Chapter 116
Estimating Fractional Snow Cover in Mountain Environments with Fuzzy Classification

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ABSTRACT

The disproportionate amount of water runoff from mountains to surrounding arid and semiarid lands has generated much research in snow water equivalent (SWE) modeling. A primary input in SWE models is snow covered area (SCA) which is generally obtained via satellite imagery. Mixed pixels in alpine snow studies complicate SCA measurements and can reduce accuracy. A simple method was developed to estimate fractional snow cover using freely available Landsat and data derived from DEMs, commercial and free software, as well as fuzzy classification and recursive partitioning. The authors attempted to develop a cost effective technique for estimating fractional snow cover for resource and recreation managers confined by limited budgets and resources. Results indicated that the method was non-sensitive (P = 0.426) to differences in leaf area index and solar radiation between 4 March 2000 and 13 March 2003. Fractional snow cover was predicted consistently despite variation in model parameters between years, indicating that the developed method may be a viable way for monitoring fractional snow cover in mountainous areas where capital and resources are limited.

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INTRODUCTION

Conceptualizing mountains as water towers is an important cornerstone of modern hydrological research. Mountainous areas, which comprise only a small percentage of the Earth's surface, supply many surrounding arid and semiarid lowlands with water for irrigation and food production (Messerli et al., 2004) as well as many other services (e.g., hydropower, ecosystem health, recreation, etc.). The distribution of runoff in mountain environments is highly disproportionate to that of lowland areas (Viviroli et al., 2007) and consequently, demand for runoff is often highly contentious. Monitoring snowpack and determining snow water equivalent (SWE) have become important factors for assessing annual variability and predicting runoff availability (Coughlan & Running, 1997; Rango et al., 1977). Many SWE models use coarse climate data that have been interpolated, downscaled, or extrapolated to make predictions at finer scales (Wilby et al., 1999; Wood et al., 2004). Although climate data are capable of enhancing SWE predictions, error associated with interpolation, downscaling, and extrapolation can greatly reduce prediction accuracy. To overcome the limitations associated with climate data, many SWE models also require extensive field data. However, field data require considerable time and capital which are not always available to local resource managers. Consequently, local resource managers are unlikely to generate the most accurate prediction of annual runoff.

Snow covered area (SCA) is a primary input in SWE models and is important to both local water resource managers estimating SWE, as well as winter and summer recreationists in mountain areas. Tourism, not often at the forefront of hydrologic or environmental research, supports many mountain communities that capitalize on recreation associated with snow cover and snowmelt. Climate change may result in a decrease in natural annual snow cover. As a result, ski resorts may need to supplement natural accumulations with artificial snowmaking (Scott et al., 2003, 2006; Steiger & Mayer, 2008; Vanham et al., 2009). Non-winter activities such as fishing and whitewater recreation (Mickelson & Hamlet, 2008) are also important to mountain communities and are directly related to snow cover and runoff. Consequently, SCA is important to both water and recreation resource managers in mountainous regions.

Early monitoring of SCA utilized 'hard' image classification (Dozier, 1989; Rango & Itten, 1976), which introduced error into classification outputs when multiple land cover classes were present in a single pixel. In an attempt to distinguish different land cover classes at the sub-pixel level, land cover classes were evaluated using spectral unmixing, which provided a deterministic method by which multiple discrete spectral signatures were identifiable in individual pixels (Vikhamar & Solberg, 2003). A more inductive method of performing sub-pixel classification, fuzzy classification, has rarely been used in SCA assessment. The objectives of this study were to (1) assess the capability of fuzzy classification to approximate fractional snow cover, (2) examine the sensitivity of fuzzy fractional snow cover predictions to small changes in environmental parameters between years, and (3) develop a cost effective, simple method of estimating SCA for resource and recreation managers who do not have access to extensive academic or governmental resources. We utilized free data sources as well as a combination of both common commercial and free software packages to achieve our objectives.

PREVIOUS WORK

For decades, the importance of SCA has been noted in climatological and runoff forecasting. Previous research has suggested that snow cover influences Earth's surficial energy balance and affects regional and global climates (Barnett et al., 1989; Clark & Serreze, 2000; Leathers & Robin-

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