Flow speed and calving rate of Kongsbreen glacier, Svalbard, using SPOT images

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Kongsbreen, a tide-water glacier located in Kongsfjorden, is the most active calving glacier in Svalbard. Three SPOT images are used to determine its flow speed and calving rate. The position of fourteen reference points was determined on the coast or mountain sides, and the changes in position of 144 characteristic features on the glacier surface were calculated. The obtained speed profiles are consistent with the findings from previous works from 1962–64 and 1983–86. When comparing the obtained longitudinal profile to the data from 1962–64, it is found that the flow velocity at a given distance from the front has been nearly constant.

The results from the SPOT images analysis are completed by using existing topographic works. The present study shows that SPOT images (panchromatic as well as multichannel), recorded with a periodicity of one year, can be used to determine precisely the annual flow speed and calving rate of active glaciers such as Kongsbreen. Images recorded with a periodicity of two, three or four weeks can allow identical determination on tide-water glaciers during a surging active phase.

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Introduction

Kongsbreen is a tide-water front of a glacier complex calving in Kongsfjorden (79°N, 12°E) (Fig. 1). In this study, the main front and ice-stream located to the south of Collethøgda (see Fig. 2) are considered. The studied calving tongue is formed by two joined ice streams, Kongsvegen and Kronebreen. Kongsvegen is a glacier with an area of 100 km^2, and Kronebreen is an outlet of Isachsenfonna, Holtedahlfonna and Infantfonna, three accumulation ice fields with a total area of 525 km^2. The Lamont expedition report (Lamont 1876) reveals that Kronebreen experienced an important surge in 1869 or in the previous year. The following retreat (more than 4 km) was interrupted by a surge (revealed by aerial photographs from 1948) of Kongsvegen which advanced about 1.5 km into the sea. Since then, the glacier front has been continually retreating for more than 4 km. The changes in front position are described by Lefauconnier (1987) and Liestøl (1988). Today, referring to the classification used by Dowdeswell (1989), Kongsbreen is in a quiescent period between surges; however, it still remains the most active tide-water glacier in Svalbard. Its tide-water tongue is partially subjected to buoyancy along about 7 km (Lefauconnier 1987) and numerous crevasses are still visible at 17 km from the front.

The aim of the present work is to use available SPOT images from 1986 to measure the change in position of characteristic features on the glacier surface, and then, to calculate flow velocity, retreat of the front and calving rate. Comparison with previous topographic (photogrammetry) works carried out in the period 1962–65 by D.D.R. expeditions (Pillewizer 1967; Voigt 1969) and in the period 1983–86 by Lefauconnier (1987) allows the study of the change in the glacier activity from 1962 to 1986.

Data sources and method

Three SPOT images from 1986 were used, two multichannel images from 23 May and 7 September and one panchromatic image from the 8

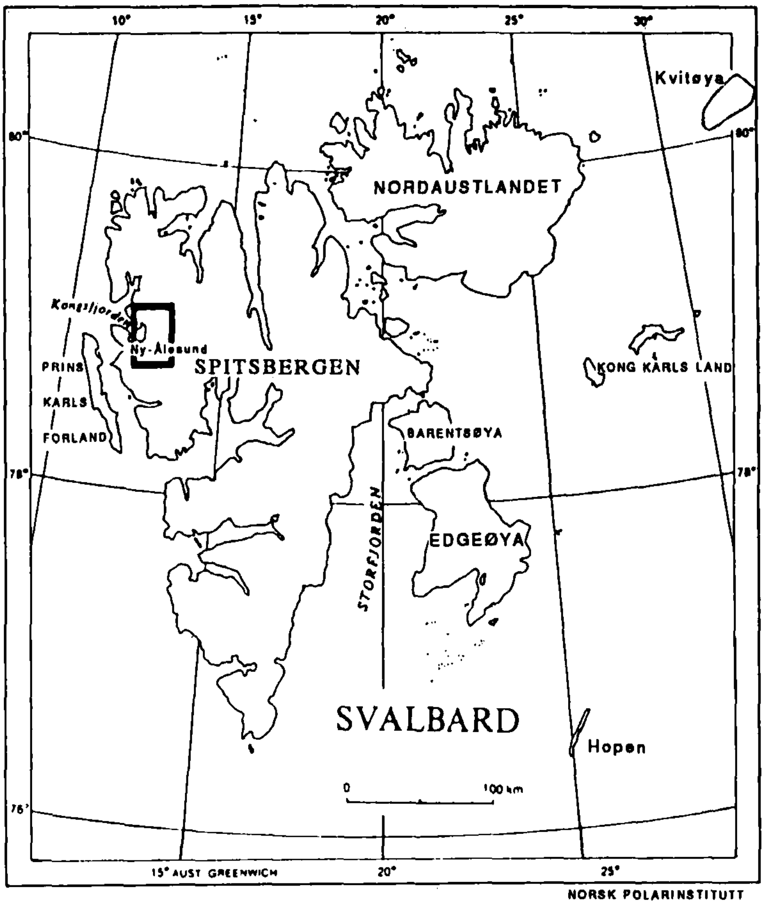

Fig. 1. Location of the studied area.

August 1986. On the rock sides, the positions of 14 reference points were determined. As numerous crevasses are visible on the surface, diverse markers are identifiable on two successive images. Two methods were used to measure the change in position of characteristic features: (1) A software program was used which combines two images at the same scale with superposition of the reference points. The displacement of characteristic features on the glacier surface was then obtained by measuring the difference of coordinates of each feature in the number of pixels; (2) slide projections of two successive images were utilised, separately side to side or superposed, to find the largest number of patterns visible on the two images. The two positions of every characteristic feature were then plotted on the same map and the displacement measured. The latter method was used primarily to control the result from digitalisation and it was, in fact, the more effective method. The large view on slide projections allowed the finding of about three times more points than from the computing method.

To prevent a systematic error due to the size of the larger pixel (20 m on the multichannel image), the displacement taken into account corresponds to the mean displacement of 3 to 6 points of a particular feature. The measurements were repeated several times to also prevent any possible error in the point determination. As an example, repeated measurements of the displacement of the most remarkable crevasse near Collethøgda diverged by no more than 6% from the mean value. Fig. 2 shows some vector plots which are representative of mean velocity values defined as above. Figs. 3 and 4 give the transverse velocity profiles for locations which correspond to mean values of all points plotted in a 400 m wide zone along the profile.

The multichannel image from the 23 May was recorded at a time when the snow cover was maximum and thus prevents the finding of features at the ice surface between crevasses. The low sun elevation and the different illumination angles between two successive images causes a change in the illuminated and shaded zone around each feature. It has thus only been possible to plot 28 common points on the images from both 23 May and 8 August, while 144 identical marks were noted on the two images from 8 August and 7 September.

Results and comparison with previous work

Surface velocity

The highest speed values are found along a longitudinal axis about 2.5 km from the south side of Collethøgda. The three transverse profiles P1, P2,

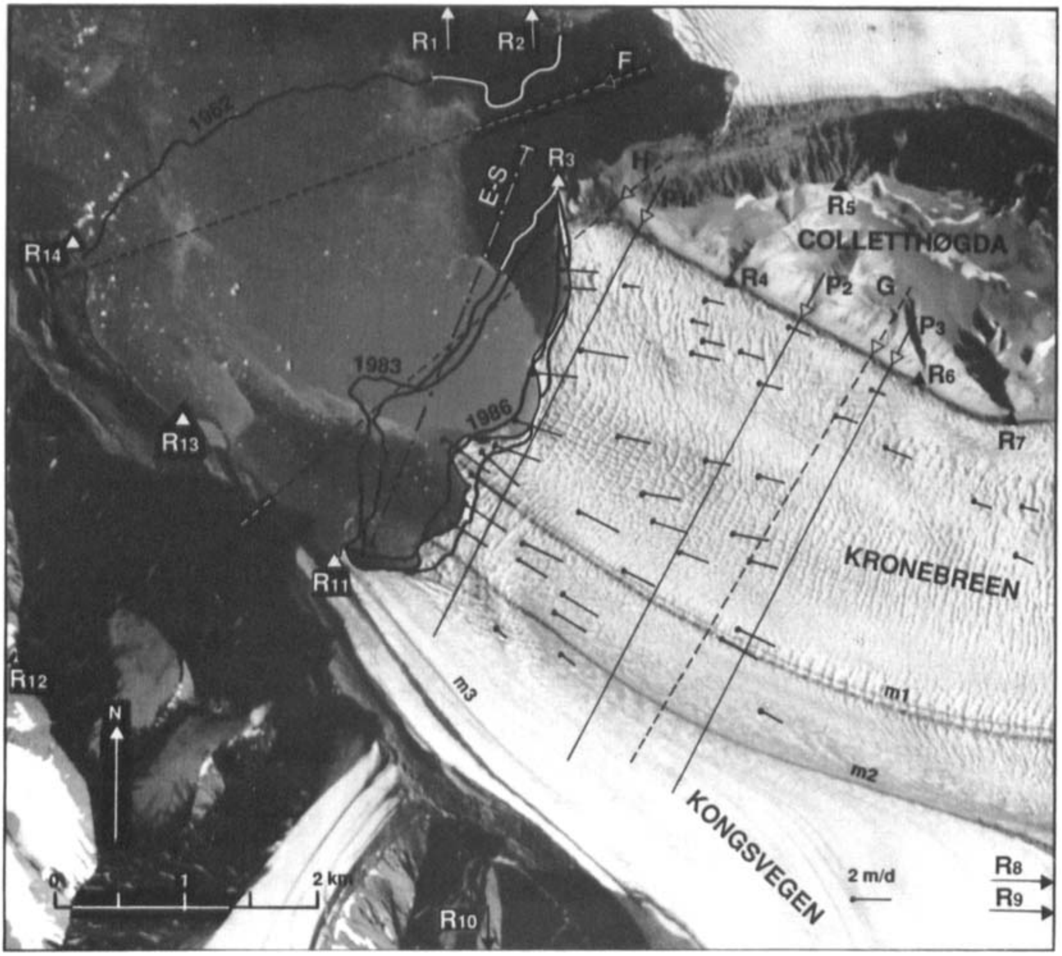

Fig. 2. Tongue of Kongsbreen. SPOT panchromatic image from the 8/08/1986. Front positions are successively from the 27/06/1962, the 08/07/1983 and 22/08/1983, the 23/05/1986, 8/08/1986 and 07/09/1986. F, H, G, P1, P2, P3 are location of profiles presented in Figs. 3 and 5. E-S is the location of a marine echo-sounding profile carried out in 1986. m1 and m2 are medial moraines. Longitudinal profiles presented in Fig. 4 are located along m1.

and P3 (see Fig. 3 and location in Fig. 2) show a declining speed from this axis towards the sides where there is no measurable movement. Longitudinal profiles (Fig. 4) indicate a slightly increasing velocity towards the front. During the period 8 August – 7 September, the velocities were 1.7 m/day at 2.4 km from the front, 2 m/day at 1.5 km and 2.4 m/day at the front. A few points plotted in May, close to the profile P2, indicate a value of 3–3.1 m/day between 23 May and 8 August against about 2 m/day between the 8 August and the 7 September. This determination agrees with the change in the velocity throughout the year (see below). Otherwise, all presented results are consistent with results from previous works.

Measurements of surface velocities were made over a one year period in 1964–65 (Pillewizer et al. 1967; Voigt 1969). A nearly constant flow velocity was found from October to mid-June and an increase by a factor of about two occurred at the end of June; the velocity then declined at the end of July. In August the value was just slightly above the annual average, and in September the velocity declined drastically to half of the mean annual value. At the most active part of the front, a maximum speed of 4.5 m/day was recorded in July and the mean annual velocity was 2.15 m/day. The ice flow speed is related to the start of the ablation period, and temporary maxima are due to an increase of the water pressure in subglacial channels (Lliboutry 1965; Pillewizer et al.

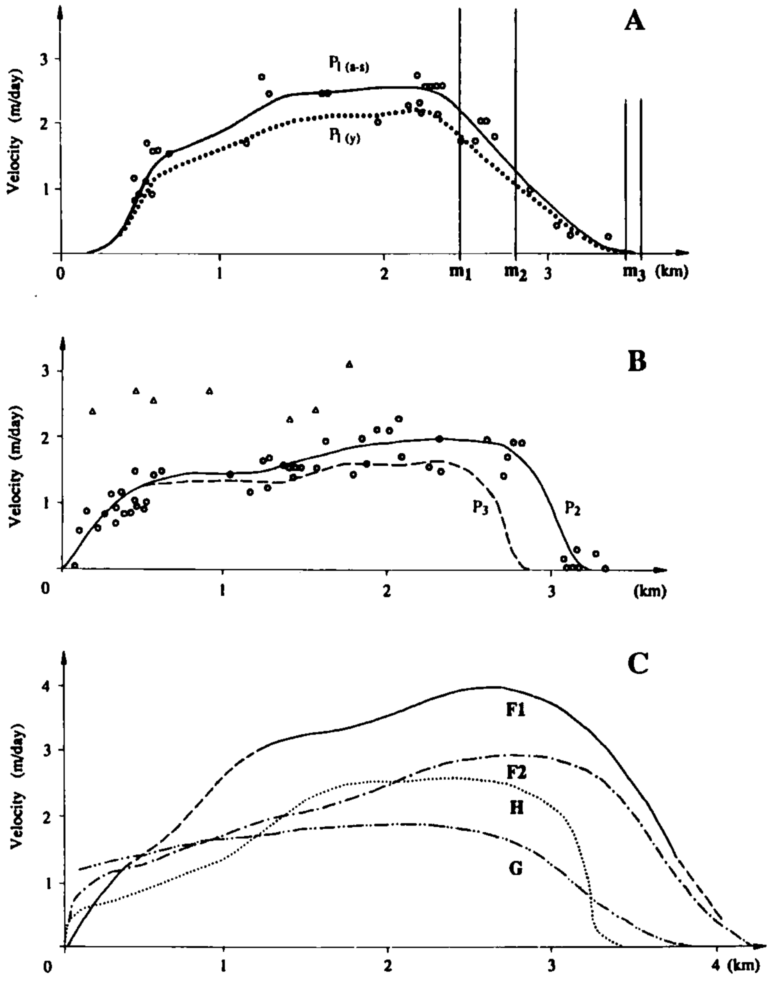

Fig. 3. Velocity transverse profiles. All profiles are seen fronting the ice flow. The 0 Km on the abscissa corresponds to the contact between the ice and Collethøgda (see Fig. 2). In A, circles are velocities between the 8/08 and 7/09/1986 as defined in the text. P1(a-s) = velocity profile at the front between the 8/08 and the 7/09/1986; P1(y) = estimated annual velocity profile at the front. In B, circles are velocities between the 8/08 and 8/09/1986, triangles are velocities between the 23/05/1986 and the 8/08/1986. P1 and P2 are velocity profiles between the 8/08 and the 7/09/1986. In C, profiles recorded by the D.D.R. expeditions, designation of profiles are retained. F = Front-Querprofilen, F1 (28/07–13/08/1962), F2 (27/06–30/06/1964); H = Haupt-Querprofil (28/07–1/08/1964); G = Grense-Querprofil (28/07–1/08/1964).

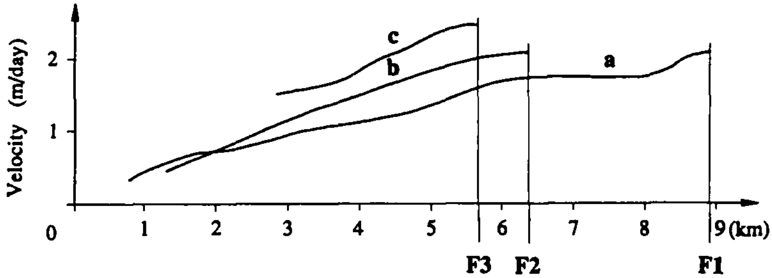

Fig. 4. Longitudinal velocity profiles. The origin on the distance axis is the confluence between Kongsvegen and Kronebreen. a and b = velocities along an axis located between the moraines m1 and m2 (see Fig. 2). a. in 1964 from D.D.R. expeditions; b. between 1962 and 1979 from Lefauconnier 1987; c. between the 8/08 and the 7/09/1986 from the present work. Dates of front positions F1: 1964, F2: 1979, F3: 1986.

1967; Vivet & Lliboutry 1978). On the other hand, the period with maximum flow speed may change from year to year but probably by no more than two or three weeks.

In July 1986, at the most active part of the front, mean velocities were 4.33 m, 4.01 m and 3.80 m/day during the periods 8–14, 14–23 and 23–29 July respectively (Lefauconnier 1987). The same author, using aerial photographs and satellite images, found a fairly constant mean annual velocity around 2.15 m/day for the whole period 1964–79. All these velocities correspond with the velocities obtained by Pillewizer et al. (1967) and those mentioned above.

The velocity profiles obtained from the present work may be compared with the profiles reported by the D.D.R. expedition. The 1986 front profile, noted P1(a-s) in Fig. 3, presents a shape similar to F1 and F2, front profiles from 1962 and 1964. The transverse profiles P2 and P3, located at 1.5 and 2.4 km respectively from the 1986 front, present a shape identical to the profile H located about 1.7 km from the 1964 front. The profile G, about 5 km from the 1964 front, is not comparable to any other profile, even though it is located very close to the profile P3. The D.D.R. profiles (see F1, F2, H and G) were used by Voigt (1969) to study and define the modes of the flow at the glacier tongue of Kongsbreen. These modes have been maintained along the discussed period. The longitudinal profiles (Fig. 4) located along a medial moraine (see m1 in Fig. 2) also present a comparable shape. Altogether this information shows that the velocity in one point is directly the ablation period, the velocity between 8 August and 7 September is logically slightly greater than the mean annual velocity. The mean annual velocity at the front was constant between 1964 and 1979. It may thus be assumed that the mean annual velocity at the front in 1986 was very close to the constant value of 2.15 m/day. The annual velocity profile at the front (P1(y) in Fig. 3) may be extrapolated from the profile during the period 8 August–7 September (P1(a-s) in Fig. 3).

Calving rate

The front positions in May, August and September 1986, and thus the annual retreat, were determined from the three SPOT images. Lefauconnier (1987) carried out echo-soundings and topographical work during the period 1983–86. Using photogrammetry, front positions and altitude of the ice were determined. Moreover, due to the retreat of the front, it was possible in 1986 to carry out one echo-sounding at a location corresponding to the 1983 front position (Fig. 2); thus the bathymetry close to the front was determined as well as the ice thickness. In the three years 1983–86, the change in ice thickness (combination of a possible increase due to the rapid ice flow and a decrease due to the melting) may be considered as negligible.

In one year, the linear calving corresponds to the flow velocity at the front plus the retreat of

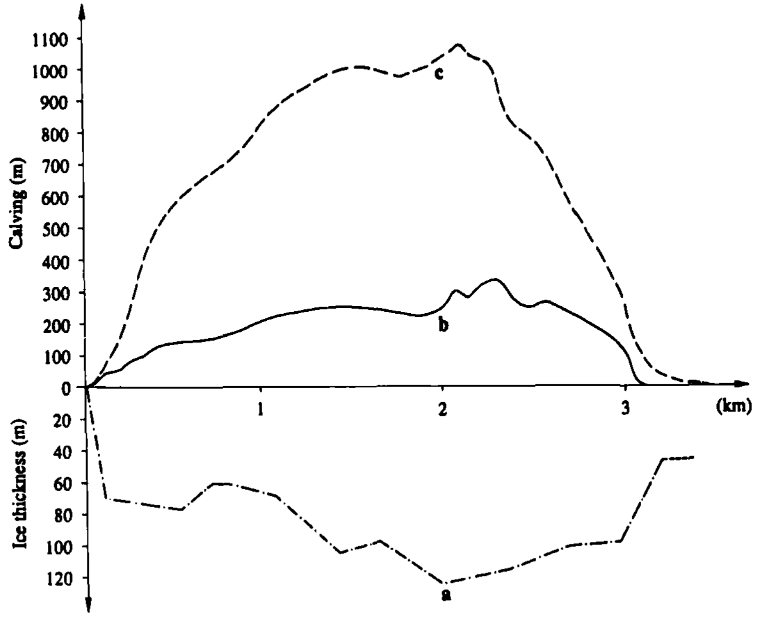

Fig. 5. Linear calving: a. ice thickness; b. retreat of the front; c. linear calving (retreat of the front plus annual ice flow at the front).

the front (Fig. 5). This linear calving is zero along both sides where the ice is stagnant or nearly stagnant, and reaches a maximum value close to 1100 m in the most active part. The measured ice thickness at the front varies from 45 up to 120 m; the total annual calving is then 0.25 km^3 per year. This is a maximum value since the volume of crevasses is not taken into account. This is also the highest present calving rate registered in Svalbard for a glacier during the quiescent period between surging active phases.

Discussion and conclusion

The combination of one panchromatic and two multichannel SPOT images from May, August and September 1986 allowed surface velocities measurement at the tongue of Kongsbreen. The accuracy of the measurements is difficult to estimate due to the use of multichannel images with a pixel of 20 m resolution and the relatively limited displacement of a number of surface features due to the close dates of recording. The present findings are consistent with the results from previous topographic works. Because the good preservation of a number of features at the glacier surface during summer which is the most active period, there is no doubt that some patterns are also preserved from year to year. For example, one of the most remarkable crevasses along Collethøgda was still observed in the field in 1987. The study shows, then, that multichannel as well as panchromatic SPOT images with a recording interval of one year will permit determination of annual flow speed and calving rate of active calving glaciers in Svalbard. Moreover, the use of panchromatic images alone will permit carrying out such work on less active Svalbard glaciers, and the use of images recorded with a periodicity of two, three or four weeks will allow identical determination on tide-water glaciers during a surge.

While the front has been permanently retreating, the velocity in one point, at a given distance from the front, was constant during the entire period 1964–86. The velocity is between zero and 2.15 m/day or zero and 785 m/year, and the annual calving is 0.25 km^3. Since the beginning of balance measurements in 1987, the net balance of Kongsvegen has been slightly positive (Hagen & Liestøl 1990). This is due to the weak calving of this glacier as its flow is blocked by Kronebreen, the main stream. The balance at the surface of Kronebreen, taking into account the accumulation and the ablation by melting (i.e., without the calving) has been recently estimated (Lefauconnier et al. in press). The balance at the glacier surface was b = + 0.12 m in water equivalent during the period 1986–1991. When introducing the calving, the net balance was bn = − 0.13 m w.eq. The front of Kongsbreen retreats between zero and 300/year at an average close to 200 m/year. Within a few years, due to the present retreat, the length of the tongue subjected to buoyancy will be reduced; the flow velocity and the calving will also decrease. Finally, the glacier will tend toward a positive balance; the ice flow will not compensate the surplus of accumulation and the glacier will start a building up which can initiate a new surge. Due to the present climate, according to the study by Lefauconnier and Hagen (1991), a possible new surge of Kongsbreen will be of a lesser scale than the 1869 surge.

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