HighNoon: Simulating the evolution of Himalayan glaciers with the regional climate model REMO

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Motivation

- Over 800 million people depend on glacier melt water runoff throughout the Hindu-Kush and the Himalayan (HKH) region. The region, also called as “Water tower of Asia”, is the location of several major rivers basins, like Ganges, Brahmaputra, and Indus etc. Glaciers in the HKH region are the primary source of water for the perennial rivers. These rivers are the lifeline of the downstream population as their water is largely used for drinking, irrigation and agriculture.

- Glaciers in the central and eastern Himalaya strongly depend on the Indian summer monsoon precipitation, whereas the western Himalaya is more dependent on the winter precipitation.

- Future climate change scenarios suggest that monsoon precipitation will be reduced over the HKH region, especially over the monsoon dominated regions (Fig-1), reducing snow accumulation and, in combination with increasing temperatures, accelerating glacier melt. Therefore, it is important to assess the glacier retreat under warming green house gases scenario.

- Since HKH region including Tibet is so large and complex, it is difficult to assess the overall glacier response based on detailed models of individual glaciers. An alternative is to use the Regional climate model (e.g. REMOGlacier) in which glaciers are interactively coupled to the atmospheric model component, and their response is therefore fully consistent with the simulated climatic changes.

- REMOGlacier is first applied over the region using reanalysis data to test the model quality.

RCM experiment set-up

RCM	:	REMOGlacier
Resolution	:	0.22x0.22 deg (~25Km)
Domain	:	60.125°E - 100.125E° & 4.125°N – 40.125°N (Fig-1)
Period	:	1989-2008
Forcing	:	ERA-Interim, Glacier Inventory

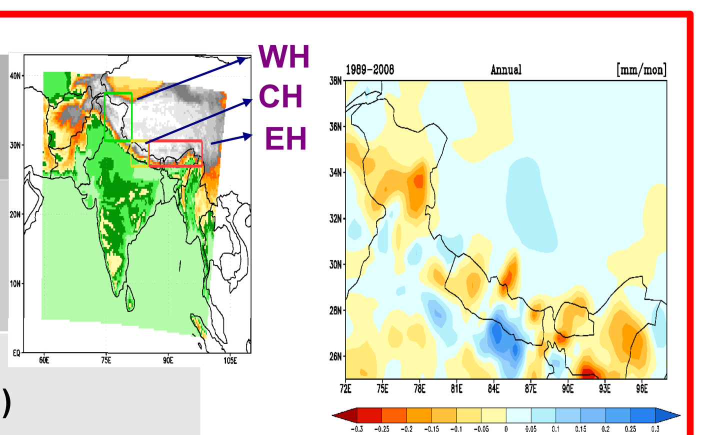


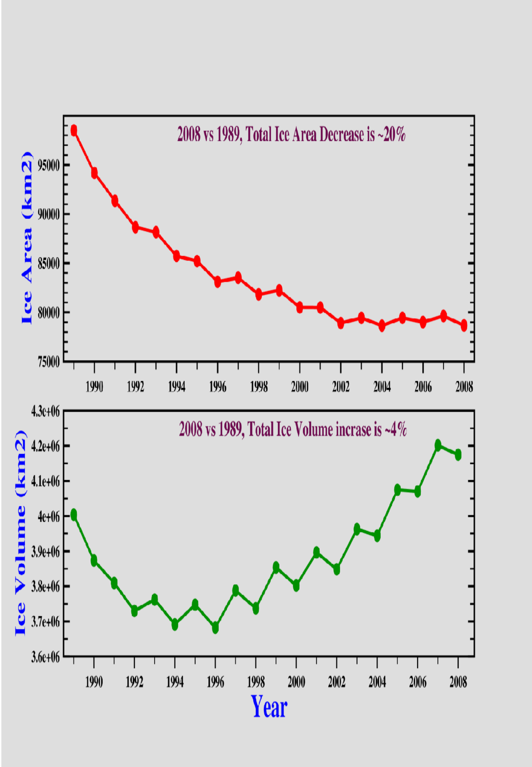
Fig-1:Regional model domain (left panel) with boxes showing the ELA study region. Yearly annual mean precipitation trend over HKH region (right panel), using GPCC gridded monthly data (0.5x0.5 deg).

In the present study, the regional climate model REMO (Jacob 2001) extended by a recently developed glacier parameterization scheme (Kotlarski et al. 2010) has been applied over the HKH mountain range. The glacier scheme interactively simulates the mass balance as well as changes of the areal extent of glaciers on a sub-grid scale.

A simulation for the period 1989-2008 using the ERA-Interim reanalysis as atmospheric boundary forcing was carried out. A regional glacier inventory, has been compiled and is used to initialize glacier area and volume in the year 1989. The results are presented for the period 1989-2008.

Results

Glacier Area and Volume



Preliminary results show a simulated decrease of glacier area (1989-2008) of ~20% with respect to 1989, Fig-2. In contrast total ice volume is showing an overall increase.

Fig-2: Upper panel, evolution of yearly mean total glacierized grid area (km²) simulated by the model. Lower panel, same as above for glacier volume (m w.e.)

Spatial change patterns (Fig-3) show a strong decrease of both glacier area and volume. Areas with local increases in glacier area and volume are found in the north-western part of the model domain, in the Karakoram ranges and in some parts of the Kashmir Great Himalayan ranges. This feature is in good agreement with reported observations, (Bolch et al., 2012).

Heavily glaciated grid cells experience a strong snow accumulation, which is subsequently turned into glacier ice and thereby increases the total ice depth (Fig-3) and hence volume. It may be an artifact of the model as it does not allow interaction between the grid boxes and hence neglects the large scale ice flow to lower ablation areas.

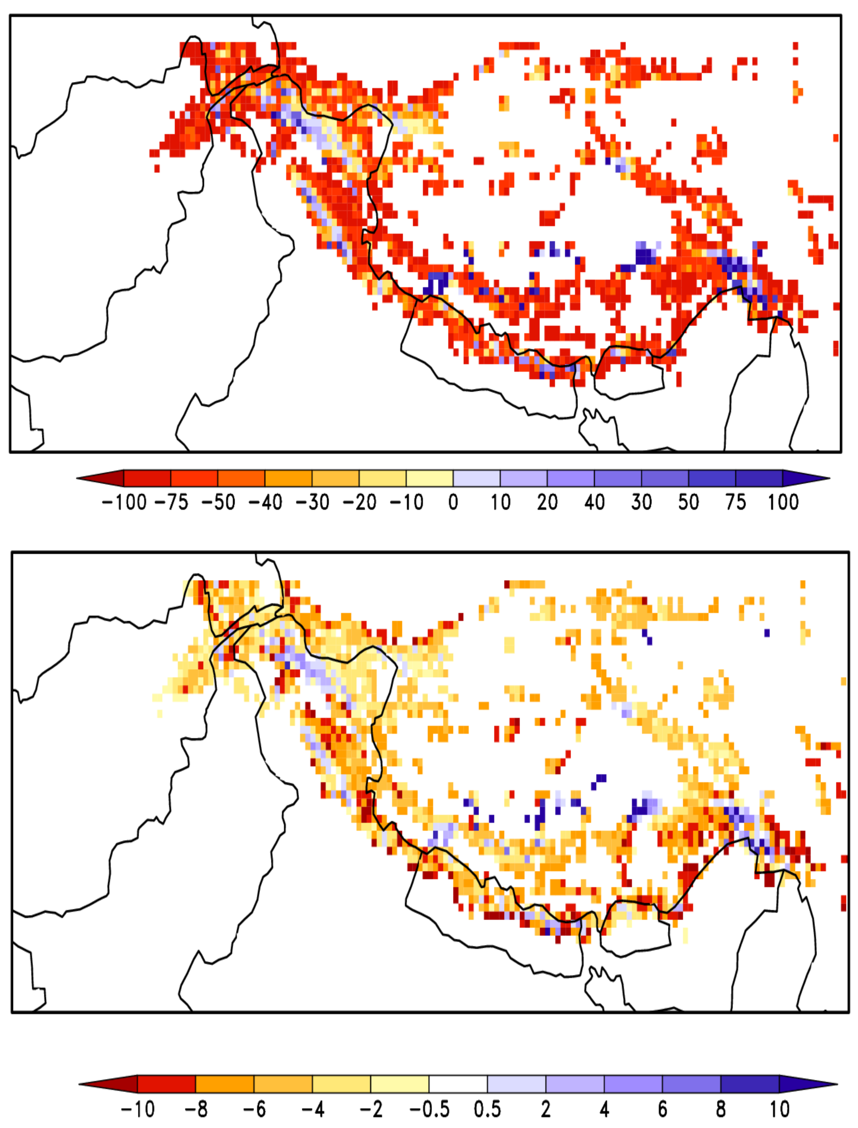


Figure-3: Change in the mean glacierized grid box area (1989-2008) with respect to 1989 in %. Lower panel same as above for ice depth (m).

ACKNOWLEDGEMENTS
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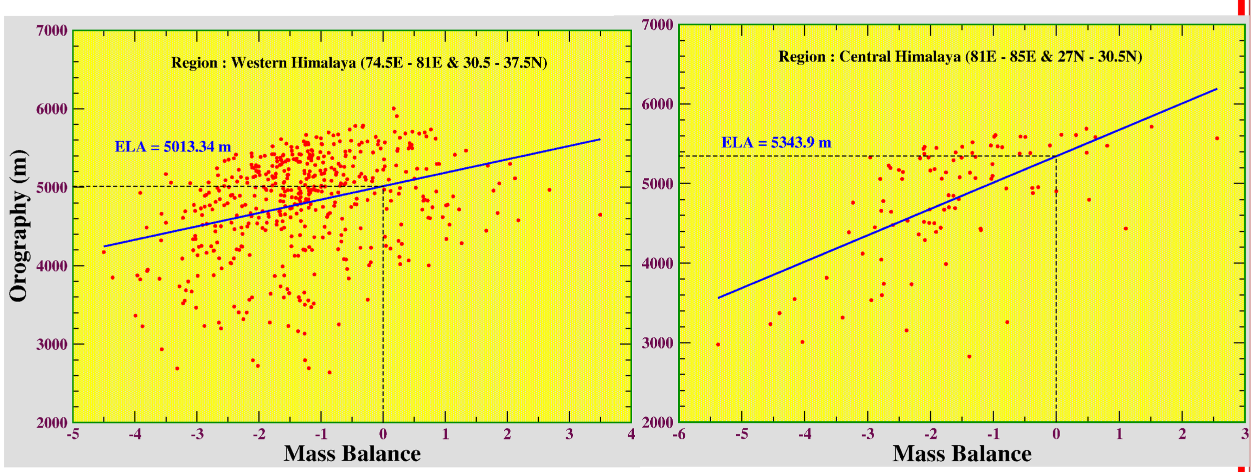
Equilibrium Line Altitude

- The equilibrium line marks the region where glacier mass balance is zero. It divides accumulation (net snow and ice gain) and ablation (net snow and ice loss) areas either for a particular year or for a longer period. It's altitude is referred to as the *Equilibrium Line Altitude* (ELA).
- For the present study ELA is calculated for the HKH region dividing the region into three zone (Fig-1) namely western Himalaya (WH), central Himalaya (CH) and eastern Himalaya (EH). The result of model simulated ELAs (referring to the mean glacier mass balance over the period 1989-2008) are presented in Fig-4.



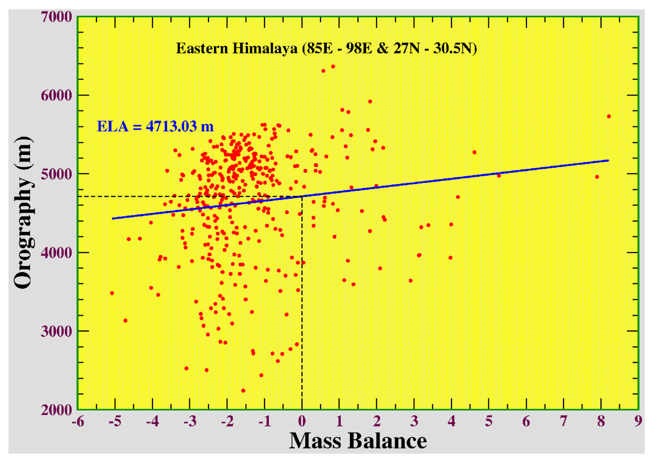


Fig-4: Scatter plot showing the mean annual mass balance (m w.e.) with respect to grid cell orography, for the period 1989-2008. The point where mass balance is zero on the regression line estimates the ELA of the selected domain.

Summary of Results

- ✓For the first time a complete simulation of glacier climate interaction over South Asia is done.
- ✓Glacier area in the whole HKH region including Tibet is reported to be ~100,000 km² (Yao et al. 2012). The glacier inventory prepared for forcing the RCM, estimates an area of ~98,504 km² Fig-2, upper panel.
- ✓The total mean glacierized area loss simulated by the model for the period 1989-2008 is ~20% with respect to 1989, Fig-2.
- ✓The spatial patterns of glacier area change show a remarkable decrease, but do show some regions of increase especially over the Karakoram (western Himalaya) region which is also reported to have a positive mass balance anomaly (Bolch et al., 2012).
- ✓The positive relation between altitude and mass balance is qualitatively reproduced by the model, Fig-4.
- ✓The model is able to approximately represent the equilibrium line altitude for selected sub-region when compared to observed values. Over HKH region the observation-based ELA estimates range from 4400 m to 5700 m (Bolch et al., 2012, Yao et al., 2012). Model simulated ELA for western, central and eastern Himalaya are 5013 m, 5344 m, and 4713 m respectively. The model estimated values are closer to reported observation but simulated ELA's seem to have a systematic negative bias which, in turn, suggests an overestimation of the mean regional mass balance, Fig-2.
- ✓Results indicate that observed glacier changes can be approximately reproduced within a regional climate model based on simplified concepts of glacier-climate interaction.
- ✓This, in turn, underlines the general applicability of the model system for scenarios of 21st century climate and glacier change.

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