AN EVALUATION OF TERRAIN-BASED DOWNSCALING OF MODIS-BASED FRACTIONAL SNOW COVERED AREA DATASETS OVER THE TUOLUMNE RIVER, CA BASED ON LIDAR-DERIVED SNOW DATA

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EXTENDED ABSTRACT

Remotely-sensed snow covered area (SCA) datasets with both high spatial and temporal resolutions are needed for research, planning, and management of hydrologic and ecologic resources. MODIS-based products provide good temporal resolution (daily), but on coarse scale grids (~463 m). This coarse spatial scale can be refined through applying downscaling procedures, which consist of using the fractional snow cover area product (fSCA, the percentage snow cover within a MODIS pixel area) to assign binary (presence/absence) SCA data on higher resolution grids. Current methods rely on representing ablation effects on snow spatial variability by using topographic radiation-derived slope factors and relative elevation as primary indicators of snow presence/absence (Walters et al., 2015), or a degree-day approach (Li et al., 2015). In both studies satellite-derived data were utilized for model input and validation. Uncertainty associated with the input and validation data in assessing downscaling performance could be better understood if reliable, platform-independent fine scale SCA data were available. Here, we propose such a framework for testing and developing a new downscaling procedure based on LiDAR-derived snow depth data collected over the Tuolumne River watershed, CA. Our new downscaling procedure is based on terrain-derived indices that are representative of both ablation and accumulation, drivers of snow spatial variability in complex terrain. The use of the LiDAR-derived dataset has several advantages over using the satellite data. First, the validation data is more accurate, as LiDAR-derived data are high resolution (1-3m). Second, accurate fSCA datasets can be derived from the high resolution LiDAR-derived snow data at the MODIS scale to be used as input data. Third, the downscaling performance can also be tested over vegetated areas, where LiDAR-derived data is presumably more accurate than the satellite data.

We focus our analysis on the Tuolumne River watershed located on the west slopes of the Sierra Nevada Mountains, California (Figure 1a). The region of interest is above the Hetch Hetchy Reservoir, which is the main source of San Francisco's water supply, and was surveyed using airborne LiDAR techniques during the 2013, 2014 and 2015 ablation seasons as part of the NASA Airborne Snow Observatory (ASO) program (Painter et al., 2016). Figure 1 b-l shows the ASO-derived snow water equivalent over the area during 2014. The upper Tuolumne

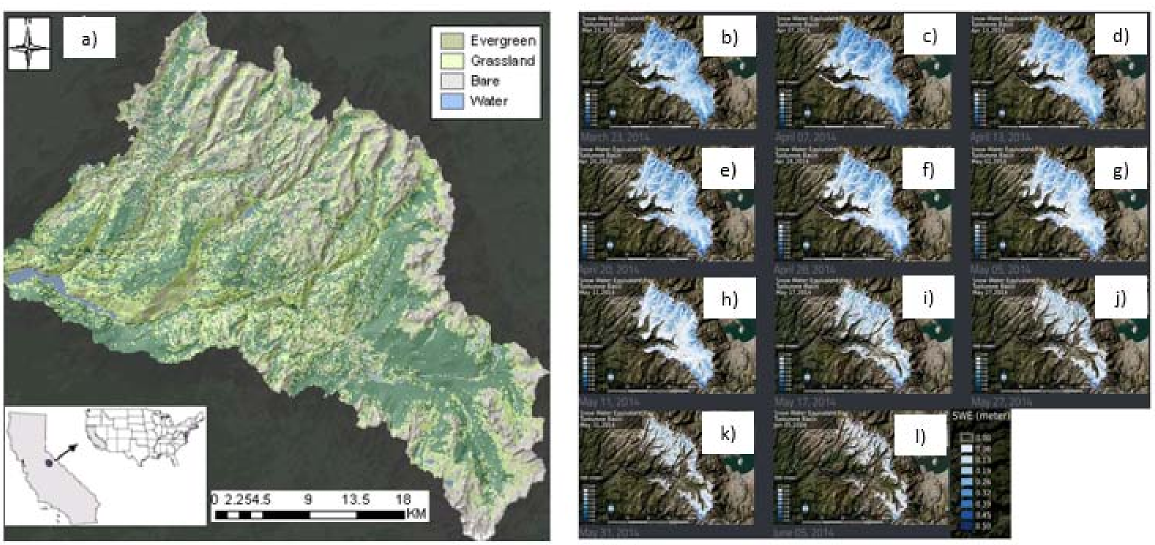

Figure 1. a) Tuolumne River watershed, California. b)–l) spatial patterns of snow water equivalent (SWE) on 11 occasions during the ablation season of 2014 (images downloaded from the ASO website, http://aso.jpl.nasa.gov/)

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watershed spans about ~3000m in elevation and covers an area of about 1190 km^2. About 30% of the watershed is forested, with the remaining grass-covered or bare (Figure 1a).

Our proposed downscaling method is based on a composite index composed of a weighted average of terms representing terrain-derived data indicative of both ablation and accumulation:

$$SI = DAH * w + (1 - w) * (1 + \alpha_r) * TPI, \quad (1)$$

where SI (-) is the snow variability index, DAH (-) is the diurnal anisotropic heating index used to represent ablation effects accounting for slope and aspect (Böhner and Antonić, 2009) , TPI (-) is the topographic position index used to represent accumulation effects (Weiss, 2001), $\alpha_r(-)$ is an estimator of the topographic exposure to wind (Böhner and Antonić, 2009), and w is a weight factor. TPI represents an indicator of the current pixel position relative to the mean elevation of a defined surrounding area/neighborhood and correlated best with snow depth in a study using LiDAR-derived snow data (Revuelto et al., 2014). The wind parameter is used to represent large scale effects of the direction of storms and orographic effects on accumulation. Within the area of the coarser pixel (i.e. MODIS size pixel), the SI pixels are ranked from low to high; and then the highest ranked pixels are assigned "snow" such that fSCA over the area of each coarser resolution pixel is preserved.

We illustrate the use of our procedure for the 2014 ASO dataset, which has 11 scenes (see example of one scene in Figure 2). We derive 30m binary SCA (Figure 2a) and MODIS scale (463 m) fSCA from the 3-m resolution LiDAR snow depth data over the Tuolumne watershed (Figure 2b). We then apply the downscaling procedure on the LiDAR-reconstructed fSCA (Figure 2b-c) and, for comparison, on MODSCAG fSCA (Figure 2e-f), a MODIS-based fSCA product (Painter et al., 2009). The matching performance is assessed using error matrix metrics in a combined score (F score, ranging from 0 to 1, with 1 indicating the best performance), accounting for both omission and commission errors.

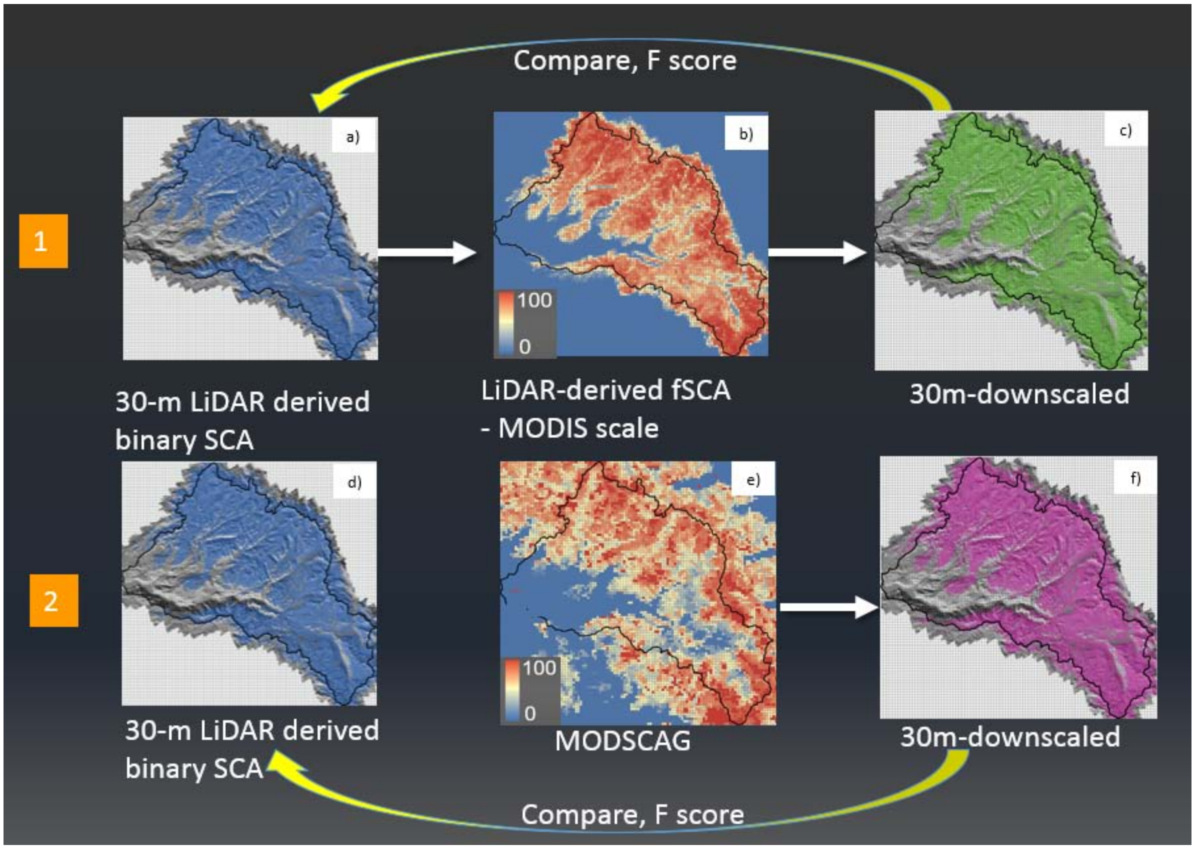

Figure 2. Example of application of the downscaling procedure on: 1) the reconstructed fSCA at the MODIS scale, and 2) the MODSCAG fSCA dataset

Figure 3a shows that the downscaling procedure performs better in the non-vegetated (0.84 season average F score) than in the vegetated areas (0.67 season average F score). These lower scores in the forested areas are determined by both the algorithm's inability to map the snow correctly, and the decreasing snow covered areas in the vegetated areas as the season progresses. The snow cover variability is affected by snow-forest interactions; therefore, snow downscaling in these areas requires an alternate scheme. The LiDAR-derived snow data in forested areas can inform a correction to our current approach.

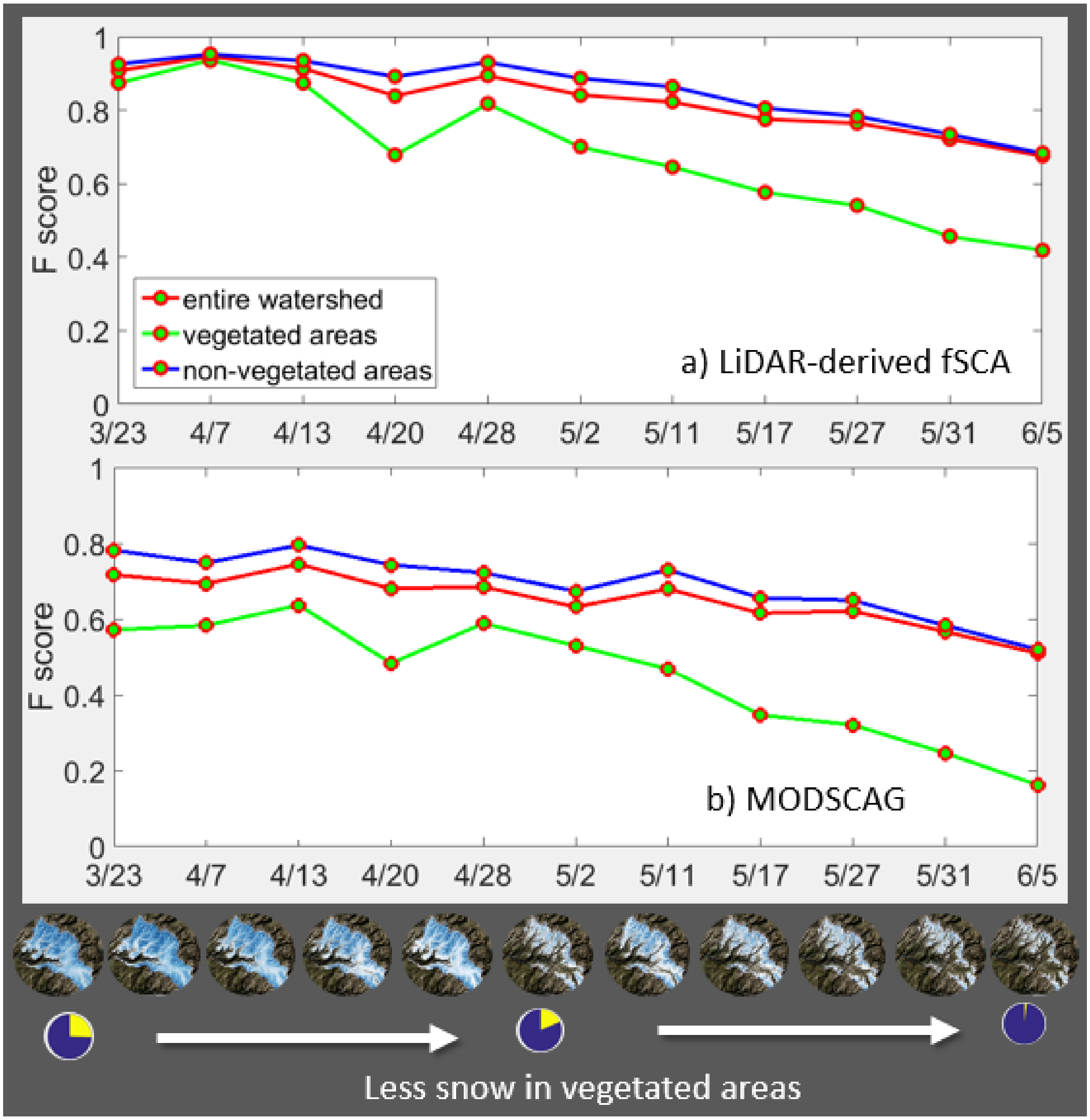

Figure 3. Matching performance F scores for: a) the LiDAR-derived downscaled fSCA, and b) for the MODSCAG fSCA during the ablation season of 2014

Figure 3a-b shows that matching performance scores are higher by 15-30% for the LiDAR-derived fSCA datasets than for the MODIS-based fSCA product. This is expected as the MODSCAG fSCA datasets are likely more uncertain than the reconstructed fSCA from the high resolution data. MODIS-derived data are affected by vegetation cover, terrain attributes and sensor view angle effects.

We conclude that the LiDAR-derived snow data provide excellent support for developing and testing downscaling procedures, by reducing the uncertainty in the input and validation data. Using such datasets over the Tuolumne River watershed, CA, we propose a new downscaling technique that takes into account both ablation and accumulation effects on snow spatial distribution. The method performs well overall; further refinements are needed for the vegetated areas. (KEYWORDS: downscaling MODSCAG, snow covered areas, topographic indices, Tuolumne)

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