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Irregularity of Inter-Event Interval of Diastrophism

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Abstract—One of the main factors of earthquake is stress increase due to mutual moving processes of base rocks in a plate deep beneath the earth's surface. Recently, the seismic activity of diastrophism has been analyzed. Using GPS-based control station data by converting into inter-event interval (IEI) of the diastrophism occurrence, we investigated its irregularity using several measures for analyzing inter-spike intervals of neural signals. As a result, we confirmed that the IEI irregularity statistics increase before large-scale earthquakes occur.

1. Introduction

Earthquakes occur during the process of the fluctuation in deep part of plates constituting the earth. Plural marine plates sink under plural continental plates around the Japanese Islands. Complicated forces are driven by plural plates. Then, Japan is one of the most eminent earthquake-prone zone in the world. Therefore, various methods are proposed to predict when, where and how large earthquake occurs[1, 2].

It has been reported that very small size diastrophism is observed by GPS(Global Positioning System)-based control station just before large-scale earthquakes occur[3]. The GPS-based control station is a device that receives the information of the position coordinate from the satellites using GPS. In Japan, there exist approximately 1,300 stations. They located approximately every 20km, and these stations are managed by Geospatial Information Authority of Japan.

2. Data

In this paper, we used a daily value of GPS-based control station data offer service offered by Geospatial Information Authority of Japan[4]. Daily position coordinate information in these data consist of the information of the GPS-based control station in all over Japan. Among various data, we used a three-dimensional coordinate values as shown in Fig. 1. The direction from the center of gravity to the intersection Greenwich meridian and the equator is set as the X-axis, the direction from the center of gravity to the intersection of 90° meridian east the equator is set as the Y-axis, and the direction from the center of gravity to the North Pole is set as the Z-axis. Figure 2 shows three-dimensional coordinate values from January 1st, 1999 until April 16th, 2016, observed in Matsunoyama[1]. From Fig. 2, we can find that these coordinate values fluctuate every day and they suddenly show a large fluctuation on March, 2011. This is because of the Great East Japan Earthquake Disaster occurred in March 11th, 2011.

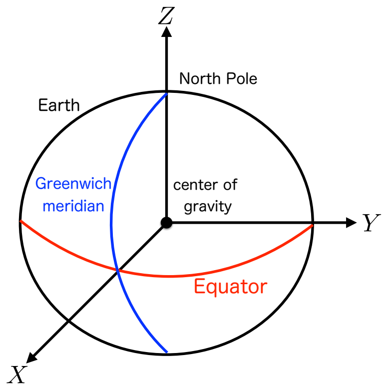

Figure 1: Schematic illustration of the three-dimensional coordinate[5].

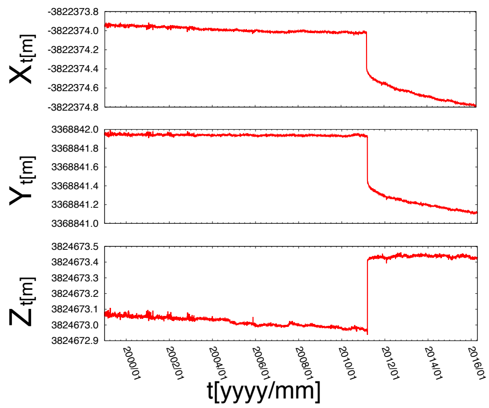

Figure 2: Time series of three-dimensional daily coordinate values from January 1st, 1999 until April 16th, 2016, observed in Matsunoyama. The horizontal axis is time [yyyy/mm] and the vertical axis is the coordinate values of each axis.

[1] 37°07′91′′ North latitude, 138°60′87′′ East Longitude

3. Method

We transformed the three-dimentional coordinate values to a distance of the movement. We defined the distance d_t by Eq. (1):

$$d_t = \sqrt{(x_t - x_{t-1})^2 + (y_t - y_{t-1})^2 + (z_t - z_{t-1})^2} \qquad (1)$$

Namely, the distance d_t is defined as difference between coordinates $(x_{t-1}, y_{t-1}, z_{t-1})$ of the day $t-1$ and (x_t, y_t, z_t) of the day t with three-dimensional coordinates values. Figure 3 shows a time series of the distance d_t using the three-dimensional coordinate values as defined by Fig. 2. From Fig. 3, we can find that these coordinate values fluctuate every day, however the values suddenly show a great fluctuation on March, 2011, which is the same tendency as shown in Fig. 2.

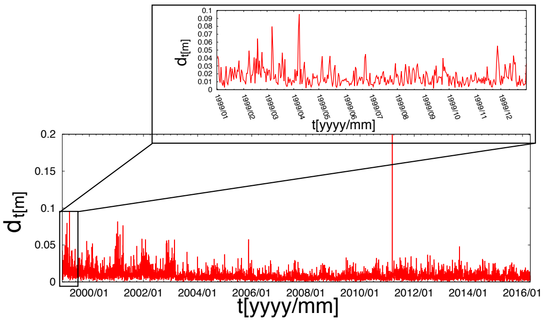

Figure 3: A time series of d_t from January 1st, 1999 until April 16th, 2016 observed in Matsunoyama. The horizontal axis is time [yyyy/mm] and the vertical axis is the distance d_t[m] defined by Eq. (1).

To analyze the data, we transformed the distance time series d_t to a point process. Namely, by setting a threshold θ for the distance d_t which we defined in Eq. (1), we generated a point process in which an event is defined as a time when d_t exceeds the threshold θ.

Using the obtained point process, we investigated an irregularity of the inter-event interval(IEI) using two statistics: LV[6] and IR[7]. These statistics are used to analyze the inter-spike interval(ISI) in the field of neuroscience. The indices, LV and IR, quantify local variations of IEI, defined as follows:

$$LV = \frac{3}{n-1} \sum_{i=1}^{n-1} \frac{(X_i - X_{i+1})^2}{(X_i + X_{i+1})^2}, \qquad (2)$$

$$IR = \frac{1}{n-1} \sum_{i=1}^{n-1} \left| \log \frac{X_i}{X_{i+1}} \right|, \qquad (3)$$

where $X_i (i = 1, 2, \cdots n)$ is the i th IEI and n is the total number of IEI.

It is possible to quantify the deviation using a statistic such as the coefficient of variation(CV). However, CV depends on the occurrence rate of IEI and it is not suitable for non-stationary data analysis. Thus, We analyzed LV and IR that do not depend on the occurrence rate of IEI.

If the observed point process obeys a Poisson process, LV takes 1 and IR takes $2 \log 2$. On the other hand, both LV and IR take 0 for perfectly a regular point process. To obtain reliable results, it is inevitable to have a larger number of IEI. Then, in this paper, we set the number of IEI as $n = 100$.

4. Results

We investigated the earthquake occurred in Niigata Prefecture, Japan, October 23th, 2004. This earthquake is called the Niigata Prefecture Chuetsu earthquake. This earthquake was a large-scale earthquake whose magnitude is 6.8 and shindo is 7, which is a Japanese intensity scale. We used the data observed in Matsunoyama and Izumozaki[2] which is located within the range of 50km from the epicenter (Fig. 4).

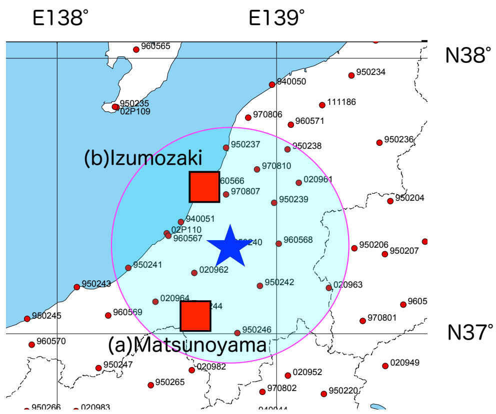

Figure 4: The observation points which we used for analyzing the data of the Niigata Prefecture Chuetsu earthquake. The epicenter is marked by ★ and ■ is the observation point: (a)Matsunoyama and (b)Izumozaki. The blue circle represents the region of radius 50km from the epicenter. This map is made based on [4].

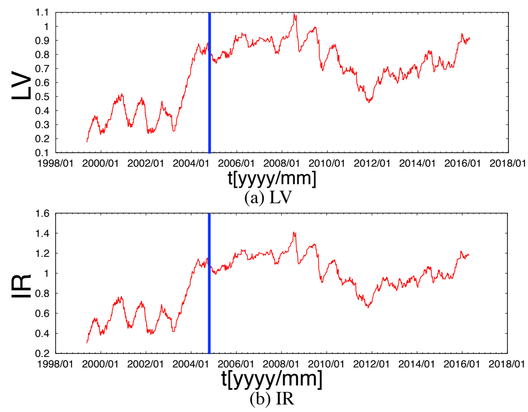

Figure 5: Temporal changes of (a)LV and (b)IR from January 1st, 1999 until April 16th, 2016 at the observation point of Matsunoyama($\theta = 0.01, n = 100$). The horizontal axis is time [yyyy/mm] and the vertical axes are (a) LV and (b) IR.

[2] 37°53′58″ North latitude, 138°70′69″ East Longitude

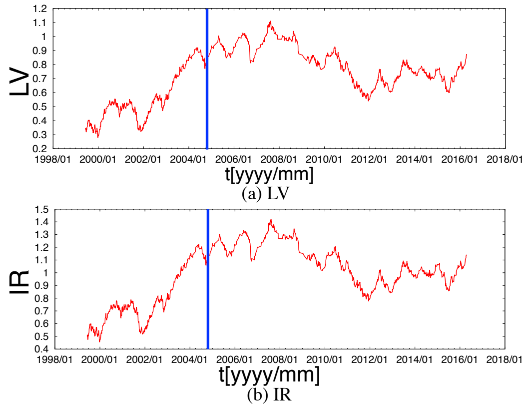

Figure 6: Temporal changes of (a)LV and (b)IR from January 1st, 1999 until April 16th, 2016 in the observation point of Izumozaki ($\theta = 0.01, n = 100$). The horizontal axis is time [yyyy/mm] and the vertical axes are (a) LV and (b) IR.

Figure 5 shows the temporal change of LV and IR obtained from IEI with $\theta = 0.01, n = 100$ in Matsunoyama. Figure 6 shows the temporal change of LV and IR obtained from IEI with $\theta = 0.01, n = 100$ in Izumozaki. Blue vertical bars in Figs. 5 and 6 show dates of the occurrence of the main shock. As shown in Fig. 5, it is also revealed that LV and IR suddenly rise from March, 2003 to March, 2004 before the occurrence of the main shock. From Fig. 6, it is also revealed that LV and IR suddenly rise from January, 2002 through March, 2004 before the occurrence of main shock. These results indicate that irregularity of the IEI of the diastrophism increases while a short time in these observation points.

Next, we investigated the behavior of each statistic when we changed the threshold of these data. The data consist of daily coordinate values. Therefore, if we set the threshold $\theta = 0$, these statistics LV and IR become 0 because point process becomes periodic. Therefore, it becomes hard to observe the change of the IEI statistics when we set the threshold too low. On the other hand, it becomes hard to get a sufficient number of IEIs when we set the threshold too high. In Figs. 5 and 6, the mean of d_t of Matsunoyama is 0.009354 and the mean of d_t of Izumozaki is 0.008536. Then, we set the threshold $\theta = 0.01$ which is close to the mean of d_t. In the following, we will investigate the behaviors of LV and IR by changing the threshold θ from 0.01.

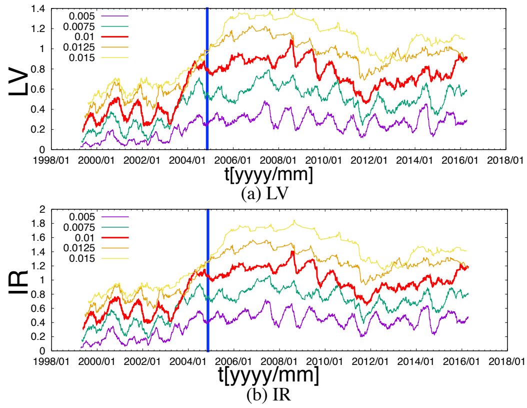

Figure 7: Temporal changes of (a)LV and (b)IR from January 1st, 1999 until April 16th, 2016 at the observation point of Matsunoyama when θ is changed from 0.005 to 0.015 by 0.0025($n = 100$). The horizontal axis is time [yyyy/mm] and the vertical axes are (a) LV and (b) IR.

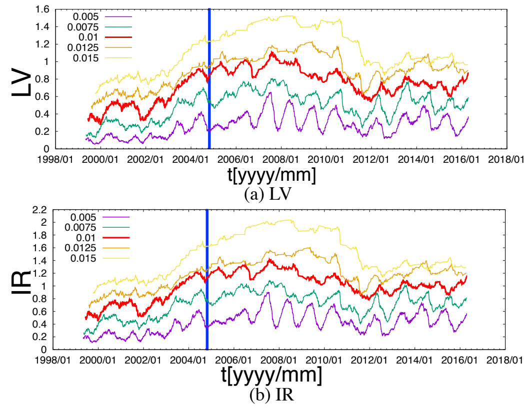

Figure 8: Temporal changes of (a)LV and (b)IR from January 1st, 1999 until April 16th, 2016 at the observation point of Izumozaki when θ is changed from 0.005 to 0.015 by 0.0025($n = 100$). The horizontal axis is time [yyyy/mm] and the vertical axes are (a) LV and (b) IR.

Figures 7 and 8 show the temporal changes of LV and IR when we changed the threshold θ from 0.005 to 0.015 in Matsunoyama and Izumozaki. Thick red lines show the statistics in case that $\theta = 0.01$. As shown in Figs. 7 and 8, statistics increase as the value of θ increases. When the threshold θ increases, only large diastrophism is detected and the obtained point process would be sparse, which makes difficult to visualize the change of the statistics with high time resolution. In addition, in the case that $\theta = 0.0075, 0.01, 0.0125$ and 0.015, we can see the increase of the statistics before the occurrence of the main shock. However, in the case that $\theta = 0.005$, the statistics fluctuate with almost constant small values and no rapid increase. Because the point process becomes regular by decreasing the threshold θ, LV and IR become low.

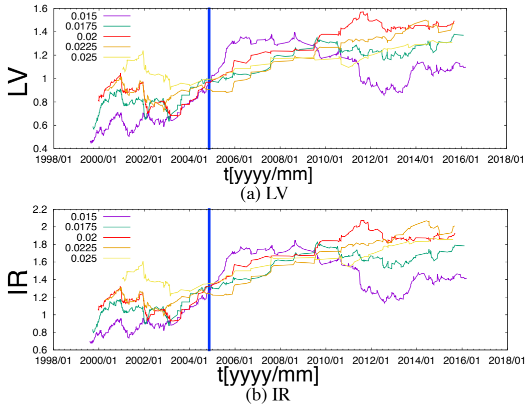

Figure 9: Temporal change of (a)*LV* and (b)*IR* from January 1st, 1999 until April 16th, 2016 at the observation point of Matsunoyama when θ is changed from 0.015 to 0.025 by 0.0025(n = 100). The horizontal axis is time [yyyy/mm] and the vertical axes are (a) *LV* and (b) *IR*.

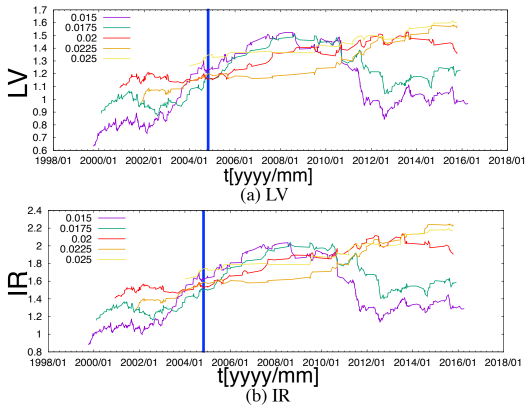

Figure 10: Temporal change of (a)*LV* and (b)*IR* from January 1st, 1999 until April 16th, 2016 at the observation point of Izumozaki when θ is changed from 0.015 to 0.025 by 0.0025(n = 100). The horizontal axis is time [yyyy/mm] and the vertical axes are (a) *LV* and (b) *IR*.

Figures 9 and 10 show *LV* and *IR* when we changed θ from 0.015 to 0.025 in Matsunoyama and Izumozaki. As shown in Figs. 9 and 10, *LV* and *IR* take high values generally and they become smaller when the threshold is higher. This is because the number of event decreases by increasing θ. According to the above results, it is indicated that appropriate value of the threshold which is close to the mean of d_t is necessary for visualizing characteristic behaviors of the statistics.

5. Conclusion

In this paper, we analyzed the interval of the change of three-dimensional coordinate values provided by GPS-based control station, using statistics of *LV* and *IR* that are often used for analyzing a point process in the field of neuroscience.

In Ref.[8], *LV* was used to analyze irregularity of IEIs transformed from time, spatial coordinate and magnitude of earthquake. Different from Ref.[8], we investigated temporal changes of the statistics of IEIs of the diastrophism observed from GPS-based control station data[4].

We analyzed the data of Niigata Prefecture Chuetsu earthquake at observation points located within the range of 50km from the epicenter. As a result, we showed that temporal changes of the statistics *LV* and *IR* were detected before the main shock occurrence. Moreover, we changed the value of the threshold and investigated how these statistics change. It is indicated that if the threshold values are set appropriately, large-scale earthquakes can be detected from the point processes.

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References

[1] T. Nagao, New development of the foretelling an earthquake study, Kin-mirai Co., Ltd, p.210, 2001.

[2] S. Bouali, Y. Shimada, K. Fujiwara and T. Ikeguchi, Possibility of predicting large scale earthquake using time-varying statistics, IEICE Technical Report, NLP2014 113-142, pp. 59-64, 2015.

[3] H. Araki and T. Murai, Earthquake and eruption foresight method, Patent disclosure 2004-226388(P2004-226388A)

[4] Geospatial Information Authority of Japan - GPS-based Control Station data offer service -
`http://terras.gsi.go.jp/ftp_guide.php`

[5] Land surveying system of Japan — Geospatial Information Authority of Japan
`http://www.gsi.go.jp/sokuchikijun/datum-main.html`

[6] S. Shinomoto, K. Shima and J. Tanji, Neural Computation, Vol. 15, No. 12, pp.2823–2842, 2003.

[7] R. M. Davies, G. L. Gerstein and S. N. Baker, Journal of Neurophysiology, Vol. 96, No. 2, pp.906–918, 2006.

[8] X. Zhao, T. Omi, N. Matsuno, and S. Shinomoto, A non-universal aspect in the temporal occurrence of earthquakes, New Journal of Physics, Vol. 12, 063010, 2010.