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*Scientific note*

# Change of glaciers in Spitsbergen Island since 1933 observed with surface photographs

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***Abstract:*** Change of several glaciers in Spitsbergen Island was investigated using surface photographs taken in 1933 and afterward. All glaciers investigated decreased their thickness and area at their terminal parts in the period from 1933 to 2004.

**key words**: Spitsbergen Island, surface photograph, glacier change, 79 degree North

## 1. Introduction

The state of glaciers in past, when no satellite or airborne data were yet available, can be investigated with photographs taken on the ground. To utilize this old data source in comparative study, aiming to reveal the long term glacier change, the pictures of the identical glaciers taken at later year are necessary.

In 1993, authors took sequential photographs of the coastal topography from the ship sailing around Spitsbergen Island, Svalbard Islands (Ito and Yoshioka, 1994).

In 1933, 60 years before the observation above, a geographer, Kouji Iizuka and an engineer, Shinji Okada visited Spitsbergen Island individually, and both of them took photographs of the coastal glaciers. They introduced Spitsbergen Island to Japanese public by publishing books which contained glacier photographs (Iizuka, 1938; Okada, 1935).

It was found, some old pictures have their modern counterparts; same glaciers were photographed at similar spots and in similar angle once again in 1993, after 60 years. One of those glaciers is Tunabreen, which is located at central Spitsbergen Island. And others are several glaciers flowing into Magdalenefjorden, northwestern Spitsbergen Island (Fig. 1).

To investigate also short term phenomena, authors took photographs of the glaciers in 2004, 11 years after the first modern observation in 1993.

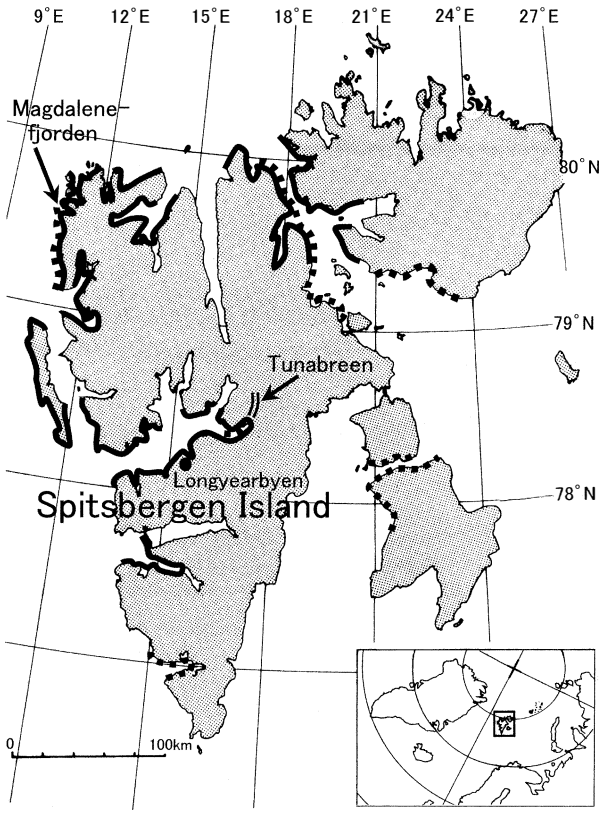


*Fig. 1. Location of Tunabreen and Magdalenefjorden. Bold lines indicate coast where sequential photographs were taken in 1993. Dotted lines indicate coast where sequential photographs were taken in 2004.*

## 2. Observations

### *2.1. Old observation I*

Kouji Iizuka got on board "Foucauld" on 7 July 1933 at Dunkerque, France. The ship arrived Spitsbergen Island on 18 July, and left on 20 July. He published a book "79 degree North" in 1938, which includes 6 photographs taken at Spitsbergen Island.

### *2.2. Old observation II*

"General van Steuben" with Shinji Okada on board left Bremerhaven, Germany on 19 July 1933. The ship arrived Spitsbergen Island on 29 July, and left on 4 August. He wrote a short article in a scientific magazine in 1935, which includes 7 photographs taken at Spitsbergen Island.

### *2.3. Modern observation I*

Authors started the cruise on board "Origo" on 16 July 1993 at Longyearbyen,

Svalbard. The ship returned Longyearbyen on 27 July. Successively, the second cruise was made from 7 August to 15 August on board "Polar Star". The coasts where sequential photographs were taken are indicated with bold lines in Fig. 1.

### *2.4. Modern observation II*

One of authors got on board "Polar Star" on 13 August 2004 at Longyearbyen, Svalbard. The ship returned Longyearbyen on 20 August. The coasts where sequential photographs were taken are indicated with dotted lines in Fig. 1.

## 3. Change of glaciers

### *3.1. Tunabreen*

Tunabreen is located at central Spitsbergen Island and flows into Tempelfjorden. Figure 2 shows the drainage basin of Tunabreen. The drainage area of the glacier is 189.8 $km^2$. Tunabreen joins with von Postbreen near the terminal. Three recent surges are recorded at Tunabreen, in 1930, 1970 and 2003 (Table 1).

Figure 3 shows photographs of Tunabreen taken in 1933, 1993 and 2004. In the three photographs, the thickness* of the glacier and terminal position are compared. (*The "thickness" in this text is that above sea level irrespectively whether the glacier is

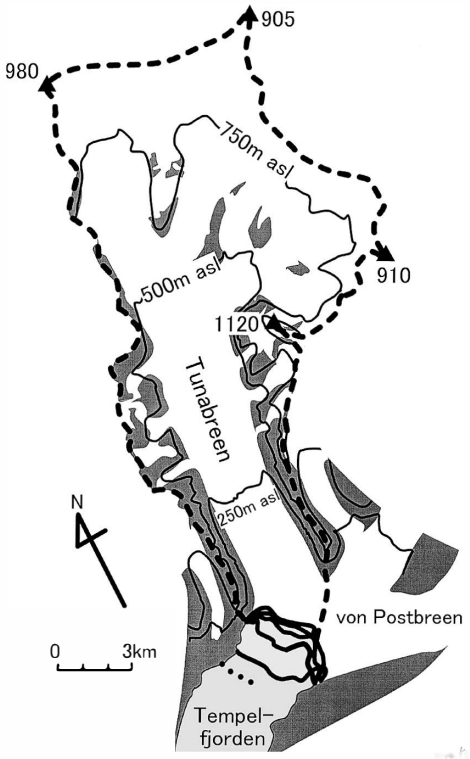


*Fig. 2. Drainage basin of Tunabreen.*

floating or not.)

The comparison of photos taken in 1933 and 1993 indicates that the glacier retreated and decreased the thickness at the terminal in 60 years.

Two recent photos indicate the state of glacier in 1993, 10 years before a surge, and that in 2004, 1 year after the surge. The position of the terminal advanced and glacier thickness increased, as if the surge restored glacier state to that of a few decades ago.

In 71 years form 1933 to 2004, the glacier retreated and decreased the thickness at the terminal area.

Thickness of the glacier was estimated, in each of the years, on the photos in Fig. 3,

*Table 1. State of Tunabreen.*

| Drainage basin | | Glacier | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| area [1] | highest altitude [1] | area [1] | length [1] | main flow direction [1] | | highest altitude [1] | lowest altitude [1] | altitude of equilibrium line [2] | estimated volume [2] | year of surge [2] |
| ($km^2$) | (m) | ($km^2$) | (km) | upper | lower | (m) | (m) | (m) | ($km^3$) | |
| 189.8 | 1120 | 158.14 | 27.1 | SW | S | 1100 | 0 | 510 | 41.00 | 1930<br>1970<br>2003* |

1) measured on 1:100,000 topographic maps C8 and D8, issued by Norsk Polarinstitutt. Glacier state refers to that of 1993.

2) extracted from Hagen *et al.* (1993), except *.

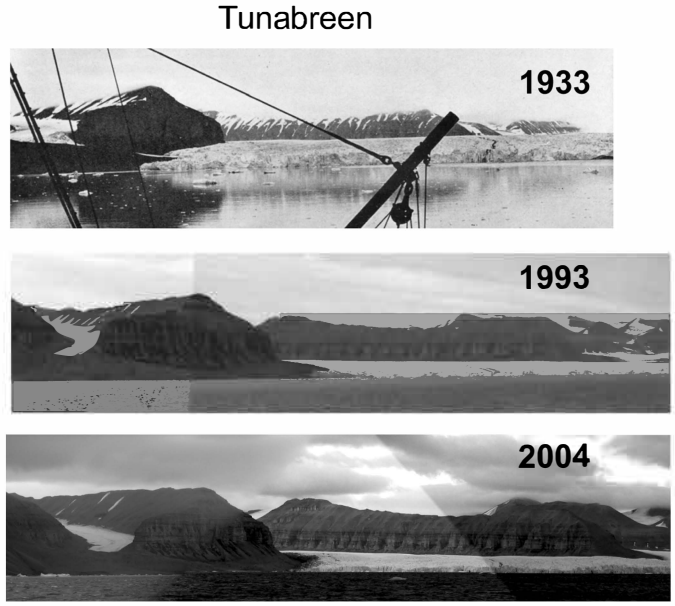


*Fig. 3. Surface photographs of Tunabreen taken in 1933, 1993 and 2004.*

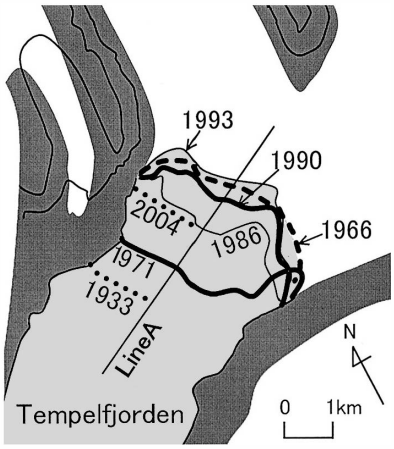


*Fig. 4. Terminal position of Tunabreen. The position in 1933 and 2004 are estimated using the photographs. Positions of other years were taken from the maps issued by Norsk Polarinstitutt.*

using the cliff top facing the glacier at left side as a scale. The cliff top is assumed to be 200 m a.s.l. The height of glacier surface is estimated to be 120 m a.s.l. in 1933, 90 m in 1993 and 95 m in 2004.

The positions of glacier terminals in various years are collected also utilizing published maps and summarized in Fig. 4. The position in 1933 and 2004 are estimated using the photographs, whilst those in other years were taken from the maps issued by Norsk Polarinstitutt: the position in 1966 and 1993 are taken from 1:100000 topographic map, No. C8. Those in 1971 and 1986 are from 1:200000 coast map, No. B3. And that in 1990 is from 1:250000 topographic map, sheet 1.

The change of glacier terminal position is schematically summarized in Fig. 5. A

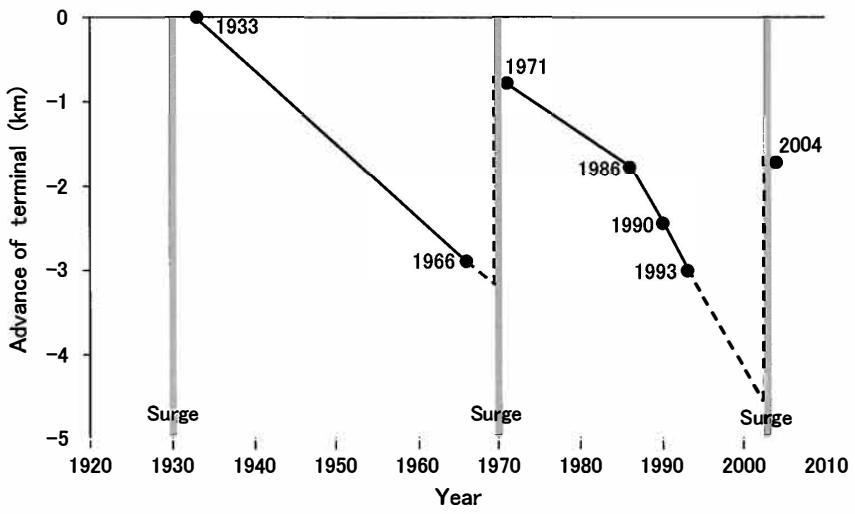


*Fig. 5. Change of terminal position of Tunabreen. The advanced distance of terminal position from that of 1933, along Line A (Fig. 4) is plotted on the ordinate. Negative value indicates distance of retreat. Three recorded surges are also indicated.*

somewhat arbitrary center line of the fjord, Line A, is drawn on Fig. 4. The point where the glacier terminal crosses the Line A is considered to represent the terminal position at that time. The distance of the terminal position in the year from that in 1933 is measured along the Line A in the flow direction, and it is plotted in the diagram, Fig. 5. The positive value indicates the advance of the front, and the negative value the retreat. Three recorded surges are also indicated in the diagram. A surge occurred in 1930. The glacier terminal of Tunabreen was located farthest offshore in 1933 among the data in this text. Then, the terminal retreated with a mean rate of 88 m/year until the next occurrence of a surge in 1970. The terminal position in 1971 shows, that the glacier advanced, but did not go beyond the position in 1933. The glacier continued to retreat through 1986, 1990 and 1993. The mean rate of retreat during 1986 to 1993 is 175 m/year. The glacier may have further retreated until the occurrence of the next surge. The latest surge occurred in 2003 and the glacier advanced. But the glacier did not advance beyond the position in 1971, the terminal position after the previous surge. The comparison of terminal positions after surges, in 1933, 1971 and 2004 indicates, that Tunabreen is generally retreating in the 71 years with a mean rate of 24 m/year, although the glacier advanced by each surge.

The glacier terminal of Tunabreen advances occasionally by a surge, but the glacier is retreating in a long period. The latter phenomenon is greater in scale, and the former is overwhelmed.

### *3.2. Waggonwaybreen and other glaciers flowing into Magdalenefjorden*

Magdalenefjorden is located at northwestern Spitsbergen Island. Several glaciers flow into the fjord at the end of the fjord and along the southern coast of the fjord, are investigated. The largest glacier among them is Waggonwaybreen, whose drainage area is 52.3 km$^2$. Figure 6 shows drainage basins of these glaciers. The numbers in

*Table 2. State of glaciers flowing into Magdalenefjorden.*

| | | Drainage basin | | Glacier | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| number | name of glacier | area[1] | highest altitude[1] | area[1] | length[1] | main flow direction[1] | | highest altitude[1] | lowest altitude[1] | altitude of equilibrium line[2] | estimated volum[2] |
| | | (km$^2$) | (m) | (km$^2$) | (km) | upper | lower | (m) | (m) | (m) | (km$^3$) |
| ① | Miethebreen | 7.36 | 1012 | 3.73 | 5.0 | N | W | 650 | 0 | – | – |
| ② | | 1.26 | 850 | 0.46 | 1.9 | NW | SW | 800 | 250 | – | – |
| ③ | Waggonwaybreen | 52.25 | 1095 | 41.42 | 12.2 | NW | NW | 950 | 0 | 410 | 6.90 |
| ④ | | 0.57 | 550 | 0.16 | 0.7 | N | N | 300 | 0 | – | – |
| ⑤ | Brokebreen | 6.51 | 785 | 4.43 | 3.3 | NW | N | 550 | 0 | – | 0.39 |
| ⑥ | Hengebreen | 1.39 | 785 | 0.76 | 1.6 | NW | W | 400 | 200 | – | – |
| ⑦ | Gullybreen | 15.52 | 805 | 11.09 | 5.4 | NW | NW | 600 | 0 | 200 | 1.20 |
| ⑧ | | 0.73 | 500 | 0.34 | 1.1 | NE | NE | 450 | 0 | – | – |

1) measured on 1:100,000 topographic map A5 issued by Norsk Polarinstitutt. Glacier state refers to that of 1990.
2) extracted from Hagen *et al.* (1993).

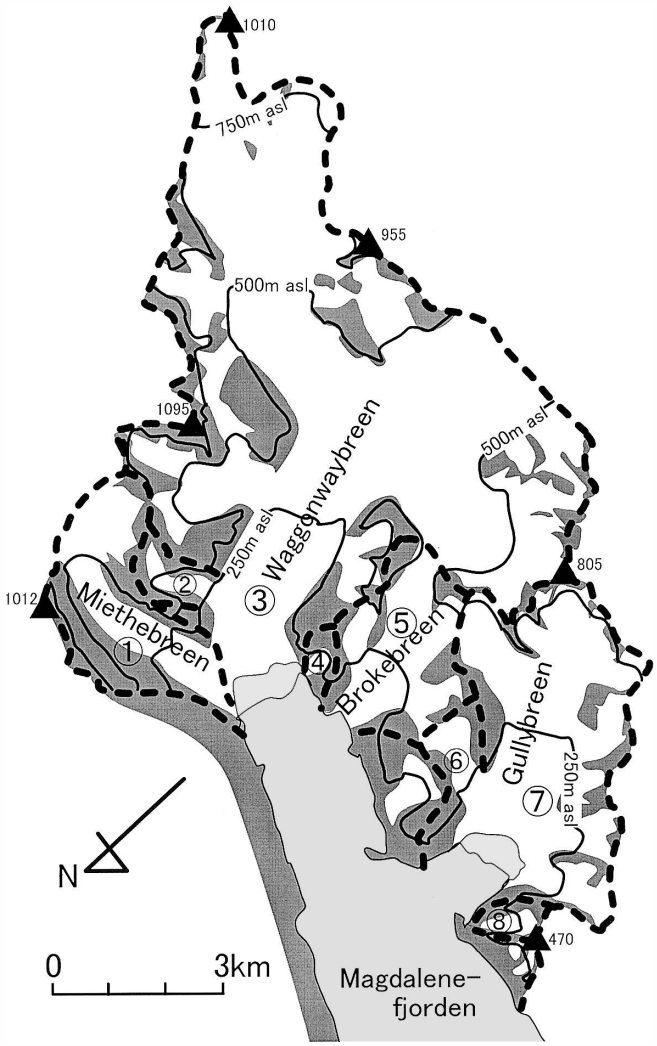


*Fig. 6. Drainage basins of glaciers investigated at Magdalenefjorden. The glaciers are numbered for distinction (in circle), and the same numbers are used in Table 2, Fig. 7 and Fig. 8.*

circle identify the glaciers in Table 2 and Figs. 7, 8. Figures 7 and 8 show photographs taken in 1933, 1993 and 2004. All glaciers in the photographs retreated and decreased their thickness as the year went by. The glacier terminal positions are estimated using photographs and indicated in Figs. 9 and 10. The positions in 1966 and 1990 are taken from a topographic map (NP 1:100000, No. A5) and added to Figs. 9 and 10. No information is available yet whether surges occurred at these glaciers in the observation period.

The change of the glacier terminal position of Waggonwaybreen and Gullybreen is summarized in Fig. 11. Lines B and C are drawn on Figs. 9 and 10 respectively, and are used in the evaluation of the terminal position. Both terminal positions retreated

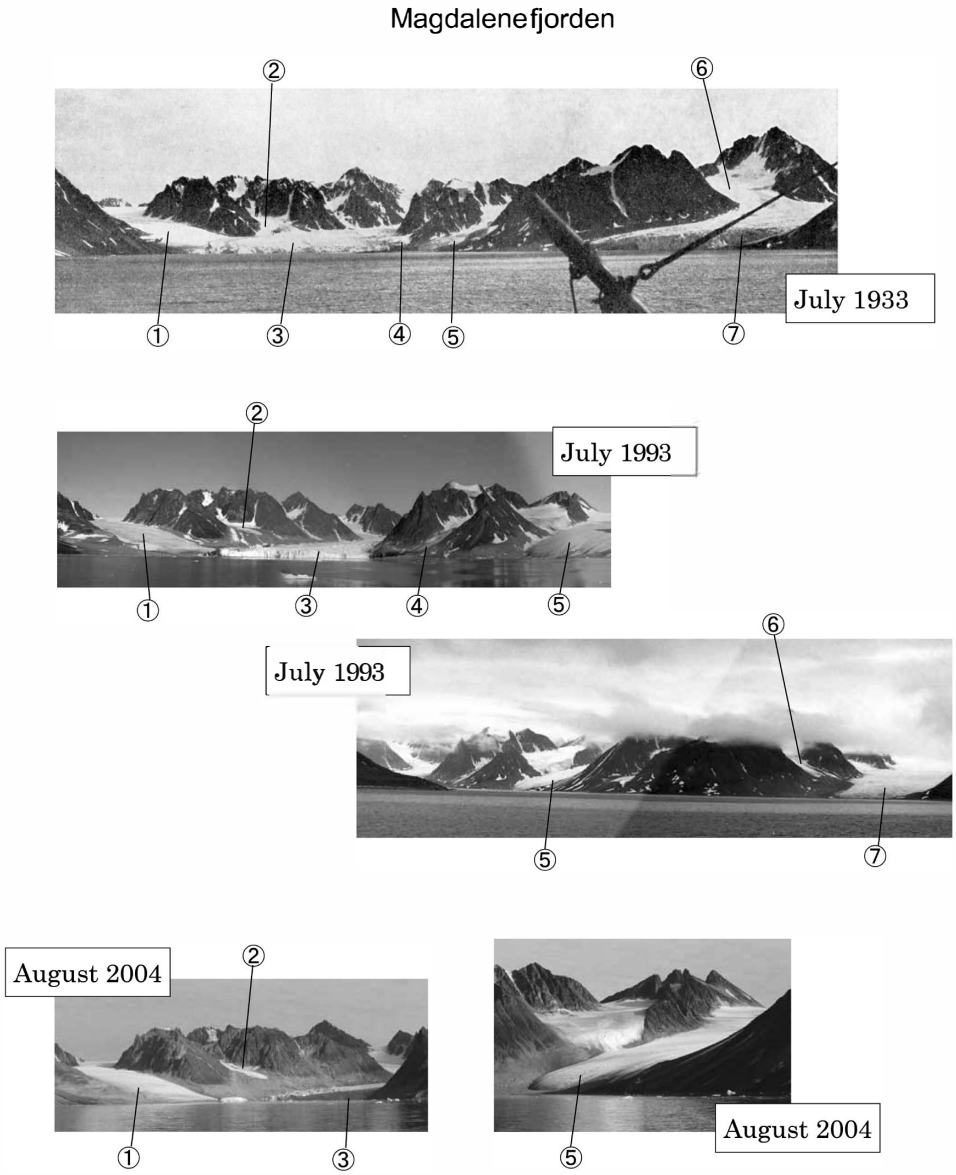


*Fig. 7. Surface photographs of Miethebreen, Waggonwaybreen and other glaciers taken in 1933, 1993 and 2004*

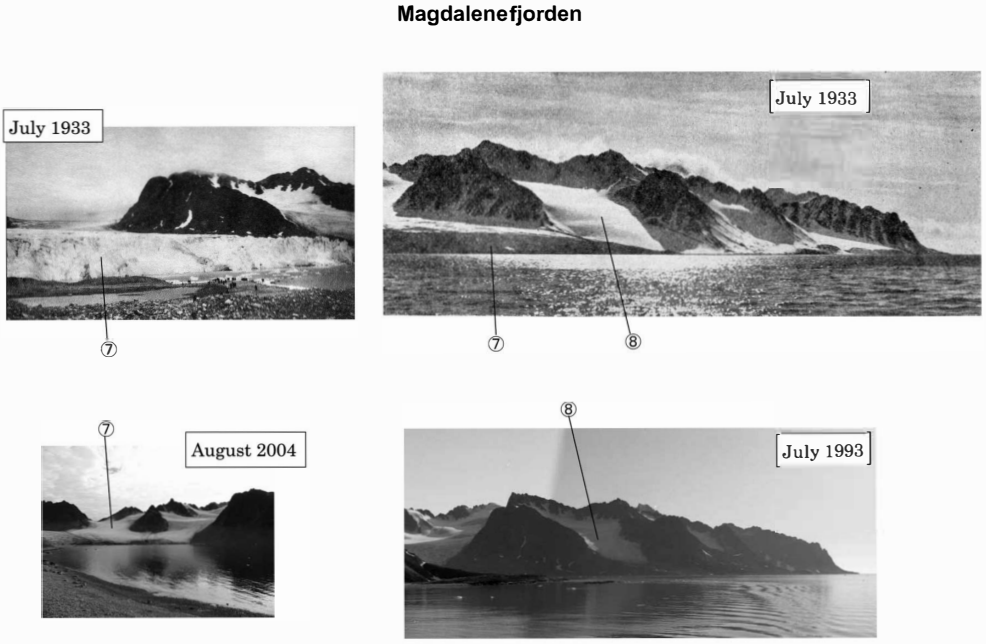


*Fig. 8. Surface photographs of Gullybreen and other glaciers taken in 1933, 1993 and 2004.*

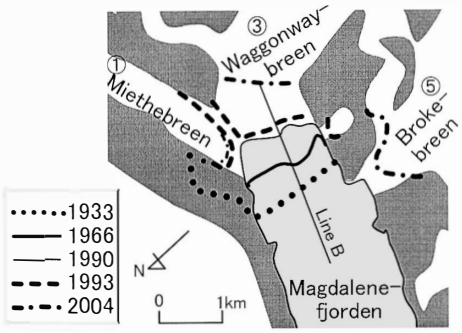


*Fig. 9. The terminal position of glaciers at the end of Magdalenefjorden area. The positions in 1966 and 1990 are taken from a topographic map.*

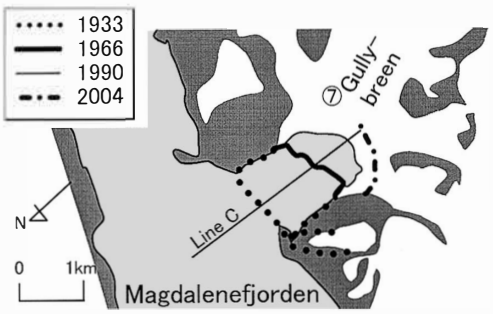


*Fig. 10. The terminal position of Gullybreen. The positions in 1966 and 1990 are taken from a topographic map.*

almost 2 km in the period, from 1933 to 2004. The manner of retreat was different for each glacier. Gullybreen retreated at a constant rate of 27 m/year during the 71 years period. Waggonwaybreen also retreated with a constant rate but slower than Gullybreen at the earlier part of the observation period with a mean rate of 16 m/year. After 1990, the rate was increased to 66 m/year and exceeded that of Gullybreen.

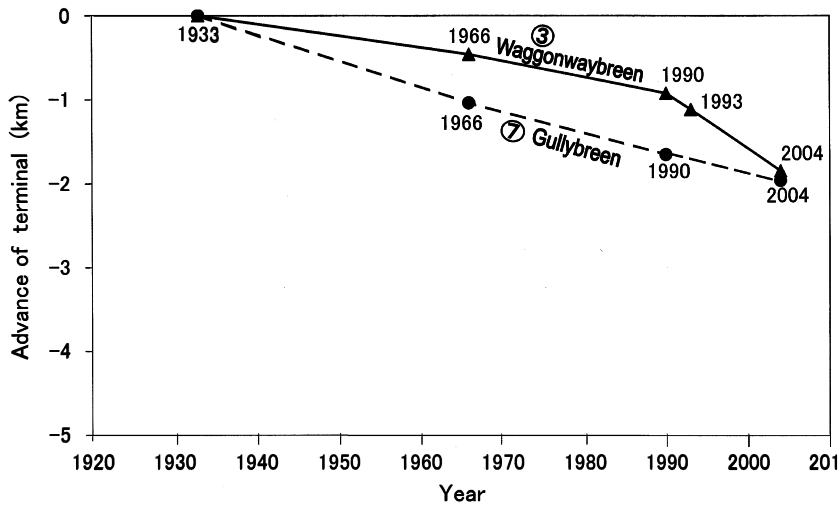


*Fig. 11. Change of terminal position of Waggonwaybreen and Gullybreen. The advanced distances of terminal position from that of 1933, along Line B (Fig. 9) and Line C (Fig. 10) are plotted on the ordinate. Negative value indicates distance of retreat.*

## 4. Conclusion

Several glaciers in Spitsbergen Island were investigated using sets of surface photographs with intervals up to 71 years. All of the glaciers decreased their thickness and area at their terminal parts in 71 years. One of the glaciers surged twice during observation period. At this glacier, Tunabreen the terminal position advanced temporally by each occurrence of surge, but retreated in a long period.

These glaciers investigated were popular glaciers for the tourist since the end of 19 century. More surface photographs in old time are expected to be found for future study. There are certain number of photograph pairs taken in 1993 and 2004, which contain glaciers other than those discussed in the text. They would serve as the material for future study as well.

The method presented is found to be useful in the estimation of glacier thickness and area, although it's application is restricted to the terminal part of glacier only.

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