S1. Qualitative analysis of some limitations

This article mentioned that some parameters, such as the threshold of cloud cover, shadow, and the number of selected images per year, are limitations for SCR and SLA calculation. Besides, imprecise glacier outline shapefiles and the Otsu method are other limitations that would influence the subsequent SCR and SLA calculation.

Because of the complex and numerous influence factors, it is difficult to quantify each of them individually. Therefore, we can only analyze the total effect of these factors on the SCR-AAR and SLA-ELA relationship. In future work, individual effects of each factor will be attempted to quantify, and thanks again for your valuable suggestions! Here, we will introduce the qualitative influence process for each factor, and then we will add the content about this question in the discussion part.

1. Cloud cover and shadow pixels would affect and reduce valid pixels for SCR calculation (Figure S1). In the algorithm, the affected area was still calculated, which means the affected pixels will lead to misclassification.

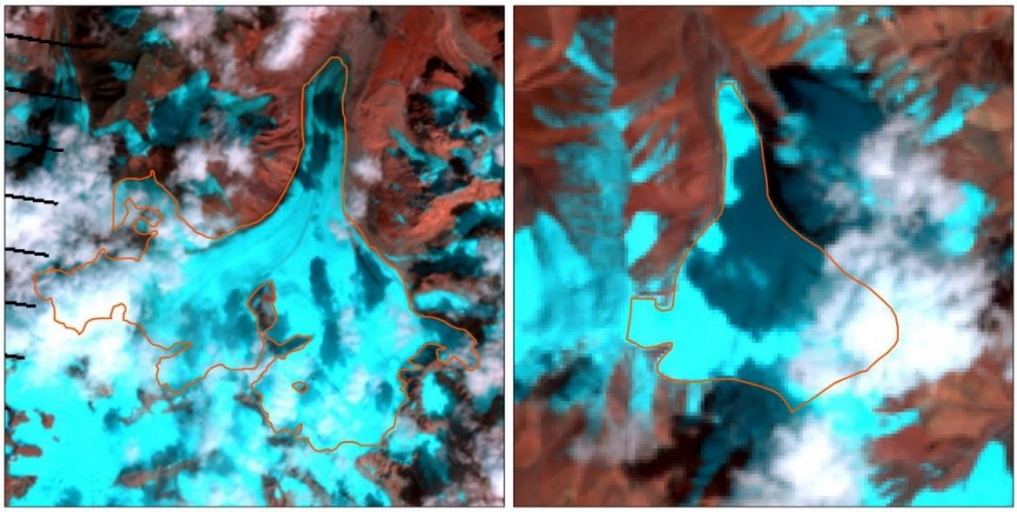

Figure S1. Two images affected by cloud cover and shadows.

The reason why we did not remove the affected pixels but detected them is because the probability of cloud cover existing above the accumulation area (top area of the glacier) is higher than the glacier terminal. If we removed all affected pixels, the SCR calculation result would be lower than reality because much snow area is removed.

Hence, we set the threshold that each image containing valid pixels over 65% can be retained as the used image for further calculation. This threshold is an empirical parameter obtained via several experiments. We tried to set the threshold as 0.5, 0.55, 0.6, 0.65, and 0.7 to testify to the SCR results, and we found that using 0.6 to 0.65 is a suitable parameter for these fourteen glaciers. If the algorithm is used for the number of glaciers for calculation, the parameter should be testified again to find the optimal threshold. This resolution can solve some problems when cloud cover and shadow do not affect the area near the SLA (Figure 12).

2. We set a valid year for SLA calculation when more than three images are selected

for that year. This is another empirical parameter. Theoretically, there are no more than 6 images during the time period per year before 2000 because of 16 days temporal resolution of Landsat-5, and no more than 12 images can be provided during time period per year after 2000. In fact, Landsat can provide 7 to 10 images during time period per year after 2000. After experiments, we found that it is suitable for regarding over 3 used images in that year as a valid year. The reason is that obtaining 3 images can cover at least one month during time period, which can be more precise for calculating SLA.

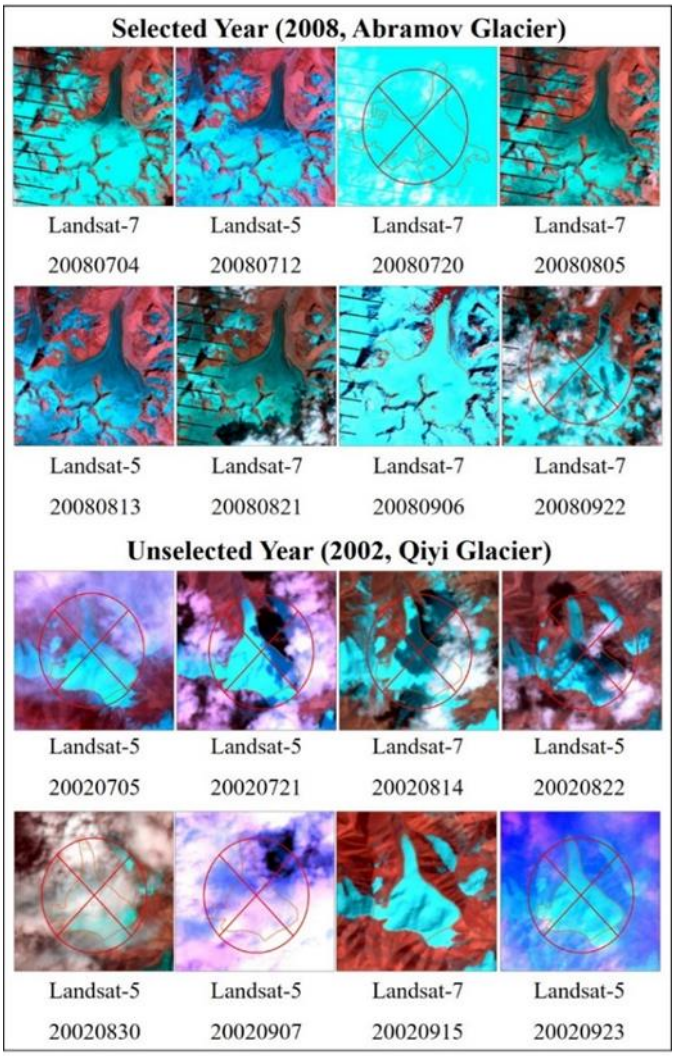

Figure S2. Images of the selected year (valid year) and unselected year. (a) The above image is a series of images located at Abramov glacier in 2008. There are eight images during time period, and six of them are selected as used images which means it is a valid year for Abramov to calculate the SCR and SLA. (b) The bottom image is a series of images of the Qiyi glacier in 2002. Seven of eight images are affected by cloud cover, and shadow, and only one image is clear. Hence, it is an unselected year for the Qiyi glacier.

However, these above limitations are difficult to quantify. The random and unpredictable nature of the satellite data makes us try to filter with the optimal threshold.

This is the limitation and resolution of preprocessing factors. Ideally, images are optimal data for calculating the precise SLA daily, with high spatial resolution and without

being influenced by cloud or other factors. However, existing satellites cannot achieve such data accuracy. To reduce the influence of these factors, we manually set the parameters like 65% of the glacier area and 3 images per year to try to calculate the suitable SLA. This threshold can result in intermittent time series, but it can also select the proper year, which can be satisfied in SLA calculation using Landsat series images.

3. For the limitation of the algorithm, we talked about glacier outline impact and Otsu method limitation.

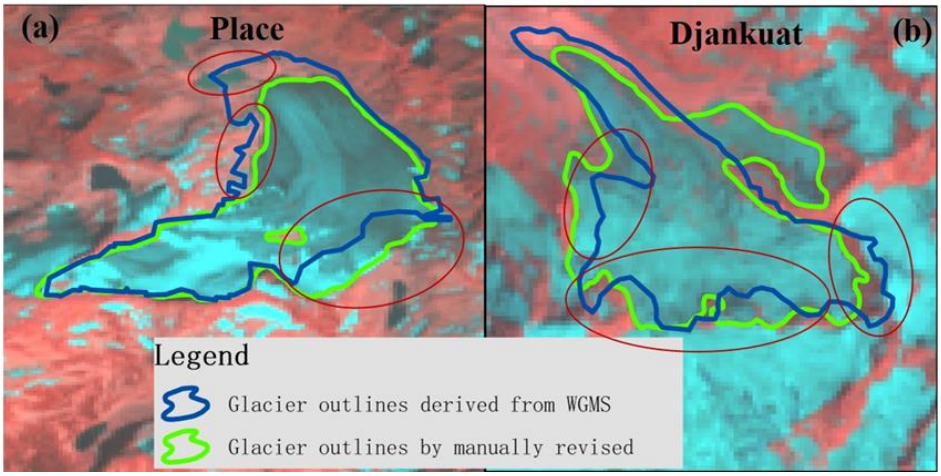

Figure S3. Glacier outlines are obtained by means of WGMS and manually revised. Blue polygons are downloaded by the WGMS website, and green polygons are manually revised by us. Red circles indicate some obvious differences between these two glacier outlines.

In the algorithm, the total calculation area is the whole glacier extent (by clipping using glacier outlines). Hence, the precise glacier extent is crucial for SLA calculation because if non-glacier pixels are put into the calculation, which will lead to misclassification resulting in incorrect estimation of SCR and SLA. The detailed answer is shown in answer 5.

The Otsu method essentially looks for the maximum intra-class variance of all pixels in the newNIR band, which means we need to assume that two types cover on glaciers, snow, and ice. Generally, the snow and ice have different reflectance in the newNIR band, which can be classified by the Otsu method (like Figure 12, the Otsu method can classify between snow cover and bare ice). However, we mentioned two extreme situations for the snow and ice classification: fresh snow covering the entire glacier and snowmelt across most of the glacier. In these situations, Otsu may occur some limitations in SLA calculation. Because if fresh snow covers all glacier surface, the real SCR is nearly 100%, and the accurate SLA is the glacier terminal. However, the Otsu method needs two types for classification, which will regard some dark pixels as ice class. It is the limitation of the Otsu method, but it will not influence the SLA at that year because this SLA is the smallest SLA at that year. Hence, this SLA is not selected as the SLA that year. If bare ice extends along the entire glacier, the real SCR is nearly 0, and the accurate SLA is the top of the glacier. This SLA may represent the maximum SLA this year, but it will be lower than the ELA

because the misclassification of snow cover reduces the real SLA.

These all are limitations when calculating the SLA. In the total process, we tried to reduce their influence on their SLA calculation. We will upload this part as supplementary materials, thank you for the comments again!

S2 Used code

We are very pleased to share code and request improvements with the scientific community. The code is still in the testing stage, and will be packaged as an app when it is stable and robust so that it can be easily used by researchers.

Here is the link: https://code.earthengine.google.com/0cdfad6785ac170efc19c0ee4a905766