SNOW ACCUMULATION PATTERNS IN THE SIERRA NEVADA

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INTRODUCTION

Winter precipitation in the Sierra Nevada is associated with the passage of midlatitude cyclones from the eastern Pacific Ocean. The amounts of precipitation released from each frontal system typically increase with elevation (for similar slopes and aspects), and at lower elevations there is a greater possibility that the precipitation will fall as rain rather than snow. Spatial variations in snowcover also result from the differing paths individual storms may take as they move across the range. Thus, a storm moving along a particular track might result in large accumulations in the southern Sierra with lower amounts accruing to the north (or vice versa).

The mean storm path through a snow season can therefore result in distinct patterns of above- or below-normal accumulations. If there is little variability in the paths taken by storms, then a large amount of spatial variability may result between watersheds. If the storms are sufficiently cold so that most elevations receive their precipitation primarily as snow, there should be a high degree of consistency (in terms of standardized values) between sites within a particular basin. Warm storms, on the other hand, may result in a high degree of within-basin variability. This study examines the role of elevation and spatial separation on the climatological variability of below- and above-normal snow accumulations during the mid-winter and early fall.

METHODOLOGY

The study subjects snow course water equivalent data reported in Bulletin 120 of the California Department of Water Resources to principal components and regression analyses. Both methods of analysis are performed for February 1 and April 1 observations. Twenty-eight stations ranging in elevation from 1650 to 3440 m were selected for the principal components analysis (PCA). The stations and the period of record were selected to achieve a resasonable number of stations available with few missing values and to have as even a spatial distribution as possible. The years 1954-83 were selected for analysis. The locations of the stations and their elevations are given in Figure 1.

The goal of PCA is to reduce a large number of correlated variables (in this case, individual snow courses) into a smaller number of mutually orthogonal (uncorrelated) components. The degree to which each variable correlates with a particular component is expressed by its component loading (analagous to a correlation coefficient). The first component obtained accounts for the greatest percentage of the variance in the data with each subsequent component accounting for decreasing amounts. One can obtain as many components as there are variables, but only the first few will be considered "principal components." In this study the rotated and unrotated components yielded similar results. Hence, all discussion will relate to the unrotated components.

The second phase of the study uses 42 stations from 5 drainage basins selected for regression analysis. The years 1951-84 provided the optimal period of record. The 5 watersheds from which the snow courses were selected are shown in Figure 1 (individual maps showing the locations of the obervation sites are not provided due to space limitations). The measuring stations used here were selected so that locations within a basin but of differing elevations could be compared to those in other watersheds with similar elevations. Correlation matrices were then obtained.

RESULTS

The regression and principal components analyses of the February 1 and April 1 data yielded highly similar results. Therefore, this section will initially discuss the February 1 data. The April 1 data will then be compared to those results obtained for the mid-winter observations.

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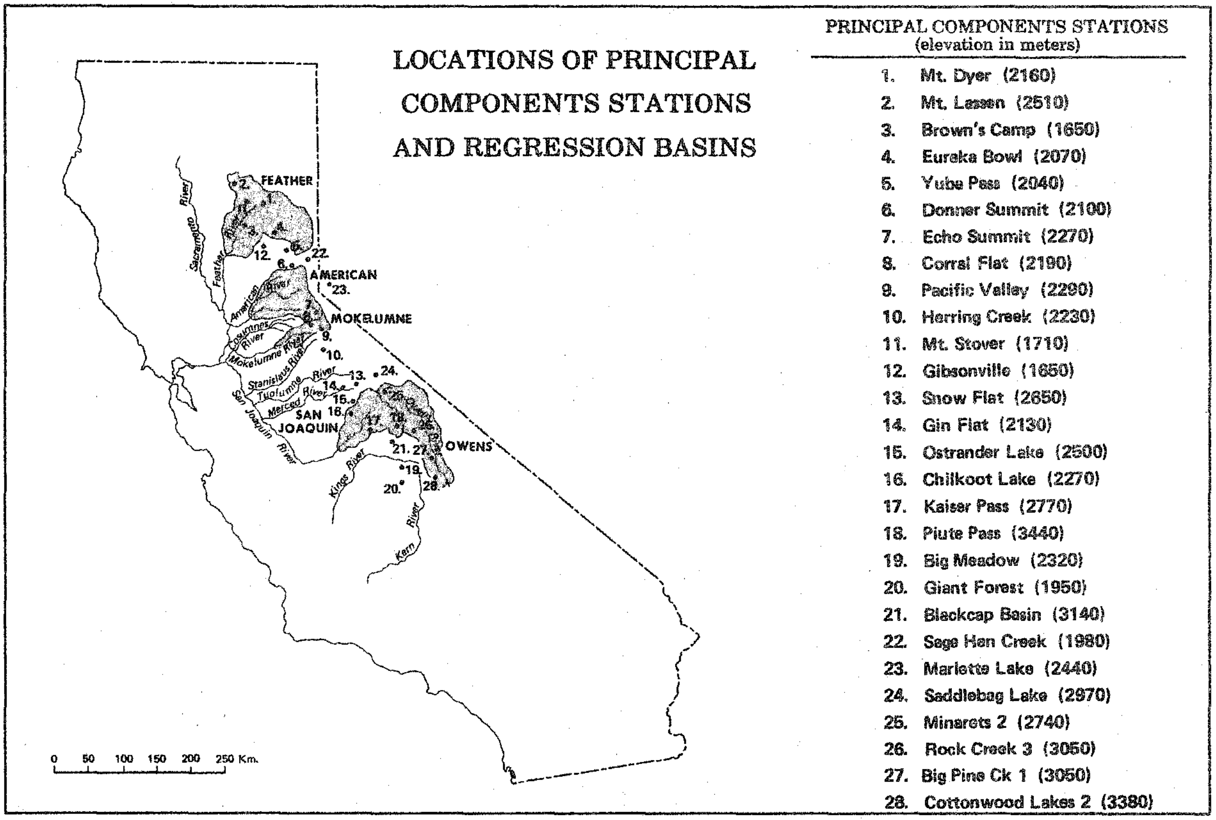

LOCATIONS OF PRINCIPAL COMPONENTS STATIONS AND REGRESSION BASINS

PRINCIPAL COMPONENTS STATIONS
(elevation in meters)

1. Mt. Dyer (2160)
2. Mt. Lassen (2510)
3. Brown's Camp (1650)
4. Eureka Bowl (2070)
5. Yuba Pass (2040)
6. Donner Summit (2100)
7. Echo Summit (2270)
8. Corral Flat (2190)
9. Pacific Valley (2290)
10. Herring Creek (2230)
11. Mt. Stover (1710)
12. Gibsonville (1650)
13. Snow Flat (2650)
14. Gin Flat (2130)
15. Ostrander Lake (2500)
16. Chilkoot Lake (2270)
17. Kaiser Pass (2770)
18. Piute Pass (3440)
19. Big Meadow (2320)
20. Giant Forest (1950)
21. Blackcap Basin (3140)
22. Sage Hen Creek (1980)
23. Marlette Lake (2440)
24. Saddlebag Lake (2970)
25. Minarets 2 (2740)
26. Rock Creek 3 (3050)
27. Big Pine Ck 1 (3050)
28. Cottonwood Lakes 2 (3380)

Figure 1.

The principal components analysis indicates that there is much uniformity in the spatial distribution of below- or above-normal snow accumulations. The first component, which can simply be interpreted as the tendency for all of the Sierra Nevada to have above- or below-normal snow water equivalents on February 1, explains 81.3% of the variance in the data. The representativeness of this component for each of the snow courses is revealed by the component loadings, all of which range between 0.705 and 0.981 (Table 1). Since the loadings are analagous to correlation coefficients, squaring these values reveals the amount of variance in the data for any one site explained by the first component. In this case, the snow course with the lowest loading (Mount Lassen with an $r = 0.705$) has 50% of all the variance explained by the first component. Seventeen of the stations have loadings greater than 0.90 and all but four exceed 0.80.

The second component accounts for an additional 6.7% of the variance, bringing the cumulative total to 88%. Clearly, although this component is significant, it is of much less importance than the first. All loadings for this component are much lower than for the first with only three snow courses, Brown's Camp, Gibsonville and Giant Forest, having loadings greater than 0.50. These three sites all ranked among the bottom four in terms of their loadings on the first component and are also among the lowest four snow courses in terms of their elevations. Thus, although they load more strongly on the first component than on the second, they have some commonality with each other missing from all the other locations. Also, several high elevation sites have negative loadings for the second component, although the absolute values of the loadings are low. This indicates a weak tendency for the high elevation sites to have below-normal accumulations when the lower snow courses have above-normal totals (and vice versa). A likely explanation for the commonality is that these low elevation sites have reduced snow accumulations with the passage of relatively warm storms by having a greater proportion of the total precipitation occurring as rain. On the other hand, higher air temperatures allow for more water vapor contents in the air and greater snow accumulations at high elevations.

TABLE 1

Component loadings for the 28 PCA stations.

	February 1		April 1	
Station	Comp. 1	Comp. 2	Comp. 1	Comp. 2
Mt. Dyer 1	.944	.085	.924	.132
Mt. Lassen	.705	.037	.791	.019
Brown's Camp	.754	.549	.850	.282
Eureka Bowl	.916	.241	.916	.267
Yuba Pass	.875	.157	.933	.211
Donner Pass	.965	.047	.948	.117
Echo Summit	.944	-.084	.914	.070
Corral Flat	.970	.022	.950	.151
Pacific Valley	.957	-.176	.956	-.015
Herring Ck.	.956	.003	.971	.014
Mt. Stover	.874	.283	.849	.311
Gibsonville	.736	.599	.788	.508
Snow Flat	.947	-.194	.964	-.101
Gin Flat	.934	.150	.939	.099
Ostrander L.	.966	-.066	.977	-.118
Chilkoot L.	.942	.057	.966	-.031
Kaiser Pass	.938	-.250	.961	-.240
Piute Pass	.957	-.196	.929	-.280
Big Meadows	.896	.045	.933	-.065
Giant Forest	.707	.519	.802	.064
Blackcap Basin	.896	-.343	.931	-.263
Sage Hen Ck.	.918	.247	.924	.258
Marlette L.	.953	-.174	.946	-.063
Saddlebag L.	.927	-.252	.917	-.304
Minarets 2	.981	-.092	.974	-.095
Rock Ck. 3	.862	-.366	.916	-.249
Big Pine Ck. 1	.893	-.245	.903	-.226
Cottonwood Lks. 2	.835	-.258	.858	-.328

None of the remaining components reduces the unexplained variance in the data to any significant extent. Therefore, further discussion of the accumulation patterns will deal with the correlation analyses of the 42 locations sampled from the five observation basins outlined in Figure 1. Eight sites were sampled from the Feather River Basin with elevations ranging from 1400 to 2510 m. Eight sites were also selected from the American River Basin (elevations from 1740 to 2590 m), 5 from the Mokelumne (1980-2380 m), 9 from the San Joaquin (2070-3440 m), and 12 from the Owens (2530-3380 m). The correlation matrix for all 44 snow courses (not shown due to space limitations) reveals that all the sites are correlated to some extent (the minimum r value was 0.33) with many pairs of locations having correlations in excess of 0.95.

There is much internal consistency within individual basins (Table 2). The Feather River Basin exhibited by far the most internal variability, despite the fact that several of the other watersheds had greater ranges in elevation for the sampling sites. This is largely due to the wider range of topographic situations for the measuring sites in the Feather River basin. The lowest correlation for any pair of snow courses occurred for two sites both located within this basin, at elevations of 1650 and 2520 m. Moreover, several snow courses outside of this watershed and at differing elevations correlated more strongly with these two localities than these two Feather River sites did with each other. Thus, local topographic conditions can lead to anomalous areas within a basin.

Between-basin variability was investigated by observing the correlation coefficients for pairs of snow courses located within different basins but at similar elevations. Snow accumulations for paired sites across the range at similar elevations are highly correlated with each other. When snow courses from the Feather, American, Mokelumne and San Joaquin basins with elevations between 2160 and 2190 m were correlated with each

Table 2

Ranges of correlation coefficients for paired sites within drainage basins.

Basin	February 1	April 1
Feather River	0.38 - 0.95	0.59 - 0.96
American River	0.76 - 0.99	0.73 - 0.99
Mokelumne River	0.84 - 0.99	0.90 - 0.96
San Joaquin River	0.56 - 0.99	0.71 - 0.98
Owens River	0.82 - 0.99	0.66 - 0.99

other, correlation coefficients ranged from 0.88 to 0.94. Interbasin correlations (from the same watersheds) for snow courses between 2040 and 2070 m were between 0.76 and 0.95. A sampling of sites from the Feather, American, San Joaquin and Owens basins ranging in elevation from 2440 to 2520 m had correlations of 0.59 to 0.96. The strength of these correlations is impressive given the fact that some of these sites are located several hundred kilometers from each other.

Results of the principal components and regression analyses for the April 1 data were similar to those obtained for February 1. The first component explains 84.1% of the variance in the April data (compared to 81.3% for February) while the second accounts for 4.5% (in contrast to the 6.7% for February). Table 1 indicates that the loadings for the two components for most stations are similar for both data sets. Thus, there is the same strong tendency for above- or below-normal accumulations to be found throughout the Sierra Nevada and that a weak temperature effect influences high and low elevation sites.

Within-basin correlations for the April 1 data were stronger than those for February 1 for three of the five basins (Table 2). This may reflect the fact that there is a lower percentage of precipitation falling as rain instead of snow at low elevations during the latter part of the snow season. The only watershed exhibiting lowered correlations for April 1 is the Owens River basin. This is the most southerly of the sampled basins and melt normally is well underway at the lower elevations by this date. Thus there are greater differences between the lowest snow courses and those at greater elevations.

The April 1 correlation coefficients for snow courses sampled from different basins but at similar elevations were remarkably close to those for the February 1 data. With only two exceptions, the April and February correlation coefficients were within 3% of each other. The other two were 10 and 11 percent higher for April 1 than February 1.

CONCLUSION

Although the observations made here are based on a limited number of observation sites, it is clear that the Sierra Nevada range has a great deal of spatial uniformity in terms of below- or above-normal snow water equivalents throughout the snow season. Further analysis with a greater number of observation sites is needed before a quantitative explanation of the effect of topography, elevation and latitude on actual snow amounts can be offered.