The Retreat of the Terminus of Gangotri Glacier in Google Earth Images

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Abstract: Here we use a time series of satellite images in Google Earth for measuring the retreat of the terminus of Gangotri Glacier, one of the largest glaciers of Himalayas. From 2010 to 2016, the terminus moved of about 150 meters. **Keywords**: Satellite Images, Google Earth, Glaciers.

The terminus of the Gangotri Glacier, one of the largest glaciers of Himalayas is known as the Gomukh, the "Mouth of the Cow", due to the presence of an ice cave (Figure 1). The place is situated at a height of about 4,000 meters, in Uttarkashi district of the state of Uttarakhand, India. From the Gomukh, the Bhagirathi River originates, which is one of the main sources of the Ganges River. For this reason, the Gomukh is also worshipped by many religious people. It is therefore a pilgrimage site, along with Gangotri, as well as a trekking destination [1,2].

Figure 1: The Gomukh of Gangotri Glacier (Courtesy, Barry Silver, Wikipedia)

As told in [3], on July 26, 2016, following heavy rains in Uttarakhand, it was reported that the front end of Gomukh "was no more, as a large chunk of the glacier had collapsed and was washed away". Actually, any glacier terminus moves due to the environmental conditions and therefore the shape of it is continuously changing.
The Gomukh had been studied in several researches. In [4], it is told that the Gangotri glacier is a significant body of ice whose loss could cause ecological problems and "also threaten the continuity of cultural-religious practices intertwined with the sacred Ganga River" [5]. The discussion on the evolution of the glacier in [4] is presented on scientific bases, "along with ethnographically documented perspectives on retreating glaciers and other ecological transformations". However, in [6], which is a work presenting a remarkable analysis of historical data, it was concluded that the retreat of the Gomukh is of 15 to 18 meters a year, and then "definitely not alarming. Some of the glaciers in Columbia and even in Alaska have recently shown an annual retreat of more than 200 metres". "If we assume that this glacier

(Gangotri) will continue to retreat, say at the rate of 15 to 18 metres a year, as it is doing at present, even then it will take almost 2,000 to 1,600 years for the glacier" to disappear [6].
The data given in [6] are in agreement to those in [7]. In this reference, the researchers report the frontal area changes at the terminus of Gangotri Glacier, after a work based on high-resolution satellite data from 1965 to 2006. The results show that the glacier exhibited retreat up to 819 ± 14 m (it means about 20 metres a year) and lost 0.41 ± 0.03 sq. km at its front from 1965 to 2006. The results from satellite images were supported by in-situ field survey conducted by the Geological Survey of India. Other measures of the retreat are 15, 19 and 40 meters a year, given in References [8], [9] and [10] respectively.
In [11], stereo images from Indian Remote Sensing satellite (IRS)-1C covering Gangotri glacier were used to identify its terminus and measure its retreat with respect to the position in a topographical map of 1962. As concluded in [11], "the precise location of the snout", that is, the terminus, “as identified on the images based on its shadow and relief variation in stereo images can serve as a standard reference for future monitoring of its movement or finding rate of retreat annually". In fact, we can also use the Google Earth imagery to study the retreat of the Gangotri glacier. Actually, we have a time series of high resolution images of the Gomukh. In the Figure 2, we see two of them.

Figure 2: The terminus of Gangotri in two images of Google Earth.

The lower panel of the Figure 2 needs some processing to see the terminus. We can use the Retinex filter of GIMP, the GNU Image Manipulation Program, to see the details in the shadows of the images (for some examples of the use of GIMP Retinex, see for instance [12-15]).

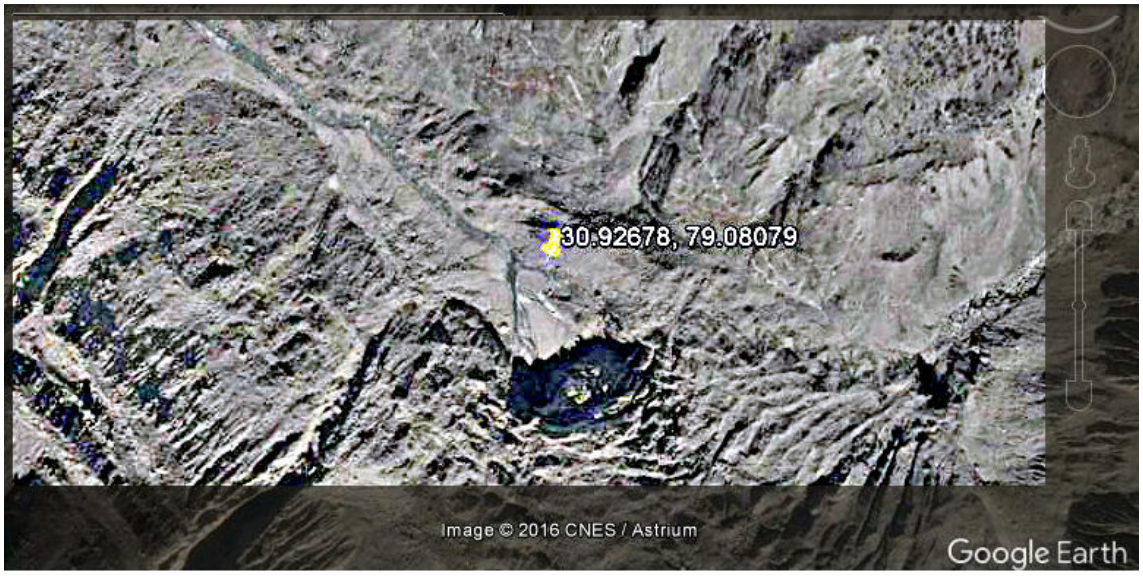

Figure 3: The lower panel of Figure 2 processed by means of the Retinex tool of GIMP.

Figure 4: Superimposing the two panels of the Figure 2, the lower one enhanced by means of the Retinex tool as in the Figure 3, we can see the terminus retreating from the position of 2010 to that of 2016. The two termini are given by the red curves. A point which has the same position in the two images (red circle) is used as reference point. From this point to the pin of the coordinates, there are 318 meters. Using this scale we can evaluate the retreat. It is of 150 ± 20 meters. It corresponds to a rate of 25 meters a year.

After processing the 2016 image, we can use the images of 2010 and 2016 to create a new image superimposing them by means of GIMP. The result is given in the Figure 4. In this image, the two termini are evidences by red curves. To measure the displacement of the terminus, we used a reference point and the ruler of Google Earth. The terminus moved of 150 ± 20 meters in 6 years, corresponding

to 25 meters a year. This measure is close to those given in [7] and [9]. The method that we have used here is the same used for determining the rate of movement of the sand dunes [16-18].

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[5] Actually, in March 2017, the highest court in Uttarakhand declared the Ganges and the Yamuna Rivers as 'living entities having the status of a legal person' and all corresponding rights. This status will help save the rivers from further harm and widespread pollution. http://www.dailymail.co.uk/news/article-4334454/India-grants-Ganges-Yamuna-legal-person-status.html

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