Variability and Vulnerability of Western US Snowpack
Potential impacts of Climactic Change
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Introduction

The Western United States is largely an arid land, and some of the driest lands are the east slopes of the numerous mountain ranges of the West. Snowpacks that develop in the winter in these mountains provide water throughout the year to humans and ecosystems creating a strong link between snowpack and virtually all life forms in the Western US. Planning for the future depends heavily upon knowing the variability of snowpack. Climatic variability increases vulnerability of the many areas relying upon snowpack as a water source because of its increased variability. Past conditions suggest credible levels of this variability, and are thus the focus of this poster.

Mountains are particularly important to precipitation processes, and since water from winter storms is sequestered in snowpacks for gradual release throughout the year, the mountains are truly the water towers of the West.
Fig. 1. April 1 Snowpack Water Equivalence (SWE) Variability. Snowpack water content is most variable in the coastal regions and least variable in the interior continental western US.

Fig. 2. Snowpack variability is greater than precipitation variability in all quadrants of the West. The greatest variability is in the northwest quadrant of the US and least in the northeast.

Seasonal Variability

PRISM 1961-1990 Mean January Precipitation, United States

Fig. 3A
January (Fig. 3A) and July (Fig. 3B) precipitation patterns are virtually opposite in the Western US.

Variability in Time, Space, and Elevation in Three select regions

April 1 Snowpack Conditions in the Highlands

Western Slope
Wetter

Eastern Slope
Dry In Rain Shadow

Northern Colorado Rockies NCR
April 1 Precipitation Conditions in the Lowlands

Western Slope
Wetter

Eastern Slope
Dry In Rain Shadow

Northern Colorado Rockies NCR
Fig. 4. Lowland and highland trends often differ. A decreasing trend in NOC snowpack, and a minimum extreme of 2 mm SWE in 1963 (Fig. 6), could mean no snowpack in some years to come. The NOC lowland precipitation trend is slightly increasing, but snowpack is more important to water supply because of its relatively slow release over time, compared to the fast runoff of rain events at lower elevations. (Locations of NCR, NSN, and NOC are shown in Fig. 1).

Variability by Topographic Aspect in Three Mountain Areas

April 1 snowpack conditions for the three mountain range sites for the full study period, 1937-2000. The maximum, minimum, and median SWE amounts are given (mm) with the year of occurrence in [brackets], and the respective east/west slope values beneath. The coefficient of variation (CV) for 1937-2000 is also shown for the east/west slopes.
Fig. 5. Snow water equivalence (SWE) in eight mountain areas of the West as a function of elevation and time.
Color changes moving up or down indicate more SWE variability by elevation. (Example: New Mexico and Colorado).
Changes moving left to right indicate more temporal variability. (Example: California).
ENSO phase variability is greatest at the NOC, and least at the NCR in general. The El Nino phase at NOC is the most variable of all possible combinations of place and phase.

Fig. 7. Mean SWE (mm), Standard Deviation (SD), and Coefficient of Variation (CV) on the east and west slopes of all three mountain range sites.

<table>
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<th>Northern Oregon Cascades (NOC)</th>
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Highlights

Snowpack in the western United States varies over time, by elevation, mountain range orientation, slope (east or west), and ENSO phase. This variability in turn, suggests the vulnerability of water supply to climatic change in the West, and points to the importance of characterizing snowpack variability. The following are some key findings of this study.

Variability of snowpack generally increases from the interior continental regions of the West towards the Pacific Ocean where both snowpack and winter precipitation are most variable (Fig. 1). Fig. 2 shows the lowest variability is in the northeast quadrant of the western US whereas the northwest quadrant is the most variable.

The eastern slopes of mountain ranges receive less precipitation than their western slope counterparts (Figs. 4&7), thus the impact on water supply in a low snowpack year is potentially greater on the east sides. Snowpack variability is greatest in those mountain ranges with only one source of moisture and atmospheric pathway to deliver that moisture. An extreme example
is the east flank of the Oregon Cascades which has received as much as 665 mm and as little as 2 mm of water in its annual snowpack. With its high coefficient of variation (CV) of 0.62 (Fig. 6) and declining trend (Fig. 4), it is feasible that no snowpack at all might occur in some future years!

The Sierra Nevada is an intermediate example. It has just one moisture source, the Pacific Ocean as do the Cascades, but more than one atmospheric circulation pattern can deliver moisture to this range. This is an effect of its geographic orientation being more NW to SE which makes southern storms precipitation producers for this range, in contrast to the Cascades. The average CV is 0.45.

The Rocky Mountains of Colorado illustrate the concept of two moisture sources, the Pacific Ocean and the Gulf of Mexico, and several atmospheric pathways deliver this moisture. Thus, western, eastern, and southern centered storm systems drop precipitation on this range. Its average CV is a low 0.28.

Fig. 4 shows that lowland and upland winter precipitation conditions are NOT necessarily well linked. Trends and characteristics of variability can be quite different even though the spatial separation is very small. This is particularly evident on both slopes of the NOC, and the east slope of the NCR.

The roles of elevation and time in snowpack variability are shown in Fig. 5. Elevation accounts for more snowpack variability in the mountains of Arizona, New Mexico, Utah, Idaho, and Montana, whereas time is the primary factor in California and Wyoming. Both time and elevation are roughly equal factors in Oregon and Washington.

The phase of the El Nino Southern Oscillation (ENSO) is a larger factor in snowpack variability in the Oregon Cascades (NOC) than in the Sierra Nevada (NSN) to its south, and is relatively unimportant in the Colorado Rocky Mountains (NCR) (Fig. 7). In the Cascades, the greatest variation occurs during the El Nino phase, but the deepest snowpacks occur during La Nina.