Provisional USGS Essential Climate Variable

Project Summary: Multi-Sensor Snow Covered Area Monitoring

This project is funded by the USGS Land Remote Sensing Program.

1. Overview

The focus of this project is the development of methodology for the production of daily high spatial resolution snow covered area (SCA) time series datasets. The spatial and temporal distribution of SCA represents an important climate record useful for hydrologists, climatologists, ecologists, and other scientists and resource managers. Snow cover exhibits tremendous spatial and temporal variability and is often concentrated in remote or inaccessible regions, making spaceborne remote sensing the most feasible approach for comprehensive SCA monitoring in most areas. Presently, no single existing or planned instrument provides daily high spatial resolution imagery suitable for SCA mapping. Combining daily imagery from a moderate resolution sensor such as the Moderate Resolution Imaging Spectroradiometer (MODIS) with historical data from a higher spatial resolution sensor such as Landsat TM or Landsat ETM+, however, allows for the possibility of constructing a daily high spatial resolution SCA time series dataset.

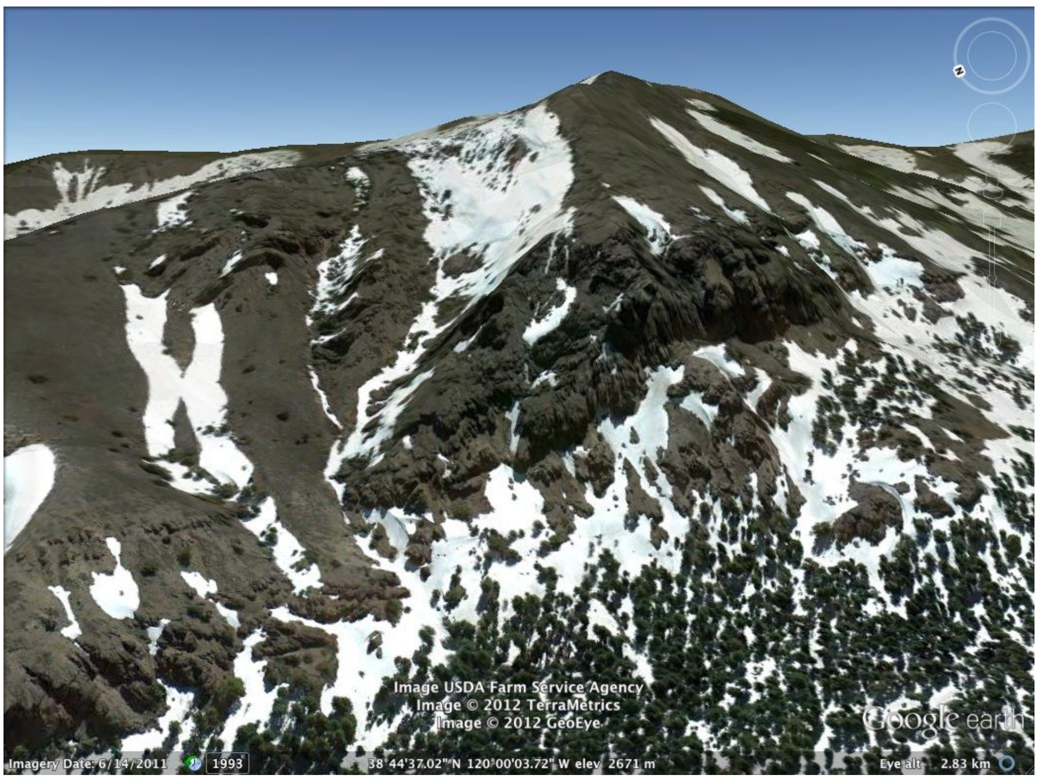

Figure 1. The complex interaction between wind, solar radiation, topography, and vegetation results in heterogeneous snow cover distributions in alpine and subalpine areas. This is a typical early summer snow cover distribution pattern in the Sierra Nevada Mountains of California.

2. Approach

The timing of the appearance and disappearance of snow cover at a specific location varies substantially between years in most regions. Even in areas where snow cover is present for lengthy periods every year, the date of snow disappearance may vary by two months or more. Despite substantial differences in the timing of snowmelt, however, the spatial patterns of snow cover at scales less than 1 km typically remain remarkably similar across most or all years (see figure 2 for an example in the Sierra Nevada mountains of California). This is particularly true in areas where the interaction of wind, solar radiation, topography, and vegetation produce distinct patterns of snow cover distribution, as is the case in nearly all arctic and alpine environments as well as many montane and boreal environments. Given consistency of snow cover patterns at scales below about 1 km, knowing the fraction of a given area unit covered by snow (such as the 500 x 500 m area represented by a single MODIS pixel) as well as the historical patterns of SCA within this area unit at a finer spatial resolution (e.g. 30 m) should allow for the construction of an accurate map of SCA within the unit at the finer spatial resolution (figure 3). Landsat TM and ETM+ data are acquired at 30 m spatial resolution at 16 day intervals at most locations, making these data unsuitable for daily snow cover monitoring. Landsat data can, however, provide historical SCA pattern information that, in combination with daily fractional SCA data from MODIS at 500 m, can be used to construct daily 30 m SCA maps.

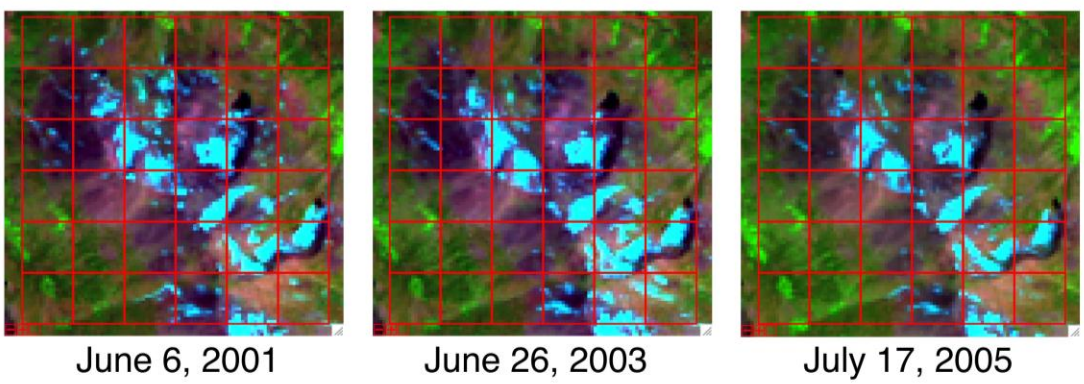

Figure 2. Landsat data indicating snow-covered (turquoise) and snow-free (all other colors) areas for the same location in the Sierra Nevada at approximately the same point during the snowmelt season for three different years. Notice the similarity in spatial patterns of snow cover despite the differences in timing. Each square outlined by the red gridlines represents 500 x 500 m on the ground.

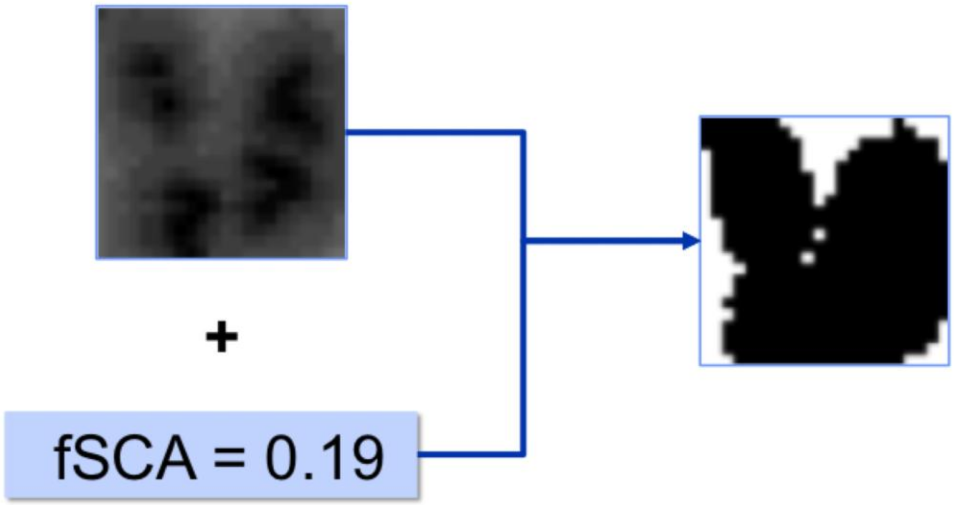

Figure 3. Proposed method for downscaling MODIS-derived fractional snow covered area (fSCA) at 500 m to 30 m binary snow covered area using historical snow covered area patterns from Landsat.

A preliminary version of the proposed dataset has been produced for the 2008-2010 period for the alpine portion of the central Sierra Nevada in California. Initial results from a limited accuracy assessment are encouraging, with accuracy typically well above 80%.

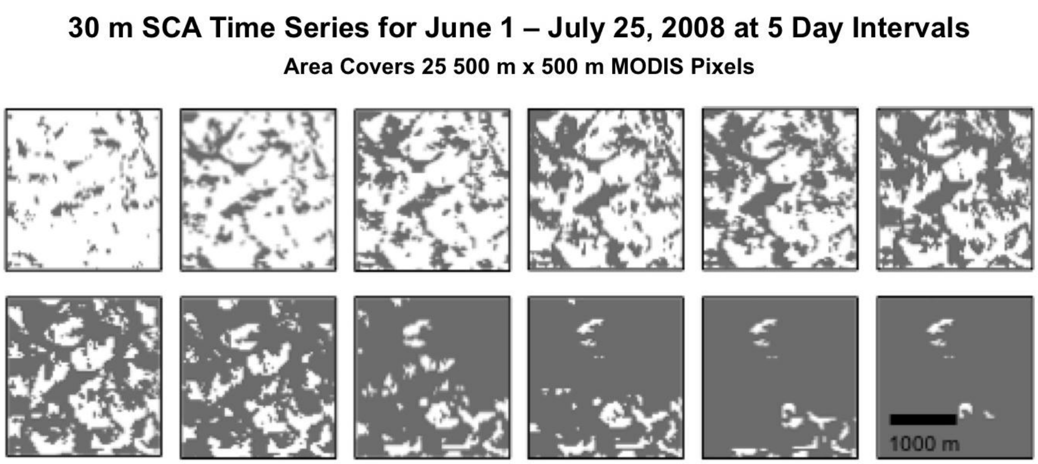

Figure 4. Snow covered area time series for the late spring/early summer period for a 12.5 x 12.5 km high elevation area in the Sierra Nevada.

3. Challenges

Prior to effective implementation of the approach described above, several challenging obstacles will need to be addressed. The two most prominent are discussed below:

3.1 Snow Covered Area Under Forest Canopy

Optical remote sensing instruments such as MODIS and Landsat can only directly map the fraction of snow cover visible from space, resulting in underestimation of SCA obscured by forest canopies. This is an active area of research for snow cover remote sensing, but provides a particularly difficult challenge when data from two sensors at two different spatial resolutions are combined. Additional research will focus on developing methods to convert visible SCA fraction to SCA fraction observed on the ground by accounting for SCA obscured by vegetation canopies.

3.2 Changes in Vegetation or Land Cover

The type, density, and spatial arrangement of vegetation cover are typically key factors that determine the spatial patterns of snow cover distribution at scales less than about 1 km. Consequently, significant changes in vegetation cover (e.g. stand replacing fires) could be expected to disrupt previously stable patterns of SCA distribution that form the basis for the SCA downscaling approach. In many cases, vegetation change is gradual and will not impact the downscaling approach as long as relatively recent SCA pattern data is used. Additional research will focus on developing methods for SCA downscaling where major vegetation or land cover changes have resulted in substantial changes in spatial patterns of SCA.

4. Validation

Understanding the limitations of any spatial dataset is essential. An extensive effort will be made to provide an assessment of accuracy of products produced using the methodology described here. Most *in situ* snow cover observations cover very limited spatial extents and are not well suited for validation of remotely sensed snow cover products.

The validation approach for the daily 30 m snow covered area time series will make use of a variety of new and existing data sources. Existing data sources will include high spatial resolution spaceborne and aerial imagery (most useful in areas where forest cover is sparse or absent) as well as existing *in situ* observations from automated stations. In addition, a network of snow cover monitoring sensors has been installed at more than 30 sites across the Western United States to monitor the extent and duration of snow cover over 30 x 30 m pixel footprints. Many of these sites are situated in areas of moderate to dense coniferous forest and will provide essential data for assessing the accuracy of approaches developed for effective SCA monitoring under forest canopies.

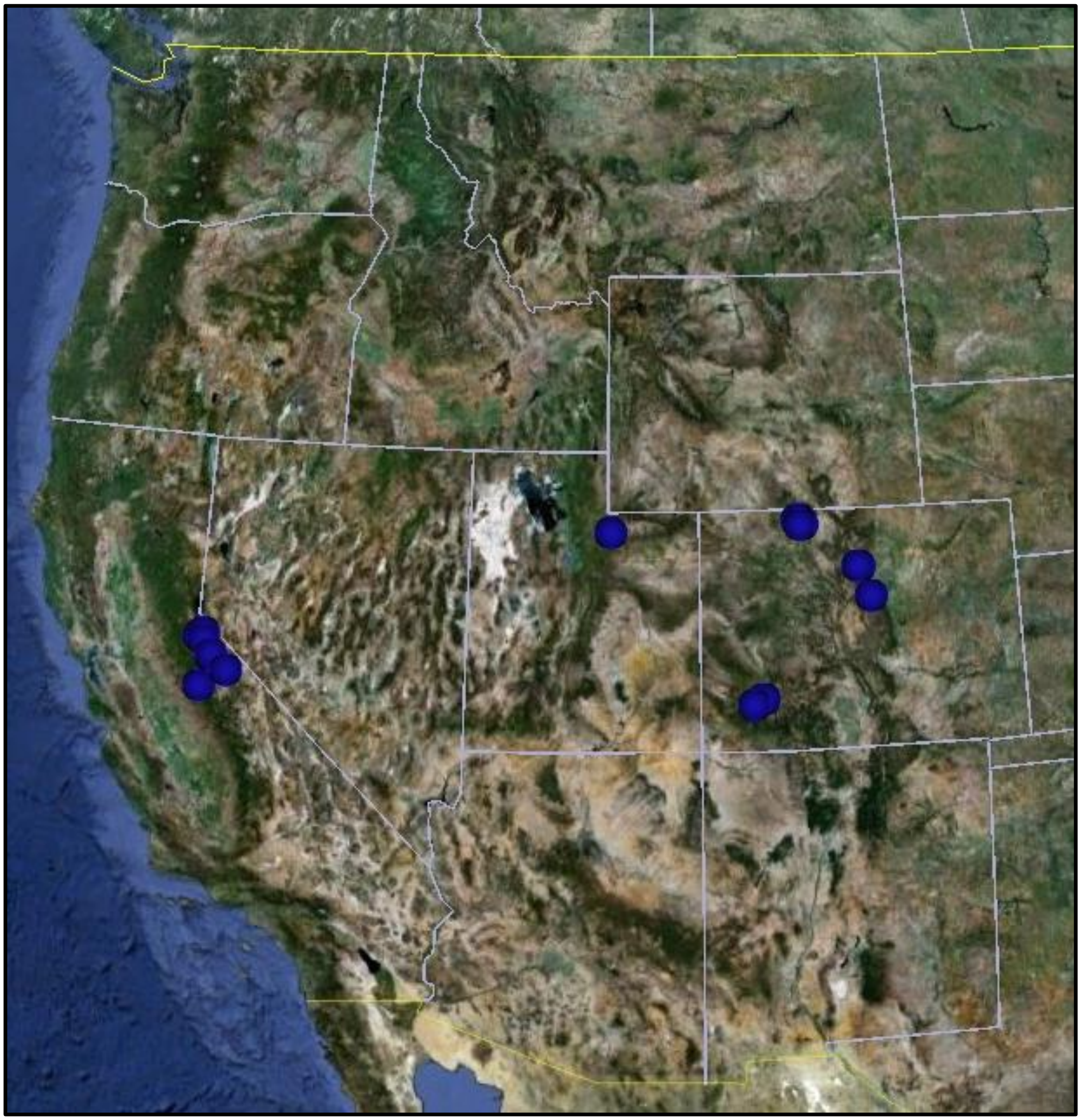

Figure 5. Clusters of 10-14 sensors arranged to monitor snow cover over 60 x 60 m footprints have been deployed at 35 sites in California, Utah, and Colorado. Additional snow monitoring cameras will be deployed during the snowmelt period in spring 2013.