GC51D-1232: Uncertain future for the water resources of high mountain Asia

Universiteit Utrecht

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Walter W. Immerzeel[1,2], Andreas Gobiet[3], Martin Suklitsch[3], Francesca Pellicciotti[2], Marc F.P. Bierkens[1], Silvan Ragettli[2]

[1]Department of Physical Geography, Utrecht University; [2]Institute for Environmental Engineering, ETH Zürich; [3]Wegener Center for Climate and Global Change, Graz University

INTRODUCTION

There has been much discussion recently about the state and fate of glacier in high mountain Asia (HMA). A comprehensive review of changes in glacier extent and mass balances in the Himalayas and the Karakoram showed that glaciers are losing mass, except in the Karakoram mountain range where there are indications of mass gain at high altitude (Bolch et al., 2012).

The contribution of glacier melt to present river runoff is substantial in the Indus and the Amu Darya river basins, and more modest in the remaining basins. In HMA basins, a large source of uncertainty in projections about future runoff is the variability in precipitation and temperature projections between global climate models (GCMS), in particular in monsoon-dominated Asia.

In this study we use results from the latest ensemble of GCMs in combination with a high-resolution glacio-hydrological model in two climatically contrasting catchments to assess the hydrological impact of climate change in HMA.

Figure 1. The 10 major river basins in Asia which find their source in HMA. The upstream parts (> 2000 m. asl) of the river basins are shown in red and the downstream parts are shown in blue. The red dots shows the locations of the Langtang catchment (inset top) and the Baltoro catchment (inset bottom left) for which glacio-hydrological simulations are conducted.

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• Immerzeel, W. W., L. P. H. Beek, M. Konz, a. B. Shrestha, and M. F. P. Bierkens (2012), Hydrological response to climate change in a glacierized catchment in the Himalayas, Climatic Change, 110, 721–736

AUTHOR ADDRESS:

Dr. W.W. (Walter) Immerzeel
Utrecht University
Department of Physical Geography
Email: w.w.immerzeel@uu.nl

METHODS AND MATERIALS

We assess the spatial variability and uncertainty in climate change projections for the 10 largest river basins in Asia with source areas in High mountain Asia (**Figure 1**), using:

• The global climate model ensemble generated for the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4) provided through the 3rd Climate Model Intercomparison Project (CMIP3),

• and the latest global climate model ensemble generated for the upcoming IPCC AR5 provided through CMIP5.

We analysed CMIP3 (130 runs) and CMIP5 simulations (147 runs) based on all available emission scenarios. We do not use any prior assumption and give the same weight to all scenarios. We use the average monthly change data in combination with a reference time series from 1961 – 1990 to generate 277 transient climate change projections for the catchment scale analysis.

We then use a high resolution fully distributed glacio-hydrological model (Immerzeel et al., 2011) in two climatically contrasting catchments (Baltoro in the Karakoram and Langtang in the greater Himalaya) to quantify how uncertainty in climate change projections translates into hydrological uncertainty and we evaluate differences in hydrological impact between CMIP3 and CMIP5.

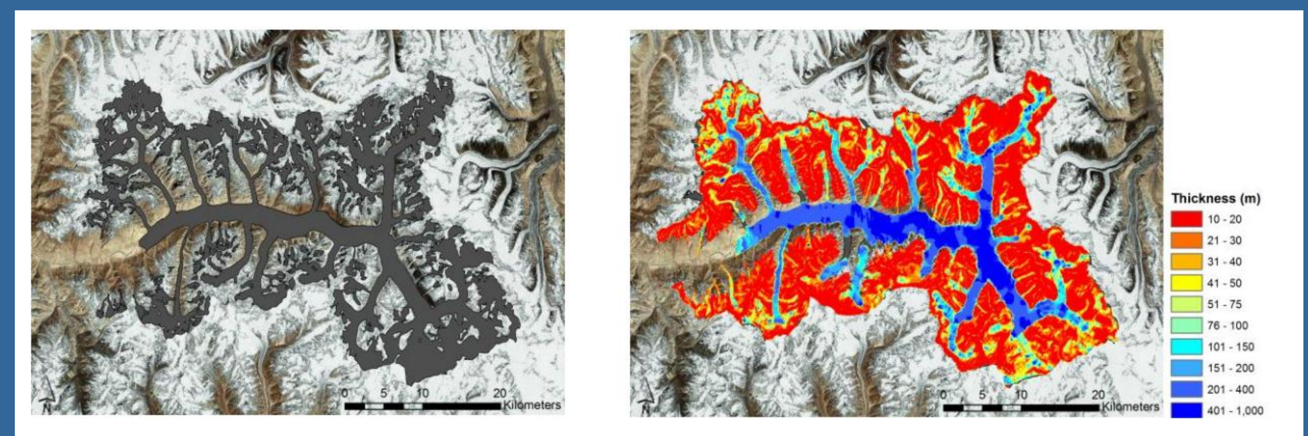

Figure 2. Observed and simulated ice extent in the Baltoro catchment after running the glacio-hydrological model for the period 1957 until 2009.

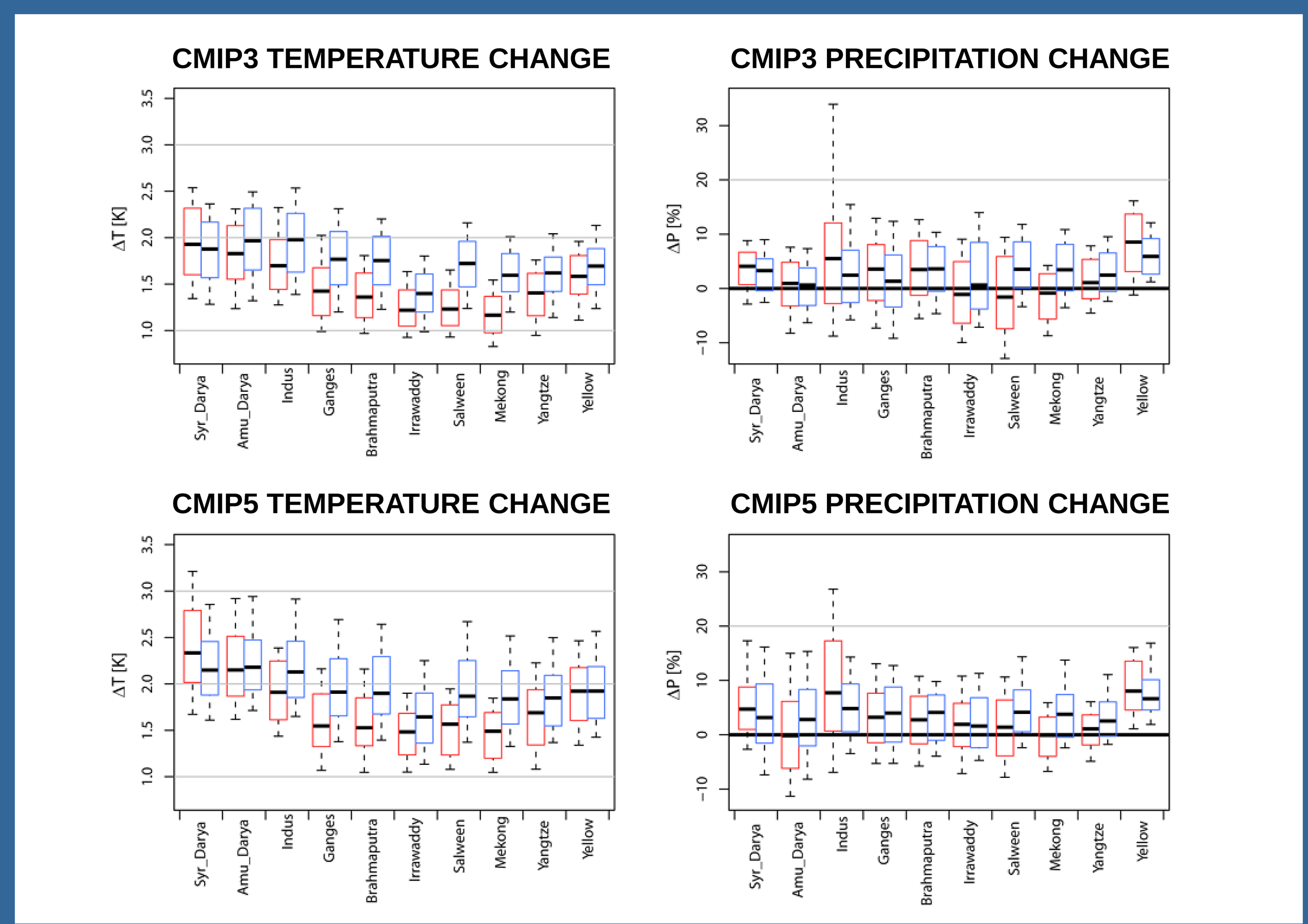

Figure 3. Box-whisker plots of projected changes per river basin in temperature (left panels) and precipitation (right panels) for the CMIP3 model ensemble (top panels) and the CMIP5 model ensemble (bottom panels) in 2021-2050 relative to 1961-1990. The blue boxes are for the upstream part of the basins (> 2000 m. asl) and the red boxes are for the downstream parts of the basins (< 2000 m. asl).

RESULTS

CHANGES IN CLIMATE

• The projected warming in 2021-2050 relative to 1961-1990 is close to 2°C on average. There is a decreasing trend from the western to the eastern basins (**Figure 3**).

• The projected warming in HMA basins is generally stronger (up to 0.25°C) at higher elevations in both the CMIP3 and CMIP5 ensemble and the strongest difference between upstream and downstream temperature increases is in the in the Indus, Ganges and Brahmaputra basins (**Figure 3**).

• The CMIP5 projected temperature increases are generally stronger than the CMIP3 projections (**Figure 3 and 4**). No evident reduction of between-climate model variability is observed from CMIP3 to CMIP5.

• Precipitation is likely to show a modest increase up to a few percent on average but there is a large spread among GCMs.

• Strong intra-annual variation in projected change in precipitation and temperature in the Upper Ganges (**Figure 4**). The monsoon season shows up to 0.5 °C less warming during the winter. The projected increase in summer monsoon precipitation varies between 7.2% in June to 11.0% according to CMIP5 projections. CMIP3 projects less increase in summer monsoon but the uncertainties are larger.

• The intra-annual variation in projected temperature change is much less for the upper Indus. The projected precipitation changes show a similar pattern. The CMIP5 projections show a slight decrease of precipitation during the accumulation season (winter) and a relatively high temperature increase during the ablation season (summer).

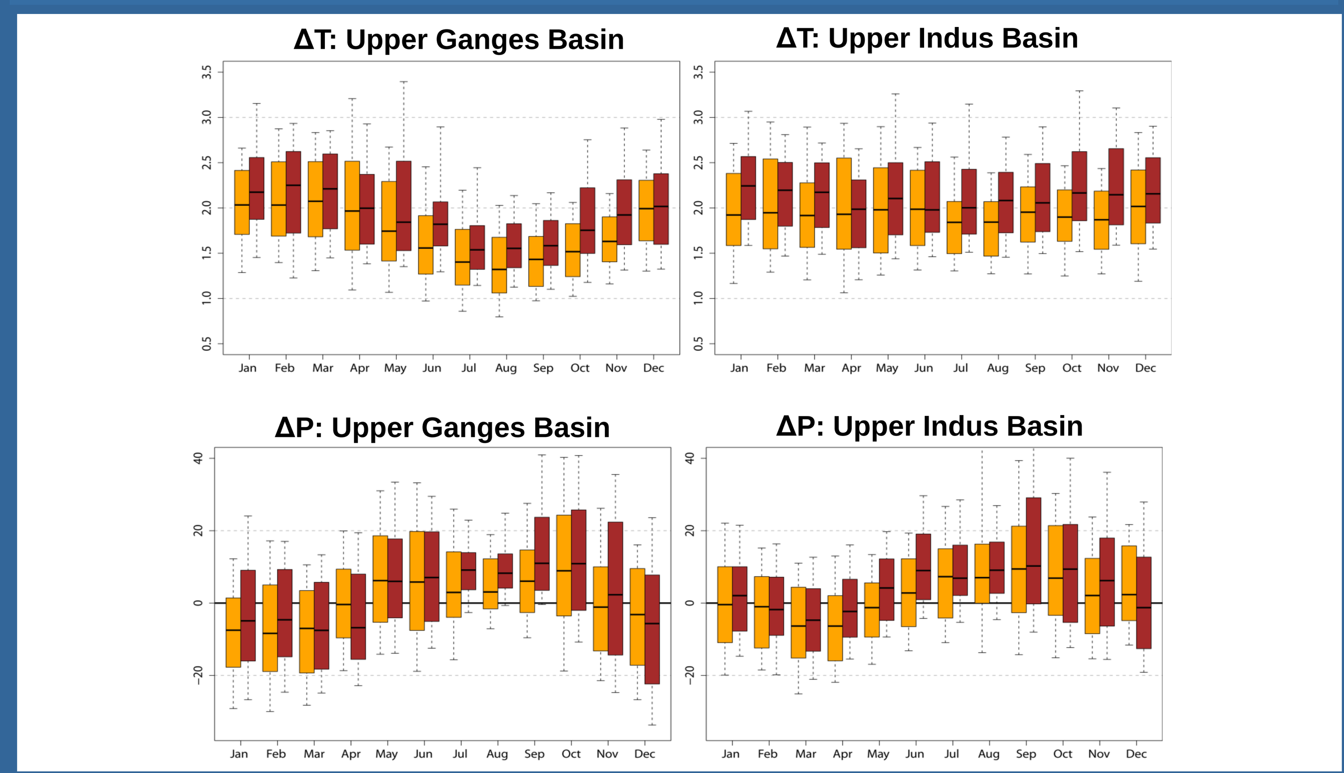

Figure 4. Box-whisker plots of monthly projected changes in temperature (top panels) and precipitation (bottom panels) for the CMIP3 model ensemble (yellow) and the CMIP5 model ensemble (brown) in 2021-2050 relative to 1961-1990 in the upper Ganges basin (left panels) and the upper Indus (right panels).

CHANGES IN RUNOFF

• For CMIP3 the average runoff in the Langtang is projected to increase by 33.7 % and by 45.1% for the Baltoro (**Figure 5**). A more extreme increase is projected for CMIP5 (42.5% and 50.9% respectively).

• The range in projected runoff change is very large (e.g. Q10-Q90: 13.9% -52.2%. for the Langtang). The range of projected changes in runoff becomes smaller in the CMIP5, largely explained by the narrower range in projections of monsoon precipitation.

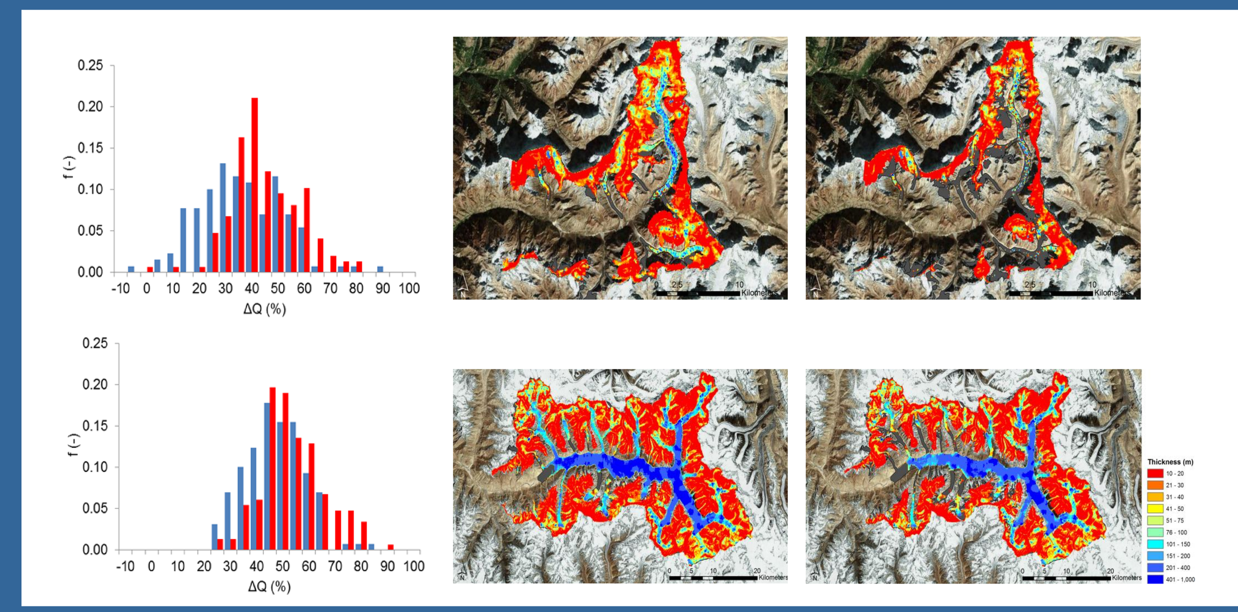

Figure 5. Left panel: Distribution of projected changes in total runoff in in 2021-2050 relative to 1961-1990 in the Langtang catchment (top) and the Baltoro catchment (bottom) for the CMIP3 (blue) and CMIP5 (red) model ensemble. Maps on the right: Simulated ice thickness in 2050 for the Langtang catchment in the upper Ganges (top panels) and the Baltoro catchment (bottom panel) for a wet (Q90 of CMIP5 ensemble) and cold (Q10 of CMIP5 ensemble) GCM (left panels) and a dry (Q10 of CMIP5 ensemble) and warm (Q90 of CMIP5 ensemble) GCM (right panels). In dark grey the glacier outlines in 2003 are shown.

DISCUSSION AND CONCLUSIONS

• Given the larger spread in climate change projections in the regions it is essential to take the full bandwidth into account when studying hydrological impact of climate change

• An increase in future runoff is predicted by the glacio-hydrological model. Earlier research at the large scale suggested a reduction in runoff in the upper Indus and Ganges basin (Immerzeel et al., 2010).The differences in models projections are explained by the following points:

➢ The scale of application is different and consequently the physical detail of the underlying model has improved

➢ Only 5 GCMs were used in the large-scale study, excluding a number of cold and wet GCM results.

➢ The large-scale study used a simple mass balance approach to estimate glacier retreat, neglecting dynamic effects that are prominent in large glaciers such as the Baltoro. This may have resulted in an overestimation of glacier retreat by 2050 and a decrease in the absolute amount of glacier melt.

• For the Baltoro the glacier melt is in a phase of net increase or stable depending on GCM, whereas for the Langtang, where glaciers are much smaller, net glacial melt is stable or just starting to decrease.

• Large spatial differences in the hydrological response to climate change of the two study catchments seem evident: in the upper Ganges, glaciers will likely disappear much faster than in the upper Indus, but due to the projected increase in precipitation and the relatively limited dependence on glacier melt water, changes in future runoff beyond 2050 might be small. In the Indus, it will take much longer until the glacier disappear but once they do, the impact on downstream water availability will be severe.

• Model projections become more constrained due to the reduced spread between GCM precipitation projections in latest global climate model ensemble.