SENSITIVITY OF THE SNOWMELT RUNOFF MODEL TO UNDERESTIMATES OF REMOTELY SENSED SNOW COVERED AREA

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1. BACKGROUND

In common with many of the major river systems in the interior Western United States, the streamflow of the Rio Grande and its tributaries is driven largely by melting winter snowpacks that accumulate annually in high altitude basins. Over the last 40 years, records indicate earlier onset of spring with concomitant reduction in snowpack and melt season streamflow [1]. Annual snowmelt supplies around 50% of the surface water for the state of New Mexico so decreasing snowpack has serious implications for future management of water resources. The surface water supplied by the melting snowpack is vital for wildlife habitat, irrigated agriculture and for the conservation of the rural cultural landscape in the Rio Grande basin.

We are using the Snowmelt-Runoff Model (SRM) to forecast future water availability. SRM is a simple degree day model that simulates streamflow in high elevation basins where melting snow is a major contributor to runoff [2]. Regular estimates of basin snow-covered area (SCA) are required over the snowmelt season to derive snow depletion curves for model input. Remotely sensed data are the most logical source for these regular, synoptic estimates of SCA. Given the size of our study area and the frequency with which we require cloud free imagery, the best sensors currently available for our research are the MODIS instruments onboard the Terra and Aqua platforms.

Various algorithms have been developed for SCA estimation from MODIS data. The most widely used is the normalized difference snow index (NDSI) [3] and variations thereof [4, 5]. The NDSI forms the basis of the MODIS 500 m resolution swath (MOD10-L2) and daily tile (MOD10A1) snow products. The main challenge in using these products in SRM is they do not register the thin snow cover that persists into early summer [6]. An alternative to the NDSI is the MODIS Snow Covered Area and Grain Size (MODSCAG) [7]. MODSCAG depends on physically-based models of snow reflectance to estimate viewable snow covered area (SCA_v) from multiple endmember spectral mixture analysis. Unlike the NDSI, MODSCAG is able to detect thin snow cover at high altitudes at the end of the melt season (Figure 1). However, the challenge when using MODSCAG is accounting for snow cover under evergreen forest canopy and adjusting for the effect on snow reflectance under deciduous trees.

The main aim of our current research is twofold: (i) to examine the sensitivity of SRM to SCA and (ii) to formulate a reclassification approach for improving the estimation of total SCA from MODSCAG estimates of fractional vegetation cover.

2. METHODOLOGY

Precipitation, temperature and streamflow data were acquired for the Del Norte watershed in the Upper Rio Grande basin. SRM was optimized using snow depletion curves interpolated from SCA estimated from nearest neighbor classification of Landsat TM data (30 m resolution). The sensitivity of SRM to SCA was then assessed using snow depletion curves interpolated from SCA estimated from the MOD10A1 snow cover product and SCA_v from MODSCAG.

MODSCAG estimates of SCA_v were reclassified to SCA using input from land cover data, digital elevation data and MODSCAG estimates for fractional vegetation cover. Pixels classified with more than 10% vegetation cover and less than 80 % snow cover were assessed for reclassification based on slope aspect, elevation zone and percent snow cover. A simple reclassification rule based on the presence / absence of snow within a 100 m elevation zone was used to reclassify forested pixels in that zone to the equivalent percent snow cover for the nearest snow covered pixels.

3. RESULTS

SRM optimized for snow depletion curves interpolated from Landsat TM data over-predicted streamflow by 11% for the 2001 snowmelt season. Running the same model with the depletion curves interpolated from the MOD10A1 snow cover product and SCA_v from MODSCAG resulted in estimates of streamflow that were 6% and 19% below actual streamflow respectively. The hydrograph created by SRM using the MOD10A1 depletion curve tracked measured streamflow, corresponding closely with peak runoff during May. From the end of May to early July, measured run-off exceeded computed runoff. The hydrograph created by SRM using SCA_v underestimated peak runoff during May and continued to underestimate runoff until early July. Depletion curves interpolated from adjusted SCA from MODSCAG yielded hydrographs comparable to those computed for Landsat TM data, resulting an over-estimate of runoff of 13%. However, runoff was still underestimated between May and July.

4. CONCLUSIONS

Even though the MOD10A1 snow cover product fails to predict thin snow cover at high elevation at the end of the snowmelt season, our research indicates that this data product a satisfactory input for estimating depletion curves for the SRM, resulting in predictions for runoff from snow melt that closely approximate actual runoff. MODSCAG data also yields estimates of SCA_v suitable for estimating snow depletion, provided those estimates are recalibrated to total SCA. This research was conducted with minimal ground reference data and requires validation with intensive ground survey to justify the proposed reclassification rules applied to the MODSCAG SCA_v. We hypothesize that the accuracy with which SCA is estimated can be improved with more intensive characterization of individual basins and with particular attention concerning local snowmelt conditions.

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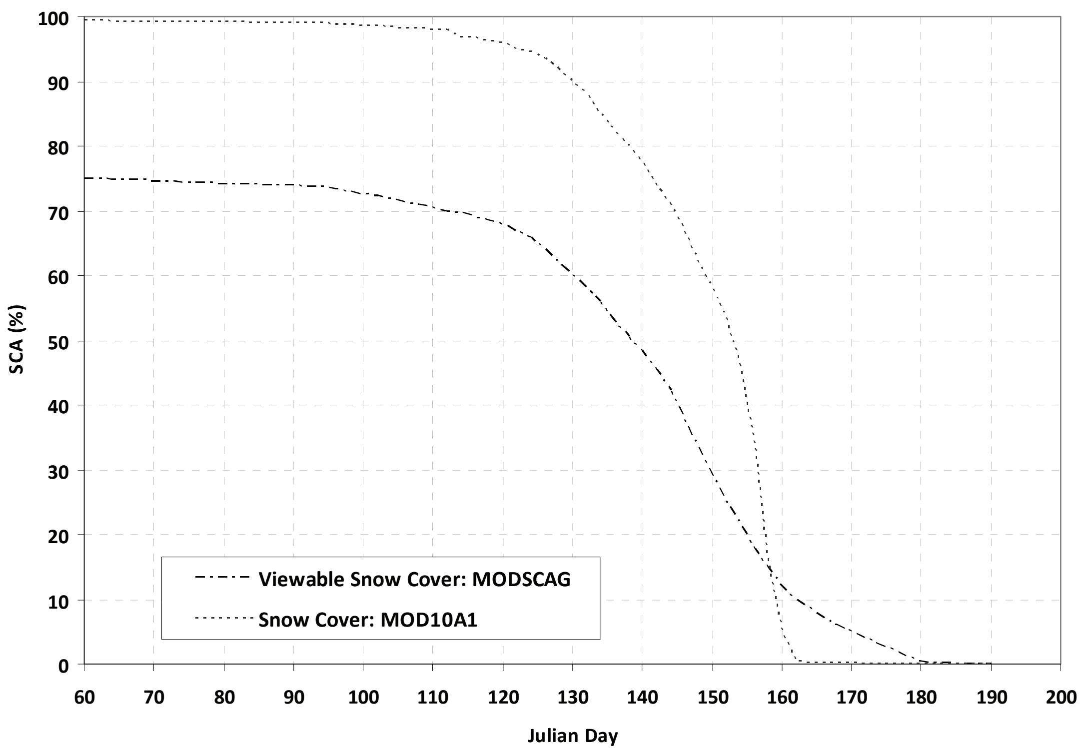

Figure 1: Snow depletion curves for the upper elevation zone, Del Norte Basin, Colorado (2001).