# Development of a Slow Earthquake Database

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## ABSTRACT

This article describes a database that provides various catalogs of slow earthquakes. The catalogs list the times and the locations of the events, with additional information depending on the catalog. Because these catalogs are provided by a variety of documents in different formats, previous studies that use them must repeat complex procedures for preparing data. To make it more convenient to use multiple catalogs and promote research on slow earthquakes, we compiled a number of catalogs into a standardized format in a single repository, the Slow Earthquake Database, at the University of Tokyo (see Data and Resources). Users can visualize the source locations of multiple slow earthquakes in the database in map views on the website. Convenient access to the database encourages researchers to work on slow earthquakes regardless of their backgrounds. We also expect the database will foster collaboration among researchers in various fields and further the understanding of the mechanisms, environmental conditions, and underlying physics of slow earthquakes. Through the compilation of this database, we established a global standard of slow earthquake catalogs.

## INTRODUCTION

The scope of this article includes describing a database on slow earthquakes (Ide *et al.*, 2007), a new type of fault slip. The deployment of seismic and geodetic networks in the late twentieth century contributed to the first discovery of slow earthquakes in southwest Japan (e.g., Hirose *et al.*, 1999; Obara, 2002). Since then, slow earthquakes have been widely detected in the world, especially in subduction zones along the Pacific Rim (Peng and Gomberg, 2010; Obara and Kato, 2016). Because slow earthquakes usually occur both on the deeper and shallower sides of megathrust seismogenic zones, slow earthquakes may interact with huge earthquakes. Therefore, revealing the generation mechanisms, environmental conditions, and principles of slow earthquakes should promote our understanding of all earthquake processes, ranging from slow transients to fast ruptures in faults.

Slow earthquakes are characterized by slower fault slips than ordinary earthquakes but faster than stable sliding, with various characteristic timescales ranging from seconds to years. For seismic signals of slow earthquakes, tectonic tremor with a dominant frequency of 2–8 Hz in their waveforms is observed by high-sensitivity seismometers (Obara, 2002) or ocean-bottom seismometers (OBSs; Obana and Kodaira, 2009; Yamashita *et al.*, 2015). Tremor is considered to be a continuous signal of low-frequency earthquakes (LFEs; Shelly *et al.*, 2006); that is, an element of tremor, and isolated pulses of tremor have also been identified as LFEs (Katsumata and Kamaya, 2003). Broadband seismometers record very low-frequency earthquakes (VLFEs) with a dominant period of a few tens of seconds (Ito *et al.*, 2007), and geodetic networks such as the Global Navigation Satellite System (GNSS), tiltmeters, and strainmeters detect slow-slip events (SSEs), lasting from days to years (Hirose *et al.*, 1999; Rogers and Dragert, 2003).

Researchers used a number of methods to estimate the source locations of LFEs, tremors, VLFEs, and SSEs. Catalogs of slow earthquakes, which list the times and the locations of the events together with additional information depending on the catalog, were detected by different researchers and became available in different formats. They are available from each original paper, which provide catalogs created upon publication, or through a website such as the Interactive Tremor Map (Wech, 2010) and the World Tremor Database (Idehara *et al.*, 2014), which provide updated catalogs with the most recent events. However, to investigate slow earthquakes, researchers must download catalogs from different sources with different formats, a complex, time-consuming process. Thus, to mitigate this problem and provide a more convenient source of information, we released the Slow Earthquake Database (see Data and Resources), a standardized compilation of slow earthquake catalogs. This article introduces an overview of the database, including its construction, contents, and availability along with underlying issues and future possible updates.

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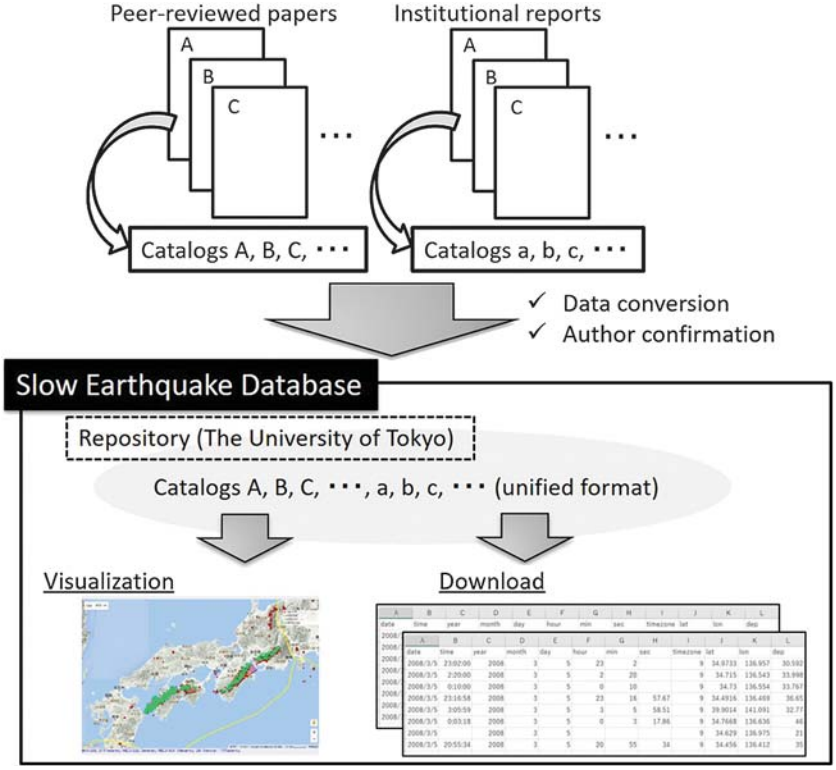
## DATABASE CONSTRUCTION AND OVERVIEW

The construction of the Slow Earthquake Database entailed the following procedure (Fig. 1). We began by compiling information about slow earthquakes such as occurrence times, locations, magnitudes, and source mechanisms of events from peer-reviewed papers and institutional reports. We used every slow earthquake catalog in the database with permission from the corresponding author(s) to include it to the database and then converted the format of the catalogs to a unified format mentioned in the Download and Catalog Format section. After the conversion, we stored all of the catalogs in a single repository at the University of Tokyo that is currently open to the public via the Slow Earthquake Database (see Data and Resources). The database consists of 29 catalogs, including 5 LFEs, 13 tremors, 5 VLFEs, and 6 SSE catalogs (as of 4 December 2017; Table 1).



▲ **Figure 1.** Schematic illustration of the database construction.

The source locations of LFEs are usually determined based on the manually picked arrival times of *P* and *S* waves (Katsumata and Kamaya, 2003; Arai *et al.*, 2016) or their difference (*S*–*P* time). For example, the Japan Meteorological Agency (JMA) routinely determines the hypocenters of LFEs in Japan. The catalog compiled by the JMA includes both volcanic and tectonic LFEs along the subducting plate (Katsumata and Kamaya, 2003). The method of locating tremor involves the relative time differences of *S*-wave arrivals detected by a cross-correlation analysis of waveform envelopes, or the envelope cross-correlation method (ECM; Obara, 2002; Wech and Creager, 2008; Ide, 2010, 2012). To determine the hypocenters of LFEs along the Ryukyu subduction zone, several studies adopted ECM and the *S*–*P* time (Arai *et al.*, 2016; Nakamura, 2017).

The ECM is fundamentally used to determine the source location of worldwide tremor such as that in southwest Japan (Obara, 2002; Obana and Kodaira, 2009; Yamashita *et al.*, 2015), Cascadia, Parkfield, Mexico, Chile, New Zealand, and Taiwan (Idehara *et al.*, 2014). By combining the ECM and information related to the squared tremor amplitudes, Maeda and Obara (2009) identified the tremor hypocenters in southwest Japan. These methods can determine one source location within a short time period (e.g., 1 min). Because tremors can be continuous signals, tremor sources for a continuous period are sometimes clustered into one or two centroid locations (Obara *et al.*, 2010; Annoura *et al.*, 2016). For example, the National Research Institute for Earth Science and Disaster Resilience (NIED) routinely constructs catalogs of clustered tremor with a maximum duration of 1 hr. In northeast Japan, tremor signals were observed by OBSs (Ito *et al.*, 2015). However, because the OBS station was insufficient for locating tremor, we used the locations of the OBSs that recorded tremor signals in the catalog instead of the source location (Ito *et al.*, 2015).

Because the observed waveforms of VLFEs are dominant in low-frequency bands of 0.05 Hz, researchers often conduct centroid moment tensor inversion analyses (Ito *et al.*, 2007) by comparing synthetic and observed waveforms, using an appropriate velocity structure. Several studies applied this approach to locate VLFEs along the Japan trench (Matsuzawa *et al.*, 2015) and to both deep (Ito *et al.*, 2007, 2009; Takeo *et al.*, 2010) and shallow (Sugioka *et al.*, 2012) VLFEs in the Nankai subduction zone. Nakamura and Sunagawa (2015) employed the maximum amplitudes of surface waves recorded by broadband seismometers to detect the epicenters of VLFEs in the Ryukyu area. Their method, however, was incapable of accurately determining the source depth.

The Slow Earthquake Database includes the source parameters of SSEs in northeast and southwest Japan, represented by a single rectangular fault model. Assuming a homogeneous half-space, we inferred the source parameters of the faults (Okada, 1992) to explain the observed GNSS displacement vectors (Heki and Kataoka, 2008; Nishimura *et al.*, 2013; Nishimura, 2014; Takagi *et al.*, 2016; Tu and Heki, 2017), tilt changes (Sekine *et al.*, 2010), strain changes (Ito *et al.*, 2013), and pressure changes on the seafloor (Ito *et al.*, 2013).

At the time of its first release, the database included catalogs of slow earthquakes detected mainly in Japan, where this phenomenon is vigorously investigated. However, we are currently in the stage of compiling more catalogs in the world in cooperation with various researchers. Among them are catalogs

**Table 1**
**Catalogs in the Slow Earthquake Database Available 4 December 2017**

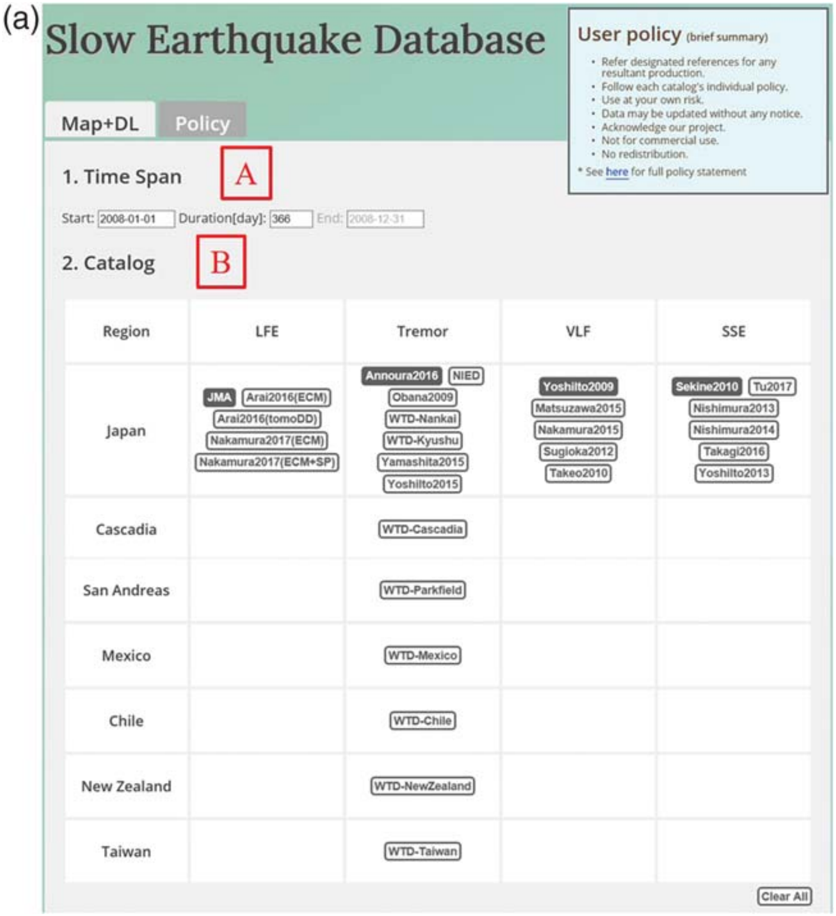
| Category | Name | Region | Time Span | Observations Used for Source Estimation | Reference(s) |
|---|---|---|---|---|---|
| LFE | Arai2016_ECM | Japan | 2013–2014 | Envelope waveform | Arai *et al.* (2016) |
| | Arai2016_tomoDD | Japan | 2014 | *P* and *S* arrival times | |
| | JMA | Japan | 1999–2017* | *P* and *S* arrival times | Katsumata and Kamaya (2003) |
| | Nakamura2017_ECM | Japan | 2004–2016 | Envelope waveform | Nakamura (2017) |
| | Nakamura2017_ECM+SP | Japan | 2004–2016 | Envelope waveform + *S*–*P* time | |
| Tremor | Annoura2016 | Japan | 2004–2015 | Envelope waveform | Annoura *et al.* (2016) |
| | NIED | Japan | 2001–2017* | Envelope waveform + average squared amplitude | Maeda and Obara (2009);<br>Obara *et al.* (2010) |
| | Obana2009 | Japan | 2003 | Envelope waveform | Obana and Kodaira (2009) |
| | WTD-Cascadia | Cascadia | 2005–2014 | Envelope waveform | Idehara *et al.* (2014) |
| | WTD-Chile | Chile | 2005–2007 | | |
| | WTD-Kyushu | Japan | 2004–2013 | | |
| | WTD-Mexico | Mexico | 2005–2007, 2009–2013 | | |
| | WTD-Nankai | Japan | 2004–2013 | | |
| | WTD-NewZealand | New Zealand | 2004–2012 | | |
| | WTD-Parkfield | San Andreas | 2005–2012 | | |
| | WTD-Taiwan | Taiwan | 2006–2009 | | |
| | Yamashita2015 | Japan | 2013 | Envelope waveform | Yamashita *et al.* (2015) |
| | YoshiIto2015 | Japan | 2011 | N/A[†] | Ito *et al.* (2015) |
| VLFE | Matsuzawa2015 | Japan | 2005–2013 | Maximum amplitude of surface waves | Matsuzawa *et al.* (2015) |
| | Nakamura2015 | Japan | 2002–2014 | Full waveform | Nakamura and Sunagawa (2015) |
| | Sugioka2012 | Japan | 2008–2009 | Full waveform | Sugioka *et al.* (2012) |
| | Takeo2010 | Japan | 2008 | Full waveform | Takeo *et al.* (2010) |
| | YoshiIto2009 | Japan | 2003–2008 | Full waveform | Ito *et al.* (2009) |
| SSE | Nishimura2013 | Japan | 1996–2012 | GNSS displacement | Nishimura *et al.* (2013) |
| | Nishimura2014 | Japan | 1997–2013 | GNSS displacement | Nishimura (2014) |
| | Sekine2010 | Japan | 2001–2008 | Tilt change | Sekine *et al.* (2010) |
| | Takagi2016 | Japan | 2004–2013 | GNSS displacement | Takagi *et al.* (2016) |
| | Tu2017 | Japan | 1997–2016 | GNSS displacement | Heki and Kataoka (2008);<br>Tu and Heki (2017) |
| | YoshiIto2013 | Japan | 2008–2011 | Strain and pressure change | Ito *et al.* (2013) |

ECM, envelope cross-correlation method; GNSS, Global Navigation Satellite System; JMA, Japan Meteorological Agency; LFE, low-frequency earthquake; NIED, National Research Institute for Earth Science and Disaster Resilience; SSE, slow-slip event; VLFE, very low-frequency earthquake; WTD, World Tremor Database.

*Indicates that the catalog will be updated.

[†] Source locations are not estimated.

of LFEs in Cascadia (Bostock *et al.*, 2015) and Nankai (Ohta and Ide, 2017), tremors in California (Chao, Peng, Fabian, *et al.*, 2012), Taiwan (Chao, Peng, Wu, *et al.*, 2012; Chao *et al.*, 2017), and Japan (Chao and Obara, 2016; Imanishi *et al.*, 2016), global triggered tremor (Chao *et al.*, 2013), VLFEs in Nankai (Baba *et al.*, 2018), and SSEs in Nankai (Itaba and Ando, 2011) and Mexico (Rousset *et al.*, 2017). In addition, we are planning to add catalogs of repeating earthquakes as indicators of slow slip along faults such as those in northeast Japan (Uchida and Matsuzawa, 2013). Therefore, the number



Slow Earthquake Database

User policy (brief summary)

- Refer designated references for any resultant production.
- Follow each catalog's individual policy.
- Use at your own risk.
- Data may be updated without any notice.
- Acknowledge our project.
- Not for commercial use.
- No redistribution.

* See here for full policy statement

1. Time Span

Start: 2008-01-01 Duration[day]: 366 End: 2008-12-31

2. Catalog

| Region | LFE | Tremor | VLF | SSE |
|---|---|---|---|---|
| Japan | JMA<br>Arai2016(ECM)<br>Arai2016(tomoDD)<br>Nakamura2017(ECM)<br>Nakamura2017(ECM+SP) | Annoura2016<br>NIED<br>Obana2009<br>WTD-Nankai<br>WTD-Kyushu<br>Yamashita2015<br>YoshiIto2015 | YoshiIto2009<br>Matsuzawa2015<br>Nakamura2015<br>Sugioka2012<br>Takeo2010 | Sekine2010<br>Tu2017<br>Nishimura2013<br>Nishimura2014<br>Takagi2016<br>YoshiIto2013 |
| Cascadia | | WTD-Cascadia | | |
| San Andreas | | WTD-Parkfield | | |
| Mexico | | WTD-Mexico | | |
| Chile | | WTD-Chile | | |
| New Zealand | | WTD-NewZealand | | |
| Taiwan | | WTD-Taiwan | | |

▲ **Figure 2.** Screenshot of the webpage showing (a) database selection and the policy tab for the catalog references and policies, (b) interactive map, and (c) download sections. Contents related to labels shown by the red characters are mentioned in the main article. (*Continued*)

of catalogs in the Slow Earthquake Database will continue to increase in the future. We welcome researchers to contribute by adding their published slow earthquake catalogs to our database. In addition, now that the accessibility to the data presented in published papers has become an essential requirement for a number of journals, researchers can refer to our database as a tool to share their catalogs. Any requests and questions regarding the details of sharing the catalogs through our database can be addressed to sloweq-ctlg-hq@eri.u-tokyo.ac.jp.

## USE OF THE SLOW EARTHQUAKE DATABASE

### Catalog Selection

Figure 2 presents a screenshot of the Slow Earthquake Database website. After logging on to the database, users select the time span of interest (A in Fig. 2a); that is, users choose the first day of the time span and its duration or the last day of interest. Next, from a table (B in Fig. 2a), users select which slow earthquake catalog(s) they wish to use. The catalogs are sorted by region and the category of slow earthquake, that is, the characteristic duration.

### Visualization

Users can view source locations of their selected slow earthquakes at the same time in Google Maps (C in Fig. 2b). The catalogs are plotted by color in the default configuration. Users can change the color scale to represent the source depth or the occurrence time of the events. The number of events in each catalog in the selected time span is also indicated below the map (D in Fig. 2b). Plate boundaries in Google Maps come from Bird (2003).

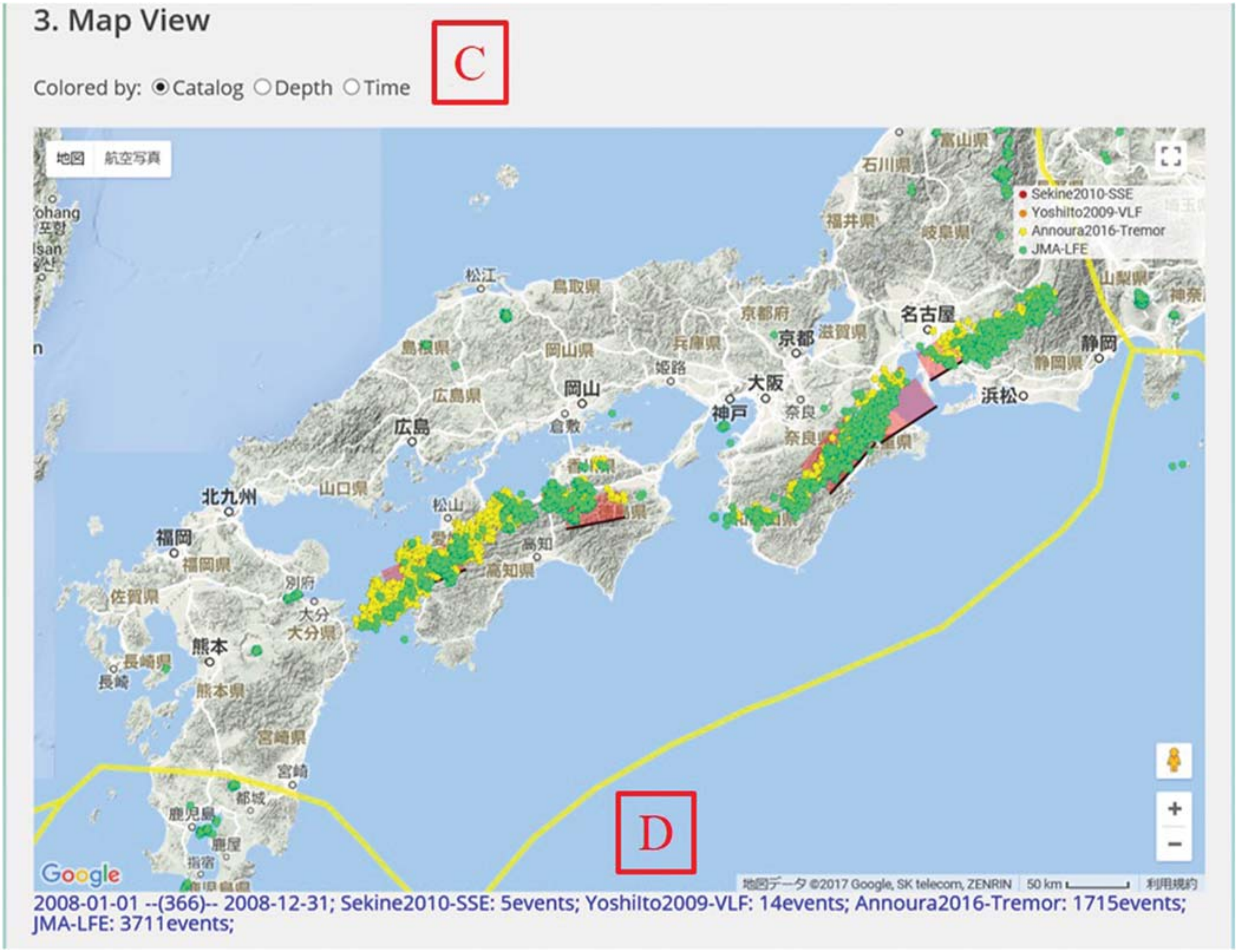
### Download and Catalog Format

The database provides the slow earthquake catalogs in a unified or standardized format or the user's preferred format, which the user can specify in the download part. Four format options are available (E in Fig. 2c). The first three are the commonly used formats for LFEs or tremor, VLFEs, and SSEs, and the other contains all information in a default format that can be customized by users. A summary of the labels in the format appear in the "Data Format" part (F in Fig. 2c). By clicking the "Download" button, users can download the selected catalogs in a specified format as a single comma-separated-value (CSV) file. Figure 3 presents a downloaded CSV file in the case of all labels selected in the format for JMA-LFE, Annoura2016-Tremor, YoshiIto2009-VLFE, and Sekine2010-SSE catalogs on 5 March 2008 (Katsumata and Kamaya, 2003; Ito *et al.*, 2009; Sekine *et al.*, 2010; Annoura *et al.*, 2016). The first 26 columns (columns A–Z in Fig. 3a,b) list occurrence times (columns A–I in Fig. 3a), source locations (columns J–L in Fig. 3a), and mechanisms (columns M–Z in Fig. 3b), respectively. The following six columns (columns AA–AF in Fig. 3c) list the information of source uncertainties in both time and space. The last seven columns (columns AG–AM in Fig. 3c) list the notices in the catalog. A description of each column is summarized in the "Data Format" on the website (F in Fig. 2c). The properties that are not included in the original catalog remain blank.

## DATABASE AVAILABILITY

The Slow Earthquake Database is an open database. Users of the database must comply with our general and individual policies. The general policy (see Fig. 4a) describes the general rules formulated for all catalogs, such as how to cite or acknowledge a database. They also outline the responsibility of the user, a prohibition of the redistribution of catalogs, and an explanation of future possible updates. In addition, each catalog has an

(b)



3. Map View

Colored by: ◉ Catalog ○ Depth ○ Time

2008-01-01 --(366)-- 2008-12-31; Sekine2010-SSE: 5events; YoshiIto2009-VLF: 14events; Annoura2016-Tremor: 1715events; JMA-LFE: 3711events;

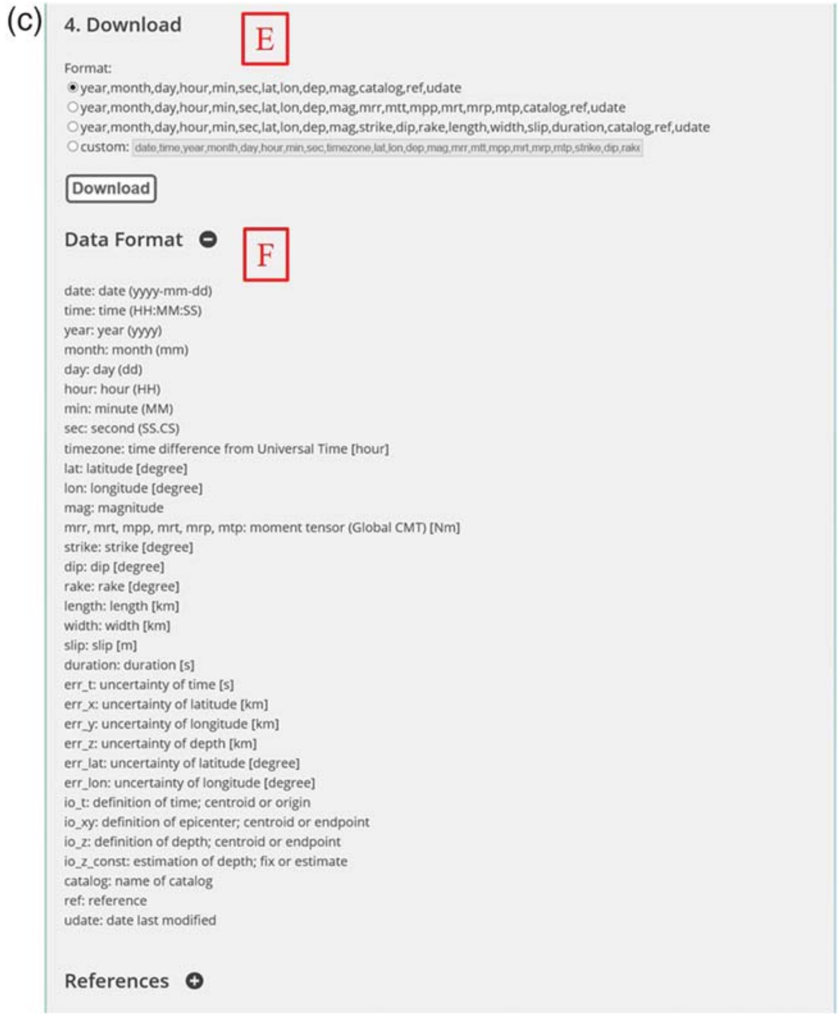
**Figure 2.** Continued.

individual policy set by the corresponding author. Figure 4b presents an example of an individual policy corresponding to the tremor catalog provided by NIED (Maeda and Obara, 2009; Obara *et al.*, 2010). Individual policies generally include citation information, the data period, and short notices about the usage of the catalog. All of the policies are summarized in the database.

## UNDERLYING ISSUES AND FUTURE UPDATES OF THE DATABASE

The Slow Earthquake Database compiles a variety of slow earthquake catalogs from a number of sources, and the information provided in each catalog differs from one source to another. For example, the source locations of LFEs, tremor, and VLFEs are estimated as corresponding to point sources. In contrast, those of SSEs are estimated as finite faults. Therefore, information about the source mechanism such as strike, dip, rake, length, width, and slip are included only in the SSE catalogs. This comes from the difference of event size and duration of interest, or originally from the difference in the types of observations used for identifying and characterizing the events. At the same time, the information may vary, even within the same category of slow earthquakes. For example, while the LFE catalog provided by JMA determines the magnitude of events, the LFE catalog in Nakamura (2017) does not. To date, our database does not clearly indicate which information is provided in each catalog; such information, however, will be included in the near future. The quality of catalogs also varies depending on the detection method, which ranges from fully automatic to manual detection. In addition, the time periods covered by each catalog can significantly differ. We are planning to incorporate such information to the webpage in the future.

There are also several issues specific to the catalogs of particular types of slow earthquakes that are currently not fully addressed in our database. For one, LFEs are often detected based on template matching, which identifies new events by comparing the similarity between observed waveforms and those of a template event. In the near future, the database will



4. Download

Format:
● year,month,day,hour,min,sec,lat,lon,dep,mag,catalog,ref,udate
○ year,month,day,hour,min,sec,lat,lon,dep,mag,mrr,mtt,mpp,mrt,mrp,mtp,catalog,ref,udate
○ year,month,day,hour,min,sec,lat,lon,dep,mag,strike,dip,rake,length,width,slip,duration,catalog,ref,udate
○ custom: date,time,year,month,day,hour,min,sec,timezone,lat,lon,dep,mag,mrr,mtt,mpp,mrt,mrp,mtp,strike,dip,rak

Download

Data Format

date: date (yyyy-mm-dd)
time: time (HH:MM:SS)
year: year (yyyy)
month: month (mm)
day: day (dd)
hour: hour (HH)
min: minute (MM)
sec: second (SS.CS)
timezone: time difference from Universal Time [hour]
lat: latitude [degree]
lon: longitude [degree]
mag: magnitude
mrr, mrt, mpp, mrt, mrp, mtp: moment tensor (Global CMT) [Nm]
strike: strike [degree]
dip: dip [degree]
rake: rake [degree]
length: length [km]
width: width [km]
slip: slip [m]
duration: duration [s]
err_t: uncertainty of time [s]
err_x: uncertainty of latitude [km]
err_y: uncertainty of longitude [km]
err_z: uncertainty of depth [km]
err_lat: uncertainty of latitude [degree]
err_lon: uncertainty of longitude [degree]
io_t: definition of time; centroid or origin
io_xy: definition of epicenter; centroid or endpoint
io_z: definition of depth; centroid or endpoint
io_z_const: estimation of depth; fix or estimate
catalog: name of catalog
ref: reference
udate: date last modified

References

**Figure 2.** Continued.

provide catalogs that have been determined by such methods (e.g., Bostock *et al.*, 2015); such catalogs, however, are not currently included in the database. As this type of catalog consists of overlapping locations corresponding to events detected using the same template, visualization on Google Maps would be less informative but results in slow response. In addition, the unified format does not include information for template events. Therefore, we are preparing a "direct download" page that will provide original catalogs, including the template information. This page will be an addition to the download page with the unified format mentioned in this article. As this issue could be problematic for other categories of slow earthquakes, we will treat it in the same way.

Tremor catalogs are roughly divided into two types in terms of duration. Because tremor can be observed as a continuous signal, the definition of tremor duration is somewhat complex. Some catalogs estimate one source location based on recorded waveforms within a short period (e.g., 1 min). Clustering catalogs, however, treat estimated source locations of tremor as one or two centroid locations during a longer period such as 1 hr. While the former catalogs enable us to examine shorter timescale tremor activity, the latter ones can be used for investigating only longer timescale tremor activity. Users should be mindful of such issues in handling tremor catalogs and are advised to consult the corresponding references.

At the stage of the initial release of the database, our database provided only SSE catalogs that represented the source of an SSE as a single rectangular fault. After all, the formatting and visualization of slip distributions for SSEs, including the temporal evolution of slips, is a complex issue currently under discussion. SSE catalogs that include fault-slip distribution and temporal evolution will be available for download in the "direct download" page in their original format.

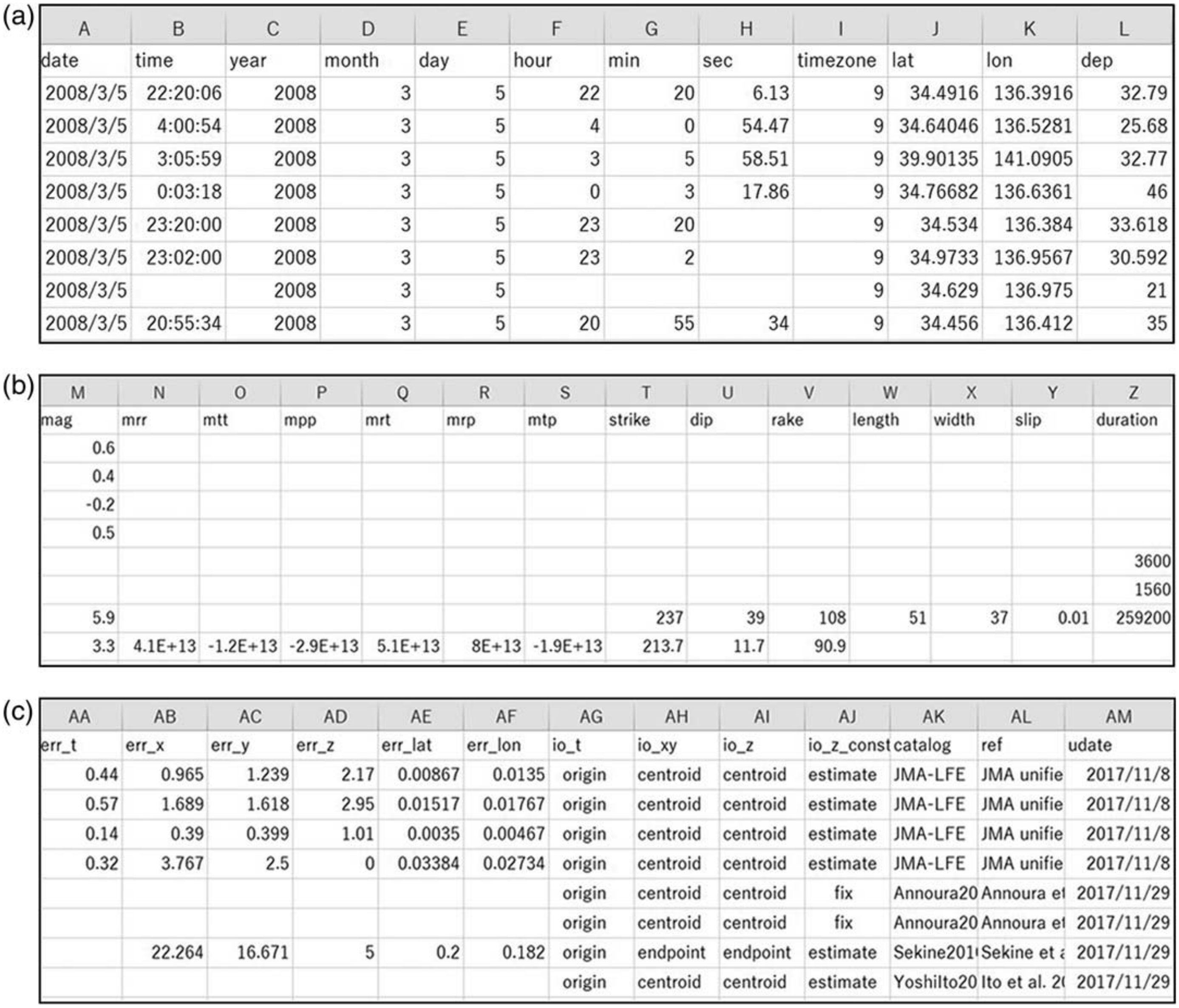
The database sometimes faces a problem when users attempt to plot or download a large number of catalogs. The maximum number of catalogs that can download from the database at one time depends on the selected format and will be noted in the database.

Although users who wish to share new catalogs must contact us before including it in the database, we plan to construct a semiautomatic system for uploading catalogs to the database in the future. Newly submitted as well as automatically updated catalogs will be released on a monthly basis.

## SUMMARY

We constructed the Slow Earthquake Database by compiling a wide variety of seismically and geodetically detected catalogs on slow earthquakes from the peer-reviewed papers and institutional reports and converted their original formats to a unified format. Based on the agreement of the corresponding authors of the original catalogs, we converted and stored the catalogs in a single repository. Users can download the multiple catalogs in either the unified format or their preferred format. This database is available for all users as long as they follow the general policy and the individual policy of each catalog. In addition, users can visualize the source distribution in Google Maps before downloading the data, which assures users that events have occurred during the selected time span.

The constructed database enables users to find where, when, and what type of slow earthquakes have occurred. Comparisons of catalogs, especially comparisons between seismically and geodetically detected slow earthquakes, will promote a more comprehensive understanding of slow earthquake activity, such as the spatial relationship among different types of slow earthquakes and regional differences among slow earthquake activity. Such comparisons can also help researchers characterize the differences among source locations found by various detection methods. Another advantage of the data-



(a)

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| date | time | year | month | day | hour | min | sec | timezone | lat | lon | dep |
| 2008/3/5 | 22:20:06 | 2008 | 3 | 5 | 22 | 20 | 6.13 | 9 | 34.4916 | 136.3916 | 32.79 |
| 2008/3/5 | 4:00:54 | 2008 | 3 | 5 | 4 | 0 | 54.47 | 9 | 34.64046 | 136.5281 | 25.68 |
| 2008/3/5 | 3:05:59 | 2008 | 3 | 5 | 3 | 5 | 58.51 | 9 | 39.90135 | 141.0905 | 32.77 |
| 2008/3/5 | 0:03:18 | 2008 | 3 | 5 | 0 | 3 | 17.86 | 9 | 34.76682 | 136.6361 | 46 |
| 2008/3/5 | 23:20:00 | 2008 | 3 | 5 | 23 | 20 |  | 9 | 34.534 | 136.384 | 33.618 |
| 2008/3/5 | 23:02:00 | 2008 | 3 | 5 | 23 | 2 |  | 9 | 34.9733 | 136.9567 | 30.592 |
| 2008/3/5 |  | 2008 | 3 | 5 |  |  |  | 9 | 34.629 | 136.975 | 21 |
| 2008/3/5 | 20:55:34 | 2008 | 3 | 5 | 20 | 55 | 34 | 9 | 34.456 | 136.412 | 35 |

(b)

| M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mag | mrr | mtt | mpp | mrt | mrp | mtp | strike | dip | rake | length | width | slip | duration |
| 0.6 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.4 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| -0.2 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.5 |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | 3600 |
|  |  |  |  |  |  |  |  |  |  |  |  |  | 1560 |
| 5.9 |  |  |  |  |  |  | 237 | 39 | 108 | 51 | 37 | 0.01 | 259200 |
| 3.3 | 4.1E+13 | -1.2E+13 | -2.9E+13 | 5.1E+13 | 8E+13 | -1.9E+13 | 213.7 | 11.7 | 90.9 |  |  |  |  |

(c)

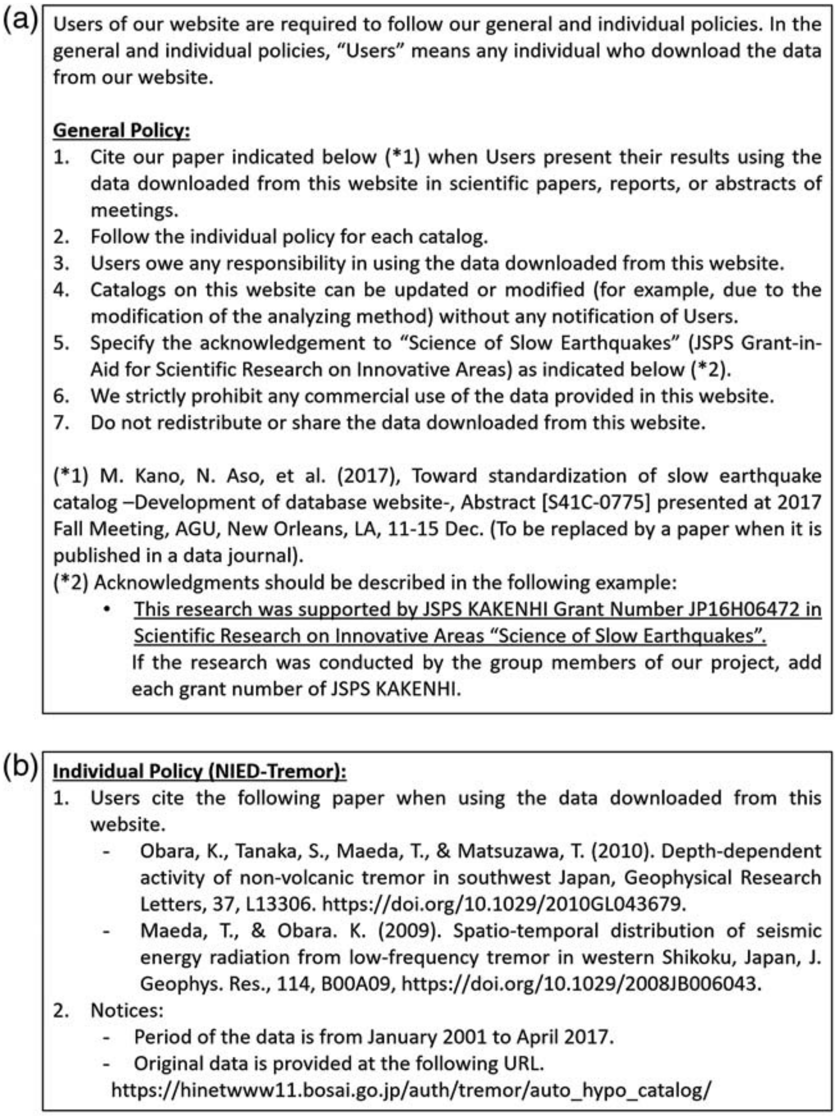
| AA | AB | AC | AD | AE | AF | AG | AH | AI | AJ | AK | AL | AM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| err_t | err_x | err_y | err_z | err_lat | err_lon | io_t | io_xy | io_z | io_z_const | catalog | ref | udate |
| 0.44 | 0.965 | 1.239 | 2.17 | 0.00867 | 0.0135 | origin | centroid | centroid | estimate | JMA-LFE | JMA unifie | 2017/11/8 |
| 0.57 | 1.689 | 1.618 | 2.95 | 0.01517 | 0.01767 | origin | centroid | centroid | estimate | JMA-LFE | JMA unifie | 2017/11/8 |
| 0.14 | 0.39 | 0.399 | 1.01 | 0.0035 | 0.00467 | origin | centroid | centroid | estimate | JMA-LFE | JMA unifie | 2017/11/8 |
| 0.32 | 3.767 | 2.5 | 0 | 0.03384 | 0.02734 | origin | centroid | centroid | estimate | JMA-LFE | JMA unifie | 2017/11/8 |
|  |  |  |  |  |  | origin | centroid | centroid | fix | Annoura20 | Annoura et | 2017/11/29 |
|  |  |  |  |  |  | origin | centroid | centroid | fix | Annoura20 | Annoura et | 2017/11/29 |
|  | 22.264 | 16.671 | 5 | 0.2 | 0.182 | origin | endpoint | endpoint | estimate | Sekine201 | Sekine et | 2017/11/29 |
|  |  |  |  |  |  | origin | centroid | centroid | estimate | YoshiIto20 | Ito et al. 2 | 2017/11/29 |

▲ **Figure 3.** Example of the downloaded comma-separated-value format, which lists (a) occurrence times (columns A–I), source locations (columns J–L), (b) source mechanisms (columns M–Z), (c) source uncertainties in both time and space (columns AA–AF), and the notices in the catalog (columns AG–AM). A description of each column is summarized in the "Data Format" on the website (F in Fig. 2c). The properties that are not included in the original catalog remain blank.

base is that users can download multiple catalogs as a single compiled catalog in the unified or preferred format. The unified catalog contains references to the original catalogs so that users can refer to them for more detailed information. As a result of such standardization, researchers will find it more convenient to access the findings of previous studies, which will promote research on slow earthquakes that may foster future collaboration among researchers from various fields and further our understanding of the mechanisms, environmental conditions, and underlying physics of slow earthquakes. Furthermore, we expect that the database will play a leading role in establishing a global standard of slow earthquake catalogs. In cooperation with many researchers, we are now compiling more catalogs, which will result in a more and more comprehensive database.

## DATA AND RESOURCES

The Slow Earthquake Database is available at http://www-solid.eps.s.u-tokyo.ac.jp/~sloweq/ (last accessed January 2018) and open to everyone as long as users follow the general policy of our database and the individual policy of each catalog. The most recent update of the database was on 4 December 2017. If users have any feedback or comments, or wish to share their catalogs, they should contact sloweq-ctlg-hq@eri.u-tokyo.ac.jp.



(a)

Users of our website are required to follow our general and individual policies. In the general and individual policies, “Users” means any individual who download the data from our website.

**General Policy:**

1. Cite our paper indicated below (*1) when Users present their results using the data downloaded from this website in scientific papers, reports, or abstracts of meetings.
2. Follow the individual policy for each catalog.
3. Users owe any responsibility in using the data downloaded from this website.
4. Catalogs on this website can be updated or modified (for example, due to the modification of the analyzing method) without any notification of Users.
5. Specify the acknowledgement to “Science of Slow Earthquakes” (JSPS Grant-in-Aid for Scientific Research on Innovative Areas) as indicated below (*2).
6. We strictly prohibit any commercial use of the data provided in this website.
7. Do not redistribute or share the data downloaded from this website.

(*1) M. Kano, N. Aso, et al. (2017), Toward standardization of slow earthquake catalog –Development of database website-, Abstract [S41C-0775] presented at 2017 Fall Meeting, AGU, New Orleans, LA, 11-15 Dec. (To be replaced by a paper when it is published in a data journal).

(*2) Acknowledgments should be described in the following example:

- This research was supported by JSPS KAKENHI Grant Number JP16H06472 in Scientific Research on Innovative Areas “Science of Slow Earthquakes”.
  If the research was conducted by the group members of our project, add each grant number of JSPS KAKENHI.

(b)

**Individual Policy (NIED-Tremor):**

1. Users cite the following paper when using the data downloaded from this website.
    - Obara, K., Tanaka, S., Maeda, T., & Matsuzawa, T. (2010). Depth-dependent activity of non-volcanic tremor in southwest Japan, Geophysical Research Letters, 37, L13306. https://doi.org/10.1029/2010GL043679.
    - Maeda, T., & Obara. K. (2009). Spatio-temporal distribution of seismic energy radiation from low-frequency tremor in western Shikoku, Japan, J. Geophys. Res., 114, B00A09, https://doi.org/10.1029/2008JB006043.
2. Notices:
    - Period of the data is from January 2001 to April 2017.
    - Original data is provided at the following URL.
      https://hinetwww11.bosai.go.jp/auth/tremor/auto_hypo_catalog/

▲ **Figure 4.** (a) General policy and (b) an example of the individual policy, from the National Research Institute for Earth Science and Disaster Resilience (NIED)-Tremor catalog.

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