the snow depth trend for 1999 melt season, based on:

1) the effect of terrain parameters, optimized for 532 snow depth measurements taken during the 1999 snow survey

The second method is based on an estimate of the mean snow depth obtained from the maximum SWE recorded at a nearby SNOTEL station (University Camp) and a trend model optimized for 5 years of depth measurements (1998, 2000, 2001, 2002, 2003) and is illustrated in Figure 3. It is important to note that Figure 3 represents an estimate of the snow depth for 1999 that is made without utilizing the snow depth measurements taken in 1999. Figure 3 predicts relative snow distribution parameters that are similar to those estimated by the snow depth map based on 1999 measurements (Figure 1), suggesting that the effect of the topographic controls is constant from year to year. Figure 3 tends to estimate slightly higher snow depths than the snow depth map based on 1999 measurements Figure 2, because the 1999 mean snow depth (190cm) is below what the regression line predicts (231cm).

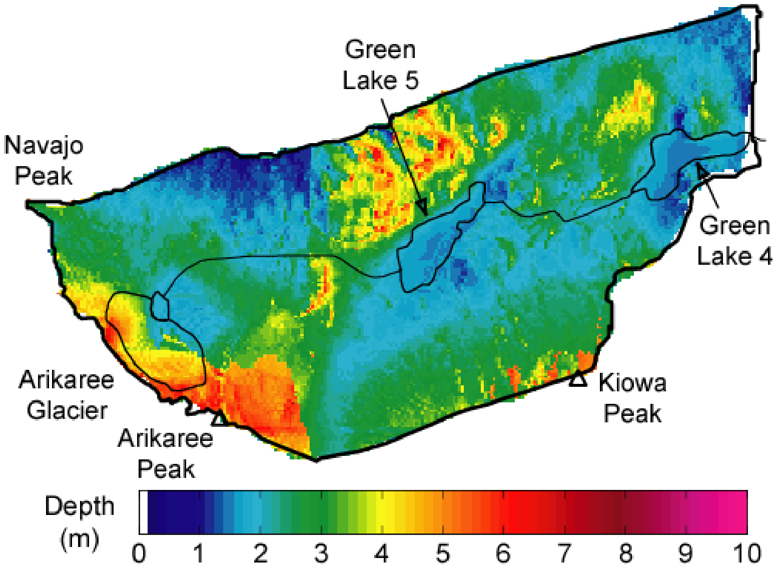


Figure 3: Best estimate of the snow depth trend for 1999 melt season, based on:
1) the mean snow depth estimated from the 1999 U-Camp SNOTEL maximum SWE, and
2) the effect of terrain parameters, optimized for 5 other snow survey datasets (1998, 2000, 2001, 2002, 2003)

The third method illustrates the improvement that can be obtained if a few measurements were taken during the year of interest, and the spatial correlation of model residuals is incorporated. These measurements are used to further improve the best estimate of snow depth (Figure 3) in the vicinity of the measurements by conditioning the estimate to the collected data. The sill variance and exponential length parameters necessary to parameterize the variogram (Figure 4) are estimated using the regression lines presented in Figure 2. In this manner, a conditioning map (Figure 5) and an estimate map (Figure 6) could be constructed that honor limited measurement points and use variogram parameters developed from other densely-sampled datasets to spatially distribute the estimate in unsampled regions.

Figure 2 (below left) - Linear regression of (a) the estimated mean snow depth, (b) exponential variance, and (c) exponential length parameter against the maximum recorded SWE (Nov 15 - May 15) at the University Camp SNOTEL site based on the 1998 through 2003 datasets.

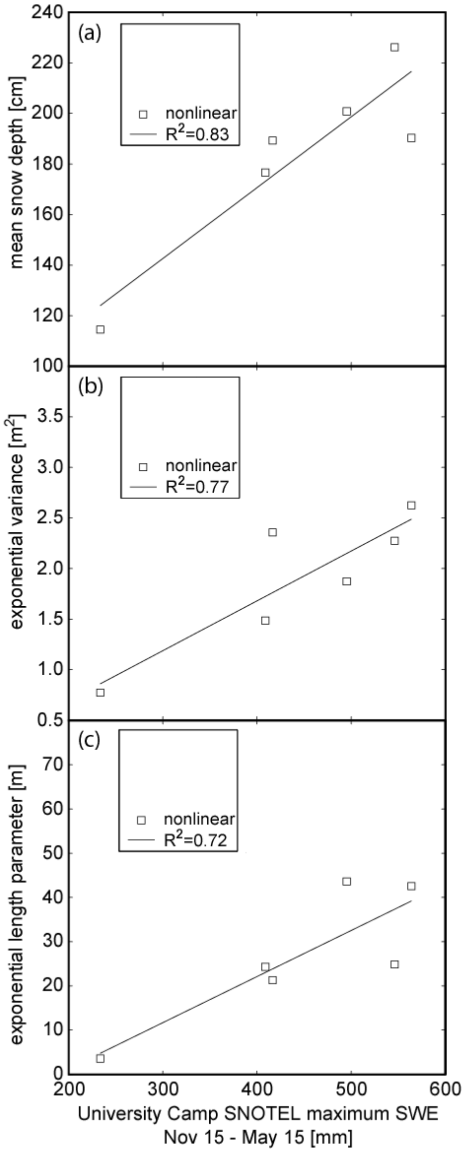
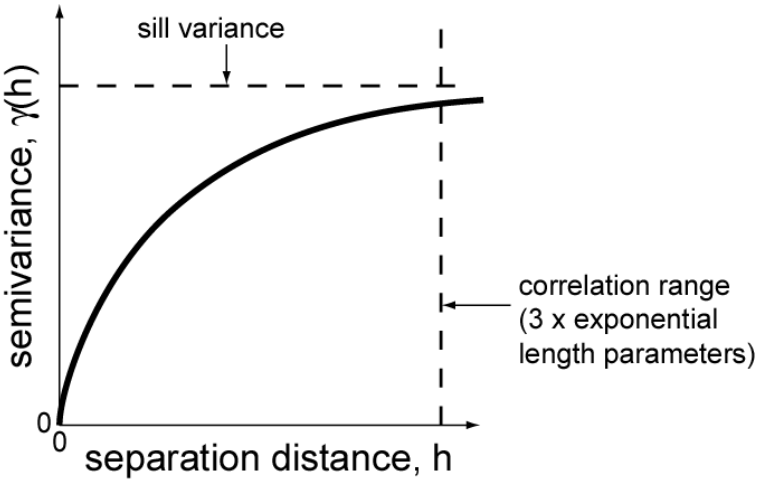


Figure 4: Exponential semi-variogram model used to describe the spatial correlation of model residuals. The exponential model is parameterized from the relationships between SNOTEL maximum SWE and the variogram parameters.



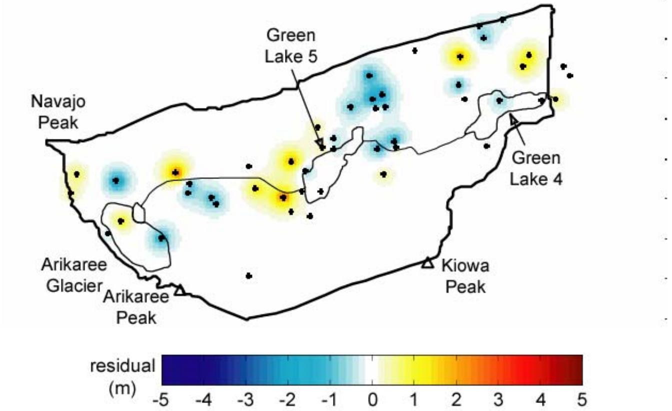


Figure 5: Residual errors (difference between measurements and the estimated trend) for 50 measurements of the 1999 snow depth survey.

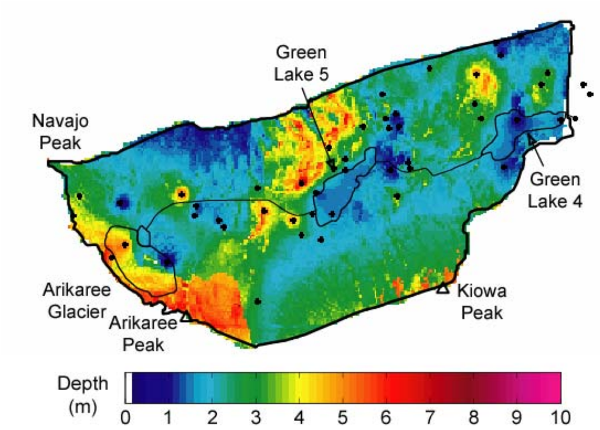


Figure 6: Best estimate of the snow depth trend for 1999 melt season, based on:

1) the mean snow depth estimated from the 1999 U-Camp SNOTEL maximum SWE,
2) the effect of terrain parameters, optimized for 5 other snow survey datasets (1998, 2000, 2001, 2002, 2003), and
3) limited measurements (50) from the 1999 snow survey