Using NASA Earth Observations to Monitor Snow Cover Extent for Water Resource Management on the Navajo Nation

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Introduction

- The southwestern U.S. is experiencing prolonged drought conditions contributing to declines in snowpack and surface water supply. On the Navajo Nation (NN), snowpack is an essential reservoir for surface water storage and aquifer recharge, but has not been extensively monitored. Only two of the six high mountain/plateau regions within the NN have *in-situ* snow monitoring stations.
- NN leaders need more frequent and spatially extensive information on snowpack to guide water resources management, particularly as the NN faces increasing stresses from drought and climate change.
- This study provides the first analysis of spatial and temporal distribution of snow cover in the NN using NASA Earth Observations to track changes in snow covered area (SCA) across all the mountain/plateau regions during winter months (November to April) over a 15-year period from 2002 to 2017.
- Remotely sensed SCA is also compared to ground-based and modeled indicators of snow water equivalent (SWE) as a first step to understand snowmelt contribution to seasonal streamflow.
- Results will be used to develop methods for snow monitoring as part of NASA's partnership with the NN to build applications that use NASA Earth Observations for ongoing water and drought management.

Study Area: The Navajo Nation

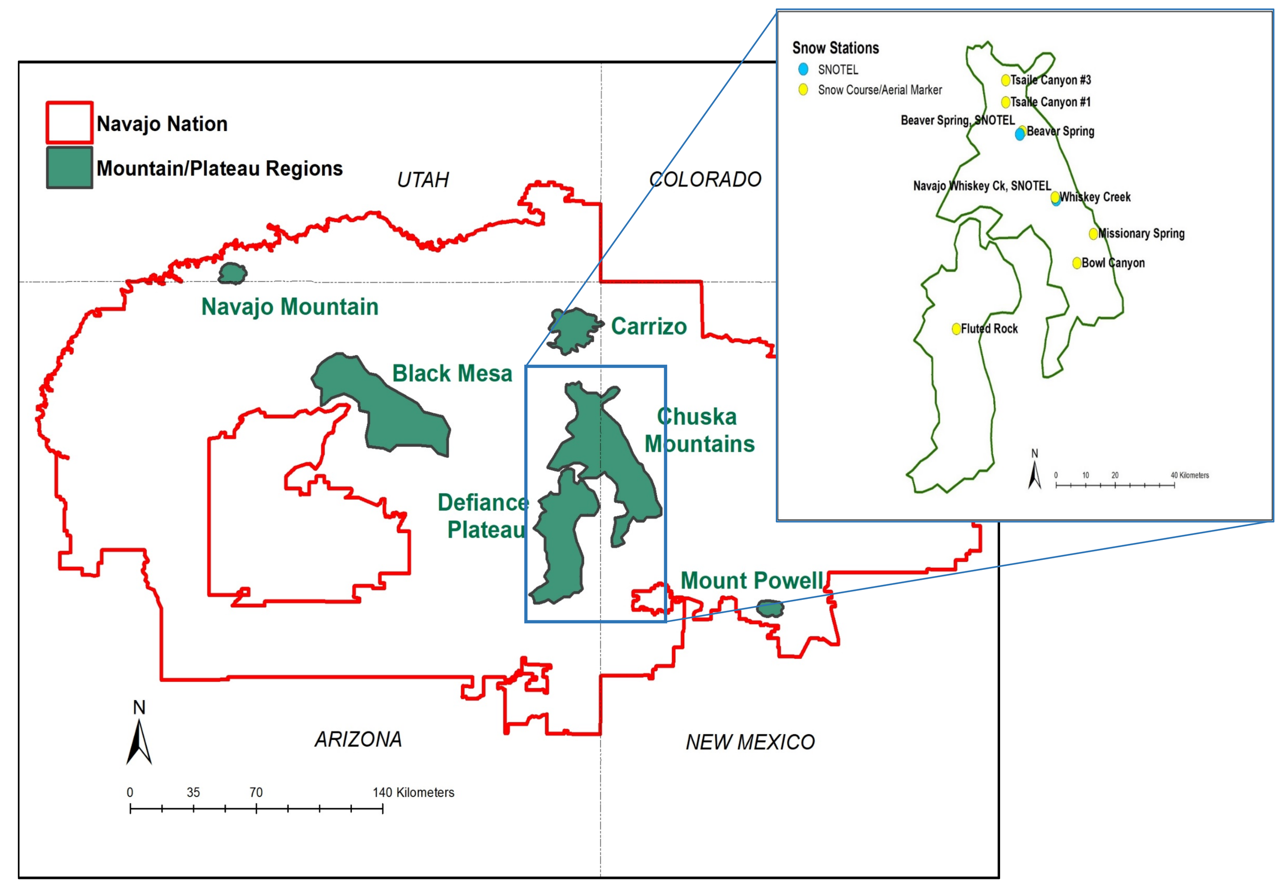

Figure 1: The six mountain/plateau regions where snowpack accumulates are shown in green. Map inlay indicates locations of SNOTEL stations (blue) and snow courses (yellow) where *in-situ* snow measurements are collected in the Chuska Mountains and Defiance Plateau.

Data and Methods

I. NASA Earth Observation Data Source

SCA data derived from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) Terra and Aqua snow products, Version 6, 500 meter daily resolution.

II. Normalized-Difference Snow Index (NDSI)

Normalized-Difference Snow Index

$$NDSI = \frac{(VIS - SWIR)}{(VIS + SWIR)}$$

$$snow = NDSI > 0$$

Fractional Snow Cover

$$FSC^1 = -0.01 + 1.45 \times NDSI$$

$$0 \leq FSC \leq 1$$

Snow Covered Area

$$SCA = FSC \times PixelArea$$

$$FSC \geq 15\%$$

III. Composite Image Mapping in Google Earth Engine

- Google Earth Engine was used to process NASA Earth Observation data to create images of daily, weekly and monthly snow cover extent.
- Daily composites were generated to minimize cloud cover and sensor errors by combining MODIS Terra and Aqua daily images. Subsequently, each remaining cloudy or missing pixel was replaced with the first corresponding cloud-gap-free pixel within 3-days prior to 1-day after the original image date.

Spatial and Temporal Distribution of Snow Covered Area (SCA)

SCA Peaks in January

Weekly mean SCA peaks generally occur between late-December and mid-January. However in drier years peaks may not be reached until later in February or March.

Weekly Maps Optimize Tracking & Accuracy

Weekly mean images can capture variability in geographic regions over short time periods, while minimizing cloud cover and other gaps.

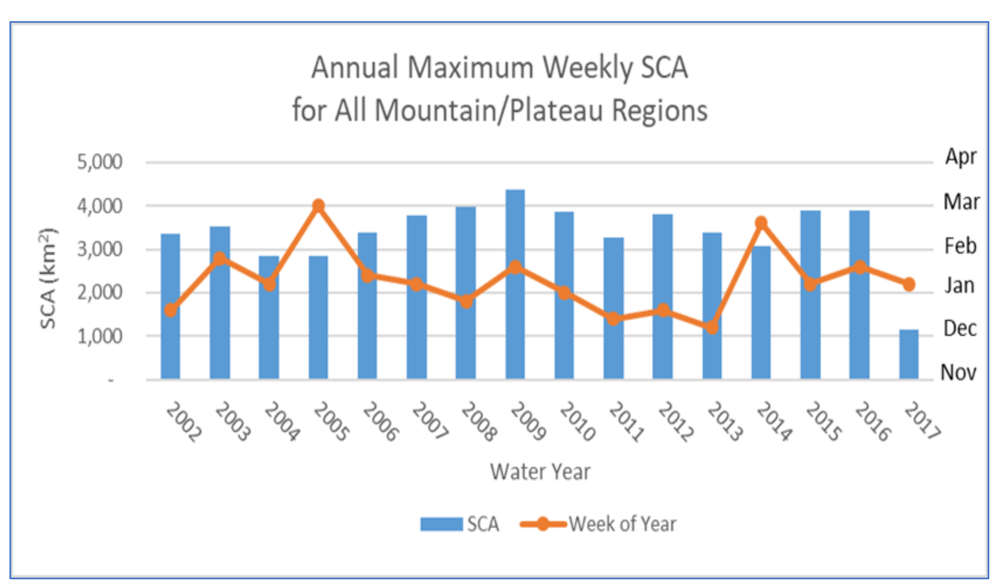

Figure 2: Annual maximum weekly SCA (left axis, blue columns) for all mountain/plateau regions, with the week during each year when the maximum was reached (right axis, orange line).

Ungauged Areas Account for 50% of Peak Winter SCA

The Chuska Mountains account for 40 – 45% of SCA during peak winter months and 55 – 70% during early winter and spring. Defiance Plateau and Black Mesa account almost equally for 50% of SCA during January to March.

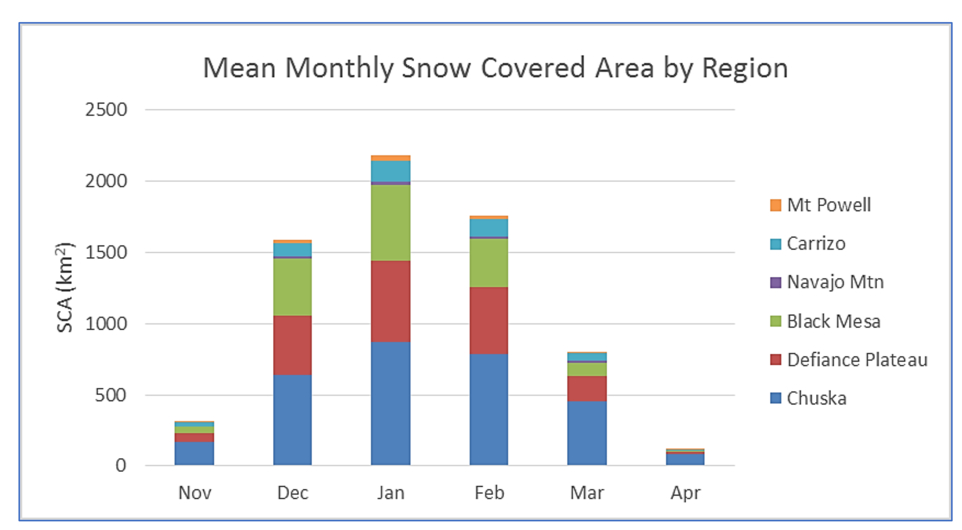

Figure 4: Mean monthly SCA for each mountain/plateau region (2002 – 2017).

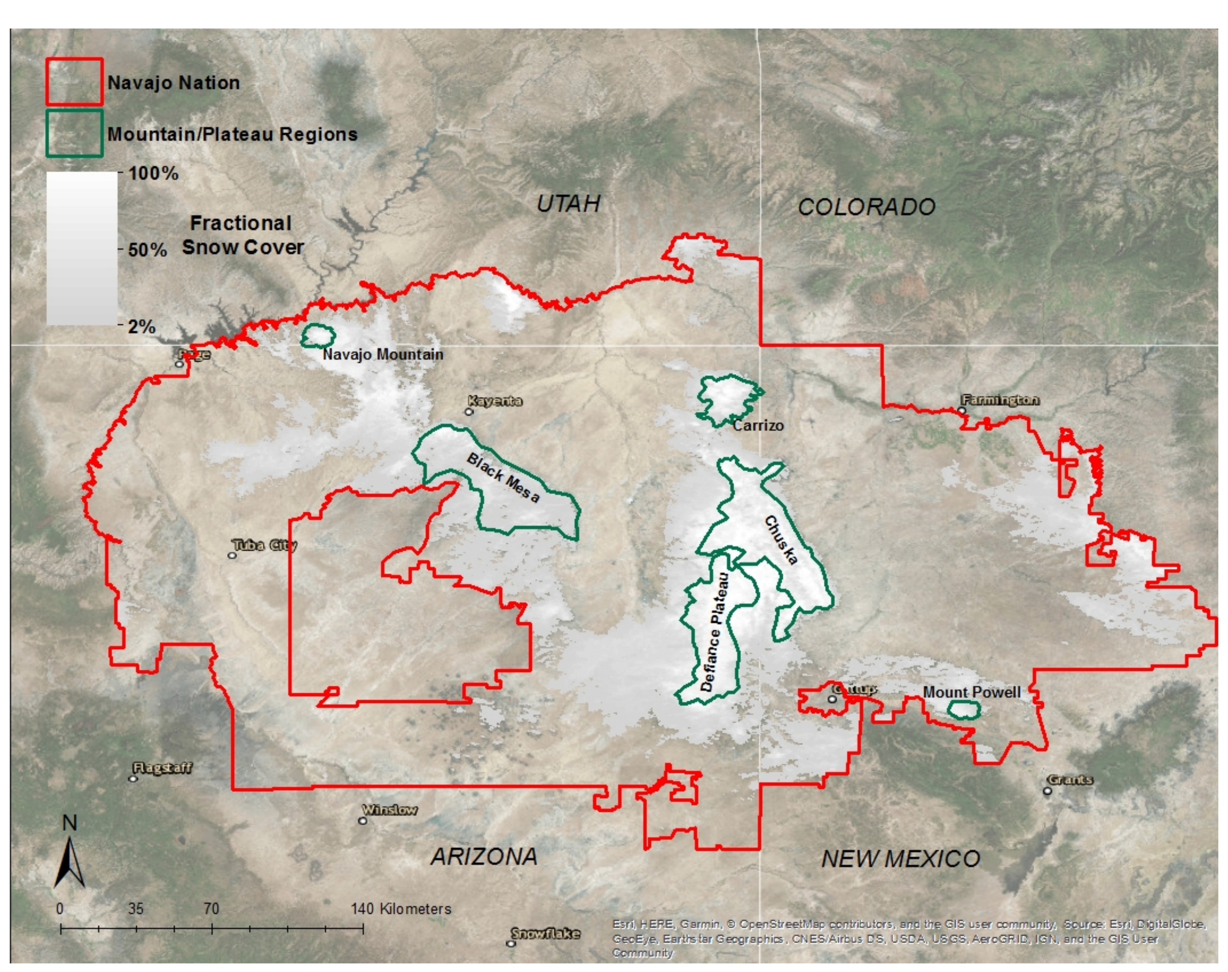

Figure 3: Map of mean weekly snow cover for week beginning February 7, 2016, showing extent of SCA and variation in FSC.

Monthly SCA Anomalies May Indicate Shifting Climate

Persistent negative anomalies in February, March and April suggest that NN snowpack is declining in the spring months. This is inversely related to temperature anomalies and consistent with broader regional climate trends. However, the declines are not statistically significant due to large inter-annual variability.

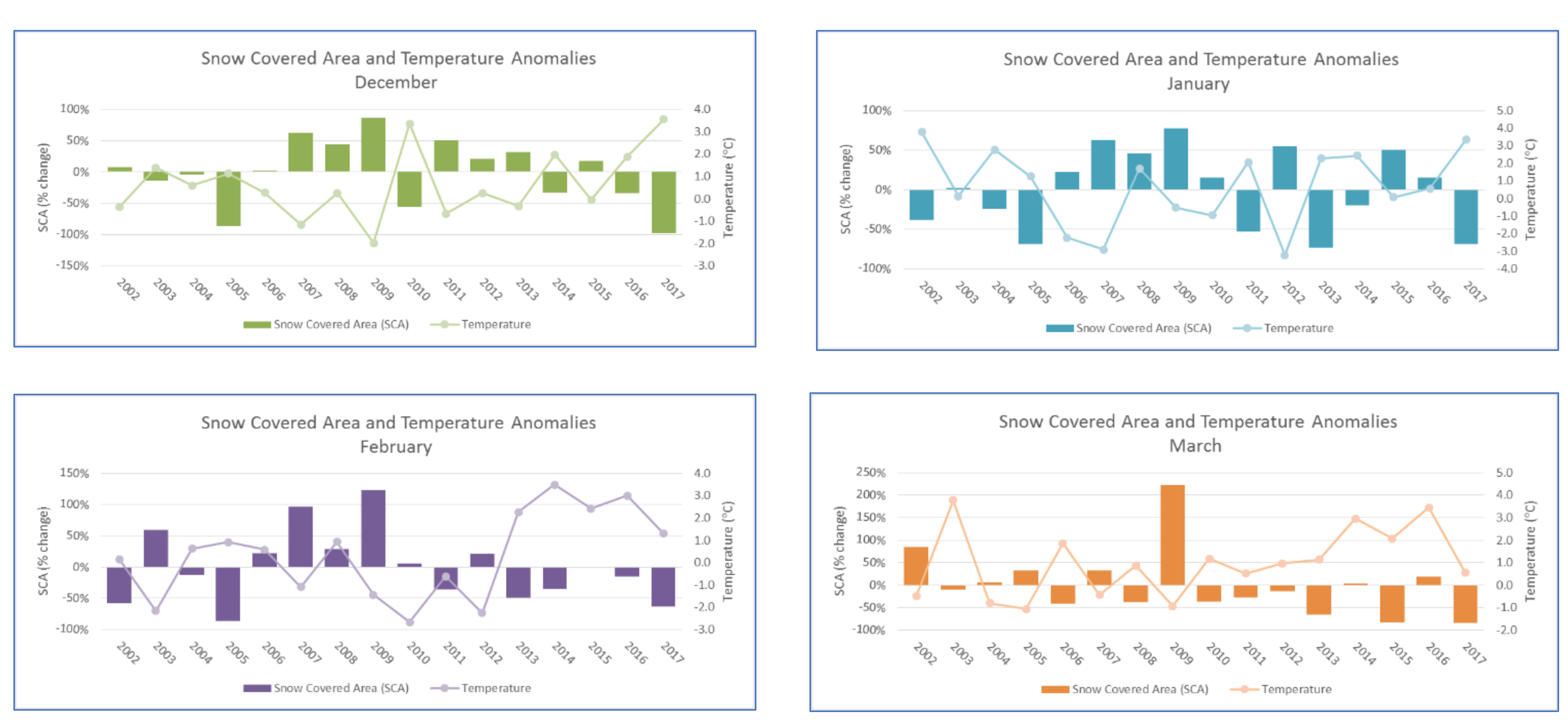

Figure 5: Mean monthly SCA and temperature anomalies for all mountain/plateau regions. SCA anomaly based on monthly average for the study period (2002 – 2017). Temperature anomaly based on 30-year normal[2] for 1981 – 2010.

SCA and Snow Water Equivalent (SWE)

SCA has limited application for water resource monitoring because it does not correlate well with SWE. Alternatively, preliminary investigation of modeled SWE from the Snow Data Assimilation System (SNODAS)[3] shows strong correlation with SNOTEL SWE measurements.

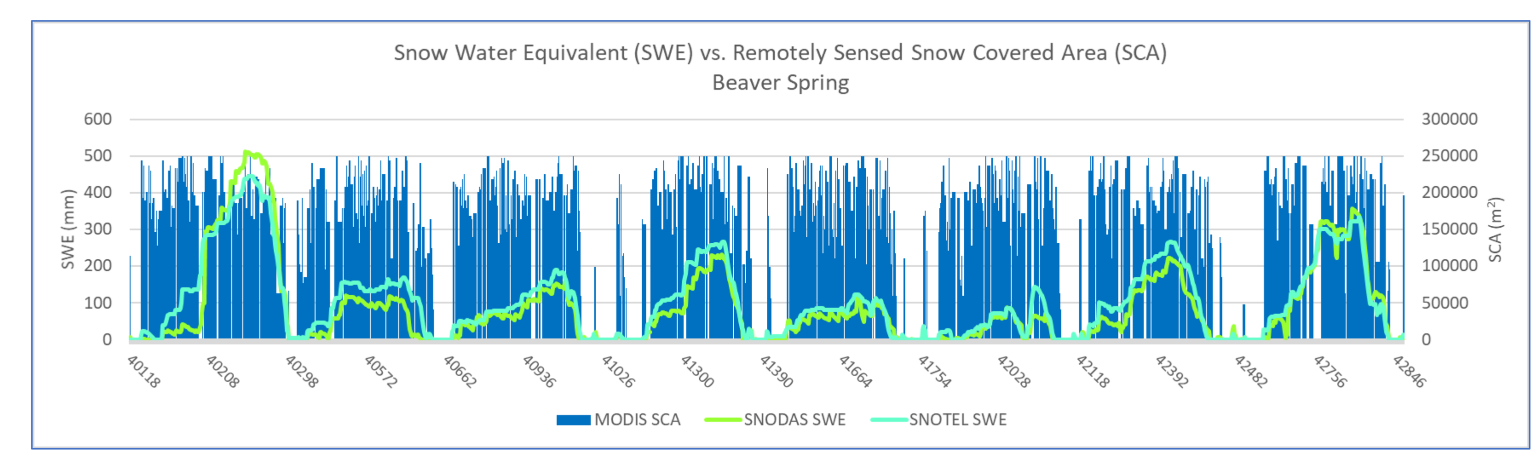

Figure 6: *In-situ* SWE measurements from the Beaver Spring SNOTEL station compared to SCA from MODIS daily composite images and modeled SWE from SNODAS.

Next Steps

Test validity of SNODAS as a primary indicator for SWE. Confirm validity of gridded SNODAS data against the snow course SWE point observations and investigate accuracy for ungauged areas of the NN.

Explore higher accuracy snow products from sources such as the MODIS Snow Covered-Area and Grain size retrieval algorithm (MODSCAG) or NASA's Airborne Snow Observatory (ASO).

Further analyze SCA to determine if there are sub-regional differences in snow cover duration, accumulation by elevation, or other spatiotemporal patterns.

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References

[1] Rittger, K., Painter, T.H., and Dozier, J., 2013. Assessment of Methods for Mapping Snow Cover from MODIS. *Advances in Water Resources* 51: 367–80.
[2] PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, August 2018.
[3] National Operational Hydrologic Remote Sensing Center, 2004. SNODAS Version 1.