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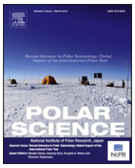

A quantitative evaluation of the annual variation in teleseismic detection capability at Syowa Station, Antarctica

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Abstract

In this study, we evaluate the annual variation in teleseismic detection capability at Syowa Station (69.0°S, 39.6°E) located in East Antarctica, a variation that has been noted in previous studies. For the quantitative evaluation of the annual variation, we introduced a statistical model of a magnitude–frequency distribution of earthquakes covering the entire magnitude range. The annual variation in the model parameter that quantifies the detection capability was then estimated by using Bayesian analysis. In the estimation, we incorporated the annual variation in air temperature at the station and succeeded in clarifying the significant effect that the variation in temperature has on the teleseismic detection capability.

Keywords: Earthquake detection capability; Annual variation; Syowa Station; Bayesian statistics; Statistical seismology

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1. Introduction

The atmosphere-ocean-cryosphere system in polar regions is currently the focus of attention from the point of view of the climate change, such as the global warming (see Kanao et al., 2012a). The quantification of the relationships between the parameters showing the behavior of the complex multi-sphere system is expected to propose a new indicator to monitor changes in environmental conditions in polar regions.

In this study, we attempt to model the teleseismic detection capability at Syowa Station (69.0˚S, 39.6˚E) located in East Antarctica by considering the effect that the annual variation in air temperature at the station has on the detection capability. Kanao et al. (2012a,b) have already noted the annual variation in the teleseismic detection capability at the station, focusing on the minimum magnitude of detected events. The main cause of the variation is thought to be the increase in the thickness of sea ice and the increase in its area in the Antarctic Ocean in winter. The increase in the coverage of sea ice restrains the generation of sea waves around the station, and consequently the noise level in seismic records in winter is lower than in summer (Grob et al., 2011). In other words, the lower temperature in winter enhances the detection capability, and it is reasonable to presume that, to some extent, the annual variation in temperature affects the detection capability.

There are climatic/environmental factors other than temperature that likely affect the detection capability.

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For instance, variations in wind speed cause variations in the amplitudes of microseisms (e.g., Hillers and Ben-Zion, 2011), resulting in variations in the detection capability (Iwata, 2014). However, as suggested by Grob et al. (2011), the increase in sea ice coverage plays the most dominant role in microseismic power in Antarctica, and it has a solid relationship with the air temperature. As described below, we applied a statistical model with a very large number of parameters to evaluating quantitatively the detection capability. Including multiple climatic/environmental factors in the statistical modeling would create many challenging problems in numerical computation, and thus we include only the air temperature in this study.

To ascertain the annual variation, the aforementioned studies focused on the time history of the minimum magnitude of detected teleseismic events at Syowa Station, which implies that the variation has been evaluated only qualitatively. However, it is fundamental to evaluate quantitatively the variation in the detection capability in order to propose an indicator to measure the environmental conditions. Likewise, quantification of the correlation between the detection capability and some of the environmental parameters is of great importance.

Therefore, in this study, our aim is a quantitative evaluation of the annual variation in the teleseismic detection capability and its modeling with the incorporation of the temperature data. In both the evaluation and the modeling, we applied a modified version of the magnitude–frequency distribution proposed by Ogata and Katsura (1993) and the Bayesian approach developed in Iwata (2008, 2013a, b).

2. Earthquake dataset

The earthquake dataset examined in this study is from the hypocentral catalog compiled by the National Institute of Polar Research, Japan. The focal parameters are determined on the basis of identified seismic phases recorded by seismograms at Syowa Station. Details of the phase identification and determination of the focal parameters are described in Kanao et al. (2012b). All the events contained in the catalog are teleseismic ones, and all event-station epicentral distances are greater than 10°, and 99% are greater than 30°. The data period ranges from January 1987 to December 2007, and all events with determined magnitudes were analyzed. Consequently, the number of analyzed events is 19,044. The magnitude scale of this catalog is given as the body-wave magnitude scale defined by the National Information Earthquake Center of the United State Geological Survey (NEIC/USGS) (e.g., Utsu, 2002).

As briefly mentioned in Section 1, the main interest of this study is the annual variation in the teleseismic detection capability at Syowa Station. Thus, the earthquake data were divided into periods of 1 year and these 1-year sequences were stacked; the stacked sequence was analyzed to determine the annual variation, which is shown in Sections 4.2 and 4.3. In the stacking procedure, there was a need to consider the difference in the number of days contained in leap and common years (366 and 365 days, respectively), and therefore we excluded the events that occurred on 29 February (leap day) of the five leap years during the data period (1988, 1992, 1996, 2000, and 2004). After the exclusion, 19,041 events remained. We also examined cases when the occurrence times, measured in days of the year, of the events in the five leap years were multiplied by 365/366 in the stacking procedure, and found that the results changed only slightly.

3. Statistical model for quantitative evaluation of detection capability

To evaluate earthquake detection capability quantitatively, we use a variation of the statistical model representing the magnitude–frequency distribution of all observed earthquakes proposed by Ogata and Katsura (1993). In the model of Ogata and Katsura (1993), the probability distribution of magnitude M is assumed to be a product of two probability density functions. The first is an exponential distribution, which is equivalent to the Gutenberg-Richter (GR) law (Gutenberg and Richter, 1944). The second is the detection rate of earthquakes $q(M)$, the probability of detecting earthquakes with magnitude M. Ringdal (1975) initially suggested using the cumulative distribution function of a normal distribution as the probability of earthquake detection:

$$q(M|\mu,\sigma) = \int_{-\infty}^{M} \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right] dx. \quad (1)$$

The parameter μ corresponds to the magnitude at which the probability of detecting an earthquake is equal to 50%, so the detection capability becomes lower as the value of μ becomes higher. Because this suggestion is supported by several studies (Ogata and Katsura, 1993; Woessner and Wiemer., 1995; Iwata,