INVESTIGATING PERIODICITY IN THE LONG TERM PRECIPITATION RECORD OF DONNER SUMMIT, CALIFORNIA

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ABSTRACT

Donner Summit, California has the longest precipitation record from any high-elevation snow-dominated environment in the western United States. Water year 2000 will complete its 130th year of record. Anecdotal evidence suggests periodic trends in the long term *snowfall* record of Donner Summit. However, the measurement of snowfall is frequency dependent, making it a less-than-ideal gauge by which to compare one season to another.

Correlation coefficients are derived between annual Donner Summit *precipitation* values X(t) and X(t+k), where k is Δt. These coefficients are combined with a periodic term to derive a spectral density which describes the amount of variance per interval of frequency within the historic record. Peak frequencies from the spectral analysis are applied to the historic data to test for periodicity. The relative strength (or weakness) of periodic cycles may improve perspective on long term trends in mountain weather, vital information for water managers.

INTRODUCTION

The close of winter 1998-1999 left the northern Sierra Nevada of California with precipitation and snowpacks well above average for the fifth year running. The southern part of the range, however, endured a well below average precipitation season. This north-to-south differential in mountain snowpack was mirrored in the spring and early summer discharge of the state's largest river systems on the west slope of the range (Gehrke et al, 1999). As the population of California continues to increase so too does pressure to wisely manage its most valuable natural resource: water. With 50 percent or more of California's usable water coming from the melting snows of the Sierra Nevada, the state is especially vulnerable to below-average high-elevation precipitation. Long-term forecasting of mountain weather would obviously be an important management tool.

In 1949, architect, author, and avid skier Weldon Heald recognized an approximate 14 year "period" in the Donner Summit snowfall data between 1870 and 1948. He successfully predicted above-average snowfall for the next three "cycle" peaks of 1952, 1969, and 1983 (Wallerstein et al, 1998). Was this coincidence or otherwise? Since the measurement of snowfall is a function of measurement frequency, thereby being somewhat subjective, it is not necessarily a reliable measure of precipitation between two sites or even between two seasons. Water equivalent of the precipitate—whether rain, snow, or a mix of the two—is the objective measure.

Long-term high elevation precipitation records are rare. The Donner Pass region (39°19'N, 120°22'W, 2134 m) of the Sierra Nevada has the longest precipitation record from any high elevation site in the western United States. Water year 2000 will complete its 130th year of record. The Donner Summit precipitation record originates from four different sites, all within five kilometers and 82 meters elevation of each other. The data sets from these individual sites have been scrutinized on a double mass curve; because of their close proximity and similar elevations, no appreciable error is accrued when composited into a single record. The latter half of the historic record is all from one site, the Central Sierra Snow Laboratory (2098 m). At the Central Sierra Snow Laboratory between 80 and 85 percent of the annual precipitation falls as snow (Osterhuber, 1997).

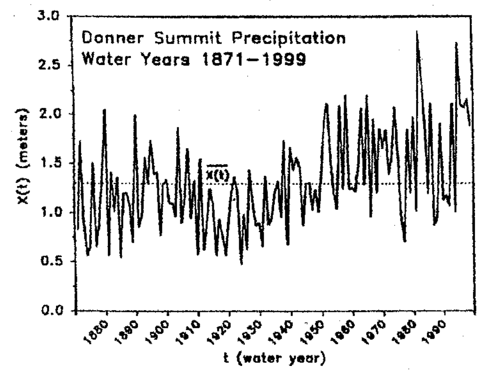

Figure 1

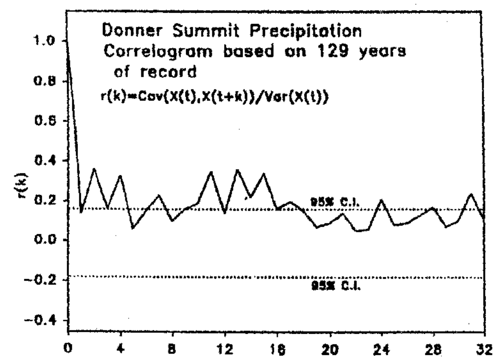

Figure 2

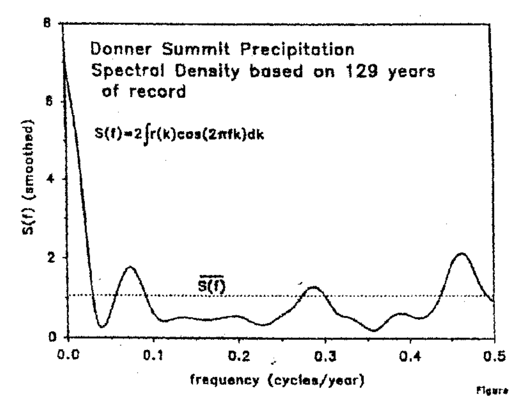

Figure 3

ANALYSIS

Heald identified peaks in the snowfall data simply by eyeballing a bar chart. A perusal of the historic annual precipitation record, X(t), in Figure 1 reveals no such obvious intervals except perhaps

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that the first half of the historic record is mostly at or below average; the most recent half tends above average. The 129 year mean, $\overline{X(t)}$, is 1311 mm, the standard deviation, σ, is 492 mm. Maximum precipitation occurred during water year 1982 (2852 mm), minimum during 1924 (480 mm). Wide annual variations are evident: ten pairings exist with only a single year separating a very wet ($> \overline{X(t)}+.5\sigma$) from a very dry ($< \overline{X(t)}-.5\sigma$) season. A linear regression of the historic record yields an increasing precipitation trend line with a slope of +5.8 mm/year. The R^2 value for this regression is 0.19.

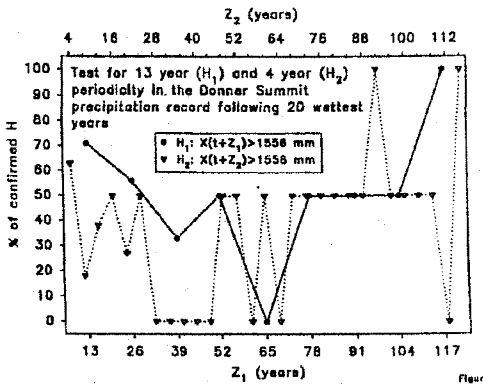

Figure 4

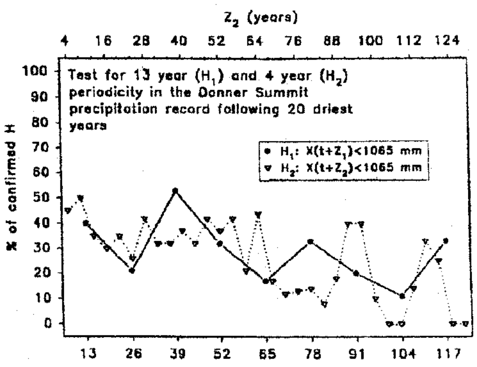

Figure 5

To test for periodicity within the data, correlation coefficients r(k) are derived where k is the number of time intervals (years) separating X(t) and X(t+Δt). As k increases, the number of pairs of observations in estimating r(k) decreases since all the summations contain n-k terms. For equally spaced observations taken k time units apart, .5 is the oscillation with the highest frequency at which any information can be obtained (Hogg and Tanis, 1988). Therefore k and frequency, f, are related by .5=32f/k, where 32 is the maximum value of k, approximately .25n (n=129). Figure 2 is the correlogram of X(t),X(t+k) as a function of k, with r(0)≡1. The dashed lines are the upper and lower limits of the 95 percent confidence interval. The plot of r(k) shows no overall apparent pattern though 37 percent of the calculated values lie outside the confidence interval, indicating at least some dependence between X(t) and X(t+k).

The spectral density function for r(k), S(f), is derived from a Fourier transform and shown in Figure 3. The plot demonstrates much "white noise", that is, the values oscillate about the mean of S(f). This is indicative of equally distributed variance among all frequencies (Hogg and Tanis, 1988). Three peaks within the power spectrum are evident: at frequency .469 (2.1 years), .281 (3.6 years), and .078 (12.8 years—close to Heald's 14 year period). The 2.1 year period is considered too short for this analysis and is not examined here. There is some evidence of an approximate 2 to 8 year cycle associated with El Niño/La Niña alternation (Baldwin, 1998), though correlation between the Southern Oscillation Index and Donner Summit annual and seasonal precipitation has proved statistically insignificant (Osterhuber, 1998). The 4 and 13 year peaks are investigated further.

To test for 4 or 13 year maxima (or minima), the 20 wettest years (2852 to 1905 mm) and the 20 driest years (480 to 858 mm) of record were selected. Multiples of years, Z, are counted forward from each of these and the resulting number of years either very wet (for the 20 wettest) or very dry (for the 20 driest) tallied (Figures 4 and 5). For the first cycle (Z=13) after the 20 wettest years, 71 percent of the water years had totals considered very wet. After that, for every 4 and 13 year cycle following both wet years and dry, the results were at best neutral. Throughout the tests, the 4 year period proved a better predictor than the 13 year period. For the wettest years, better than half (59 percent) of the tested cycles confirmed at least 50 percent of H_2 (Figure 4). For the driest years on record, again the 4 year period proved slightly better than the 13 year, though all but one of the tested cycles confirmed only 44 percent or less of H_2 (Figure 5). Where 100 percent of hypotheses H_1 and H_2 are confirmed (Figure 4) is a result of only single data points that far into the record.

The spectral analysis indicates independence of the X(t) values; because of this independence, it is valid to rank the seasonal totals from largest to smallest and derive a recurrence interval (Figure 6). Figure 6 shows the mean annual event, $\bar{x}$, as having a recurrence interval of approximately 2.3 years; a $1.5\bar{x}$ event occurring on average every 8.8 years; and a $2\bar{x}$ event every 75.0 years.

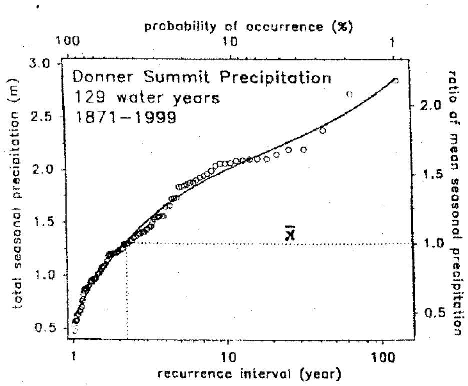

Figure 6

CONCLUSIONS

A time series can be represented by linear, periodic, and random components (Kite, 1989). The linear and periodic elements are significant as they describe the variance during some defined frequency. With these components we endeavor to predict future trends based on past trends. Since in this analysis correlation is poor or nonexistent with these elements, it is hypothesized that the annual precipitation on Donner Summit is driven by random mechanisms not mathematically represented here. Both the correlogram and spectral density indicate the annual precipitation on Donner Summit to be a random, stochastic process. Even though the first test of a 13 year cycle seemed promising, and the 4 year period tested better than the 13, a 4 or 13 year period have no apparent utility as predictors within the historic record for either very wet or very dry years. It should be noted that the 4 year period falls within the hypothesized 2 to 8 year El Niño cycle. Evidence of periodicity may not be recognized for a number of reasons: 1.) there may be none; 2.) the mathematical operations employed here may be inadequate to uncover periodicity; or 3.) if periodicity exists, the historic record may not yet be long enough for a cycle to appear. The linear trend shows a significantly increasing slope through the record, though the correlation coefficient is poor. Periodicity tests of the 129 year precipitation record from the central Sierra Nevada reveal no improved perspective on long range weather or potential water supplies.

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