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The Impact of Fluctuations in Precipitation and Temperature on the Seasonal Snowpack

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The development and melting of the seasonal snowpack depends on complex interactions among climate elements. Previous work (Woods 2009, Adv. Wat. Res.) showed how the typical seasonal variation of temperature and precipitation rate influence snowpack development. Results were expressed in terms of three dimensionless variables for: seasonal temperature regime; seasonality of precipitation; and depth of the snowpack relative to the energy available for melting. However, that theory does not take account of sub-seasonal fluctuations in temperature and precipitation, and as a consequence, makes poor predictions of snow storage in some climates.
Here we write a stochastic differential equation for point-scale snow water equivalent (SWE), and then derive an equation for time variation of the probability distribution (pdf) of SWE. This provides a detailed but compact understanding of how temperature and precipitation interact to influence the seasonal accumulation and melt of snow. From this equation, we can estimate statistics such as the mean and standard deviation of SWE on any day of the year, and the mean residence time of snow, and see how they are related to climate characteristics.
To develop the equation, we first describe temperature and precipitation with 4 parameters each, defining the mean, seasonal amplitude, seasonal timing, and sub-seasonal fluctuations. To simulate the response of the snowpack to climate, we use a temperature index model with two parameters: a degree-day melt factor and a threshold temperature.
By writing the equation for snow storage in dimensionless form, we reduce the problem to five dimensionless parameters, three of them the same as found by Woods (2009), plus one each for the sub-seasonal fluctuations in precipitation and temperature. In the special case of no fluctuations in temperature and precipitation, the new equation reduces to the deterministic case of Woods (2009).
We verify by Monte Carlo simulation that that the probability distribution of snow water equivalent is correctly reproduced for an idealised case. Examples will be presented using SNOTEL data from the USA, in a variety of climates, and possible applications to catchment hydrology will be briefly introduced, by integrating the point-scale snowmelt hydrograph over the distribution of elevation.