Trends in Snowfall versus Rainfall for the Western United States

Abstract. The western U.S. depends heavily on snowpack to help sustain its water-use ecosystems, and the climatic factors behind it, it is useful to distinguish reduced initial snowfall and earlier snowmelt as separate causes of early runoff. Warming trends have historically been (and are projected to continue) marked by strong seasonal patterns (Knowles and Cayan, 2002). The topographically complex process of snow deposition and melt are therefore subject to different warming trends, and trends in these processes follow accordingly. This study isolates the effect of thermal warming on snow deposition throughout the western U.S.

Data and Methods
NCEP Summary of the daily historical data comprising snowfall depth (S), precipitation (P), minimum (TMIN) and maximum (TMAX) surface air temperature for the contiguous U.S. were ascendent for the 53-year period 10/1/1948-9/30/2001. For precipitation and snowfall, there were 1,675 stations actively supplying some or all of the data for temperature, the number of stations was 1,575. Emulating the approach of Hamilton et al. (2004), the data pair of precipitation and snowfall were processed according to the following sequential steps:

1) Any year for which at least 10 days between 11/1 and 3/31 have missing precipitation or snowfall data was considered incomplete and was excluded from the analysis.
2) Any station which was missing >50% of precipitation or snowfall data in any given 10-year period was discarded.
3) Any station whose mean total annual SWE (see below) was less than 50mm was discarded.

Steps 1-2 were applied to the pair TMAX and TMIN. Daily snow-water equivalent (SWE) of deposited snow (not to be confused with the SWE of the accumulated snowpack) was determined by assuming that any precipitation measured on a given day was also measured in solid form; for non-measured snowfall, any measured P was assumed liquid. Time series of winter (Nov-Mar) and monthly totals of SWE and P were calculated, the corresponding ratio SWE/P were calculated, and a Kendall's-tau trend analysis was performed on all time series.

Results

a. Winter Trends
SWE/P trended negatively for winter years 1949-2001 over most of the West (Figure 1a). Of all 222 stations, 136 trend negative and 63 trend positive (64 vs. 15 at p<0.05). In each winter, the ratio SWE/P was most pronounced at low-elevation sites in WA, OR, and CA, though significant negative trends occur throughout the West.

Figure 2 shows the corresponding individual trends in SWE and P. The dominance of trends in SWE deposition in generating the SWE/P trends is evident. SWE trends generally correlate with the direction of trends in total rainfall (SWE), although trends in P are in the “wet” direction, with the slight exception of CO and NM, where higher P has led to higher SWE, with the ratio SWE/P still generally decreasing.

b. Monthly and Seasonal Changes
Plotting trends in SWE/P by month (Figure 3) reveals that the strongest declines occur in January along the West Coast and March throughout the entire West. How do the underlying factors contribute to this relationship? Table 1 shows the results of a non-parametric Kendall's-tau analysis for the various contributing factors in which factor's rank correlation with Z was calculated, along with statistical significance.

Changes in SWE/P and in SWE/P become less negative with altitude. This appears to be the result not only of colder average conditions with altitude, but also a general tendency toward less long-term warming at higher elevations, particularly in the Rockies. In fact, the highest altitudes show evidence of cooling (not shown here) and a general tendency toward less long-term warming at higher elevations, particularly in the Rockies

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References