PREDOMINANT FREQUENCIES IN THE SPECTRUM OF ICE-VIBRATION EVENTS

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Abstract

Examples of ice-vibrations recorded in the Hans Glacier (South Spitsbergen) in spring-summer 2002, and in the Pasterze Glacier (Alps) in the fall of 2003 have been analysed. The spectral analysis of the recorded vibrations reveals a relationship between the period of vibrations and the scale of dynamic processes in a given glacier. Predominant frequency of ice-vibrations recorded in the Pasterze Glacier is higher than that of the events in the Hans Glacier, where the scale of dynamic processes in much greater. The presented spectra of the ice-vibration seismic events display characteristic frequency maxima related to the scale of dynamic processes taking place within a given glacier.

Key words: glacier seismicity, icequakes, ice vibrations.

1. INTRODUCTION

Seismic events in a glacier region can be divided into two categories: icequakes associated with the release of stresses accumulated in ice, and ice-vibrations of a relatively long duration (from few to tens of seconds), in the spectrum of which a relatively low frequency (1-12 Hz) predominates. The latter events are most probably related to large-scale dynamic processes within the glacier, e.g., a flow of a considerable part of the glacier due to gravity or uplift forces (Górski, 1997).

We present here a comparison of selected seismic events of ice-vibration type recorded at the Hans Glacier in Spitsbergen and Pasterze Glacier in the Alps. The two glaciers differ considerably as to their location and climatic conditions.
The study of seismic events in the Hans Glacier was begun in 1962 (Lewandowska and Teisseyre, 1964). For the last 25 years the study has been made incessantly, based on the recordings of seismological observatory of Polish Polar Station Hornsund. Also, seasonal measurement campaigns have been organized, using seismometers placed at the glacier surface. The analysed ice-vibrations in the Hans Glacier were recorded in August 2002 both by the stationary seismometers and the seismometers placed directly on ice.

The recording on Pasterze Glacier was part of a broad project of the study of rotation waves. The recording was made from 30 September through 2 October 2003.

2. BACKGROUND

The Hans Glacier is a Subarctic Glacier flowing into the sea, located at a distance of 13° from the North Pole. It is a polythermal glacier, its length reaches 16 km, mean dip is 1.7°, the width nearby the head (500 m from the head) is about 2.5 km, from the side of the sea the glacier is bounded by a 1.5 km wide ice cliff. The Hans Glacier occupies an area of approximately 57 km². It is an outlet glacier with many side glaciers. The substratum in the major part of its main stream is below the sea level (the maximum depression reaches 100 m), the ice thickness in the ablation zone is 100-200 m, the maximum glacier thickness being 400 m. The head retreats some 17 m per year (the mean value estimated since 1936).

The Pasterze Glacier is an Alpine Glacier situated in the Eastern Alps. It is about 9 km long and about 1 km wide. It starts at an elevation of 3454 m and extends down to 2100 m asl. Its mean dip is 8° but in the recording site the dip is comparable to that of the Hans Glacier. Every year the glacier looses 20 m of its length. The maximum glacier thickness exceeds hundred meters.

![Fig. 1. Location of sources of ice-vibrations on the Hans Glacier (Spitsbergen). The gray circles indicate sources of ice-vibrations, squares are sites of seismometers, asterisk marks the icequake epicenter. The heavy line marks the glacier margin.](image)
At the Hans Glacier (Fig. 1) the ice-vibrations were recorded by seismometers placed in 11 sites (5 being the station network sites and 6 the glacier network sites). At a relatively large number of sites, the recordings made it possible to determine the location of the ice-vibration source area. The source location procedure was based on the determination of time differences in the whole wave packets recorded at particular sites (on the seismograms of vibration events, neither the arrival of phases of different wave types nor the exact beginning of the record can be distinguished). At the Pasterze Glacier the recording was made at one site. For analysis we used a seismogram recorded by one of the vertical seismometers belonging to the rotation wave recording arrangement. The seismometers of the Hornsund station, Hans Glacier network, and those at the Pasterze Glacier are all a short-period \((T = 1.5 \text{ s})\) seismometers of the same type. The seismometers were placed in the ablation zone of the Pasterze Glacier (Fig. 2).

3. RESULTS AND CONCLUSIONS

For comparison we chose two events from each glacier. The displacement seismograms of vertical components of ice-vibrations recorded at the Hans Glacier are shown in Figs. 3 and 4; the figures present also three-dimensional spectra. On both seismograms there is a main phase of the event denoted by letter \(a\). As follows from an analysis of seismograms recorded at all 11 recording sites, the precursory vibrations \(b\) were generated in the same source as vibrations \(a\). The events shown in Figs. 3 and 4 have durations of about 18 and 30 s, respectively. In the region of the main stream of the Hans Glacier, ice-vibrations whose duration was even in excess of 1 minute have been recorded in the past (Górska, 1997). An analysis of recordings at sites nearby the source and those far away of the source leads to the conclusion that the time span through which the vibrations are generated in the source, is comparable to the time of recording. This property has already been observed previously, when the recordings of vibrations at near and very distant sources have been compared (Górska and Teisseyre, 1991). The three-dimensional pattern of the spectrum reveals a distinct maximum around 3 Hz frequency. This frequency occurs throughout the whole recording of the
event and is characteristic for both events analysed. The sources of both vibration events (Figs. 3 and 4) are located within the main stream of the glacier; the event of Fig. 3 is situated at the eastern side and that of Fig. 4 at the western side of the main stream, both being at a distance of few hundred meters from the glacier head. In both regions, the glacier bottom is at a depth of 50 meters below sea level, and the average ice layer thickness is 120 m (Górski, 2003). In both regions, large-scale displacements of ice toward the glacier head take place in the summer, leading to glacier calving.

Fig. 3. Ice-vibration event recorded on the Hans Glacier at 6:27 UTC on 21 August 2002. The displacement seismogram recorded on the glacier is shown in the middle of the diagram. The upper and lower diagrams present three-dimensional spectra as seen from different directions. The horizontal axes are in linear scale, the vertical one in logarithmic scale.
The calving phenomena occur when part of ice in the glacier head whose junction with the rest of the glacier body has been broken slips into the sea, producing short-lived, weak seismic effects. In August, the intraglacial waters have already flown away, and, as a consequence, there do not occur changes in glacier vertical hydrostatic forces related to the displacement and run-off of these waters.

The displacement seismograms and spectra recorded in the ablation zone of the Pasterze Glacier, which in this region is several tens meters thick and about 1 km wide, are shown in Figs. 5 and 6. In the time of measurements (turn of September and October), the Alpine glaciers experience down-going motions. Likewise the Hans
Glacier, the Pasterze Glacier at the time of measurement was deprived of intraglacial waters, regardless, of course, of free streams flowing down. In spite of the previously mentioned large differences in climatic zones of the two glaciers, similar dynamic processes took place in them during measurements: the displacement of ice masses in the direction of glacier flow. In the three-dimensional spectra presented in the figures we observe maxima for frequencies of 9 Hz (Fig. 5) and 10 Hz (Fig. 6); they are three times greater than those observed in the Hans Glacier. This difference may be related to a smaller scale of glacial-dynamic processes in the Pasterze Glacier. The ice-vibrations recorded in this glacier had no precursory phase and were of shorter duration,

Fig. 5. Ice-vibration event recorded on the Pasterze Glacier at 00:53 UTC on 30 September 2003 (description in Fig. 3).
5 and 8 s, respectively. It is to be noted (Figs. 3 and 4) that the precursory-phase vibrations \( b \) at Hans Glacier are slightly shifted towards higher frequencies relative to the main-phase vibrations \( a \), which is probably associated with the growing source area of vibrations in the main phase. The velocity of the recorded waves was estimated at about 2000 m/s. The \( P \)-wave velocity generated by icequakes is 3620 m/s, the ratio of \( P \)- over \( S \)-wave velocity is 2 (Górski, 1999).
A typical icequake spectrum is shown in Fig. 7. The event was recorded on the same day as the ice-vibrations in the Hans glacier described above. In Fig. 1, the icequake focus location is marked by an asterisk. The spectrum has a characteristic flat part in the low-frequency region, which is not observed in the ice-vibrations spectra.

References


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