# Changing ice sheets of the northern Indian Himalaya during last decades using LANDSAT (optical satellite image) and GRACE-Tellus (Monthly Mass Grid-Land) data

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## Objectives

Ice sheets and glaciers are sensitive to climate and act as reliable indicators to climate change. The objectives of this study are

- To calculate the **change in area of ice mass** in the study area
- Analyse the **spatial-temporal variability of the change in ice mass** measured as equivalent water thickness.

## Study Area

The area of study is the **western part of the Himalayan range** situated in the Northern part of India in the states of Jammu & Kashmir, Himachal Pradesh and Uttarakhand and Pakistan Administered Kashmir (Fig. 1a).

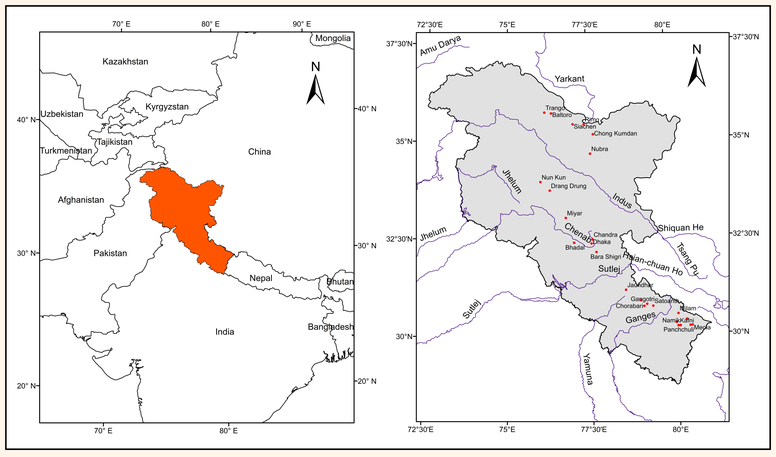


Fig. 1: (a) Location of the study area (left), (b) River network and glaciers in the study area (right)

The study area contains a **large number of glaciers** and is criss-crossed by a **complex network of rivers** (Fig. 1b) which are **of primary importance** in India and Pakistan for **irrigation, agriculture, industries and their associated livelihoods**.

## Data

Data from **Landsat TM and OLI** missions were used for calculating the change in area of the glaciers. Monthly gravimetry data from **G**ravity **R**ecovery **A**nd **C**limate **E**xperiment (**GRACE**) mass grids for land as well as Mass Concentration blocks (*mascons*) were used to determine the rate of ice mass change.

## Methods

LANDSAT series **images from 2000 and 2016 were classified** using unsupervised classification **to find regions under ice sheets** (Fig. 2)

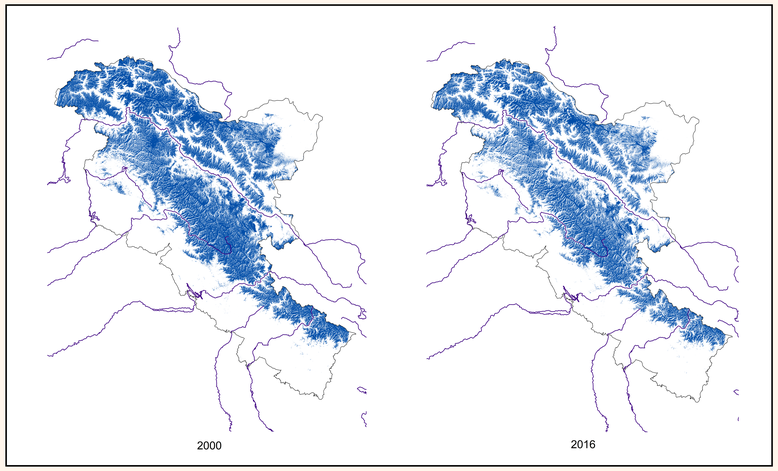


Fig. 2: Area under ice sheets in the month of February in (a) 2000 (left) and (b) 2016 (right). Important rivers including the Ganges and the Indus passes through the troughs in the ice sheets

- **GRACE's mass grids for Land** were used. The available data in [1] is already corrected for atmospheric mass changes, 1st and 2nd degree spherical harmonics, Glacial Isostatic Adjustment (GIA), de-striping, smoothing etc.
- However, according to [2] using the Land data could result in contamination of signal and bleeding from surrounding water bodies in the vicinity. Therefore the ***mascon* data** was also used which **provides an alternative approach** by putting constrains to reflect the local properties of the study area without using spherical harmonics (as in the Land data).
- In order to correct the signal which was attenuated during the data correction, the **data was re-scaled** for each grid using the available scaling factors for both the Land grid and the *mascons*.
- Finally, **the corrected data was temporally aggregated for each year** and analysed for long-term variations in the **anomaly of equivalent water thickness with respect to a time-averaged baseline** (from January, 2004 to December, 2009) which could be **interpreted as a proxy to the change in mass of the ice sheets**.

## Results

The **area under ice cover** was calculated to have **decreased** from 115283.97km$^2$ **by 3537.54km$^2$** indicating a **loss of over 3%** between 2000 and 2016 in the study area.

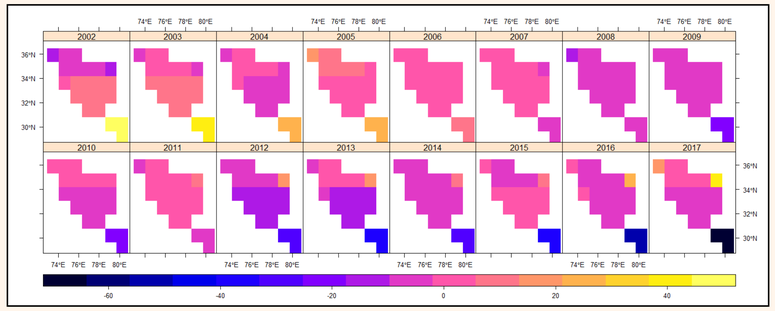


Fig. 3: Temporally aggregated anomaly (with respect to long-term mean) in equivalent water thickness (in cm) from 2002 to 2017 as derived from monthly data from GRACE

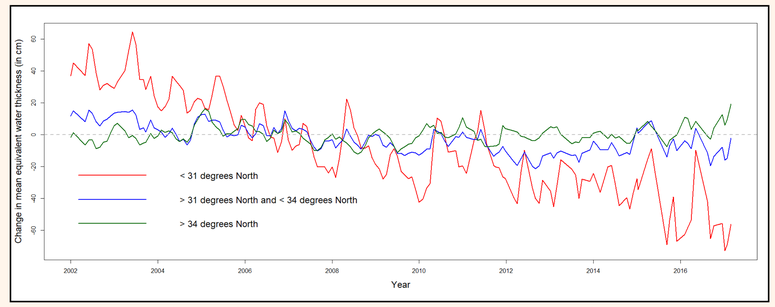


Fig. 4: Change in mean equivalent water thickness from 2002 to 2017 at different latitudes

From Figs. 3 & 4 it is evident that **ice sheets located at latitudes less than 31°N are being lost rapidly** while ice sheets lying between 31°N and 34°N show a moderate rate of loss. **Ice sheets above 34°N show a slight increasing trend** in its mass.

## Conclusion

**Rivers passing through the lower latitudes** where ice mass is being lost at an alarming rate highly influence **agriculture and irrigation**. This could have **negative climatic and economic repercussions for the Indian subcontinent in the near future**.

**References**

1. GRACE Land and other associated data are available at http://grace.jpl.nasa.gov, supported by the NASA MEaSUREs Program.
2. Jacob T., J. Wahr, W.T. Pfeffer, and S. Swenson, Recent contributions of glaciers and ice caps to sea level rise. Nature 2012, doi:10.1038/nature10847, 2012.