THE EFFECT OF PHYSIOGRAPHIC PARAMETERS ON THE SPATIAL DISTRIBUTION OF SNOW WATER EQUIVALENT IN A LARGE MOUNTAINOUS BASIN

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Extended Abstract

Water accumulated and stored is the winter snowpack throughout the mountainous regions of the Western United States is a critical, yet poorly understood resource. An improved understanding of the correlations between basin physiography (e.g. elevation, land cover, incoming solar radiation, etc.) and snow water equivalence (SWE) in large and diverse landscapes could lead to better estimates of the total volume of water stored in the winter snowpack. This study quantifies the effect of the physiography of a large (207 km^2) and complex mountainous basin (West Fork of the Gallatin River basin in SW Montana) on the spatial distribution of SWE and snow density. Sampling took place near the time of peak SWE accumulation (~April 1st 2012).

Due to the large spatial extent of the basin (particularly with respect to previous work) sampling throughout its entirety was not a practical option. SWE and snow density were sampled in areas of the basin that were physiographically representative (based on unique combinations of elevation, potential incoming solar radiation, and land cover) to the basin as a whole. Representative sampling areas were defined and quantified through the use of Geographic Information Science (GIS) terrain analysis and the use of the aforementioned parameters.

Within the defined sampling areas SWE and snow depth samples were acquired over a variety of spatial scales (10m-400m) in a semi-random and structured manner. Sampling teams traveled throughout each defined sampling area on skis stopping at pre-defined distances which had been randomly generated a priori to take three SWE and snow depth (so density could be calculated) measurements in a 10m equilateral triangle pattern, to minimize bias due to anisotropy. Using this method over 1,000 direct measurements of SWE and snow depth (allowing for the calculation of density) were obtained.

Three modeling approaches were used in the analysis of the SWE data; regression tree, conditional inference tree (CI tree), and mixed effects multiple regression (MEMR). The three modeling approaches were similar in their estimates of total basin SWE (approximately within 1% of their averages) but provided very different patterns of how SWE is spatially distributed throughout the basin. All three methods showed elevation and potential incoming solar radiation to have the most significant influence on the spatial distribution of SWE, with land cover also being significant in the mixed effects and conditional inference tree models.

Aside from similar estimates of total basin SWE, several key differences existed between the three models representing the spatial distribution of SWE. The MEMR model provided the widest range of SWE values (0-859mm), which was most similar to that observed in the field. The regression and CI tree models estimated smaller ranges of values of 43-546mm and 0-486mm, respectively. Additionally the MEMR model provided unique estimates of SWE for each 30mx30m raster pixel in the basin while the two tree-based models estimated only a discreet number of unique SWE values to be spatially distributed throughout the basin. The regression tree modeled seven unique SWE values and the CI tree modeled 16.

The continuous range of values modeled by MEMR more accurately represents the continuous increase in SWE with elevation than with tree based models, but leads to overestimation of SWE in many high elevation areas of the

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basin. The discreet values modeled by the regression and CI trees lead to large gaps in SWE values which represented some of the most commonly observed SWE depths (162-359mm) in the field.

Using raster algebra in ArcGIS 10.0 the spatial distributions of SWE as estimated by the three different models were averaged. The average of the three spatial distributions was determined to provide the most overall realistic representation of SWE values observed in the field by "dampening" the effect of some of the less realistic attributes of the various models. Through spatial averaging the problems of overestimation of SWE depth at high elevation with the MEMR model and underestimation with the tree based models were resolved to provide more values similar to those observed than did any individual model. The averaged model also resolved the issue of large gaps in modeled values that was presented by tree-based models by simulating a continuous increase in SWE with respect to elevation throughout the basin.

Snow density was observed to vary widely throughout the basin with a standard deviation of 61 kg/m^3 around a mean of 349 kg/m^3. The spatial distribution of density was modeled using regression tree and multiple linear regression analysis. Both models estimated similar basin average snow density using elevation and radiation as explanatory variables, but displayed considerably different spatial distributions and ranges of modeled densities. Density models were also combined with spatially distributed models of snow depth to quantify the effect of varying parameterizations of depth and density (as this is what has been done in most previous work) on estimates of total basin SWE. Six SWE models were developed using various combinations of depth and density models, which provided a substantially wider range of total basin SWE estimates than with the models utilizing direct SWE measurements. The combined models had a 14% range of estimates around the mean compared to the approximately 1% range from utilizing direct measurements.

Overall, this study provides a replicable method for sampling, analyzing, and modeling the spatial distribution of SWE and snow density. In all models, elevation and potential incoming solar radiation were shown to have the strongest correlations to both SWE and snow density, with land cover having a significant influence in two of the SWE models. This study also showed that varying parameterizations of snow depth and snow density to estimate total basin SWE can provide a much wider range of estimates than through using direct SWE measurements, particularly in basins with a large elevation range. This information could provide guidance for future studies as to the importance of this issue for maximizing the accuracy of an analysis. (KEYWORDS: snow density, snow spatial distribution, SWE, Gallatin, Montana, SWE)