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GSP 270
April 8, 2018
Final Draft

Snow Cover in the Sierra Nevada

Abstract

It is a well known fact that climate change and global warming contribute to the overall declination of snow cover all across the globe. Our question is, “How is global warming impacting California’s largest mountain ranges, the Sierra Mountains?”. To understand how much snowfall there has been within the last decade, we want to accurately determine the amount of snow cover area within each year since 2010. A spatial analysis was done on the proximity of Sierra Mountains to calculate the total snow cover area. The results from the data suggest that in recent years there have been some periods of sporadic inclines and declines in the total amount of snow cover. From the graph, it's difficult to predict the amount of snowfall for the next given year. We believe that this shows how climate change and global warming amplifies rainfall and drought periods. In the conclusion we discuss the methods inaccuracies when it comes to manually digitizing areas and give our final thoughts of this project.

Introduction

For our project, we examined spatial data on snow covering regions in the Sierra Mountains. The general assumption is that snow cover regions are declining due to climate change. The regions in the Sierras with an overall decline of snow from the last decade were examined. The purpose of this project is to understand in which areas and in which year the drought has impacted the Sierra Mountains the most and to demonstrate that there is an overall declination of snow cover area that shows a correlation between global warming and the California Drought. According to a recent article, “Welcome Snow Slows California's Plunge Back to Drought,” written on March 5, 2018, states that there has not been a sufficient amount of snowfall in the Sierras this year in 2018, in fact there is, “less than a quarter of its normal snowpack this year, [even with recent storms]” (No author et al, 2018). It would take about six more storms to bring the Sierras back to a normal state this year alone. Technically, California is still in a drought and is still experiencing rainfall fluctuations (No author et al, 2018). Many people have the misconception that California is not in a drought because of the massive amounts of rainfall seen in 2017; however, this project aims to show how climate change and global warming are still an issue causing a depletion of snowpacks in the Sierra Mountains. Due to rising temperatures, snow melt has become a prevalent problem on the Sierra Mountains. This snow melt results in increased runoff (Hayhoe et al, 2004). The four-year-average snowpack has decreased by 25% in the Sierra Mountains due to climate change, which has contributed to California’s drought. Studies show a clear correlation between global warming caused by humans and California’s drought (Berg and Hall et al, 2017). We use spatial analysis to calculate the snowpack area in the Sierra Mountains and analyze the data to answer our research question.

Methods

For our methods and analysis, we used Ersi's ArcMap software program to examine how the Sierra Mountains have been fluctuating in its snow cover rates in the last decade from the years (2010-2018). The raster data was downloaded from Earth Explorer (2018) [https://earthexplorer.usgs.gov/] for the years (2010-2018) (refer to figure 1). We prepared our data for analysis by downloading several maps, made sure all snow cover was visible, and used the mosaic tool to combine maps for each year. We used the datum NAD 1983 UTM Zone 1 N. Once all the data was configured, ArcMap was used to digitize snow cover areas in blue (refer to figure 2). The attribute table was opened up, and a new shape field was created for the snow cover area. The snow cover area was set to type double, and the field calculator was used to calculate the snow cover area for each year.

It's important to note the data that came from LandSat 7, which unfortunately experienced a failure in its scan line corrector (SLC) in the year 2011. As a result, some data was missing for the years 2011-2012, because some pixels were not able to be viewed. Others have the same images when downloading data from LandSat 7. According to a study called, "A Landsat-Era Sierra Nevada Snow Reanalysis (1985–2015)" they had similar issues with trying to analyze images from Landsat 7. In their report, they state that "Landsat 7 ETM+ data from 2003 to present include missing data in each scene because of the scan line corrector (SLC) malfunction" (Margulis and Cortes et al, 2016). This is the same issue faced in this project when trying to gather the images from LandSat 7. However, the analysis was still performed, and the missing data was not expected to significantly skew the final results. The issue was addressed by ignoring the lines, because we were still able to digitized within the areas of snow coverage that could be clearly viewed. It's important to address that this issue came up for future analysis done using LandSat 7 and show that there are physical or digital malfunctions that happen within Geospatial technologies, which are uncontrolled to factors within spatial analysis.

Results

Our analysis resulted in a series of eight maps showing the differentiation of snowpack coverage within the years, 2010-2018. Snowpack coverage for all years is shown in figure 3, and the digitized maps for each year are shown in figure 4. The year 2017 had the most snow cover, and the least amount of snow cover was in 2013.

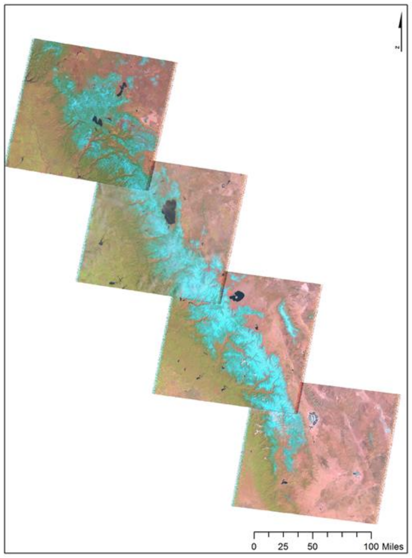

Figure 1. Non-Digitized LandSat image of the Sierra Mountains snowpack cover for 2010.

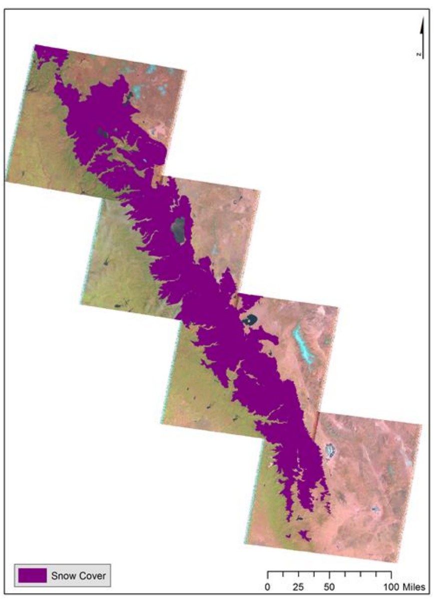

Fig 2 Digitized LandSat image of the Sierra Mountains snowpack cover for 2010

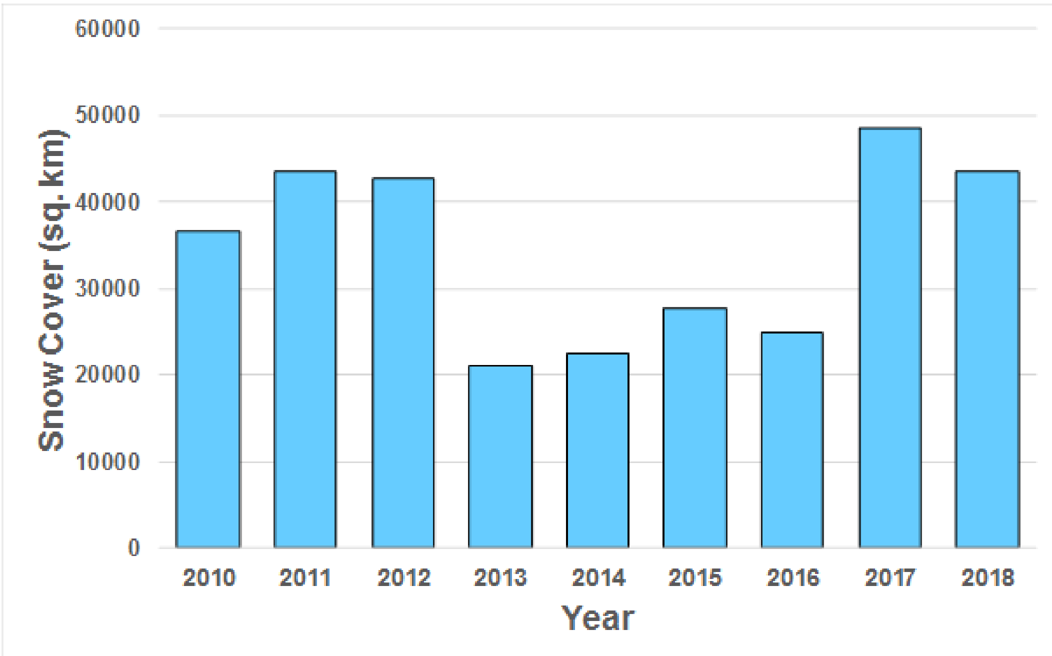

Figure 3. Shows a bar graph of the snowpack total area calculated for a given year,

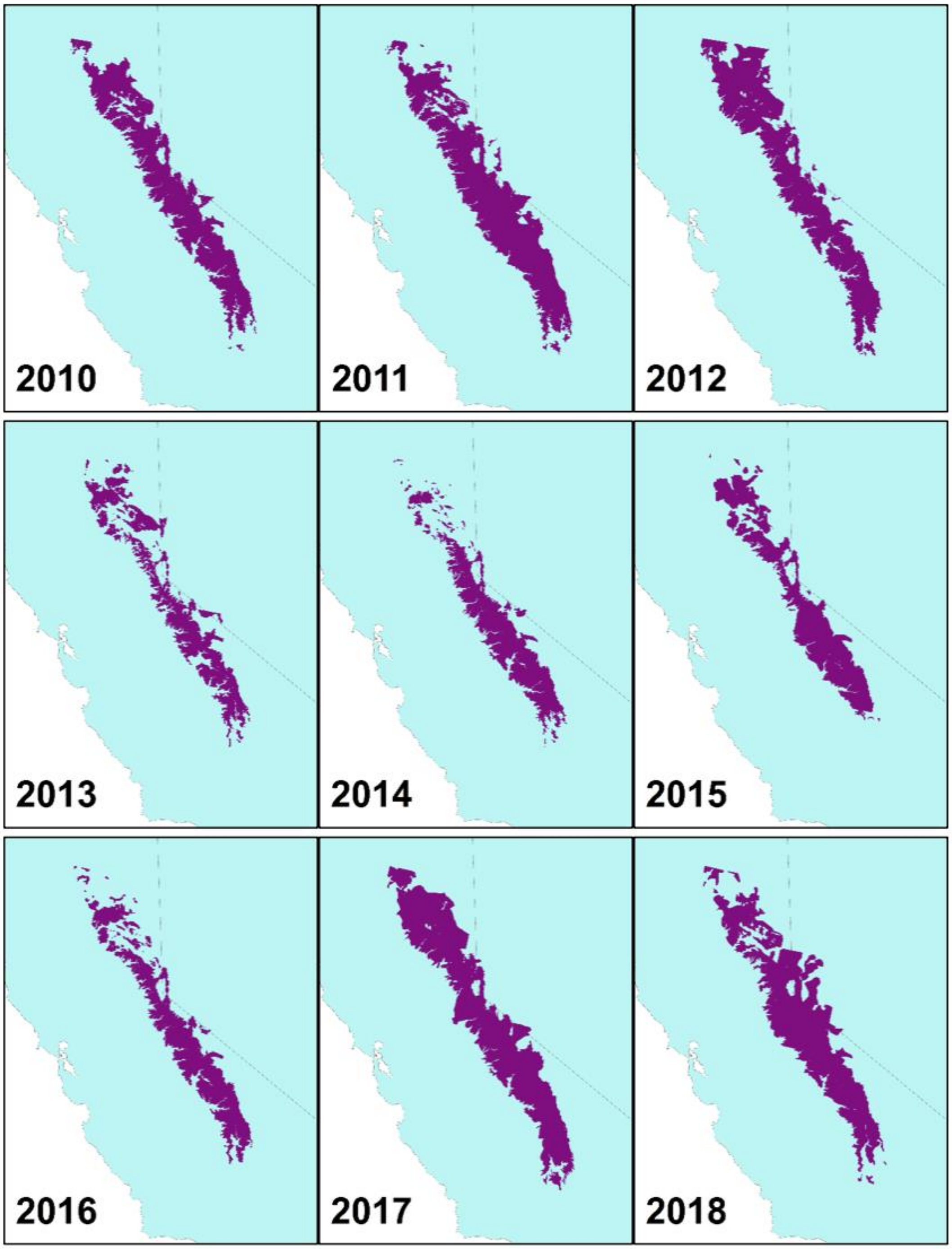

Figure 4. LandSat images of the Sierra Mountains snowpack cover years (2010-2018)

Discussion

In the efforts to show the correlation between global warming and infrequent rainfall, we came to the conclusion that it's not easy to show how the data demonstrates this fact in only one decade worth of data. It takes more than one decade to understand how the Sierra Mountains snow coverage is overall receiving less and less rainfall each year. Instead it makes more sense for our project's purpose to show the correlation between climate change and global warming intensive periods of heavy rainfall and severe drought periods. In the results, it's clear that the overall trend has been sporadic with periods of inclines and declines in rainfall. Therefore, it's impossible to show the overall declination of rainfall in California during the drought because the worst of the drought period happened from 2012 to 2014. According to an academic article called, "How unusual is the 2012–2014 California drought?" the author states. "Precipitation for 2012–2014 was indeed low but is less than 1.5 standard deviations below the reconstructed long-term normalized regional mean and not unprecedented over the last seven centuries" (Griffin et al, 2014). Our data parallels this statement because the years with the least amount of rainfall in the Sierras were 2013 and 2014. It's clear from figure 3, when we digitized the data, 2013 and 2014 are the years with the least amount of snow coverage. Another article called, "Causes of the 2011-14 California Drought, " gives some insight of the causes of the drought and how there is a differentiation between rainfall and snowfall and how that plays a role when determining the amount of total precipitation. This article states, "Human-driven climate change will primarily impact California hydroclimate via continued warming causing more precipitation to fall as rain instead of snow and stressing surface moisture via increases in potential evapotranspiration" (Seager et al, 2015). This information is important and this statement clearly reflects our results. Even though winter 2017 was a wetter year in the amount of precipitation, it does not necessarily mean that the drought is over; because human driven factors are a major concern and we will continue to monitor future snowpack and rainfall rates. There is a clear distinction of how humans cause more precipitation to fall as rain instead of snow, which is very concerning to areas in the Sierra Mountains and other snowy areas in California.

One reason for having complications in the gathering of information is because of the technological complications on capturing images. In a study from February 2018, titled "Potential for Western US Seasonal Snowpack Prediction," there is evidence of having technological malfunctions when calculating snowpack predictions. The report focuses on understanding how snowpack variability has predominantly been focused on either weekly weather or decadal to centennial (climate variability and change) timescales. And the problem they ran into is that "AOGCM [Atmosphere-Ocean Global Circulation Model] snowpack predictions lose statistical significance over the Sierra Nevada" (Kapnick et al, 2018). Because there are certain challenges in documenting the precipitation rates of the Sierra mountains, fog cover on certain days, and the physical topography of the Sierras to get to certain places makes it difficult to have an accurate reading on how much snowfall accumulates overnight. In the same study, the researchers concluded that "We [they] cannot conclude definitively whether this is due to a lack of predictability in the system or a model deficiency in capturing subgrid-scale orographic precipitation dynamics in a region where snowfall is highly sensitive to storm direction and vertical temperature profiles (i.e., determining transitions between rain and snow) and trends can vary in elevation" (Kapnick, Sarah et al, 2018). For our research purposes, it's essential to have the most accurate information on the current snowfall this winter and in recent years. However, since there is evidence that there are factors of technological malfunctions, uncontrollable weather interferences, and elevation restrictions to have the most accurate information of snowfall rates from winter 2018, the amount of snowfall is currently still being calculated. However, we are fortunate enough to gather significant amounts of data that allowed us to get an accurate amount of snow coverage.

In further, a discussion about our process of digitization to calculate areas, areas from the hard copy image were digitized, and the amount of digitizing was split between group members. User inconsistency may have affected the results of this study; however, manual digitizing methods were decided upon to get the most accurate results. The darker blue tones indicate denser snowpack patches, and the lighter blue tones indicate that there are fewer snowpack patches within these areas (refer to figure 1.). The problems we came across is some grassy areas had snow, but were different shades of greenish-blue instead of pure blue. It was difficult to pinpoint amongst three digitizers which shades of greenish-blue were considered covered. Those in the group did come to an agreement on which shades of greenish-blue should count as covered, but there was probably still some inconsistency regardless. To conclude, manual digitization had some conflicted issues decided which areas we should and shouldn't digitize; however, digitization provided more accurate results in calculating the amount of snow cover.

Conclusion

Snowpack melt within the area of the Sierra Nevada analyzed in this study occurred during some years in the observed range. Snow cover from the years (2013-2016) was smaller than the snow cover in the years (2010-2012). This indicates that the drought was at its worst between (2013-2014). However, in 2017, snowpack has been at roughly the same level as the 2012 snowpack, which implies that the precipitation rates of the drought have stabilized to a rate that was similar to the beginning of the drought. One other possible reason for examining the sporadic declination of snow coverage, is the possibility of how temperature variability by location plays an important role in snow transpiration rates. The entire Sierra Nevada is a large area, and no two locations within this area are guaranteed to have the same temperature. Therefore, it is possible that some areas observed might have a higher microclimate temperature due to lower elevation levels and other factors, and can therefore cause snow to melt at a faster rate.

Further studies and analyses are recommended before concluding that snowpack melt has decreased for the entire Sierra Nevada. The causes of decreased snowpack are still yet to be determined; however, there are studies that have linked human-driven factors to increased global warming and climate change. These anthropogenic sources can explain this global phenomenon. Different methods from the one used in this project are recommended for determining the amount of snowpack melt. The data from LandSat 7 and the potential errors from manual digitization in ArcMap may be problematic if increased accuracy is required. Further analysis should be performed on the Sierra Nevada utilizing different methods from those used in this project. First, Envi 5.4 should be used to estimate snow cover instead of ArcMap, because digitization in ArcMap is a time-consuming process that is not as accurate. Also, this study only analyzed snow cover, which is a measure of area, when snowpack, a measure of volume, would be a more useful quantity to work with for estimating snowmelt. Overall, the data collected and the maps created for this project indicate that snow melt has occurred in the the Sierra Nevada, but they do not illustrate the current problem of snow melt as effectively as originally anticipated. The sporadic nature of the data makes future snowfall predictions difficult to make. Thus, there is an urgency for an accurate record of precipitation rates including snowfall within the Sierras.

Acknowledgements

This study would not have been possible without the data supplied by Earth Explorer.

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