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17. Monthly Distribution of Large Earthquakes in Japan.

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Abstract

Monthly distributions of small and large earthquakes in the Japanese region are discussed based on recent seismic data. Smaller earthquakes do not show any systematic annual variations. But large earthquakes with magnitude 7.5 and over occurred concentratively in some limited seasons and the active season is different in the two adjacent active regions. This regularity of large earthquakes in the Japanese region is confirmed by historical earthquake data. Regarding all the large earthquakes in the Northern and the Southern Hemispheres, no systematic annual variations can be concluded. This is not inconsistent with the above-mentioned regional regularity.

1. Introduction

Regular temporal distributions of earthquakes, such as the diurnal or the annual periodicity, have been studied by many investigators (e.g. Omori, 1902). According to the fracture theory of earthquakes, earthquakes occur by brittle fracture of the earth's crust when the stress increases to a critical value. If the stress level is held near the critical value for a long time, the time of earthquake occurrence may be markedly affected by a small increase in stress. Therefore, regional variations of small external stresses sometimes cause noticeable regular temporal variations of earthquakes. An example of the very remarkable cases is the typical periodic variation of earthquakes in the Itō earthquake swarm in 1930 in relation to the oceanic tidal loading (Nasu et al, 1931). The study of the regularity in temporal distributions may give a clue to making clear a trigger mechanism of earthquake occurrences.

On the annual variation of earthquakes, a large number of investigations have been made (e.g. Omori, 1902; Davison, 1928; Yamaguchi, 1938). Omori (1902, 1908) concluded, from his observational data, the annual periodicity of small earthquakes in the Japanese region. Davison (1928) who systematically studied this subject for different regions in the world, also concluded that earthquake activity shows annual periodicity in many regions and the maximum epoch in the Northern and the Southern Hemispheres occurs in the same season. Thus, marked annual variations were pointed out in many studies in the initial stage of modern seismology. However, Matuzawa et al (1937), who examined the statistical significance of the annual variation of earthquakes, noted that monthly distributions of small earthquakes in the Japanese region did not show such significant annual periodicity, except for some limited districts. Thereafter, although reliable data have been accumulated, any noticeable studies of this subject have not been made.

For investigation of this subject, sufficient accumulation of data and their suitable analysis are essential. It is interesting to investigate again this subject based on recent reliable data. In this paper, the conclusion obtained by Omori and Davison are reexamined with modern seismic data. The most noticeable result found in this study is that the time of occurrence of large earthquakes in the Japanese region markedly concentrates in certain months.

2. Small earthquakes in the Japanese region

As mentioned above, Omori (1902, 1908) pointed out the annual periodicity of small earthquakes in the Japanese region. However, his earthquake data were often insufficient in number and his conclusion was obtained without any suitable examination for statistical significance. Matuzawa et al (1937) obtained a conclusion different from Omori's results, as mentioned above.

To examine these results, the following earthquake data were used: *the Seismological Bulletin of the Japan Meteorological Agency* (or *JMA*) and *Statistical Data for Earthquakes and Seismological Data for Special Earthquakes* by the Meteorological Research Institute. Some examples of annual distributions of small earthquakes (M: about $4\sim6$) are shown in Figs. 1 and 2. Figure 1 shows some of seasonal frequency distributions of earthquakes which were observed at each seismological observatory of JMA within the P-S time interval of 15 or 30 seconds during the period (1954-1964). Figure 2 shows some of the monthly distributions of earthquakes felt in various districts in Japan and in the whole Japanese region durings the period (1944-1967). To avoid the complexity due to abnormal activities, such as aftershocks and earthquake swarms, abnormally active periods (Yamakawa, 1966) were excluded in this analysis. Aftershock sequences regarded as abnormal activities are generally the events following the main shocks with magnitude 6 and over, so they are discussed as in the case of large earthquakes in a later section. These curves in Figs. 1 and 2 show rather uniform monthly distributions of earthquakes.

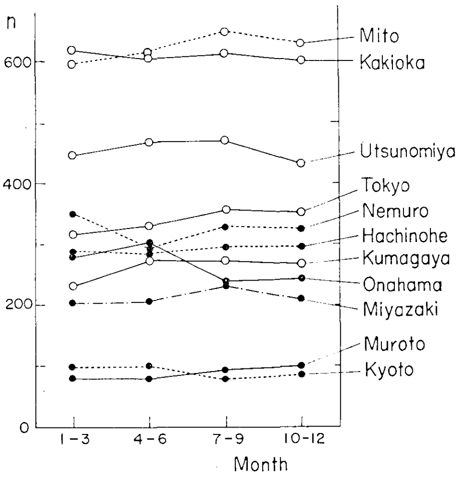

Fig. 1 Seasonal frequency distributions of earthquakes observed at seismological observatories of JMA during the period (1954–1964). open circle: P-S time interval 15 sec or less; closed circle: P-S time interval 30 sec or less.

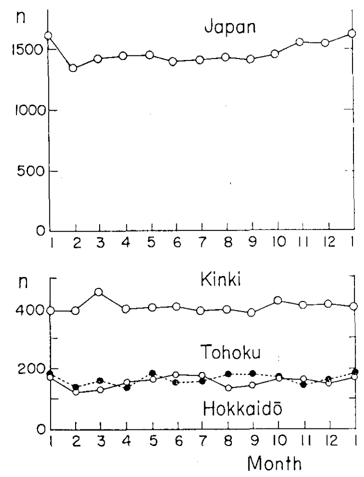

Fig. 2 Monthly distributions of earthquakes felt in Hokkaidō, Tohoku and Kinki districts and in the whole area of Japan during the period (1944–1967). Aftershocks and earthquake swarms are not included.

Thus, it is concluded that small earthquakes (M: about $4\sim6$) during certain recent years in most regions in Japan do not show any noticeable annual variations. The above-mentioned analysis is limited to the Japanese region, and it must be also interesting to investigate this problem in other regions, such as continental regions.

3. Large earthquakes in the Northern and the Southern Hemispheres

One of the conclusions obtained by Davison (1928) is that large earthquakes in either hemisphere occur more frequently in summer. If such systematic annual variation is definitely established, it may give a clue to the trigger mechanism of earthquake generation.

In order to examine the conclusion given by Davison, monthly distributions of shallow earthquakes of magnitude 7 and over since 1900 are used for either hemisphere based on the earthquake list given by Duda (1965), because nearly uniform data in certain long time interval in the world-wide area are available only for earthquakes of magnitude 7 and over. In this analysis, a group of earthquakes, such as a main shock-aftershock sequence and an earthquake swarm, is taken as one earthquake with the magnitude of the largest earthquake among the group, because the earthquakes in the group except the largest one are not regarded as independent events.

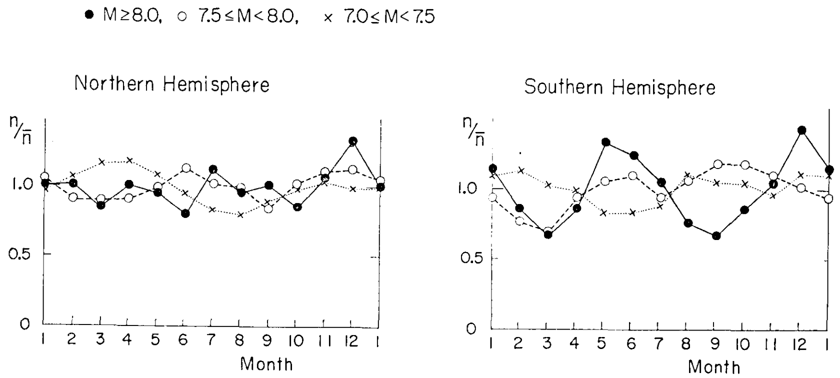

Fig. 3 Monthly distributions of shallow earthquakes with magnitude 7.0 and over in the Northern and the Southern Hemispheres. Earthquakes with focal depths greater than 100 km are excluded.

Figure 3 shows the annual distribution of earthquakes by relative three-monthly mean, for different magnitude ranges ($7.0 \leq M < 7.5$), ($7.5 \leq M < 8.0$) and ($M \geq 8.0$). These distributions show no significant annual variations. Therefore, Davison's conclusion, that large earthquakes show the annual periodicity with the maximum epoch in summer months, is not supported by the present result.

4. Large earthquakes in the Japanese region

As mentioned above, no annual periodicity is seen for all the large earthquakes in the great areas, such as either hemisphere. In smaller areas, however, there is a possibility to show some annual variation of large earthquakes. Recently, Fedotov (1965) pointed out that the strong Kuril-Kamchatka earthquakes ($M \geq 7$ 3/4) during the period (1904–1963) markedly concentrated at a certain month interval. That is, four earthquakes among eleven occurred in monthly intervals from October to November. In this case, however, other earthquakes occurred nearly uniformly in the remaining months: two earthquakes in May and one earthquake in January, February, June and September. In the following, a striking regularity in the Japanese region is described.

Figure 4 shows the locations of focal regions of earthquakes of magnitude 7.5 and over, during the period (1920–1968) in and near Japan, with the numerals indicating the months when earthquakes occurred. These earthquakes are listed in Table 1. For an earthquake sequence, only the largest earthquake is taken, because foreshocks or aftershocks are not independent events. In Fig. 4, it can be pointed out that earthquakes within the areas **A** and **B** surrounded by broken curves

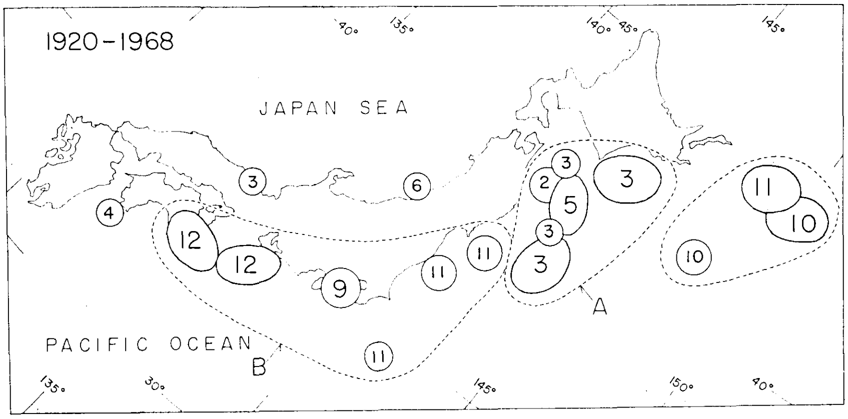

Fig. 4 Locations of focal regions of shallow earthquakes with magnitude 7.5 and over, during the period (1920-1968) in the Japanese region. Numerals indicate the months in which earthquakes occurred.

occurred concentratively in certain seasons. That is, all earthquakes in Region A including the Sanriku-oki earthquake of 1933 and the Tokachi-oki earthquakes of 1952 and 1968, occurred in four months from February to May, particularly four earthquakes in March. All earthquakes in

Table 1. List of earthquakes with magnitude 7.5 and over in and near Japan during the period (1920-1968).

Year	Month	Day(J.S.T.)	Epicenter		Magnitude (JMA)	Region
1920	2	8	40.8°N	142.5°E	7.8	A
1920	10	18	41.4	148.0	7.9	
1923	9	1	35.2	139.3	7.9	B
1927	3	7	35.6	135.1	7.5	
1931	3	9	41.2	142.5	7.6	A
1933	3	3	39.1	144.7	8.3	A
1936	11	3	38.2	142.2	7.7	B
1938	11	5	37.1	141.65	7.7	B
1944	12	7	33.7	136.2	8.0	B
1946	12	21	33.0	135.6	8.1	B
1952	3	4	42.15	143.85	8.1	A
1953	11	26	34.3	141.8	7.5	B
1958	11	7	44.3	148.5	8.1	
1960	3	21	39.8	143.5	7.5	A
1963	10	13	43°45′	149°58′	8.1	
1964	6	16	38 21	139 11	7.5	
1968	5	16	40 44	143 35	7.9	A
1968	4	1	32 17	132 32	7.5	

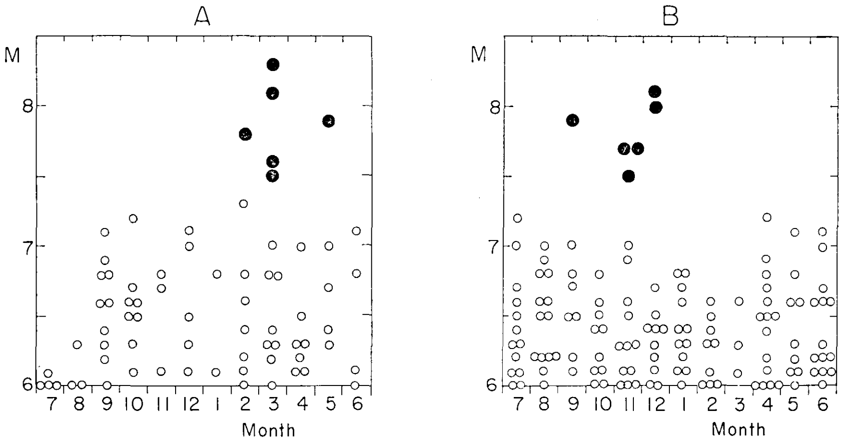

Fig. 5 Monthly distributions of earthquakes with different magnitudes in Regions **A** and **B**. *M*: magnitude of earthquakes.

Region **B** occurred in four months from September to December, particularly the two adjacent great earthquakes, the Tōnankai and the Nankaidō earthquakes, in December at a two-year interval. Figure 5 indicates monthly distributions of earthquakes with various magnitudes which occurred in Regions **A** and **B** during the period (1920–1968). In this figure, the above-mentioned concentration of the largest earthquakes ($M \geq 7.5$) (closed circles) in certain months can be clearly seen, but smaller earthquakes ($6.0 \leq M \leq 7.4$) (open circles) do not show such marked annual variation.

To establish the above-mentioned regularity that the largest earthquakes in both regions concentrate in limited months, the monthly distribution was studied in the case of earthquakes during the period before 1920. For this purpose, the earthquake list obtained from historical documents (Kawasumi, 1961; Usami, 1966) was available. In this case, earthquakes with magnitude 7.9 and over were discussed, because the precision of magnitude determination in historical earthquakes is considerably low. The number of historically recorded earthquakes has appreciably increased since 1600, so the present discussion is made for the period since 1600. These large earthquakes with magnitude 7.9 and over during the period (1600–1919) are listed in Table 2. The epicentral locations of earthquakes listed in Tables 1 and 2 are shown by circles with the numerals indicating the months in which the earthquakes occurred, in Fig. 6. In this figure, also, the above-mentioned concentration of earthquakes at certain months can be pointed out without any serious exceptions. Figure 7 shows histograms of monthly distributions of large earthquakes in Regions **A** and **B**. According to

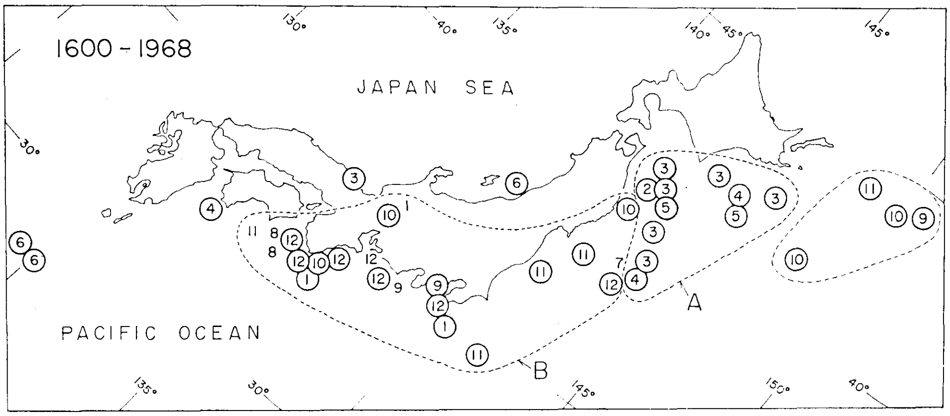

Fig. 6 Locations of large earthquakes during the period (1600–1968) with the months in which earthquakes occurred (circles with numerals showing the months). (Numerals without circles: earthquakes during the period before 1600).

Table 2. List of earthquakes with magnitude 7.9 and over in and near Japan during the period (1600–1919).

Year	Month	Day (J.S.T.)	Epicenter		Magnitude	Region
1605*	1	31	34.3°N	140.4°E	7.9	B
1605*	1	31	33.0	134.9	7.9	B
1611	12	2	38.2	143.8	8.1	B
1677	4	13	38.7	144.0	8.1	A
1703	12	31	34.7	139.8	8.2	B
1707	10	28	33.2	135.9	8.4	B
1843	4	25	41.8	144.8	8.4	A
1854*	12	23	34.1	137.8	8.4	B
1854*	12	23	33.2	135.6	8.4	B
1891	10	28	35.6	136.6	8.4	B
1894	3	22	42.4	146.3	7.9	A
1901	6	24	28°18′	129°18′	7.9	
1910	5	22	41.7	145.3	8.1	A
1911	6	15	28	130	8.2	
1913	10	3	40.0	142.5	8.0	B
1915	3	18	40.7	143.1	(8.0)	A
1918	9	8	45.7	151.8	7.9	

*) These two earthquakes may not be independent events.

the χ^2 test of statistics, the concentration in March or the four months from February to May in Region **A** is highly difficult to be expected from the random occurrence of earthquakes, and the concentration to

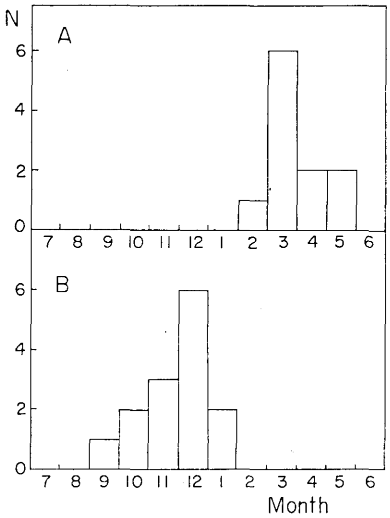

Fig. 7 Histograms of monthly distributions of large earthquakes during the period (1600–1968) in Regions **A** and **B**.

December or the five months from September to January in Region **B** is also an extremely rare case.

Thus, the sharp concentration of the largest earthquakes in a certain season and the marked calmness in the remaining seasons are established in the Japanese region. The boundary between Regions **A** and **B** seems to correspond to a boundary deduced from the seismic activity in the area. Furthermore, in Fig. 6, the concentration of the four earthquakes in the three months from September to November in the region southeast off Hokkaidō, is noticed. In other regions in Japan, however, any noticeable regularity cannot be pointed out because of less activity.

5. Concluding remarks

As mentioned above, smaller earthquakes occur without any appreciable seasonal variations. The large earthquakes in the Pacific side of Japan, however, occurred in the very limited seasons and the active season is clearly different between Regions **A** and **B**. This striking result is not easily explained by current thinking. And its physical interpretation is a future problem in relation to the earthquake generation mechanism. Concerning this problem, it is suggestive that the abovementioned active seasons in Regions **A** and **B** correspond to the seasons in which the mean sea level goes down in each region (cf. Tsumura, 1963).

The empirical law, that large earthquakes occur only in certain seasons, may be very useful to predict the time of the occurrence of large earthquakes, if it is used as a supplement to other seismological techniques.

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17. 日本の大地震の月別頻度分布

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地震の頻度が季節変化を示すということが大森や Davison, その他の多くの人によって報告されているが, 近年この問題を論じたものはほとんどみられない. この問題を論ずるには, 信頼すべき資料にもとづいて, 適切な解析を行うことが重要であるので, 最近の高精度の地震資料によって再検討を加えることは有意義である. 今回の結果によると, 大森や Davison らの指摘した規則性は認められないが, 日本付近の大地震について, 極めて著しい季節的集中性があることが見出された. 要約すると,

1. 日本各地の小さい地震については, 一般に, 有意な季節変化は認められない.
2. 1920 年以降の M 7.5 以上の大きい地震は特定の季節にのみ集中して起こる傾向がみられる. この傾向は, 1600 から 1919 までの大地震 (M 7.9 以上) についても認められ, その集中性は統計的に有意である. その活動の季節は場所によってちがい, 大きい地震は, 北海道・三陸の太平洋側沖合では 2 月から 5 月まで, とくに 3 月に集中し, 宮城県沖から関東・東南海道にかけては 9 月から 1 月まで, とくに 12 月に集中して起こった.
3. 世界中の大きい地震については, 南北両半球の大きい地震がとくに夏に多いという規則性 (Davison による) は認められない.
