

Additional file1 for

Migration Diffusivity as a Controlling Factor in the Duration of Earthquake Swarms

by Yuta Amezawa¹, Takuto Maeda¹, and Masahiro Kosuga¹

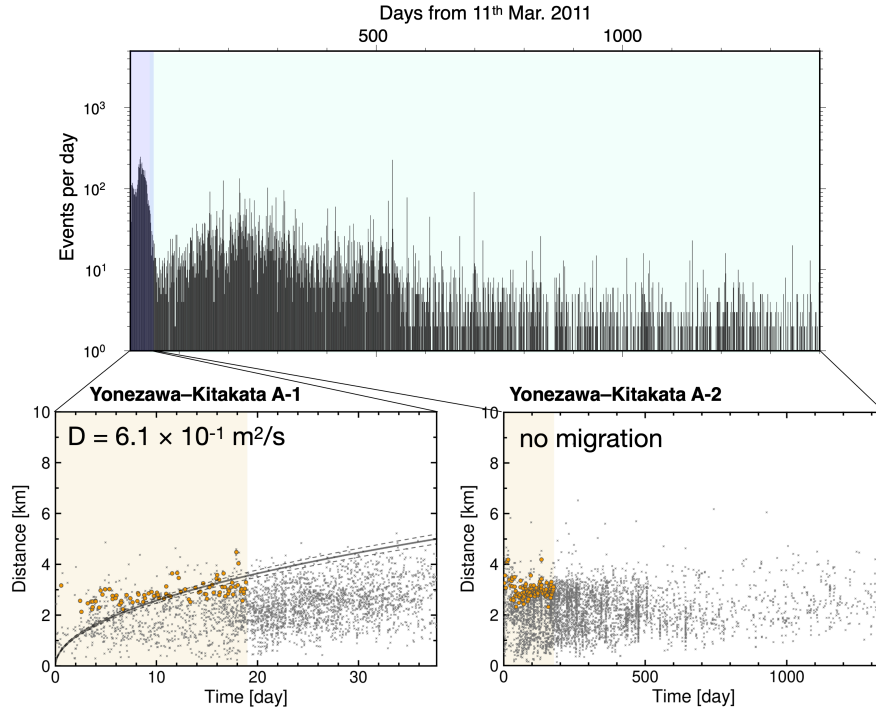
(1 Graduate School of Science and Technology, Hirosaki University, Aomori, Hirosaki, Japan)

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(a) Yonezawa–Kitakata A



(b) Yonezawa–Kitakata B

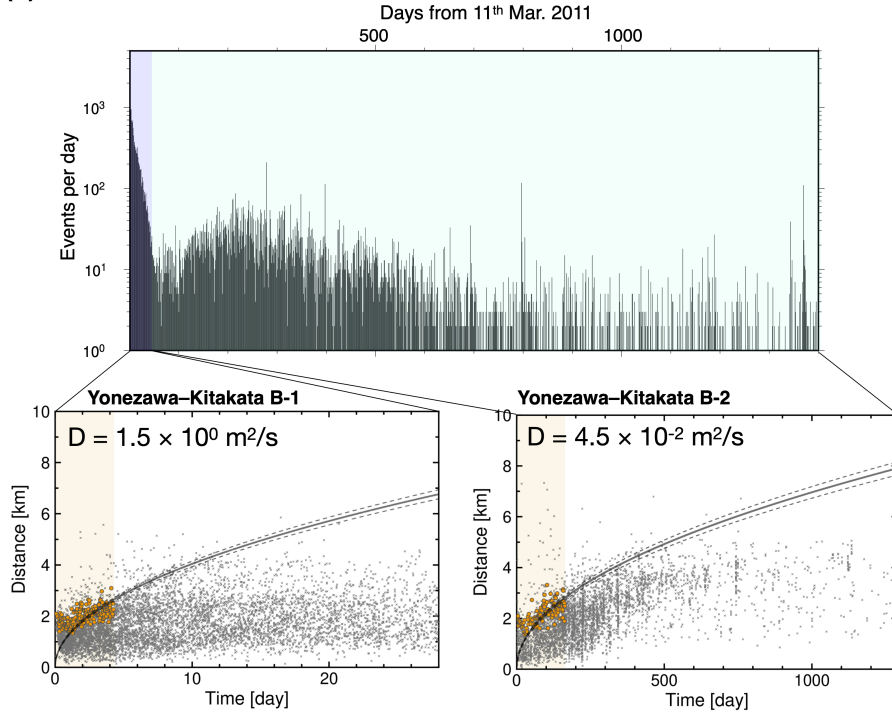


Figure S1. Frequency distribution (top) and distance versus time plot for two periods (bottom). (a) and (b) are for two distinct sequences from Yonezawa–Kitakata A and B. The whole period in the top figures is 1400 days from 11 March 2011 to 31 December 2019. Solid and dashed curves in the bottom figures show the theoretical diffusion curve with $D \pm 2\sigma$. Values of the diffusivity (D) are shown at the left top of each figure. Orange circles indicate the data used for the model fitting. We indicate no D value for Yonezawa–Kitakata A-2 because of no apparent migration.

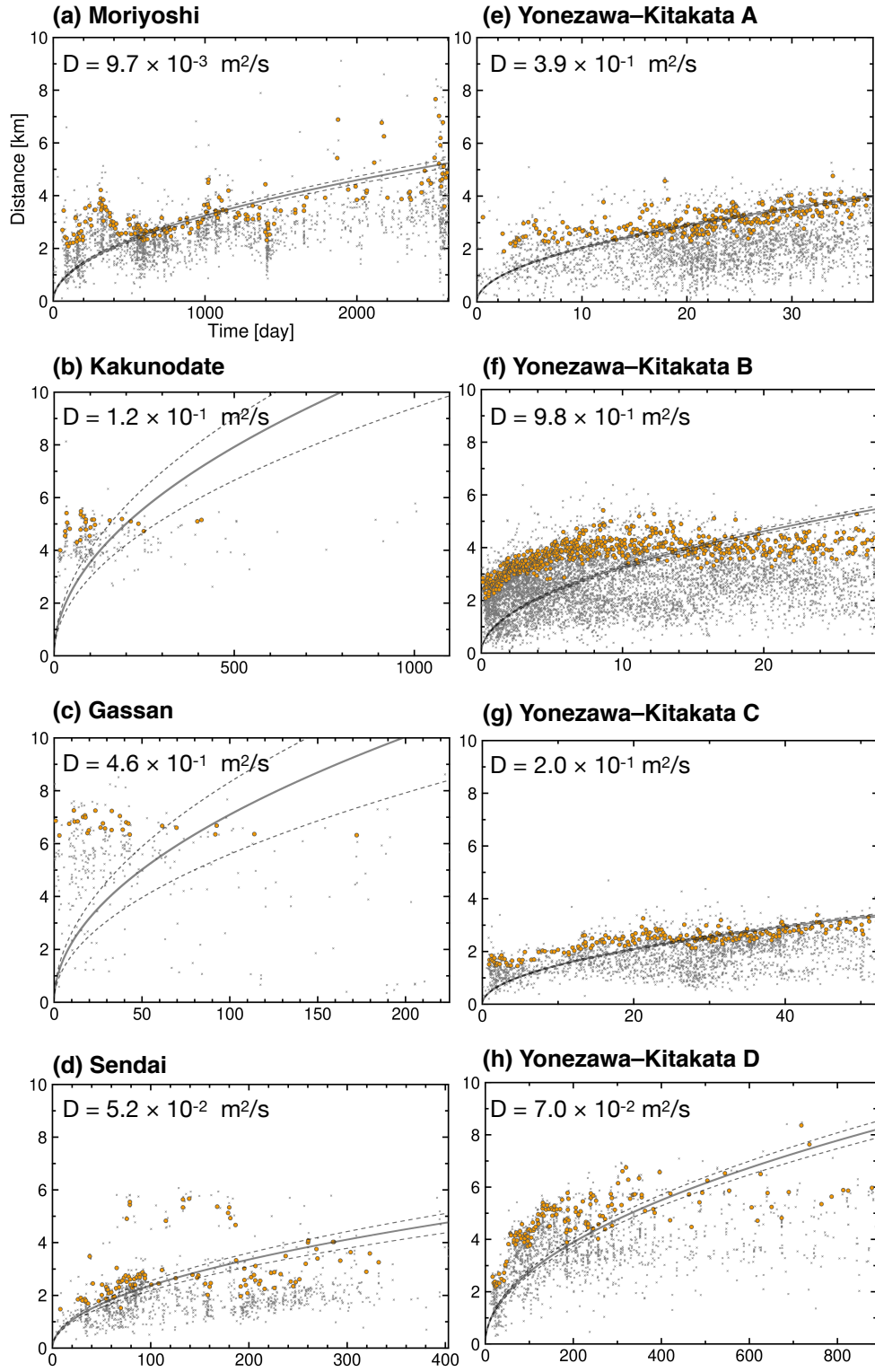


Figure S2. Distance versus time plot for all areas shown in Figure 1. The spatiotemporal origin to measure the distance and time is the hypocenter and the origin time of the first event in each area. Orange circles denote the data used for the model fitting. Solid and dashed lines show the theoretical diffusion curve and its 2σ variation. Values of the diffusivity (D) are shown at the left top of each figure.

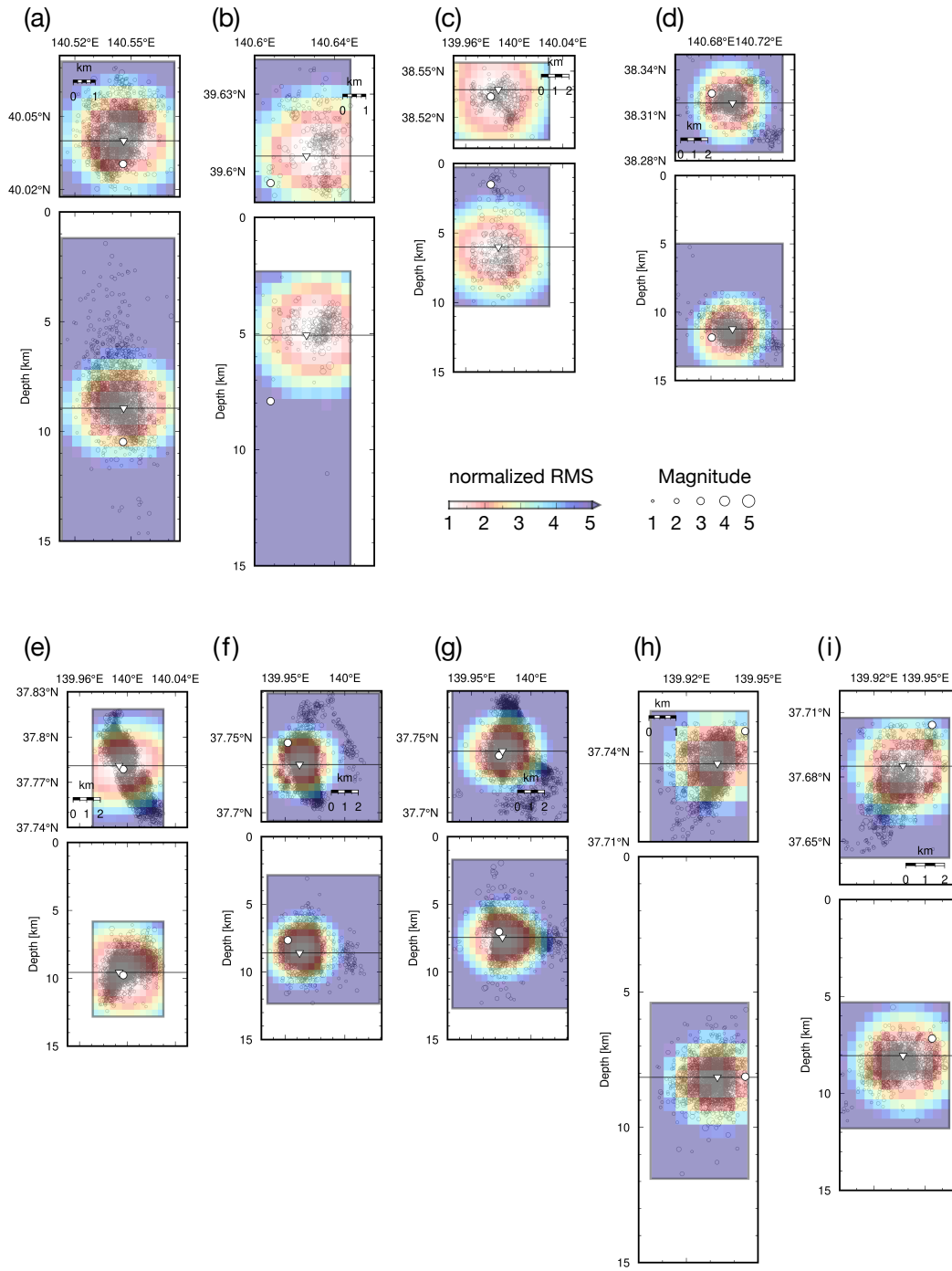


Figure S3. Spatial distribution (plan view and E-W cross-section) of RMS misfit to the diffusion model with spatial origin assigned to the 3D grids in each panel. Panels (a) to (i) show the result for all the areas shown in Figure 1: Moriyoshi, Kakunodate, Gassan, Sendai, Yonezawa–Kitakata A-1, B-1, B-2, C, and D, respectively. The color indicates the normalized RMS by the minimum RMS. The inverted triangle and open circle represent the location of the grid with minimum RMS and the hypocenter of the first event, respectively. The horizontal bars indicate the position of the cross-section and plan view. Black circles denote the hypocenters of earthquakes ($M \geq 1.0$) that occurred from 11 March 2011 to 31 December 2019.

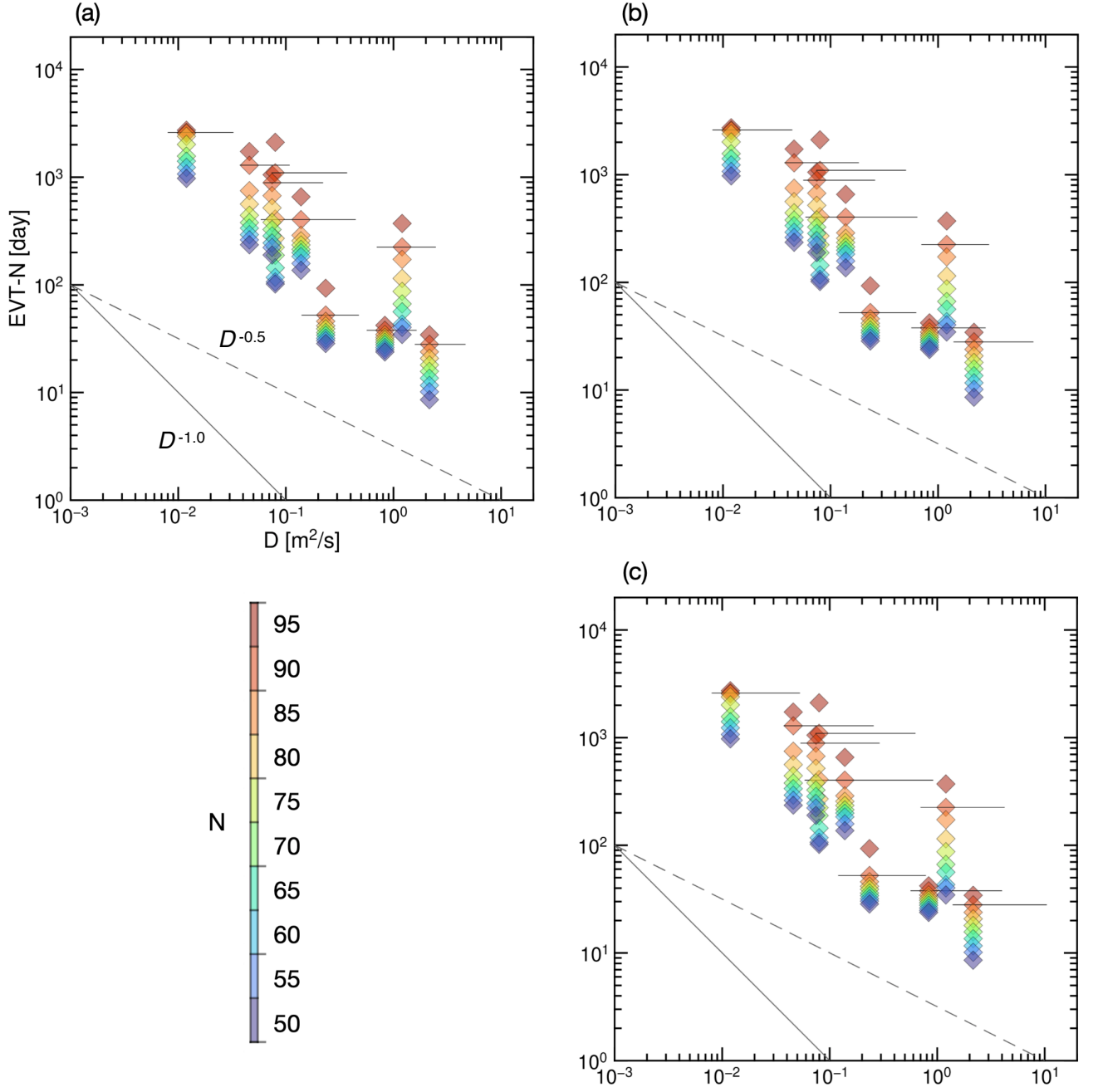


Figure S4. Scatter plot between the diffusivity and swarm duration to assess their uncertainty for the areas shown in Figure 4(a). The color of diamonds represents N value for EVT- N [days] as the duration of each swarm, which are common for all panels. Horizontal bars attached to the diamonds in the panel (a), (b), and (c) indicate the range of diffusivity with allowed normalized RMS by the minimum RMS of 1.5, 2.0, 3.0, respectively. Two lines proportional to $D^{-0.5}$ and $D^{-1.0}$ are shown for reference.

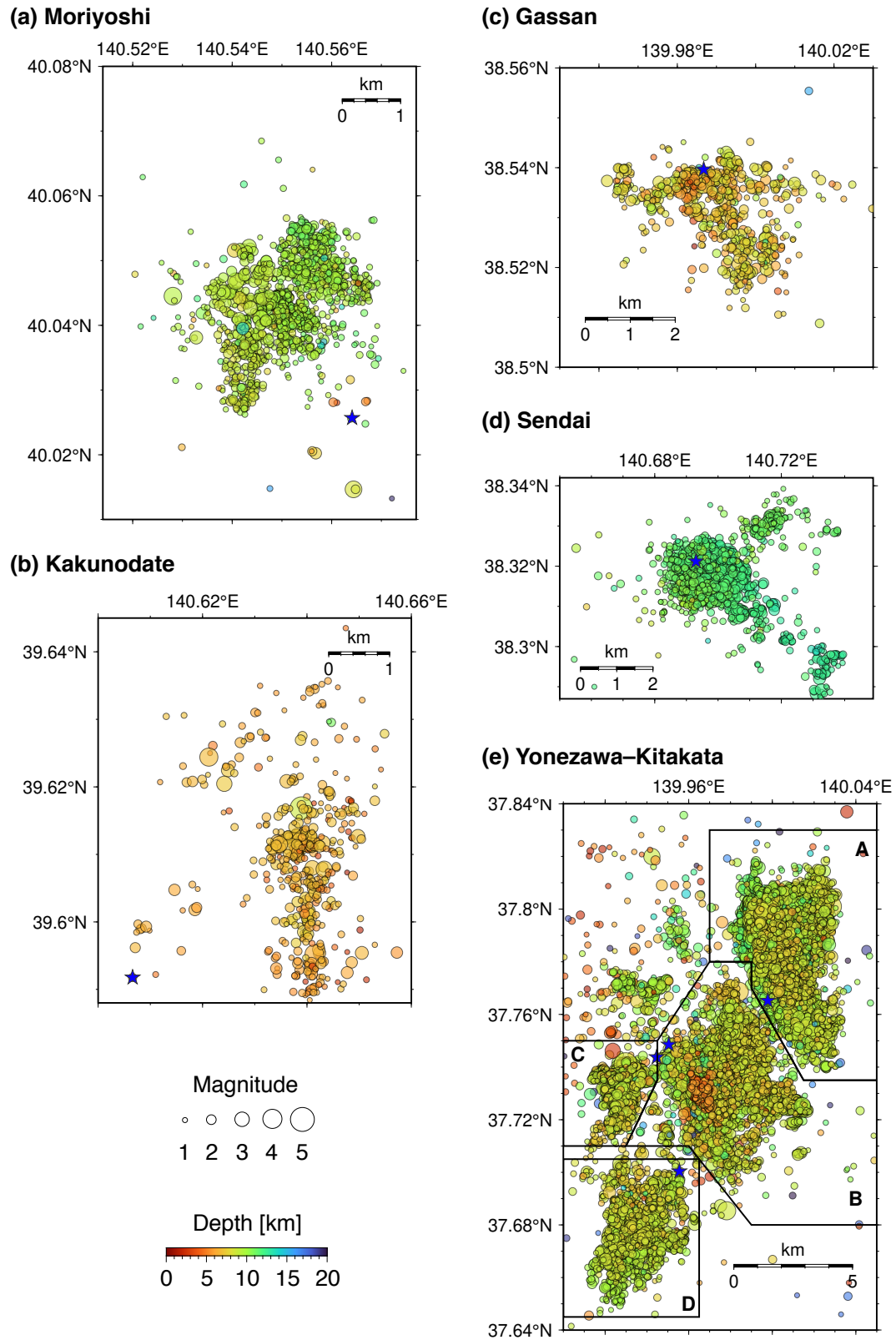


Figure S5. Hypocenter distribution plotted by the JUICE catalog (Yano et al., 2017). Colored circles denote epicenters of earthquakes ($M \geq 1.0$) that occurred from 11 March 2011 to 31 December 2012. The color and size of each circle represent depth and magnitude, respectively. Blue stars represent the first event in each area.

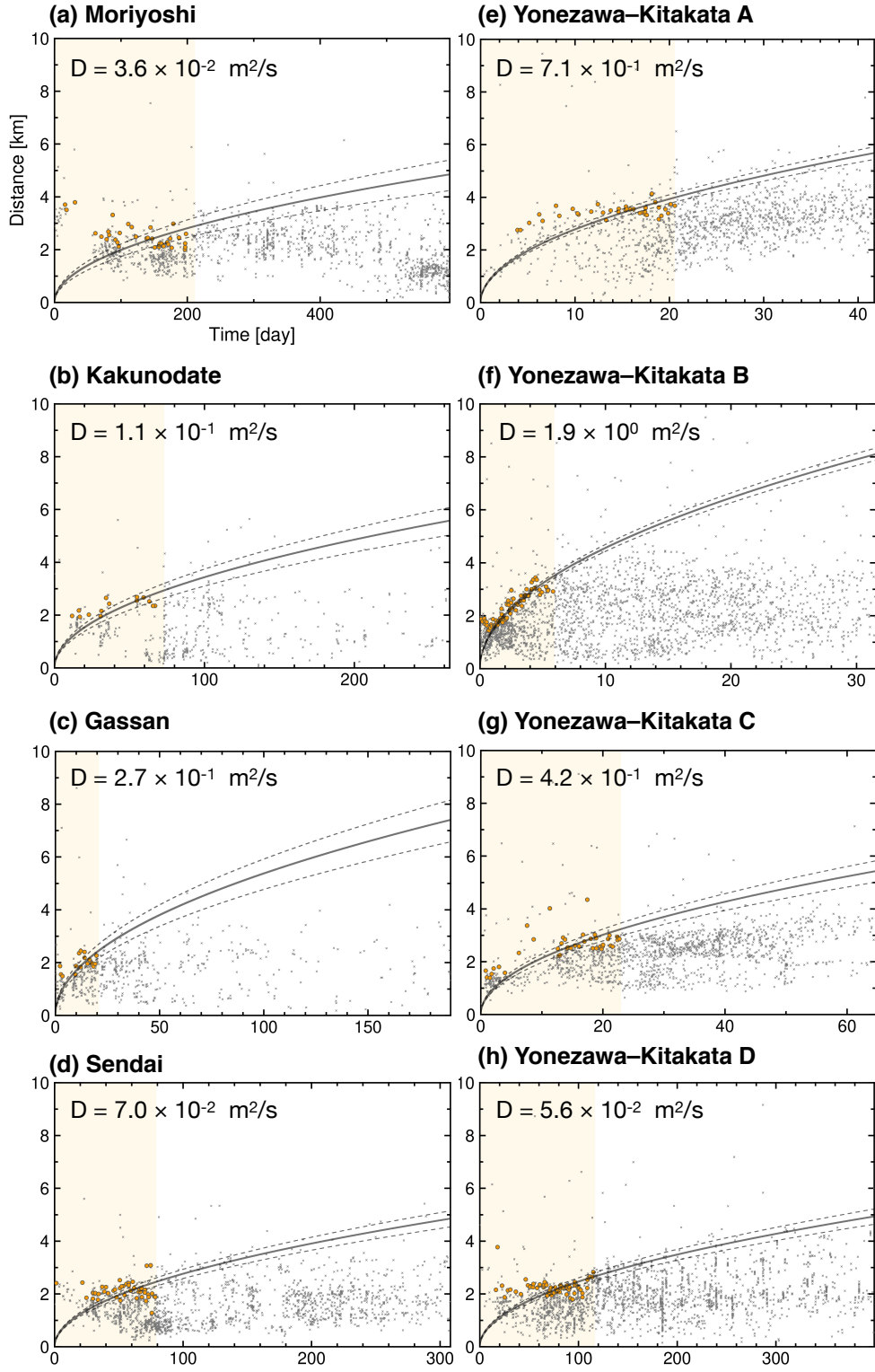


Figure S6. Same as Figure S2 but using the JUICE catalog and the spatial origin determined by a grid search. Gray crosses denote distance and time calculated from the spatial origin and the origin time of the first event. Orange circles denote the data used for the fitting to the diffusion model. Solid and dashed lines show the theoretical diffusion curve and its 2σ variation. Values of diffusivity (D) are shown at the left top of each figure.

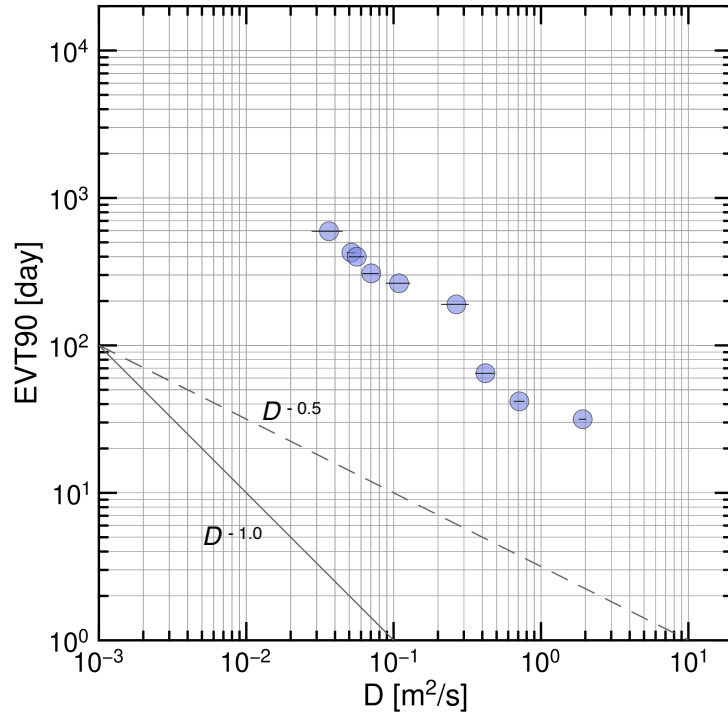
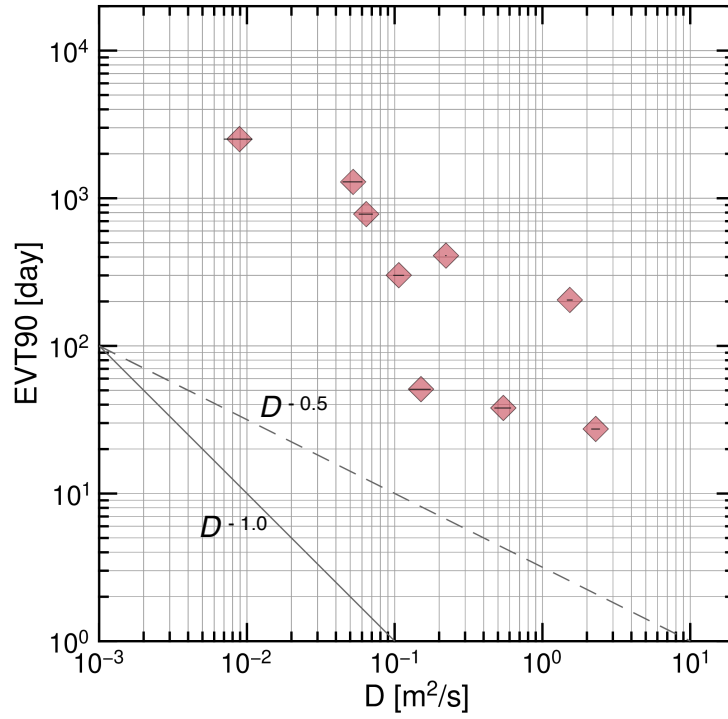


Figure S7. Diffusivity (D) versus duration (EVT90) plot estimated from the JUICE catalog. Horizontal bars indicate the 2σ range of diffusivity. Two lines proportional to $D^{-0.5}$ and $D^{-1.0}$ are shown for reference.

(a) JMA catalog ($M \geq 1.5$)



(b) JUICE catalog ($M \geq 1.5$)

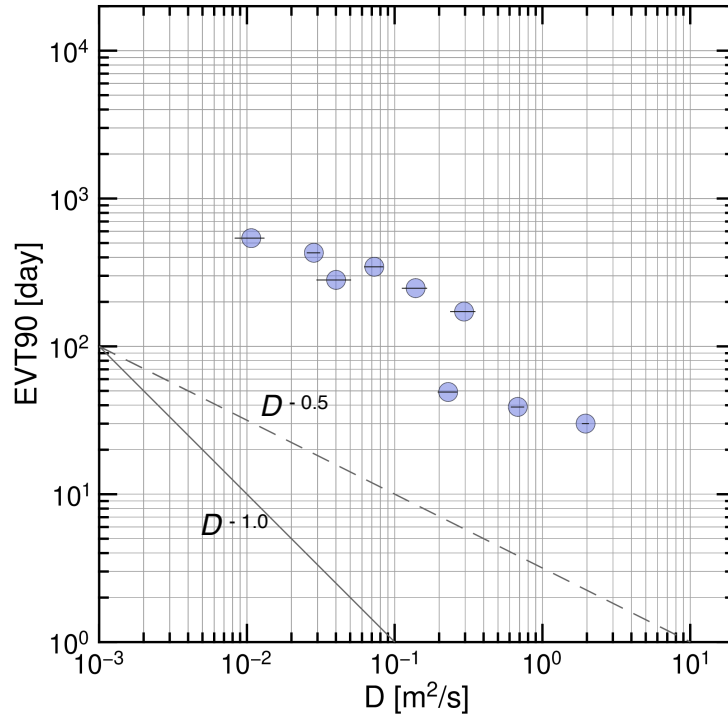


Figure S8. Diffusivity (D) versus duration (EVT90) plot estimated from the JMA (top) and JUICE (bottom) catalogs with the cut-off magnitude of 1.5. Horizontal bars indicate the 2σ range of diffusivity. Two lines proportional to $D^{-0.5}$ and $D^{-1.0}$ are shown for reference.

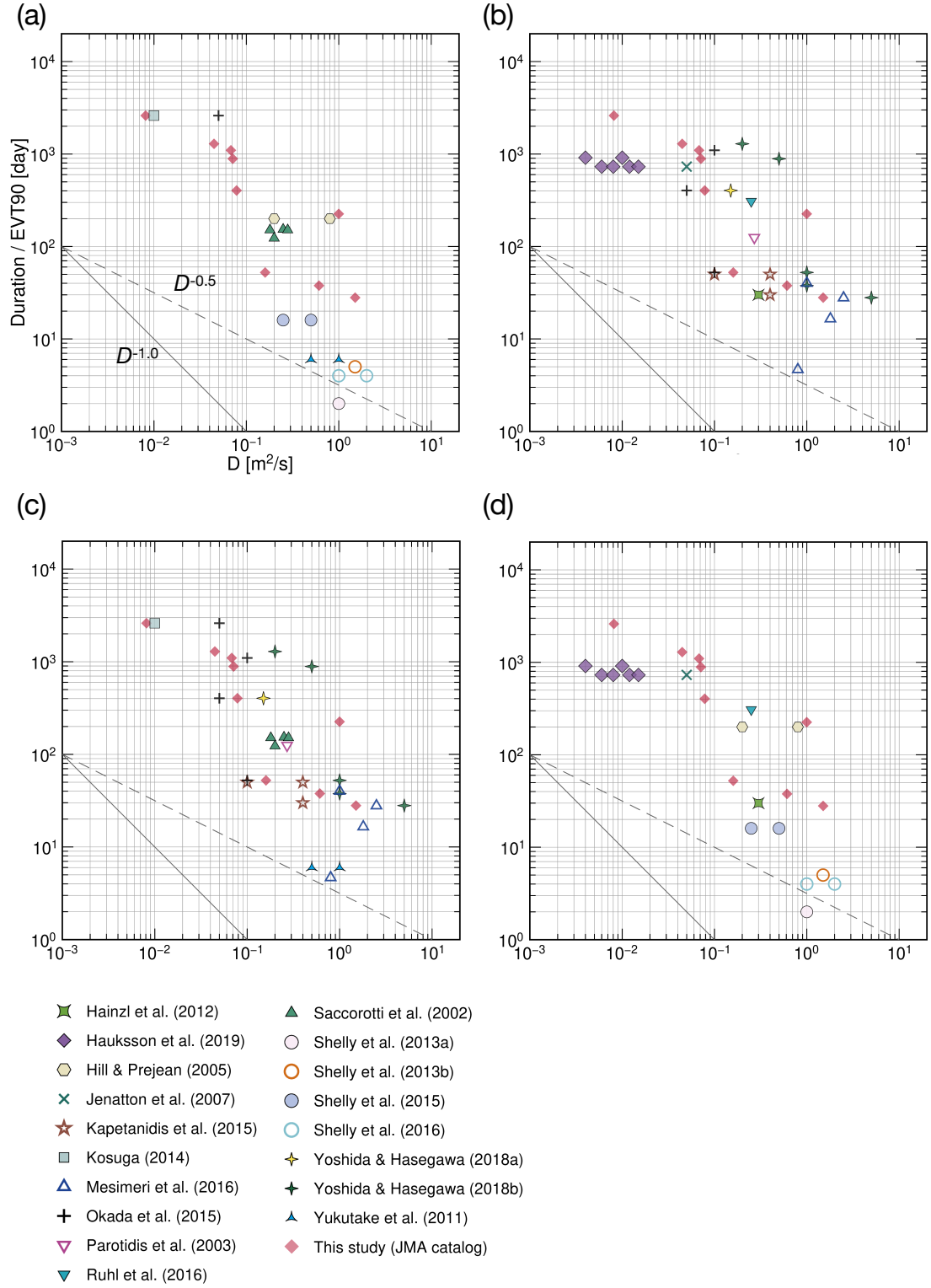


Figure S9. Diffusivity (D) versus duration (EVT90) plot from previous studies grouped according to the tectonic environment: (a) volcanic, (b) non-volcanic, (c) subduction zone, and (d) non-subduction zone. Two lines proportional to $D^{-0.5}$ and $D^{-1.0}$ are shown for reference.

Table S1. The duration (EVT90) and diffusivity (D) with its range ($D - 2\sigma$ and $D + 2\sigma$) for the areas shown in Figure 2. These values were estimated for earthquakes with $M \geq 1.0$ in the JMA catalog.

Area	EVT90 [day]	D [m ² /s]	$D - 2\sigma$ [m ² /s]	$D + 2\sigma$ [m ² /s]
Moriyoshi	2604	0.00813	0.00727	0.00899
Kakunodate	1098	0.0680	0.0408	0.0953
Gassan	225	0.999	0.756	1.24
Sendai	403	0.0784	0.0672	0.0896
Yonezawa–Kitakata A-1	38	0.610	0.563	0.657
Yonezawa–Kitakata B-1	28	1.50	1.43	1.58
Yonezawa–Kitakata B-2	1289	0.0447	0.0417	0.0476
Yonezawa–Kitakata C	52	0.160	0.145	0.174
Yonezawa–Kitakata D	889	0.0713	0.0674	0.0751

Table S2. Same as Table S1, but for earthquakes in the JUICE catalog.

Area	EVT90 [day]	D [m ² /s]	$D - 2\sigma$ [m ² /s]	$D + 2\sigma$ [m ² /s]
Moriyoshi	595	0.0364	0.0278	0.0451
Kakunodate	264	0.109	0.0885	0.129
Gassan	190	0.266	0.210	0.323
Sendai	308	0.0704	0.0616	0.0793
Yonezawa–Kitakata A-1	42	0.713	0.653	0.773
Yonezawa–Kitakata B-1	32	1.92	1.81	2.01
Yonezawa–Kitakata B-2	426	0.0517	0.0482	0.0552
Yonezawa–Kitakata C	65	0.420	0.358	0.482
Yonezawa–Kitakata D	400	0.0562	0.0496	0.0627

Table S3. Same as Table S1, but for earthquakes with $M \geq 1.5$ in the JMA catalog.

Area	EVT90 [day]	D [m ² /s]	$D - 2\sigma$ [m ² /s]	$D + 2\sigma$ [m ² /s]
Moriyoshi	2517	0.00891	0.00697	0.0109
Kakunodate	409	0.222	0.220	0.224
Gassan	205	1.53	1.46	1.60
Sendai	301	0.107	0.0979	0.115
Yonezawa–Kitakata A-1	38	0.543	0.474	0.612
Yonezawa–Kitakata B-1	27	2.29	2.14	2.44
Yonezawa–Kitakata B-2	1289	0.0524	0.0444	0.0604
Yonezawa–Kitakata C	51	0.150	0.126	0.175
Yonezawa–Kitakata D	781	0.0642	0.0573	0.0710

Table S4. Same as Table S2, but for earthquakes with $M \geq 1.5$ in the JUICE catalog.

Area	EVT90 [day]	D [m ² /s]	$D - 2\sigma$ [m ² /s]	$D + 2\sigma$ [m ² /s]
Moriyoshi	539	0.0107	0.00827	0.0131
Kakunodate	248	0.139	0.112	0.165
Gassan	172	0.295	0.238	0.352
Sendai	282	0.0401	0.0296	0.0507
Yonezawa–Kitakata A-1	39	0.681	0.610	0.752
Yonezawa–Kitakata B-1	30	1.96	1.85	2.06
Yonezawa–Kitakata B-2	430	0.0284	0.0255	0.0313
Yonezawa–Kitakata C	49	0.230	0.196	0.265
Yonezawa–Kitakata D	345	0.0728	0.0621	0.0834

Table S5. The durations and diffusivity (D) from previous studies. For the same areas as we investigated, we employed our estimates of duration (colored by blue) using earthquakes with $M \geq 1.0$ in the JMA catalog.

Reference	Duration [day]	D [m^2/s]	Area
Hainzl et al., 2012	30	0.3	Vogtland / NW Bohemia
Hauksson et al., 2019	730	0.006	Cahuilla Valley, California
Hauksson et al., 2019	730	0.012	Cahuilla Valley, California
Hauksson et al., 2019	730	0.008	Cahuilla Valley, California
Hauksson et al., 2019	730	0.015	Cahuilla Valley, California
Hauksson et al., 2019	913	0.004	Cahuilla Valley, California
Hauksson et al., 2019	913	0.01	Cahuilla Valley, California
Hill & Prejean, 2005	200	0.2	Mt. Mammoth, California
Hill & Prejean, 2005	200	0.8	Mt. Mammoth, California
Jenatton, et al., 2007	731	0.05	Ubaye, France
Kapetanidis, et al., 2015	50	0.1	Helike, Greece
Kapetanidis, et al., 2015	50	0.4	Helike, Greece
Kapetanidis, et al., 2015	30	0.4	Helike, Greece
Kosuga 2014	2604	0.01	Moriyoshi, Japan
Mesimeri et al., 2016	4.67	0.8	Helike, Greece
Mesimeri et al., 2016	16.52	1.8	Helike, Greece
Mesimeri et al., 2016	27.86	2.5	Helike, Greece
Mesimeri et al., 2016	40.15	1.0	Helike, Greece
Okada et al., 2015	52	0.1	Yonezawa–Kitakata, Japan
Okada et al., 2015	403	0.05	Sendai, Japan
Okada et al., 2015	1098	0.1	Kakunodate, Japan
Okada et al., 2015	2604	0.05	Moriyoshi, Japan
Parotidis et al., 2003	125	0.27	Vogtland / NW Bohemia
Ruhl et al., 2016	308	0.25	Mogul, Nevada
Saccorotti et al., 2002	153	0.25	Vesuvius, Italy
Saccorotti et al., 2002	151	0.28	Vesuvius, Italy
Saccorotti et al., 2002	151	0.18	Vesuvius, Italy
Saccorotti et al., 2002	123	0.2	Vesuvius, Italy
Shelly et al., 2013a	2	1.0	Mt. Rainier, Washington
Shelly et al., 2013b	5	1.5	Yellowstone, California
Shelly et al., 2015	16	0.25	Mt. Mammoth, California
Shelly et al., 2015	16	0.5	Mt. Mammoth, California
Shelly et al., 2016	4	1.0	Long Valley, California
Shelly et al., 2016	4	2.0	Long Valley, California
Yoshida & Hasegawa, 2018a	403	0.15	Sendai, Japan
Yoshida & Hasegawa, 2018b	38	1.0	Yonezawa–Kitakata, Japan
Yoshida & Hasegawa, 2018b	52	1.0	Yonezawa–Kitakata, Japan
Yoshida & Hasegawa, 2018b	28	5.0	Yonezawa–Kitakata, Japan
Yoshida & Hasegawa, 2018b	1289	0.2	Yonezawa–Kitakata, Japan
Yoshida & Hasegawa, 2018b	889	0.5	Yonezawa–Kitakata, Japan
Yukutake et al., 2011	9	0.5	Hakone, Japan
Yukutake et al., 2011	9	1.0	Hakone, Japan