Trends in Mountain Snowpack in the Western United States

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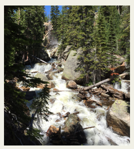
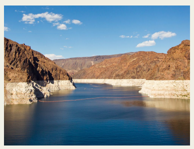
Western Water Supply

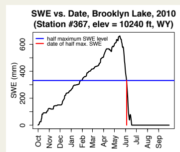
Mountain snowpack is the largest form of water storage for regions in the western U.S. such as California, Oregon, Washington, and Colorado (Mote, 2005). Spring and summer snowmelt supplies rivers and reservoirs with the water needed to sustain urban areas and agriculture, and is vital to the health of coastal, river, and high-altitude ecosystems (Kapnick and Hall, 2011). Over the past decade, various studies have shown declines in mountain snowpack, and trends towards an earlier onset of melting. This work uses data from SNOTEL sites to investigate these trends.

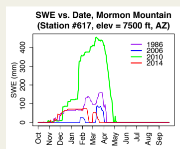
Snow Telemetry System (SNOTEL)

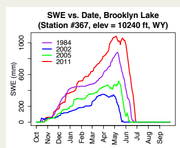
- Measures snow mass, depth, precipitation, and temperature
- 858 automated stations in 13 Western states
- Mainly in high wilderness areas
- In operation since approx. 1980

Brooklyn Lake SNOTEL site, WY. From left to right: antenna with temperature sensor, solar panels; snow pillow and ground truth markers; precipitation gauge (pressure transducer); snow depth sensor (radar).

Methodology





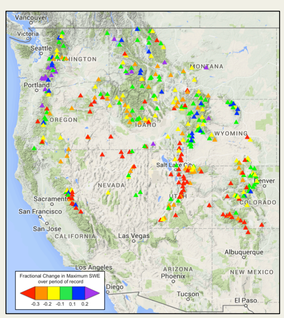


- Snow water equivalent (SWE) data and date read for each SNOTEL site in the western U.S., then separated by water year (Oct 1st to Sept 1st)
- Maximum SWE found for each water year. Date at which snowpack reaches half of max SWE recorded
- Some sites do not have full winter snowpack (see Mormon Mountain vs. Brooklyn Lake). Years with SWE below threshold level of 200mm excluded. Sites with more than 5 years below threshold excluded
- Sites with fewer than 20 years' valid data excluded
- Trends in max SWE and trends in date of half max SWE found by linear regression
- Fractional change in SWE over period of record calculated for each station

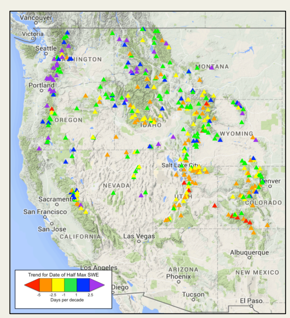
Results

Maps of trends and fractional change in SWE show regional differences:

- Sites south of CA-OR border show greater decreases in SWE
- Trend for half max SWE date moves earlier south of CA-OR border
- Pacific North West shows increasing SWE, later half max SWE dates
- All sites in NM and AZ excluded due to insufficient snowpack

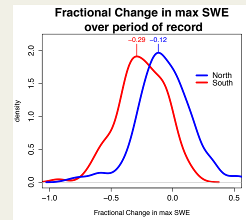


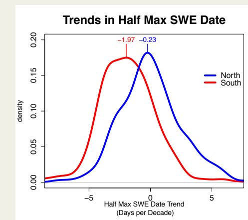
Fractional change in maximum SWE for period SNOTEL site has been in operation



Trends in date at which snowpack reaches half the value of maximum SWE

Regional Differences





Empirical probability density function shows different distributions for sites on opposite sides of 42°N (CA-OR border)

- 30% decrease in maximum SWE is most common value for sites in south, 12% decrease for sites in north
- Most common southern trend for day at which half maximum SWE is reached is -2 days per decade, -0.23 days per decade in north

Comparison with Literature

- Multiple studies (many for longer time periods than considered here) have shown temperature increasing and snowpack decreasing overall for all regions of western U.S. (Knowles, 2005, Mote, 2006, Pederson, 2013) but with north-south SWE variation due to differences in precipitation
- Cayan et al. (2001) used ecological markers to show earlier spring onset in western U.S. since 1970
- Mote (2006) attributed 50% of observed decrease in snowpack to Pacific Decadal Oscillation (PDO) and North Pacific Index effects, remainder to anthropogenic forcing
- Wise (2010) showed that western US precipitation closely correlated to patterns of PDO, Southern Oscillation Index and Atlantic Multidecadal Oscillation
- Stoelinga (2010) found a 19% increase in Cascade Mountain spring snowpack from 1997-2007, correlation with Cascade snowpack and natural variability of North Pacific region
- Casola et al. (2008) modeled temperature sensitivity of Cascade spring snowpack , argued that natural fluctuations mask any basin-wide trends of less than 40%, minimum detectable trend greater for individual stations