Response of the Indus Watershed to Climate Change in Central Asia

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Motivation and Study Area

The uncertain impacts of climate change on the Indus River and it's drainage basin has been historically understudied. This drainage basin is divided among 4 different countries and home to over 200 million people. Therefore, understanding the regional trends and magnitude of climate change is crucial to the future welfare of this transboundary region.

Glacial/Snowmelt vs. Precipitation Fed Rivers

Immerzeel et al., 2010

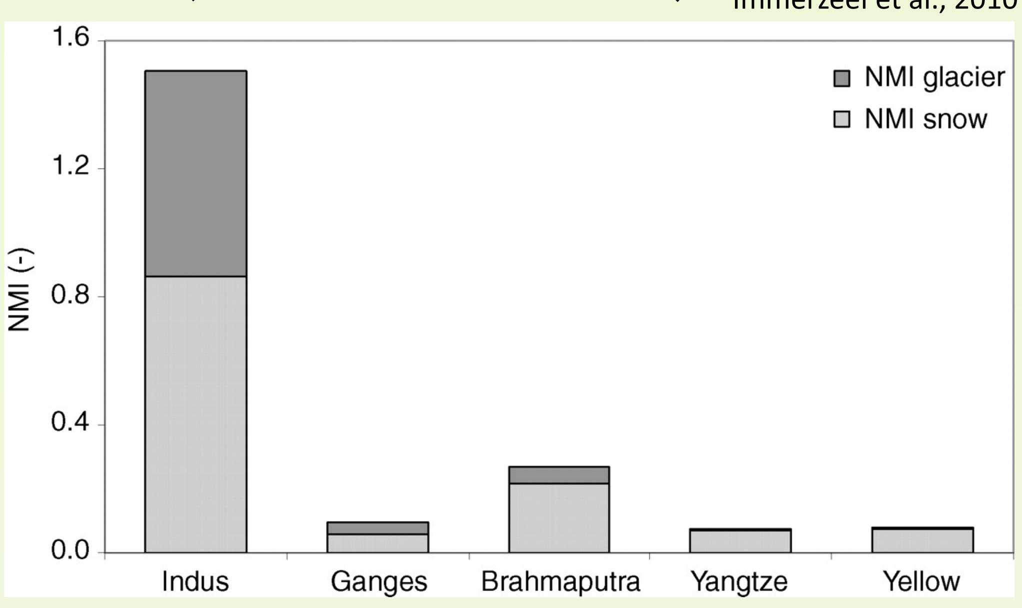


Figure 1. Normalized Melt Index (NMI) of different Asian Rivers. NMI is defined as the percentage of Snow and Glacial discharge to total downstream discharge.

The Indus River is a glacial / snowmelt fed river while rivers such as the Ganges are more precipitation driven. Illustrated by figure 1, the glacial wastage of Western Himalayan glaciers significantly contributes to the total Indus river streamflow. Consequently, the changing dynamics of Western Himalayan Glaciers are additional components that determines the health of the Indus River and its drainage basin.

The Indus River Basin

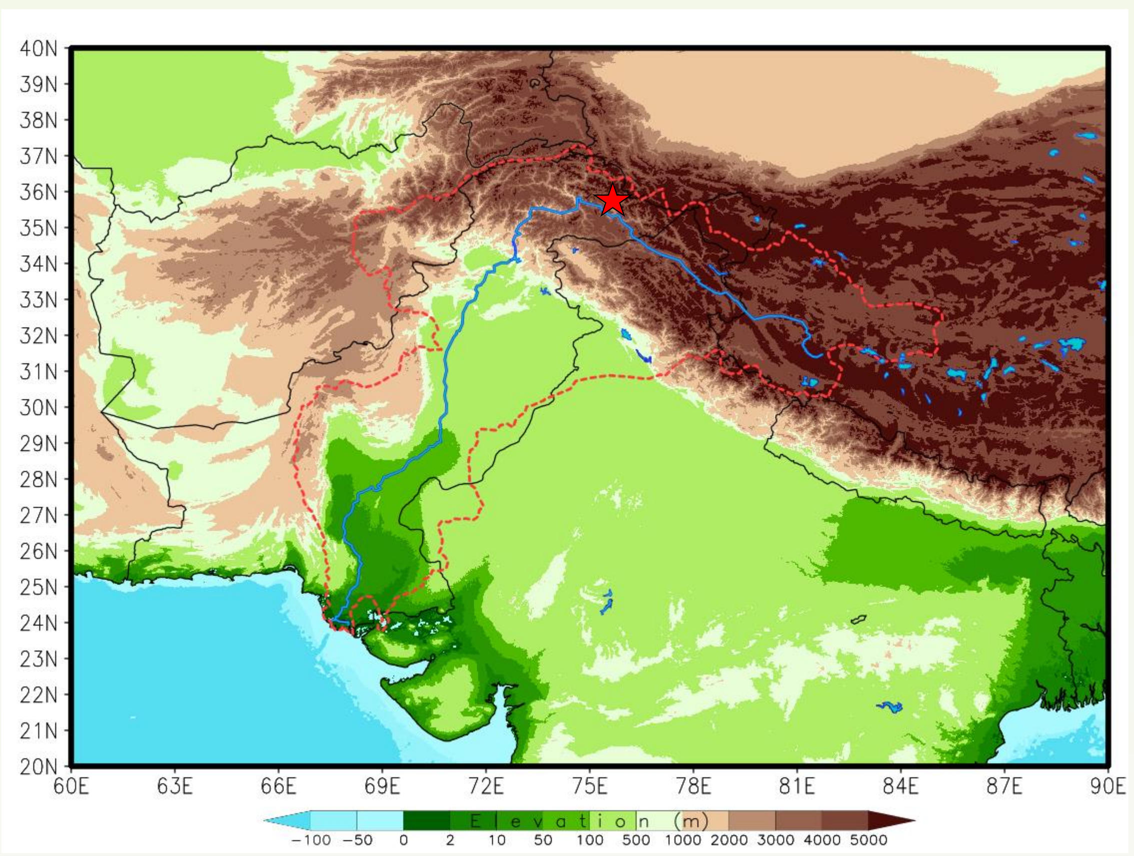


Figure 2. Elevation map of the Indus valley region. The Indus river is represented by the solid blue line, while its drainage basin is enclosed by the red dashed line. The Karakoram Mountain Range is marked by the red star.

As shown below by figure 3, the Western Himalayas are influenced by winter westerly low pressure systems. This climate pattern results in the establishment of winter accumulation glaciers, which contributes to the Indus river streamflow. To the contrary, summer accumulation glaciers on the Eastern Himalayas are products of the Indian Monsoon.

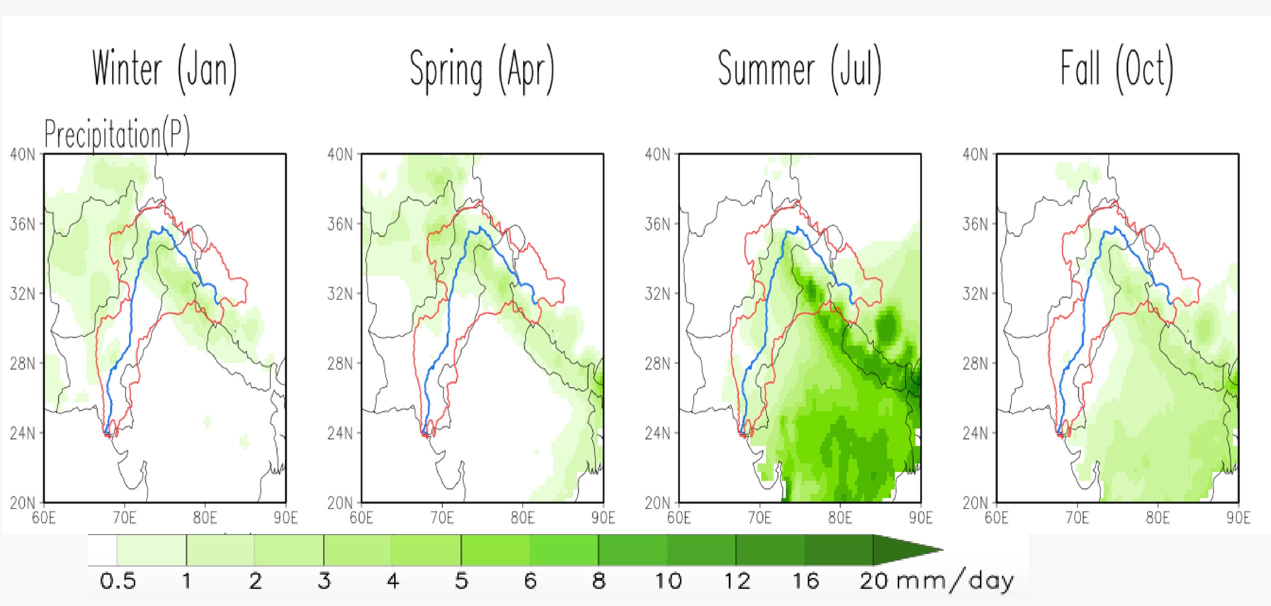


Figure 3. Average seasonal precipitation for the Indus Basin and its immediate surroundings from 1980 to 2010. Data from the University of Delaware Terrestrial Water Budget Time Series.

Many previous research has highlighted the uncertain trends in climatology within the Indus Basin, including:

- <u>**Karakoram Anomaly**</u>: Karakoram glaciers in the Western Himalayas experienced a positive mass balance since the late 1990s and remained mostly stable from 2003 - 2008
- Average winter precipitation has been increasing since the 1960s
- Average summer precipitation has been decreasing since the 1960s
- Mean summer surface temperature has slightly decreased since the 1960s
- Observed wider DTR for the UIB and the Western Himalayas, opposite of global trend

Datasets Analyzed / Procedures

Variable Analyzed	Dataset Name	Spatial Resolution	Temporal Resolution
Average Temperature Min/Max Temperature Average Precipitation Diurnal Temp. Range	CRU TS 4.00	0.5 * 0.5 degree	Seasonal (Monthly) 1901 (1950) – 2015
Average Precipitation	TRMM 3B42v7 / GPCC	0.25 * 0.25 degree	Seasonal (Monthly) 1998 – 2012 TRMM 2013 – 2017 GPCC
Mean Monthly Precipitation Mean Monthly Evapotranspiration Mean Monthly Storage	University of Delaware (UDel) Gridded Monthly Time Series	0.25 * 0.25 degree	Seasonal (Monthly) 1900 (1950) - 2014
Mean Snow Water Equivalent Mean Snow Melt	UDel Monthly Terrestrial Water Budget Time Series (V. 3.01)	0.25 * 0.25 degree	Seasonal (Monthly) 1900 (1950) - 2014

Table 1. The list of studied climate datasets and its variables partaken by this project. The temporal and spatial resolution is also mentioned with parenthesis indicating the beginning of the specified base period.

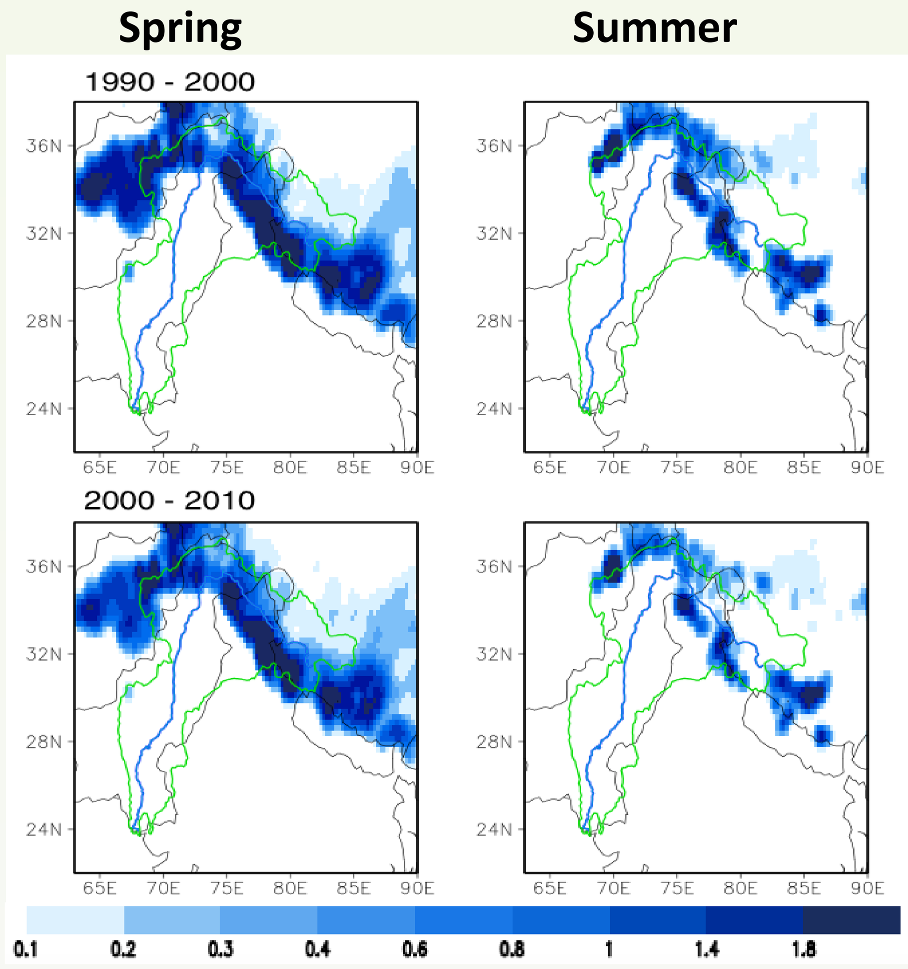
To get a better grasp of how climate change will impact the Indus Basin:

- Calculate the seasonal climatology for the base period
  - Compare climatology between different datasets
- Difference in climatology with respect to the base period
  - Verify previous research
- Determine the trends for other climatological variables

Results

Snowmelt Climatology (mm/day/decade) (U.Delaware Dataset)

Spring Summer



Snowmelt Climatology Trends (mm/day/decade) (U.Delaware Dataset)

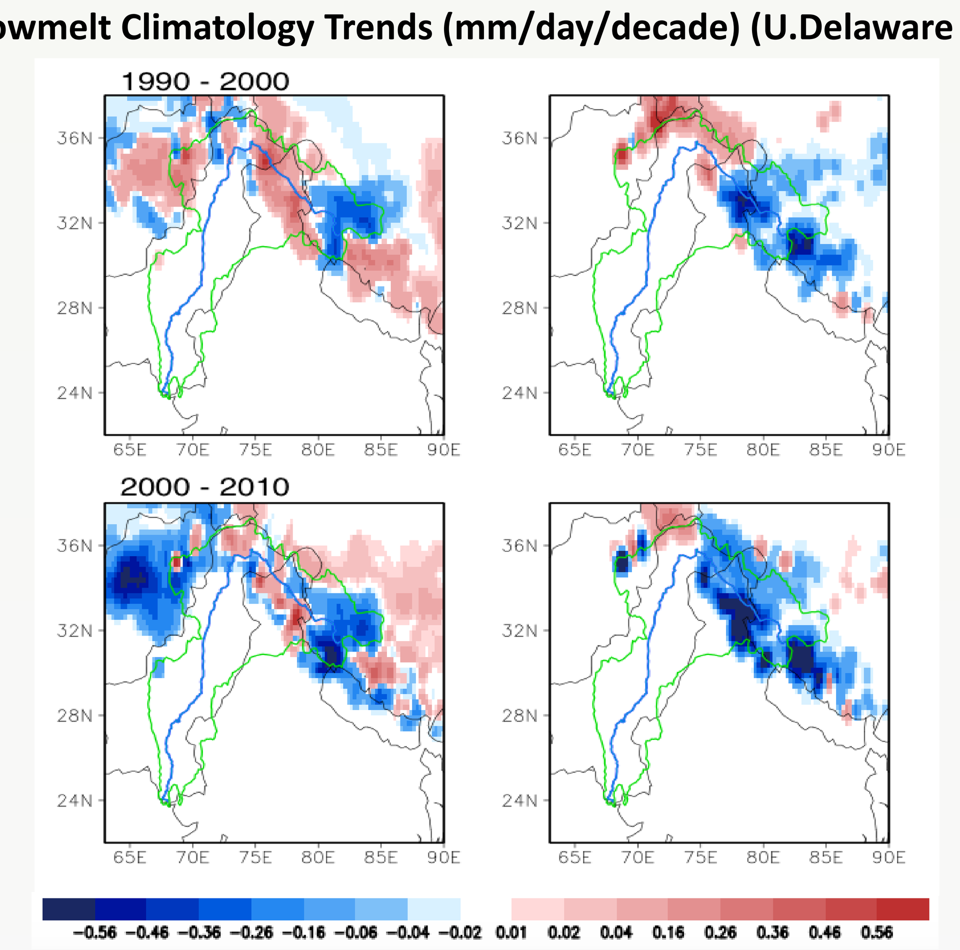
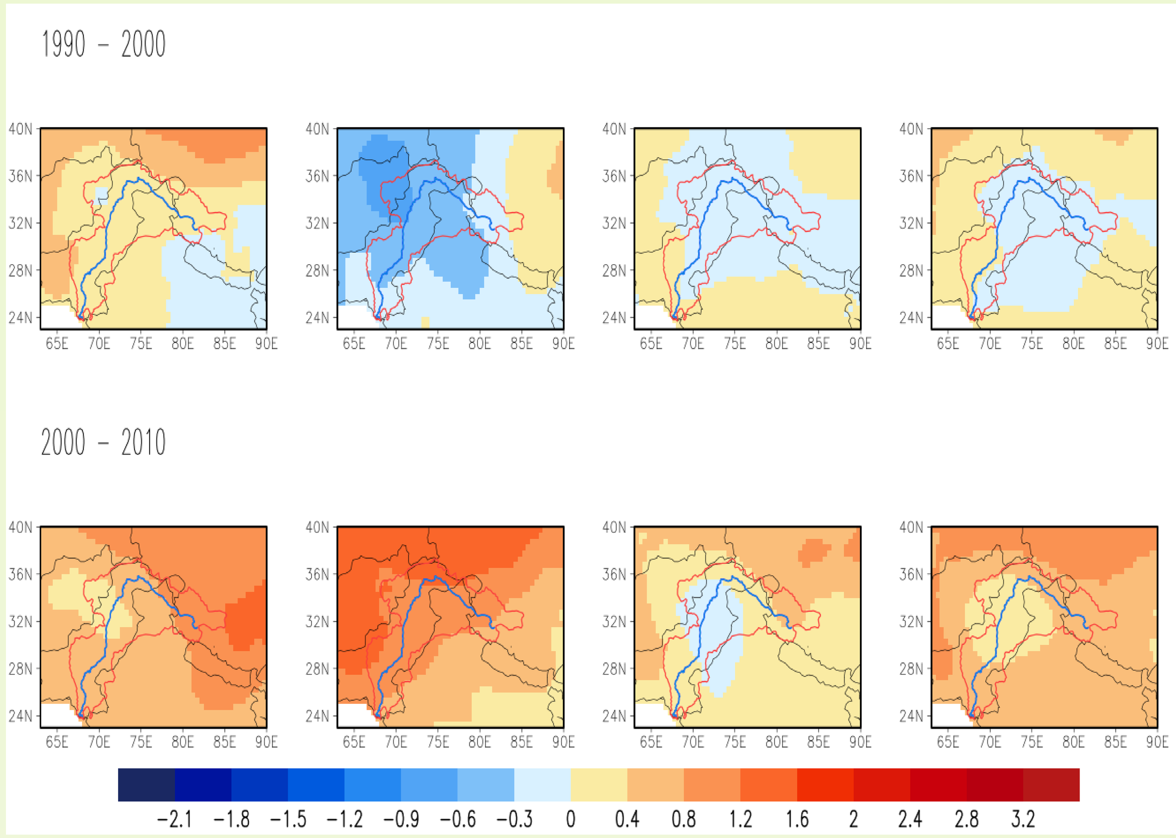


Figure 4. University of Delaware Decadal Average Snowmelt Climatology for the for Spring / Summer
Figure 5. University of Delaware Decadal Changes in Snowmelt Climatology for selected seasons with respect to the base period

Changes in Climatology (Temperature) from Base Period (1950 - 2010) CRU TS4 (Celsius/year/decade)

Winter Spring Summer Fall



Changes in Climatology (Precipitation) from Base Period (1950 - 2010) UDel. Dataset

Winter Spring

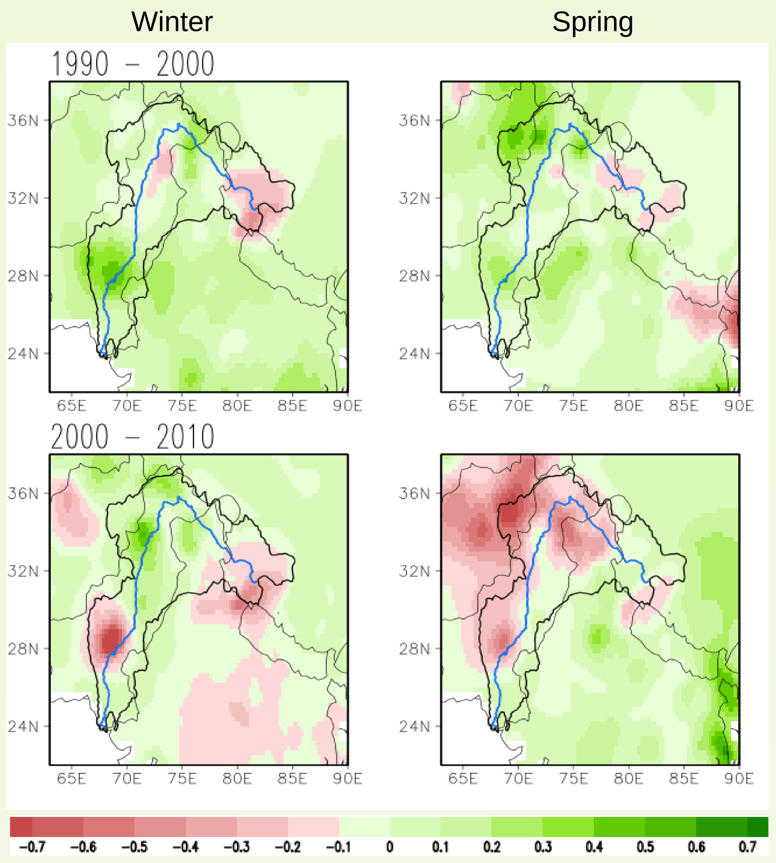


Figure 6. (Above) Decadal changes in temperature climatology for all seasons using the CRU TS 4.0 dataset

Figure 7. (Left) Decadal changes in precipitation climatology for spring and summer seasons using the University of Delaware dataset

Discussion / Observations

- In the 1990s, the Upper Indus Basin (UIB) has experienced below average temperatures for all seasons except for winter. Below average temperatures was especially severe for the spring seasons.
- In the 2000 – 2010 decade, this UIB is warming at a slower rate compared to its surrounding regions, with below average summer temperatures.
- The UIB has experienced cooler summers since the 1990s. This led to below average snow melt and could be a factor behind the Karakoram Anomaly.
- As the glaciers in the UIB are winter accumulation glaciers, the slight increase of winter precipitation may be another factor driving the Karakorum Anomaly.

Future Works

Overall results of this study highlighted the magnitude and general pattern of climate change within the Indus Basin Region. This paves the way for the implementation of more extensive types of analysis. A weak point within this project is the low temporal resolution chosen to track changes in the climatology. In future works, a time series that incorporates area averaged changes in climatology will provide a more detailed representation that does not rely on intervals containing numerous years. Eventually, additional outside climatological factors (winds, sea level pressure, sea surface temperatures) can also be studied to determine its connection to climatological trends within the Indus Basin.

References

Figure 1: Immerzeel, W. W., van Beek Ludovicus P. H., & Bierkens, M. F. P. (2010). Climate Change Will Affect the Asian Water Towers. Science. https://doi.org/10.1126/science.1187443