APPENDIX of the paper: Increased Probability of Large Earthquakes Near Aftershock Regions With Relative Quiescence

Yosihiko Ogata
Institute of Statistical Mathematics, Tokyo, Japan

In this appendix we describe the details of the results which are given in the main paper of the above title. We examined most of the aftershock sequences in Japan and its neighboring areas during the period since 1926 that have enough number of events (say, more than about 20 events which are associated with magnitude values) for the ETAS model to apply. Table 1 in the main text of the paper lists the earthquakes whose aftershocks are studied, which may be roughly divided into six regions: (1) Off the east coast of Hokkaido, (2) Off the east coast and inland of Tohoku District, (3) Eastern margin in Sea of Japan, (4) Kanto and Tokai District and their offshore regions including Izu Peninsula and Islands, (5) Hokuriku and Chubu District, (6) Kinki District and offshore regions, and (7) Southwestern Japan, which are indicated in Figure 6 of the main paper.

Matsu'ura (1986) is concerned with relative quiescence lasting a few days or longer before a large aftershock which ruptures the boundary of the mainshock's source region. The study in this paper, on the other hand, is concerned with relative quiescence as a cue to forecasting earthquakes of about the same size or larger occurring near the source region of the considered aftershock activity. It will be shown that such relative quiescence in the aftershock activity can range a number of months or more.

Therefore, in this paper, we examine aftershock activity for the period from the mainshock occurrence time up to either of the following three cases: (i) the occurrence time of the suspected subsequent large event in the neighborhood (within about 5 degrees; see Appendix), (ii) elapsed time at about $10^{0.5M-1}$days or more for the magnitude M of the mainshock (due to Utsu, 1969), as far as no other conspicuously large event occurred so as not to contaminate the considered aftershock activity, in the case where the background seismicity around source region is active, or (iii) the end of the available period in the JMA hypocenter catalog at the date of the analysis (e.g., the end of Febrary 1997 for the 1995 Kobe event) in cases where the background seismicity around the source region is not active.

The detection rate of small earthquakes by the JMA network has been increasing very rapidly in recent years. Thus, we can set a smaller threshold magnitude than ever for the complete detection of events so that we have as many aftershocks as we like nowadays. However, as the number of events increases, the complexity of the activity increases depending on the location of the source region. Thus it becomes more difficult to represent ordinary seismic activity by just a single ETAS model throughout the whole region and period.
In addition, from my experience, the level of threshold magnitude and length of relative quiescence seems to correlate to the size of the expected event so that the analysis of data with larger magnitude thresholds appears to take on more importance.

When we have only a small number of aftershocks listed in the JMA hypocenter catalog in early years, we sometimes additionally use felt and unfelt earthquakes which are listed in *the Kisho-Yoran* (*the Geophysical Review of the JMA*) or *the Zisin-Geppo* (*the Seismological Bulletin of the JMA*). Unfelt events were recorded when the maximum amplitude of the seismic waves were over a certain threshold level at a JMA observatory, and felt earthquakes were recorded based on the observation of JMA staffs and reports from nominated individuals who are distributed widely throughout Japan. In order to apply the ETAS model, the corresponding magnitude of such event is very roughly estimated based on the Gutenberg-Richter's magnitude frequency relation.

1. Off the east coast of Hokkaido

The 1995 Off the coast of the Iturup Island earthquake

On December 4, 1995, an earthquake of $M_J 7.9$ ($M_w 7.9$) occurred off the east coast of Iturup Island on the plate boundary between the North American plate and the subducting Pacific Plate.

For a short time span right after the mainshock, heavy contamination by seismic waves of intensive activity prevents us from detecting arrivals of new waves of smaller aftershocks. Thus, the detection rate of events with magnitude M4.0, for example, are drastically changing in the first time interval [0, 0.10]days (within about 2.4 hour) whereas, in the rest of the investigated time span, the events of the same size or larger appear to be completely detected. Therefore, as described in Section 3 of the main text, I fitted the ETAS models to the events (N=307) from the time $S = 0.10$ to $T = 453$days conditional on history of the occurrence times and magnitude of large events in $[0, S]$ including the main shock: this is sensible because, despite the fact that the occurrence history of events in $[0, S]$ is incomplete and inhomogeneous, the missed smaller events are not very influential in determining the intensity rate of the ETAS model in the following time span $[S, T]$.

The significance of any suspicious change-points are thoroughly examined by calculating the values $\xi(t)$ of all t, as shown in **Figure A1.1** (see Section 4 in the main text for the definition). From here on, when a change-point is found, the broken line for $\xi(t)$ values during the times between S and the change-point is displayed in the Frequency Linearized Time (FLT) diagram on the right in order to confirm no further change-point. On the other hand, when no change-point is found, the broken line in the FLT diagram (right) for the same $\xi(t)$ function as the diagram in the ordinary time (left) is displayed in order to clearly show its change right after the mainshock. Thus, from the figure, we see the very significant change-point after about a week has elapsed since the mainshock occurrence.

The estimated parameter values of the ETAS model fitted to the aftershocks during the time span up until the change-point is printed in Figure A1.1 (see the top left corner in the FLT diagram (b)). Here the bottom number indicates the AIC value of the ETAS model applied to the data in the period up until the change-point, but, if there is no change-point, it indicates the AIC value of the ETAS model applied to the data in the whole period. Hereafter, in addition to these numbers, all the figures indicate the number of events n in the whole interval of the length t, time of change-point tc, the start time t0 of the target interval of the analysis, year and name of the mainshock, its magnitude and the threshold magnitude of the events (see top of figures).

From the Frequency Linearized Time (FLT) diagram in Figure A1.1 (right), relative quiescence appears recovered to normal within about a month, and the largest aftershock of M_J6.6 took place at 66 days after the mainshock. Therefore, I considered the sequence of larger aftershocks with M4.5 or larger in the period for 67days. **Figure A1.2** shows the emergence of clear relative quiescence before the largest aftershock.

Also, I examined the sequence of aftershocks with M4.5 or larger for the longer period of 453days up until the end of March 1996. **Figure A1.3** shows significant seismicity change at elapsed time 303.73days. However, from the FLT diagram, we see neither relative quiescence nor activation after that. Further, we cannot see any significant change-point in the data set of events with the cut-off (threshold) magnitude M_c5.0 (**Figure A1.4**); namely, the time series $\{\xi(t)\}$ shown by broken line in the figure is all below the horizontal dotted line of the significance. Thus we can conclude that this aftershock sequence with the magnitude threshold has been developed normally.

The analyzed data sets and the corresponding results in Figures A1.1–A1.4 are summarized in the following table.

The 1995 Off Iturup Island aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.0	307	148.5–154.0	43.0–46.5	0.10	453.0	7.182	quiescent	A1.1
4.5	62	148.5–154.0	43.0–46.5	0.03	67.0	7.199	quiescent	A1.2
4.5	106	148.5–154.0	43.0–46.5	0.10	453.0	303.73	not quiescent	A1.3
5.0	40	148.5–154.0	43.0–46.5	0.03	453.0	–	normal	A1.4

M_c stands for the cut-off (threshold) magnitude, N shows the number of aftershocks with magnitude M_c or larger on the time span $[0, T]$, S is the starting time for the target interval for the analysis of the log-likelihood in (3) in Section 2 of the main text, T_c is the time of change-point.

After this event, we have no large events of M_J7.0 or larger in sea or of M_J6.0 or larger in land until now within a distance of five degrees.

The 1994 Hokkaido-Toho-Oki earthquake

This event of M_J8.3 (M_s8.3, M_w8.3), occurred off the east coast of Hokkaido (or, off the coast of the Kuril Islands), is the largest event in and around Japan for the last ten-odd years. This is an intraplate event within the subducting Pacific Plate. Ogata (1998) analyzed the seismicity of events with M6.0 or larger before this, the greatest event since 1926, in the wide rectangular region bounded by 43–46°N and 149-152°E to show the emergence of clear relative quiescence.

Here, the aftershocks of this great event are examined for the data with M$\geq$ 4.5 and for the time span of T = 878days up to the end of 1997 (available JMA data at the time of the analysis). In this case, the events with magnitude M4.5 or larger are substantially missing in $[0, 0.05]$ days owing to the incomplete detection caused by the contamination of seismic waves, but the data appear to be completely detected in the rest of the investigated time span. Therefore, as described in Section 3 of the main text, we fitted the ETAS models to the events (N=370) from the time $S = 0.05$ to $T = 878$days but conditional on the history of the occurrence times and magnitudes of events in $[0, S]$ including the main shock. Note here the mainshock and even incompletely detected history of large aftershocks in $[0, S]$ are essential for predicting the intensity rate of aftershock activity in the future by ETAS, while the small events are not very influential contributors to the intensity changes.

The existence of the change-point is thoroughly examined by calculating the function $\xi(t)$ (cf. Section 4) for all t as shown by broken line in **Figure A2.1**. All of them are below the horizontal dotted line of the significance $k(N) = 3.11$ for $N = 370$. Thus no significant change-point has been found. Therefore we conclude that this aftershock sequence with the magnitude cut-off (threshold) M$_c$4.5 has developed normally.

Hereafter, when no change-point is found, the broken line for $\xi(t)$ in FLT diagram (right) is represented the same as in the ordinary time diagram (left) in order to clearly show its changes in the beginning. I then examined the sequence of aftershocks with magnitude equal to the threshold level M$_c$5.0 or larger. For this threshold magnitude, the events seem to be completely detected for the longer time span $[S, T]$ with S =0.01. **Figure A2.2** shows no significant change-point for the aftershock activity. However, **Figure A2.3** representing the activity with M$_c$5.5 or a larger indicates the significant change-point at the elapsed time T_c =99.88 days where $\xi(T_c)$ is above the dotted line $k(N) = 2.76$ for $N = 51$. Nevertheless, the extrapolated residual process for the interval $[S, T_c]$ shows a larger number of events than expected. This is called relative activation.

The above stated results in addition to the data set of events with the cut-off (threshold) magnitude M$_c$6.0 shown in **Figure A2.4** are summarized in the following table.

The 1994 Hokkaido-Toho-Oki aftershock activity

M$_c$	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.5	370	146.0–148.5	42.5–44.5	0.05	878.0	–	normal	A2.1
5.0	119	146.0–148.5	42.5–44.5	0.01	878.0	–	normal	A2.2
5.5	51	146.0–148.5	42.5–44.5	0.01	878.0	99.88	activate	A2.3
6.0	16	146.0–148.5	42.5–44.5	0.01	878.0	–	normal	A2.4

M_c stands for the threshold (cut-off) magnitude, N shows the number of aftershocks with magnitude M_c or larger for the time span $[0, T]$, S is the starting time of the target interval for the analysis of the log-likelihood (3) in Section 2 of the main text, T_c is the time of the change-point.

The next table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart. Here, as mentioned in the Section 7 of the main text, large earthquakes that occurred on land are equal to or larger than $\mathrm{M}_J6.0$ and those that occurred in the sea are equal to or larger than $\mathrm{M}_J7.0$.

Subsequent neighboring events after the 1994 Oct 04 (147.7°E 43.4°N) $\mathrm{M}_J8.1$ $\mathrm{M}_S8.4$

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.0	0.0	0.2	1994 10 09	147.8 43.6	Hokkaido-Toho-Oki aftershock
7.5	0.2	4.1	1994 12 28	143.7 40.4	Sanriku-Haruka
7.2	0.3	5.0	1995 01 07	142.3 40.2	Sanriku-Haruka aftershock
7.9	1.2	2.1	1995 12 04	150.1 44.6	Off Iturup
				Land	
–	–	–	–	–	–

Large earthquakes which occurred after this event within ten years time-lag and within five degrees apart are listed. Hereafter, earthquakes that occurred on land are equal to or larger than $\mathrm{M}_J6.0$ and those that occurred in the sea are equal to or larger than $\mathrm{M}_J7.0$.

The 1994 Hokkaido-Toho-Oki swarm

Swarm-like aftershock activity including the earthquake of $\mathrm{M}_J6.2$ appeared at about the same source region as the 1995 Off coast of the Iturup Island event starting from the 4th of October 1994 prior to the 1994 Hokkaido-Toho-Oki great event. This seismic activity up until the occurrence time of the 1994 great event ($T = 63.0$days) is considered. The result for the sequences of events with the threshold magnitudes $\mathrm{M}_c3.5$, 4.0 and 4.5 are summarized in the table below. The data appears to be complete for the aftershock events above a threshold magnitude $\mathrm{M}_c3.4$ on the basis of the Gutenberg-Richter's law. Since the accuracy of the epicenter location in this area appears poor due to the northern limitation of the JMA network, we took the sequence in the wide rectangular region 43–46°N and 149–152°E. Accordingly, the ETAS model with a positive μ for the background seismicity shows better fit to the sequences of the thresholds $\mathrm{M}_c3.5$, 4.0 and 4.5 than the ETAS with $\mu = 0$.

A significant time-change at about one month before the great event is indicated for the sequence with events $\mathrm{M}_c3.5$ or larger, and relative quiescence emerged after that (**Figure A3.1**). The same results are obtained for the sequences of the events with $\mathrm{M}_c4.0$ and 4.5 (**Figures A3.2 and A3.3**, respectively).

The following table summarizes the considered data set and the corresponding results.

The 1994 Hokkaido-Toho-Oki swarm

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.5	116	149.0–152.0	43.0–46.0	0.0	63.0	18.13	quiescent	A3.1
4.0	56	149.0–152.0	43.0–46.0	0.0	63.0	29.26	quiescent	A3.2
4.5	27	149.0–152.0	43.0–46.0	0.0	63.0	29.26	quiescent	A3.3

The following table lists the large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1994 Aug 18 (150.9°E 45.1°N) M_J6.4

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
8.1	0.1	2.8	1994 10 04	147.7 43.4	Hokkaido-Toho-Oki
7.0	0.1	2.7	1994 10 09	147.8 43.6	Hokkaido-Toho-Oki aftershock
7.9	1.3	0.8	1995 12 04	150.1 44.6	Off Iturup
				Land	
–	–	–	–	–	–

The 1993 Kushiro-Oki earthquake

The Kushiro-Oki earthquake of M_J7.8 took place within the subducting Pacific Plate at the depth of 107.3 km. Since the depths of the aftershocks were larger than 60km, the JMA did not determine their magnitudes except for some large events. Therefore I used the microearthquake data for the period up until the end of 1993 determined by the Japan University Network and compiled by the Earthquake Prediction Data Center, the Earthquake Research Institute, University of Tokyo (1993). It is clearly seen from **Figures A4.1–A4.3** that the aftershock activity lasted normally for the sequences of the cut-off magnitude M_c3.0, 3.5 and 4.0.

The following table summarizes the considered data sets and the corresponding results.

The 1993 Kushiro-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.0	144	143.5–145.5	42.5–43.5	0.2	350.0	–	normal	A4.1
3.5	64	143.5–145.5	42.5–43.5	0.2	350.0	–	normal	A4.2
4.0	18	143.5–145.5	42.5–43.5	0.01	350.0	–	normal	A4.3

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1993 Jan 15 (144.4°E 42.9°N) M_J7.8

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.8	0.5	3.8	1993 07 12	139.2 42.8	Hokkaido-Nansei-Oki
8.1	1.7	2.5	1994 10 04	147.7 43.4	Hokkaido-Toho-Oki
7.0	1.7	2.6	1994 10 09	147.8 43.6	Hokkaido-Toho-Oki aftershock
7.5	2.0	2.5	1994 12 28	143.7 40.4	Sanriku-Haruka
7.2	2.0	3.1	1995 01 07	142.3 40.2	Sanriku-Haruka aftershock
7.9	2.9	4.5	1995 12 04	150.1 44.6	Off Iturup
				Land	
6.3	0.6	3.4	1993 08 08	139.9 42.0	Hokkaido-Nansei-Oki aftershock
6.1	5.6	4.0	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

This table indicates, for example, that the 1993 Hokkaido-Nansei-Oki event of M_J7.8, the 1994 Hokkaido-Toho-Oki event of M_J8.1 and the 1994 Sanriku-Haruka-Oki of M_J7.5 followed 0.5, 1.7 and 2.0 years after this mainshock with 3.8° eastward distance apart, 2.5° northeastward and 2.5° southward, respectively.

However, as seen in Figures A4.1–A4.3, no change-point is found in the aftershock activity. A possible explanation for this would be that the event took place within the subducting Pacific Plate with an intermediate depth, so that there was little stress propagation to suppress this aftershock activity from the stress in the last preparatory stage to the shallow great events with or within the different plates.

The 1990 Hokkaido-Toho-Oki earthquake

About 4.5 years preceding to the 1994 Hokkaido-Toho-Oki great event, an earthquake of M_J6.0 took place close to the southern boundary of the great event's source region. Its aftershock region does not appear clear due to the inaccuracy of epicenter locations in this area of the north end of the JMA seismic network. Therefore, I chose relatively wide rectangular region bounded by 42°30′–43°N and 146°45′E–147°15′E which includes all the events clustered in time. There are 72 such events selected from this region up to the occurrence time of the great event (T=1646days). However, half of those events are not associated with magnitude data in the JMA catalog owing to the fact that such events are detected by only several stations being able to determine the hypocenter but not being able to determine its magnitude. The JMA denotes such events by magnitude 0.0 in the hypocenter catalog. The detection rate of such events appear independent of elapsed time (namely, a constant detection rate) except for a short time span right after the mainshock's occurrence. Thus such events are also used for the analysis. According to the magnitude frequency diagram in view of the Gutenberg-Richter's law, aftershocks with M3.6 or larger seem to be completely detected.

The following table summarizes the considered data sets and the corresponding results.

The 1990 Hokkaido-Toho-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	72	146.75–147.25	42.5–43.0	0.02	1646.0	12.58	quiescent	A5.1
3.6	32	146.75–147.25	42.5–43.0	0.02	1646.0	10.79	quiescent	A5.2
3.8	20	146.75–147.25	42.5–43.0	0.02	1646.0	10.79	quiescent	A5.3
4.0	14	146.75–147.25	42.5–43.0	0.02	1646.0	1.59	quiescent	A5.4

The data of events with M≥0.0 (namely, all the events taken from the JMA hypocenter catalog for the region and period) seem to include the background seismicity, so that the ETAS model with $\mu > 0$ is chosen for the data for the whole time span from 0.02days up to the great event. See the estimated value printed in **Figure A5.1** (b): the top right corner. Besides this, **Figures A5.2–A5.4** show significant time-changes and then the following relative quiescence for about a 4.5 year span (T=1646days) in cases where the data set of the threshold (cut-off) are magnitudes M_c3.6, 3.8 and 4.0, respectively.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1990 Apr 01 (147.1°E 42.8°N) M_J6.0

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
8.1	4.5	0.7	1994 10 04	147.7 43.4	Hokkaido-Toho-Oki
7.0	4.5	0.9	1994 10 09	147.8 43.6	Hokkaido-Toho-Oki aftershock
7.5	4.7	3.4	1994 12 28	143.7 40.4	Sanriku-Haruka
7.2	4.8	4.4	1995 01 07	142.3 40.2	Sanriku-Haruka aftershock
				Land	
–	–	–	–	–	–

The 1994 Hokkaido-Toho-Oki event of M_J8.1, and the 1994 Sanriku-Haruka-Oki of M_J7.5 followed 4.5 and 4.7 years after this mainshock with distance 0.7° northeastward and 3.4° southwestward apart, respectively.

The 1982 Urakawa-Oki earthquake

The 1982 Urakawa-Oki earthquake of M_J7.1 took place off the south coast of Hokkaido, near Urakawa. Since the seismicity around this area has always been active, the time span of the aftershock activity is taken to be $T = 10^{0.5M-1}$ (Utsu, 1969), namely, approximately one year for the mainshock of M=7.1. Then, the events are selected from the rectangular area bounded by 41.8°–42.5°N and 142°–143°E. The events with M3.3 or larger seem complete in detection according to the Gutenberg-Richter's magnitude frequency relation except for a short time span immediately after the mainshock. Therefore $S = 0.03$days is taken due to the incomplete and inhomogeneous detection during the period $[0, S]$ with the same magnitude level.

The following table summarizes the considered data sets and corresponding results shown in **Figures A6.1–A6.4**.

The 1982 Urakawa-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.3	246	142.33-143.0	41.83-42.5	0.03	365.0	–	normal	A6.1
3.6	138	142.33-143.0	41.83-42.5	0.03	365.0	–	normal	A6.2
4.0	64	142.33-143.0	41.83-42.5	0.03	365.0	–	normal	A6.3
4.2	48	142.33-143.0	41.83-42.5	0.03	365.0	–	normal	A6.4

After all, no change-point is seen in Figures A6.1–A6.4, although the 1983 Nihonkai-Chubu earthquake of M_J7.7 followed 1.2 years after this mainshock with distance 3.1° southwestward apart.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1982 Mar 21 (142.6°E 42.1°N) M_J7.1

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.7	1.2	3.1	1983 05 26	139.1 40.4	Nihonkai-Chubu
7.1	1.2	2.8	1983 06 21	139.0 41.3	Nihonkai-Chubu aftershock
7.1	7.6	2.3	1989 11 02	143.1 39.9	Iwate-Ken-Oki
				Land	
–	–	–	–	–	–

The 1973 Nemuro-Hanto-Oki earthquake

On June 17, 1973, the Nemuro-Hanto-Oki earthquake of M_J7.4 (M_S7.7) occurred in a seismic gap off Nemuro Peninsula which had been suggested by Utsu (1970). After the occurrence of this event, there was argument for the possibility of a further large event because the occurred event was smaller than the estimated size of the suggested gap. Although we have had no such large event since then in the neighboring region, it may be interesting to see whether the aftershocks of the Nemuro-Hanto-Oki earthquake developed normally or abnormally for the time span $T = 10^{0.5M-1} \approx 708$days, namely, up to the end of 1973.

The following table summarizes the data sets taken from the region, 42°–44°N, 145°–148°E. The following table summarizes the considered data sets and corresponding results.

The 1973 Nemuro-Hanto-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.0	132	145.0–148.0	42.0–44.0	0.3	712.0	467.18	quiescent	A7.1
4.5	119	145.0–148.0	42.0–44.0	0.3	712.0	467.18	quiescent	A7.2, A7.3
4.8	86	145.0–148.0	42.0–44.0	0.3	712.0	167.81	quiescent	A7.4
5.2	41	145.0–148.0	42.0–44.0	0.3	712.0	–	normal	A7.5

Magnitude M4.8 is the lowest level of completely detected aftershocks in this area and period.

The data set of events with M_c4.0 or larger appears homogeneous except for the short time span right after the mainshock, namely, detection rate is independent of elapsed time during the period $[0.3, 712.0]$days. According to the analysis a significant time-change is revealed at $T_c = 467.18$ and 167.81days for the data set with threshold magnitude M_c0.0 and 4.8, respectively, and then followed by emergence of relative quiescence (see **Figures A7.1 and A7.4**). For the sequence of events with M_c4.5, we first found the significant change-point at $T_c = 467.18$ (**Figure A7.2**). However, then we see further change-point T_c =169.90 in between 0.3 and 467.18days, which precedes relative quiescence (**Figure A7.3**). On the other hand, no change-point is found for the data set with M_c5.2 (**Figure A7.5**) showing that the sequence is well fitted by the single ETAS model.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1973 Jun 17 (146.0°E 43.0°N) M_J7.4

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.0	4.8	3.1	1978 03 23	149.4 44.8	Etorofu-Oki (Ms7.4)
7.3	4.8	3.1	1978 03 25	149.8 44.3	Etorofu-Oki (Ms7.5)
7.0	7.6	4.9	1981 01 19	143.0 38.6	Miyagi-Ken-Oki
7.1	8.8	2.7	1982 03 21	142.6 42.1	Urakawa-Oki
			Land		
–	–	–	–	–	–

This table indicate, for example, that the 1978 Etorofu-Oki (Off Iturup Island) events of M_s7.4 and M_s7.5, and the 1982 Urakawa-Oki event of M_J7.1 followed this event in 4.8 and 8.8 years after this mainshock at 3.1° distant northeastward and 2.7° southwestward apart, respectively.

The 1952 Tokachi-Oki earthquake

This great event of M_J8.2 (M_s8.3) occurred off the southeastern coast of Hokkaido. The total number of aftershock data for this event is fewer than expected from its magnitude because the source region is located offshore of Hokkaido, one of the areas with poor detection rates in and around Japan at that time. The lowest magnitude of complete detection appears at M5.5. We also use the events whose magnitude is not determined but only the location is provided. In the JMA hypocenter catalog this type of event's magnitude is denoted as M0.0, which roughly corresponds to M4.5 according to the Gutenberg-Richter's frequency law. Such data set's threshold magnitude is denoted as M_c0.0 in the tables from here on. The sequences of M_c0.0 and M_c5.0 appear homogeneously detected except for the first 0.5 day right after the mainshock owing to the similarity of the cumulative curves in ordinary time and the distribution of such events shown in the M-T diagram of linearized frequency time.

Aftershocks about this size in the time span of a half day right after the mainshock are substantially missing. Therefore, the sequence is examined from 0.5 day till 1031 days which is about three years owing to $T = 10^{0.5M-1}$ (Utsu, 1969). For these threshold magnitudes, we cannot see any significant change-points.

The following table summarizes the considered data sets and the corresponding results which are shown in **Figures A8.1–A8.4**.

The 1952 Tokachi-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	195	143.33–146.5	41.0–43.33	0.5	1031.0	–	normal	A8.1
5.0	88	143.33–146.5	41.0–43.33	0.5	1031.0	–	normal	A8.2
5.5	48	143.33–146.5	41.0–43.33	0.5	1031.0	–	normal	A8.3
6.0	16	143.33–146.5	41.0–43.33	0.5	1031.0	–	normal	A8.4

Here, in particular, the estimated value $\hat{\alpha} = 16.329$ suggests that the estimated ETAS indicates that the effect of secondary aftershocks is very small, namely, the sequence is very close to the simple modified Omori formula with $\hat{p} = 0.9823$.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1952 Mar 04 (144.1°E 41.8°N) M_J8.2 M_S8.3

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.2	8.0	2.0	1960 03 21	143.4 39.8	Iwate-Ken-Oki
			Land		
6.3	4.0	2.5	1956 03 06	144.1 44.3	Abashiri-Oki
6.0	4.6	4.6	1956 09 30	140.6 38.0	Miyagi-Ken South
6.3	6.9	1.5	1959 01 31	144.6 43.3	Teshikaga earthquake

It is seen from this table that, after this great event, no conspicuously large events took place during the ten years span and within 5°apart.

1932 Hidaka-Chubu earthquake

About 3 months prior to the 1933 great Sanriku tsunami earthquake, this intraplate earthquake of M_J 7.0 took place in the area including the mouth of the Niicappu river, Southern Hokkaido, 3.5° (about 400km) northward from the source of the great event. This aftershock sequence is examined by using the list of felt and unfelt earthquakes in *Kisho-Yoran* (*Geophysical Review of the JMA*, 1932-1933) most of which are recorded at Urakawa Observatory of the JMA.

There are $N = 287$ felt shocks in the time span of $T = 96$ days up until the occurrence time of the Sanriku event. The event whose magnitude is listed in the JMA hypocenter catalog adopts the same magnitude. Otherwise, $M \approx 4.3$ is set for the felt shocks, and $M \approx 3.5$ is set for the unfelt shocks so that the cumulative frequency roughly satisfies the Gutenberg-Richter's law for magnitude frequency (Gutenberg and Richter, 1944). The occurrence time data are provided up to the accuracy of minute, but there are a number of couples and triplets which occurred at the same minute. This causes an unfavorable effect in the estimation of the ETAS parameters. Thus, occurrence times of these are shifted to separate the couples and triplets from each other.

The following table summarizes the considered data sets and the corresponding results.

The 1932 Hidaka-Chubu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
unfelt	287	142.0–143.0	42.0–43.0	0.04	96.0	–	normal	A9.1
felt	46	142.0–143.0	42.0–43.0	0.04	96.0	49.6	quiescent	A9.2
4.5	26	142.0–143.0	42.0–43.0	0.04	96.0	49.6	quiescent	A9.3

From **Figure A9.1** we see no change-point. However, from **Figures A9.2 and A9.3**, we see that no felt aftershocks took place up until the occurrence of the great Sanriku event for 45 days and 57 days, respectively. The significance of the relatively quiet stage is shown By $\xi(t)$ (broken line) in the figure. Here we see a further change-point at 2.822days right after the mainshock for the sequence of felt events. However, it preceds the pattern of relative activation before about 20days.

I am not sure whether this relative quiescence is related to the forthcoming great Sanriku earthquake or not. Another possibly correlated large events might be the 1935 Hidaka-Oki earthquake that occurred very near the present mainshock. Unfortunately, no further data set of events with different threshold magnitude is available to confirm it.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1932 Nov 26 (142.5°E 42.4°N) M_J7.0

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
8.1	0.3	3.5	1933 03 03	144.5 39.2	Sanriku-Oki
7.1	0.6	4.3	1933 06 19	142.5 38.1	Miyagi-Ken-Oki (Ms7.3)
7.1	2.9	2.1	1935 10 18	144.3 40.8	Aomori-Ken-Toho-Oki swarm (M7.2)
7.5	3.9	4.3	1936 11 03	142.1 38.1	Miyagi-Ken-Oki (Ms7.2)
7.1	4.7	4.1	1937 07 27	142.1 38.3	Miyagi-Ken-Oki (m_B7.1)
7.4	5.9	5.0	1938 11 06	141.9 37.4	Shioya-Oki great swarm
7.0	6.9	4.1	1939 10 11	142.8 38.3	Miyagi-Ken-Oki (Ms7.4)
7.5	7.7	2.9	1940 08 02	139.5 44.2	Shikotan-Oki (Ms7.5)
				Land	
6.7	2.8	0.2	1935 09 18	142.6 42.2	Hidaka-Oki
6.1	5.5	1.8	1938 05 29	144.4 43.5	Kussharo earthquake
6.8	6.4	3.2	1939 05 01	139.5 40.1	Oga-Hanto-Oki

2. Off the east coast and inland of Tohoku District

The 1996 Onikobe earthquake

Onikobe is in volcanic area in the central Tohoku District. The aftershock activity of this event is clearly classified as a swarm of the 2nd kind (Utsu, 1971) because the mainshock of M_J5.9 is followed by M_J5.4 and M_J5.7 within 0.2days, and each of them seems to accompany its aftershocks. Therefore the ETAS model is applied to the sequence of events with $M \geq 2.5$ in the time span from 0.22days up to 200days (end of data analyzed then). For the data sets with the larger threshold magnitudes, the ETAS is applied to the events with $M \geq 3.1$ for the whole time span from 0.0 to 200 days.

The following table summarizes the considered data sets and corresponding results.

The 1996 Onikobe aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.5	476	140.5–140.75	38.75–39.0	0.22	200.0	–	normal	A10.1
3.1	100	140.5–140.75	38.75–39.0	0.0	200.0	–	normal	A10.2
3.5	43	140.5–140.75	38.75–39.0	0.0	200.0	–	normal	A10.3
3.8	17	140.5–140.75	38.75–39.0	0.0	200.0	3.19	quiescent	A10.4
4.0	13	140.5–140.75	38.75–39.0	0.0	200.0	3.19	quiescent	A10.5

No significant change-point is seen for the sequences with lower threshold magnitudes, i.e., M_c2.5, 3.1 and 3.8 (**Figures A10.1–A10.3**), However, it turns out that no events of M3.8 and larger occurred after an elapsed time of 3.19days. We see that this is significant relative quiescence (**Figures A10.4 and A10.5**).

The following table lists large earthquakes which occurred after this event within ten years time-lag and within the distance of five degrees.

Subsequent neighboring events after the 1996 Aug 11 (140.6°E 38.9°N) M_J5.9

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
–	–	–	–	–	–
			Land		
6.1	2.1	0.9	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

On 3 September 1998 after two-odd years, an event of M_J6.1 occurred at the northward neighborhood, northern Iwate Prefecture. This event seem to be associated with the volcanic activity of Iwate-San (Iwate Mountain).

The 1994 Sanriku-Haruka-Oki aftershock activity

On December 28, 1994, this event of M_J7.5 took place at far off the east coast of Sanriku, near the trench of subducting Pacific Plates. This is the largest event to occur off the east coast of the Tohoku District since the 1968 Tokachi-Oki great earthquake of $M_J7.9$, the aftershock area of which overlaps with the present area. About ten days after the occurrence of the mainshock, aftershock activity is extended to the western region, near land, initiated by the largest aftershock of $M_J7.2$.

The overall aftershock area is almost bounded by the rectangular 142–144.5°E and 39.5–41°N. However, similar to the case of the 1968 Tokachi-Oki aftershocks which will be discussed later, the aftershock activity in the wide focal region is heterogeneously dependent on the locations: that is, coefficients of the ETAS model are not the same throughout the whole aftershock region. Therefore, the whole aftershock region is divided into two subregions by the line of longitude 143°E in order to maintain the homogeneity of the ETAS's parameters.

Then, firstly, we consider the major part, the ruptured source immediately after the mainshock, included in the rectangular area bounded by 143–144.5°E and 39.5°–41°N.

The following table summarizes the considered data sets and corresponding results which are shown in **Figures A11.1–A11.4**.

The 1994 Sanriku-Haruka-Oki aftershock activity: Eastern region

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.0	145	143.0–144.5	39.5–41.0	0.02	794.0	–	normal	A11.1
4.5	53	143.0–144.5	39.5–41.0	0.01	794.0	–	normal	A11.2
5.0	28	143.0–144.5	39.5–41.0	0.01	794.0	–	normal	A11.3
5.4	16	143.0–144.5	39.5–41.0	0.01	794.0	–	normal	A11.4

Besides the above data sets, events of M3.5 or larger appear complete during the period [0.1, 794]days, and a significant change-point is seen. However, from the space-time observation, this change-point indicates the commencement of a swarm-type burst of activity in the northern edge of the aftershock area. In this way, it becomes difficult to carry out the analysis as the threshold magnitude gets smaller than M4.0. This is because the regional heterogeneity of the seismicity is enhanced by the increase of events.

In order to examine the aftershock activity prior to the largest aftershock of $M_J7.2$, the sequences in the shorter time span up until the event ($T = 9.4$days) are considered for the threshold magnitudes $M_c4.0$, 4.5 and 4.9 and for all region including both the Eastern and Western regions (**Figures A11.5–A11.7**). These figures indicate the emergence of relative quiescence except for the data set with $M_c4.0$. We summarize the results in the following table.

The 1994 Sanriku-Haruka-Oki aftershock activity: till the largest aftershock of $M_J7.2$

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.0	73	142.0–144.0	39.5–41	0.025	9.40	–	normal	A11.6
4.5	29	142.0–144.0	39.5–41	0.015	9.40	0.44	quiescent	A11.7
4.9	29	142.0–144.0	39.5–41	0.001	9.40	0.44	quiescent	A11.8

However, these were not listed in Table 1 in the main text since our major interest is to forecast large separated events based on relative quiescence lasting for a long period of a few months or more, not to forecast large aftershocks based on the quiescence of short period.

The western part of the aftershock region corresponds to the region of the secondary aftershocks of the largest aftershock event of M_J7.2 occurred at 7th January 1995, where substantial aftershock activity was observed because the source is near land.

The following table summarizes the considered data sets and corresponding results which are shown in **Figures A12.1–A12.4**.

The 1994 Sanriku-Haruka-Oki aftershock activity: Western region

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.0	700	142.0–143.0	39.5–41.0	0.10	782.0	–	normal	A12.1
3.5	203	142.0–143.0	39.5–41.0	0.05	782.0	–	normal	A12.2
4.0	60	142.0–143.0	39.5–41.0	0.03	782.0	–	normal	A12.3
4.5	19	142.0–143.0	39.5–41.0	0.03	782.0	–	normal	A12.4

The following table lists large earthquakes which occurred after the two events within ten years time-lag and within five degrees apart, respectively.

Subsequent neighboring events after the 1994 Dec 28 (143.7°E 40.4°N) M_J7.5

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.2	0.0	1.1	1995 01 07	142.3 40.2	Sanriku-Haruka aftershock
				Land	
6.1	3.7	2.2	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

The 1994 Sanriku-Oki earthquake

This event of M_J6.7 took place at the southern edge of the source area of the forthcoming 1994 Sanriku-Haruka-Oki earthquake, after about nine months. We investigate aftershock activity for the time span from the mainshock up until the occurrence time of the December event of M_J7.5.

The following table summarizes the considered data sets and corresponding results which are shown in **Figures A13.1 and A13.2**.

The 1994 Sanriku-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.5	50	143.67–144.5	40.0–41.0	0.02	263.0	–	normal	A13.1
4.0	17	143.67–144.5	40.0–41.0	0.02	263.0	–	normal	A13.2

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1994 Apr 08 (144.0°E 40.6°N) M_J6.6

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
8.1	0.5	4.1	1994 10 04	147.7 43.4	Hokkaido-Toho-Oki
7.0	0.5	4.3	1994 10 09	147.8 43.6	Hokkaido-Toho-Oki aftershock
7.5	0.7	0.2	1994 12 28	143.7 40.4	Sanriku-Haruka-Oki
7.2	0.8	1.3	1995 01 07	142.3 40.2	Sanriku-Haruka-Oki aftershock
				Land	
6.1	4.4	2.4	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

The 1992 Sanriku-Oki Swarm

Initiated by this event of M_J5.9 a swarm of the 2nd kind (Utsu, 1971) followed with a spatially concentrated cluster off the east coast of southern Sanriku. The events are taken from the Hypocenter catalog of the JMA for the rectangular area bounded by 38.75°–39°N and 142.25°–143°E, and we consider the activity in the period from the 1st December 1992 up until 27th December 1994 when the Sanriku-Haruka-Oki large event of M_J7.5.took place.

The following table summarizes the considered data sets and corresponding results.

The 1992 Sanriku-Oki swarm activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.0	301	143.25–144.0	39.0–39.75	0.75	730.0	19.27	quiescent	A14.1
3.5	90	143.25–144.0	39.0–39.75	0.80	730.0	34.24	quiescent	A14.2
3.9	30	143.25–144.0	39.0–39.75	0.80	730.0	25.16	quiescent	A14.3
4.4	11	143.25–144.0	39.0–39.75	0.00	730.0	16.38	quiescent	A14.4

All data sets have a change-point which was followed by emergence of relative quiescence (see **Figures A14.1–A14.4**).

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1992 Dec 28 (142.6°E 38.9°N) M_J5.9

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.8	0.5	4.7	1993 07 12	139.2 42.8	Hokkaido-Nansei-Oki
7.5	2.0	1.8	1994 12 28	143.7 40.4	Sanriku-Haruka
7.2	2.0	1.3	1995 01 07	142.3 40.2	Sanriku-Haruka aftershock
				Land	
6.6	0.1	4.3	1993 02 07	137.3 37.6	Noto-Hanto-Oki
6.3	0.6	3.7	1993 08 08	139.9 42.0	Nansei-Oki aftershock
6.1	5.7	1.6	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

This table indicates, for example, that the 1993 Hokkaido-Nansei-Oki earthquake of M_J7.7, the 1994 Sanriku-Haruka-Oki earthquake and the 1993 Noto-Hanto-Oki earthquake took place shortly in the neighboring areas.

The 1992 Sanriku-Haruka-Oki earthquake

This event of M_J6.9 occurred in July 18 far off Sanriku Coast preceded by a number of foreshocks including one of M_J6.1. The considered time span is 890 days from the mainshock up until the 1994 Sanriku-Oki event of M_J7.5. The aftershock events are taken from the rectangular region bounded by 39°- 39.75°N and 143.25°- 144°E.

The following table lists the analyzed data sets and corresponding results which are shown in **figures A15.1–A15.6**.

The 1992 Sanriku-Haruka-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.5	210	143.25–144.0	39.0–39.75	0.1	890.0	312.01	quiescent	A15.1
3.7	141	143.25–144.0	39.0–39.75	0.1	890.0	312.01	quiescent	A15.2
3.8	111	143.25–144.0	39.0–39.75	0.1	890.0	–	normal	A15.3
4.0	78	143.25–144.0	39.0–39.75	0.1	890.0	–	normal	A15.4
4.5	48	143.25–144.0	39.0–39.75	0.1	890.0	415.37	quiescent	A15.5
5.0	36	143.25–144.0	39.0–39.75	0.01	890.0	–	normal	A15.6

Some explanation is necessary for Figure A31.3 for the sequence of events M3.0 or larger. Though there is a further change-point in the sequence for the period up until the primary change-point shown in the FLT diagram, this is related to a temporal activation for a half month. After that relative quiescence seems substantial. Incidentally, the number of aftershocks with M≥5.0 is large relative to the size of the mainshock.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1992 Jul 18 (143.4°E 39.4°N) M_J6.9

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.8	1.0	4.7	1993 07 12	139.2 42.8	Hokkaido-Nansei-Oki
7.5	2.4	1.1	1994 12 28	143.7 40.4	Sanriku-Haruka
7.2	2.5	1.2	1995 01 07	142.3 40.2	Sanriku-Haruka aftershock
				Land	
6.6	0.6	5.0	1993 02 07	137.3 37.6	Noto-Hanto-Oki
6.3	1.1	3.7	1993 08 08	139.9 42.0	Nansei-Oki aftershock
6.1	6.1	2.0	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

1989 Iwate-Ken-Oki earthquake

Aftershocks of this event of M_J7.1 are examined for the time span of 334days from the mainshock which is determined by taking account of the mainshock's size (namely, $T \approx 10^{0.5M-1}$). The events in the rectangular region bounded by 39–41°N and 142–145°E were taken from the JMA catalog.

The following table summarizes the considered data sets and corresponding results.

The 1989 Iwate-Ken-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.0	126	142.0–145.0	39.0–41.0	0.10	334.0	–	normal	A16.1
4.5	56	142.0–145.0	39.0–41.0	0.10	334.0	–	normal	A16.2
5.0	32	142.0–145.0	39.0–41.0	0.10	334.0	–	normal	A16.3

No significant change-point is found for the threshold levels of M4.0, 4.5 and 5.0 (see **Figures A16.1–A16.3**).

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1989 Nov 02 (143.1°E 35.8°N) M_J7.1

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.5	5.2	4.7	1994 12 28	143.7 40.4	Sanriku-Haruka
7.2	5.2	4.5	1995 01 07	142.3 40.2	Sanriku-Haruka aftershock
				Land	
6.5	0.3	3.3	1990 02 20	139.2 34.8	Izu-Oshima Kinkai
6.1	8.8	4.4	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

The 1987 Iwate-Ken-Hokubu earthquake

This earthquake of M_J6.6 occurred at the intermediate depth (72 km) beneath northern part of Iwate Prefecture. Aftershock events are taken from the JMA hypocenter catalog from the rectangular region bounded by 141.6°–141.84°E and 39.78°–40°N for the period till the end of 1989. Since the aftershocks were deeper than 60km, the JMA did not determine magnitude of these events (except for certain relatively large events) but determined only their location. These events appear homogeneously detected except for the short time span right after the mainshock.

The analyzed data sets and the corresponding results in **Figures A17.1 and A17.2** are summarized in the following table.

The 1987 Iwate-Ken-Hokubu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	316	141.6–141.84	39.78–40.0	0.005	1086.0	–	normal	A17.1
3.0	18	141.6–141.84	39.78–40.0	0.005	1086.0	–	normal	A17.2

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1987 Jan 09 (141.8°E 39.8°N) M_J6.6

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.1	2.8	1.0	1989 11 02	143.1 39.9	Iwate-Ken-Oki
7.8	6.5	3.6	1993 07 12	139.2 42.8	Hokkaido-Nansei-Oki
7.5	8.0	1.6	1994 12 28	143.7 40.4	Sanriku-Haruka
7.2	8.0	0.6	1995 01 07	142.3 40.2	Sanriku-Haruka aftershock
				Land	
6.6	6.1	4.1	1993 02 07	137.3 37.6	Noto-Hanto-Oki
6.3	6.6	2.6	1993 08 08	139.9 42.0	Nansei-Oki aftershock

The 1981 Miyagi-Ken-Oki earthquake

This earthquake of M_J7.0 occurred off the east coast of Miyagi Prefecture, northeastern neighborhood of the 1978 Miyagi-Ken-Oki earthquake of M_J7.4. Aftershock events are taken from the JMA hypocenter catalog from the rectangular region bounded by 142.5°–144°E, and 35.75°–36.5°N for the period till the end of 1983. We use all events listed in the JMA hypocenter catalog (denoted by M_c0.0 below), which appear homogeneously detected throughout the considered period except for the short span (0.1days) after the mainshock.

The analyzed data sets and the corresponding results in **Figures A18.1–A18.4** are summarized in the following table.

The 1981 Miyagi-Ken-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	88	142.5–144.0	38.0–39.0	0.10	1070.0	–	normal	A18.1
3.6	69	142.5–144.0	38.0–39.0	0.10	1070.0	–	normal	A18.2
4.1	41	142.5–144.0	38.0–39.0	0.10	1070.0	–	normal	A18.3
4.6	28	142.5–144.0	38.0–39.0	0.10	1070.0	–	normal	A18.4

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1981 Jan 19 (143.0°E 38.6°N) M_J7.0

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.1	1.2	3.5	1982 03 21	142.6 42.1	Urakawa-Oki
7.0	1.5	2.5	1982 07 23	141.9 36.2	Ibaragi-Ken-Oki
7.7	2.3	3.5	1983 05 26	139.1 40.4	Nihonkai-Chubu
7.1	2.4	4.1	1983 06 21	139.0 41.3	Nihonkai-Chubu aftershock
7.1	8.8	1.3	1989 11 02	143.1 39.9	Iwate-Ken-Oki
				Land	
6.0	2.5	4.4	1983 08 08	139.0 35.5	Yamanashi-Ken-Tobu
6.0	5.8	4.9	1986 11 22	139.5 34.5	Izu-Oshima Kinkai
6.0	8.1	3.4	1989 03 06	140.7 35.7	Chiba-Ken-Hokubu 1
6.5	9.1	4.8	1990 02 20	139.2 34.8	Izu-Oshima Kinkai
6.0	9.4	3.4	1990 06 01	140.7 35.6	Chiba-Ken-Hokubu 2

The 1978 Miyagi-Ken-Oki earthquake

This earthquake of M_J7.4 occurred off the coast of Miyagi Prefecture, and caused some destruction in Sendai, the largest city in Tohoku District. The aftershock events are selected from the JMA catalog for the rectangular area bounded by 38°–39°N and 141.25°–144°E for the period till the end of 1979. Since this focal area has been active with substantial background seismicity, aftershock events of M3.4 or larger in the period [0.05, 567]days are taken for the analysis by consideration of the mainshock's size and the detection ability of shocks by the JMA network at the period.

The following table summarizes the considered data sets and the corresponding results.

The 1978 Miyagi-Ken-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.4	194	141.25–144.0	38.0–39.0	0.05	567.0	–	normal	A19.1
4.0	67	141.25–144.0	38.0–39.0	0.05	567.0	–	normal	A19.2
4.2	50	141.25–144.0	38.0–39.0	0.05	567.0	–	normal	A19.3
4.5	32	141.25–144.0	38.0–39.0	0.05	567.0	32.12	quiescent	A19.4
4.9	16	141.25–144.0	38.0–39.0	0.05	567.0	9.15	quiescent	A19.5

From the analysis we have no significant change-point in the data sets with threshold magnitudes M_c3.4, 4.0 and 4.2 (**Figures A19.1–A19.3**). However, a significant change-point is revealed in the data sets with larger threshold magnitudes M_c4.5 and 4.9 (**Figures A19.4 and A19.5**).

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1978 Jun 12 (142.2°E 38.2°N) M_J7.4

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.0	2.6	0.8	1981 01 19	143.0 38.6	Miyagi-Ken-Oki
7.1	3.8	3.9	1982 03 21	142.6 42.1	Urakawa-Oki
7.0	4.1	2.0	1982 07 23	141.9 36.2	Ibaragi-Ken-Oki
7.7	5.0	3.3	1983 05 26	139.1 40.4	Nihonkai-Chubu
7.1	5.0	4.0	1983 06 21	139.0 41.3	Nihonkai-Chubu aftershock
				Land	
6.7	2.1	4.0	1980 06 29	139.2 34.9	Izu-Hanto-Toho-Oki
6.4	4.6	4.8	1982 12 28	139.4 33.9	Miyake-Is-Nanpo-Oki
6.0	5.2	3.7	1983 08 08	139.0 35.5	Yamanashi-Ken-Tobu
6.2	5.3	4.7	1983 10 03	139.5 34.0	Miyake-Is-Near
6.8	6.3	4.4	1984 09 14	137.6 35.8	Nagano-Ken-Seibu
6.0	8.5	4.2	1986 11 22	139.5 34.5	Izu-Oshima Kinkai

The 1978 Ojika-Hanto-Oki earthquake

On February 20, 1978, about four months preceding the 1978 Miyagi-Ken-Oki earthquake, an earthquake of M_J6.7 took place near Ojika Peninsula, at the north-eastern neighborhood of the source region of the forthcoming large event. The events are selected from the rectangular area bounded by 38°35′–39°N and 141°35′–142°15′E. Since the aftershocks occurred nearer to the land than the source of the Miyagi-Ken-Oki event, we can take small threshold magnitudes M_c3.0 and 3.3 compared with those of the 1978 event. The time span [0.005, 106]days is considered up until the Miyagi-Ken-Oki earthquake. However, no change-point is found (**Figures A20.1 and A20.2**).

On the other hand, the sequence of events with threshold magnitude M_c3.5 or larger should be carefully analyzed. If we only assume $\mu = 0$, then we see no change-point as shown in **Figure A20.3**. However, it should always be considered to include the case of $\mu > 0$. Thus the overall minimum AIC model is attained by the model shown in **Figure 20.4**. Therefore, the sequence has a significant change-point followed by the emergence of relative quiescence.

The following table summarizes the considered data sets and the corresponding results.

The 1978 Ojika-Hanto-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.0	48	141.25–144.0	38.0–39.0	0.005	112.0	–	normal	A20.1
3.3	35	141.25–144.0	38.0–39.0	0.005	112.0	–	normal	A20.2
3.5	23	141.25–144.0	38.0–39.0	0.005	112.0	50.56	quiescent	A20.3

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1978 Feb 20 (142.2°E 38.8°N) M_J6.7

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.4	0.3	0.6	1978 06 12	142.2 38.1	Miyagi-Ken-Oki
7.0	2.9	0.6	1981 01 19	143.0 38.6	Miyagi-Ken-Oki
7.1	4.1	3.3	1982 03 21	142.6 42.1	Urakawa-Oki
7.0	4.4	2.6	1982 07 23	141.9 36.2	Ibaragi-Ken-Oki
7.7	5.3	2.9	1983 05 26	139.1 40.4	Nihonkai-Chubu
7.1	5.3	3.5	1983 06 21	139.0 41.3	Nihonkai-Chubu aftershock
				Land	
6.7	2.4	4.5	1980 06 29	139.2 34.9	Izu-Hanto-Toho-Oki
6.0	5.5	4.1	1983 08 08	139.0 35.5	Yamanashi-Ken-Tobu
6.8	6.6	4.7	1984 09 14	137.6 35.8	Nagano-Ken-Seibu
6.0	8.7	4.7	1986 11 22	139.5 34.5	Izu-Oshima Kinkai
6.6	8.9	1.1	1987 01 09	141.8 39.8	Iwate-Ken-Hokubu

1968 Tokachi-Oki earthquake

The aftershock activity of this great event of M_J7.9 (M_s8.1) is complex and the aftershock area is extraordinarily large. About a month after the occurrence of the mainshock, aftershock activity is extended to the southern region, initiated by the second largest aftershock of M_J7.2. First, in order to examine the aftershock activity prior to the second largest aftershock of M_J7.2, the sequences in the shorter time span up until $T = 27.5$days are considered for the threshold magnitudes M_c0.0, 4.5 5.0 and 5.5 (**Figures A21.1–A21.4**). These figures indicate the normal activity on the whole. However, from the study of a space-time plot the anomalous activity seems to emerge in the source region of the secondary aftershocks in the southern part, although the major aftershock activity is in the northern part of the whole source including the mainshock. The results are summarized in the following table.

The 1968 Tokachi-Oki aftershock activity till the 2nd largest aftershock

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	181	142.0–145.0	39.0–42.0	0.15	27.0	–	normal	A21.1
4.5	158	142.0–145.0	39.0–42.0	0.15	27.0	–	normal	A21.2
5.0	87	142.0–145.0	39.0–42.0	0.15	27.0	–	normal	A21.3
5.5	30	142.0–145.0	39.0–42.0	0.15	27.0	–	normal	A21.4

These results were not listed in Table 1 of the main text since our major interest is to forecast large separated events based on relative quiescence lasting for a long period of a few months or more, not the forecast of large aftershocks based on quiescence over a short period.

The activity in longer periods appeared complex. After some preliminary analysis I found that the aftershock activity of the whole area cannot be represented by a single ETAS model by assuming the same set of the parameter values throughout the area as shown in the case of the 1994 Sanriku-Haruka-Oki earthquake.

Therefore, the aftershock area is divided into two subregions by the line of the latitude 40°N to fit two ETAS models to the data sets from the two subregions, respectively. In fact, the aftershock sequence in the northern part of the source has p-value near the original Omori formula ($\hat{p} = 1.0$; see **Figures A21.5–A21.8**) while the one in the southern part has the larger p-value and α-value (**Figures A22.1–A22.4**).

The sequence from the northern part includes the mainshock of M_J7.9, and the span [0.2, 959.0]days is considered for the analysis taking account of the size of the mainshock. The sequences of events with threshold magnitudes M_c4.5, 5.0 5.5 and 5.9 are examined by applying the ETAS model. All $\xi(t)$-value are below the horizontal dotted line for the level of significance in Figures A21.1–A21.4, which indicate no significant change-point for all the examined cases.

The following table summarizes the considered data sets in the mainshock's source area (northern region) and corresponding results.

The 1968 Tokachi-Oki aftershock activity (Northern region)

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.5	291	141.0–145.0	40.0–42.0	0.10	959.0	–	normal	A21.5
5.0	142	141.0–145.0	40.0–42.0	0.10	959.0	–	normal	A21.6
5.5	51	141.0–145.0	40.0–42.0	0.20	959.0	–	normal	A21.7
5.9	20	141.0–145.0	40.0–42.0	0.01	959.0	–	normal	A21.8

Thus, we can conclude that this aftershock activity in the northern region has been normal. Similarly, the sequences of events with M_c4.5, 5.0 and 5.5 in the southern part are examined for the time span [34.52, 959.0]days where 34.52days is a bit later than the occurrence time of the largest aftershock, taking into account the missing secondary aftershocks. Here, the mainshock of M$_J$7.9, the largest aftershock of M$_J$7.3 and all the events during the span [0, 34.52)days in the considered subregion are used for the history of occurrences in applying the ETAS model to the secondary aftershocks in the rest of the period up to 959days. After all, we see no significant change-point as shown in Figures A22.1–A22.3.

The following table summarizes the considered data sets and corresponding results.

The 1968 Tokachi-Oki secondary aftershock activity (Southern region)

M$_c$	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.5	128	141.0–144.0	39.0–40.0	34.52	959.0	–	normal	A22.1
5.0	60	141.0–144.0	39.0–40.0	34.52	959.0	–	normal	A22.2
5.5	27	141.0–144.0	39.0–40.0	34.52	959.0	–	normal	A22.3

Thus we can conclude that this secondary aftershock activity lasted normally.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1968 May 16 (143.6°E 40.7°N) M$_J$7.9 M$_s$8.1

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.2	0.1	1.3	1968 06 12	143.1 39.4	Tokachi-Oki aftershock
7.8	1.2	3.6	1969 08 12	147.6 42.7	Shikotan-Oki (Ms7.8)
7.0	3.2	0.5	1971 08 02	143.7 41.2	Hidaka Northeast (Ms7.1)
7.4	5.1	2.9	1973 06 17	145.9 43.0	Nemuro-Oki
7.1	5.1	3.3	1973 06 24	146.8 43.0	Nemuro-Oki
				Land	
6.2	2.4	2.6	1970 10 16	140.8 39.2	Akita-Ken Southeast

The 1962 Miyagi-Ken-Hokubu earthquake

This event of M$_J$6.5 occurred in the northern part of Miyagi Prefecture. We took the occurrence data from the JMA hypocenter catalog in the rectangular region bounded by 140.8°–141.4°E and 38.4°–38.8°N for the period till the end of 1964. According to the magnitude frequency distribution M$_c$4.4 appears to be the lowest magnitude that was completely detected. We also use events whose magnitude is not determined but whose location is identified. The data including such events appears homogeneously detected throughout the considered period except for the short time span right after the mainshock: namely, the rate of the incompletely detected events is a constant throughout the target period of the analysis.

The analyzed data sets and the corresponding results shown in **Figures A23.1 and A23.2** are summarized in the following table.

The 1962 Miyagi-Ken-Hokubu earthquake

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	57	140.8–141.4	38.4–38.8	0.05	989.0	110.83	quiescent	A23.1
4.0	21	140.8–141.4	38.4–38.8	0.05	989.0	–	normal	A23.2

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1962 Apr 30 (141.1°E 38.7°N) M_J6.5

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.5	2.1	1.6	1964 06 16	139.2 38.4	Niigata earthquake
6.1	2.1	1.5	1964 06 16	139.3 38.4	Niigata aftershock
7.9	6.0	2.8	1968 05 16	143.6 40.7	Tokachi-Oki
7.5	6.0	3.0	1968 05 16	142.8 41.4	Tokachi-Oki aftershock
7.2	6.1	1.7	1968 06 12	143.1 39.4	Tokachi-Oki aftershock
7.0	9.3	3.2	1971 08 02	143.7 41.2	Hidaka Northeast (Ms7.1)
				Land	
6.1	3.0	4.4	1965 04 20	138.3 34.9	Shizuoka-Ken Central
6.6	7.4	4.3	1969 09 09	137.1 35.8	Gifu-Ken Central
6.2	8.5	0.6	1970 10 16	140.8 39.2	Akita-Ken Southeast

The 1960 Iwate-Ken-Oki earthquake

This event of M_J7.2 occurred off the east coast of Iwate Prefecture. The data are taken from the JMA hypocenter catalog in the rectangular region bounded by 143°–144°N and 39°–40.25°E. We also include events whose magnitude is not determined (printed as M0.0 in the catalog) but whose location is identified. Such data set's threshold magnitude is denoted by M_c0.0 in the tables from here on.

The analyzed data sets and the corresponding results shown by **Figures A24.1–A24.4** are summarized in the following table.

The 1960 Iwate-Ken-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	141	143.0–144.0	39.0–40.25	0.25	1015.0	–	normal	A24.1
4.4	88	143.0–144.0	39.0–40.25	0.25	1015.0	–	normal	A24.2
4.9	53	143.0–144.0	39.0–40.25	0.25	1015.0	–	normal	A24.3
5.4	29	143.0–144.0	39.0–40.25	0.05	1015.0	–	normal	A24.4

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1960 Mar 21 (143.4°E 39.8°N) M_J7.2 M_s7.7

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.0	2.1	2.4	1962 04 23	143.9 42.2	Tokachi-Oki
7.5	4.2	3.6	1964 06 16	139.2 38.4	Niigata
6.1	4.2	3.5	1964 06 16	139.3 38.4	Niigata aftershock
7.9	8.2	0.9	1968 05 16	143.6 40.7	Tokachi-Oki
7.5	8.2	1.6	1968 05 16	142.8 41.4	Tokachi-Oki aftershock
7.2	8.2	0.5	1968 06 12	143.1 39.4	Tokachi-Oki aftershock
7.8	9.4	4.3	1969 08 12	147.6 42.7	Shikotan-Oki (Ms7.8)
			Land		
6.5	2.1	2.1	1962 04 30	141.1 38.7	Miyagi-Ken-Hokubu
6.5	7.6	3.7	1967 11 04	144.3 43.5	Kushiro North

The 1938 Fukushima-Ken-Oki great swarm

This swarm consists of a series of large events including M_J7.5 (M_s7.7, November 5), M_J7.3 (M_s7.7, November 5), M_J7.4 (M_s7.6, November 6), M_J6.9 (M_s7.0, November 6) and M_J7.0(M_s7.0, November 14) that occurred at Shioya-Oki (Off the coast of Fukushima Prefecture). The data is taken from the JMA hypocenter catalog for the rectangular region bounded by 36.5–38°N and 141–143°E for about three year's period till the end of October 1941, taking into account the total energy of the largest events.

The analyzed data sets and the corresponding results shown by **Figures A25.1–A25.4** are summarized in the following table.

The 1938 Fukushima-Ken-Oki great swarm activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.5	239	141.0–143.0	36.5–38.0	0.10	1090.0	–	normal	A25.1
4.7	189	141.0–143.0	36.5–38.0	0.10	1090.0	–	normal	A25.2
5.0	111	141.0–143.0	36.5–38.0	0.10	1090.0	664.4	quiescent	A25.3
5.5	65	141.0–143.0	36.5–38.0	2.0	1090.0	–	normal	A25.4

The swarm sequence of events with M5.5 and larger was a very complex data set for applying the ETAS model. In particular, after the second largest event of M_J7.4 (M_s7.6, November 6), we had a burst of such large events that it seemed very different from the activity in other periods.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1938 Nov 05 (142.2°E 39.8°N) M_J7.5 M_s7.7

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.0	0.9	1.1	1939 10 11	142.8 38.3	Miyagi-Ken-Oki (Ms7.4)
7.1	4.6	4.0	1943 06 13	143.3 41.3	Aomori-Ken-Toho-Oki
7.1	6.3	3.7	1945 02 10	142.1 41.0	Aomori-Ken-Toho-Oki
			Land		
6.8	0.5	3.5	1939 05 01	139.5 40.1	Oga-Hanto-Oki
6.1	2.7	3.2	1941 07 15	138.2 36.7	Nagano earthquake
6.2	4.8	1.8	1943 08 12	139.9 37.3	Fukushima-Ken South
6.3	6.1	4.1	1944 12 09	139.0 34.2	Miyakejima-Seiho-Oki
6.8	6.2	4.9	1945 01 13	137.1 34.7	Mikawa earthquake
7.1	9.7	4.9	1948 06 28	136.2 36.2	Fukui earthquake

The 1933 Sanriku earthquake

This tsunami earthquake of M_J8.1 (M_s 8.5) took place within the subducting Pacific Plate with a normal fault type mechanism (Kanamori, 1971). For the investigation of the long term aftershock activity, we consider data for about a two year span taking into account the size of the mainshock.

The following table summarizes the considered data sets and corresponding results shown in **Figures A26.1–A26.6**.

The 1933 Sanriku-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	137	143.0–146.0	38.0–41.0	0.10	730.0	29.94	activate	A26.1
5.0	88	143.0–146.0	38.0–41.0	0.10	730.0	79.07	normal	A26.2
5.5	51	143.0–146.0	38.0–41.0	0.10	730.0	–	normal	A26.3
5.8	28	143.0–146.0	38.0–41.0	0.10	730.0	29.94	normal	A26.4
6.0	19	143.0–146.0	38.0–41.0	0.10	730.0	202.68	quiescent	A26.5
6.2	10	143.0–146.0	38.0–41.0	0.01	730.0	140.24	quiescent	A26.6

The data of the completely detected lowest magnitude is around M5.5. Further, we consider another data set with threshold magnitude M_c5.0 where the curve of the cumulative number appears similar to that of $M \geq 5.5$ as shown in Figures A26.2 and A26.3. This shows that the data set with $M \geq 5.0$ is homogeneous, namely, the detection rate of the shocks down to the threshold magnitude does not change in time during the considered period. The same homogeneity appears to hold for the data set with M≥0.0 (Figure A26.1). The ETAS model was fitted to these data sets.

The data set with $M \geq 5.5$ has no significant change-point (see Figure A26.3). On the other hand, the data sets of events with threshold magnitude M_c0.0, 5.0 and 5.8 have a significant change-point, but we can see no relative quiescence after that. The cumulative curve of these data sets extend either on or over the line of the expected rate (Figures A26.1, A26.2 and A26.4). However, for the large aftershocks with threshold magnitudes such as M_c6.0 and 6.2, we see relative quiescence after the significant change-point (Figures A26.5 and A26.6).

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1933 Mar 03 (144.5°E 39.2°N) M_J8.1 M_s8.5

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.1	0.3	1.9	1933 06 19	142.5 38.1	Miyagi-Ken-Oki (Ms7.3)
7.1	2.6	1.6	1935 10 18	144.3 40.8	Aomori-Ken-Toho-Oki swarm (M7.2)
7.5	3.7	2.1	1936 11 03	142.1 38.1	Miyagi-Ken-Oki (Ms7.2)
7.1	4.4	2.1	1937 07 27	142.1 38.3	Miyagi-Ken-Oki (mB7.1)
7.0	5.2	3.4	1938 05 23	141.6 36.6	Ibaragi-Ken-Oki
7.5	5.7	2.6	1938 11 05	142.2 37.3	Shioya-Oki Great swarm
7.3	5.7	2.9	1938 11 05	141.7 37.3	Shioya-Oki Great swarm
7.4	5.7	2.7	1938 11 06	141.9 37.4	Shioya-Oki Great swarm
7.0	6.6	1.6	1939 10 11	142.8 38.3	Miyagi-Ken-Oki (Ms7.4)
				Land	
6.1	0.6	4.8	1933 10 04	138.8 37.3	Niigata-Ken South
6.7	2.5	3.3	1935 09 18	142.6 42.2	Hidaka-Oki
6.1	5.2	4.4	1938 05 29	144.4 43.5	Kussharo earthquake
6.8	6.2	4.0	1939 05 01	139.5 40.1	Oga-Hanto-Oki

In Ogata (1992) relative quiescence of seismicity prior to the Sanriku great earthquake was investigated. It shows extraordinarily short relative quiescence when compared to the size of the forth coming earthquake (Ohtake, 1980 and 1993). The area where the quiescence was seen to be restricted runs southward from the source although it is very wide extending down off the coast of the Tokai area. In contrast, the region of the higher latitude than the source was active.

In particular, during a few year period prior to this great event, there were conspicuously many shallow and deep major earthquakes of $M_J 6.5 \sim 7.8$ around the focal region, which could be seen as foreshocks in wide sense (see Mogi, 1973, and Shimazaki, 1978). Most of these occurred at the northern area of the focal region. Those include the 1931 Aomori-Toho-Oki earthquake of M_J7.6 (M_s7.8), but unfortunately the detection rate in this offshore area is too low to obtain enough aftershock data for the analysis. The exceptions are two events that occurred inland of northern Tohoku and in southwestern Hokkaido, namely, the 1932 Hidaka-Chubu earthquake of M_J7.0 analyzed previously, and the event discussed in the following section.

The 1931 Iwate-Ken-Tobu earthquake

This event of M_J6.5 took place in November 1931 at Oguni-Machi, Iwate Prefecture, Northern

Tohoku District about 250km westward from the epicenter and about 16 months before the great Sanriku event. This aftershock sequence is examined by using the list of felt and unfelt shocks in *Kisho-Yoran* (*Geophysical Review of the JMA*, 1931-1933) which are mainly observed at Morioka and Miyako Observatories of the JMA. There are $N = 279$ felt and unfelt events in the time span until the occurrence of the Sanriku event. The events whose magnitude is listed in the JMA hypocenter catalog adopt the same magnitude. Otherwise, $M_c \approx 3.3$ is set for the felt shocks, and $M_c \approx 2.5$ is set for the unfelt shocks so that the cumulative frequency roughly satisfies the Gutenberg-Richter's law for magnitude frequency (Gutenberg and Richter, 1944). The occurrence time data are provided up to the accuracy of the minute, but there are a number of couples and triplets which occurred during the same minute. This causes an unfavorable effect in the estimation of the ETAS parameters. Thus, occurrence times of these are shifted to separate the couples and triplets from each other.

For the unfelt shock data emergence of relative quiescence after the change-point appears clear (**Figure A27.1**). On the other hand, the activity seems complex in the felt shock data. At first the change-point is indicated at 48.99 days after the mainshock, followed by relative activation (**Figure A27.2**). However there is a considerable number of events left in the remaining interval [48.99, 485.0]days in which another change-point is revealed at 130.53 days after the mainshock, followed by a relatively quiet period (**Figure A27.3**). The normal activity is seen for the data set of events with M_c4.0 or larger although the suspected change-point at t=71.399days is nearly significant (**Figure A27.4**).

The following table summarizes the considered data sets and the corresponding results described above.

The 1931 Iwate-Ken-Tobu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
unfelt	279	141.0-142.5	39.0–40.0	0.03	485.0	232.14	quiescent	A27.1
felt	66	141.0-142.5	39.0–40.0	0.03	485.0	48.99	activate	A27.2
felt	66	141.0-142.5	39.0–40.0	48.99	485.0	130.53	quiescent	A27.3
4.0	18	141.0-142.5	39.0–40.0	0.03	485.0	–	normal	A27.4

It may be possible that the relative quiescence is related to the forthcoming great Sanriku earthquake which appears to have occurred in the recovering stage of the aftershock activity.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1931 Nov 04 (141.7°E 39.5°N) M_J6.5

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
8.1	1.3	2.2	1933 03 03	144.5 39.2	Sanriku-Oki
7.1	1.6	1.5	1933 06 19	142.5 38.1	Miyagi-Ken-Oki (Ms7.3)
7.1	4.0	2.4	1935 10 18	144.3 40.8	Aomori-Ken-Toho-Oki swarm (M7.2)
7.5	5.0	1.4	1936 11 03	142.1 38.1	Miyagi-Ken-Oki (Ms7.2)
7.1	5.7	1.2	1937 07 27	142.1 38.3	Miyagi-Ken-Oki (mB7.1)
7.0	6.6	2.9	1938 05 23	141.6 36.6	Ibaragi-Ken-Oki
7.5	7.0	2.2	1938 11 05	142.2 37.3	Shioya-Oki great swarm
7.3	7.0	2.2	1938 11 05	141.7 37.3	Shioya-Oki great swarm
7.4	7.0	2.1	1938 11 06	141.9 37.4	Shioya-Oki great swarm
7.0	7.9	1.5	1939 10 11	142.8 38.3	Miyagi-Ken-Oki (Ms7.4)
				Land	
7.0	1.1	3.0	1932 11 26	142.5 42.4	Hidaka-Chubu
6.0	1.9	4.3	1933 09 21	137.0 37.1	Noto-Hanto East
6.1	1.9	3.1	1933 10 04	138.8 37.3	Niigata-Ken South
6.7	3.9	2.8	1935 09 18	142.6 42.2	Hidaka-Oki
6.1	6.6	4.6	1938 05 29	144.4 43.5	Kussharo earthquake
6.8	7.5	1.8	1939 05 01	139.5 40.1	Oga-Hanto-Oki
6.1	9.7	3.9	1941 07 15	138.2 36.7	Nagano

The 1928 Iwate-Ken-Oki earthquake

This event of M_J7.0 occurred off the coast of Iwate Prefecture. The considered rectangular region is bounded widely by 39–41°N and 143–144°E, taking into account the inaccuracy of epicenters. Therefore, the ETAS model with $\mu > 0$ fits the data set better than that with $\mu = 0$, and **Figures A28.1–A28.4** displays the results of the analysis.

The analyzed data sets and the corresponding results are summarized in the following table.

The 1928 Iwate-Ken-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	40	143.0–144.0	39.0–41.0	0.9	651.0	–	normal	A28.1
5.1	30	143.0–144.0	39.0–41.0	0.9	651.0	–	normal	A28.2
5.3	19	143.0–144.0	39.0–41.0	0.5	651.0	5.51	quiescent	A28.3
5.5	15	143.0–144.0	39.0–41.0	0.5	651.0	5.51	quiescent	A28.4

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1928 May 27 (143.3°E 40.0°N) M_J7.0

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.6	2.8	1.4	1931 03 09	142.5 41.2	Aomori-Ken-Toho-Oki (Ms7.8)
8.1	4.8	1.2	1933 03 03	144.5 39.2	Sanriku-Oki
7.1	5.1	2.0	1933 06 19	142.5 38.1	Miyagi-Ken-Oki (Ms7.3)
7.1	7.4	1.2	1935 10 18	144.3 40.8	Aomori-Ken-Toho-Oki swarm (Ms7.2)
7.5	8.4	2.0	1936 11 03	142.1 38.1	Miyagi-Ken-Oki (Ms7.2)
7.1	9.2	1.9	1937 07 27	142.1 38.3	Miyagi-Ken-Oki (mB7.1)
				Land	
6.0	3.0	3.9	1931 06 09	140.7 36.6	Ibaragi-Ken Northeast
6.9	3.3	4.9	1931 09 21	139.2 36.1	Saitama-Ken-West
6.5	3.4	1.1	1931 11 04	141.9 39.5	Iwate-Ken-Tobu
7.0	4.5	2.5	1932 11 26	142.5 42.4	Hidaka-Chubu
6.1	5.3	4.3	1933 10 04	138.8 37.3	Niigata-Ken South
6.7	7.3	2.3	1935 09 18	142.6 42.2	Hidaka-Oki

3. Eastern margin in Sea of Japan

The 1995 Niigata-Ken-Chubu earthquake

This earthquake of M_J5.5 hit a local area in the central part of Niigata Prefecture. The events with $M \geq 3.0$ till the end of the available data are analyzed.

The data sets and corresponding results shown in **Figures A29.1–A29.4** are summarized in the following table.

The 1995 Niigata-Ken-Chubu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.8	79	139.0–139.5	37.75–38.0	0.01	702.0	–	activate	A29.1
3.0	79	139.0–139.5	37.75–38.0	0.01	702.0	–	normal	A29.2
3.2	43	139.0–139.5	37.75–38.0	0.01	702.0	–	normal	A29.3
3.5	21	139.0–139.5	37.75–38.0	0.01	702.0	13.89	quiescent	A29.4

The relative activation in the sequence of events with M≥2.8 seems to take place owing to the substantial amount of secondary aftershocks triggered by the largest aftershock in comparison with its magnitude. Similarly, another activation is seen right after the second largest aftershock (see the FLT diagram of Figure A29.1). In case of M_c3.5 (Figure A29.4) the selected change-point is of significance in the second stage, that is, this is the furthest change-point in the interval between 0.01 and the time of the largest significance.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1995 Apr 01 (139.3°E 37.9°N) M_J5.5

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
–	–	–	–	–	–
			Land		
6.1	3.4	2.3	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

The 1993 Hokkaido-Nansei-Oki earthquake

The source region of this event is located near to the Okushiri Island, about 400km distant at south-westward from the source of the 1994 Hokkaido-Toho-Oki (Off Kuril Islands) earthquake.

The time span is taken up until the last date before the occurrence of the 1994 Hokkaido-Toho-Oki earthquake (namely, $T = 448$days). Aftershock data sets of events with threshold magnitudes M_c4.0, 4.5 and 5.0 are considered. For the data set of events with threshold magnitude M_c4.0 a significant change-point ($T_c = 12.23$days) is found and followed by relative quiescence for a short time span up until the occurrence of the largest aftershock ($T = 26.25$days), but it appears to recover to normal activity after that (see **Figure A30.1**). For the data set with M≥4.5 no change-point is seen (**Figure A30.2**).

For the data set with M≥5.0 there were no such events for a year time span, but this is not a significant relative quiescence (**Figure A30.3**) owing to the high p-value. Indeed, a characteristic feature of the aftershock activity in this area seems to be high p-value for the modified Omori function. Similar high p-value is revealed in the 1940 Shikotan-Hanto-Oki earthquake of M_J7.5 ($p = 1.55$, Matsu'ura, 1994, personal communication) in the northern neighborhood of the present source.

The data sets and corresponding results are summarized in the following table.

The 1993 Hokkaido-Nansei-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.0	217	138.0–142.0	40.0–45.0	0.018	448.0	12.23	normal	A30.1
4.5	67	138.0–142.0	40.0–45.0	0.018	448.0	–	normal	A30.2
5.0	15	138.0–142.0	40.0–45.0	0.018	448.0	–	normal	A30.3

In order to examine the aftershock activity prior to the largest aftershock of M_J6.3, the sequences in the shorter time span $T = 26.25$days up until the event are considered for the threshold magnitudes M_c4.0, 4.2, 4.5 and 4.8 (**Figures A30.4–A30.7**). These figures indicate the emergence of relative quiescence except for the data set of events with M_c4.0. The data sets and corresponding results are summarized in the following table.

The 1993 Hokkaido-Nansei-Oki aftershock activity: till the largest aftershock

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.0	180	138.0–142.0	40.0–45.0	0.018	26.25	–	normal	A30.4
4.2	110	138.0–142.0	40.0–45.0	0.018	26.25	12.23	quiescent	A30.5
4.5	60	138.0–142.0	40.0–45.0	0.018	26.25	12.23	quiescent	A30.6
4.8	25	138.0–142.0	40.0–45.0	0.018	26.25	7.25	quiescent	A30.7

However, these results are not listed in Table 1 of the main text since our aim of investigation is to forecast events of similar magnitude or larger in the neighborhood based on relative quiescence lasting for a relatively long period of a few months or more, not the forecasting of large aftershock events based on the quiescence of short periods as studied by Matsu'ura (1986).

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1993 Jul 12 (139.2°E 42.8°N) M_J7.8

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.5	1.5	4.1	1994 12 28	143.7 40.4	Sanriku-Haruka
7.2	1.5	3.4	1995 01 07	142.3 40.2	Sanriku-Haruka aftershock
6.3	0.1	1.0	1993 08 08	139.9 42.0	Hokkaido-Nansei-Oki aftershock
				Land	
6.1	5.1	3.3	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

The 1993 Noto-Hanto-Oki earthquake

This event of M_J6.6 occurred off the northern coast of Noto Peninsula, Fukui Prefecture, about a half year preceding the Hokkaido-Nansei-Oki earthquake of M_J7.8. Thus the aftershock activity is examined for the period up until the forthcoming great event (T=154days) in addition to the periods till the end of March 1996 (T=781days) and February 1998 (T=1482). The events with $M \geq 3.0$ appear complete in detection from the Gutenberg-Richter's magnitude frequency relation except for the span [0, 0.03]days due to the incomplete and inhomogeneous detection caused by the contamination of waves.

The analyzed data sets and the corresponding results shown in **Figures A31.1–A31.5** are summarized in the following table.

The 1993 Noto-Hanto-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.0	238	137.0–137.7	37.5–37.8	0.03	1482.0	19.13	quiescent	A31.1
3.0	204	137.0–137.7	37.5–37.8	0.03	781.0	19.10	quiescent	A31.2
3.0	161	137.0–137.7	37.5–37.8	0.03	154.0	107.02	quiescent	A31.3
3.5	64	137.0–137.7	37.5–37.8	0.03	781.0	–	normal	A31.4
4.0	29	137.0–137.7	37.5–37.8	0.03	781.0	123.07	quiescent	A31.5

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1993 Feb 07 (137.3°E 37.7°N) M_J6.6

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.2	1.9	4.7	1995 01 07	142.3 40.2	Sanriku-Haruka aftershock
				Land	
6.3	0.5	4.7	1993 08 08	139.9 42.0	Hokkaido-Nansei-Oki aftershock
7.2	1.9	3.6	1995 01 17	135.0 34.6	Kobe earthquake
6.1	5.6	3.5	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

Here the Hokkaido-Nansei-Oki is not listed due to the distance of 5.3 degrees.

The 1983 Nihonkai-Chubu earthquake

This event of M_J7.7 occurred off the western coast of Akita Prefecture in the Sea of Japan and the tsunami killed quite a few people. The aftershock sequences are analyzed using data taken from the JMA catalog for the term ending 1991 and for the rectangular region bounded by 39.75°–42°N and 138°–140°E.

The following table summarizes the considered data sets and the corresponding results shown in **Figures A32.1–A32.4**. We conclude that these aftershock sequence data sets with magnitude thresholds M_c4.0 and 4.5 have developed normally (Figures A32.1 and A32.2). However, for the data sets consisting of events with the thresholds M_c5.0 and 5.3, respectively, all the events took place by the 922th day after the mainshock and no such events occurred in the rest of the period (Figures A32.3 and A32.4).

The 1983 Nihonkai-Chubu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.0	399	138.0–140.0	39.75–42.0	0.06	3141.0	–	normal	A32.1
4.5	115	138.0–140.0	39.75–42.0	0.10	3141.0	–	normal	A32.2
5.0	64	138.0–140.0	39.75–42.0	0.10	3141.0	921.18	quiescent	A32.3
5.3	15	138.0–140.0	39.75–42.0	0.10	3141.0	921.18	quiescent	A32.4

Indeed, Figures A32.1 and A32.2 show that no change-point exists for the sequences of magnitude thresholds M_c4.0 and 4.5, respectively.

However, in the sequences of magnitude thresholds M_c5.0 and 5.3, we have had no such event at least for the 6 year period since 2.6 years after the mainshock: this is shown to be significantly quiet by $\xi(t)$ in Figures A32.3 and A32.4, respectively. This analysis of significance is made by comparing the single ETAS model for the whole period with the two-stage model where the ETAS model is applied for the former span and the Poisson process with no event is applied for the latter time span.

The largest aftershock of M_J7.1 occurred at the northern edge of the main source and on the 26th day after the mainshock. In order to examine the aftershock activity prior to the largest aftershock of M_J7.1, the sequences in the shorter time span ($T = 26.14$days) up until the event are also considered for the sequences of events with threshold magnitudes M_c4.0, 4.5 and 5.0 (**Figures A32.5, A32,6 and A32.7**, respectively). These figures indicate the normal activity except for the data set with M_c4.5 which indicates an apparently significant change-point owing to the burst-like activity around that time.

The following table summarizes the considered data sets and the corresponding results shown in Figures A32.5–A32.7.

The 1983 Nihonkai-Chubu aftershock activity till the largest aftershock of M_J7.1

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.0	232	138.0–140.0	39.75–42.0	0.03	26.14	–	normal	A32.5
4.5	69	138.0–140.0	39.75–42.0	0.03	26.14	14.42	quiescent	A32.6
5.0	36	138.0–140.0	39.75–42.0	0.03	26.14	–	normal	A32.7

However, these were not listed in Table 1 of the main text since our focus of investigation is to forecast events of similar magnitude or larger in the neighborhood based on the emergence of relative quiescence lasting for a relatively long period of a few months or more, not the forecast of large aftershocks based on the quiescence of short periods as studied by Matsu'ura (1986).

The following table lists large earthquakes which occurred after this event within about ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1983 may 26 (139.1°E 40.4°N) M_J7.7

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.1	0.1	0.9	1983 06 21	139.0 41.3	Nihonkai-Chubu aftershock
7.1	6.4	3.1	1989 11 02	143.1 39.9	Iwate-Ken-Oki
				Land	
6.0	0.2	4.9	1983 08 08	139.0 35.5	Yamanashi-Ken-Tobu
6.8	1.3	4.7	1984 09 14	137.6 35.8	Nagano-Ken-Seibu
6.0	5.8	4.9	1989 03 06	140.7 35.7	Chiba-Ken-Hokubu
6.0	7.0	4.9	1990 06 01	140.7 35.6	Chiba-Ken-Hokubu
6.6	9.7	3.1	1993 02 07	137.3 37.6	Noto-Hanto-Oki
7.8	10.1	2.4	1993 07 12	139.2 42.8	Hokkaido-Nansei-Oki

Here, the long term relative quiescence shown above may be a precursor to the forthcoming large event off the southwest coast of Hokkaido (the Hokkaido-Nansei-Oki of M_J7.8), but this is not listed here owing to the 10.1 years' time-lag.

The 1964 Niigata earthquake

This event of M_J7.5 occurred off the eastern coast of Niigata Prefecture, near Sado Island. The aftershock data from the JMA hypocenter catalog includes 96 events with $M \geq 4.0$ for the time span of 215days till the end of the year. Also, the felt shock data is available (236 events) taken from the Bulletin of the JMA (1964), and the threshold level of such events are roughly estimated to be M3.5 by extrapolating Gutenberg-Richter's magnitude-frequency relation. Since these events appear homogeneous except for a three hour span right after the mainshock, we fitted ETAS to the events in the period from S=0.05 to T=215 days, conditional on the history of events in [0, 0.05]days.

The analyzed data sets and the corresponding results shown in **Figures A33.1–A33.4** are summarized in the following table.

The 1964 Niigata aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
felt	236	138.0–140.0	37.75–39.25	0.05	198.0	–	normal	A33.1
4.0	96	138.0–140.0	37.75–39.25	0.05	198.0	–	normal	A33.2
4.5	50	138.0–140.0	37.75–39.25	0.05	198.0	–	normal	A33.3
5.0	22	138.0–140.0	37.75–39.25	0.02	198.0	–	normal	A33.4

Incidentally, the estimated value $\hat{\alpha} = 33.9$ shown in the figures suggests that the estimated ETAS models are very close to the modified Omori formula with the same $\hat{p}$.

After all, we see no significant change-point for the sequence of events with the considered threshold magnitudes (Figures A33.1–A33.4).

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1964 Jun 16 (139.2°E 38.4°N) M_J7.5

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.9	3.9	4.2	1968 05 16	143.6 40.7	Tokachi-Oki
7.5	3.9	4.2	1968 05 16	142.8 41.4	Tokachi-Oki aftershock
7.2	4.0	3.2	1968 06 12	143.1 39.4	Tokachi-Oki aftershock
7.0	7.1	4.5	1971 08 02	143.7 41.2	Hidaka Northeast (Ms7.1)
				Land	
6.1	0.8	3.6	1965 04 20	138.3 34.9	Shizuoka-Ken Chubu
6.6	5.2	3.1	1969 09 09	137.1 35.8	Gifu-Ken-Chubu
6.2	6.3	1.5	1970 10 16	140.8 39.2	Akita-Ken South-east
6.0	8.2	3.2	1972 08 31	136.8 35.9	Fukui-Ken East
6.9	9.9	3.8	1974 05 09	138.8 34.6	Izu-Hanto-Oki

The 1964 Oga-Hanto earthquake

This event of M_J6.9 took place 40days prior to the occurrence of the 1964 Niigata earthquake. Only 12 events with $M \geq 4.5$ were completely detected out of 21 events for the mainshock and aftershocks listed in the JMA hypocenter catalog. Further, we also use all recorded earthquakes (felt and unfelt events) in the Bulletin of the JMA (1964) detected mainly at Akita Observatory. The number of those events in the considered time span is 375, and among them 153 events are felt shocks. The magnitude of felt and unfelt shocks are roughly evaluated to be about M3.0 and M2.5, respectively, by extrapolating the magnitude frequency of events from the JMA hypocenter catalog based on the Gutenberg-Richter's relation.

The following table summarizes the considered data sets and the corresponding results shown by **Figures A34.1–A34.3**.

The 1964 Oga-Hanto-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
unfelt	375	138.0–140.0	39.5–41.0	0.03	40.0	–	normal	A34.1
felt	153	138.0–140.0	39.5–41.0	0.03	40.0	–	normal	A34.2
0.0	21	138.0–140.0	39.5–41.0	0.03	40.0	–	normal	A34.3

All the aftershock sequences are concluded to have developed normally although there are nearly significant change-points at about a week to ten days after the mainshock which could initiate relative quiescence.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1964 May 07 (139.0°E 40.3°N) M_J6.9

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.5	0.1	2.0	1964 06 16	139.2 38.4	Niigata earthquake
6.1	0.1	1.9	1964 06 16	139.3 38.4	Niigata aftershock
7.9	4.0	3.5	1968 05 16	143.6 40.7	Tokachi-Oki earthquake
7.5	4.0	3.1	1968 05 16	142.8 41.4	Tokachi-Oki aftershock
7.2	4.1	3.3	1968 06 12	143.1 39.4	Tokachi-Oki aftershock
7.0	7.2	3.7	1971 08 02	143.7 41.2	Hidaka Northeast (Ms7.1)
				Land	
6.6	5.3	4.8	1969 09 09	137.1 35.8	Gifu-Ken-Chubu
6.2	6.4	1.7	1970 10 16	140.8 39.2	Akita-Ken Southeast
6.0	8.3	4.7	1972 08 31	136.8 35.9	Fukui-Ken East

The 1939 Oga-Hanto-Oki earthquake

This event of M_J6.8 took place off the Oga Peninsula, Akita Prefecture. The data is taken from the JMA hypocenter catalog for the rectangular region bounded by 39–41°N and 138–141°E for the period up until the end of January 1942. We first consider a sequence of events of threshold magnitude M_c4.1 or larger. We further use the events whose magnitude is not determined but location is identified in the JMA hypocenter catalog. Such event's magnitude is printed as M0.0 in the catalog. The data including all events from the JMA hypocenter catalog including the events of M0.0 (denoted as M_c0.0) is also considered.

The analyzed data sets and the corresponding results shown in **Figures A35.1 and A35.2** are summarized in the following table.

The 1939 Oga-Hanto-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	59	138.0–141.0	39.0–41.0	0.05	1006.0	–	normal	A35.1
4.1	35	138.0–141.0	39.0–41.0	0.05	1006.0	–	normal	A35.2

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1939 May 01 (139.5°E 40.1°N) M_J6.8

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.0	0.4	3.1	1939 10 11	142.8 38.3	Miyagi-Ken-Oki (Ms7.4)
7.5	1.2	4.1	1940 08 02	139.5 44.2	Shikotan-Oki (Ms7.5)
7.1	4.1	3.1	1943 06 13	143.3 41.2	Aomori-Ken-Toho-Oki (Ms7.2)
7.1	5.8	2.1	1945 02 10	142.1 41.0	Aomori-Ken-Toho-Oki (Ms7.1)
				Land	
6.1	2.2	3.5	1941 07 15	138.2 36.7	Nagano earthquake
6.2	4.3	2.8	1943 08 12	139.9 37.3	Fukushima-Ken South
6.2	7.8	3.3	1947 02 05	142.7 42.4	Aomori-Ken-Toho-Oki
7.1	9.2	4.7	1948 06 28	136.2 36.2	Fukui earthquake

4. Kanto and Tokai District and their offshore regions including Izu Peninsula and Islands

The 1990 Chiba-Ken-Hokubu earthquake

This event of M_J6.0 occurred at June 1, 1990, in the depth of about 60km near Choshi city, Chiba Prefecture, one year and 9 months after the preceding event of M_J6.0 northward and within a distance of 10km. Aftershocks are taken from the JMA hypocenter catalog for the rectangular region bounded by 140.5°–141°E and 35.6°–35.9°N and for the period till the end of February 1992.

The analyzed data sets and the corresponding results shown in **Figures A36.1–A36.3** are summarized in the following table.

The 1990 Chiba-Ken-Hokubu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.0	152	140.5–141.0	35.6–35.9	0.05	637.0	–	normal	A36.1
2.5	65	140.5–141.0	35.6–35.9	0.05	637.0	–	normal	A36.2
3.0	23	140.5–141.0	35.6–35.9	0.05	637.0	–	normal	A36.3

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1990 Jun 01 (140.7°E 35.6°N) M_J6.0

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.2	4.6	4.8	1995 01 07	142.3 40.2	Sanriku-Haruka-Oki aftershock
				Land	
6.6	2.7	3.4	1993 02 07	137.3 37.6	Noto-Hanto-Oki
7.2	4.6	4.7	1995 01 17	135.0 34.6	Kobe earthquake
6.1	8.3	4.2	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

The 1989 Chiba-Ken-Hokubu earthquake

This event of M_J6.0 occurred at March 6, 1989, in the depth of about 60km near Choshi city, Chiba Prefecture. Then, another event of M_J6.0 discussed in the above took place at June 1, 1990, southward within distance of 10km. The aftershocks are taken from the JMA hypocenter catalog for the rectangular region bounded by 140.5°–141°E and 35.6°–35.9°N and, at first, for the period (T=451days) up until about a half day before the 1990 Chiba-Ken-Hokubu earthquake. From the cumulative curves and magnitude-time plots emergence of relative quiescence is suspected and it seems to have terminated 240days after the mainshock. Therefore, we also investigate the activity for the first period of 240days.

The analyzed data sets and the corresponding results shown in **Figures A37.1–A37.4** are summarized in the following table.

The 1989 Chiba-Ken-Hokubu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.0	118	140.5–141.0	35.6–35.9	0.05	240.0	71.35	quiescent	A37.1
2.5	51	140.5–141.0	35.6–35.9	0.05	240.0	71.35	quiescent	A37.2
3.0	26	140.5–141.0	35.6–35.9	0.05	451.0	–	normal	A37.3
3.5	16	140.5–141.0	35.6–35.9	0.05	451.0	39.73	quiescent	A37.4

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1989 Mar 06 (140.7°E 35.7°N) M_J6.0

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.1	0.6	4.6	1989 11 02	143.1 39.9	Iwate-Ken-Oki
7.2	5.8	4.7	1995 01 07	142.3 40.2	Sanriku-Haruka-Oki
			Land		
6.0	1.2	0.1	1990 06 01	140.7 35.6	Chiba-Ken-Hokubu
6.5	1.0	1.5	1990 02 20	139.2 34.8	Izu-Oshima Kinkai
6.6	3.9	3.4	1993 02 07	137.3 37.6	Noto-Hanto-Oki
7.2	5.9	4.7	1995 01 17	135.0 34.6	Kobe earthquake
6.1	9.5	4.1	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

The 1987 Chiba-Ken-Toho-Oki earthquake

This event of M_J6.7 occurred off the east coast of Chiba Prefecture. The aftershock events are taken from the rectangular region bounded by 35°15′–35°35′N and 140°15′–140°40′E and for the period till the end of August 1990.

The data sets considered and the corresponding results shown in **Figures A38.1–A38.4** are summarized in the following table.

The 1987 Chiba-Ken-Toho-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.5	430	140.25–140.67	35.25–58	0.50	981.0	68.22	quiescent	A38.1
3.0	194	140.25–140.67	35.25–58	0.10	981.0	126.46	quiescent	A38.2
3.5	82	140.25–140.67	35.25–58	0.01	978.0	120.63	quiescent	A38.3
4.0	18	140.25–140.67	35.25–58	0.01	978.0	120.63	quiescent	A38.4

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1987 Dec 17 (140.5°E 35.4°N) M_J6.7

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.1	1.9	4.9	1989 11 02	143.1 39.9	Iwate-Ken-Oki
7.2	7.1	5.0	1995 01 07	142.3 40.2	Sanriku-Haruka West
6.5	2.2	1.2	1990 02 20	139.2 34.8	Izu-Oshima Kinkai
6.6	5.2	3.4	1993 02 07	137.3 37.6	Noto-Hanto-Oki
			Land		
6.0	1.2	0.3	1989 03 06	140.7 35.7	Chiba-Ken-Hokubu 1
6.0	2.5	0.3	1990 06 01	140.7 35.6	Chiba-Ken-Hokubu 2
7.2	7.1	4.5	1995 01 17	135.0 34.6	Kobe earthquake

The 1983 Yamanashi-Ken-Tobu earthquake

This event of M_J6.0 occurred at the north-eastern neighborhood of Mt. Fuji around the border of Yamanashi and Kanagawa Prefectures. The considered area is bound by 35°20′–35°40′N and 138°50′–139°10′E and for the period of a one year span. For all the examined data sets of aftershocks with magnitude thresholds M_c2.5, 2.7 and 3.0, inclusion of the parameter μ for background activity (i.e. $\mu > 0$) improves the AIC value substantially, and the estimated value $\hat{\alpha} = 38.3$ suggests that the fitted ETAS is close to the modified Omori formula. One of the main reasons for this may be that the largest aftershock of M_J5.2 occurred on February 14, 1984, and had no secondary aftershocks.

We see no change-point for the sequence of events with $M \geq 2.5$ from **Figure A39.1**. On the other hand, however, we have no aftershock events with magnitude M_c2.7 or larger for the last 4.5 months in the data set. Therefore, by fitting the stationary Poisson for the latter half span where no such event occurred, this quiescence is shown to be significant (see ξ-plot in **Figure A39.2**). The same result is obtained for the data sets of events with threshold magnitudes M_c2.8, 2.9 and 3.0 (**Figure A39.3**).

The data sets and the corresponding results shown in Figures A39.1–A39.3 are summarized in the following table.

The 1983 Yamanashi-Ken-Tobu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.5	68	138.83–139.17	35.33–35.67	0.01	366.0	–	normal	A39.1
2.7	54	138.83–139.17	35.33–35.67	0.01	366.0	225.80	quiescent	A39.2
3.0	30	138.83–139.17	35.33–35.67	0.01	366.0	126.46	quiescent	A39.3

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1983 Aug 08 (139.0°E 35.5°N) M_J6.0

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
–	–	–	–	–	–
			Land		
6.2	0.2	1.6	1983 10 03	139.5 34.0	Miyake-Is-Near
6.2	0.2	4.1	1983 10 31	133.9 35.4	Tottori-Ken
6.8	1.1	1.2	1984 09 14	137.6 35.8	Nagano-Ken-Seibu
6.0	3.3	1.0	1986 11 22	139.5 34.5	Izu-Oshima Kinkai
6.0	5.6	1.4	1989 03 06	140.7 35.7	Chiba-Ken-Hokubu 1
6.5	6.5	0.8	1990 02 20	139.2 34.8	Izu-Oshima Kinkai
6.0	6.8	1.4	1990 06 01	140.7 35.6	Chiba-Ken-Hokubu 2
6.6	9.5	2.6	1993 02 07	137.3 37.6	Noto-Hanto-Oki

The 1982 Ibaragi-Ken-Oki earthquake

This earthquake of M_J 7.0 occurred off the east coast of Ibaragi Prefecture. The aftershock events are taken from the JMA hypocenter catalog for the rectangular region bounded by 141.5°–142.5°E and 35.75°–36.5°N and for the period till the end of 1984.

The analyzed data sets and the corresponding results shown in **Figures A40.1–A40.3** are summarized in the following table.

The 1982 Ibaragi-Ken-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.2	158	141.5–142.5	35.75–36.5	0.03	922.0	–	normal	A40.1
3.7	80	141.5–142.5	35.75–36.5	0.03	922.0	412.45	quiescent	A40.2
4.2	43	141.5–142.5	35.75–36.5	0.03	922.0	–	normal	A40.3

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1982 Jul 23 (142.0°E 36.2°N) M_J7.0

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.7	0.8	4.8	1983 05 26	139.1 40.4	Nihonkai-Chubu
7.1	7.3	3.8	1989 11 02	143.1 39.9	Iwate-Ken-Oki
			Land		
6.4	0.4	3.1	1982 12 28	139.4 33.9	Miyake-Is-Nanpo-Oki
6.0	1.0	2.4	1983 08 08	139.0 35.5	Yamanashi-Ken-Tobu
6.2	1.2	2.9	1983 10 03	139.5 34.0	Miyake-Is-Near
6.8	2.1	3.6	1984 09 14	137.6 35.8	Nagano-Ken-Seibu
6.0	4.3	2.5	1986 11 22	139.5 34.5	Izu-Oshima Kinkai
6.0	6.6	1.1	1989 03 06	140.7 35.7	Chiba-Ken-Hokubu 1
6.5	7.6	2.6	1990 02 20	139.2 34.8	Izu-Oshima Kinkai
6.0	7.9	1.1	1990 06 01	140.7 35.6	Chiba-Ken-Hokubu 2

The 1972 Hachijo-Jima-Oki earthquake (December)

Nine months after the event of M_J7.1 (M_s7.4) occurred at east off Hachijo Island (Hachijo-Jima-Oki earthquake), this event of M_J7.2 (M_s7.5) occurred in December 4, 1972 at the eastern neighborhood of the first event's source region. The accuracy of location of aftershocks was not good because the source region is far from the seismic network of both JMA and the Earthquake Research Institute, University of Tokyo, so that we take a wide region 140 $\sim$ 142°E and 33 $\sim$ 34°N to obtain the events from the catalogs. The JMA catalog is used for the events with M4.5 and larger for the period (T=391days) till the end of 1973. The microearthquake catalog compiled by Matsu'ura et al. (1988) is used for the events with smaller threshold magnitudes for the period of T=230days.

The considered data sets and corresponding results shown in **Figures A41.1–A41.3** are summarized in the following table.

The 1972 Hachijo-Jima-Oki aftershock activity (December)

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.6	353	140.0–141.5	33.0–34.0	0.03	230.0	–	normal	A41.1
4.0	102	140.0–141.5	33.0–34.0	0.03	230.0	–	normal	A41.2
4.5	68	140.0–141.5	33.0–34.0	0.03	391.0	–	normal	A41.3

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1972 Dec 04 (141.1°E 33.3°N) M$_J$7.2 M$_s$7.5

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.4	5.5	4.9	1978 06 12	142.2 38.1	Miyagi-Ken-Oki
7.0	9.6	3.0	1982 07 23	141.9 36.2	Ibaragi-Ken-Oki
			Land		
6.9	1.4	2.3	1974 05 09	138.8 34.6	Izu-Hanto-Oki
6.1	1.6	1.7	1974 06 27	139.2 33.8	Miyake-Is-Northwest-Oki
7.0	5.1	2.1	1978 01 14	139.2 34.8	Izu-Oshima-Kinkai
6.7	7.6	2.3	1980 06 29	139.2 34.9	Izu-Hanto-Toho-Oki

The 1972 Hachijo-Jima-Oki (February) earthquake

On February 29, 1972, an event of M$_J$7.1 (M$_s$7.4) occurred east of Hachijo Island. Matsu'ura (1986) studied this aftershock activity by applying the modified Omori formula to the events with M2.8 or larger in the microearthquake catalog compiled by Matsu'ura et al. (1988). Here, we first use the same catalog selecting events in the rectangular region bounded by 140.5–141.5°E and 33–34°N, and in the time span (T=279.04days) up until the occurrence time of the Hachijo-Jima-Oki earthquake (December) of M$_J$7.2 (M_s7.5). The sequence of events with M3.6 and larger appear completely detected except for the first 0.07days right after the mainshock. Further, the JMA hypocenter data is also used for the event M4.6 or larger which appears complete except for the first 0.5days right after the mainshock.

The considered data sets and corresponding results shown in **Figures A42.1–A42.3** are summarized in the following table.

The 1972 Hachijo-Jima-Oki aftershock activity (February)

M$_c$	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.6	271	140.5–141.5	33.0–34.0	0.07	279.04	163.71	quiescent	A42.1
4.0	121	140.5–141.5	33.0–34.0	0.07	279.04	163.71	quiescent	A42.2
4.6	39	140.5–141.5	33.0–34.0	0.50	279.00	142.65	quiescent	A42.3

Perhaps, some explanation is necessary for the result shown in the FLT diagram (right) in Figure A42.1. There seems to be a further change-point around 80days in the interval between 0.07 and 163.71days However, this change-point precedes a relative activation, and the significance is less substantial than that of 163.71days which precedes relative quiescence.

Two other figures (Figures A42.2 and A42.3) from mutually independent data sources and of different magnitude thresholds show that relative quiescence emerged after the respective change-point.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1972 Feb 04 (141.1°E 33.4°N) M$_J$7.1 M$_s$7.4

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.2	0.9	0.2	1972 12 04	141.1 33.2	Hachijo-Is-Oki
7.4	6.4	4.8	1978 06 12	142.2 38.1	Miyagi-Ken-Oki
			Land		
6.0	0.6	4.4	1972 08 31	136.8 35.9	Fukui-Ken East
6.9	2.3	2.2	1974 05 09	138.8 34.6	Izu-Hanto-Oki
6.1	2.5	1.6	1974 06 27	139.2 33.8	Miyake-Is-Northwest-Oki
7.0	6.0	2.1	1978 01 14	139.2 34.8	Izu-Oshima-Kinkai
6.7	8.5	2.2	1980 06 29	139.2 34.9	Izu-Hanto-Toho-Oki

The 1953 Boso-Oki earthquakes

This event of M$_J$7.4 (M$_s$7.9) occurred off Boso coast of Chiba Prefecture on November 26, 1953. In Ogata (1992) it is shown that this great event was preceded by relative quiescence in a very wide region 138–44°E and 32–8°N. Here, for the investigation of the aftershock activity, we consider the events in the rectangular region bounded by 140.5°–141°E and 33°–35°N and for the period of T=980days based on the mainshock's magnitude. The events of M5.0 or larger listed in the JMA hypocenter catalog in this area and period are complete except for the first 0.25days right after the mainshock.

We also use the events whose magnitude is not determined but location is identified in the JMA hypocenter catalog. Such data set's threshold magnitude is denoted by M0.0 in the catalog, and appear homogeneously detected throughout the considered period except for the first short time span. This is also shown by the apparent constant ratio of M≥5 events to M0.0 events seen in the magnitude versus frequency linearized time (FLT) in Figure A43.1.

The p-value of this aftershock activity is high, and, because of this, the long absence of aftershocks in the sequences with M$_c$5.0 and 5.5 lead to less significance for relative quiescence.

The analyzed data sets and the corresponding results shown in **Figures A43.1 and A43.3** are summarized in the following table.

The 1953 Boso-Oki aftershock activity

M$_c$	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	236	140.5–143.0	33.0–35.0	0.25	980.0	–	normal	A43.1
5.0	42	140.5–143.0	33.0–35.0	0.25	980.0	–	normal	A43.2
5.5	17	140.5–143.0	33.0–35.0	0.25	980.0	–	normal	A43.3

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1953 Nov 26 (141.7°E 34.0°N) M_J7.4 M_s7.9

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
–	–	–	–	–	–
			Land		
6.0	2.8	4.1	1956 09 30	140.6 38.0	Miyagi-Ken South
6.0	3.1	1.8	1956 12 22	139.5 33.7	Miyake-Is Kinkai
6.0	4.0	2.0	1957 11 11	139.3 34.2	Niijima-Kinkai
7.0	7.7	4.6	1961 08 19	136.8 36.0	Kitamino
6.5	8.4	4.8	1962 04 30	141.1 38.7	Miyagi-Ken-Hokubu

The 1949 Imaichi earthquakes

On December 26, 1949, earthquakes of M_J6.2 and 6.4 occurred subsequently within 7 minutes. The aftershocks for the time span of 370days up until the end of 1950 are considered. Less than 50 events' magnitudes in the area 36.25°–37°N and 139.25°–140°E and the time period are determined in the JMA hypocenter catalog. According to the Gutenberg-Richter's magnitude frequency law the events with $M \geq 4.2$ appear to be completely detected.

In addition to the events from the JMA catalog, felt shocks are available from the Bulletin of the JMA (1949). These felt shocks with undetermined magnitudes are roughly evaluated to be M3.5 by the extrapolation of Gutenberg-Richter's magnitude frequency relation. These events appear homogeneously detected throughout the considered period except for the first 0.02days right after the mainshock. This is also shown by the apparent constant ratio of M≥4.2 events to M3.5 events seen in the magnitude versus frequency linearized time (FLT) in Figure A44.1.

The analyzed data sets and the corresponding results shown in **Figures A44.1 and A44.2** are summarized in the following table.

The 1949 Imaichi aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
felt	147	139.25–140.0	36.25–37.0	0.02	370.0	–	normal	A44.1
4.2	31	139.25–140.0	36.25–37.0	0.02	370.0	–	normal	A44.2

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1949 Dec 26 (139.8°E 36.6°N) M_J6.4

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.4	3.9	3.0	1953 11 26	141.7 34.0	Boso-Oki (Ms 7.9)
			Land		
6.3	0.7	1.5	1950 09 10	140.3 35.2	Chiba-Ken East
6.5	2.2	2.9	1952 03 07	136.2 36.5	Daishoji-Oki
6.0	6.8	1.5	1956 09 30	140.6 38.0	Miyagi-Ken South
6.0	7.0	2.9	1956 12 22	139.5 33.7	Miyake-Is Kinkai
6.0	7.9	2.4	1957 11 11	139.3 34.2	Niijima-Kinkai

The 1938 Ibaragi-Ken-Oki earthquake

This event of M_J7.0 took place on May 23, 1938 off the coast of Ibaragi Prefecture. The data is taken from the JMA hypocenter catalog for the period up until the 1938 Fukushima-Ken-Oki great swarm including the event of M_J7.5 that occurred in November in the northern neighborhood. We take threshold magnitude M_c4.1 as the magnitude of complete detection, and also use the events whose magnitudes are not determined (printed M0.0) but whose locations are identified in the JMA hypocenter catalog: these data set's threshold magnitude is denoted by M_c0.0 in the tables hereafter.

The analyzed data sets and the corresponding results shown in **Figures A45.1 and A45.2** are summarized in the following table.

The 1938 Ibaragi-Ken-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	43	140.83–142.0	36.5–37.0	0.07	166.0	–	normal	A45.1
4.1	29	140.83–142.0	36.5–37.0	0.07	166.0	–	normal	A45.2

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1938 May 23 (141.6°E 36.7°N) M$_J$7.0

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.5	0.4	2.7	1938 11 05	142.2 37.3	Shioya-Oki great swarm
7.3	0.4	2.9	1938 11 05	141.7 37.3	Shioya-Oki great swarm
7.4	0.4	2.7	1938 11 06	141.9 37.4	Shioya-Oki great swarm
7.0	1.4	1.7	1939 10 11	142.8 38.3	Miyagi-Ken-Oki (Ms7.4)
7.1	5.1	1.3	1943 06 13	143.3 41.2	Aomori-Ken-Toho-Oki (Ms7.2)
7.1	6.7	1.4	1945 02 10	142.1 41.0	Aomori-Ken-Toho-Oki (Ms7.1)
				Land	
6.1	0.0	3.7	1938 05 29	144.4 43.5	Kussharo earthquake
6.8	0.9	2.9	1939 05 01	139.5 40.1	Oga-Hanto-Oki
6.1	3.1	5.0	1941 07 15	138.2 36.7	Nagano
6.2	5.2	3.7	1943 08 12	139.9 37.3	Fukushima-Ken South
6.2	8.7	2.5	1947 02 05	142.7 42.4	Aomori-Ken-Toho-Oki

The 1931 Nishi-Saitama earthquake

This event of M$_J$6.9 that occurred in Saitama Prefecture, a northwestern neighborhood of Tokyo, is the largest destructive inland earthquake in Kanto District since the Meiji Era (1868∼) when the instrumental seismic network was started. The aftershocks were taken from the JMA hypocenter catalog for the rectangular region bounded by 35.8–36.6°N and 139–139.5°E. We consider data sets with threshold magnitudes M$_c$3.0 and 3.5. We also use the events whose magnitude are not determined (denoted as M0.0) but whose location is identified in the JMA hypocenter catalog. These data set's threshold magnitude is denoted by M$_c$0.0 in the tables below.

The analyzed data sets and the corresponding results shown in **Figures A46.1–A46.5** are summarized in the following table.

The 1931 Nishi-Saitama aftershock activity

M$_c$	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	110	139.0–139.5	35.8–36.6	0.05	1063.0	–	normal	A46.1
3.0	65	139.0–139.5	35.8–36.6	0.05	1063.0	–	normal	A46.2
3.5	44	139.0–139.5	35.8–36.6	0.05	1063.0	–	normal	A46.3
3.8	29	139.0–139.5	35.8–36.6	0.01	1063.0	11.64	quiescent	A46.4
4.0	24	139.0–139.5	35.8–36.6	0.01	1063.0	11.64	quiescent	A46.5

Incidentally, the large α-values for the sequences with all threshold magnitudes indicate that the aftershock activity is close to the modified Omori decay. We have high p-values for the data sets with M_c0.0, 3.0 and 3.5, while $p \approx 1.0$ in the first subinterval before the change-point for the data sets with M_c3.8 and 4.0.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1931 Sep 21 (139.2°E 36.2°N) M_J6.9

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.1	1.7	3.3	1933 06 19	142.5 38.1	Miyagi-Ken-Oki (Ms7.3)
7.5	5.1	3.1	1936 11 03	142.1 38.1	Miyagi-Ken-Oki (Ms7.2)
7.1	5.9	3.1	1937 07 27	142.1 38.3	Miyagi-Ken-Oki (m_B7.1)
7.0	6.7	2.0	1938 05 23	141.6 36.6	Ibaragi-Ken-Oki
7.5	7.1	2.7	1938 11 05	142.2 37.3	Shioya-Oki great swarm
7.3	7.1	2.3	1938 11 05	141.7 37.3	Shioya-Oki great swarm
7.4	7.1	2.5	1938 11 06	141.9 37.4	Shioya-Oki great swarm
7.0	8.1	3.6	1939 10 11	142.8 38.3	Miyagi-Ken-Oki (Ms7.4)
				Land	
6.5	0.1	4.0	1931 11 04	141.9 39.5	Iwate-Ken-Tobu
6.0	2.0	2.0	1933 09 21	137.0 37.1	Noto-Hanto East
6.1	2.0	1.2	1933 10 04	138.8 37.3	Niigata-Ken South
6.3	2.9	1.9	1934 08 18	137.0 35.6	Gifu-Ken Chubu
6.4	3.8	1.3	1935 07 11	138.4 35.0	Shizuoka earthquake
6.4	4.4	3.2	1936 02 21	135.7 34.6	Kawachi-Yamato earthquake
6.3	5.3	1.7	1936 12 27	139.0 34.4	Niijima-West-Oki
6.8	6.3	4.2	1938 01 12	135.1 33.6	Wakayama-Ken-Oki
6.8	7.6	4.0	1939 05 01	139.5 40.1	Oga-Hanto-Oki
6.1	9.8	1.0	1941 07 15	138.2 36.7	Nagano earthquake

5. Chubu and Hokuriku District

The 1984 Nagano-Ken-Seibu earthquake

This earthquake of M_J6.8 took place near the western border of Nagano Prefecture and the largest aftershock of M_J6.2 occurred on a conjugate fault to the mainshock. A clear relative quiescence preceding the largest aftershock was investigated in Matsu'ura (1986) by applying the modified Omori formula to the record at Dodaira station, of the Earthquake Research Institute, University of Tokyo. Ogata (1989) applied the ETAS model to the sequence of events with M2.9 or larger from the JMA catalog for a short period about a month to find similar relative quiescence before the largest aftershock.

However, for a longer time span, the activity appears complex owing to the swarm being mixed in the focal region. Thus, the analysis is restricted to events in the eastern region relative to the longitude 137.6°E to remove the swarm events but so as to include most of the aftershocks: namely, the area in focus is the rectangular area bounded by 35°40′–36°N and 137°20′–137.6°E.

The analyzed data sets and the corresponding results shown in **Figures A47.1–A47.3** are summarized in the following table.

The 1984 Nagano-Ken-Seibu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.5	106	137.33–137.75	35.66–36.0	0.01	2665.0	–	normal	A47.1
4.0	34	137.33–137.75	35.66–36.0	0.01	2665.0	–	normal	A47.2
4.5	13	137.33–137.75	35.66–36.0	0.01	2665.0	–	normal	A47.3

Incidentally, from the cumulative curve of events in the FLT diagram of Figure A47.1, we can see the trace of a relatively quiet period before the largest aftershock which was shown in Matsu'ura (1986) and Ogata (1989) for the sequences of smaller threshold magnitudes as described in the above paragraph. Further, although we do not have the aftershock events of M4.0 or larger for about seven years, this has not been significant relative quiescence (Figure A47.3) probably owing to the relatively high p-value ($p \approx 1.2$).

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1984 Sep 14 (137.6°E 35.8°N) M_J6.8

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
–	–	–	–	–	–
			Land		
6.0	2.2	2.0	1986 11 22	139.5 34.5	Izu-Oshima Kinkai
6.0	4.5	2.5	1989 03 06	140.7 35.7	Chiba-Ken-Hokubu 1
6.5	5.4	1.7	1990 02 20	139.2 34.8	Izu-Oshima Kinkai
6.0	5.7	2.5	1990 06 01	140.7 35.6	Chiba-Ken-Hokubu 2
6.6	8.4	1.9	1993 02 07	137.3 37.6	Noto-Hanto-Oki

The 1978 Nagano-Ken-Seibu swarm

Before the 1984 Nagano-Ken-Seibu earthquake took place, a swarm had been active in the southern area overlapping with the aftershock region of the 1984 event. This activity was initiated by the large event of M_J5.3 that took place on October 7, 1978. The considered rectangular area is bound by 35°40′–36°N and 137°20′–137.5°E. Events with M2.5 or larger in the span from the beginning of 1978 up until the occurrence of the 1994 event are considered. The data of swarm events with magnitude M2.5 or larger appears homogeneous although the accuracy of the hypocenters is poor relative to that after the 1984 Nagano-Ken-Seibu event.

The ETAS model can be applied to the swarm activity with M_c2.5, and a significant change-point is seen at 894days after January 1978 (614.79days after the M_J5.3 event). From the events during the interval up until the change-point, no further change-point is seen (**Figure A48.1**). Thus relative quiescence emerged in the latter subinterval right after the change-point preceding the 1984 mainshock. Similarly, for the sequence of events with M_c3.0, relative quiescence emerged right after the change-point at the 286.58days, while no significant change-point is seen for the sequences of events with M_c3.5.

The analyzed data sets and the other results shown in **Figures A48.2 and A48.3** are summarized in the following table.

The 1978 Nagano-Ken-Seibu swarm activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.5	174	137.33–137.84	35.66–36.0	0.1	2170.0	614.79	quiescent	A48.1
3.0	69	137.33–137.84	35.66–36.0	0.1	2170.0	286.58	quiescent	A48.2
3.5	19	137.33–137.84	35.66–36.0	0.1	2170.0	–	normal	A48.3

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1978 Oct 07 (137.5°E 35.8°N) M_J5.3

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.0	3.8	3.6	1982 07 23	141.9 36.2	Ibaragi-Ken-Oki
7.7	4.6	4.7	1983 05 26	139.1 40.4	Nihonkai-Chubu
			Land		
6.7	1.7	1.7	1980 06 29	139.2 34.9	Izu-Hanto-Toho-Oki
6.4	4.2	2.5	1982 12 28	139.4 33.9	Miyake-Is-Nanpo-Oki
6.0	4.8	1.3	1983 08 08	139.0 35.5	Yamanashi-Ken-Tobu
6.2	5.0	2.4	1983 10 03	139.5 34.0	Miyake-Is-Near
6.2	5.1	2.9	1983 10 31	133.9 35.4	Tottori-Ken
6.8	5.9	0.1	1984 09 14	137.6 35.8	Nagano-Ken-Seibu
6.0	8.1	2.1	1986 11 22	139.5 34.5	Izu-Oshima Kinkai

There was a sequence of large intraplate earthquakes in Hokuriku area; the 1948 Fukui earthquake of M_J7.1, the 1952 Daishoji-Oki earthquake of M_J6.5, the 1961 Kita-Mino earthquake of M_J7.0, the 1963 Echizen-Misaki-Oki earthquake of M_J6.9, the 1969 Gufu-Ken-Chubu earthquake of M_J6.6. These occurred in a relatively narrow region and short time span: The Daishoji-Oki earthquake took place about 30km north of the source of the Fukui event. About 6 years later the Kita-Mino earthquake took place about 50km east of the epicenter of the Fukui event. Then, about two years later the Echizen-Misaki-Oki earthquake took place at Wakasa Bay about 50km south-west of the Fukui event.

The 1969 Gifu-Ken-Chubu earthquake

This event of M_J6.6 occurred in the central part of Gifu Prefecture. The aftershocks were selected from the JMA hypocenter catalog in the rectangular area bounded by 136.9°–137.5°E and 35.5°–36°N and for the period ending April 1971. Since the listed aftershock events are very limited in number, we also use events whose magnitude is not determined (M0.0) but whose location is identified, which appears homogeneously detected throughout the considered period except for the first 0.01days right after the mainshock.

The analyzed data sets and the corresponding results shown in **Figures A49.1 and A49.2** are summarized in the following table.

The 1969 Gifu-Ken-Chubu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	47	136.9–137.5	35.5–36.0	0.01	964.0	–	normal	A49.1
3.9	26	136.9–137.5	35.5–36.0	0.01	964.0	–	normal	A49.2

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1969 Sep 09 (137.1°E 35.8°N) M_J6.6

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.2	3.2	4.2	1972 12 04	141.1 33.2	Hachijo-Is-Oki
7.4	8.8	4.8	1978 06 12	142.2 38.1	Miyagi-Ken-Oki
			Land		
6.2	1.1	4.5	1970 10 16	140.8 39.2	Akita-Ken Southeast
6.0	3.0	0.3	1972 08 31	136.8 35.9	Fukui-Ken East
6.9	4.7	1.9	1974 05 09	138.8 34.6	Izu-Hanto-Oki
6.1	4.8	2.7	1974 06 27	139.2 33.8	Miyake-Is-Northwest-Oki
7.0	8.4	2.0	1978 01 14	139.2 34.8	Izu-Oshima-Kinkai
6.1	8.7	3.6	1978 06 04	132.7 35.1	Simane-Ken-Chubu

The 1963 Echizen-Misaki-Oki earthquake

This event of M_J6.9 occurred in Wakasa Bay, Fukui Prefecture. The aftershocks were selected from the JMA hypocenter catalog in the rectangular area bounded by 135.5°–136°E and 35.5°–36°N and for the period ending July 1968. Since the listed aftershock events are very limited in number, we also use events whose magnitude is not determined (denoted as M0.0) but whose location is identified, which appears homogeneously detected throughout the considered period except for the first 0.03days right after the mainshock.

The analyzed data set and the result shown in **Figure A50.1** are summarized in the following table.

The 1963 Echizen-Misaki-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	49	135.5–136.0	35.5–36.0	0.03	1944.0	–	normal	A50.1

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1963 Mar 27 (135.8°E 35.8°N) M_J6.9

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.5	1.2	3.8	1964 06 16	139.2 38.4	Niigata earthquake
6.1	1.2	3.9	1964 06 16	139.3 38.4	Niigata aftershock
7.5	5.0	4.4	1968 04 01	132.5 32.3	Hyuganada (Ms7.6)
7.2	9.7	5.0	1972 12 04	141.1 33.2	Hachijo-Is-Oki
			Land		
6.1	2.1	2.2	1965 04 20	138.3 34.9	Shizuoka-Ken-Chubu
6.6	5.4	3.7	1968 08 06	132.4 33.3	Ehime-Ken-Seigan
6.6	6.4	1.1	1969 09 09	137.1 35.8	Gifu-Ken-Chubu
6.0	9.4	0.8	1972 08 31	136.8 35.9	Fukui-Ken East

The 1961 Kita-Mino earthquake

This event of M_J7.0 occurred at the border between Fukui and Gifu Prefectures. The data is taken from the JMA hypocenter catalog in the rectangular region bounded by 136.5°–137°E and 35.75–36.25°N and for the period ending July 1963. Since the selected events are limited in number, we also use events whose magnitude is not determined (denoted as M0.0) but whose location is determined. The detection rate of such events seems homogeneous throughout the whole time span except for the first 0.03days right after the mainshock, and their roughly estimated magnitude is about M4.5.

The considered data set and the results shown in **Figure A51.1** are summarized in the following table.

The 1961 Kita-Mino aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	58	136.5–137.0	35.75–36.25	0.03	705.0	–	normal	A51.1

Although the present aftershock data reveals no change-point probably owing to the limited number of events, we could have found a change-point at about two months after the mainshock if the data size would increase as the smaller events had been detected. It would be worthwhile to make such an analysis in relation to the forthcoming 1969 Gifu-Ken-Chubu earthquake of M_J6.6 which took place in the neighborhood about 8 years later.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1961 Aug 19 (136.8°E 36.0°N) M_J7.0

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.5	2.8	3.0	1964 06 16	139.2 38.4	Niigata earthquake
6.1	2.8	3.1	1964 06 16	139.3 38.4	Niigata aftershock
			Land		
6.5	0.7	4.4	1962 04 30	141.1 38.7	Miyagi-Ken-Hokubu
6.9	1.6	0.8	1963 03 27	135.8 35.8	Echizen-Misaki-Oki
6.1	3.7	1.7	1965 04 20	138.3 34.9	Shizuoka-Ken-Chubu
6.6	8.1	0.3	1969 09 09	137.1 35.8	Gifu-Ken-Chubu
6.2	9.2	4.5	1970 10 16	140.8 39.2	Akita-Ken Southeast

The 1952 Daishoji-Oki earthquake

The Daishoji-Oki earthquake may be regarded as an aftershock of the Fukui event in a wide sense. First, we fitted the ETAS model to the whole aftershock data for the long period up until the Kita-Mino event (3450days span). The considered region is taken to be a relatively wide rectangular area bounded by 35.75–36.75°N and 135.75–137°E. While the region includes the aftershock source of the Fukui event, there are only a few aftershocks in the corresponding source because it had been already 1.5 years since the Fukui event.

The data of events with M4.2 or larger taken from the JMA hypocenter catalog in this area and period are complete, except for the short time span right after the mainshock, due to the Gutenberg-Richter's magnitude frequency law. We also use the events whose magnitude is not determined but whose location is identified in the JMA hypocenter catalog. Such an event is printed M0.0 in the catalog, and is roughly equivalent to M3.5 according to the Gutenberg-Richter's law.

Furthermore, since the felt aftershock data of the Daishoji event is available (Bulletin of the JMA, 1952), we use it for the short period ending 1952 (298 days span). Their magnitude is estimated to be about M3.7 by the Gutenberg-Richter's relation. The detection rate of those events seems homogeneous throughout the investigated period except for a short time span right after the mainshock.

The data sets analyzed and the corresponding results shown in **Figures A52.1–A52.6** are summarized in the following table.

The 1952 Daishoji-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	89	135.75–136.75	35.75–36.75	0.05	3450.0	463.63	quiescent	A52.1
4.2	28	135.75–136.75	35.75–36.75	0.05	3450.0	1164.81	quiescent	A52.2
4.5	16	135.75–136.75	35.75–36.75	0.05	3450.0	1164.81	quiescent	A52.3
felt	71	135.75–136.75	35.75–36.75	0.05	298.0	13.85	quiescent	A52.4, A52.5
4.2	28	135.75–136.75	35.75–36.75	0.05	298.0	–	normal	A52.6

Here Figure A52.4 shows that the aftershock activity during the period up until the change-point of the largest significance (77.83 days) has a further change-point. Then Figure A52.5 shows that the activity up until the change-point of the early large significance at the time of 13.85 days elapsed has no change-point. Thus, these two figures lead to the result printed in the fourth row in the above table.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1952 mar 07 (136.2°E 36.5°N) M_J6.5

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
–	–	–	–	–	–
			Land		
6.4	3.4	3.2	1955 07 27	134.3 33.7	Tokushima-Ken-Nanbu
6.0	4.6	3.8	1956 09 30	140.6 38.0	Miyagi-Ken South
6.0	4.8	3.9	1956 12 22	139.5 33.7	Miyake-Is Kinkai
6.0	5.7	3.4	1957 11 11	139.3 34.2	Niijima-Kinkai
7.0	9.4	0.7	1961 08 19	136.8 36.0	Kita-Mino earthquake

The 1948 Fukui earthquake

This event of M_J7.1 occurred on 28th June 1948 across the Fukui plain and caused serious damage around Fukui city, Fukui Prefecture. Firstly, we analyze the felt aftershocks extracted from the Bulletin of the JMA (1948, 1949) for a period of about one and a half years. These data are used in conjunction with the events from the JMA hypocenter catalog. The considered rectangular area from the JMA hypocenter catalog is bounded by 135.75°–137°E and 35.75°–36.75°N. The estimated magnitude of felt shocks is about M3.5 according to the Gutenberg-Richter's relation.

Figures A53.1 and A53.2 show the analysis of the data sets of events with $M \geq 3.5$ (felt shocks) and $M \geq 4.0$, respectively, for the period ending 1949 (T=551days). The time series $\xi(t)$ shown by broken lines in the diagrams are all below the horizontal dotted line of significance although it is close to the level of significance at about 3.5 month elapsed in the sequence of events with M3.5 or larger. We conclude that these aftershock sequences have developed normally.

On the other hand, for the data consisting of events with $M \geq 4.5$, all the events took place by the 75th day after the mainshock and no such events occurred during the rest of the period (**Figure A53.3**).

Next, we investigate the aftershock activity of the Fukui earthquake up until the occurrence time of the Daishoji-Oki earthquake (T=1348days). Here, we also use the events whose magnitudes are not determined but whose location is identified in the JMA hypocenter catalog. These data set's threshold magnitude is denoted by M0.0 in the catalog and it is roughly equal to M3.5 according to the Gutenberg-Richter's relation. **Figures A53.4 and A53.5** show the analysis of the data sets of events with $M \geq 3.5$ (i.e., events of identified location) and $M \geq 4.0$, respectively. Both sequences are concluded to be normally developed although, in Figure A53.4, the $\xi(t)$ function approaches the level of significance at about 3.5 months elapsed.

However, again for the data set of events with $M \geq 4.5$, all the events took place by the 75th day after the mainshock, and no such events occurred after the time up until the occurrence of the Daishoji-Oki earthquake (1375th day). This quiescence is significant if the stationary Poisson process is applied to the events in the latter time span after every candidate for change-point (**Figure A53.6**).

Finally, we examine the data sets of a longer period up until the Kita-Mino event occurred in May 1961. The region is taken broadly, 35.75°- 36.75°N and 135.75°- 137°, compared to the estimated source area of the 1961 Kita-Mino earthquake. **Figures A53.7–A53.9** show the analysis for the data sets with the threshold magnitudes discussed above.

Thus the analyzed data sets and the corresponding results shown in Figures A53.1–A53.9 are summarized in the following table.

The 1948 Fukui aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
felt	123	145.75–136.75	35.75–36.75	0.02	551.0	–	normal	A53.1
4.0	48	145.75–136.75	35.75–36.75	0.02	551.0	–	normal	A53.2
4.5	21	145.75–136.75	35.75–36.75	0.02	551.0	47.15	quiescent	A53.3
0.0	140	145.75–136.75	35.75–36.75	0.02	1348.0	–	normal	A53.4
4.0	55	145.75–136.75	35.75–36.75	0.02	1348.0	–	normal	A53.5
4.5	21	145.75–136.75	35.75–36.75	0.02	1348.0	47.15	quiescent	A53.6
0.0	160	145.75–136.75	35.75–36.75	0.05	4975.0	–	normal	A53.7
4.2	45	145.75–136.75	35.75–36.75	0.05	4975.0	–	normal	A53.8
4.7	15	145.75–136.75	35.75–36.75	0.01	4975.0	–	normal	A53.9

Here, the data sets for the 4th, 8th and 9th rows in the table are concluded to be normal activity but, in fact, these are close to significance for relative quiescence (see Figures A53.4, A53.8 and A53.9) owing to the anomalous occurrence pattern; no event in a very long period. In particular, the data set of events with M≥4.5 have no event in the span [47.15, 2098]days though the figure is not shown here.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1948 Jun 28 (136.2°E 36.2°N) M_J7.1

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.4	5.4	5.0	1953 11 26	141.7 34.0	Boso-Oki earthquake
			Land		
6.3	0.6	1.5	1949 01 20	134.5 35.6	Hyogo-Ken North
6.2	1.5	2.8	1949 12 26	139.6 36.6	Imaichi earthquake
6.4	1.5	2.9	1949 12 26	139.8 36.6	Imaichi earthquake
6.3	2.2	3.5	1950 09 10	140.3 35.2	Chiba-Ken East
6.5	3.7	0.3	1952 03 07	136.2 36.5	Daishoji-Oki earthquake
6.4	7.1	2.9	1955 07 27	134.3 33.7	Tokushima-Ken-Nanbu
6.0	8.3	4.0	1956 09 30	140.6 38.0	Miyagi-Ken South
6.0	8.5	3.6	1956 12 22	139.5 33.7	Miyake-Is Kinkai
6.0	9.4	3.2	1957 11 11	139.3 34.2	Niijima-Kinkai

The 1941 Nagano earthquake

This event of M_J6.1 took place near Nagano city, Nagano Prefecture. We use felt aftershocks recorded mainly at Nagano Observatory in conjunction with events from the JMA hypocenter catalog. The magnitude of the felt events is roughly estimated to be about M3.0 by the Gutenberg-Richter's frequency-magnitude relation. Also, the magnitude (M0.0) of events in the JMA catalog where only the location is available is roughly estimated to be about M3.1. The considered period is 819.0days up until the occurrence date of the 1943 Nagano-Ken-Hokubu earthquake of M_J5.9. Both data sets have an absence of events for a substantially long period up until the 1943 M_J5.9 earthquake. (see **Figures A54.1 and A54.2**).

The data sets analyzed and the corresponding results shown in Figures A54.1 and A54.2 are summarized in the following table.

The 1941 Nagano aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
felt	121	137.66–138.5	36.33–37.0	0.02	819.0	714.70	quiescent	A54.1
0.0	15	137.66–138.5	36.33–37.0	0.02	819.0	3.552	quiescent	A54.2

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1941 Jul 15 (138.2°E 36.7°N) M_J6.1

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.9	3.4	4.1	1944 12 07	136.6 33.8	Tonankai earthquake
7.1	3.6	4.5	1945 02 10	142.1 41.0	Aomori-Ken-Toho-Oki (Ms7.1)
7.0	6.8	4.9	1948 04 18	135.6 33.3	Kii-Hanto-Oki (Ms7.3)
				Land	
6.2	1.6	3.9	1943 03 04	134.2 35.4	Tottori-Ken East
6.2	2.1	1.4	1943 08 12	139.9 37.3	Fukushima-Ken South
7.2	2.2	3.9	1943 09 10	134.1 35.5	Tottori earthquake
5.9	2.2	0.1	1943 10 13	138.1 36.8	Nagano-Ken-Hokubu
6.3	3.4	3.6	1944 12 09	139.0 34.2	Miyake-Is-West-Oki
6.8	3.5	3.1	1945 01 13	137.1 34.7	Mikawa earthquake
6.0	5.4	4.6	1946 12 21	135.4 33.6	Nankaido earthquake
6.7	6.9	4.5	1948 06 15	135.4 33.8	Wakayama-Ken Southeast
7.1	7.0	2.2	1948 06 28	136.2 36.2	Fukui earthquake
6.3	7.5	3.6	1949 01 20	134.5 35.6	Hyogo-Ken North
6.2	8.4	1.5	1949 12 26	139.6 36.6	Imaichi earthquake
6.4	8.4	1.7	1949 12 26	139.8 36.6	Imaichi earthquake
6.3	9.2	3.0	1950 09 10	140.3 35.2	Chiba-Ken East

6. Kinki District and offshore regions

The 1995 Hyogo-Ken-Nanbu (Kobe) earthquake

This event of M_J7.2 hit Kobe city and its vicinity seriously. The aftershocks are examined for 774 days, the available time span ending February 1997. The existence of the change-point is thoroughly examined as explained in the main text, but no significant change point is found. The time series of $\xi(t)$ shown by broken lines in **Figures A55.1–A55.4** are all below the horizontal dotted line for significance of a change-point. Thus, we can conclude that these aftershock sequences have developed normally. Here it is noted that, in the data sets of events with threshold magnitudes M_c4.0 and 4.2, no event took place for a long period of 17 months. Nevertheless, we see these are far from significance, perhaps owing to the high p-value (p=1.31 and 1.38, respectively).

The analyzed data sets and the corresponding results shown in Figures A55.1–A55.4 are summarized in the following table.

The 1995 Hyogo-Ken-Nanbu (Kobe) aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.0	541	134.66–135.42	34.33–34.83	0.02	773.0	–	normal	A55.1
3.5	160	134.66–135.42	34.33–34.83	0.02	773.0	–	normal	A55.2
4.0	52	134.66–135.42	34.33–34.83	0.02	773.0	–	normal	A55.3
4.2	32	134.66–135.42	34.33–34.83	0.02	773.0	–	normal	A55.4

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1995 Jan 17 (135.0°E 34.6°N) M_J7.2

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
–	–	–	–	–	–
				Land	
6.5	2.2	4.7	1997 03 26	130.4 32.0	Kagoshima-Ken-Hokuseibu
6.3	2.3	4.7	1997 05 13	130.3 31.9	Kagoshima-Ken-Hokuseibu
6.3	2.4	2.8	1997 06 25	131.7 34.4	Yamaguchi/Shimane-Ken Border

The 1994 Inagawa earthquake

Ogata (1997) showed relative quiescence for the period of several years prior to the Kobe event in the seismicity of $M \geq 5.5$ events in the very wide region including central and western Japan. Meanwhile, about two months prior to the Kobe earthquake, a conspicuous swarm started in Inagawa-Cho near the source region of the Kobe event (about 20km apart), which is now recognized as a precursory activity of the event.

However, there are also many swarms which do not seem to correlate with any large event. Therefore, it is worthwhile to fit the ETAS model to such swarms trying to determine if relative quiescence could somehow discriminate precursory swarms before the large event occurs.

The largest events in the swarm are of M_J4.0. The sequence events are taken from the JMA hypocenter catalog for the period from 9th November up until the Kobe event and in the rectangular region bounded by area 34.75°–35°N and 135°–136°E. The ETAS model is applied to the data with $M \geq 2.0$ for both cases of μ>0 and μ=0 to find that the former case is better fitted. However, ETAS with μ=0 fits better to the sequences of events with higher threshold magnitudes,

The analyzed data sets and the corresponding results shown in **Figures A56.1–A56.4** are summarized in the following table.

The 1994 Inagawa aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.0	133	135.0–136.0	34.75–35	0.06	69.0	14.48	quiescent	A56.1
2.3	70	135.0–136.0	34.75–35	0.06	69.0	16.81	quiescent	A56.2
2.5	43	135.0–136.0	34.75–35	0.06	69.0	16.56	quiescent	A56.3
2.6	29	135.0–136.0	34.75–35	0.06	69.0	12.90	quiescent	A56.4

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1994 Nov 09 (135.4°E 34.9°N) M_J4.0

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
–	–	–	–	–	–
				Land	
7.2	0.2	0.4	1995 01 17	135.0 34.6	Kobe earthquake
6.3	2.6	3.1	1997 06 25	131.7 34.4	Yamaguchi/Shimane-Ken Border

The 1984 Hyogo-Ken-Nanseibu earthquake

This event of M_J5.6 took place in Yamasaki Fault, in the southwestern part of Hyogo Prefecture. Since the epicenter of this event is rather near to the location of the 1995 Kobe earthquake (2.4degrees), we here take a long time interval to study whether or not any quiescence can be found in some period prior to the 1995 Kobe event. For example, taking account of the long interval in which there are no events with completely detected lowest magnitude M_c2.5, we take $T = 3197$days (up until March 4, 1993).

The analyzed data sets and the corresponding results shown in **Figures A57.1–A57.3** are summarized in the following table.

The 1984 Hyogo-Ken-Nanseibu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.5	89	134.5–134.7	34.9–35.0	0.03	3197.0	1392.54	quiescent	A57.1
2.6	77	134.5–134.7	34.9–35.0	0.03	3197.0	–	normal	A57.2
3.0	42	134.5–134.7	34.9–35.0	0.03	3197.0	–	normal	A57.3

Although we see relative quiescence in the data set of events with M_c2.5 (Figure A57.1), the significance depends on the choice of T as was established above: indeed, we have 4 events with $M \geq 2.5$ in the interval from 4 March 1993 till the end of this year. The other examined data sets with threshold magnitudes M_c2.6 and 3.0 are shown have normal activity. (see Figures A57.2 and A57.3, respectively). In the end we conclude that this aftershock activity developed normally even for such a long time span.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1984 may 30 (134.6°E 35.0°N) M_J5.6

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.1	0.2	3.3	1984 08 07	132.2 32.4	Miyazaki-Ken-Oki
			Land		
6.8	0.3	2.6	1984 09 14	137.6 35.8	Nagano-Ken-Seibu
6.0	2.5	4.1	1986 11 22	139.5 34.5	Izu-Oshima Kinkai
6.5	5.7	3.8	1990 02 20	139.2 34.8	Izu-Oshima Kinkai
6.6	8.7	3.5	1993 02 07	137.3 37.6	Noto-Hanto-Oki

Here the 1995 Kobe event is not listed because the time-lag is 10.4 years while the distance is 266km (2.4 degrees).

The 1946 Nankaido earthquake

This great event of M_J8.0 (M_s8.2) took place on 13th December 1946 on the plate boundary between the Eurasian Plate and the subducting Philippine Sea Plate. The largest aftershock of M_J7.1 (M_S7.3) off the coast of Kii Peninsula (Kii-Hanto-Oki) occurred on April 18, 1948. Here we take the period of study up until the Kii-Hanto-Oki event (i.e.,T=483.8 days after the occurrence of the mainshock), since this largest aftershock event took place a considerable period after the mainshock and also since the seismicity after this event seems too complex (including swarms in the source region of the great event) to use ETAS models. Thus the aftershocks with threshold magnitudes M_c5.5, 5.0, 4.9, 4.5 and 4.0 are explored for the mentioned period. Such events within 0.25 days right after the mainshock appear inhomogeneous.

The results are shown in **Figures A58.1–A58.6**, and summarized in the following table.

The 1946 Nankaido aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.0	133	133.0–137.0	32.0–34.5	0.25	483.8	35.14	quiescent	A58.1, A58.2
4.5	82	133.0–137.0	32.0–34.5	0.25	483.8	362.20	quiescent	A58.3
4.9	50	133.0–137.0	32.0–34.5	0.25	483.8	362.20	quiescent	A58.4
5.0	46	133.0–137.0	32.0–34.5	0.25	483.8	–	normal	A58.5
5.5	19	133.0–137.0	32.0–34.5	0.25	483.8	–	normal	A58.6

It is seen that the aftershock activity appears to have normally developed for the sequence of events with threshold magnitudes M_c5.0 and 5.5, while becoming relatively quiet for the sequences of events with thresholds M_c4.9 4.5 and 4.0.

Figures A58.1 and A58.2 show the results for the same data of events with M_c4.0. In Figure A58.1 another significant change-point is shown in between the 0.25days and 362.20days where, at first, the largest ξ-value is attained in the span up until the Kii-Hanto-Oki event. Thus, Figure A58.2 shows the final result for the sequence of events with M_c4.0.

Figure A18.5 ($M_c5.0$) shows that the activity has developed normally although the maximum ξ-value is nearly attained at t=362.20days for relative quiescence (no events).

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1946 Dec 21 (135.6°E 33.0°N) $M_J8.0$ $M_s8.2$

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.0	1.3	0.3	1948 04 18	135.6 33.3	Kii-Hanto-Oki (Ms7.3)
				Land	
6.7	1.5	0.8	1948 06 15	135.4 33.8	Wakayama-Ken Southeast
7.1	1.5	3.2	1948 06 28	136.2 36.2	Fukui earthquake
6.3	2.1	2.8	1949 01 20	134.5 35.6	Hyogo-Ken North
6.2	3.0	5.0	1949 12 26	139.6 36.6	Imaichi earthquake
6.4	3.0	5.0	1949 12 26	139.8 36.6	Imaichi earthquake
6.3	3.7	4.5	1950 09 10	140.3 35.2	Chiba-Ken East
6.5	5.2	3.5	1952 03 07	136.2 36.5	Daishoji-Oki
6.4	8.6	1.3	1955 07 27	134.3 33.7	Tokushima-Ken-Nanbu

The 1945 Mikawa earthquake

On January 13, 1945, a few weeks after the 1944 Tonankai great event, an earthquake of $M_J6.8$ occurred in a northern region contiguous to the source region of the Tonankai event. This event, preceded by many foreshocks, may be considered an aftershock of the Tonankai event in a broad sense. The period up until the 1946 Nankaido earthquake is considered. Most of the aftershocks of the Mikawa earthquake took place on land with a high detection rate, so that the aftershock data appears interesting and useful for an investigation of the seismicity prior to the Nankaido earthquake.

The selected rectangular region is bounded by 34.5°–35.5°N and 136°–138°E. According to the magnitude frequency distribution M4.4 appears to be the lowest magnitude completely detected except for the first 0.05days right after the mainshock. We also use events whose magnitude is not determined but whose location is identified which appear homogeneously detected throughout the considered period. Their magnitude is estimated to be about M4.0 by the Gutenberg-Richter's relation.

In addition, the felt shocks listed in the *Kisho-Yoran* (*Geophysical Review of the JMA*, 1944-1946) are available, their magnitude is roughly assessed to be M3.8. The occurrence time data are provided up to the accuracy of the minute, but there are a number of couples and triplets which occurred at the same minute. This causes an unfavorable effect in the estimation of the ETAS parameters. Thus, occurrence times of these events are shifted to separate the couples and triplets from each other.

These data sets appear to include the background seismicity (i.e., $\mu > 0$) as is determined by the AIC comparison with the ETAS model with $\mu = 0$. In particular, this is clear for the data set of felt shocks, perhaps because the Mikawa earthquake was preceded by 22 felt foreshocks in the period of 12.15days. Remember that the present felt shock data start from the beginning of 1945.

The overall analysis is shown in **Figures A59.1–A59.4** where the cumulative curve in the FLT diagram extended to the latter time span right after the change-point shows substantial lowering from the extended linearity (expected activity by ETAS).

The analyzed data sets and the corresponding results shown in Figures A59.1–A59.4 are summarized in the following table.

The 1945 Mikawa aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
felt	282	136.75–137.5	34.5–35.16	12.20	730.0	171.90	quiescent	A59.1
0.0	191	136.75–137.5	34.5–35.16	0.05	696.0	161.14	quiescent	A59.2
4.4	72	136.75–137.5	34.5–35.16	0.05	696.0	161.14	quiescent	A59.3
4.8	31	136.75–137.5	34.5–35.16	0.02	696.0	–	normal	A59.4

Note here that feltshock data include 22 foreshocks since January 1, 1945, while the other data sets start from the occurrence of the mainshock. Therefore, S=12.20days in the first row is about an hour after the occurrence of the main shock.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1945 Jan 13 (137.1°E 34.7°N) M_J6.8

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
8.0	1.9	2.1	1946 12 21	135.6 33.0	Nankaido earthquake
7.0	3.3	1.9	1948 04 18	135.6 33.3	Kii-Hanto-Oki (Ms7.3)
7.4	8.9	3.9	1953 11 26	141.7 34.0	Boso-Oki
				Land	
6.0	1.9	1.7	1946 12 21	135.4 33.6	Nankaido aftershock
6.7	3.4	1.7	1948 06 15	135.4 33.8	Wakayama-Ken Southeast
7.1	3.5	1.6	1948 06 28	136.2 36.2	Fukui earthquake
6.3	4.0	2.3	1949 01 20	134.5 35.6	Hyogo-Ken North
6.2	4.9	2.8	1949 12 26	139.6 36.6	Imaichi earthquake
6.4	4.9	2.9	1949 12 26	139.8 36.6	Imaichi earthquake
6.3	5.6	2.7	1950 09 10	140.3 35.2	Chiba-Ken East
6.5	7.1	1.9	1952 03 07	136.2 36.5	Daishoji-Oki

The 1944 Tonankai earthquake

This great event of M_J7.9 (M_s8.0) occurred on the plate boundary of the Eurasian and subducting Philippine Sea Plate about two years prior to the 1946 Nankaido earthquake (T=743.5days) of M_J8.0 (M_s8.2) occurred in the neighborhood.

Matsu'ura (1986) examined the aftershock activity of the Tonankai earthquake up until the Nankaido earthquake, but an answer could not be found in the residual analysis using the nonstationary Poisson model with the modified Omori intensity function, which unlike the ETAS model, does not take account of the effect of magnitude. On the other hand, Oike et al. (1989) reported seismic quiescences in several areas throughout Japan and its vicinity such as western Chugoku, northern Kyushu, western Kanto, eastern Izu, Shizuoka, and the southern islands on the Philippine Sea Plate during the period between the two great events.

Although the Mikawa aftershocks can be considered secondary aftershocks of the Tonankai earthquake, contrary to the analysis by Matsu'ura (1986), we exclude these from the current aftershock data of the Tonankai earthquake. This is not only because there is a significantly different detection rate for these events, but also because the ETAS models have significantly distinct parameters owing to their tectonic feature: the first one is an intraplate event inland and the other is an interplate event in the sea (see Guo and Ogata, 1997).

Thus, the analyzed data sets and the corresponding results shown in **Figures A60.1–A60.4** are summarized in the following table.

The 1944 Tonankai aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
4.0	174	133.91–138.0	32.75–35.5*	0.10	743.50	–	normal	A60.1
4.5	57	133.91–138.0	32.75–35.5*	0.04	743.50	578.01	quiescent	A60.2
4.8	41	133.91–138.0	32.75–35.5*	0.04	743.50	40.92	quiescent	A60.3
5.0	28	133.91–138.0	32.75–35.5*	0.04	743.50	–	normal	A60.4

*) Note that from the area, Mikawa aftershocks are removed.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1944 Dec 07 (136.6°E 33.8°N) M_J7.9 Ms8.0

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
8.0	2.0	1.1	1946 12 21	135.6 33.0	Nankaido earthquake
7.0	3.4	1.0	1948 04 18	135.6 33.3	Kii-Hanto-Oki (Ms7.3)
7.4	9.0	4.3	1953 11 26	141.7 34.0	Boso-Oki
			Land		
6.3	0.0	2.0	1944 12 09	139.0 34.2	Miyake-Is-West-Oki
6.8	0.1	1.0	1945 01 13	137.1 34.7	Mikawa earthquake
6.0	2.0	1.0	1946 12 21	135.4 33.6	Nankaido earthquake
6.7	3.5	1.0	1948 06 15	135.4 33.8	Wakayama-Ken Southeast
7.1	3.6	2.4	1948 06 28	136.2 36.2	Fukui earthquake
6.3	4.1	2.5	1949 01 20	134.5 35.6	Hyogo-Ken North
6.2	5.1	3.8	1949 12 26	139.6 36.6	Imaichi earthquake
6.4	5.1	3.8	1949 12 26	139.8 36.6	Imaichi earthquake
6.3	5.8	3.4	1950 09 10	140.3 35.2	Chiba-Ken East
6.5	7.3	2.7	1952 03 07	136.2 36.5	Daishoji-Oki

The 1927 Kita-Tango earthquake

On March 7, 1927, an event of M_J7.3 took place in northern Kyoto Prefecture. There are not very many aftershock events listed in the JMA hypocenter catalog. Events of M4.5 and larger appear completely detected. On top of all the aftershock events listed in the JMA hypocenter catalog, we use events whose magnitude is not determined (M0.0) but whose location is determined. The detection rate of such events seems homogeneous throughout the whole time span except for the first 0.04days right after the mainshock. These events are roughly assessed to be M4.0 according to the Gutenberg-Richter's law. Time spans considered are around 2000 days and also 7224 days up until the 1946 Nankaido great event.

The analyzed data sets and the corresponding results shown in **Figures A61.1–A61.3** are summarized in the following table.

The 1927 Kita-Tango aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	77	134.6–135.5	35.3–36.0	0.04	2000.0	–	normal	A61.1
4.5	27	134.6–135.5	35.3–36.0	0.04	2100.0	–	normal	A61.2
4.5	30	134.6–135.5	35.3–36.0	0.04	7224.0	–	normal	A61.3

Incidentally, we had no events of M$\geq$4.5 for about 60 years until 1986 (Ogata, 1989). However this is not significant quiescence owing to the large p-value (≈ 1.3).

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1927 Mar 07 (135.2°E 35.5°N) M_J7.3 M_s7.6

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.1	4.6	3.9	1931 11 02	132.6 32.2	Miyazaki-Ken-Oki (Ms7.6)
				Land	
6.3	2.4	3.2	1929 07 27	139.1 35.5	Yamanashi-Ken East
6.1	3.4	4.1	1930 08 17	140.2 35.1	Chiba-Ken South
6.3	3.6	1.2	1930 10 17	136.3 36.3	Ishikawa-Ken South
7.3	3.7	3.2	1930 11 26	139.1 35.1	Kita-Izu earthquake
6.1	3.8	2.2	1930 12 20	132.6 34.8	Hiroshima-Ken North
6.0	4.3	4.6	1931 06 09	140.7 36.6	Ibaragi-Ken Northeast
6.3	4.3	3.4	1931 06 17	139.4 35.8	Saitama-Ken South
6.9	4.5	3.3	1931 09 21	139.2 36.1	Saitama-Ken-West
6.0	6.5	2.2	1933 09 21	137.0 37.1	Noto-Hanto East
6.1	6.6	3.4	1933 10 04	138.8 37.3	Niigata-Ken South
6.3	7.4	1.5	1934 08 18	137.0 35.6	Gifu-Ken Chubu
6.4	8.3	2.7	1935 07 11	138.4 35.0	Shizuoka earthquake
6.4	9.0	1.0	1936 02 21	135.7 34.6	Kawachi-Yamato earthquake
6.3	9.8	3.3	1936 12 27	139.0 34.4	Niijima-West-Oki

1925 Tajima earthquake

About two years preceding the 1927 Kita-Tango earthquake, this event of M_J7.1 took place in northern Hyogo Prefecture at about 30km west of the source of the 1926 Kita-Tango event. The time span from the mainshock till the end of 1926 is considered where only eight events whose magnitudes as well as epicenter location are identified in the JMA hypocenter catalog. Nevertheless, the record of felt shocks mainly observed at Toyooka Observatory is available in the *Kisho-Yoran* (*Geophysical Review of the JMA*, 1925, 1926). The magnitude of the felt shocks are roughly estimated as M4.5 by the Gutenberg-Richter's relation. The occurrence time data are provided up to the accuracy of minute, but there are a number of couples and triplets which occurred at the same minute. This causes an unfavorable effect in the estimation of the ETAS parameters. Thus, occurrence times of these events are shifted to separate the couples and triplets from each other.

The analyzed result is shown in **Figures A62.1 and A62.2** and summarized in the following table.

The 1925 Tajima aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
felt	228	134.0–135.5	35.0–36.0	0.03	588.0	10.02	quiescent	A62.1
5.0	10	134.0–135.5	35.0–36.0	0.03	588.0	31.08	quiescent	A62.2

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1925 may 23 (134.8°E 35.6°N) M_J6.8

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.1	6.4	3.8	1931 11 02	132.6 32.2	Miyazaki-Ken-Oki (Ms7.6)
				Land	
6.3	1.2	4.2	1926 08 03	140.0 35.2	Chiba-Ken Chubu
7.3	1.8	0.3	1927 03 07	135.2 35.5	Kita-Tango earthquake
6.3	4.2	3.5	1929 07 27	139.1 35.5	Yamanashi-Ken East
6.1	5.2	4.4	1930 08 17	140.2 35.1	Chiba-Ken South
6.3	5.4	1.4	1930 10 17	136.3 36.3	Ishikawa-Ken South
7.3	5.5	3.5	1930 11 26	139.1 35.1	Kita-Izu earthquake
6.1	5.6	1.9	1930 12 20	132.6 34.8	Hiroshima-Ken North
6.0	6.0	4.9	1931 06 09	140.7 36.6	Ibaragi-Ken Northeast
6.3	6.1	3.7	1931 06 17	139.4 35.8	Saitama-Ken South
6.9	6.3	3.6	1931 09 21	139.2 36.1	Saitama-Ken-West
6.0	8.3	2.3	1933 09 21	137.0 37.1	Noto-Hanto East
6.1	8.4	3.7	1933 10 04	138.8 37.3	Niigata-Ken South
6.3	9.2	1.8	1934 08 18	137.0 35.6	Gifu-Ken Chubu

7. Southwestern Japan

The 1997 Yamaguchi/Shimane-Ken-Kyoukai earthquake

This event of M_J6.1 occurred at the border between Yamaguchi and Shimane Prefectures. It has been quiet around the source region of this event so that the aftershock activity is clearly discriminated from the background micro-seismicity.

First, we analyzed them for the short period (T=25days) due to the available events in the JMA hypocenter catalog at the time, but then analyzed for the longer period (T=705days) until the end of May 1999. For the longer period, we see relative quiescence in plural aftershock sequences with different threshold magnitudes. For example, in Figure A63.3 another significant change-point (91.76days) is shown in between 0.01days and 527.71days which is the change-point of the first stage. Therefore Figure A63.4 shows the final result for the data set of events with M_c2.6. Also, for the sequence of events with M_c3.0 Figure 63.5 shows that the most significant change-point is located at 1.34days right after the mainshock where this is clearly shown in the FLT diagram (right), and Figure 63.6 shows that no more significant change-point exists in between 0.01 and 1.34days (see FLT diagram in the right).

The analyzed data sets and the corresponding results shown in **Figures A63.1–A63.7** are summarized in the following table.

The 1997 Yamaguchi/Shimane-Ken-Kyoukai aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.1	451	131.5–131.8	34.3–34.5	0.05	25.0	–	normal	A63.1
2.6	190	131.5–131.8	34.3–34.5	0.01	25.0	–	normal	A63.2
2.6	227	131.5–131.8	34.3–34.5	0.01	705.0	91.76	quiescent	A63.3, A63.4
3.0	70	131.5–131.8	34.3–34.5	0.01	705.0	1.34	quiescent	A63.5, A63.6
3.4	26	131.5–131.8	34.3–34.5	0.01	705.0	–	normal	A63.7

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1997 Jun 25 (131.7°E 34.5°N) M_J6.1

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
–	–	–	–	–	–
			Land		
7.1	1.2	8.8	1998 08 20	139.9 28.9	Ogasawara Islands
6.1	1.2	9.3	1998 09 03	140.9 39.8	Iwate-Ken-Hokubu

The 1997 Kagoshima-Ken-Hokuseibu earthquake (May)

This earthquake of M_J6.2 ruptured in parallel to the first 1997 Kagoshima-Ken-Hokuseibu event of M_J6.5 in the southern neighborhood after about one and a half months time span. The data sets are carefully selected discriminating the aftershocks from those of the first primary event and also from those of swarms in the southern area in the latitudes lower than 31.9°.

First, we analyzed them for the short period (42.33days) up until the end of July 1997 due to the available events in the JMA hypocenter catalog at the time, but then analyzed for the longer period until the end of May 1999 (T=748days). For the short period both **Figures A64.1 and A64.2**) show the normal activity. For the longer period, we see relative quiescence for a single aftershock sequence (**Figure A64.3**), but normal activity for the other sequences (**Figures A64.4–A64.6**).

The analyzed data sets and the corresponding results shown in Figures A64.1–A64.6 are summarized in the following table.

The 1997 Kagoshima-Ken-Hokuseibu aftershock activity (May)

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.1	970	130.25–130.5	31.83–32.0	0.10	42.33	–	normal	A64.1
2.5	298	130.25–130.5	31.83–32.0	0.04	42.33	–	normal	A64.2
2.5	325	130.25–130.5	31.83–32.0	0.15	748.0	139.32	quiescent	A64.3
2.8	104	130.25–130.5	31.83–32.0	0.15	748.0	–	normal	A64.4
3.0	48	130.25–130.5	31.83–32.0	0.01	748.0	–	normal	A64.5
3.3	23	130.25–130.5	31.83–32.0	0.01	748.0	–	normal	A64.6

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1997 May 13 (130.3°E 31.9°N) M_J6.2

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
–	–	–	–	–	–
				Land	
6.3	0.1	2.8	1997 06 25	131.7 34.4	Yamaguchi/Shimane-Ken Border

The 1997 Kagoshima-Ken-Hokuseibu aftershock activity (March)

This earthquake of M_J6.5 ruptured a west-east strike slip in northwestern Kagoshima Prefecture, southern Kyushu Island, and about one and a half months later another large earthquake of similar size (M_J6.2) which ruptured in parallel to the first primary event in the neighborhood. The time span up until the occurrence of the second primary event is considered.

The analyzed data set and the corresponding result shown in **Figures A65.1–A65.3** are summarized in the following table.

The 1997 Kagoshima-Ken-Hokuseibu aftershock activity (1)

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.7	521	130.25–130.5	31.83–31.0	0.03	47.88	5.39	quiescent	A65.1
3.0	197	130.25–130.5	31.83–31.0	0.03	47.88	25.33	quiescent	A65.2
3.5	54	130.25–130.5	31.83–31.0	0.03	47.88	14.47	quiescent	A65.3

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1997 Mar 26 (130.4°E 32.0°N) M_J6.5

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
–	–	–	–	–	–
				Land	
6.3	0.1	0.1	1997 05 13	130.3 31.9	Kagoshima-Ken-Hokuseibu
6.3	0.2	2.7	1997 06 25	131.7 34.4	Yamaguchi/Shimane-Ken Border

The 1995 Amami-Oshima-Oki aftershock activity

This event of M_J6.6 occurred off the south coast of the Amami-Oshima Island and large aftershocks of M_J5.9, M_J6.3 and M_J6.5 took place about 13, 14 and 16 hours elapsed time from the mainshock, respectively. The aftershocks are taken from the JMA hypocenter catalog in the rectangular area bounded by 129.8°–131°E and 27.5°–28.5°N for the period ending February 1997. Before the largest aftershock, activation with large aftershocks of M_J6.5 including events of M5.9 and 6.3 took place, so that we took $S = 0.68$days as the start of the target interval for the analysis of long-term aftershock activity.

At first the highest significance is attained at 499days after the mainshock as is shown in **Figure A66.1**, but we find a further significant change-point at 6.66days after the mainshock as shown in the FLT diagram (right) in Figure A66.1. Thus, **Figure A66.2** is obtained for the events with threshold magnitude M_c3.5.

In addition to these, further analyzed data sets and their results shown in **Figures A66.3–A66.5** are summarized in the following table.

The 1995 Amami-Oshima-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.5	736	129.8–131.0	27.5–28.5	0.68	499.0	6.66	quiescent	A66.1, A66.2
3.8	249	129.8–131.0	27.5–28.5	0.68	499.0	–	normal	A66.3
4.0	110	129.8–131.0	27.5–28.5	0.68	499.0	–	normal	A66.4
4.5	34	129.8–131.0	27.5–28.5	0.68	499.0	–	normal	A66.5

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1995 Oct 18 (130.4°E 28.0°N) M_J6.6

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
–	–	–	–	–	–
			Land		
–	–	–	–	–	–

The 1987 Miyazaki-Ken-Oki earthquake

This event of M_J6.6 took place off the east coast of Miyazaki Prefecture, southern Kyushu, near the source of the 1984 Miyazaki-Ken-Oki earthquake of M_J7.1. The data is taken from the JMA hypocenter catalog for the rectangular region bounded by 131.9°–132.3°E and 31.75°–32.3°N.

The analyzed data sets and the corresponding results shown in **Figures A67.1–A67.3** are summarized in the following table.

The 1987 Miyazaki-Ken-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.5	156	131.9–132.3	31.75–32.3	0.005	1109.0	–	normal	A67.1
2.9	63	131.9–132.3	31.75–32.3	0.005	1109.0	–	normal	A67.2
3.4	20	131.9–132.3	31.75–32.3	0.005	1109.0	–	normal	A67.3

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1987 Mar 18 (132.1°E 32.0°N) M_J6.6

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
–	–	–	–	–	–
			Land		
6.0	2.2	4.2	1989 03 06	140.7 35.7	Chiba-Ken-Hokubu 1
6.5	3.1	5.4	1990 02 20	139.2 34.8	Izu-Oshima Kinkai
6.0	3.4	4.3	1990 06 01	140.7 35.6	Chiba-Ken-Hokubu 2
7.2	7.8	3.6	1995 01 17	135.0 34.6	Kobe earthquake

The 1984 Miyazaki-Ken-Oki earthquake

This event of M_J7.1 took place on the plate boundary between the Eurasian and the subducting Philippine Sea Plates, off the east coast of Miyazaki Prefecture, southern Kyushu.

The analyzed data sets and the corresponding results shown in **Figures A68.1–A68.3** are summarized in the following table.

The 1984 Miyazaki-Ken-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.8	243	132.05–132.3	32.3–32.55	0.03	2701.0	–	normal	A68.1
3.3	93	132.05–132.3	32.3–32.55	0.03	2701.0	–	normal	A68.2
3.8	25	132.05–132.3	32.3–32.55	0.03	2701.0	–	normal	A68.3

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1984 Aug 07 (132.2°E 32.4°N) M_J7.1

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
–	–	–	–	–	–
			Land		
–	–	–	–	–	–

The 1983 Tottori-Ken earthquake

The aftershocks of this event of M_J6.2 taken from the rectangular region bounded by 35°–36°N and 133°–135°E are considered for a period of about two months till the end of 1983.

The analyzed data sets and the corresponding results shown in **Figures A69.1–A69.5** are summarized in the following.

The 1983 Tottori-Ken aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
2.3	89	133.0–135.0	35.0–36.0	0.01	60.0	10.38	quiescent	A69.1
2.5	61	133.0–135.0	35.0–36.0	0.01	60.0	10.19	quiescent	A69.2
2.7	41	133.0–135.0	35.0–36.0	0.01	60.0	39.62	quiescent	A69.3
2.8	34	133.0–135.0	35.0–36.0	0.01	60.0	39.62	quiescent	A69.4
3.0	25	133.0–135.0	35.0–36.0	0.01	60.0	–	normal	A69.5

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1983 Oct 31 (133.9°E 35.4°N) M_J6.2

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.1	0.8	3.3	1984 08 07	132.2 32.4	Miyazaki-Ken-Oki
			Land		
6.8	0.9	3.0	1984 09 14	137.6 35.8	Nagano-Ken-Seibu
6.0	3.1	4.7	1986 11 22	139.5 34.5	Izu-Oshima Kinkai
6.5	6.3	4.4	1990 02 20	139.2 34.8	Izu-Oshima Kinkai
6.6	9.3	3.6	1993 02 07	137.3 37.6	Noto-Hanto-Oki

The 1980 Okinawa-Hokusei-Oki earthquake

This event of M_J6.7 occurred off the northwest coast of Okinawa Island. The aftershock data is taken from the JMA hypocenter catalog for the rectangular area bounded by 126°–127°E and 26.5°–27.25°N and for the period ending February 1983. Due to the small number of events whose magnitude is listed in this area, we also use events whose magnitude is not determined but whose location is identified, and which appear homogeneously detected throughout the considered period except for the first 0.1days right after the mainshock.

The analyzed data sets and the corresponding results shown in **Figures A70.1–A70.6** are summarized in the following table.

The 1980 Okinawa-Hokusei-Oki aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	40	126.0–127.0	26.5–27.25	0.10	1070.0	6.38	quiescent	A70.1, A70.2
4.2	31	126.0–127.0	26.5–27.25	0.10	1070.0	6.38	quiescent	A70.3, A70.4
4.5	12	126.0–127.0	26.5–27.25	0.10	1070.0	6.38	quiescent	A70.5, A70.6

Here, in each sequence of events with M_c0.0, 4.2 and 4.5, there is a further change-point in the period up to the change-point of the largest significance, which is shown in Figures A70.1, A70.3 and A70.5, respectively. Thus, Figures A70.2, A70.4 and A70.6 provide the final result for the sequence of events with M_c0.0, 4.2 and 4.5, respectively.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within ten degrees apart.

Subsequent neighboring events after the 1980 Mar 03 (126.6°E 27.0°N) M_J6.7

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.1	4.4	7.3	1984 08 07	132.2 32.4	Miyazaki-Ken-Oki
			Land		
–	–	–	–	–	–

The 1978 Simane-Ken-Chubu earthquake

This earthquake of M_J6.1 occurred in the central part of Shimane Prefecture, Chugoku District. The data sets analyzed and the corresponding results shown in **Figures A71.1–A71.3** are summarized in the following table.

The 1978 Simane-Ken-Chubu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	53	132.5–132.75	35.0–35.25	0.01	880.0	–	normal	71.1
3.3	34	132.5–132.75	35.0–35.25	0.01	880.0	–	normal	71.2
3.7	17	132.5–132.75	35.0–35.25	0.01	880.0	–	normal	71.3

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1978 Jun 04 (132.7°E 35.1°N) M_J6.1

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.1	6.2	2.7	1984 08 07	132.2 32.4	Miyazaki-Ken-Oki
			Land		
–	–	–	–	–	–

The 1968 Ehime-Ken-Seigan earthquake

This event of M_J6.6 occurred near the west coast of Ehime Prefecture, Shikoku Island. The aftershock data is taken from the JMA hypocenter catalog for the rectangular area bounded by 132°–132.5°E and 33°–33.5°N and for the period till the end of 1970.

The analyzed data sets and the corresponding results shown in **Figures A72.1 and A72.2** are summarized in the following table.

The 1968 Ehime-Ken-Seigan aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
3.5	25	132.0–132.5	33.0–33.5	0.30	961.0	–	normal	72.1
4.0	19	132.0–132.5	33.0–33.5	0.50	961.0	–	normal	72.2

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1968 Aug 06 (132.4°E 33.3°N) M_J6.6

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
–	–	–	–	–	–
				Land	
6.6	1.1	4.6	1969 09 09	137.1 35.8	Gifu-Ken-Chubu
6.0	4.1	4.5	1972 08 31	136.8 35.9	Fukui-Ken East
6.1	6.5	1.1	1975 01 23	131.1 33.0	Kumamoto-Ken-Northeast
6.4	6.7	0.9	1975 04 21	131.3 33.1	Oita-Ken-Chubu
6.1	9.8	1.8	1978 06 04	132.7 35.1	Simane-Ken-Chubu

The 1955 Tokushima-Ken-Nanbu earthquake

This event of M_J 6.4 occurred in Tokushima Prefecture, Shikoku Island. The aftershock data is taken from the JMA hypocenter catalog for the rectangular area bounded by 134°–134.5°E and 33.5°–34°N. Since the aftershock events associated with their magnitude is limited in number, we even use events whose magnitude is not determined but whose location is identified (printed as M0.0 in the catalog).

The analyzed data sets and the corresponding results shown in **Figures A73.1 and A73.2** are summarized in the following table.

The 1955 Tokushima-Ken-Nanbu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	63	134.0–134.5	33.5–34.0	0.4	63.0	–	normal	73.1
3.0	18	134.0–134.5	33.5–34.0	0.1	63.0	–	normal	73.2

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1955 Jul 27 (134.3°E 33.8°N) M_J6.4

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.0	5.6	3.0	1961 02 27	131.8 31.6	Hyuganada (Ms7.6)
			Land		
6.0	1.4	4.3	1956 12 22	139.5 33.7	Miyake-Is Kinkai
6.0	2.3	4.2	1957 11 11	139.3 34.2	Niijima-Kinkai
7.0	6.1	3.1	1961 08 19	136.8 36.0	Kitamino earthquake
6.9	7.7	2.4	1963 03 27	135.8 35.8	Echizen-Misaki-Oki
6.1	9.7	3.5	1965 04 20	138.3 34.9	Shizuoka-Ken Chubu

The 1943 Tottori earthquake

This event of M_J7.2 is one of the intra-plate earthquakes that occurred shortly prior to the 1944 Tonankai and 1946 Nankaido great events. The aftershock events listed in the JMA hypocenter catalog appear to be complete at magnitude M4.4 or larger except for a short time span right after the mainshock owing to the Gutenberg-Richter's relation. All events of any magnitude are taken from the rectangular region bounded by 35°–36°N and 133°–135°E and for the period up until the 1946 Nankaido event. We also use events whose magnitude is not determined but whose location is determined in the JMA hypocenter catalog. The detection rate of such events seems homogeneous throughout the whole time span except for a short period right after the mainshock. The size of such events is assessed to be M4.0 according to the Gutenberg-Richter's magnitude frequency law.

The analyzed data sets and the corresponding results shown in **Figures A74.1–A74.5** are summarized in the following table.

The 1943 Tottori aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
0.0	235	133.0-135.0	35.0–36.0	0.2	1197.0	2.42	quiescent	A74.1, A74.2
4.4	73	133.0-135.0	35.0–36.0	0.2	1197.0	208.23	quiescent	A74.3
4.7	40	133.0-135.0	35.0–36.0	0.2	1197.0	208.23	quiescent	A74.4
5.0	18	133.0-135.0	35.0–36.0	0.005	1197.0	–	normal	A74.5

Incidentally, Figure A74.2 shows the same result as Figure 74.1, but the time span shown is restricted to 10days after the mainshock.

The quiescence can be related not only to the Nankaido event but also to the Tonankai event. This is seen by the similar analysis for the sequence during the time span [0.2, 441.85]days although the figure is not provided here.

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1943 Sep 10 (134.1°E 35.5°N) M_J7.2 M_s7.4

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
			Sea		
7.9	1.2	2.7	1944 12 07	136.6 33.8	Tonankai earthquake
8.0	3.3	2.8	1946 12 21	135.6 33.0	Nankaido earthquake
7.0	4.6	2.5	1948 04 18	135.6 33.3	Kii-Hanto-Oki (Ms7.3)
			Land		
6.3	1.2	4.2	1944 12 09	139.0 34.2	Miyake-Is-West-Oki
6.8	1.4	2.6	1945 01 13	137.1 34.7	Mikawa earthquake
6.0	3.3	2.2	1946 12 21	135.4 33.6	Nankaido earthquake
6.7	4.8	2.0	1948 06 15	135.4 33.8	Wakayama-Ken Southeast
7.1	4.8	1.8	1948 06 28	136.2 36.2	Fukui earthquake
6.3	5.4	0.4	1949 01 20	134.5 35.6	Hyogo-Ken North
6.2	6.3	4.6	1949 12 26	139.6 36.6	Imaichi earthquake
6.4	6.3	4.7	1949 12 26	139.8 36.6	Imaichi earthquake
6.5	8.5	2.0	1952 03 07	136.2 36.5	Daishoji-Oki

The 1943 Tottori-Ken-Tobu earthquake

This event of M_J6.2 took place in the eastern Tottori Prefecture in March 1943, about six months before the 1943 Tottori earthquake of M_J7.2 occurred in September 1943. The aftershock activity of the Tottori-Ken-Tobu earthquake is rather swarm like in such a way that M_J5.7, 6.2 and 5.8 occurred after twenty minutes, ten hours and eight days, respectively. Therefore, as Matsu'ura (1986) describes, a sequence of this type can hardly be handled by the nonstationary Poisson-process models using the simple or multiple modified Omori intensity functions (Ogata, 1983).

We also use events whose magnitude is not determined but whose location is determined in the JMA hypocenter catalog. The detection rate of such events seems homogeneous throughout the whole time span except for a short time span immediately after the mainshock. Such events are roughly assessed to be M3.6 according to the Gutenberg-Richter's frequency law. Also, we use the list of felt earthquakes in *Kisho-Yoran* (Geophysical Review of the JMA, 1944-1946), mainly detected at Tottori Observatory. The lowest bound of sizes for such events are assessed to be about M3.5. Time span is up until the occurrence of the Tottori event of M_J7.2 in the contiguous area. The occurrence time data are provided up to the accuracy of minute, but there are a number of couples and triplets which occurred at the same minute. This causes an unfavorable effect in the estimation of the ETAS parameters. Thus, occurrence times of these are shifted to separate the couples and triplets from each other.

The analyzed data sets and the corresponding results shown in **Figures A75.1 and A75.2** are summarized in the following table.

The 1943 Tottori-Ken-Tobu aftershock activity

M_c	N (events)	Longitudes (deg. E)	Latitudes (deg. N)	S (days)	T (days)	T_c (days)	Result	Figure
felt	561	133.0–135.0	35.0–36.0	0.40	189.90	51.49	quiescent	A75.1
0.0	27	133.0–135.0	35.0–36.0	0.45	189.90	67.39	quiescent	A75.2

The following table lists large earthquakes which occurred after this event within ten years time-lag and within five degrees apart.

Subsequent neighboring events after the 1943 Mar 04 (134.2°E 35.4°N) M_J6.2

M_J	Δt (years)	Δr (deg)	Date year mo.day	Location long. lat.	Name
				Sea	
7.9	1.7	2.5	1944 12 07	136.6 33.8	Tonankai earthquake
8.0	3.8	2.6	1946 12 21	135.6 33.0	Nankaido earthquake
7.0	5.1	2.4	1948 04 18	135.6 33.3	Kii-Hanto-Oki (Ms7.3)
				Land	
6.2	0.4	5.0	1943 08 12	139.9 37.3	Fukushima-Ken South
7.2	0.5	0.2	1943 09 10	134.1 35.5	Tottori earthquake
6.3	1.8	4.1	1944 12 09	139.0 34.2	Miyake-Is-West-Oki
6.8	1.9	2.4	1945 01 13	137.1 34.7	Mikawa earthquake
6.0	3.8	2.0	1946 12 21	135.4 33.6	Nankaido earthquake
6.7	5.3	1.9	1948 06 15	135.4 33.8	Wakayama-Ken Southeast
7.1	5.3	1.8	1948 06 28	136.2 36.2	Fukui earthquake
6.3	5.9	0.3	1949 01 20	134.5 35.6	Hyogo-Ken North
6.2	6.8	4.6	1949 12 26	139.6 36.6	Imaichi earthquake
6.4	6.8	4.7	1949 12 26	139.8 36.6	Imaichi earthquake
6.3	7.5	5.0	1950 09 10	140.3 35.2	Chiba-Ken East
6.5	9.0	2.0	1952 03 07	136.2 36.5	Daishoji-Oki

References

Gutenberg, B. and Richter, C.F. (1944). Frequency of earthquakes in California, *Bull. Seismol. Soc. Am.* **34**, pp. 185-188.

Kanamori, H. (1971). Seismological evidence for a lithospheric normal faulting – the Sanriku earthquake of 1933, *Phys. Earth Planet. Interiors*, **4**, 289-300.

Matsu'ura R.S. (1986). Precursory quiescence and recovery of aftershock activities before some large aftershocks, *Bull. Earthq. Res. Inst., Univ. Tokyo* **61** pp. 1-65.

Matsu'ura R.S., Karakama, I. and Tsumura, K. (1988). *List of Earthquakes in Kanto Area and its Vicinity*, Part 1 and Part 2, Earthquake Research Institute, University of Tokyo, Japan.

Mogi, K. (1973). Relationship between shallow and deep seismicity in the western Pacific region, *Tectonophysics*, **17**, pp. 1-22.

Ohtake, M. (1980). Earthquake prediction based on the seismic gap with special reference to the 1978 Oaxa, Mexico Earthquake, *Research Report of the National Research Center for Disaster Prevention*, **23**, pp.65-110, in Japanese.

Ohtake, M. (1993). Does an earthquake take place in a seismic gap?, *Zisin Journal*, **15**, 12-19, in Japanese.

Ogata, Y. (1983). Estimation of the parameters in the modified Omori formula for aftershock frequencies by the maximum likelihood procedure, *J. Phys. Earth*, **31**: 115-124.

Ogata, Y. (1989). Statistical model for standard seismicity and detection of anomalies by residual analysis, *Tectonophysics*, **169**, pp. 159-174.

Ogata, Y. (1992). Detection of precursory relative quiescence before great earthquakes through a statistical model, *J. Geophys. Res.*, **97**, 19845-19871.

Ogata, Y. (1998) Quiescence Relative to the ETAS Model, *Zisin II (J. Seismol. Soc. Japan)*, **10**, 35-45, in Japanese with English summary and figure captions.

Oike, K., Ishikawa, Y. and Shimizu, H. (1989). On the seismic activity in Japan before and after the Tonankai and Nankaido earthquakes, *Abstr. Seismol. Soc. Japan*, No. 2, p. 155, (in Japanese).

Utsu, T. (1969). Aftershocks and earthquake statistics (I): some parameters which characterize an aftershock sequence and their interrelation, *J. Faculty Sci., Hokkaido Univ., Ser. VII*, **3**: 129-195.

Utsu, T. (1970). Seismic activity and seismic observation in Hokkaido in recent years, *Report of the Coordinating Committee for Earthquake Prediction*, **2**, Edited by Geographical Survey Institute, Ministry of Construction, pp. 1-2 (in Japanese).

Utsu, T. (1971). Aftershocks and earthquake statistics (III): Analyses of the distribution of earthquakes in magnitude, time, and space with special consideration to clustering characteristics to earthquake occurrence (1), *J. Faculty Sci., Hokkaido Univ., Ser. VII,* **4**: 1-42.

Y. Ogata, Institute of Statistical Mathematics, Minani-Azabu 4-6-7, Minato-Ku, Tokyo 106-8569, Japan. (e-mail: ogata@ism.ac.jp)

Received ____________________

Submitted to the *JGR, 2000.*