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Seismicity Monitoring based on Time Intervals between Successive Earthquakes

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Abstract

We propose a method to monitor regional seismicity based on time intervals Δt between successive earthquakes. We make use of frequency distribution of Δt accumulated from its shorter side and set a criterion to specify degree of seismic activity in a small block divided within a wide region. Through the criterion which varies block by block depending on its past seismicity, we can know present seismic state in every block. Finally we obtain regional seismicity as a whole by integrating individual block seismicities.

Applying this method to the region in and around Hokkaido, we examined how it monitored actual seismicity from April, 1999 to October, 2000. Eight earthquakes of M 5.5 or larger occurred in the above period and low seismicity appeared before six of eight. Only one low seismicity did not precede any large event. However, it was accompanied by the eruption of Usu volcano and also by many earthquake clusters occurring in wide region of Hokkaido.

These results suggest that the method is sensitive to regional stress change in the crust. It may be a promising tool to predict a remarkable crustal event in time, though it does not show where the event occurs.

1. Introduction

It has been reported that seismicity far beyond the focal region of a large earthquake changes before and/or after its occurrence. Fig. 1 shows epicenter distribution of shallow earthquakes in and around Hokkaido located by Japan Meteorological Agency (JMA), with focal regions of some large earthquakes. Fig. 2 represents cumulative number of earthquakes occurring in the boxed area shown in Fig. 1. A decrease in seismicity is recognized several years prior to the 1982 Urakawa-oki Earthquake of M 7.1 (star in Fig. 1). The investigated region is clearly wider than the focal region of this event. Moreover, other decreases in occurrence rate of earthquakes are seen before both the 1952 Tokachi-oki Earthquake of M 8.2 and the 1968 Tokachi-oki Earthquake of M

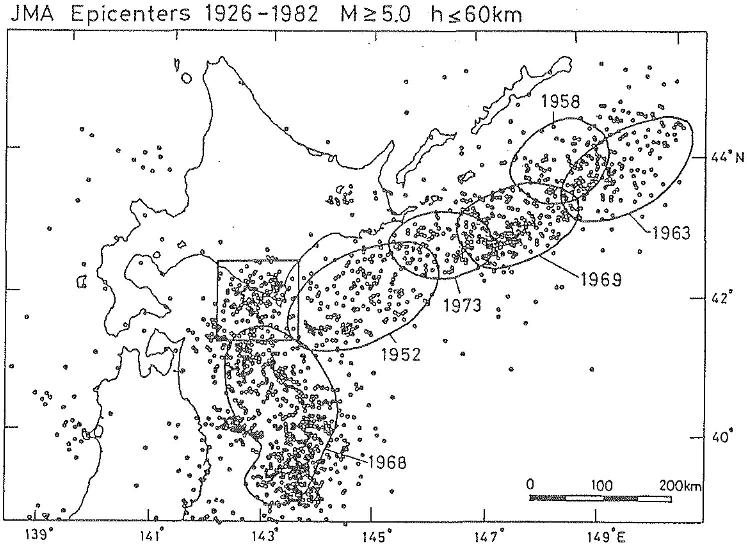

Fig. 1. Epicenter distribution of earthquakes located by Japan Meteorological Agency (JMA). Enclosed regions are focal regions of large earthquakes of M≧7.4 which occurred in the marked year along the Pacific coast. See Fig. 2 for the boxed area. A star there represents the 1982 Urakawa-oki Earthquake of M 7.1.

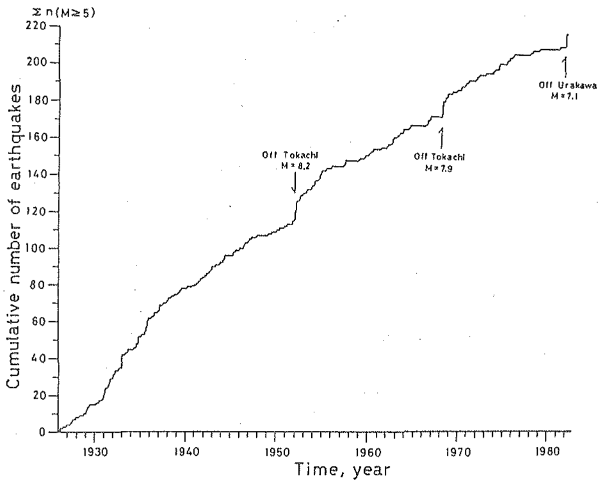

Fig. 2. Cumulative number of earthquakes which occurred in the boxed region shown in Fig. 1.

7.9. The investigated area is far from the focal regions of the two large earthquakes as shown in Fig. 1.

The case above shows that it is important to investigate seismicity in rather wide area. We propose a method to monitor seismicity in and around Hokkaido and note a preliminary result obtained hitherto.

2. A method to monitor regional seismicity

For the study of seismicity in some region, it is necessary to use a complete earthquake catalog which contains all earthquakes larger than some magnitude occurring in the region concerned. However, there is hardly such catalog especially over long time span because of change in detection capability of earthquakes in seismic networks. Usually the more recent, the more events in a catalog. If we use only earthquakes large enough not to be lost, we must miss information from smaller events. And also, as larger events occur much less frequently, we encounter a difficulty to detect short term change in seismicity.

We propose a method based on time intervals Δt between successive earthquakes to specify seismicity in a wide region as a whole, using all earthquakes located there. We can naturally assume that Δt become shorter when earthquake occurrence rate, or seismicity is high.

2.1 Seismicity in a small block

We divide the region in and around Hokkaido into $1^{\circ}\times 1^{\circ}$ blocks and calculate Δt, time intervals of successive events which occurred in every block. In order to specify degree of seismic activity in a block, we make use of frequency distribution of Δt accumulated from its shorter side.

In a block where many earthquakes occur frequently, most of Δt are expected to be short. For example the case that no earthquake occurs for only two days off Urakawa, known as one of the most seismically active regions in our territory, is considered rare. On the contrary, in a block where earthquakes occur infrequently, Δt over one month is not so rare. Thus, we can take degree of rarenesss of some Δt as an index of low seismicity for every block.

Though we are free to fix the rareness level, we tentatively take the time interval when cumulative frequency of Δt reaches 80% of the total as a threshold value L for low and 90% as VL for very low seismicity, respectively. We consider seismicity to be low or very low when no earthquake occurs beyond these intervals.

Earthquakes occurring in and around Hokkaido have been observed by

Research Center for Earthquake Prediction (RCEP) from July 1976 to March 1998 and later on by Institute of Seismology and Volcanology (ISV), Hokkaido University. We use all hypocenters of earthquakes shallower than 100 km located by RCEP or ISV.

Taking a dataset composed of recent successive 100 earthquakes including the latest one which occurred in a block, we determine values of L and VL. If number of events located from the beginning of our observation is still under 100 there, the block is not used. Examples of cumulative Δt curve are shown in Fig. 3. The ordinate is the cumulative frequency of Δt and considered as an experiential probability. In the block off Urakawa, half of successive events occur within 0.3 days, indicating the block is in very high seismicity. For this region L is 1.0 and VL is 1.5 days, respectively. In the block off Shakotan, on the other hand, median of the distribution of Δt is 8.6 days and intervals longer than two weeks or so are not rare.

When an earthquake occurs in a block, it is added to and the oldest event is removed from the dataset. Thus L and VL are always renewed. The renewal of thresholds is preferable to fixed ones, because the renewed one reflects temporal background seismicity changes occurring, for example, in an aftershock sequence or earthquake swarm. This is the case of blocks being aftershock regions of the 1993 Hokkaido Nansei-oki Earthquake of M 7.8, west coast of Oshima Peninsula and the 1994 Hokkaido Toho-oki Earthquake of M 8.1, off Shikotan Island.

Finally we can determine whether seismicity in every block on any day is low L or very low VL, comparing it with the past seismic activity there. Examples of spatial distribution of seismicities of every block are shown in Fig. 4. It is clearly seen that the pattern of distributions changes rather drastically. The day, February 3, 2000, showed that most of inland Hokkaido was in normal and that small number of blocks were under normal seismicity. On the contrary, nearly half of blocks were of low or very low seismicity on April 28, 2000.

We have investigated temporal change in each block seismicity with relation to some remarkable crustal activity such as, large earthquake, earthquake swarm, or volcanic activity. However, any profitable result has not been obtained yet.

2.2 Regional seismicity

We simply define low seismicity index R for regional seismicity in and around Hokkaido as a whole with the ratio of number of blocks of low seismicity (L and VL blocks) to total number of blocks. In this case spatial

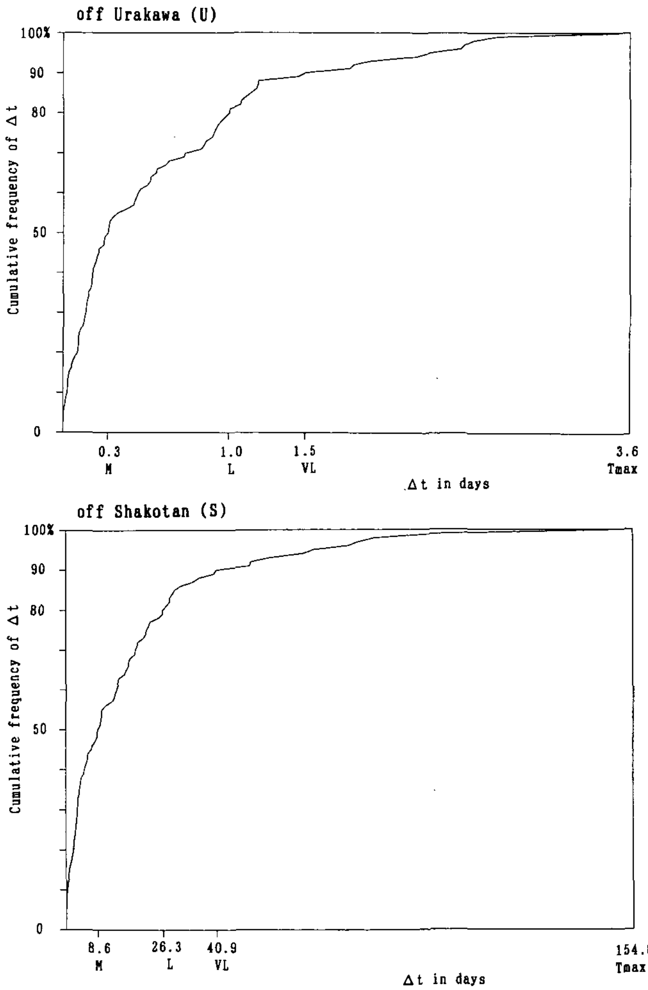

Fig. 3. Cumulative frequency of Δt, time intervals between successive earthquakes. M, L, VL, and $T_{\max}$ are median, threshold for low, that for very low seismicity, and the longest interval, respectively. Dataset as of October 1, 2000 is used. See Fig. 3 for the block region (U) and (S).

distributions are not considered. Moreover, present seismicity depends on the past seismicities during various lengths in every block. So, R may be a value of some strange aspect.

Anyway we can monitor regional seismicity using R every day. In section 4, we show that temporal change in R may have some relation to remarkable crustal activities.

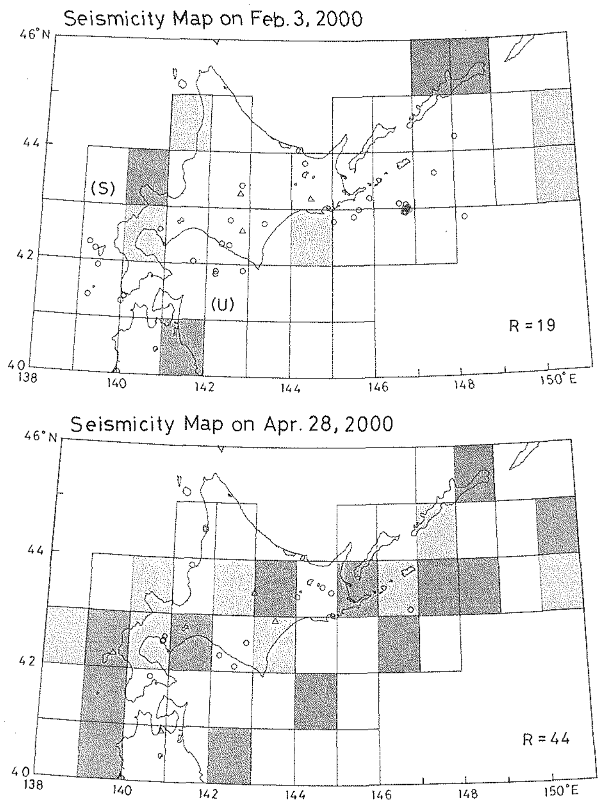

Fig. 4. Spatial distributions of block seismicities. Thick, thin, and open blocks are of very low, low, and normal seismicity, respectively. Epicenters of earthquakes occurring on the day are shown with circles (shallow) and triangles (deep focal depth). *R* is the low seismicity index. See Fig. 3 for (S) and (U).

3. Seismicity in and around hokkaido from April, 1999 to October 2000

Fig. 5a shows the investigated region and epicenters determined by JMA from April, 1999 to October, 2000. Plotted earthquakes are shallower than 120 km depth and larger than or equal to M 3.0. They are large enough to be located without missing, judging from linearity of the Gutenberg-Richter relationship. An earthquake of M 6.8, the largest in the investigated period, occurred off Shikotan Island on January 28, 2000 and was accompanied by many aftershocks. No change in occurrence rate of earthquakes is recognized before this event (Fig. 6).

Motoya (1999) showed that stress state of the crust is well expressed by

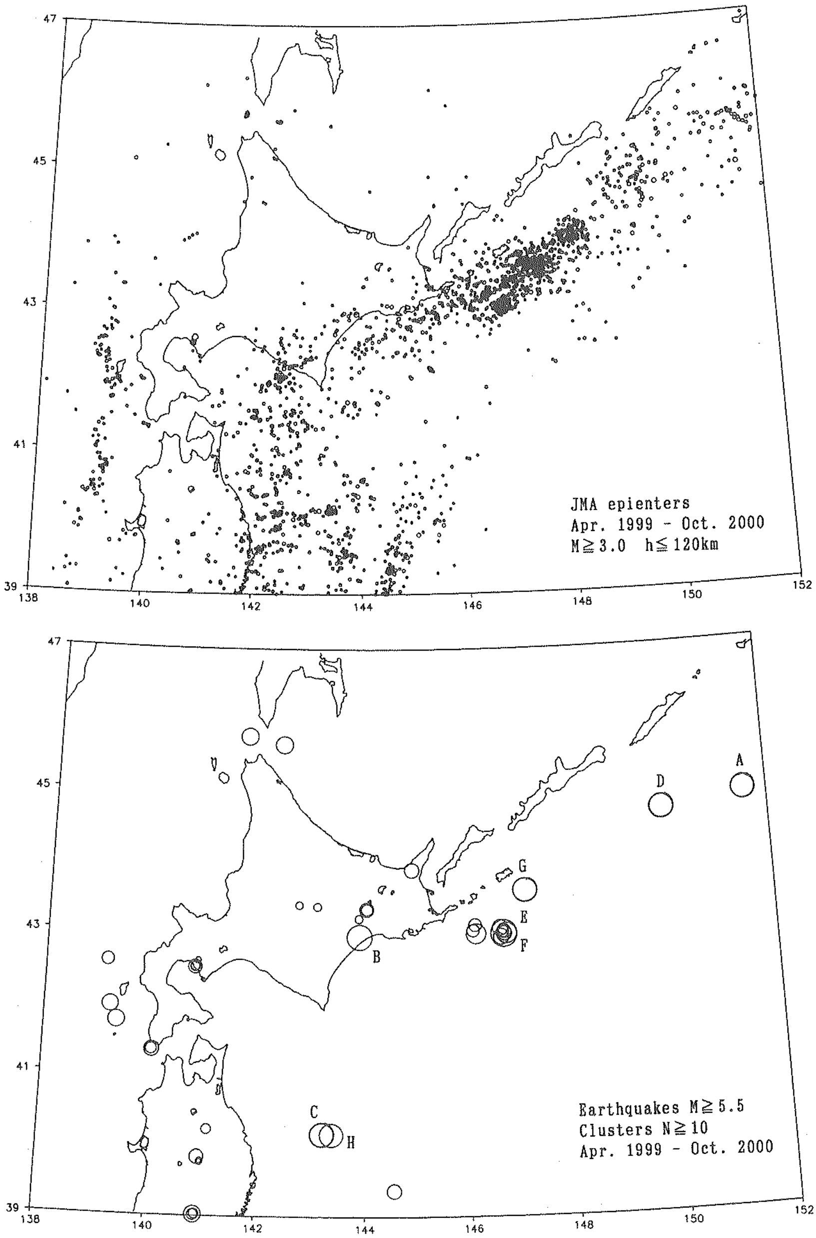

Fig. 5a. (Upper) Distribution of earthquake epicenters.
5b. (Lower) Distribution of earthquake clusters in which ten or more events are included. Epicenters of earthquakes of M≧5.5 are also shown. A-H is the same as in Fig. 8.

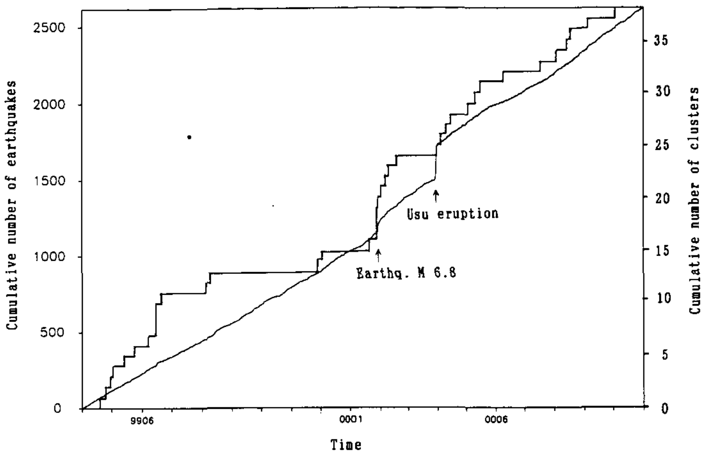

Fig. 6. Cumulative number of earthquakes shown in Fig. 5a and clusters in Fig. 5b.

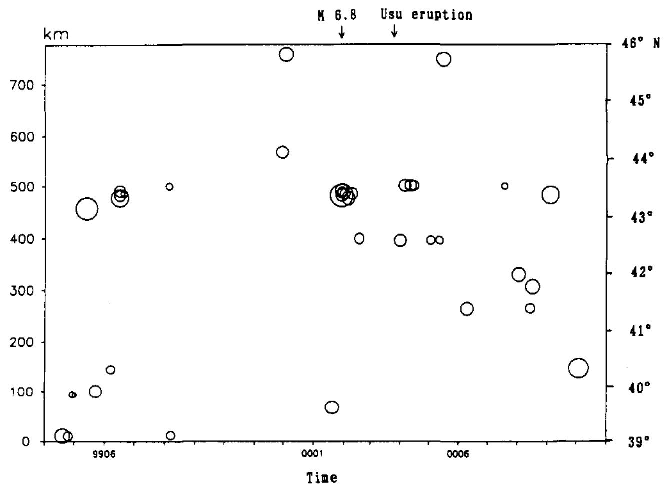

Fig. 7. Space-time plot of earthquake clusters shown in Fig. 5b.

earthquake clusters defined by a criterion which requests that successive events in a cluster are within both 1 day and 5 km each other. We find out earthquake clusters in the region shown in Fig. 5 by the same method. But in this case we use all events regardless of their magnitude. Fig. 5b shows spatial distribution of rather large scale earthquake clusters in which more than or equal to ten events are contained. While occurrence rate of earthquakes does not change before the largest earthquake of M 6.8 as mentioned above, frequency of clusters decreased clearly several months prior to the event (Fig. 6). Time-space distribution of earthquake clusters (Fig. 7) shows that most of clusters inland of northern Honshu and off Sanriku occurred before June, 1999. Many earthquakes occurred in and around Usu volcano from March 27 and the volcano erupted on March 31, 2000, after 23 years dormancy. Fig. 7 also shows that many earthquake clusters occurred in wider region after this volcanic activity.

4. Monitoring seismicity

We describe how our method monitors characteristics of the seismicity mentioned in the previous section. Fig. 8 shows the result of monitoring regional seismicity. Occurrence times of earthquakes larger than or equal to M 5.5 which occurred in the region shown in Fig. 5 are marked with long arrows.

A previous study (Kasahara et al., 1993) in which seismicity was investigat-

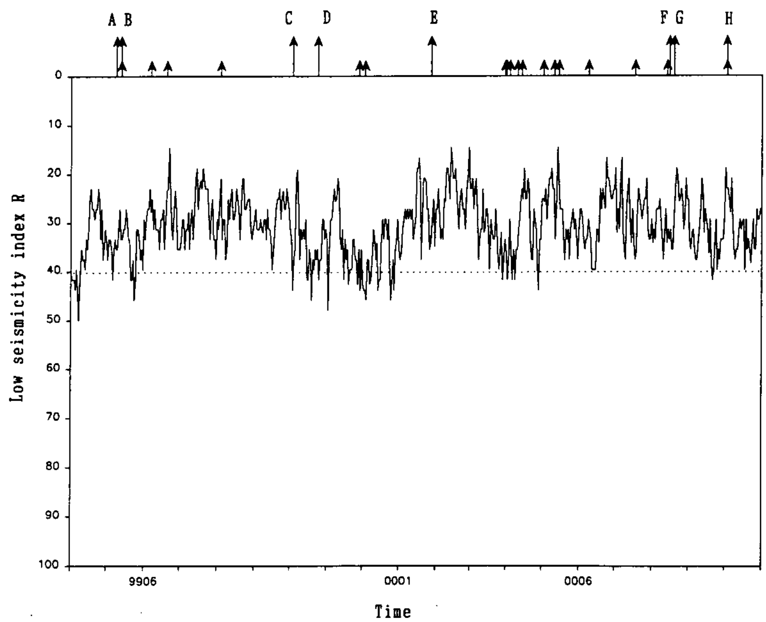

Fig. 8. Daily change of low seismicity index R. Long arrows show occurrence times of earthquakes of M≧5.5 whose epicenters A-H are given in Fig. 5b. Short ones represent earthquake clusters in Fig. 5b, excluding clusters south of 40°N and in the focal regions of the 1993 Hokkaido Nansei-oki Earthquake of M 7.8 and the 1994 Hokkaido Toho-oki Earthquake of M 8.1. Dotted line is a tentative warning level for low seismicity which may precede some remarkable crustal activity.

ed by nearly the same method in this paper shows that change in regional seismicity has a good relation to occurrence of large earthquakes. Decreases in seismicity appeared before 11 of 16 events of M larger than or equal to 6.5 which occurred in and around Hokkaido from July, 1976 to March, 1993. Fig. 8 reveals that the largest earthquake of M 6.8 (E) occurred after low seismicity before this event recovered from around end of 1999 and that low seismicity appeared also before the second largest earthquake on M 6.4 on May 13, 1999 (A). If we tentatively take a warning level of R 40%, low seismicity is seen before 6 of 8 events of M 5.5 or larger.

Another previous study (Faculty of Science, Hokkaido University, 1988) suggests that low seismicity appears before some remarkable seismic activity such as main shock-aftershock sequence or earthquake swarm, even if the largest event in the sequence is smaller than M 5.5. We remove earthquake clusters occurring south of 40°N and in the two aftershock regions of the 1993 Hokkaido Nansei-oki Earthquake and the 1994 Hokkaido Toho-oki Earthquake from ones shown in Fig. 5b. Occurrence times of the remaining clusters are added with short arrows in Fig. 8. These clusters concentrate in nearly the same time of or after the Usu volcano activity. They may relate to the low seismicity from end of March to April, 2000 which did not precede any earthquake of M 5.5 or larger.

5. Discussion and concluding remarks

We propose a method to monitor regional seismicity based on time intervals between successive earthquakes. We estimate seismicity in every small block divided from a wide region and simply define a low seismicity index R for regional seismicity with the ratio of number of blocks under normal seismicity to total number of blocks.

As regional seismicity is integrated with seismicities in a small block in which earthquake detection capability is safely stable, we can use all earthquakes regardless of their magnitude. If we fear that small events are not always located all over the region and use only events larger than some level, we must miss information from smaller events. We believe that even a microearthquake should have some background to occur, even if we do not understand what it is at present.

Estimated seismicity of some blocks may not be correct because of mislocation of earthquakes. However, it may not affect regional seismicity R seriously because the number of defective blocks is only a part of the total. Moreover, a short interruption of seismic observation may not make R change so much because the period without data occupies usually a small part in the span from the latest earthquake to present time. So, R is considered to be rather robust in actual use.

Applying it to the region in and around Hokkaido from April, 1999 to October, 2000, we examined how our method monitored characteristics of actual seismicity and confirmed it worked rather well. Low seismicities were recognized before six of eight earthquakes of M 5.5 or larger. The only one low seismicity not accompanied by any large event relates to remarkable earthquake clusters. These results suggest that the method is sensitive to regional stress change in the crust.

Finally, we remark that R has some strange aspect. Regional seismicity is integrated with block seismicities during variously long past time block by block. Figuratively speaking, we see various afterimages at the same time. As mentioned above, however, R can be a good indicator for stress change over a wide area as a whole. This means that using even small earthquakes in low seismic block and not using earthquakes over 100 in high seismic block may balance delicately.

Considering that remarkable crustal activity follows regional low seismicity in many cases, the method may be a promising tool to predict large earthquake, remarkable earthquake swarm, or volcanic eruption in time, though it does not show where the event occurs.

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