Spatiotemporal Patterns of Snow Mass Variations and the Local Climatic Factors in the Riparian Zone of Central Valley, California

MISSISSIPPI STATE UNIVERSITY
Department of Geosciences

By Pushkar Inamdar and Shrinidhi Ambinakudige

Department of Geosciences, Mississippi State University, Starkville, USA

Introduction

Water is essential not only to human sustenance, but it is also vital for all lifeforms on earth. Water covers more than 75% of the Earth's surface, yet just 3% of it is freshwater. Of this, ice caps and glaciers are the primary contributors. In the state of California, snow mass plays a significant role as natural water reservoirs. Because of the Mediterranean climatic conditions, the region gets most of its precipitation in winter. It makes snow mass as a primary source of freshwater. Typically, it provides one-third of the water utilized in California's urban areas and ranches every year (Chou, 2014). Thus bearing in mind the water scarcity in California (Swain et al., 2014), it is essential to analyze the existing state of perennial and seasonal snow masses in the region.

In California and other western states, many small perennial snow and ice covered regions exist over a vast area. Because of this scattered distribution pattern, the region lacks in the comprehensive historical records of glacier extent before the development of modern topographic maps (Krimmel, 2002). Also, the California region has suffered from the absence of a systematic, long-term and validated mass balance program (Basagic & Fountain, 2011). In this study, we use data that was generated using remote sensing techniques to analyze the state of perennial and seasonal snow covered regions in the California during 2002 through 2015. Moreover, we analyzed Gravity Recovery and Climate Experiment (GRACE) and Landsat images to find impacts snow melting patterns on a billion-dollar agricultural industry in the central valley. Considering current water crises in California our study provides valuable insights into the possible role of climatic factors snow cover and total water storage anomalies in the region.

Research Objectives

In this study primary objective is to analyze a decadal state of snowpack's on mountain glaciers in the Sierra Nevada and Mt. Shasta, California. In the second objective, we study possible effects of snow melting anomalies on total water storage and agricultural practices in the central valley region.

Objective I

- To quantify snow cover extent variations in the Sierra Nevada and Mt. Shasta, California.
- To estimate snow mass change in the Sierra Nevada and Mt. Shasta, California.
- To evaluate an impact of climatic variables on the snow mass change.

Objective II

- To estimate total water storage anomalies and changing agricultural practices in the Central valley California
- To assess the effect of local climatic factors in the riparian zone of the central valley.

Data and Methods

Snow Cover Analysis: Landsat images with minimal cloud cover were acquired for the month of August of years 2000, 2002-03, 2008, 2010-11, and 2014-15. Later zonal Statistic Tool in the ARCGIS 10.2 was used to develop raster models of the snow cover change based on the extent of the glacier and Red/SWIR band ratio.

Snow Mass Anomalies: We used (June/July/August/September/October) Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEMs for years 2002-03, 2008, 2010-11, 2012 and 2015. Elevation differences were calculated by subtracting ASTER DEMs of 2002-03, 2008, 2010-11, 2012 and 2015 from the reference ASTER elevation (the year 2000). As we are specifically comparing snow mass cover in dry season, we decided to use density value of 750 kg m^{-3} .

Agricultural Land Use Analysis: We acquired Landsat images in late growing season with minimal cloud cover for the Central Valley region. Later Normalized difference vegetation index was generated and compared to find a difference in vegetation in the central valley region between 2003 and 2016.

Uncertainty in the Estimation of Elevation Differences calculated as the root sum square of the standard error of the mean (SE_{nongl}) and mean elevation difference (ED_{mean}) of the non-glaciated region. While DEM_{bias} (systematic error) in the equation, measures the degree to which predicted successive elevation models (ASTER) are on average differs the true elevation.

$$\mathrm{EDu} = \sqrt{\mathrm{ED_{mean}}^2 + \mathrm{SE_{nongl}}^2 + DEM_{bias}}$$

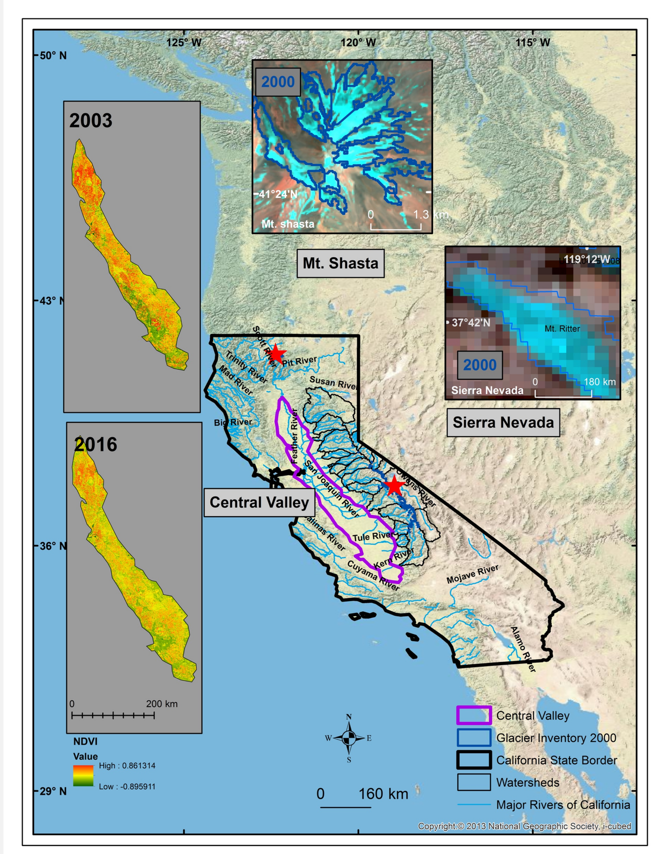
Total Water Storage Analysis

We use Gravity Recovery and Climate Experiment (GRACE) gravity coefficients from Release-05 processed at the University of Texas to compute total water storage in the Central Valley region, California.

Climate Data Analysis

Monthly climate summaries were acquired from NOAA's National Centers for Environmental Information (NCEI). Fluctuations in temperature (°C) and snowfall (mm) parameters analyzed for the years between 2000 and 2015.

Study Area

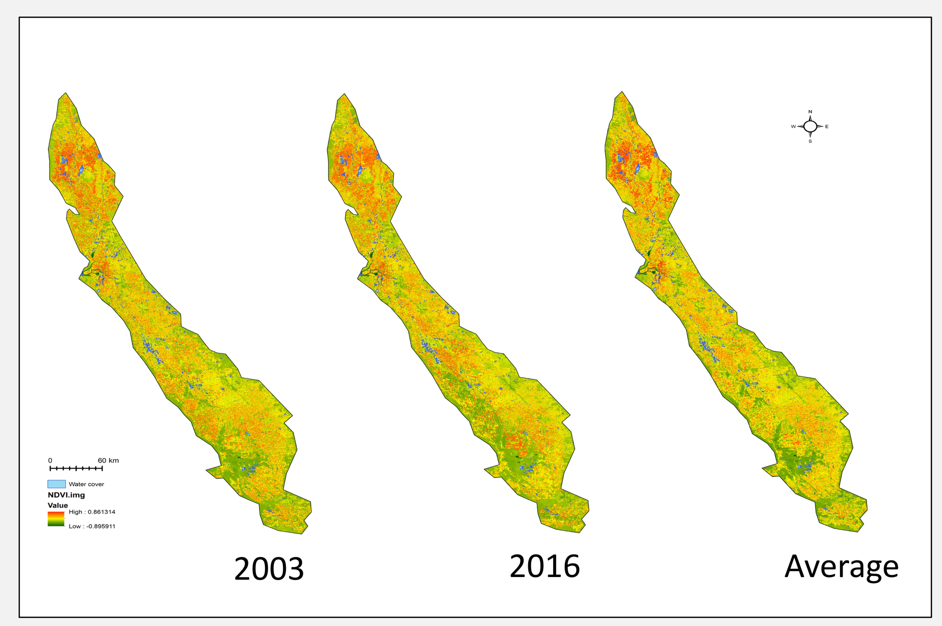


- Perennial snow and ice covered regions in California are mainly located in the Sierra Nevada and Mt. Shasta
- The Sierra Nevada mountain range extends from around 35°N to 39°N about 650 km
- Mt. Shasta is located at 44.4°N -112.20°W
- Low-pressure systems over the Pacific Ocean control the moisture deposition in the region.
- Central Valley is the major valley of central and northern California. Region is composed of the San Joaquin Valley south of the Sacramento-San Joaquin River Delta area, and the Sacramento north of it.
- Central Valley is a large, flat valley that dominates the geographical center of the California. It is 40 to 60 miles wide and stretches approximately 450 miles

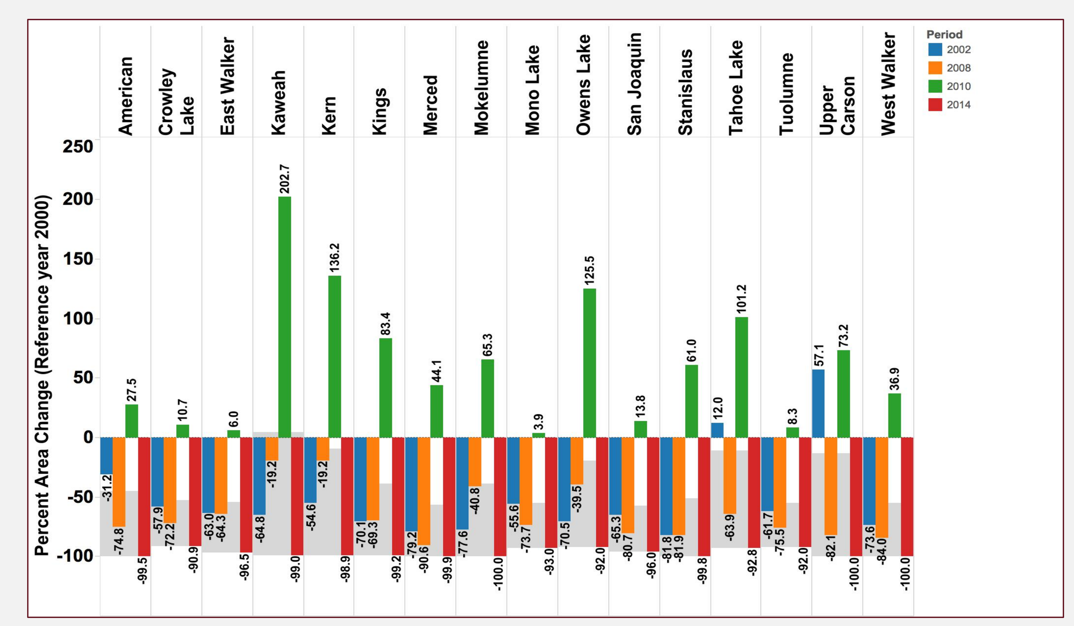
Conclusions

- This study highlights patterns of snow mass balance change and depleting water storage in California.
- In all regions, the elevation values were lower than the 2000 year's ASTER elevation values. Snow mass differences were always negative as compared to the reference year. After comparing glacier inventories and mass loss, it is evident that there is a substantial extent loss as well recession in the snow mass. Outcome clearly indicates that snow mass never recovered after heavy snowfall event of 1998.
- Also, preliminary analysis of GRACE data shows depletion of Total Water Storage in Central Valley region might be a result of negative Snowmass in the Sierra Nevada and Mt. Shasta regions. Further comparison of vegetation index data between 2003 and 2016 shows a change in agricultural land use practices. We suspect changing agricultural practices in the region is a direct result of depleting water storage.
- Our results also can be compared to the observations of McCabe and Fountain (2012) where they noticed spatiotemporal variation between 1900-2000 on some of the glaciers of Sierra Nevada. The possible reason for higher recession rate in the Sierra Nevada might be the result of increased heat in the wet season as compared to dry months.
- It is important to study microclimatic conditions for the individual glaciers as well as regions. More work is required to understand the role of different climatic factors as well ENSO effects because of the importance of these freshwater reservoirs.

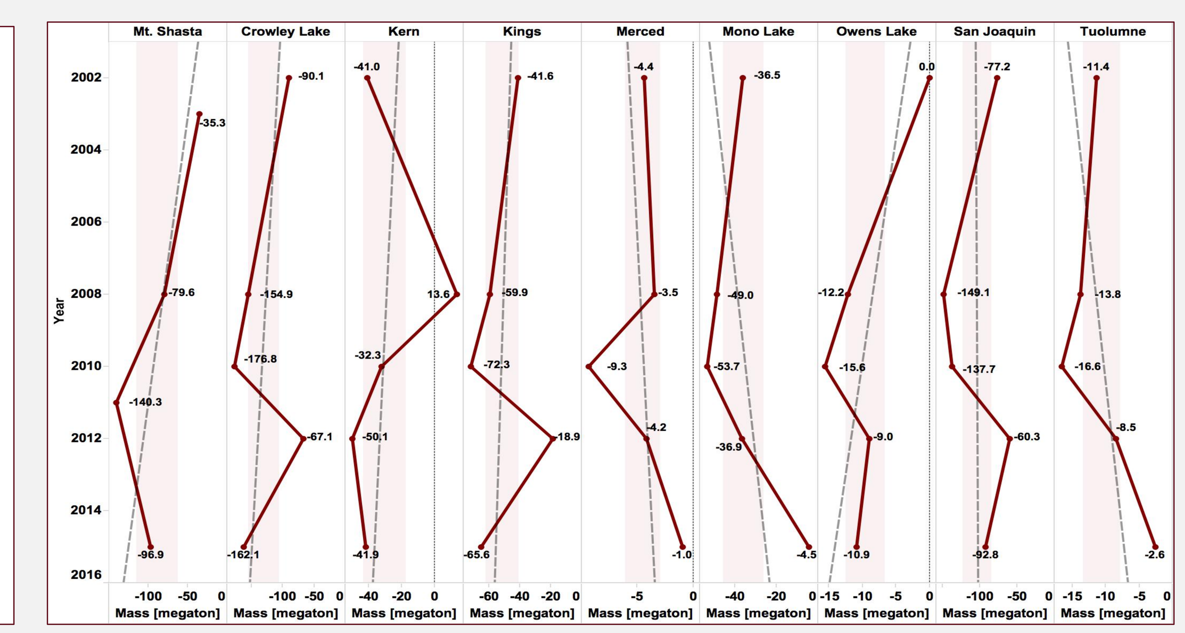
Results



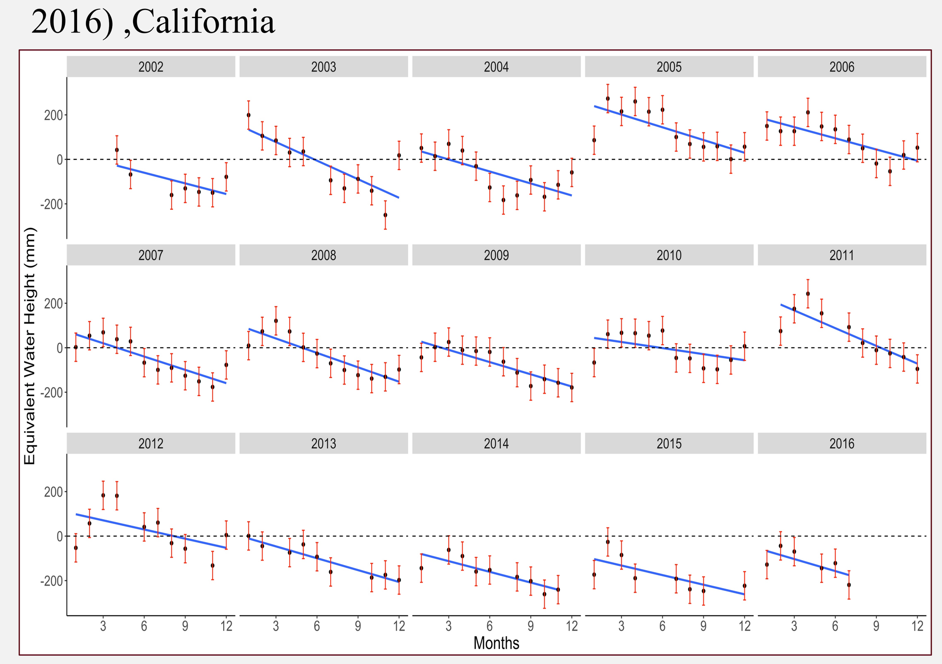
Changes in Agricultural Land Use in Central Valley (2003-2016) ,California



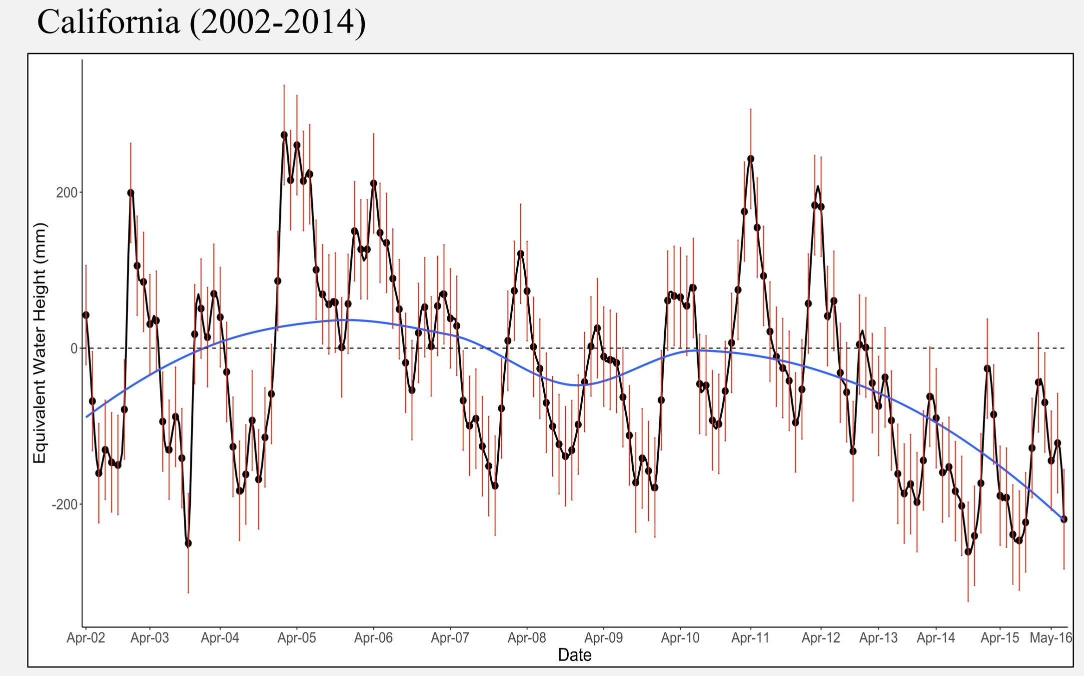
Percent snow cover extent loss in major watersheds in Sierra Nevada, California (2002-2014)



Average snow mass differences (megaton) and linear trends between reference ASTER 2000 and ASTER data through 2002- 2015 (Base year: 2000)



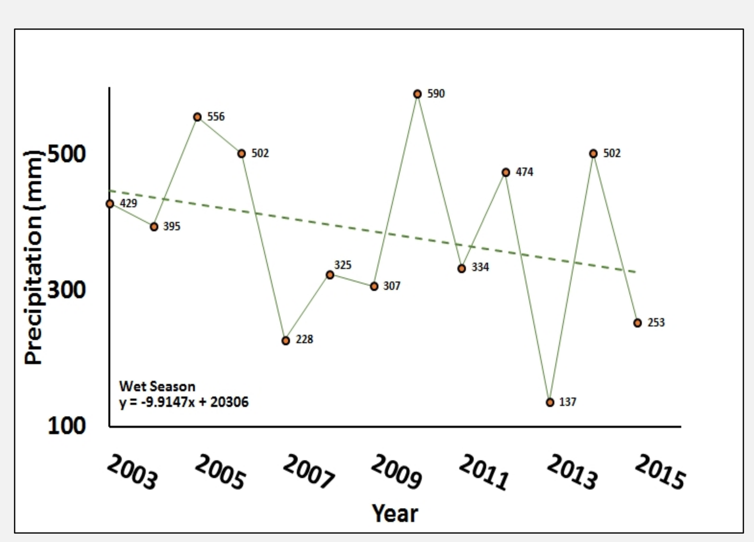
Total Water Storage Monthly Anomalies (2002-2016)



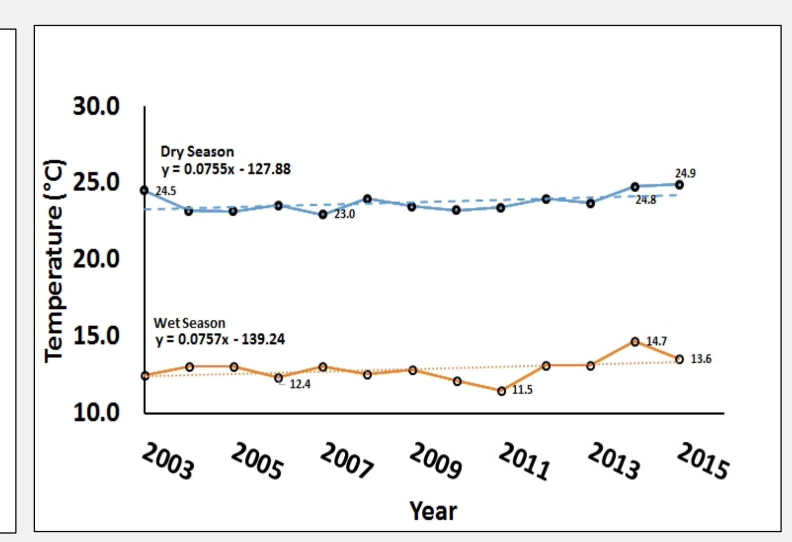
Total Water Storage Anomalies (2002-2016)

	Snow mass variation (megaton)				
	2002	**2008**	**2010**	**2012**	**2015**
Crowley Lake	-90.10 ± 35.49	-154.87 ± 100.12	-176.76 ± 173.43	-67.12 ± 70.05	-162.12 ± 130.49
Kern	-41.00 ± 17.40	13.63 ± 28.18	-32.27 ± 25.05	-50.08 ± 30.96	-41.88 ± 25.89
Kings	-41.58 ± 23.20	-59.88 ± 48.11	-72.34 ± 63.11	-18.88 ± 18.73	-65.63 ± 53.71
Merced	-4.35 ± 1.01	-3.48 ± 2.22	-9.26 ± 9.19	-4.20 ± 1.81	-1.01 ± 1.66
Mono Lake	-36.49 ± 19.63	-48.97 ± 30.81	-53.68 ± 44.34	-36.93 ± 18.48	-4.51 ± 10.34
Owens Lake	0.05 ± 1.41	-12.16 ± 5.11	-15.63 ± 14.60	-8.99 ± 5.19	-10.90 ± 5.78
San Joaquin	-77.17 ± 30.38	-149.12 ± 102.23	-137.69 ± 119.55	-60.28 ± 37.51	-92.82 ± 68.02
Tuolumne	-11.38 ± 6.35	-13.80 ± 8.47	-16.56 ± 11.05	-8.54 ± 4.84	-2.61 ± 1.94
	2003	**2008**	**2011**	**2015**	
Mt. Shasta	-35.29 ± 38.15	-79.61 ± 68.19	-140.33 ± 111.18	-96.85 ± 67.35	

Snow mass variations in watersheds of Sierra Nevada and Mt. Shasta , CA



Average monthly mean precipitation from 2003 through 2015 during the wet season, California



Average monthly mean temperature from 2003 through 2015 during dry and wet seasons, California

- *An extreme loss of perennial and seasonal snow in an extent of about 80% between 1992 and 2014-15 was observed in Mount Shasta and the Sierra Nevada.*
- *Overall snow mass variation between 2000 and 2015 in Mount Shasta and Crowley lake watershed (Sierra Nevada mountain ranges) were –96.85± 67.35 megaton and –162.12 ±130.49 megaton respectively*
- *All the watersheds showed increased snow extent coverage in the year 2010*
- *Comparison of vegetation index shows changes in the crop patterns in the Central Valley*
- *Gravity Recovery and Climate Experiment satellite data analysis shows continuous depletion in total water storage in the Central Valley, California*
- *Results show loss that the Central Valley lost -31 ± 5.3 mm yr^{-1} of total water storage during 2002 to 2016*
- *Climate data analysis shows positive trend in anomalies in temperature , while negative trend accompanied precipitation between 2003-2015*