Glacier Elevation Change Study by Means of TanDEM-X

Pandey P., Venkataraman G., and Bhattacharya A.
Indian Institute of Technology Bombay,
India

Objectives

- To determine the surface elevation change between 2000 and 2011, of a benchmark glacier of Indian Himalaya, involving TanDEM-X of September 2011 and subtracting it from SRTM DEM of 2000

- Evaluation of usage of TanDEM-X DEM for further computation of glacier volume loss and mass loss

Background

Glacier

- A glacier is a solid body of ice formed when snowfall exceeds snowmelt year after year.
- Over many years layers of snow compressed into a plastic ice mass, forming glacier.

Mass balance

Mass balance is the difference between the amount of snow and ice accumulation on the glacier and the amount of snow and ice ablation (melting and sublimation) lost from the glacier.

Glaciers gain mass by accumulation of snow during winter

Glaciers lose mass by ablation of snow (melting) during summer

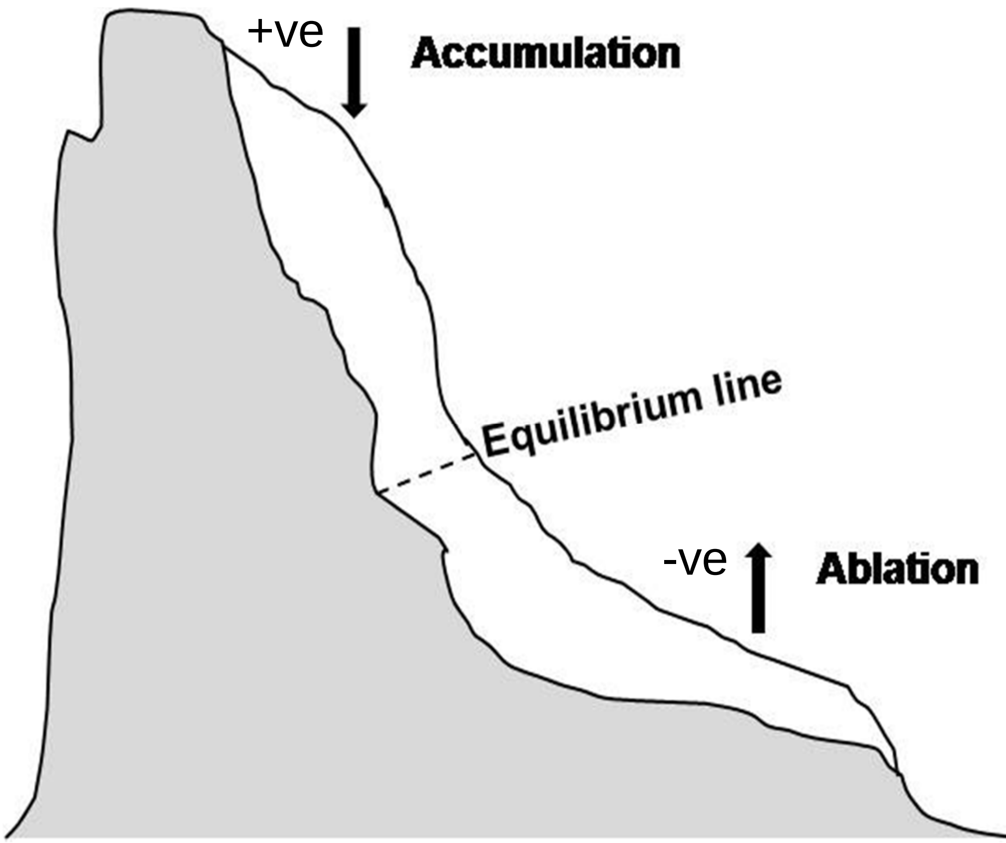
A glacier's budget refers to how much a glacier has gained or lost in a year. If, on the glacier, snow accumulation and ablation---loss---are about equal, the budget is balanced.

If there has been a net accumulation, the budget is positive.

If there has been more ablation than accumulation, the budget is negative.

If there has been more ablation than accumulation over time, the glacier's boundary recedes and the glacier's size decreases.

Accumulation processes: snowfall, freezing of rain
Ablation processes : melting, evaporation
Equilibrium line : the line divides accumulation zone from ablation zone



Background.. Glacier study and Climate change

- A glacier is an indicator of climate change
- Any change in the climate is reflected in glacier's behavior
- Glaciers respond directly to climatic parameters such as temperature and precipitation
- Mass balance of a glacier is the direct and undelayed response of climate change
- Climate change causes variation in temperature and snowfall which in turn causes changes in the mass balance of glacier
- Under an unfavorable climatic condition of decreasing solid precipitation and rising temperature, glaciers receive less snowfall and also melt faster, causing lowering of glaciers' surface elevation and consequently mass loss

Background.. Present study

- Recent observations report significant rise in temperature of Western Himalaya and a decreasing trend of seasonal snowfall (Shekhar *et al.* 2010)

- Change in the glacier surface elevation is directly linked to the climate change

- Under a scenario of rising temperature and decreasing snowfall in the Northwest Himalaya, the status of the glacier surface elevation change in the past 11 years was computed by subtracting TanDEM-X DEM of 2011 from SRTM DEM of 2000

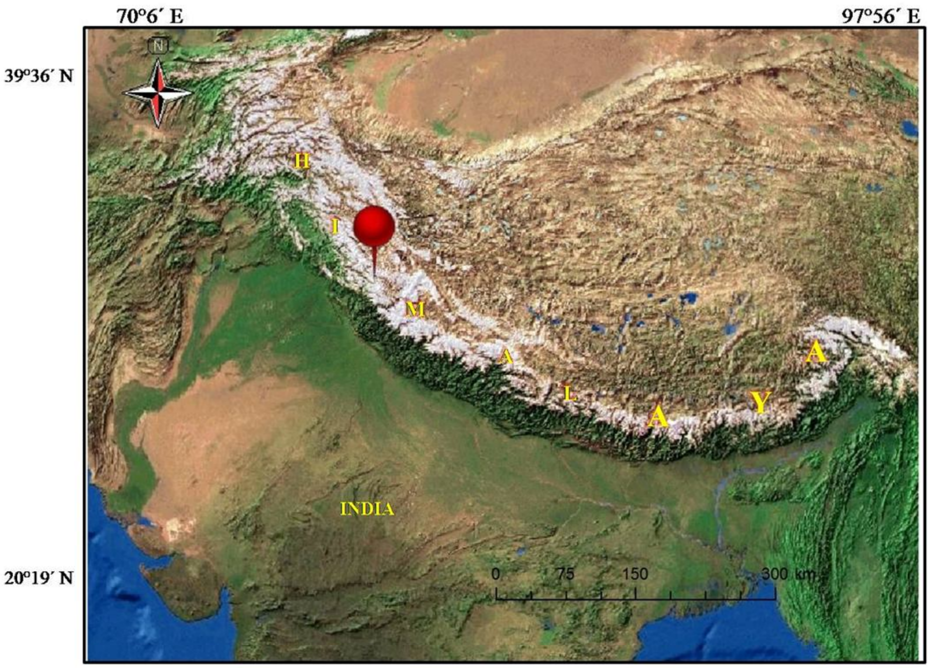
- Since Himalayan glaciers are located at higher altitudes, under extreme weather conditions, conventional methods of monitoring are though recommended but very difficult to carry out. However, comparisons of digital terrain models (DEMs) for different years can replace field measurements, and allow regional elevation change, volume change and mass balance to be estimated

- The major objective of the present study is to compare and evaluate SRTM and TanDEM-X DEMs for the elevation change study of Himalayan glaciers which further can be used for the computation of volume change and geodetic mass balance of the glaciers

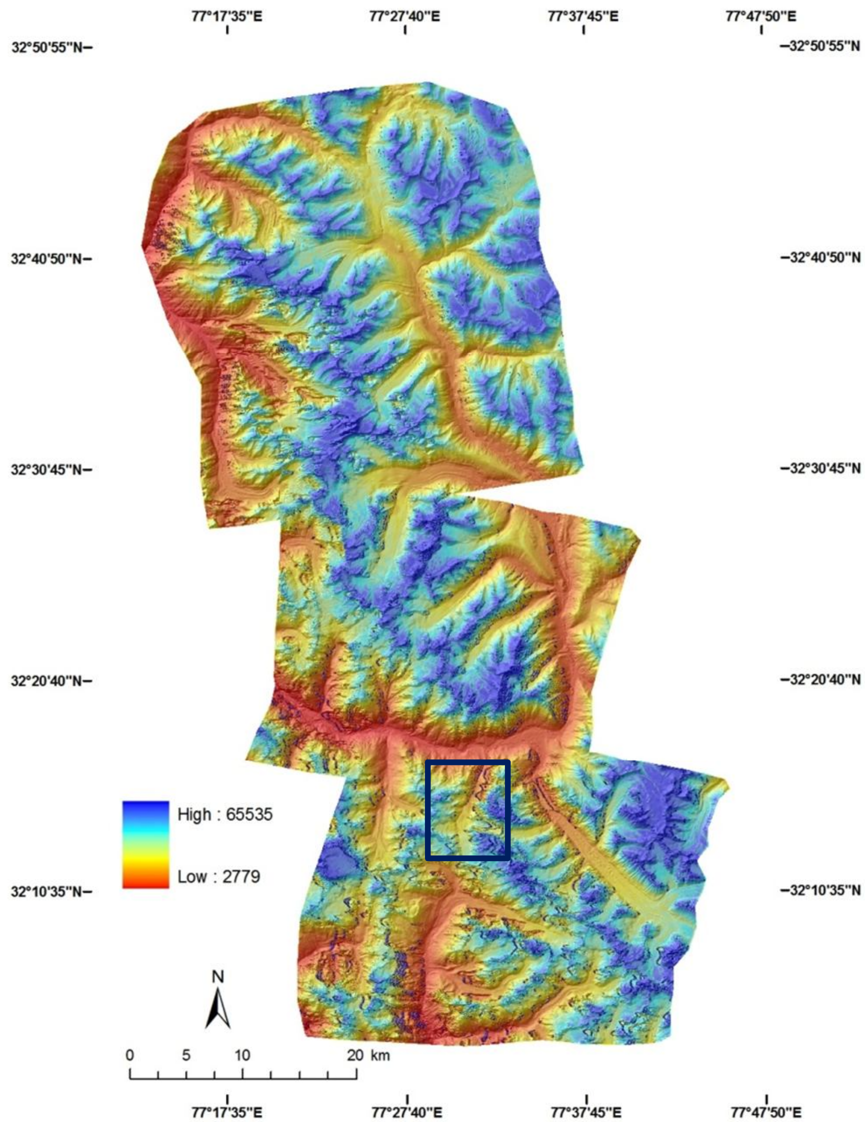
TanDEM-X DEM generation

- For generation of DEM from co- registered TanDEM-X pairs, the standard InSAR technique was used using evaluation module of SARscape software.
- The generation of DEM consisted of the steps of interferogram generation, phase unwrapping, phase to height conversion and geocoding.
- The SRTM DEM was used as height reference. The Goldstein method is used for filtering.
- The filtered interferogram was unwrapped using Minimum Cost Flow (MCF) method.
- The DEM was generated with a 10x10 m horizontal grid.
- The interpolation window size was chosen relatively small (5x5) to keep the information real as much as possible.

Study area



70°6′ E
97°56′ E
39°36′ N
20°19′ N
H
I
M
A
L
A
Y
A
INDIA
0 75 150 300 km



77°17'35"E
77°27'40"E
77°37'45"E
77°47'50"E
32°50'55"N
32°40'50"N
32°30'45"N
32°20'40"N
32°10'35"N
High : 65535
Low : 2779
N
0 5 10 20 km

Prior to comparison...

Before evaluating the surface elevation change of Chhota Shigri glacier, Indian Himalaya using TanDEM-X DEM, by subtracting from SRTM DEM, following steps were carried out:

i) Both the DEMs were resampled to 30 m by bilinear resampling method

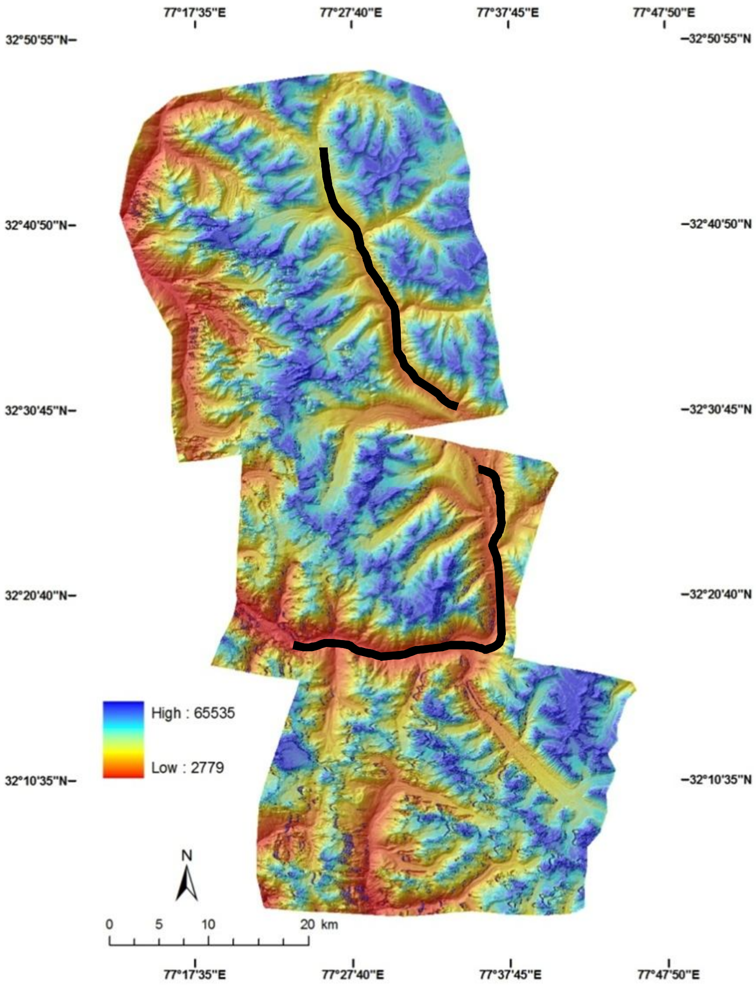
ii) Both the DEMs were corrected for horizontal shifts for planimetric adjustment by reducing the RMSE of co- registration

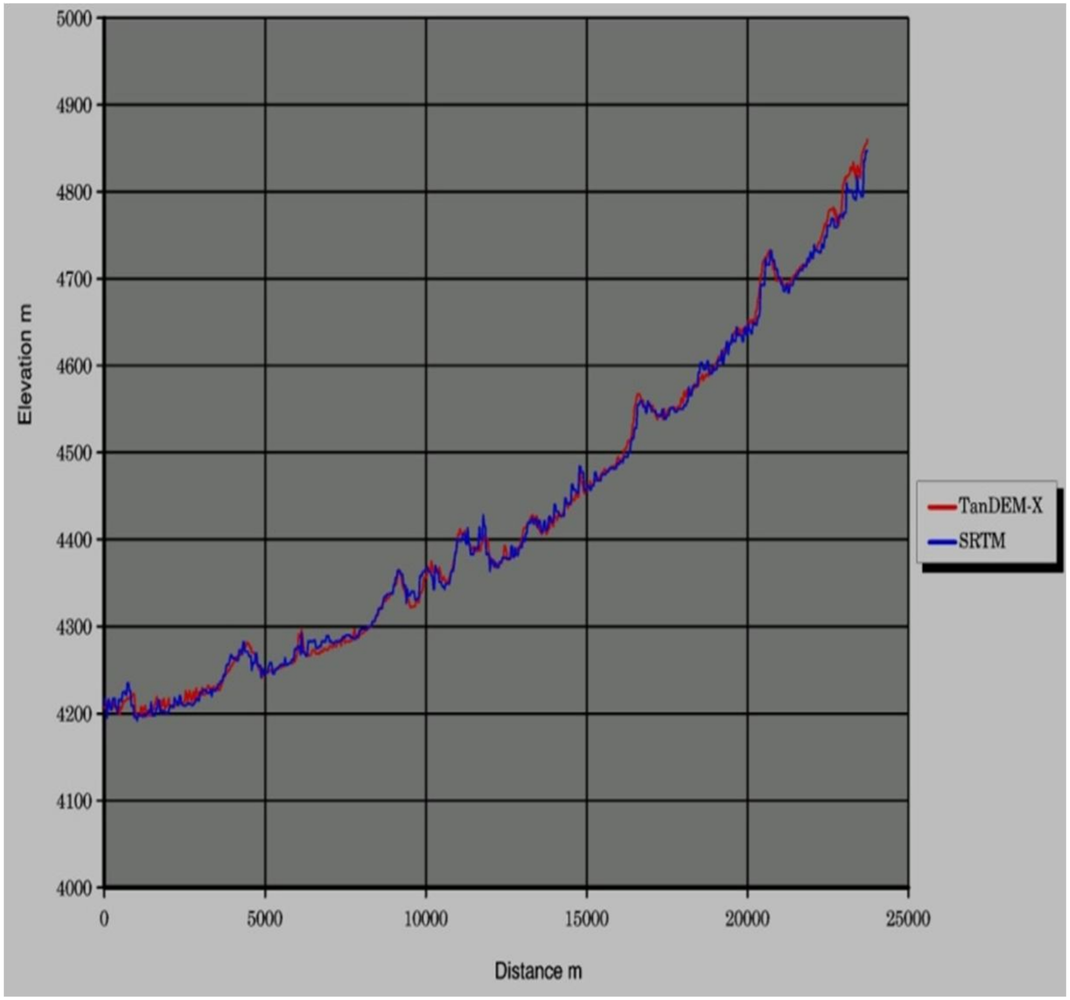
iii) The vertical biases were identified at the non-glaciated, stable areas of the study region which are not expected to change in 11 years of period

iv) The vertical biases in the two DEMs were identified at each altitude range and were corrected from the surface elevation change on the glacier surface

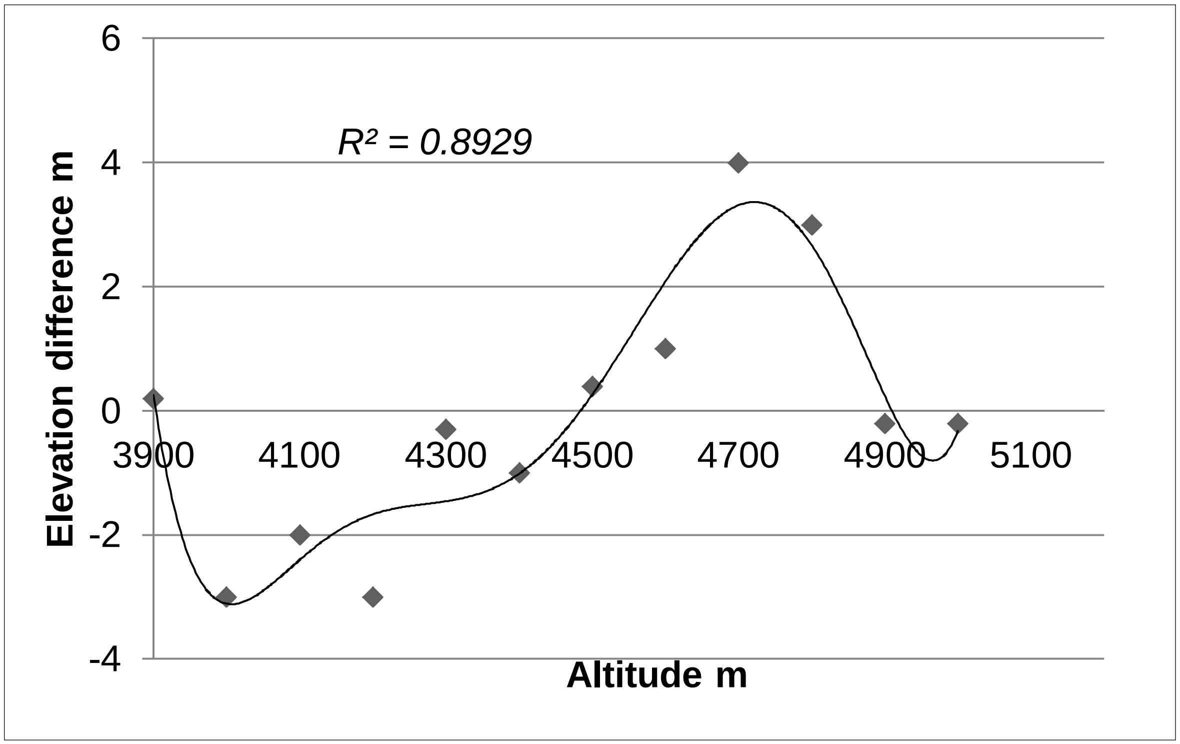
v) Any elevation change observed at the non-glaciated region at a particular altitude was the measure of vertical bias between the two DEMs at that altitude

Non Glaciated portions comparisons





At each altitude range, on the non-glaciated-stable portions, elevations from TanDEM-X DEM and SRTM DEM closely following each other



Elevation difference between TanDEM-X DEM and SRTM DEM at each altitude range of stable area

Uncertainty in elevation change

The uncertainties in elevation differences on glacier region are estimated by formula used by Bolch *et al.* (2011). The uncertainty is the standard error of the mean (SE) defined as

$$SE = \frac{STDnoglac}{\sqrt{n}}$$

where n is the number of the included pixels

The standard error (SE) and the mean elevation difference (MED) have been taken as the estimation of uncertainty according to the law of error propagation (Bolch *et al.* 2011)

$$e = \sqrt{SE^2 + MED^2}$$

The uncertainty of the elevation change measurement was found to be ±1.5 m. The error calculated using equation has been considered as the uncertainty of thickness change measurements

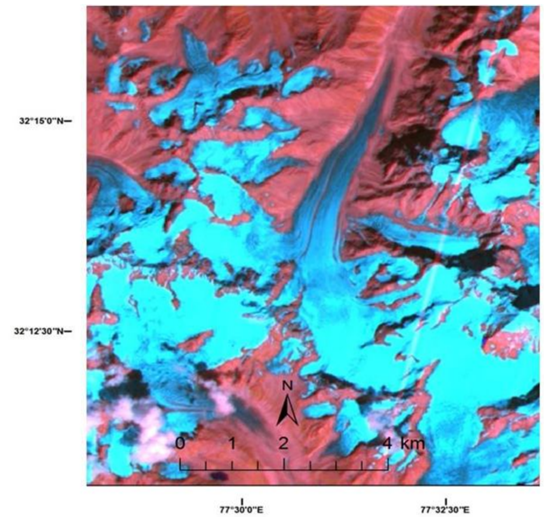
Assumptions

- The C-Band radar signal from SRTM has capability to penetrate into the snow/ice. Previous studies have also reported that the penetration depth of C-band can reach 4 m in the accumulation areas of Alaskan maritime glaciers. However no study has yet reported the amount of penetration depth of C-band of SRTM for Himalayan glaciers. In the absence of information the penetration properties of SRTM DEM was not taken into account in this study.

Elevation change of Chhota Shigri glacier, Indian Himalaya

- A hypsometric approach was used to determine the elevation change of the glacier in 11 years period.
- In hypsometric approach, the glacier was divided into 100 m elevation bin.
- Average elevation changes within elevation bins were calculated and it was assumed that these average changes were representative for the entire bin area within the corresponding elevation bins.
- On an average more than 2000 points were taken to calculate the average of elevation change and even more points, depending on the elevation bin area.
- The average elevation change for each elevation bins was then considered as the total elevation change for entire glacier.

In hypsometric approach at each 100 m altitude band elevation change were calculated



Results from Chhota Shigri glacier

- The glacier is a benchmark glacier in the Northwestern Himalaya
- This glacier is approximately of 15 km^2 in area
- It has been monitored since 2002
- The field data reports moderate mass loss of glacier between 2002 and 2010 (Azam et al. 2012)

In this study

- The surface elevation change of the glacier in the past 11 years of observation is computed at each 100 m elevation band between 4200 m and 5600m

Results..

- It is observed that the glacier has thinned by 5.67±2.69 m in the past 11 years

- The rate of surface elevation change is -0.52 m year^{-1} between the years 2000 and 2011

- The maximum lowering of glacier has occurred at the middle part of the glacier

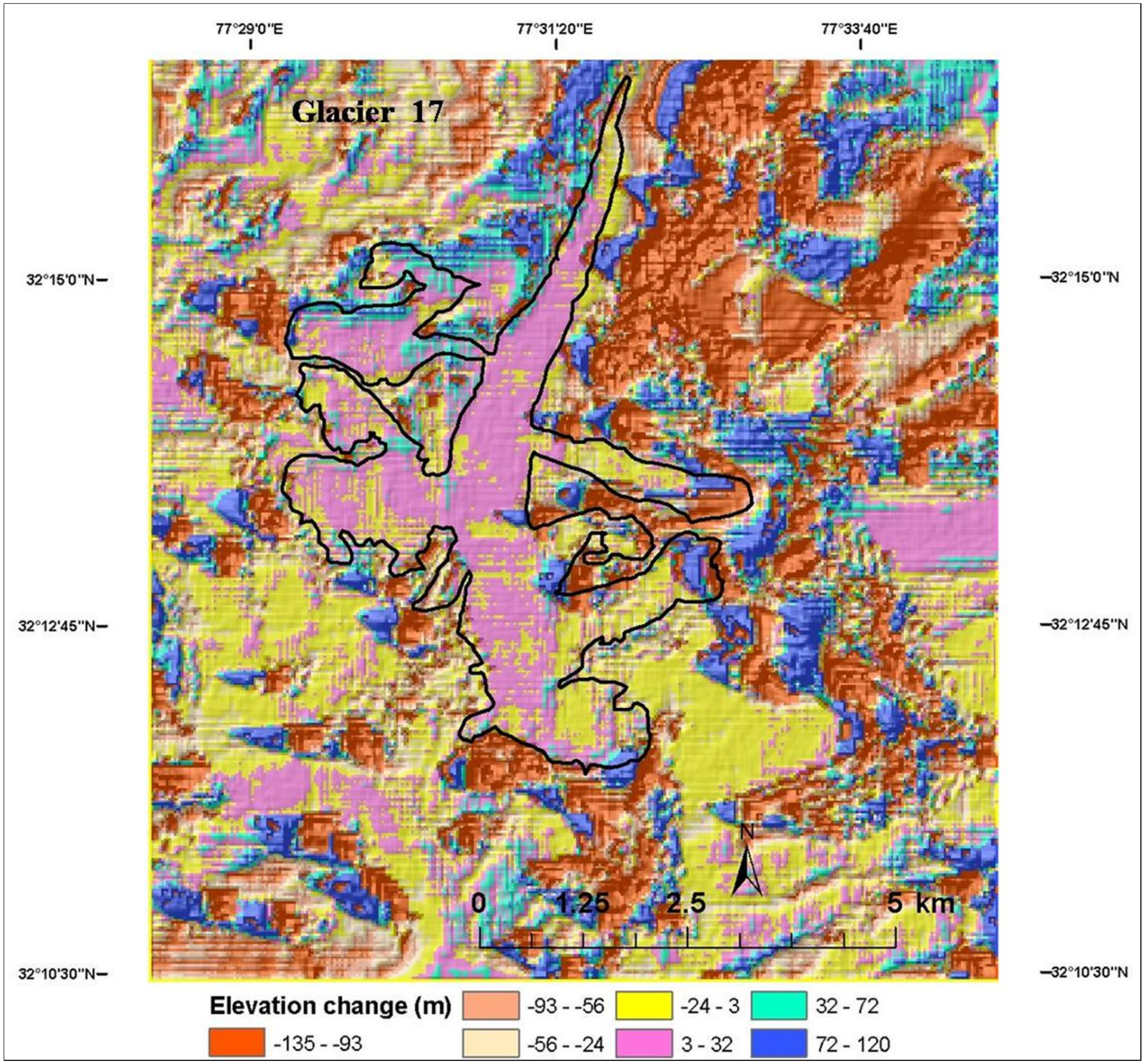
- The terminus region of the glacier has lowered only slightly

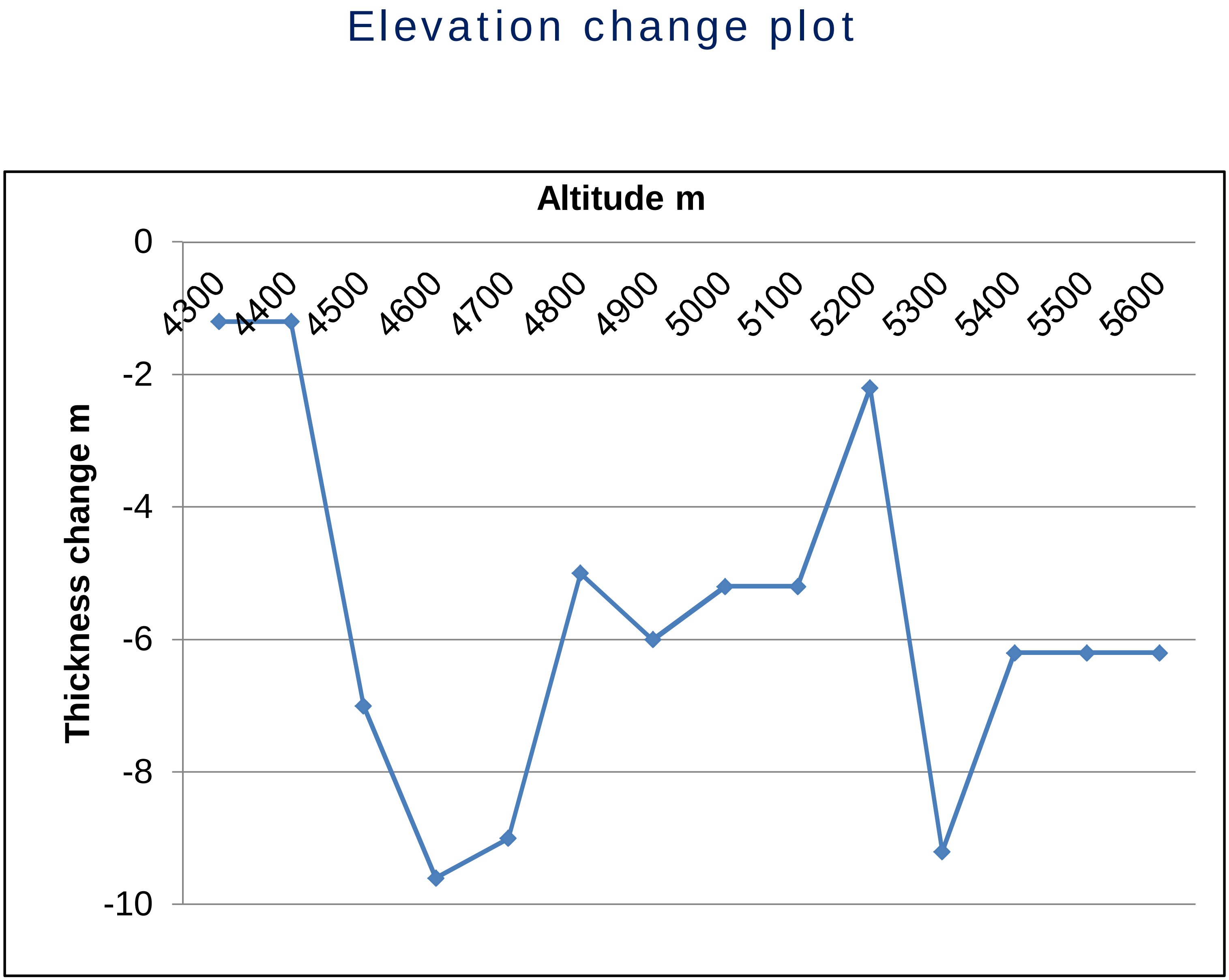
- The lowering was also experienced at the higher elevations of accumulation zone

Elevation change at each altitude range

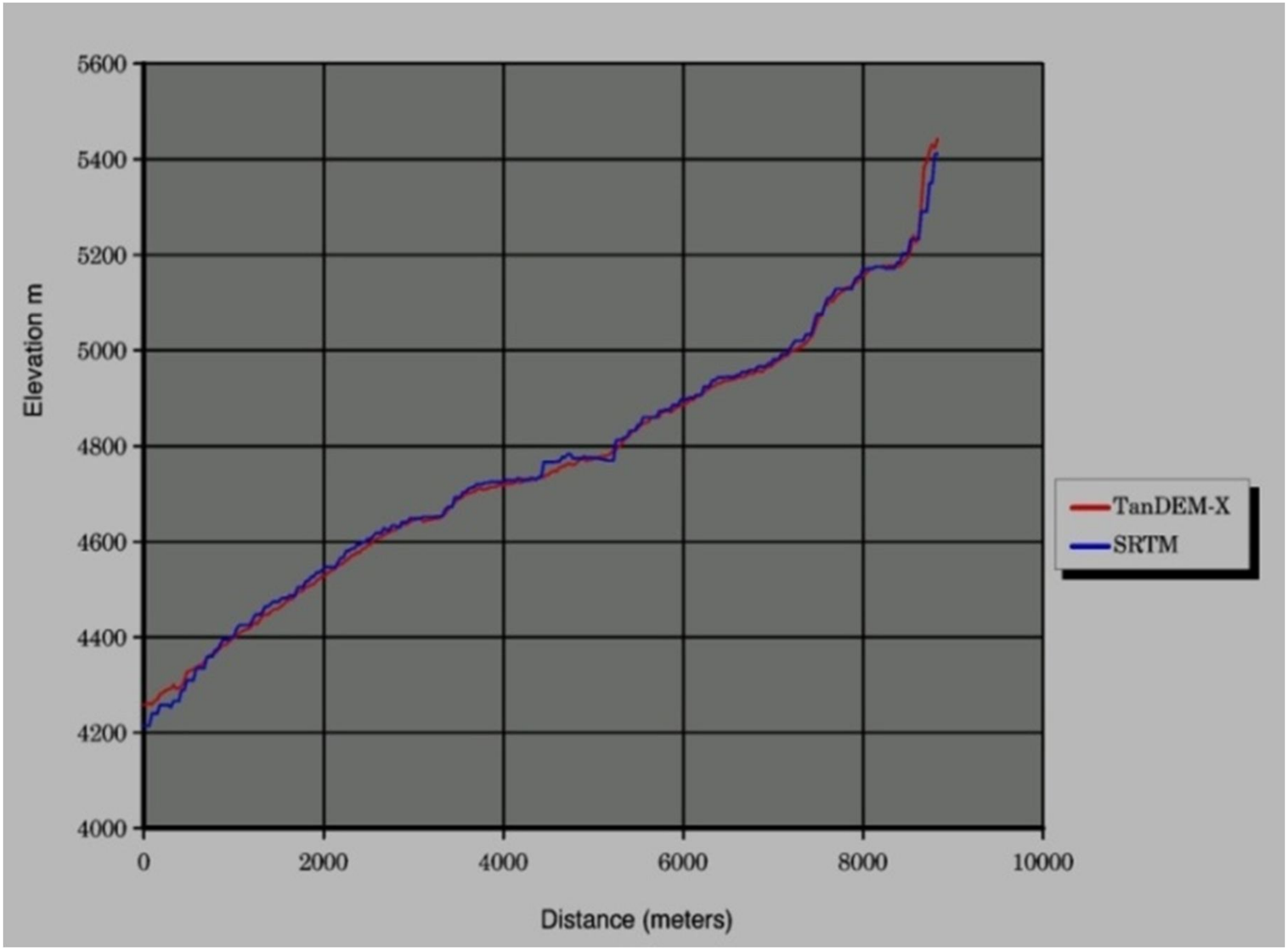
Altitude range m	Elevation change m
4200-4300	-1.2
4300-4400	-1.2
4400-4500	-7
4500-4600	-9.6
4600-4700	-9
4700-4800	-5
4800-4900	-6
4900-5000	-5.2
5000-5100	-5.2
5100-5200	-2.2
5200-5300	-9.2
5300-5400	-6.2
5400-5500	-6.2
5500-5600	-6.2

Elevation change map of the glacier

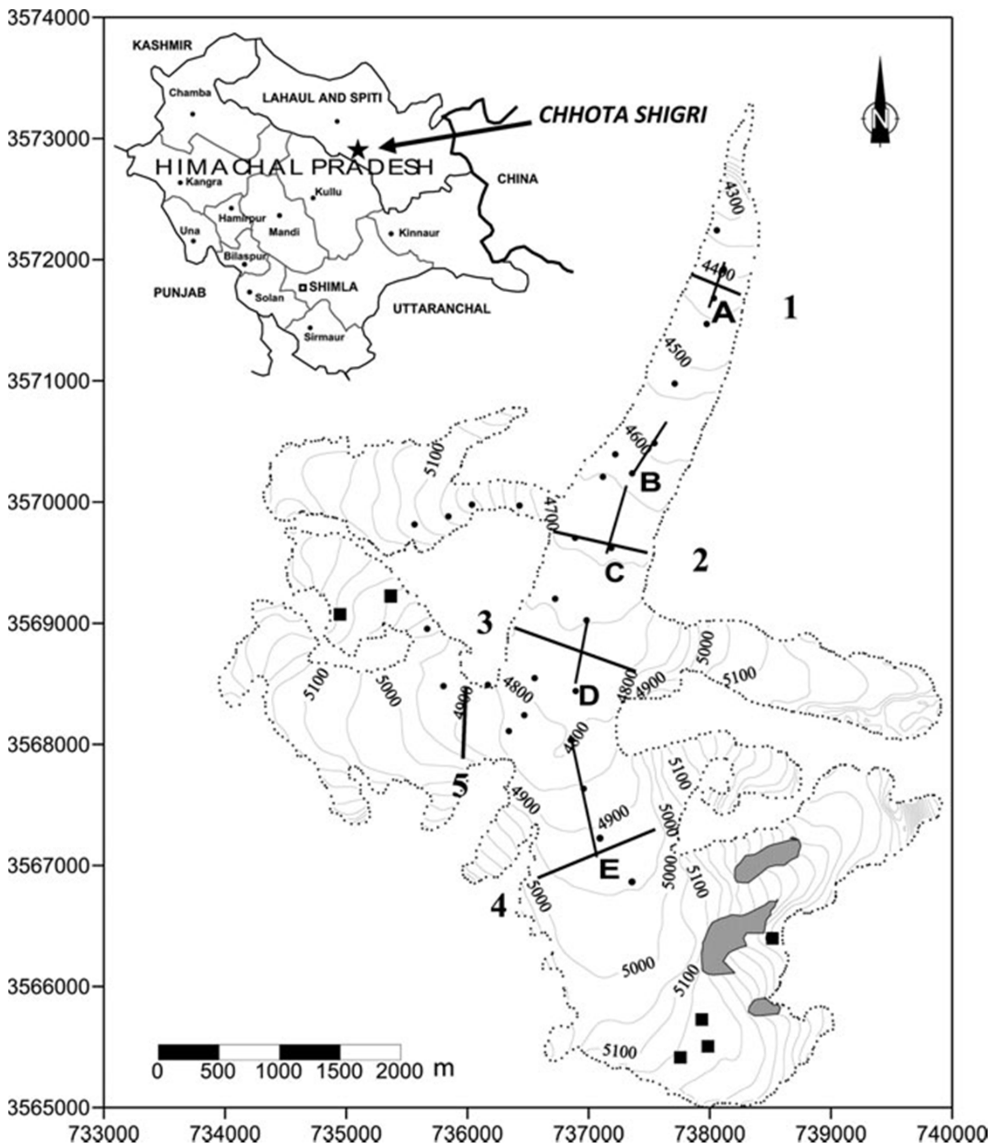



Elevation change plot
Altitude m
Thickness change m
0
-2
-4
-6
-8
-10
4300
4400
4500
4600
4700
4800
4900
5000
5100
5200
5300
5400
5500
5600

Elevation profile on the tongue of the glacier



Comparison from the published field data



Section	Elevation change (2003-2010) (m)
A	-5.3
B	-8.6
C	-7.5
D	-2.8
E	-5.6

Elevation change map at different altitude band between 2003 and 2010 (from Azam et al. 2012)

Comparison

Section	Elevation change from field (2003-2010)	From this study (2000-2011)
A	-5.3	-7
B	-8.6	-9.6
C	-7.5	-9
D	-2.8	-5
E	-5.6	-6

The field observation shows that the glacier is thinning with a rate of about -0.85 m year^{-1} between 2003 and 2010, the present study finds a rate of -0.67 m year^{-1} of surface thickness loss between 2000 and 2011 between the particular altitude range. The results of elevation change are comparable.

Conclusions

- The TanDEM-X DEMs are useful for carrying out elevation change study of Himalayan glaciers

- The elevation change can be used to study the volume loss and mass balance (geodetic method) of glaciers without going to the field

- A large number of glaciers can be monitored and studied

- The quantification of glacier mass balance directly relates change in climate in terms of temperature and precipitation

Future objectives

- Comparing TanDEM-X DEM with the X-band SRTM DEM for more accurate elevation change study

- Study of glacier velocity (also of surging glaciers)


Thank you for your attention !!