Glacial Fluctuation in the Source Region of the Yangtze River

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Abstract: Glaciers in the source region of the Yangtze River are not only water resources but also important energy and environmental resources. Glacial fluctuation is an important component of the study of changes in the natural environment, including climate change. We investigated the glaciers in the source region of the Yangtze River, and analyzed the fluctuations using multi-temporal remote sensing data. The trend in glacial fluctuation and the factors that influence it were determined. The results have implications for water resource management and environmental conservation in the Yangtze River region.

1. Introduction

The source region of the Yangtze River lies between the Kunlun and Tanggula Mountains in the hinterland of the Qinghai-Xizang Plateau. The Qumar River, Tuotuo River, and Dam Qu River are the three largest rivers in this region, and are called, respectively, the north source, main source, and south source. The north source originates in the Hoh Xil Mountain, the south source originates in the eastern side of the Tanggula Mountains, and the main source originates in the Geladandong snowberg of the Tanggula Mountains. The Jianggendiru Glacier on the southwest side of Geladandong Peak is the source of the Tuotuo River. [1]

Seventy per cent of the glaciers in the Yangtze River basin are found in the region above the Tongtian river; the total ice volume of the glaciers in this region is 100.414 km³, which is equivalent to a water volume of 88,752×109 m³ [2]. Glacier meltwater is both an important water source for rivers and an important resource for nomadic herders. It is also the main source of domestic water in the source region of the Yangtze River and the freshwater resource relied on by the wild animals of the plateau.

To study glacial fluctuation in the source region of the Yangtze River, we focused on glaciers in the Geladandong snowberg area. We used the trend in local glacial fluctuation to analyze the trends in the source region. Using both manual interpretation and computer-aided interpretation of the remote sensing imagery (i.e., a Geographic Information System), we determined the spatial distribution of the glaciers in the source region of the Yangtze River. We compared this data with the multi-temporal
remote sensing imagery collected in the late 70s, in the 90s, and in the 21st century, and to the meteorological data collected over the same period. The factors that influenced the trends in glacial fluctuation were then deduced.

2. Glacial fluctuation

2.1. Change in the area of glaciers in the source region

We focused on the glaciers of the Geladandong snowberg area in the main source region of the Yangtze River. The spatial distribution of the glaciers was determined using remote sensing data from six periods between 1977 and 2009. The changes in the areas covered by the Mengdakangri Glacier, the Geladandong Glacier and the Sedopu Kangri, the main water sources of the Tuotuo River, were calculated. The distribution of the glaciers in the Geladandong snowberg area can be seen in Figure 1. The total area of the glaciers in each of the six years and the changes from the 1977 baseline are given in Table 1.

| Year of Imagery | Month of Imagery | Total Area of Glaciers (km²) | Variation (km²) | Mean Annual Change Rate (%) | Area Change Rate (%) |
|----------------|-----------------|-----------------------------|-----------------|-----------------------------|---------------------|
| 1977           | March           | 1067.21                     |                 |                             |                     |
| 1992           | August          | 999.72                      | -67.49          | -4.50                       | -6.32               |
| 1999           | July            | 965.83                      | -33.89          | -4.84                       | -3.39               |
| 2004           | September       | 949.75                      | -16.08          | -3.22                       | -1.67               |
| 2007           | May             | 944.30                      | -5.45           | -1.82                       | -0.57               |
| 2009           | November        | 940.88                      | -3.42           | -1.71                       | -0.36               |
| Total Change   |                 | -126.33                     |                 |                             | -11.84              |

Table 1. Change in the total area of the glaciers over time

Figure 1. Glacier distribution in the Geladandong snowberg area
Table 1 shows that the trend in the total glacier area near the Geladandong Glacier was downwards. The highest rate of change occurred between 1977 and 1999 when the mean annual change was 4.6 km². The rate of change slowed after 2004 when the mean annual change was less than 2 km². Although the area covered by the glaciers fluctuated, the general trend was downwards. The black blocks in Figure 2 highlight the degraded areas in the Geladandong snowberg area.

In the 32 years from 1977 to 2009, the total area of the glaciers decreased 126.33 km², which was a total decrease of 11.84%. The downward trend can be seen in Figure 3.

2.1.1. Change in the area of the Geladandong Glacier

The Geladandong Glacier is comprised of the Jianggendiru Glacier, the Qiemeisu Glacier, and the Gangjiaquba Glacier; the glacier on the south slope of Geladandong is also part of the Geladandong Glacier. Figure 4 shows the fluctuation in the Geladandong Glacier according to the remote sensing imagery. According to the statistical analysis, the area of the Geladandong Glacier decreased 66 km² in 32 years, which was a 9.7% decrease in area. The total area of the Geladandong Glacier in each of the six years and the changes from the 1977 baseline are shown in Table 2.
Table 2. Change in the area of the Geladandong Glacier

| Year of Imagery | Month of Imagery | Total Area of Glaciers (km²) | Variation (km²) | Mean Annual Change Rate (%) | Area Change Rate (%) |
|-----------------|------------------|-----------------------------|----------------|-----------------------------|----------------------|
| 1977            | March            | 678.27                      |                |                             |                      |
| 1992            | August           | 644.22                      | -34.05         | -2.27                       | -5.02                |
| 1999            | July             | 630.95                      | -13.27         | -1.90                       | -2.06                |
| 2004            | September        | 617.03                      | -13.91         | -2.78                       | -2.21                |
| 2007            | May              | 614.82                      | -2.22          | -0.74                       | -0.36                |
| 2009            | November         | 612.23                      | -2.58          | -1.29                       | -0.42                |
| Total Change    |                  |                             | -66.04         |                             | -9.74                |

Clearly, the speed of change was relatively large before 2004, but became relatively stable after 2004. Figure 4 illustrates the trend in the changes in the area of the Geladandong Glacier.

Figure 4. The trend in the total area of the Geladandong Glacier

2.1.2. Glacial fluctuation analysis

By overlapping images of the glaciers taken in 1977 and 2009, the upgraded and degraded areas of the glaciers in the Geladandong snowberg area were determined. The comparison showed that the most degraded glacier was the Gangjiaquba Glacier (5K444B0064) in the south of Geladandong. In the fluctuations between 1977 and 2009 the maximum degrading distance was 4470 meters, and the minimum distance was 2000 meters. The average degrading distance was 3200 meters. The changes occurred most rapidly between 1992 and 2004, with an average annual shrinkage of 160 meters. From 1977 to 2009 the average annual degrading distance was 100 meters. Table 3 shows the changes in the area of the Gangjiaquba Glacier over the 32 years. Figure 6 shows the overall degradation of the Gangjiaquba Glacier.

The south branch (5K451F0033) of the Jianggendiru Glacier (5K451F0033) had an area 690 meters smaller in 2009 than in 1977, and the north branch (5K451F0030) was 490 meters smaller.

Table 4 shows the degradation of the Jianggendiru Glacier over the years. Figure 7 shows the degradation of the south branch of the Jianggendiru Glacier.

The glacier No. 5K451F0012, in the northwest area of the Qiemeisu Glacier, upgraded 680 meters over the 32-year period. Figure 8 shows the increase in the area of the glacier.
Table 3. The change in the area of the Gangjiaquba Glacier

| Year | Maximum Distance (m) | Minimum Distance (m) | Average Distance (m) |
|------|----------------------|-----------------------|----------------------|
| 1977 | 0                    | 0                     | 0                    |
| 1992 | 2080                 | 430                   | 1255                 |
| 1999 | 3130                 | 1250                  | 2190                 |
| 2004 | 4300                 | 2000                  | 3150                 |
| 2007 | 4340                 | 2000                  | 3170                 |
| 2009 | 4470                 | 2000                  | 3235                 |

Table 4. The change in the area of the Jianggendiru Glacier

| Year | Degrading Distance in the North Branch (m) | Degrading Distance in the South Branch (m) |
|------|-------------------------------------------|-------------------------------------------|
| 1977 | 0                                         | 0                                         |
| 1992 | 330                                       | 560                                       |
| 1999 | 500                                       | 630                                       |
| 2004 | 480                                       | 660                                       |
| 2007 | 450                                       | 700                                       |
| 2009 | 490                                       | 690                                       |

Figure 5. Upgrading of the Geladandong snowberg area

Figure 6. Degradation of the Gangjiaquba glacier

Figure 7. Degradation of the south branch of the Jianggendiru Glacier

Figure 8. Upgrading of glacier 5K451F0012
2.2. Causes of glacial fluctuation

2.2.1. Analysis of meteorological change
The Tuotuo weather station is the closest weather station to the Geladandong snowberg. The meteorological data from this station is appropriate for analyzing the factors that influence glacial fluctuation.

(1) Analysis of temperature change
We obtained the monthly average temperature data from the Tuotuo weather station for the 1958-2009 period. To evaluate the influence of summer temperatures above 0°C, we used the data from May to September to analyze trends in temperature. Overall, the average summer temperature at the Tuotuo weather station increased from 4.42°C in 1977 to 5.82°C in 2009. The monthly average temperature in the summer increased 1.4°C in 32 years. The trend is illustrated in Figure 9.

![Figure 9. Temperature change at the Tuotuo weather station](image)

(2) Analysis of changes in sunshine
We used the data from May to September to analyze how changes in the amount of sunshine affected the size of the glacier. The number of monthly average sunshine hours was relatively stable in the 32-year period. The trend in monthly average sunshine is shown in Figure 10.

![Figure 10. Hours of sunshine at the Tuotuo weather station](image)

(3) Analysis of precipitation
The annual precipitation, shown in Figure 11, increased only slightly and did not affect the glacier fluctuation.

![Figure 11. Annual precipitation at the Tuotuo weather station](image)
2.2.2. Analysis of influence factors

The area of the glaciers in the source region shrank as the average temperature increased. The degradation of the glaciers was directly related to increasing temperatures.

There were distinct differences in the rate of change in the size of the Gangjiaquba Glacier and other nearby glaciers. The current analysis does not suggest any reason for these differences.

3. Conclusions

The following conclusions can be drawn from this analysis.

(1) In general, the glaciers in the source region of the Yangtze River decreased in area between 1977 and 2009. The rate of change slowed after 2004. The total area of the glaciers decreased 126.33 km² between 1977 and 2009, a total of 11.84%. The result is a reduction in the amount of water resource storage.

(2) In general, the glaciers degraded over the study period. The degradation of the Gangjiaquba Glacier was the most serious. Using 1977 as a base year, the maximum degradation in 2009 was 4470 meters, and the minimum degradation was 2000 meters. The average degrading distance of the Gangjiaquba Glacier was 3200 meters and the average annual degrading distance was 100 meters.

(3) The Jianggendiru glacier is the most important glacier in the source region of the Tuotuo River. Using 1977 as a base year, our research showed that by 2009 the south branch of the Jianggendiru Glacier had degraded 690 meters and had an annual average degrading distance of 21 meters. The north branch degraded 490 meters and had an annual average degrading distance of 15 meters.

(4) The glacier (5K451F0012) at 33°33′N and 91°03′E expanded by 680 meters between 1977 and 2009. It was the only glacier in the Geladandong snowberg area to do so during the study period.

4. References

[1] Changjiang Water Resources Commission 2011 Comprehensive Investigation and Research on the source region of Yangtze River (Wuhan: Changjiang Press)

[2] Shi Yafeng 2008 Concise Glacier Inventory of China (Shanghai: Shanghai Popular Science Press)