Iceshock Swarms Observed at Mizuho Camp, Antarctica*

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みずほ観測拠点で観測した氷震*

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要旨: 1973年9月，第14次越冬隊により，上下動1成分の地震計を用いた地震観測がみずほ観測拠点で行われた．観測条件の悪い南極の内陸基地での地震観測の試みは南極点基地以外には例が無いと思われる．基地内の人工的雑音などのため十分な観測ができなかったが合計210時間の間の記録をとることに成功し多くの氷震を観測した．その結果，この地域では気温が −35°C 以下で，その変化の割合が1時間に −2.5°C 以下，または −1°C/hour が数時間続く時には例外なく氷震が発生している．

Abstract: The wintering party of the 14th Japanese Antarctic Research Expedition carried out a temporary seismological observation with one vertical component seismograph at the Mizuho Camp on September 10–27, 1973. The Mizuho Camp is located at about 300 km southeast of Syowa Station in Antarctica, where the ice thickness is about 2,100 m.

The seismological observation was disturbed by the ground noise of many kinds of artificial origin, but good records for 210 hours in total were obtained. Natural earthquakes were not detected by this temporary observation, but many iceshocks, mostly of swarm type, were recorded.

These swarms occurred in the nighttime. The air temperature during the iceshocks was below −35°C, and the falling rate of temperature was −2.5°C per hour for a short period, or about −1°C/hour though the lowering continued for a few hours.

When the largest swarm during this observation period occurred, the wintering members at the Mizuho Camp heard sound from shocks and recognized many cracks on the snow surface around the area of the sound. Therefore, the depth of the swarm was estimated to be very

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shallow. Some shocks were interpreted to have been originated from the upper snow layers quite near the surface, so they may be called snowquakes.

1. Introduction

The studies of iceshocks by Japanese seismologists have been carried out at Lake Suwa and Lake Tatenoumi in Nagano Prefecture of central Japan (OMOTE *et al.*, 1955, 1961), for the purpose of finding out the characteristics of earthquake through the phenomenon of iceshock.

Recently, the movement of glaciers has become worthy of notice as a model of platetectonics (FRANK, 1972). The studies of ice sheets and glaciers in connection with seismology and tectonophysics have been made on several subjects (NEAVE and SAVAGE, 1970; UYEDA, 1974; etc.).

The reason why the seismologists are interested in iceshock is the mechanism of generation of elastic waves in the ice which is a rather homogeneous medium in comparison with the Earth's crust. Merits of applying the physical studies of ice sheets and glaciers to the solid earth physics are considered as follows: 1) Physical constants of ice single crystal and its aggregate (glacier) in which cracks, shocks and other phenomena occur are known. 2) Various physical phenomena such as deformation of ice sheets occur in a much shorter time than the phenomena in the Earth's crust. 3) A kind of large scale model experiment in the model seismology can be done to compare with laboratory experiments on the generation of shock and crack.

On the other hand, only the Antarctica is the main model seismology field of large mass for Japanese seismologists, though the seismic and geodetic observations in Antarctica have many difficulties in actual operation.

In September 1973, the 14th Japanese Antarctic Research Expedition (JARE-14) wintering party at the Mizuho Camp carried out a temporary seismological observation with one vertical component seismograph. The present paper discusses ice and/or snowquake swarms which were recorded during this period.

2. Observation

The Mizuho Camp which is located at 70°42.1′S and 44°17.5′E, 2,180 m in elevation and 2,100 m in ice thickness, about 300 km southeast of Syowa Station. In September 1973, a seismograph with one vertical component was installed in a snow pit of the Camp. The position of the seismograph installed was changed a few times in the Camp, selecting the most suitable place for the observation. However, the ground noise originated from artificial sources such as the power supply generator was large in the pit.

The frequency-magnification curve is given in Fig. 1. The observation with high magnification was not carried out because of the high microtremors in the pit. The maximum magnification was 2×10^4 at the frequency of 20 Hz. Time signals of every second, minute and hour sent from a crystal clock were recorded on the seismogram. The observation was frequently disturbed by the electric noise during the communication with Syowa Station.

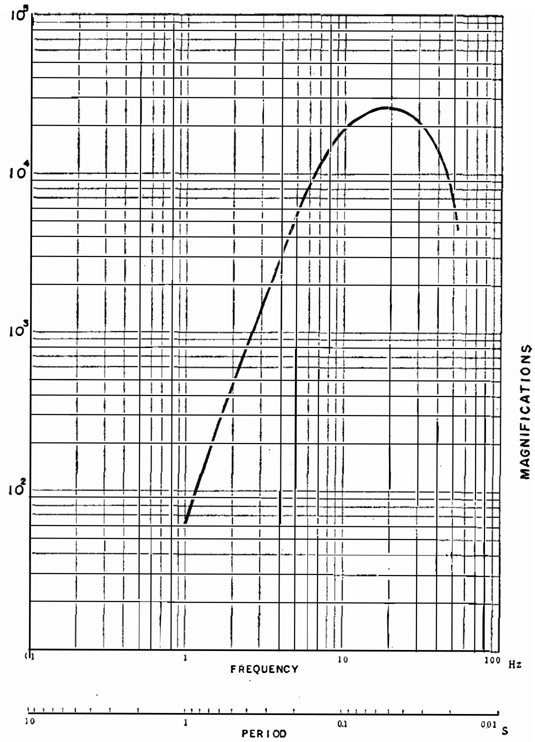

Fig. 1. Frequency-magnification curve of vertical seismograph at Mizuho Camp.

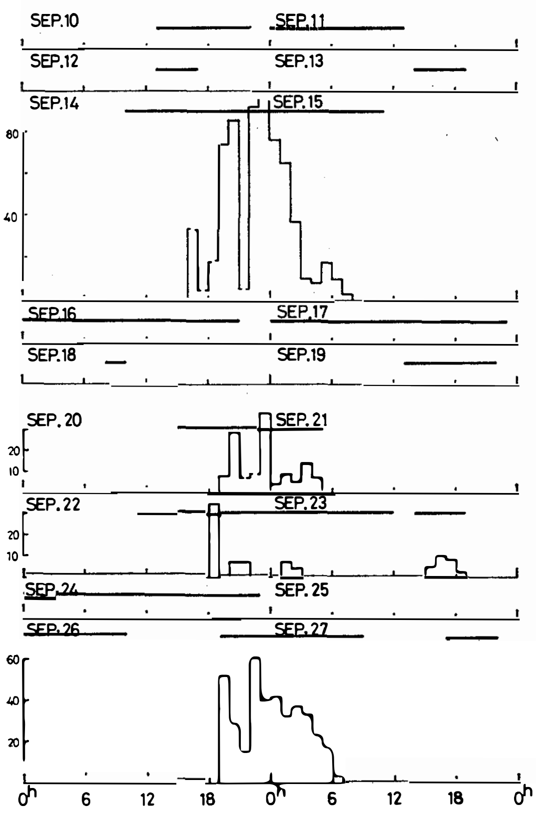

Fig. 2. The hourly occurrence of iceshocks recorded at Mizuho Camp. Columns with open tops are the number of shocks counted on seismogram, but exact number was not counted due to some trouble of recording system. The solid horizontal lines show the periods of observation in which shocks are detected on seismograms.

The observation was carried out between September 10 and 27. The seismogram on which earthquakes are detected was obtained through 210 hours. No natural earthquakes were observed during this period, but a great many iceshocks, mostly of swarm type, were recorded.

3. Iceshock Swarm

The period of observation in which the earthquakes are detected on the seismograms is shown by a solid horizontal line in Fig. 2. The hourly numbers of occurrence of iceshocks counted from 00 min to 59 min of each hour on the seismograms are shown in the histgrams in Fig. 2. The abscissa of Fig. 2 is the hours in two days. Columns with open tops show the number of shocks which were counted on the seismogram in one hour. The exact numbers of shocks in those columns were not counted because

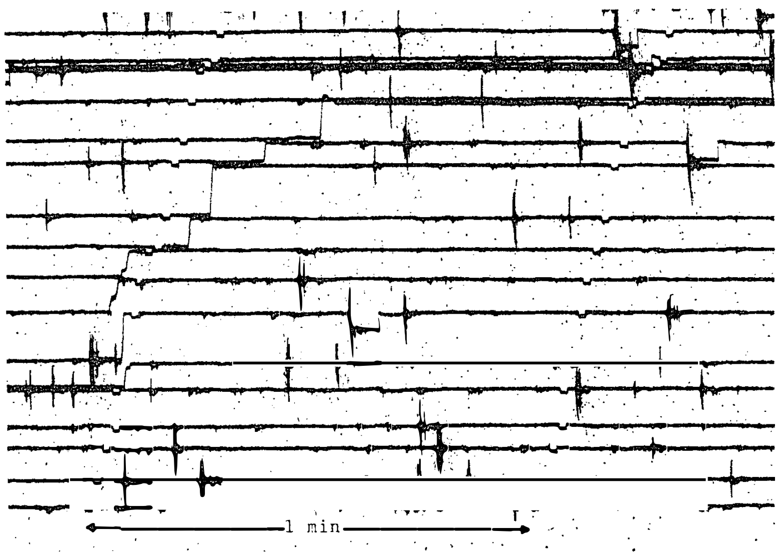

Fig. 3. An iceshock (or snowquake) swarm recorded at Mizuho Camp from September 14 to 15, 1973.

the lines of records overlapped. As is shown in Fig. 2, the maximum hourly number of iceshocks was 103 from 23: 00 to 24: 00 hours of the 14th, and the largest iceshock swarm occurred from the evening of September 14th to the morning of the 15th; a part of seismogram is shown in Fig. 3. About 320 shocks were recorded during three hours from 22: 00, 14th to 00: 40 on the 15th. More than 200 shocks have amplitudes larger than 10 mm on the seismogram, which will be discussed later.

In the midnight of the 14th men at the Mizuho Camp were surprised at remarkably strong sounds. They found a very large iceshock swarm trace on the seismogram.

After they recognized the swarm on seismogram they went out to an area, about 100 m from the Camp, where the sound was supposed to be generated. They observed many cracks there on the snow surface.

Several iceshock swarms were recorded during the observation period of 210 hours. Almost all the swarms occurred in nighttime, especially at midnight.

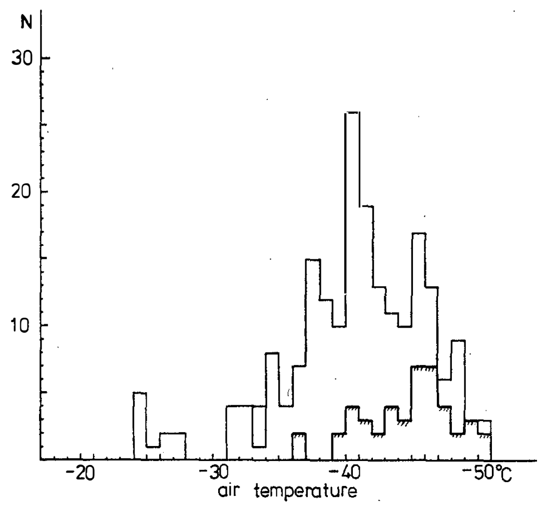

Fig. 4. The number of occurrence of air temperature at every hour during 210 hours in which the good records were obtained. The hatched column means the number of occurrence of iceshocks recorded within one hour after reading the temperature.

4. Analysis and Discussion

4.1. Relation between iceshocks and air temperature

The air temperature around the Mizuho Camp in September was between -20°C and -50°C. Hourly readings of air temperatures during the observation period of 210 hours were classified into intervals of 1°C such as -20.0°C~ -20.9°C. The accuracy of temperature measurement is about ± 0.5°C. The number of occurrence of air temperature readings is given in Fig. 4. The hatched column means the number of occurrence of air temperature that iceshocks occurred within one hour after recording the temperature. The temperature most frequently recorded ranged between -30°C and -50°C and the highest frequency was around -40°C. It is clear in Fig. 4 that the iceshocks occurred when air temperatures were below -35°C. In other words, air temperature below -35°C is one of the causes to generate iceshocks.

An abrupt change in air temperature will give thermal stress on the surface layer of ice sheet and will cause iceshocks, so the time variation of air temperature will be statistically treated. For the period of seismological observation, frequencies of decreasing and increasing rate of air temperature within one hour were counted at intervals of 0.5°C and the results are shown in Fig. 5. The abscissa is the rate of temperature change and the ordinate is the number of occurrence; the column with a solid line is the frequency of the air temperature change. The column with a broken line is the frequency of air temperature change when iceshocks occurred within one hour

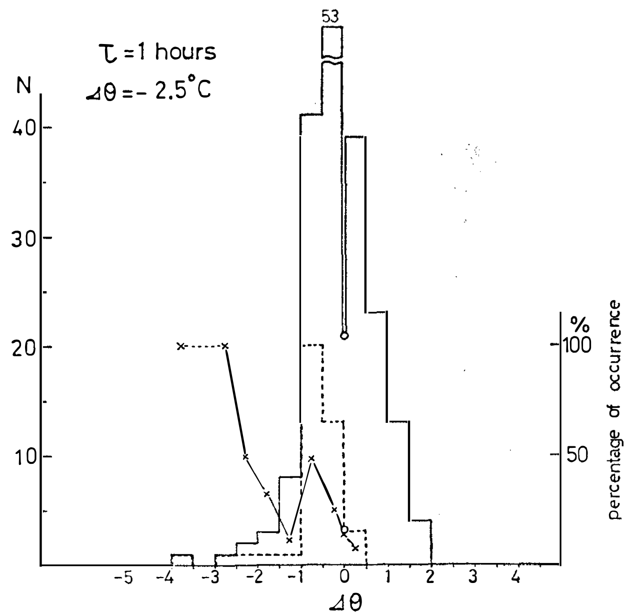

Fig. 5. Frequencies of air temperature change within one hour. The column with broken lines is the frequency of air temperature change accompanying iceshock occurrences within one hour after that temperature change. Crosses are the percentage of iceshock occurrence versus the air temperature change. Open circle in the upper part is the frequency of occurrence of no air temperature change within one hour. Open circle below is the frequency of air temperature change accompanying iceshock occurrences within one hour after no temperature change.

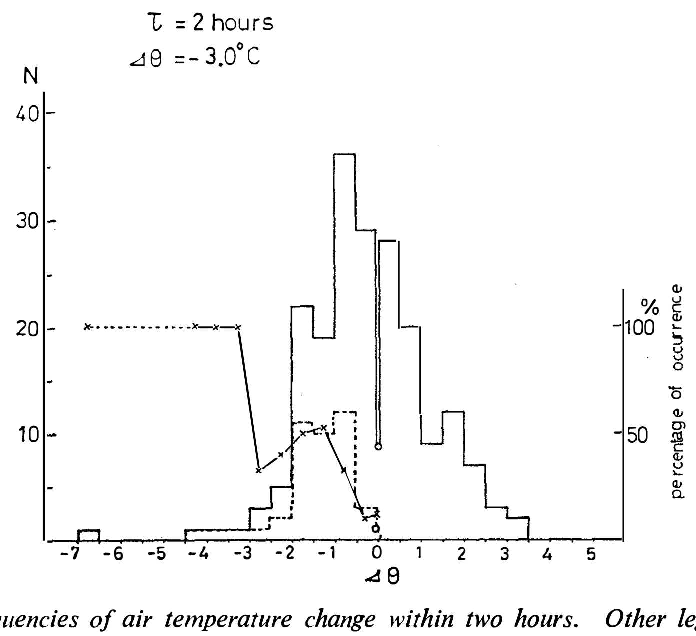

Fig. 6. Frequencies of air temperature change within two hours. Other legends are the same as in Fig. 5.

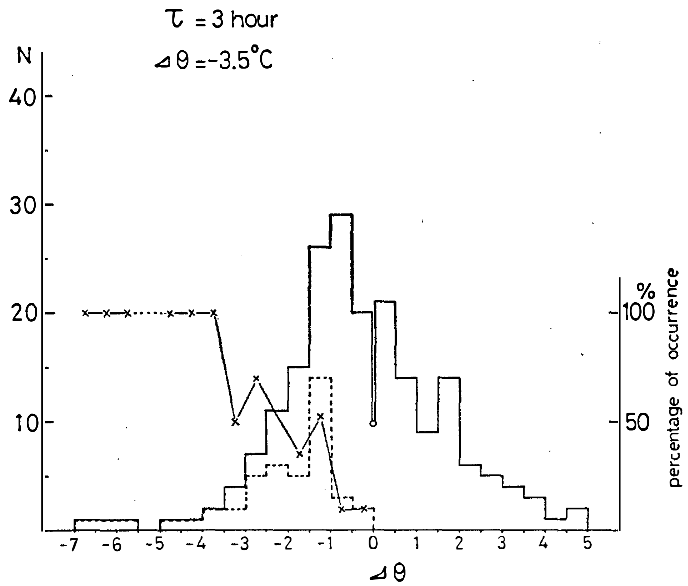

Fig. 7. Frequencies of air temperature change within three hours. Other legends are the same as in Fig. 5.

after that temperature change. The cross symbol is the percentage of iceshock occurrence against the occurrence of temperature change. Open circles show the frequencies when there was no temperature change. Similar statistics were obtained for two different rates of air temperature change within 2 and 3 hours; the results are shown in Figs. 6 and 7 respectively.

The iceshocks always occurred when the temperature decreased; one exception was shown in Fig. 5 when the rate of the change was possitive at the interval of 0.0°C/hour to 0.5°C/hour. The critical values of temperature decreasing rate to generate iceshocks were −2.5°C per one hour (Fig. 5), −3.0°C per two hours (Fig. 6) and −3.5°C per three hours (Fig. 7). It was −3.5°C per four hours, though not shown in the figure.

The conditions of air temperature at which the iceshocks always occur are as follows: 1) The air temperature is below −35°C. 2) The decreasing rate of air temperature is −2.5°C per one hour or the decreasing rate is about −1°C/hour but it continues for a few hours.

4.2. Amplitude

Neither the location of shocks nor the depth was determined, because the observation was made with only one vertical component. As mentioned before, a few members at the Mizuho Camp observed many cracks on the snow surface of the area of the sound

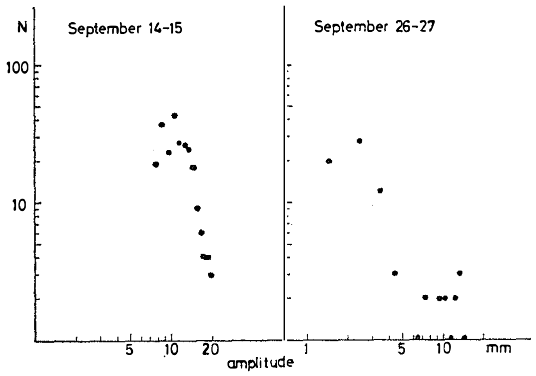

Fig. 8. The relation between maximum amplitude and frequency of shocks that occurred on September 14 ~ 15 and September 26 ~ 27, 1973.

when the largest swarm occurred from September 14th to 15th. Therefore, the depths of these shocks are estimated to be very shallow, nearly the surface snow layer of the ice sheet. But the horizontal distribution of this swarm and the locations of other swarms were not identified. The maximum amplitude of shocks and its frequency for two large swarms on September 14 ~ 15 and on September 26 ~ 27 are shown in Fig. 8.

There is a well-known relation called ISHIMOTO-IIDA's equation between the maximum amplitude of natural earthquakes and its frequency expressed as

$$N(A)\,dA = KA^{-m}\,dA$$

where A is the observed maximum amplitude of an earthquake, $N(A)$ is the number of earthquakes with the maximum amplitude between A and $A+dA$, and K and m are numerical constants.

The meaning of m value in this equation has been discussed by many researchers.

The large m value means relatively heterogeneous and the small one means relatively homogeneous medium in which earthquakes occur. The m value for volcanic earthquakes is mostly larger than 2.0 and that for earthquake swarms is also sometimes larger than 2.0. The m value of iceshocks obtained by OMOTE *et al.* (1955) is $m=1.8\pm0.2$, that of iceshocks recorded at Syowa Station is $m=1.99$ (KAMINUMA, 1971) and that reported by LUOSTO and SAASTAMOINEN (1970) who discussed iceshocks recorded in the Nurmijärvi seismological station of Finland is 1.55. These values of m are almost identical with the values of natural earthquakes.

It seems impossible to find out ISHIMOTO-IIDA's relation for iceshock swarms as given in Fig. 8. The shocks with the maximum amplitude less than 8 mm on the seismograms are hardly observed in the case of the swarm on September 14 ~ 15, although the seismograph used in the observation at the Mizuho Camp was capable to record all shocks which amplitudes were larger than few milimeters. It is clear in Fig. 8 that the shocks with amplitude less than 5 mm did not occur in this swarm.

The shocks that occurred on September 14~15 are not icequakes in ice-medium but quakes in the snow layers very close to the surface. The main reason for identifying the shocks as snowquakes is that men at the Camp heard sound and observed many cracks on the snow surface of the area of the sound when the shocks were recorded.

The reason why no large shocks with the amplitude more 15 mm were recorded in the swarm on September 26~27 is explained as follows: 1) The magnitude of this swarm is smaller than that on September 14~15. 2) The shocks on September 26~27 were located in a more distant place than those on September 14~15.

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