DETERMINING TRENDS IN SNOWLINE ELEVATION IN THE INDUS BASIN USING MODSCAG

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ABSTRACT

The amount of streamflow within the Indus Basin is highly dependent on snowmelt from the Himalayan mountains, even in comparison to other contributing factors such as glaciers and monsoonal rainfall. Because snow levels are sensitive to changes in climate, the water supply in this region and the millions of people downstream who rely on this finite resource are particularly susceptible to any change in temperature or precipitation. In order to observe the climate patterns in this basin, we produced a snowline elevation using both the MODIS Snow Cover and Grain Size product (MODSCAG) to determine the snow cover extent as well as ASTER data to determine the elevation. The changes in snowline elevation in the Indus Basin were assessed over a large portion of the current MODIS record (2000-2017). Based on these results, we are able to identify major climate trends and determine how such changes have impacted the Indus Basin over approximately the last two decades. (KEYWORDS: snowline elevation, Indus Basin, MODSCAG, remote sensing, snow cover)

INTRODUCTION

The Indus Basin is of primary concern when evaluating snow cover in the Himalayan region because a large population depends on this basin for water supply and, consequently, numerous strains are placed upon this critical water source. Pakistan encompasses most of the Indus Basin, although the basin also includes India, Afghanistan, and China. With nearly 237 million people depending on this basin for water, the numbers are expected to rise to approximately 383 million people by 2050 (Laghari et al., 2012). With population growth also comes increased urbanization, deterioration of the environment, and often poor water management (Archer et al., 2010). Laghari et al. (2012) noted that the Indus Basin Irrigation System is not only the largest irrigation system in the world but it is also one of the most depleted basins in the world as well; thus, an increase in population will only increase the water demand of this basin that is already limited in supply (Archer et al., 2010). Therefore, without even considering the effects of climate change, there is already the concern of how to manage the water supply properly from this finite resource.

While global temperatures are expected to increase, temperatures in the Himalayan region are expected to increase even more so relative to other parts of the world (Nepal, 2016; Archer et al., 2010). Thus, in order to mitigate the impacts of climate change, it is beneficial to focus on where the water originates and how much runoff can be expected in order to prepare accordingly downstream. Archer et al. (2010) determined that snowmelt, glacier melt, and monsoonal rainfall each contribute to the water supply in the Indus Basin; however, out of the three suppliers, snowmelt contributes the most to streamflow. Likewise, Singh and Jain (2003) estimated that 60% of annual streamflow occurs during the summer and 75% of that flow originates from snowmelt. Monitoring snow cover, therefore, is a fundamental component in regard to estimating the availability of water in this region. Furthermore, as Fowler and Archer (2005) determined, snowfed basins in the Himalaya are more sensitive to the impacts of climate change when compared to glacier-fed basins (Singh and Bengtsson, 2005). Thus, snow cover should be the primary focus when predicting streamflow in the Indus Basin because snow's sensitivity to climate change will be a determining factor in the amount of runoff as well as when the maximum runoff can be expected. This study, therefore, examines the changes in snowline elevation as a method of monitoring snow cover and climate in this basin from 2000 to 2017.

However, monitoring snow cover in the Himalayan region can be challenging. The high elevation and rugged terrain make some areas nearly inaccessible and difficult to collect data. Thus, the use of consistently collected satellite data is the preferred method for monitoring snow cover across this vast region (Singh and Bengtsson, 2005). As a result, this study uses remote sensing data to evaluate snowline elevation over approximately two decades. By observing these trends in snowline, we can better understand the climate patterns in the Indus Basin and how such trends may impact the populations that depend on this water source.

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METHODS

Data

Data for this study originate from the following two instruments: the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). Both sensors are aboard NASA's Terra satellite which was launched in December 1999.

MODIS data are used in this study to examine snow cover in the Indus Basin. Although the 500-meter spatial resolution is relatively large, the nearly 1-day temporal resolution allows for frequent monitoring of snow cover. Similar studies have used MODIS snow cover products when developing snowline elevation (Lei et al., 2012; Krajčí et al., 2014). However, we selected the MODIS Snow Cover and Grain Size product (MODSCAG), which has been noted as a more accurate snow cover estimation in comparison to other MODIS snow cover products due to its fractional snow cover and spectral mixture analysis (Painter et al., 2009; Rittger et al., 2013). Verbyla et al. (2017) also used MODSCAG to monitor snowline elevation with a focus on alpine areas in the northwestern United States and Canada. Rather than using a contour line approach, they incorporated elevation zones and climate data into a snowline elevation regression model.

The 30-meter ASTER Global DEM Version 2 dataset is used in this study to determine elevation. Both MODSCAG and the ASTER GDEM V2 datasets were accessed via NASA JPL and NASA Earthdata, respectively.

Snowline Elevation Contours

The study period includes the first week of March through the last week of June (weeks 10 and 26, respectively) over the years 2000 to 2017.

MODSCAG tiles H23V5 through H26V5 and H23V6 through H26V6 were used to create a mosaic for each day within the study period. The mosaics were then clipped to the Indus Basin boundaries as defined by USGS HydroSHEDS. In order to utilize MODSCAG's fractional snow cover capabilities, we created a threshold that would only retain pixel values for each dataset between 15 and 100; thus, a pixel value of 15 indicates that only 15% of snow cover exists within the given area and a pixel value of 100 indicates an area fully covered in snow. We then produced 8-day composites in order to diminish any type of interference inherent in the daily mosaics, such as cloud cover.

For each MODSCAG weekly composite, we produced contour lines as a measurement of snowline elevation for each contour is based on the percentage of snow cover within a pixel. A minimum of 20% snow cover within a pixel is the standard used for the base snowline elevation. A value of 100% snow cover is also used for the maximum snowline elevation. Then, using the ASTER GDEM Version 2 dataset, we applied the elevation data to the contours. This process was consistently repeated for each week from the beginning of March through the end of June for the years 2000 to 2017.

RESULTS AND DISCUSSION

Figures 1 and 2 show the seasonal variation in snowline elevation within the Indus Basin. Figure 1 shows the increase in snowline elevation as the warmer months approach and snow begins to melt. Figure 2 also shows the spatial variation in snowline elevation as the season progresses. For instance, Week 10 (or the beginning of March) for the year 2000 has the majority of snow near the Himalayan mountains as represented by the 100% snow cover contours. By Week 26 (or the end of June) for the same year, the amount of snow cover has started to decrease as the 20% snow cover contours emerge across the basin. Furthermore, Figure 2 also shows snow covered areas within the lower portion of the basin for Week 26 that are not present for Week 10. Such snow cover may be attributed to monsoons that occurred later in the season. Because this late snow occurs where the elevation is much lower relative to the northern portion of the Indus Basin, this may influence the mean snowline elevation for the basin in June and should be considered in future work.

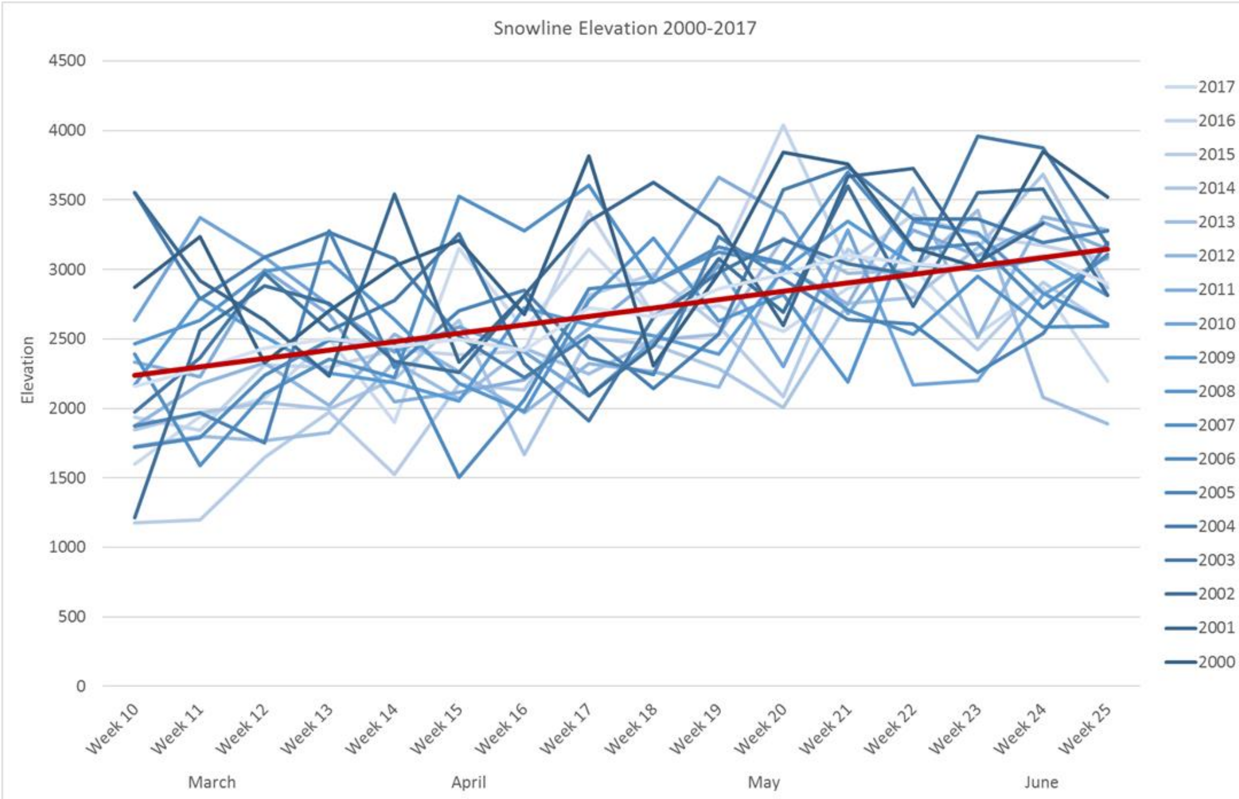

Figure 1. The change in snowline elevation from the beginning of March to the end of June for each year (2000-2017)

In addition to observing the seasonal trends, Figures 3 and 4 observe the interannual trends for a given week. Figure 3, for instance, shows the comparison between the 20% snow cover contour to the 100% snow cover contour for Week 15, or mid-April, throughout the 18-year period. Although the contours correspond to a similar pattern, the overall trend throughout the study period is not apparent. Figure 4 also shows Weeks 10 (early March) and 20 (mid-May) for the 20% snow cover contour throughout the 18-year period. Week 20 consistently had a higher snow elevation compared to Week 10, with the exception of 2001 and 2010 in which Week 10 had a higher snow elevation and 2004 in which the snowline elevation was approximately the same for both weeks. The interannual trends in both Figures 3 and 4 do not display a distinct pattern. However, due to changes in temperature and precipitation, we would expect an increase in snowline elevation throughout the years. Thus, further study should be conducted to determine whether the current pattern truly reflects snowline elevation trends in the Indus Basin or whether the process in estimating snowline elevation should be refined.

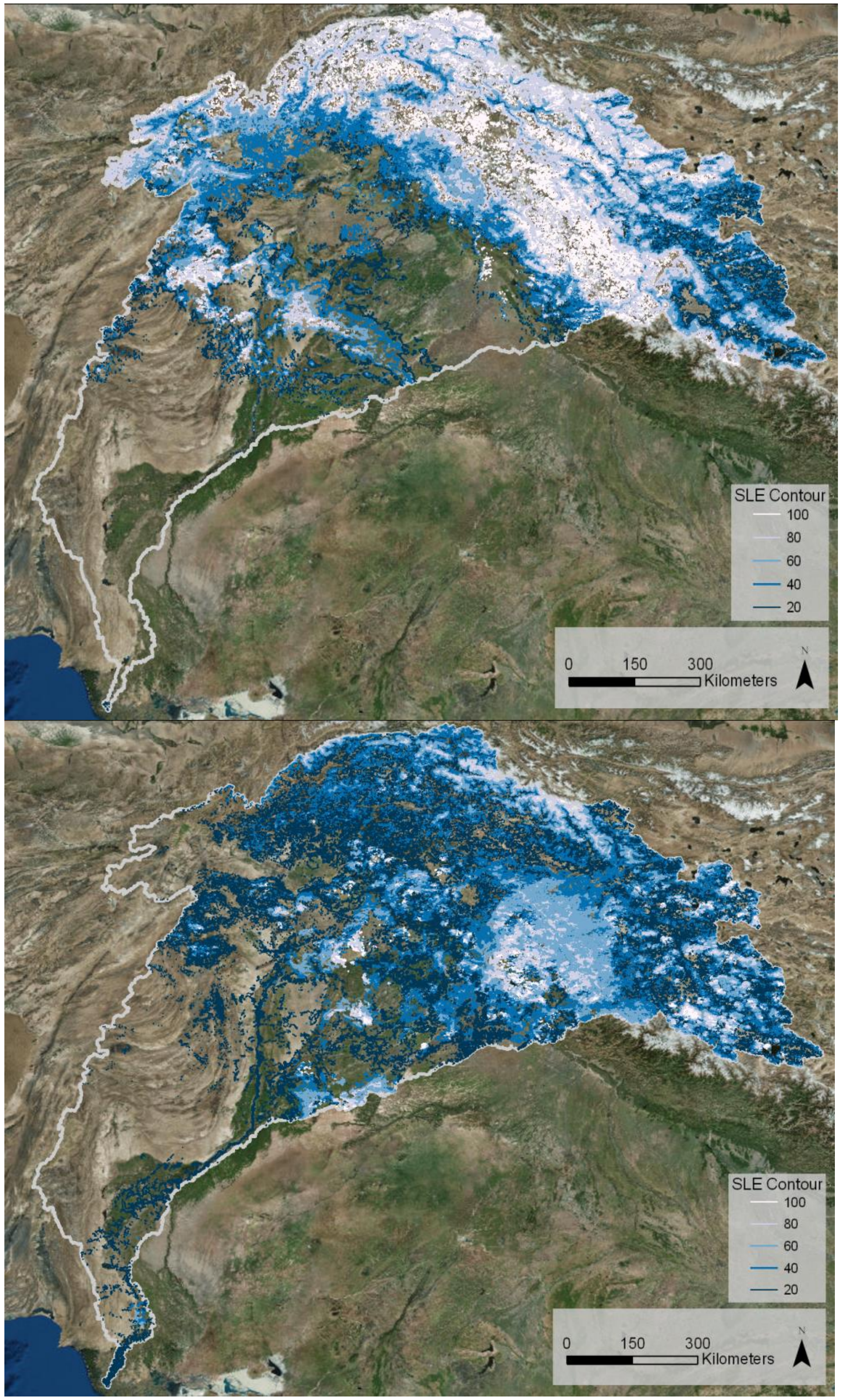

Figure 2. Snowline elevation contours for the year 2000: March Week 10 (top); June Week 26 (bottom)

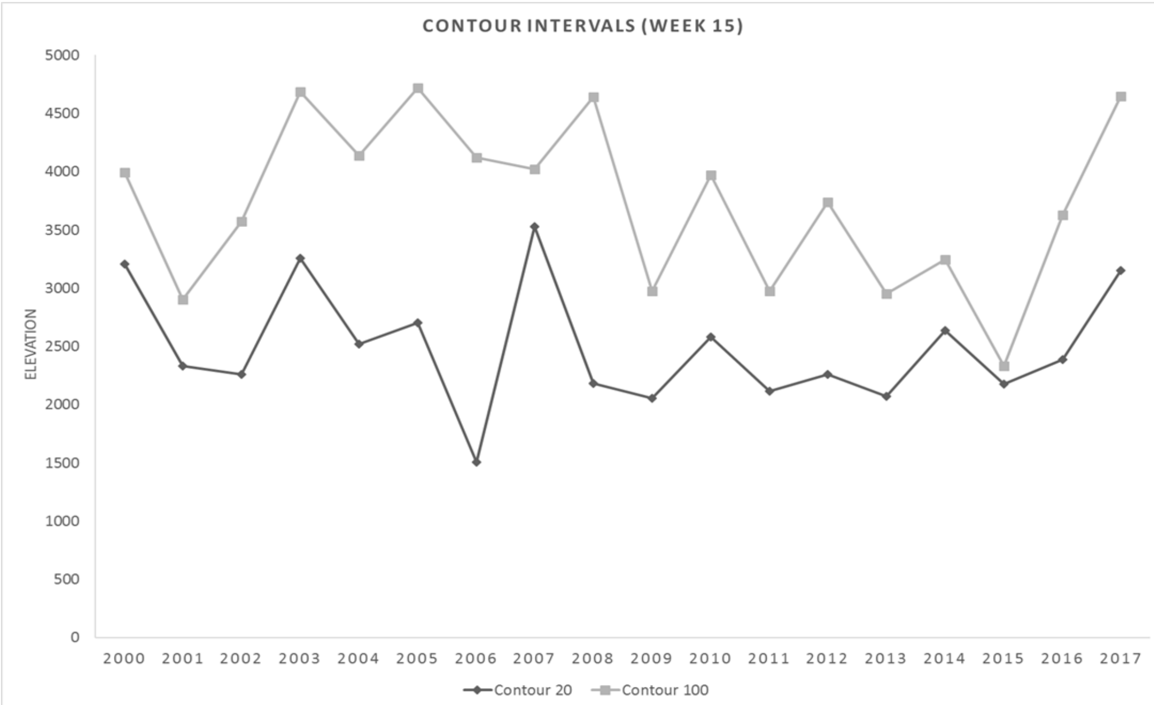

Figure 3. Snowline elevation for Week 15 from 2000 to 2017, representing contours for both 20% and 100% snow cover pixels

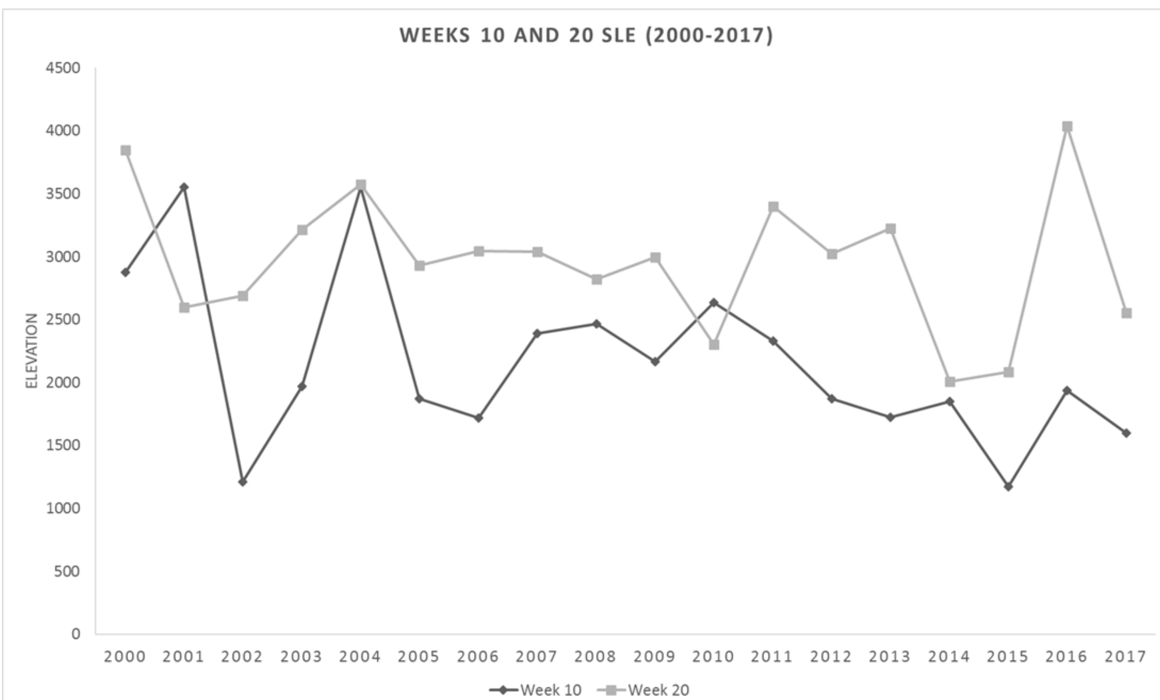

Figure 4. Snowline elevation for Weeks 10 and 20 throughout the 18-year period (20% snow cover contour)

CONCLUSION

Because streamflow in the Indus Basin highly depends on snowmelt, monitoring the snow cover extent or snowline elevation in this region is critical for the millions who rely on this resource. This study presents a method for monitoring snowline elevation using remote sensing data, specifically MODSCAG and ASTER datasets. Although the snowline elevation contour lines do reflect an increase in snowline elevation as the season progresses and the snow begins to melt, it does not present a clear pattern in terms of interannual trends as anticipated. Such results may reflect the influence of monsoons and may require a study period that also includes the months of July and August. By lengthening the study period and carefully considering the spatial pattern of the contour intervals, we can evaluate both climate trends and snow patterns within this region.

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