The water balance as a confirmation of glacial melt in the upper Indus basin

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Introduction

More than one sixth of the global population depends on water supplied by mountains and changes in hydrology and water availability due to climate change are expected to be large in mountain basins. The spatial variation in observed and projected climate change is large and mountain ranges and their downstream areas are particularly vulnerable for several reasons. Especially the diminishing role of snow and ice as a natural store for water supply may have a large impact. For all of these reasons knowledge on snow cover and ice dynamics and how it influences water availability is of great importance and surprisingly regional studies on this topic are largely lacking. The focus of this study is on the upper Indus basin, where snow and ice melt from the Himalayan and Karakoram ranges constitute the most dominant part of river discharge in comparison with other large Asian rivers. Similar to other glaciated areas global warming also has its effect here. However the effects of climate change on the cryosphere and subsequently on the basin hydrology remain largely unknown.

Objectives

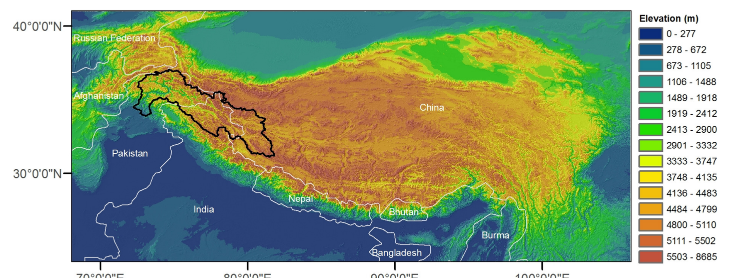
For all of these reasons knowledge on snow cover dynamics is of great importance and surprisingly regional studies on this topic are largely lacking. The focus of this study is on two topics.

Firstly, the snow cover dynamics in Asia are analyzed in time and space using remote sensing. The spatial-temporal snow cover patterns across the 23-41°N and 68-106 °E domain are quantified per major river basin. Inter-annual and seasonal differences in snow coverage between the major river basins are assessed.

Secondly focus is on the Indus basin, where snowmelt is a major determinant in water supply. Using a calibrated snowmelt runoff model the relationship between air temperature, precipitation, snow cover and runoff is analyzed. We conclude this analysis by an assessment of the potential effects of climate change on the runoff characteristics of the upper Indus basin.

Method

- MODIS snow cover products (MOD10C2) are used to assess trends in snow cover. Snow is identified using the normalized difference snow index (NDSI). NDSI is
- The runoff modeling in the upper Indus basin is based on the Snowmelt Runoff Model (SRM). The model has been applied in over 100 basins ranging in surface area from 0.8 km² to 917,444 km² in 29 different countries and results are published in about 80 scientific journals. SRM is a conceptual, deterministic, degree day hydrologic model used to simulate daily runoff resulting from snowmelt and rainfall in mountainous regions. The original model has been adapted to include glacial melt.
- The Tropical Rainfall Measuring Mission (TRMM) precipitation estimates are used to force the SRM. In this study the 3B43 product is used, which is a multi-satellite gauge corrected monthly gridded product at a resolution of 0.25°



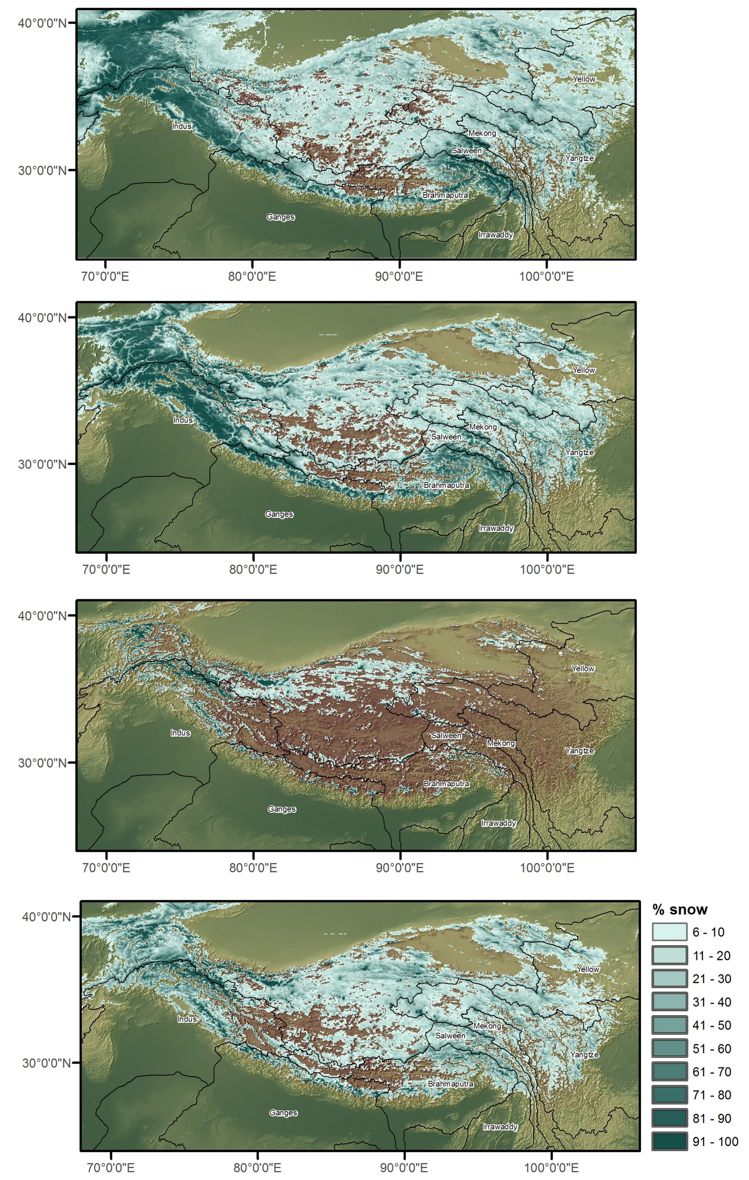
Study area. The black polygon outlines the upper Indus basin.

- The analysis of snow cover dynamics covers includes the Tibetan-Qinghai plateau and the Hindu-Kush, Pamir, Karakoram and Himalaya mountain ranges. The SRM is setup for the upper Indus basin upstream of the Tarbela dam, which regulates water supply to the Indus irrigated areas together with the Mangla dam as part of the Indus Basin project. The total basin area is 200,677 km² and the length of the river upstream the dam is approximately 1125 km

Variation in ecosystems in the Upper Indus basin. Mountain deserts in Ladakh (top), Spillway of the Mangla dam (bottom left) and the K2 (bottom right)

Results

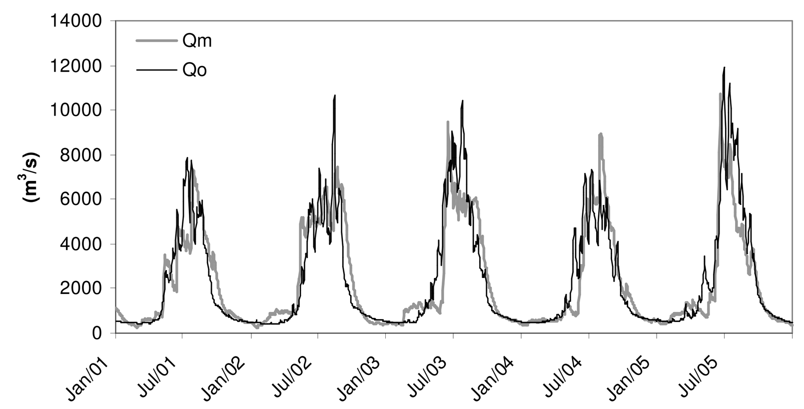
- Across the Himalayan river basins there is a large spatial variation in snow cover due to the large climate and altitudinal differences. There is an obvious relation with the elevation and a clear decreasing west-east trend in snow cover persistency in all seasons can be observed.
- Only for the Indus basin a significant negative trend in snow cover was identified in winter (-1.3 % y^{-1}).



Seasonal snow cover (winter (top), spring, summer, autumn (bottom)) based on MOD10C2 snow cover time series from March 2000 to February 2008. The values show the percentage of time that a pixel was snow covered during the specified season within the entire time series.

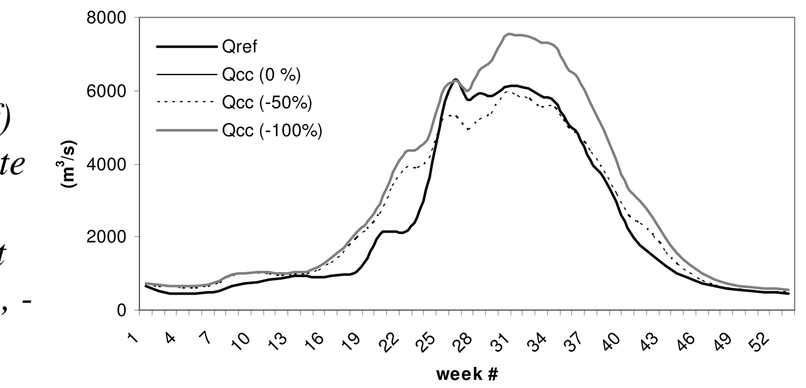
- Stream flow in the Upper Indus is realistically simulated using the SRM based approach. The Pearson correlation coefficient equals 0.88, the bias is 0.02 and the Nash-Sutcliffe criterion equals 0.78.

Modeled and observed daily stream flow at Besham Qila from 2001 to 2005



- The most striking feature of these SRM results is that the total TRMM 3B43 precipitation for the entire basin based equals 311 mm y^{-1}, while the total modeled stream flow equals 360 mm y^{-1}. There must be an additional source of water to explain the reported stream flow → climate change could be an explanation.
- The effects of climate change on the stream flow are significant and these are assessed using results of the PRECIS RCM for the SRES A2 scenario to force the SRM assuming three glacier scenarios.

Modeled weekly stream flow from 2001 to 2005 (Qref) and for three climate change scenarios (Qcc) with different glacier extents (0%, -50%, -100%).



Conclusions

- Of all Asian river basins the Indus basin is, for its water resources, most dependent on snow and ice melt and large parts are snow covered for prolonged periods of the year.
- The climate change scenarios studied and presented here may have a beneficial effect on the downstream water availability of the Indus basin and consequently on the agricultural potential of the area.
- There are indications that regional warming is affecting the hydrology of the upper Indus basin due to accelerated glacial melting during the simulation period. This conclusion is primarily based on the observation that the average annual precipitation over a five year period is less than the observed stream flow and supported by positive temperature trends in all seasons. The annual melting rate is conservatively estimated at 1% of the total ice reserve.

Acknowledgements

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